AN ABSTRACT OF THE THESIS OF

Waheed Ibrahim Bajwa for the degree of Doctor of Philosophy in Entomology presented on March 22, 1996.

Title: Integration of Microbial and Chemical Controls against Codling Moth, *Cydia pomonella* (L.): Laboratory and Field Evaluation.

Abstract approved: _____

M. T. AliNiazee

The feasibility of managing codling moth, *Cydia pomonella* (L.), with mixtures of *Bacillus thuringiensis*-based microbial and selected chemical insecticides was studied under laboratory and field conditions. Joint actions (synergism, additivity and antagonism) of these mixtures were determined for both egg and larval stages. Higher rates of microbial control agents (MCAs), Dipel® 2X and MVP®, combined with low to medium rates of chemical insecticides gave additive or synergistic egg and/or larval mortality. Esfenvalerate and permethrin synergised the effect of these MCAs, whereas carbaryl, azinphosmethyl, phosmet and diflubenzuron had an additive effects. For all chemical insecticides, often the interactions were better with Dipel than MVP. Generally, egg exposure to low rates of the chemical insecticides alone or in combination with MCAs, caused the larvae hatching from these eggs to be more susceptible to insecticides-MCA mixtures. Most mixtures produced better results when treated at the blackhead stage of egg development.

Adult and larval exposure to sublethal rates of azinphosmethyl, phosmet, carbaryl, esfenvalerate and permethrin manifested short- and long-term effects. Adult exposure caused deleterious effects on the survival and oviposition, and the larval exposures affected survival and pupal formation. Carbaryl, esfenvalerate and permethrin affected the pupal survival and subsequent eclosion of adults. Only

esfenvalerate and permethrin significantly extended the larval period and reduced pupal weight and subsequent egg deposition. The deleterious sublethal effects of pyrethroids observed in the present study may provide added control of codling moth in the field. Diflubenzuron and MCAs had neither adulticidal activity nor long-term effects on codling moth biology.

Results of field efficacy tests indicate that utilization of mixtures of Dipel with low rates of pyrethroids (0.1-0.2X) or diflubenzuron (0.25-0.50X) in the codling moth management is possible and indeed might be beneficial. Dipel-diflubenzuron mixtures were only suitable when applied 3 times/generation. These mixtures were environmentally safe and did not cause any outbreak of phytophagous mites. Standard application rate (2 times/generation) and timing were found to be appropriate for Dipel-pyrethroid (esfenvalerate and permethrin) mixtures. These pyrethroids at all test rates (0.1-1.0X), applied alone or mixed with MCAs, were toxic to predatory phytoseiids, thus caused an outbreak of European red mite and yellow spider mites particularly at higher rates. However, mixtures of Dipel and 0.1X of esfenvalerate/permethrin were less disruptive than corresponding 0.2-1.0X standard rate. These mixtures were selective to most predatory insects, spiders and *Zetzellia mali*. Hence, use of these mixtures instead of full rate of pyrethroids may improve the prospects of biological control of insect and mite pests in apple orchards.

INTEGRATION OF MICROBIAL AND CHEMICAL CONTROLS AGAINST CODLING MOTH, *Cydia pomonella* (L.): LABORATORY and FIELD EVALUATION

By

Waheed Ibrahim Bajwa

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Dean of Graduate School

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Waheed Ibrahim Bajwa, Author

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IN THE NAME OF ALLAH, THE COMPASSIONATE, THE MERCIFUL

Dedicated
to

My Father, Ch. Mohammed Ibrahim Bajwa,
for his refined habits and noble principles that make
him a role model

My Mother, Mrs. Mumtaz Fatima Bajwa,
for her love, commitment, inspiration and devotion

My Wife, Farrah Waheed,
for her love, understanding and encouragement

My Son, Saad,
whose love gave me strength

My Brothers and Sisters
for their love, and encouragement

&

Sheikh Atta-ul-Haq
for his efforts for the benefit of humanity

INTEGRATION OF MICROBIAL AND CHEMICAL CONTROLS AGAINST CODLING MOTH, *Cydia pomonella*(L.): LABORATORY AND FIELD EVALUATION

Chapter 1

INTRODUCTION

The codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae), is a key pest of apple throughout the world (Bajwa 1984, Putman 1963) as well as in the Western U.S.A. (Croft & Penman, 1989, Setyobudi 1989). Its control is generally based on prophylactic use of broad-spectrum insecticides. The excessive and incessant use of these insecticides has been implicated in many undesirable side effects namely environmental pollution, poison hazard to man and livestock, destruction of useful predators and parasites and consequently domination of secondary pests, development of resistance to pesticide and enhancement in production cost. One frequent consequence of chemical application against codling moth is the rapid elimination of beneficial predators and parasites allowing other pest species to resurge. Such resurgence can lead to the need for additional pesticide application. As a response to these shortcomings, over the past two decades, alternate methodologies have been investigated (Croft & Penman, 1989). The alternate approach includes using selective pesticides and to increase use of biological control agents (Croft & AliNiazee 1996). However the progress in finding effective biological control agents and other alternatives to chemical insecticides has been slow.

Based on the aforementioned problems and possible solutions, it is highly desirable that we investigate and develop a safer alternative management program with greatly reduced input of chemical pesticides for our modern day agriculture. A program that can prevent/delay development of insecticide resistance in the codling moth is a dire need. Among the different alternatives considered for codling moth control, microbial insecticide *Bacillus thuringiensis* Berliner and viruses have been mentioned. *B. thuringiensis* and Codling moth Granulosis virus (CpGv) were found to

be active against neonates in laboratory bioassays but their effectiveness in the field was not established. Integration of microbial and chemical insecticides is another way of minimizing the environmental contamination caused by using chemical insecticides alone while still maintaining an effective pest control program. Among microbial insecticides, *B. thuringiensis* is the most versatile entomopathogen for use in pest management systems mainly because of its selective activity against many lepidopterous pest species (Ignoffo & Gregory 1972) and its compatibility with many chemical pesticides (Benz 1971, Chen *et al.* 1974). Most insecticides are compatible with *B. thuringiensis* with little or no adverse effect on spore germination or cell multiplication. However, information on toxicity and interaction of various combination of *B. thuringiensis* and sublethal dosages of chemical insecticide against codling moth is limited, although there is repeated mention of this in some papers. It is possible that the approach based on using low rates of registered chemical insecticides with *B. thuringiensis* may not only provide an effective control of the codling moth but also prolong the effective life of insecticides such as azinphosmethyl and phosmet and ensure preservation of the key predatory phytoseiid mites such as *Galendromus* (*Typhlodromus*) *occidentalis*, *T. pyri* and *T. arboreus* in addition to greatly reducing the residue on the harvested fruits.

Recent developments in genetic engineering have significantly increased the potential of microbial insecticides in pest control (Kurstak & Tinjsen, 1982). For example, today's *B. thuringiensis* produces ten times more endotoxin (Anony. 1989), and are standardized for field use at 16,000-32,000 International Units/mg (IU / mg) activity. Efficacy of the available *B. thuringiensis* formulations has improved and became more consistent (Knowles & Dow 1993, Knowles 1994). MVP, a genetically engineered insecticide, reportedly has greater environmental stability than other *B. thuringiensis*-based formulations (Gelernter 1990b). All the previous studies on the use of *B. thuringiensis* against codling moth were undertaken by using formulations containing spores as their chief ingredient and crystals as a minor component. The lethality of *B. thuringiensis* is mainly due to crystal and the presence of spore is supplemental (Dulmage 1981, Andrews *et al.* 1987, Anony. 1989, Federici 1993,

Knowles and Dow 1993, Knowles 1994). *B. thuringiensis* formulations have generally been tested against the larval stages with variable results (Falcon 1971, Fedorinchik 1977, Morris 1988). I feel, therefore, that there is a need to reinvestigate the *B. thuringiensis* efficacy against codling moth and to evaluate the possibility of using *B. thuringiensis*-insecticide mixtures. A proper evaluation of effect of this bacteria is of utmost importance because mortality does not always occur during larval stage but may be delayed until pupation and even adult eclosion (Falcon 1971).

Microbial agent-chemical insecticide interactions and their advantages have been recognized (Benz 1971, Jaques & Morris 1881). More recently, there have been several reports of *B. thuringiensis* tested in combination with chemical insecticides against various agriculture pests (Richter & Fuxa 1984, Salama *et al.* 1984, Tompkins *et al.* 1986, Jaques 1988, Jaques *et al.* 1989). However, relatively little information is available on compatibility, toxicity and interactions of various combinations of *B. thuringiensis* and low/sublethal dosages of commonly used insecticides against codling moth in the apple ecosystems. The present project was designed to determine the feasibility of introducing *B. thuringiensis* - chemical insecticide mixtures as effective and safer alternatives to present codling moth management practices which depend almost exclusively on the use of highly toxic organophosphate insecticides. The effectiveness of the mixtures of selected chemical insecticides and *B. thuringiensis* against codling moth, *Cydia pomonella* (L.), was evaluated under the laboratory and field conditions. The synergistic, additive, or antagonistic effects of these mixtures on insect mortality and sublethal effects on various biological parameters such as survival to adult and ovipositional rates were investigated in detail. The impact of these mixtures on some non-target arthropods such as pests and predatory mites, entomophagous insects and spiders was also determined. Conclusions are drawn on the basis of fundamental as well as the applied implications of the present studies.

Chapter 2

LITERATURE REVIEW

The insecticidal bacterium *Bacillus thuringiensis* Berliner is the most widely used alternative insect control agent at present (Luthy & Ebersold 1981, Morris *et al.* 1994), and the one most likely to be used even more extensively in the future. There have been a number of recent reviews on the use of *B. thuringiensis* as a biological control agent (Peferoen 1991, Feitelson *et al.* 1992, Lambert & Peferoen 1992), mode of actions (Gill *et al.* 1992, Federici 1993, Knowles & Dow 1993, Knowles 1994), and diversity and expression of genes (Hofte & Whitely 1989). *B. thuringiensis* is a Gram-positive, aerobic, spore-forming bacterium (Andrews *et al.*1987, Knowles 1994). This bacterium, at the end of the vegetative growth, forms a so-called spore which is able to survive for long periods of time, even under most unfavorable conditions (Luthy & Ebersold 1981). During sporulation in nutrient media, this bacterium produces a parasporal protoxin. This parasporal protoxin is also called as parasporal body, crystalline inclusion body, crystal protein, insecticidal crystal protein fragments (ICPF) or most commonly δ-endotoxin (delta-endotoxin) (Dulmage 1981, Luthy and Ebersold 1981, Andrews *et al.* 1987, Vail *et al.* 1992, Gill *et al.* 1992, Knowles 1994). The δ-endotoxin, when ingested by the susceptible larva, is cleaved into toxic subunits of various molecular weights by gut alkaline proteases. These toxins are bound to the specialized receptor cells in the gut epithelium and cause disruption of the gut epithelium. The disruption leads to morphological and pathological changes in many cellular organelles, increases in haemolymph pH, disturbance of ionic balance, and eventually, gut paralysis and death of the host (English & Slatin 1992).

B. thuringiensis is primarily a pathogen of insect larval stages. Younger larvae of most insect species are more susceptible to the toxic agent than are older larvae (Andrews *et al.* 1987). Some insects are highly susceptible and are killed by δ-endotoxin alone, whereas other insects are less susceptible and require the simultaneous presence of the toxin and the spores (Noyouki 1996). As the route of

entry of *B. thuringiensis* is through the oral cavity, feeding activity of larvae is a prerequisite of insecticidal activity (Luthy and Ebersold 1981). Different subspecies (subsp.) of this bacterium make insecticidal proteins that are effective against a particular group of insect pests (Aronson *et al.* 1986). In most cases, the activity of an isolate of *B. thuringiensis* is limited to a single order of insects. Subspecies *kurstaki* and subsp. *berliner* are most active against Lepidoptera (Vaeck *et al.* 1987); subsp., *israelensis* is the most active against Diptera (Yamamoto & McLaughlin 1981, Fischhoff *et al.* 1987) and subsp. *tenebrionis* and subsp. *san diego* are the most active against Coleoptera (Herrnstadt *et al.* 1986). *B. thuringiensis* based insecticides are considered to be not harmful to predatory arthropods and other animals including man (Andrews *et al.* 1987). This highly selective action offers effective and environmentally safe control of several pests.

Recent developments in genetic engineering have significantly increased the potential of microbial insecticides in pest control (Kurstak & Tinjsen, 1982). For example, today's *Bacillus thuringiensis* Berliner produces ten times more endotoxin (Anony. 1989), and are standardized for field use at 16,000-32,000 IU / mg activity. Efficacy of the available *B. thuringiensis* formulations has improved (Andrews *et al.* 1987). This bacterium is a safe and efficacious pest control agent against many lepidopterous larvae of agricultural crops. Certain characteristics of this microbial control agent, however, can reduce its efficacy. One such characteristic is its poor persistence on vegetation surfaces (Gardner & Hornby 1987, Ali & Young 1993, Nyouki & Fuxa 1994). The entomocidal crystal, δ-endotoxins of *B.* thuringiensis, are subject to rapid inactivation by environmental factors such as sunlight, rain, and wind (Griego and Spence 1978, Gelernter 1990a & b, McGuire *et al.* 1994, Nyouki & Fuxa 1994). Various methods have been developed to increase the persistence of *B. thuringiensis*. The most common has been the use of spray adjuvants such as ultraviolet photostabilizer (Griego & Spence 1978, Morris 1983, Dunkle & Shasha 1989, Nyouki & Fuxa 1994). Recently, a cell-encapsulation techniques was developed. A detailed account of this technique is given by Gelernter (1990a, b). A δ-endotoxin

gene of *B. thuringiensis* subsp. *Kurstaki* was bioengineered into the bacterium *Pseudomonas fluorescens* Migula . These recombinant-DNA bacteria, grown in culture, produce δ-endotoxin crystals at the end of the growth stage. However, unlike *B. thuringiensis*, the *P. fluorescens* cells do not lyse. Therefore, the crystal δ-endotoxin remains enclosed within the cell. The bacteria are killed by heat and iodine. This cell-encapsulation process stabilizes the cell walls, thereby enclosing the crystal proteins. The insecticidal activity of this recombinant-DNA bacterium reportedly has greater environmental stability than *B. thuringiensis* formulations based on natural strains (Gelernter 1990a, b). Mycogen Vegetable Product (MVP®), a commercial microbial formulation, is based on this technology.

A large amount of information is found on the *B. thuringiensis* and its uses in the literature. For this reason, I have narrowed it down only to the literature dealing with codling moth. *B. thuringiensis* was tested to control *C. pomonella*, but results were inconclusive (Falcon 1971, Fedorinchik 1977, De Reede *et al.* 1985, Tkachev & Romanova 1985). *B. thuringiensis* was found to be very active against neonates larvae in laboratory bioassays but field effectiveness was questionable (Luthy *et al.*, 1982). This may be related to the fact that neonates feed very little before entering the fruit. And as such they can not consume a lethal dose of *B. thuringiensis*. Nevertheless, there have been many discrepancies among the results obtained by scientists in different geographical regions. The use of *B. thuringiensis* against codling moth was considered to be less effective to ineffective by some authors (Niemczyk & Dawydko 1970a, Karadzhov 1973, Tkachev *et al.* 1975, De Reede *et al.* 1985), whereas others (Jaques 1965, Burov *et al.* 1967, Karadzhov 1974, Niemczyk *et al.* 1976, Kholopov 1978, Korchagin 1983, Tkachev & Romanova 1985) reported moderate efficacy (50-65% control). Dolphin (1967) noted that only higher rates of application were effective but even those rates failed to prevent all damage.

Some authors have indicated that effectiveness of *B. thuringiensis* could be enhanced against several lepidopterous larvae by combination with low/sublethal rates of some chemical insecticides. Most insecticides at these rates are compatible with *B.*

thuringiensis with little or no adverse effect on spore germination or cell multiplication. Low concentrations of some carbamates, organophosphates and pyrethroids either did not affect bacterial growth or improved it (Morris *et al.* 1975b, 1977b, Chen *et al.* 1974, Salama *et al.* 1984). A general compatibility of δ-endotoxin with different chemical insecticides has also been established (Benz 1971, Morris 1977). Microbial agent-chemical insecticide interactions and their potential advantages have been recognized (Benz 1971). This integrated approach is a way of minimizing the environmental contamination while still maintaining an effective pest control program (Jaques 1988).

Laboratory and field tests against agricultural and forest pest have shown that the amount of chemical insecticide can be greatly reduced by integrating entomopathogens into spray program, without sacrifying crop quality (Morris 1977, Jaques & Morris 1981, Jaques 1989). When microbial and chemical insecticides are mixed together, whether applied simultaneously or separately, the potential exits for alteration of the microbial activity. The chemical pesticide may provide added control without interactions, but synergism or antagonism can occur (Mohamed *et al.*, 1983a, b). Potentiation has been documented for interactions using the *B. thuringiensis* and several chemical insecticides against a number of insect pests on various crops (Chen *et al.* 1974, Morris 1975a & b, Hamilton & Attia 1977, Habib & Garcia 1981, Mohamed *et al.* 1983, Salama *et al.* 1984, Luo *et al.* 1986, Yeh *et al.* 1986, Jaques 1988). Baicu and Hussein (1984) confirmed the synergistic effect between *B. thuringiensis* and pyrethroids such as fenvalerate, deltamethrin, cypermethrin and permethrin, in laboratory tests against a noctuid *Mamestra brassicae*.

The combined application of chemical and microbial insecticide, particularly reduced-dosage mixtures, is of considerable interest not only as a method of reducing the amount of chemical insecticide applied to the crop but also as a means of enhancing effectiveness of pathogenic organisms in protecting crop (Jaques, 1988). Other objectives of reducing dosage of chemical insecticide is to reduce environmental contamination and the effects on predacious and parasitic arthropods. *B. thuringiensis*

has little or no effect on beneficial arthropods (Jaques 1965, Kennedy & Oatman 1976, Wilkinson *et al.* 1975, Kurstak & Tinjssen 1982, Andrews *et al.* 1987). Low doses of insecticides (one-fifth to one-tenth of normal field rate) are thought to be harmless to many beneficial insects (Mosievskaya & Makarov, 1974). In apple and pear orchards, reduced dosages compared with standard rates of organophosphorous and pyrethroid insecticides enabled sufficient survival of arthropod predators, thus lessened disruption of tetranychid mite populations (Hoyt 1969, Madge 1972, Thwaite 1976, Hardman & Gaul 1990). This suggests that the target species can be controlled with reduced insecticide rates in combination with *B. thuringiensis* without greatly affecting natural enemies. This would reduce the selection pressure and conserve the susceptible gene pool (Brattsten *et al.*, 1986) and can result in reduced or delayed insecticide resistance. Reduced dosage mixtures of *B. thuringiensis* and chemical insecticides can also reduce the problem of pest resurgence, and would be highly compatible with IPM approach.

Potential microbial agent-chemical pesticides interactions and their effects on the target insects are poorly understood (Mohamed *et al.* 1983a,b). Insects like other organisms, are more susceptible to a disease when under the influence of stress produced by crowding, malnutrition and environmental factors (Benz, 1971). Preliminary data suggest that chemical insecticides can act as stressors and make them more susceptible to the action of microbial toxins (Benz, 1971), and are frequently synergistic when combined with microorganisms (Chen *et al.* 1974). Telenga and Dyadechko (1957) reported that healthy larvae of codling moth and other species of insects could not be infected with spores of muscardine fungus, *Beauveria bassiana* unless the insect has first been treated with weak doses of DDT and BHC.

Some studies in Europe and former USSR have demonstrated that combining low rates of chemical insecticides especially organophosphate and carbamate compounds with *B. thuringiensis* and *B. bassiana* can provide effective control of codling moth (G"onev 1975, Karadzhov 1973 & 74, Malevez 1978, Tomova & Rangelova, 1977). Relatively little or no information is available on compatibility, toxicity, interactions of various combinations of *B. thuringiensis* and sublethal dosages

of commonly used insecticide against codling moth in the orchard ecosystem of the United States. The impact of *B. thuringiensis*-insecticide mixtures on beneficial arthropods in apple ecosystem and sublethal effects of chemical and microbial insecticides against codling moth have never been studied.

A proper evaluation of *B. thuringiensis*-insecticide mixture is not possible without studying sublethal impact of these insecticides on biology of codling moth, and population dynamics of beneficial arthropods in the field. This is because, the sublethal concentrations of these pesticides may have deleterious or beneficial effect on the target pest, that could lead to an added control or resurgence/permanence of codling moth or other pests in the field. Deleterious effects that have been reported for other insect species include reduction in growth rate, depletion of carbohydrate, protein, and lipid reserves, and decrease in adult fecundity, fertility, and longevity (Boles 1974, Zettler & LeCato 1974, Grosch 1975, Wongkobrat & Dahlman 1976, Kumar & Chapman 1983, Smirnoff 1983, Alford & Holmes 1986, Moore *et al.* 1992). These effects are often realized as reduction in the reproductive ability of the insects. Conversely, advantageous effects have also been documented. These include increased larval weights, greater pupal energy reserves and developmental rates, and increased adult fertility (Kuenen 1958, Honek & Novak 1978, Smirnoff 1983, Stewart & Philogene 1983). These effects could ensure the survival of rigorous population and may contribute to permanence or resurgence or both, of epidemics of pests (Alford & Holmes 1986). Therefore, the consequences of sublethal exposure may have important implications in using an approach based on combinations of MCAs with low or sublethal doses of chemical insecticides.

Chapter 3

Susceptibility of Codling Moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae) to Microbial Agent-Chemical Insecticide Mixtures

Abstract

Effectiveness of mixtures of some chemical insecticides and microbial control agents (MCAs), Dipel and MVP, was evaluated against neonate larvae of codling moth, *Cydia pomonella* (L.) under laboratory condition at 24 ± 1 ^{0}C, 60-65% RH and 16 L: 8 D photoperiod. Joint action (synergism, additivity and antagonism) of these mixture was determined for both egg and larval stages. Higher rates of natural (Dipel) and genetically engineered (MVP) insecticides based on *B. thuringiensis* combined with low to medium rates of chemical insecticides gave additive or synergistic joint mortality. Esfenvalerate and permethrin at low to moderate test concentrations in combination with moderate to high test concentrations of Dipel or MVP were synergistic. Low to high rates of organophosphates azinphosmethyl and phosmet, carbamate carbaryl, and insect growth regulator diflubenzuron, with moderate to high concentrations of either MCA showed the additive effect. At highest doses of both MCAs and chemical insecticides, the joint mortality of most mixtures was marginally antagonistic (P=0.1), subadditive (effect less than or the same as that of most active component in the mixture) or not significantly different from the combinations with lower concentrations of either microbial or chemical components. Dipel and MVP produced almost similar responses with a given chemical insecticides.

There was no significant ($P \leq 0.05$) difference between egg mortalities produced by chemical insecticides alone or in combination with microbial insecticides. Egg exposure to low rates of chemical insecticides alone or in combination with MCAs, made the larvae hatching from these eggs more susceptible to insecticides-MCA mixtures. The joint effect was additive in case of organophosphate insecticides, carbaryl, diflubenzuron and with most combinations of higher rates of pyrethroids, producing a significantly higher combined ovo-larvicidal activities (egg and larval mortality) than those of each mixture component tested alone. Combinations with the lower rates of pyrethroids were synergistic in producing combined ovo-larval activity against both newly laid or blackhead eggs. Pyrethroids potentiated (synergised) the

effect of microbial insecticides. On the other hand, carbaryl, azinphosmethyl, phosmet and diflubenzuron had an additive effects. These insecticides, however, significantly enhanced the activity of *B. thuringiensis*-based insecticides in some combinations. As a general rule all test combinations produced better results when treated at blackhead egg stage and using Dipel.

Introduction

The codling moth, *Cydia pomonella* (L.), is a major pest in most pome fruit growing regions of the world (Bajwa 1984, Reed *et al.* 1985). The high quality standards of modern fruit production do not tolerate more than 1-2% of damaged apples or pears (Andermatt *et al.* 1988). At present, application of chemical insecticides is the only effective, practical and economical control measure available against this pest (Croft & Riedl 1991). Repeated treatments with efficient and persistent insecticides are required in order to produce high-quality fruit. The control of codling moth is based almost entirely on organophosphate compounds. These insecticides have controlled codling moth and other insect pests in apple for over 35 years (Croft 1982). Organophosphate (OP) insecticides have a broad spectrum of activity and are toxic to many non-target organisms, including several parasitoids (Talitskii & Kondrya 1970, Hagley & Laing 1989, Purcell & Granett 1986) and predators (Hagely 1978, Hardman & Gaul 1990). Moreover, their extensive use has resulted in resistance development in many pest populations including codling moth, and outbreaks of non-target apple pests (Hardman & Gaul 1990).

Resistance to organophosphate azinphosmethyl has been reported for codling moth in field populations in Oregon, California, Washington and Utah (Varela *et al.* 1993, Knight *et al.* 1994). This has threatened integrated pest management programs of apple pests, which was developed over a period of 30 years (Croft & Hoyt 1983). Now, many growers have started using organophosphates at the maximum label rate per season (Knight *et al.* 1994), that may lead to a further increase in the present level of resistance. Also, some growers have replaced OP insecticides with synthetic pyrethroids. This shift may threaten the integrated control of spider mites (Croft & Riedl 1991) which is based on the use of predaceous mites, and limit the potential for biological control of other pests (Croft & Hoyt 1983). In Nova Scotia, development of resistance against organophosphate insecticides in populations of winter moth, *Operophtera brumatta* (L.) and spotted tentiform leafminer,

Phyllonorycta blancardella (F.), has already led to recommended use of pyrethroids in apple orchards (Hardman & Gaul 1990). However, some integrated pest control systems based on the use of lower concentrations of chemical insecticides have been very effective. Use of lower concentrations may reduce the development of resistance in pest populations (Gist & Pless 1985) and minimize detrimental effects to beneficial arthropods (Jaques & Morris 1981, Ross & Brown 1982, Dutcher 1993). In apple and pear orchards, using reduced rates of organophosphate and pyrethroid insecticides has enabled sufficient survival of arthropod predators, thus resulting in less disruption of tetranychid mites populations (Hoyt 1969, Madge 1972, Thwaite 1976, Hardman & Gaul 1990). It is, therefore, highly desirable to develop a safer alternative management program based on markedly reduced rates of insecticides, and perhaps mixing them with some microbial agents.

The insecticidal bacterium *Bacillus thuringiensis* (*B. thuringiensis*) is the most widely used alternative insect control agent at present, and the one most likely to be used even more extensively in the future. Formulations of the *B. thuringiensis* that are effective in control of many lepidopterous pests of agricultural crops, are usually not effective against codling moth (Reissig *et al.* 1984, de Reed *et al.* 1985, Andermatt 1988, Croft & Riedl 1991). This failure is unfortunate because this microbial insecticide is relatively nontoxic to the environment and its novel mode of action could be useful in a pesticide rotation schedule to help combat pesticide resistance (Moar & Trumble 1987). However, *B. thuringiensis* in combination with low or sublethal doses of chemical insecticides have been shown to be more effective in killing various lepidopterous larvae than either agent alone (Morris 1972 & 1975, Hamilton & Attia 1977, Creighton & McFadden 1974, Mohammed *et al.* 1983a & b, Salama *et al.* 1984, Richter & Fuxa 1984, Jaques & Laing 1989). Such an approach is of considerable interest not only as a method of reducing amount of chemical insecticides applied to the crop but also as a means of enhancing effectiveness of pathogenic organism in protecting crop without sacrifying quality or quantity of yield. Also, it is a way of minimizing the environmental effects of chemical insecticides while still making effective use of them.

Several workers have reported the potentiation of microbial insecticides by mixing them with chemical insecticides (Chen *et al.* 1974, Mohammed *et al.* 1983b, Salama *et al.*,. 1984, Richter & Fuxa 1984, Luo *et al.* 1986, Yeh *et al.* 1986, Jaques 1988, Jaques & Laing 1989) and, indeed, if no interaction occurs between molecules of different types of insecticidal agents in an insect, an additive effect may be expected (Morris 1972). Nevertheless, antagonism or synergism also have been observed in some cases (Jaques & Morris 1981). Many studies demonstrated that synergism and antagonism are sometimes rather a question of concentrations than of which microorganism is combined with which insecticide (Benz 1971). There have been many attempts to find synergistic pathogen-insecticides combinations for insect control (Jaques & Morris 1981). Synergistic combinations involving microbial agents could partially offset their disadvantage of being too specific when pest complexes must be controlled in a crop (Richter and Fuxa 1984). Hardman and Gaul (1990) found mixtures of *B. thuringiensis* and some pyrethroids efficacious against *Operophtera brumata* (L.) and other apple pests in Nova Scotia without causing outbreaks of mite pests. Combining low rates of organophosphate and carbamate compounds with *B. thuringiensis* and *Beauveria bassiana* has provided effective control of codling moth in Europe (G"onev 1975, Karadzhov 1973a & 1974, Malevez 1978, Tomova & Rangelova 1977, Croft & Riedl 1991). However, no laboratory study has been ever performed to investigate compatibility, toxicity and interactions of various combinations of *B. thuringiensis* and lower or sublethal dosages of commonly used chemical insecticides against codling moth.

The study reported here presents the result of experiments conducted to evaluate the effectiveness of mixtures of some chemical and *Bacillus thuringiensis*-based formulations, Dipel and MVP, and to determine type of their joint action (synergism, additivity and antagonism) against codling moth.

Materials and Methods

Insects:

Insects needed for this study were obtained from a laboratory culture of codling moth maintained in our laboratory using method similar to those described by Riedl and Loher (1980) with some modifications. Laboratory culture was established and reared from larvae/pupae collected from the study orchards in 1990. Batches of larvae from the same orchard were added annually to maintain genetic diversity and vigor in the colony (Riedl *et al.* 1985). The culture was maintained on thinning apples at 24 $\pm$ 1°C and 16 L: 8 D photoperiod. Under these conditions, an average of 90.5 $\pm$ 3.4 % of mature larvae pupated without entering diapause. The adults were fed on 5 % sucrose solution as food, and eggs obtained on wax papers. Generally eggs were stored for a short period at 10°C, and used as needed. To ensure emergence of sufficient larvae on the day of an experiment, eggs that were about to hatch, that is , those that had the blackhead stage, were held at 5-10 °C until the required day. Newly laid eggs (1 day old), 3 days old eggs, and eggs about to hatch (blackhead eggs) were used in ovo-larval (combined egg and larval) mortality tests.

Chemical Insecticides:

The insecticides tested represented various chemical classes, including organophosphorous compounds, azinphosmethyl (Guthion® 50WP) and phosmet (Imidan® 50WP); pyrethroids esfenvalerate (Asana® XL) and permethrin (Ambush® 25.6%); carbamate carbaryl (Sevin® 50WP) and the growth regulator diflubenzuron (Dimilin® 25WP). The insecticides were obtained from different manufacturers as technical material or from a freshly prepared batch of formulated material.

Microbial Control Agent:

Two formulations based on *B. thuringiensis* were used in the experiment. The formulation Dipel® 2X(Abbott Laboratories), based on the natural strain of *B.*

thuringiensis subsp. *Kurstaki*, is rated at 32,000 International Units of potency per mg (IU/mg). This formulation contained the spore and two different δ-endotoxins produced by CryIA(a) and CryIA(c) genes. The other formulation MVP® (Mycogen Corporation) is a product of the CellCap technology based on a single δ-endotoxin gene [CryIA(c)] of *B. thuringiensis* subsp. *kurstaki* genetically engineered into *Pseudomonas fluorescens* Migula, the cells of which are killed at the end of the bacterial growth phase (Feitelson *et al.* 1990). Thus, MVP is composed of one δ-endotoxin and no spores.

Insecticide Solutions:

The solution of each pesticide, alone or in mixture with microbial control agents (MCAs), was formulated in the water on the basis of weight per volume (w/v) of active ingredient. A fresh solution was prepared for each replication. A control group treated with water only was included in each replication of an experiment with a chemical, MCAs or their mixtures. The relationships between concentrations to cause mortality of neonate codling moth larvae was first established independently for MCAs and each of test insecticides. The standardized bioassay based on international unit (Dulmage *et el.* 1971) was used for *B. thuringiensis*. Several mixtures of MCAs and test insecticides were formulated on the basis of data from these independent test studies. Concentrations of chemical insecticides and MCAs causing 30-90% and 15-45% larval mortality, respectively, were mixed together in various combinations (mixtures). Mixtures having low dose of test insecticide combined with low dose of MCAs for high effectiveness (synergism or strong additivity) was sorted out as the most effective combinations for further studies.

Larval Bioassay:

The test procedures of Gratwick (1964) and Knight *et al.* (1994) were followed with minor modifications. Red delicious immature apples were thinned from the unsprayed trees in May/June and kept in a cold storage at 4°C for the year-long

supply. Apples of equal size and weight were washed, dried and then treated by dipping for 10 seconds in the insecticide solution, MCA solution or their mixtures. Control apples were dipped only in water. After air-drying for 2 hours, they were provided as food for neonate larvae in plastic cups covered with fine screen mesh for ventilation. In the present investigation a single larva was exposed to a whole apple, so that it could wander freely over the treated surface and select its point of entry in any region and to avoid cannibalism. Also, this technique ensures larval exposure to the whole residual deposit. Twenty five to thirty larvae were tested per treatment, and the experiment was repeated 4 - 5 times. These conditions provided a rigorous test for MCAs-insecticide mixtures along with a close approximation to field conditions.

One first-instar codling moth larva, less than six hours old, was placed on the upper side of each apple. This was done in a replicate fashion as described by Barnes (1958), that is one fruit of each treatment and untreated control at a time, in series. The plastic cups with larvae and treated fruit was kept at room temperature. After three days, the apples and containers were examined until the larvae were found. Where an entry was made, the apple was dissected with the aid of a binocular microscope. As a shallow entry indicated a fairly early death of the larvae (Jaques, 1961), larval mortality was evaluated in term of their ability to enter the fruit as described by Riedl *et al.* (1986). Penetration into the fruit for more than 6 mm was considered as a successful entry. Larvae which died without feeding or penetrated less than 6 mm before dying were categorized as unsuccessful. Few larvae left the apples on which they were placed, except when poisoning caused them to release their hold and drop off. The presence of low doses of some insecticides extended the wandering period or induced more surface feeding than control.

Bioassay with artificial diet was not much different from that with apple. In this case, cubes (2.2 cm^3) of artificial diet were surface-treated by dipping for 5 seconds in the test solution. Preliminary tests suggested that dipping for more than 5 seconds could result in excessive absorption of solution by the diet cube. After air-drying for 2-4 hours, the diet cubes were fed to neonates held in a plastic cup covered with fine

screen mesh for ventilation. Mortality was recorded after 3 days using the same methods as described above.

Ovo-larval Bioassay:

The test procedure for egg mortality was as described by Pree and Hagely (1977), and Hoying and Riedl (1980) with some modifications. In the present studies joint ovicidal and larvicidal activities (ovo-larval mortality or ovo-larvicidal effect from hereinafter) of low/sublethal concentrations of each insecticide and MCA, and their mixture were also recorded. Codling moth eggs were collected on wax paper in the oviposition cages. Newly laid eggs (up to 1 day old) and eggs about to hatch (blackhead: 4-5 days old) were used in the tests. With diflubenzuron 3-days old eggs also were used. Newly laid eggs were treated within 24 hours whereas as blackhead eggs were often held up to 7 days in a refrigerator to accumulate sufficient number for testing. Solutions of each and mixtures of the chemical and *B. thuringiensis*-based insecticides were prepared daily. Waxed paper strips with eggs were dipped for 10 seconds in agitated aqueous suspensions of the various treatments. Controlled eggs were dipped in water only. For each treatment and control, a total of 160 eggs were used. After the treatment, excess liquid was shaken free from the waxed paper strips. After air-drying for one hour, small pieces of wax paper with a single egg were cut and placed individually in plastic cups which were capped with thinning apple previously dipped in the same formulation. Egg mortality was assessed in term of failure of eggs to hatch and larval mortality in term of their ability to enter the fruit.

The egg and first instar mortality was adjusted for the control by using Abbott's formula. Rest of the statistical analysis was performed using adjusted values.

Statistical Procedure:

Microbial control agents and chemical insecticides have very different types of mode of actions. An additive effect is expected, if no interaction occurs between molecules of different types of insecticidal action in an insect (Morris 1972). The combined effect of a microorganism and an independently acting chemical substance

can be calculated if the effect of each agent alone is known. Observed joint mortality of larvae fed upon mixtures of these components in the absences of interaction between them should be at least as great as the mortality caused by the more active component, but not greater than the sum of the activities (additive relationship) of the component acting separately, depending on the degree of correlation (Jaques *et al.* 1989). Therefore, the null hypothesis used in these studies was that of independent, uncorrelated joint action as described by Bliss (1939). Under this hypothesis, the toxicity of each component in the mixture is unaffected by other (i.e. independent) and susceptibility to one mixture component is not correlated with susceptibility to the other component (i.e. uncorrelated). This represents an additive effect or additivity. Robertson and Smith (1984) defined *synergism* as the occurrence of significantly greater mortality than that predicted by a mathematical equation/model of an additive effect (independent, uncorrelated action) and *antagonism* as significantly reduced mortality.

Procedure described by Finney (1964), used recently by a number of authors (McVay *et al.* 1977, Salama *et al.* 1984, Richter and Fuxa 1984, Morris 1988 and Gardner 1988, Morris *et al.* 1994) for similar type of studies, for determining expected mortality was used for the present studies (as given below):

$$E = O_m + O_i \ (1 - O_m)$$

where E is percentage of mortality expected, O_m is the observed percentage mortality produced by microbial agent alone and O_i is the observed percentage mortality produced by insecticide alone. The derivative of this equation and the Abbot's formula, a test for independent action (Benz 1971), is the same. Chi-square test was used to compare expected and observed mortality. The Chi-square (χ^2) value was calculated as:

$$\chi^2 = (O_c - E)^2 / E$$

where O_c is observed mortality for the combination and E is the expected value. Results from χ^2 test was compared to the χ^2 tabulated value. If the Chi-square value was < 3.84 (Table chi-square = 3.84, df = 1, P = 0.05), then the mortalities were within the range expected for additive effects. If chi-square was > 3.84, the mortalities from the expected, and the effects of the synergistic or antagonistic (Salama *et al.* 1984). However, in order to define and explain a general trend of joint activity, we designated some interactions as weakly synergistic or antagonistic (chi-square = 2.71, df = 1, P = 0.1), moderately synergistic (chi-square = 3.84, df = 1, P = 0.05), and strongly synergistic (chi-square = 6.63, df = 1, P = 0.01).

A cotoxicity factor *(CTF)* was also calculated (Mansour *et al.* 1966, Morris *et al.* 1994) with the formula:

$$CTF = \frac{O_c - O_e}{O_c} \times 100$$

where O_c is the observed percentage mortality produced by the combination, O_e is the expected percentage mortality. Morris *et al.* (1994) suggested that a factor of +21 or more indicates synergism; -21 or less indicates antagonism; and -21 to +21 indicates an additive effect. Mansour *et al.* (1966) proposed a factor of 20 for the same. This factor is usually allowed to cover experimental and biological variation associated with a response. In general, *CTF* defines percentage deviation in observed mortality of a mixture from an expected calculated value (mortality). Hence, a positive factor of 21 means 21% increase in observed joint mortality over an expected joint mortality.

Analysis of variance (ANOVA) and Fisher's Protected Least Significant Difference (FPLSD) were used to analyze significant difference between mortalities produced by different treatments.

Results

Data (Table 3.1-3.7) show the response of codling moth neonates to *Bacillus thuringiensis* based formulations, chemical insecticides and their mixtures. Ovicidal and combined ovo-larvicidal (ovicidal and larvicidal) activity of the individual insecticides and their different combinations are presented in Tables 3.8 and 3.9. A slightly higher larval mortality with surface-treated diet (Table 3.7) compared to that of treated apples (Table 3.1-3.6) at the same concentration of a given pesticide suggests increased feeding activity of codling moth neonates on treated diets. Artificial diet may have absorbed higher amounts of insecticides. In addition, this differential response may be a result of presence of plant allelochemicals in apples. Such allelochemicals are considered to modify levels of detoxifying enzymes in herbivores and, therefore, their susceptibility to insecticides (Lindroth *et al.* 1989 & 1990, Berry *et al.* 1993).

Toxicity of Natural and Genetically Engineered Insecticides Based on *Bacillus thuringiensis* [Microbial Control Agents (MCAs)]:

Four different formulations of *B. thuringiensis* were tested against the neonate larvae of codling moth in another laboratory study (Bajwa and AliNiazee 1995). Based on these preliminary data two *B. thuringiensis*-based insecticides, Dipel 2X and MVP were selected in this study. Dipel was selected because of its versatile availability, and MVP because of its reported greater environmental stability than other *B. thuringiensis* formulations (Gelernter 1990a, b). Dipel (active ingredient) concentrations of 0.5-1.0 MIU/liter and MVP (active ingredient) concentrations of 125-250 ppm were used. Data from treated apples (Tables 3.1-3.6) and surface treated diet (Table 3.7) showed a low level susceptibility of codling moth neonates to these bacterial insecticides at the dosages tested. Even the higher concentrations of

Table 3.1: Interactions of Microbial Control Agents and Azinphosmethyl in Neonate Codling Moth.

For all interactions and control, n = 120 (four replications). Chi Square = 2.71 and 3.84 at df=1 respectively for alpha = 0.1 and 0.05). *, significant at P= 0.1, **, significant at P= 0.05 and ***, significant at P= 0.01. Values followed by different letters are significantly different at 95% confidence interval.

Insecticide Concentration			Observed mortality (%)		Expected mortality (%)	Chi-Square	Cotoxicity factor	Conclusion
Dipel (MIU/L.)	MVP (ppm)	Azinphos-methyl (ppm						
0.50	-	-	12.3	u	-	-	-	-
1.00	-	-	25.7	t	-	-	-	-
2.00	-	-	35.3	r	-	-	-	-
4.00	-	-	41.9	q	-	-	-	-
					-	-	-	-
-	125	-	7.0	v	-	-	-	-
-	250	-	31.2	rs	-	-	-	-
-	500	-	35.0	r	-	-	-	-
-	750	-	50.0	op	-	-	-	-
-	-	10	28.3	st	-	-	-	-
-	-	25	62.7	l	-	-	-	-
-	-	50	72.3	k	-	-	-	-
-	-	75	80.8	hij	-	-	-	-
-	-	150	92.5	cd	-	-	-	-
-	-	300	100.0	a	-	-	-	-
0.50	-	10	35.8	r	37.2	0.1	-3.7	Additivity
0.50	-	25	57.3	m	67.3	1.5	-14.8	Additivity
0.50	-	50	75.8	jk	75.7	0.0	0.2	Additivity
0.50	-	75	82.8	ghi	83.1	0.0	-0.4	Additivity
0.50	-	150	93.3	bcd	93.4	0.0	-0.1	Additivity
1.00	-	10	49.0	op	46.7	0.1	4.8	Additivity
1.00	-	25	84.4	fgh	72.3	2.0	16.8	Additivity
1.00	-	50	94.2	bcd	80.4	2.4	17.2	Additivity
1.00	-	75	98.2	ab	85.7	1.8	14.6	Additivity
1.00	-	150	91.5	cde	94.4	0.1	-3.1	Additivity
2.00	-	10	54.0	mno	53.7	0.0	0.7	Additivity
2.00	-	25	86.8	efg	75.9	1.6	14.4	Additivity
2.00	-	50	93.7	bcd	82.1	1.7	14.2	Additivity
2.00	-	75	91.2	cde	87.6	0.2	4.2	Additivity
2.00	-	150	89.3	def	95.2	0.4	-6.1	Additivity
-	125	10	35.9	r	33.4	0.2	7.5	Additivity
-	125	25	63.7	l	65.3	0.0	-2.4	Additivity
-	125	50	66.5	l	74.2	0.8	-10.4	Additivity
-	125	75	76.9	jk	82.1	0.3	-6.3	Additivity
-	125	150	91.7	cde	93.0	0.0	-1.5	Additivity
-	250	10	45.6	pq	50.7	0.5	-10.0	Additivity
-	250	25	78.0	ij	74.3	0.2	5.0	Additivity
-	250	50	86.1	efg	80.9	0.3	6.4	Additivity
-	250	75	95.9	abc	86.8	1.0	10.6	Additivity
-	250	150	91.1	cde	94.9	0.1	-3.9	Additivity
-	500	10	52.1	no	53.4	0.0	-2.5	Additivity
-	500	25	80.6	hij	75.7	0.3	6.4	Additivity
-	500	50	94.1	bcd	82.0	1.8	14.7	Additivity
-	500	75	87.1	efg	87.5	0.0	-0.5	Additivity
-	500	150	84.6	fgh	95.1	1.2	-11.1	Additivity

Dipel (2.00-4.00 MIU/l a.i.) and MVP (500-750 ppm a.i.) did not give adequate suppression. The response of larvae to both MCAs increased with increasing concentrations, but, these high concentrations are unfeasible for use. None of MCA formulations tested showed any ovicidal activity except the two highest concentrations of MVP, even those were statistically non-significant (Tables 3.6, 3.8 & 3.9). The susceptibility of larvae hatching from newly laid or blackhead eggs treated with the MCA-insecticide mixtures, suggests some residual effect. However, MCAs did not enhance the ovicidal activity of chemical insecticides. In general, the data presented here showed that *B. thuringiensis* based insecticides (using spores and/or δ-endotoxin) were ineffective for the control of codling moth even at 3-4 times the recommended field rate.

Interaction between MCAs and Organophosphorous Insecticides

Interaction between MCAs and Azinphosmethyl:

Based on the mortality noticed in MCA and azinphosmethyl treatments, an expected mortality table was developed to show the additive effect (Table 3.1). Chi-square values and cotoxicity index is also provided. Data (Table 3.1) show that at different combination levels of MCA and azinphosmethyl, the difference between the expected and observed mortality was not significant. Both MCAs tested (Dipel and MVP) in combination with azinphosmethyl produced almost the same effects. All interactions were generally additive. Mortality increased as azinphosmethyl concentration was increased to 75 ppm combined with 1.0 MIU/l (a.i.) of Dipel or 250 ppm (a.i.) MVP. At 150 ppm, azinphosmethyl produced no apparent (inapparent antagonism: Habib and Garcia, 1981) effect at all MCA concentrations. It seems that the highest concentration of this chemical apparently had no effect on total mortality. Most mixtures with moderate to higher MCA concentrations produced significantly higher mortality than either ingredient alone. Strong additive effect (CTF = 10-20)

Table 3.2: Interactions of Microbial Control Agents and Phosmet in neonate Codling moth.

Insecticide Concentration			Observed		Expected	Chi-	Cotoxicity	Conclusion
Dipel (MIU/L.)	MVP (ppm)	Phosmet (ppm)	mortality (%)		mortality (%)	Square	factor	
0.50	-	-	12.3	p	-	-	-	-
1.00	-	-	25.7	o	-	-	-	-
2.00	-	-	35.3	mn	-	-	-	-
4.00	-	-	41.9	l	-	-	-	-
-	125	-	7.0	p	-	-	-	-
-	250	-	31.2	n	-	-	-	-
-	375	-	35.0	mn	-	-	-	-
-	500	-	50.0	k	-	-	-	-
-	-	50	38.6	lm	-	-	-	-
-	-	100	58.8	ij	-	-	-	-
-	-	150	73.0	gh	-	-	-	-
-	-	200	80.5	def	-	-	-	-
-	-	600	100.0	a	-	-	-	-
0.50	-	50	39.4	lm	46.2	1.0	-14.8	Additivity
0.50	-	100	62.6	i	63.9	0.0	-2.0	Additivity
0.50	-	150	73.2	gh	76.4	0.1	-4.2	Additivity
0.50	-	200	85.8	bcd	82.9	0.1	3.6	Additivity
1.00	-	50	48.9	k	54.4	0.6	-10.1	Additivity
1.00	-	100	76.0	fgh	69.4	0.6	9.6	Additivity
1.00	-	150	86.1	bc	80.0	0.5	7.6	Additivity
1.00	-	200	87.0	bc	85.5	0.0	1.8	Additivity
2.00	-	50	60.6	ij	60.3	0.0	0.6	Additivity
2.00	-	100	78.7	efg	73.4	0.4	7.3	Additivity
2.00	-	150	86.3	bc	82.6	0.2	4.5	Additivity
2.00	-	200	85.7	bcd	87.4	0.0	-1.9	Additivity
-	125	50	38.5	lm	43.0	0.5	-10.5	Additivity
-	125	100	56.1	j	61.7	0.5	-9.1	Additivity
-	125	150	72.6	h	74.9	0.1	-3.1	Additivity
-	125	200	87.0	bc	81.9	0.3	6.2	Additivity
-	250	50	58.8	ij	57.8	0.0	1.7	Additivity
-	250	100	73.6	gh	71.7	0.1	2.7	Additivity
-	250	150	87.6	b	81.5	0.5	7.6	Additivity
-	250	200	85.9	bc	86.6	0.0	-0.8	Additivity
-	375	50	57.6	ij	60.1	0.1	-4.3	Additivity
-	375	100	75.5	fgh	73.2	0.1	3.1	Additivity
-	375	150	87.2	b	82.5	0.3	5.7	Additivity
-	375	200	81.8	cde	87.3	0.3	-6.3	Additivity

For all interactions and control, n=120 (four replications). Values followed by different letters are significantly different at P = 0.05.

was observed with moderate to higher MCA and low to moderate concentrations of azinphosmethyl. As the MCA concentrations were increased (from moderate to the highest), the additive effect apparently weakened. Mortality by most mixtures containing the lowest test concentrations of MCAs or the highest test concentration of azinphosmethyl was less, or if higher, it was not significantly different from that of azinphosmethyl alone. In experiments with surface-treated diet (Table 3.7), azinphosmethyl in combination with Dipel or MVP produced a similar additive effect. This confirmed the result obtained in experiments with apples. Overall, azinphosmethyl in combination with Dipel gave better results than with MVP but none of the combination resulted in synergism.

Results in Tables 3.8 and 3.9 indicate that azinphosmethyl had some ovicidal effects. It was considerably more toxic to blackhead eggs than to newly laid eggs. When the larvae emerged from treated blackhead eggs, they were exposed to the mixtures of MCAs and insecticide, the joint ovo-larvicidal activity showed a moderate to strong additivity or marginal synergism (P = 0.1). Usually, an additive effect was observed in case of newly laid eggs. The combined effects were slightly better in combinations with Dipel at either stage of eggs than with MVP.

Interaction between MCAs and Phosmet:

Phosmet in combination with both Dipel and MVP produced results (Table 3.2) similar to azinphosmethyl. In general, phosmet was highly effective against the codling moth larvae. When applied in a mixture of insecticide and MCA, the ovo-larval mortality increased (Table 3.8 and 3.9) indicating an additive response. The general mortality levels were pretty close to the expected mortality levels. No synergistic or antagonistic response were noticed.

Table 3.3: Interactions of Microbial Control Agents and Carbaryl in neonate Codling moth.

Insecticide Concentration			Observed		Expected	Cotoxicity	Chi-	Conclusion
Dipel (MIU)	MVP (ppm)	Carbaryl (ppm)	mortality (%)		mortality (%)	factor	Square	
0.50	-	-	14.08	t	-	-	-	-
1.00	-	-	23.10	s	-	-	-	-
2.00	-	-	31.80	r	-	-	-	-
4.00	-	-	41.30	p	-	-	-	-
-	125	-	12.83	t	-	-	-	-
-	250	-	28.07	rs	-	-	-	-
-	500	-	33.28	qr	-	-	-	-
-	750	-	47.50	o	-	-	-	-
		30	29.79	r	-	-	-	-
		60	63.52	l	-	-	-	-
		90	77.27	ij	-	-	-	-
		120	86.79	d-g	-	-	-	-
		300	100.00	a	-	-	-	-
0.50	-	30	41.67	p	39.68	5.03	0.10	Additivity
0.50	-	60	73.58	jk	68.66	7.17	0.35	Additivity
0.50	-	90	85.35	e-h	80.47	6.06	0.30	Additivity
0.50		120	92.67	bcd	89.84	3.15	0.09	Additivity
1.00	-	30	50.96	no	46.01	10.76	0.53	Additivity
1.00	-	60	83.53	gh	71.95	16.10	1.87	Additivity
1.00	-	90	95.39	abc	82.52	15.60	2.01	Additivity
1.00	-	120	100.00	a	89.84	11.31	1.15	Additivity
2.00	-	30	55.99	mn	52.11	7.44	0.29	Additivity
2.00	-	60	87.62	d-g	75.12	16.64	2.08	Additivity
2.00	-	90	94.01	bc	84.50	11.26	1.07	Additivity
2.00	-	120	90.76	cde	90.99	-0.25	0.00	Additivity
-	125	30	37.70	pq	38.80	-2.83	0.03	Additivity
-	125	60	69.99	k	68.20	2.62	0.05	Additivity
-	125	90	80.58	hi	80.19	0.49	0.00	Additivity
-	125	120	89.81	c-f	88.48	1.50	0.02	Additivity
-	250	30	54.46	mn	49.50	10.02	0.50	Additivity
-	250	60	84.37	fgh	73.76	14.38	1.53	Additivity
-	250	90	97.25	ab	83.65	16.26	2.21	Additivity
-	250	120	100.00	a	90.50	10.50	1.00	Additivity
-	500	30	59.88	lm	53.15	12.65	0.85	Additivity
-	500	60	82.69	ghi	75.66	9.29	0.65	Additivity
-	500	90	93.92	bc	84.83	10.71	0.97	Additivity
-	500	120	92.40	bcd	91.19	1.33	0.02	Additivity

For all interactions and control, n=120 (four replications). Values followed by different letters are significantly different at P = 0.05.

Interaction between MCAs and Carbamates

Only one carbamate insecticide carbaryl was tested in these experiments. Since carbaryl is registered for use on apples and is used both as a fruit thinning and an insecticidal agent, we selected this insecticide for our tests. Data (Table 3.3) show the effect of MCAs alone and in combination with carbaryl. Significantly higher mortalities were noticed in mixtures than in either insecticide alone. Dipel at the lowest concentration with carbaryl produced better results than with the organophosphates (Tables 3.1 and 3.2). The effect of most mixtures containing low to moderate concentrations of carbaryl (30, 60 and 90 ppm) and moderate concentrations of MCAs was highly additive (CTF = 10-20). Except with moderate concentrations of either MCA, the response of the neonates did not increase appreciably with an increased concentration of carbaryl in the mixture beyond 90 ppm. Overall, the observed activity of the mixtures was pretty close to the expected levels and no significant difference were noticed. Results clearly establish an additive response of combinations of carbaryl with MCAs. Similar results were obtained when surface treated diet was used with some selected combinations (Table 3.7).

Carbaryl like organophosphorous insecticides were more toxic to the blackhead eggs than newly laid eggs (Table 3.8 and 3.9). When both codling moth eggs (at either stage) and 1st instar larvae were exposed to the mixtures of carbaryl and MCAs, the joint ovo-larval mortality was found to be additive of the effects produced by individual components alone. In experiments with newly laid eggs, 100% combined ovo-larval mortality was obtained with carbaryl at 90 ppm and Dipel at 1.0 MIU/l (a.i.) or MVP at 250 ppm (a.i.), whereas, with blackhead stage eggs the same was achieved at lower rate of 60 ppm of the chemical at the same levels of MCAs.

Table 3.4: Interactions of Microbial Control Agents and Permethrin in Neonate Codling Moth.

Insecticide Concentration									
Dipel (MIU/L.)	MVP (ppm)	Permethrin (ppm)	Observed mortality		Expected mortality	Chi-square		Cotoxicity factor	Conclusion
0.50	-	-	9.2	r					-
1.00	-	-	20.9	q					-
2.00	-	-	31.8	p					-
4.00	-	-	38.4	op					-
-	125	-	15.3	qr	-	-			-
-	250	-	32.9	p	-	-			-
-	500	-	36.5	op	-	-			-
-	750	-	46.6	n	-	-			-
-	-	0.50	40.3	o	-	-			-
-	-	1.00	62.0	l	-	-			-
-	-	2.00	71.7	ij	-	-			-
-	-	4.00	87.7	de	-	-			-
-	-	16.00	100.0	a	-	-			-
0.50	-	0.50	53.2	m	45.8	1.2		16.1	Additivity
0.50	-	1.00	72.8	ij	65.5	0.8		11.2	Additivity
0.50	-	2.00	82.2	fg	74.3	0.8		10.6	Additivity
0.50	-	4.00	95.7	abc	88.8	0.5		7.7	Additivity
1.00	-	0.50	69.3	jk	52.8	5.2	*	31.3	Synergism
1.00	-	1.00	88.2	de	69.9	4.8	**	26.2	Synergism
1.00	-	2.00	95.1	abc	77.6	3.9	**	22.5	Synergistic
1.00	-	4.00	100.0	a	90.3	1.0		10.8	Additivity
2.00	-	0.50	71.8	ij	59.3	2.7		21.2	Additivity
2.00	-	1.00	92.9	cd	74.1	4.8	**	25.4	Synergism
2.00	-	2.00	83.6	efg	80.7	0.1		3.7	Additivity
2.00	-	4.00	87.6	de	91.6	0.2		-4.4	Additivity
	125	0.50	48.4	mn	49.5	0.0		-2.2	Additive
-	125	1.00	66.3	kl	67.8	0.0		-2.2	Additivity
-	125	2.00	73.7	ij	76.0	0.1		-3.0	Additivity
-	125	4.00	88.3	de	89.6	0.0		-1.4	Additivity
-	250	0.50	71.7	ij	59.9	2.3		19.7	Additivity
-	250	1.00	91.6	d	74.5	4.0	**	23.0	Synergistic
-	250	2.00	98.7	ab	81.0	3.9	**	21.9	Synergistic
-	250	4.00	85.9	ef	91.8	0.4		-6.4	Additivity
-	500	0.50	79.8	gh	62.1	5.1	**	28.5	Synergistic
-	500	1.00	94.4	bc	75.8	4.5	**	24.5	Synergistic
-	500	2.00	83.6	efg	82.0	0.0		1.9	Additivity
-	500	4.00	75.6	hi	92.2	3.0	*	-18.0	Antagonistic

For all interactions and control, n=120 (four replications). Chi Square=2.71 and 3.84 at df=1, respectively for alpha=0.1 and 0.05. *, significance at P=0.1; **, significance at P= 0.05.

Table 3.5: Interactions of Microbial Control Agents and Esfenvalerate in Neonate Codling Moth.

Insecticide Concentration			Observed	Expected	Chi-square		Cotoxicity	Conclusion
Dipel	MVP	Esfenvalerate	mortality	mortality			factor	
(MIU)	(ppm) a.i.	(ppm) a.i.	(%)	(%)				
0.50	-	-	9.2 r	-	-		-	-
1.00	-	-	20.9 q	-	-		-	-
2.00	-	-	31.8 op	-	-		-	-
4.00	-	-	38.4 o	-	-		-	-
-	125	-	13.5 r	-	-		-	-
-	250	-	28.8 p	-	-		-	-
-	500	-	34.4 op	-	-		-	-
-	750	-	44.8 mn	-	-		-	-
-	-	0.25	36.6 o	-	-		-	-
-	-	0.50	48.0 m	-	-		-	-
-	-	1.00	73.3 ij	-	-		-	-
-	-	2.00	85.3 def	-	-		-	-
-	-	4.00	89.5 cd	-	-		-	-
-	-	12.00	100.0 a	-	-		-	-
0.50	-	0.25	46.5 m	42.4	0.4		9.6	Additivity
0.50	-	0.50	61.6 k	52.8	1.5		16.7	Additivity
0.50	-	1.00	83.6 d-g	75.7	0.8		10.4	Additivity
0.50		2.00	89.4 cd	86.7	0.1		3.1	Additivity
1.00	-	0.25	68.0 jk	49.9	6.6	**	36.4	Synergism
1.00	-	0.50	81.6 e-h	58.9	8.7	***	38.5	Synergism
1.00	-	1.00	96.1 abc	78.9	3.8	*	21.9	Synergism
1.00		2.00	100.0 a	88.4	1.5		13.1	Additivity
2.00		0.25	72.0 j	56.8	4.1	**	26.9	Synergism
2.00	-	0.50	84.6 d-g	64.5	6.2	**	31.0	Synergism
2.00	-	1.00	93.6 bc	81.8	1.7		14.5	Additivity
2.00	-	2.00	89.6 cd	90.0	0.0		-0.5	Additivity
-	125	0.25	44.7 mn	45.1	0.0		-1.0	Additivity
-	125	0.50	54.3 l	55.0	0.0		-1.3	Additivity
-	125	1.00	79.1 ghi	76.9	0.1		2.9	Additivity
-	125	2.00	86.7 de	87.3	0.0		-0.7	Additivity
-	250	0.25	71.6 j	54.9	5.1	**	30.5	Synergism
-	250	0.50	80.7 fgh	63.0	5.0	**	28.0	Synergism
-	250	1.00	100.0 a	81.0	4.5	**	23.5	Additivity
-	250	2.00	97.3 ab	89.6	0.7		8.6	Additivity
-	500	0.25	75.5 hij	58.4	5.0	**	29.3	Synergism
-	500	0.50	84.0 d-g	65.9	5.0	**	27.5	Synergism
-	500	1.00	87.1 de	82.5	0.3		5.6	Additivity
-	500	2.00	79.5 fgh	90.4	1.3		-12.0	Additivity

For all interactions and control, n=120 (four replications). Chi Square=2.71, 3.84 and 6.63 at df=1 respectively for alpha=0.1,0.05 and 0.01). *, significance at P=0.1; **, significance at P= 0.05 and ***, significance at P= 0.01.

Interaction between MCAs and Pyrethroids

Interaction between MCAs and Permethrin:

Data in Table 3.4 indicate that mixtures containing the lowest concentrations of Dipel (0.5 MIU/l a.i.) or MVP(125 ppm a.i.) gave an additive interaction with most joint mortalities; it was significantly higher than that of most active component alone. Interactions between Dipel at 1.00 MIU/l (a.i.) (moderate concentration) and permethrin at 0.5, 1.0 and 2.0 ppm were synergistic. At this rate of Dipel, the combined mortality apparently increased as permethrin concentration was increased to 4 ppm. With an increase of Dipel concentration from 1.0 to 2.00 MIU/l, this synergistic effect apparently weakened or changed to additivity. Synergistic interactions also occurred between moderate to high concentrations of MVP and low to moderate concentrations of permethrin. However, an interaction between the high rate of MVP at 500 ppm and permethrin at 4 ppm was marginally (lower-range) antagonistic ($P = 0.1$). In case of surface-treated diet experiments, all combinations with Dipel and MVP were highly additive, indicating a potentiating trend (Table 3.7).

In general, the joint action of the mixtures of these insecticides varied with concentrations of the components. Permethrin synergized the activities of both Dipel and MVP at some concentrations. However, additive interactions were observed at the lowest concentrations of both Dipel (0.5 MIU/l a.i.) and MVP (125 ppm a.i.). Among all the synergistic combinations, level of synergism was better with lower concentrations of either insecticides. Generally, the highest test concentration of either insecticides produced an additive effect with observed mortalities appreciably less than or not significantly different from that of their moderate concentrations.

Data in Table 3.8 and 3.9 indicate that permethrin was more toxic to newly laid egg than to blackhead eggs. However, the low concentrations were principally larvicidal. Synergism of joint ovo-larval mortality was observed with combinations of 1 ppm permethrin and MCAs at both egg stages. At higher rates of the chemical, however, this synergism was masked. This interaction suggests that codling moth

Table 3.6: Interaction of Microbial Control Agents and Diflubenzuron in Codling Moth.

Insecticide Concentration			Treatment		Mortality (%)			Cotoxicit	Chi-squa	Conclusion
Dipel MIU/L.	MVP (ppm)	Dimilin (ppm)	Egg	Apple	Observed		Expected	Factor		
0.50	-	-	-	+	12.31	r	-	-	-	-
0.50	-	-	+	-	0.00	t	-	-	-	-
1.00	-	-	-	+	25.67	q	-	-	-	-
1.00	-	-	+	-	0.00	t	-	-	-	-
2.00	-	-	-	+	35.33	nop	-	-	-	-
2.00	-	-	+	-	0.00	t	-	-	-	-
4.00	-	-	-	+	41.89	klm	-	-	-	-
4.00	-	-	+	-	0.00	t	-	-	-	-
-	125	-	-	+	7.04	rs	-	-	-	-
-	125	-	+	-	0.00	t	-	-	-	-
-	250	-	-	+	31.19	pq	-	-	-	-
-	250	-	+	-	0.00	t	-	-	-	-
-	500	-	-	+	35.03	nop	-	-	-	-
-	500	-	+	-	3.50	st	-	-	-	-
-	750	-	-	+	50.00	ij	-	-	-	-
-	750	-	+	-	4.68	st	-	-	-	-
-	-	11	-	+	0.00	t	-	-	-	-
-	-	11	+	-	37.93	mno	-	-	-	-
-	-	11	+	+	33.54	op	37.93	-11.56	0.51	Additivity
-	-	22	-	+	0.00	t	-	-	-	-
-	-	22	+	-	44.00	j-m	-	-	-	-
-	-	22	+	+	46.32	jkl	44.00	5.27	0.12	Additivity
-	-	55	-	+	0.00	t	-	-	-	-
-	-	55	+	-	55.56	hi	-	-	-	-
-	-	55	+	+	57.58	gh	55.56	3.63	0.07	Additivity
-	-	110	-	+	2.50	st	-	-	-	-
-	-	110	+	-	74.00	cd	-	-	-	-
-	-	110	+	+	78.35	abc	74.65	4.96	0.18	Additivity
0.50	-	11	+	+	46.91	jkl	41.72	12.42	0.64	Additivity
1.00	-	11	+	+	59.04	gh	50.60	16.67	1.41	Additivity
2.00	-	11	+	+	65.93	ef	57.02	15.62	1.39	Additivity
0.50	-	22	+	+	57.85	gh	52.93	9.30	0.46	Additivity
1.00	-	22	+	+	70.01	de	60.10	16.49	1.63	Additivity
2.00	-	22	+	+	75.89	bcd	65.29	16.24	1.72	Additivity
0.50	-	55	+	+	66.31	ef	62.80	5.59	0.20	Additivity
1.00	-	55	+	+	80.37	abc	68.47	17.39	2.07	Additivity
2.00	-	55	+	+	84.24	a	72.56	16.09	1.88	Additivity
-	125	11	+	+	40.50	lmn	36.43	11.18	0.46	Additivity
-	250	11	+	+	63.65	fg	54.27	17.28	1.62	Additivity
-	500	11	+	+	67.59	ef	56.82	18.95	2.04	Additivity
-	125	22	+	+	55.26	hi	50.10	10.30	0.53	Additivity
-	250	22	+	+	74.79	cd	63.06	18.60	2.18	Additivity
-	500	22	+	+	77.92	abc	65.12	19.65	2.51	Additivity
-	125	55	+	+	66.18	ef	60.56	9.27	0.52	Additivity
-	250	55	+	+	80.01	abc	70.81	13.00	1.20	Additivity
-	500	55	+	+	81.27	ab	72.44	12.20	1.08	Additivity

For all interactions and control, n=120 (four replications). Observed mortality values followed by different letters are significantly different at P = 0.05.

Table 3.7: Interaction of Microbial Control Agents and Chemical Insecticides in Neonate Codling Moth on Artificial Diet.

For all interactions and control, n=120 (four replications). Chi Square = 2.71 and 3.84 at df=1 respectively for alpha = 0.1 and 0.05. *, significant at P= 0.1, **, significant at P= 0.05 and ***, significant at P = 0.01. Values followed by different letters are significantly different at 95% confidence interval.

Insecticide (ppm/MIU/l)	Observed mortality: insecticide alone (%)		With Dipel (%)		With MVP (%)		Expected mortality With Dipel (%)	With MVP (%)	Cotoxicity factor With MVP	With MVP	Conclusion With Dipel	With MVP
Dipel												
0.5 MIL/l	19.54	g		-			-	-	-	-	-	-
1.0 MIU/l	31.00	f		-			-	-	-	-	-	-
MVP												
125.00	15.85	g		-			-	-	-	-	-	-
250.00	36.79	f		-			-	-	-	-	-	-
Azinphosmethyl												
10	46.27	e	63.28	d	70.12	e	0	0.25	0.56	6.18	Additivity	Additivity
25	67.95	c	87.93	b	83.87	cd	1.3	0.21	12.90	5.18	Additivity	Additivity
50	85.87	a	100.00	a	97.85	ab	1.05	0.51	10.80	7.45	Additivity	Additivity
Phosmet												
50	57.02	d	69.30	d	67.99	e	0.02	0.32	-1.49	-6.65	Additivity	Additivity
100	75.60	b	80.44	c	78.77	d	0.09	0.4	-3.27	-6.87	Additivity	Additivity
Carbaryl												
60	72.47	bc	92.70	b	86.98	c	1.69	0.23	14.44	5.30	Additivity	Additivity
90	85.90	a	100.00	a	100.00	a	1.05	0.87	10.78	9.78	Additivity	Additivity
Dimilin												
22	3.15	h	35.78	e	40.26	f	0.2	0.06	7.86	3.81	Additivity	Additivity
55	7.06	h	40.69	e	45.25	f	0.65	0.39	13.43	9.69	Additivity	Additivity
Esfenvalerate												
0.50	70.58	bc	91.91	b	93.63	b	1.87	1.84	15.32	15.02	Additivity	Additivity
1	85.17	a	100.00	a	100.00	a	1.17	0.97	11.40	10.35	Additivity	Additivity
Permethrin												
1	72.27	bc	89.95	b	96.19	ab	1.93	2.28	15.78	16.63	Additivity	Additivity
2	83.16	a	100.00	a	100.00	a	2.12	1.27	15.67	11.91	Additivity	Additivity

neonates hatched from the insecticide alone or mixture treated eggs, would be considerably more susceptible (P = 0.5) to the mixtures, i. e., on subsequent exposure to the mixture, they produced significantly higher mortality (P = 0.5) than if these neonates had been exposed to the mixture-component alone.

Interaction between MCAs and Esfenvalerate:

Table 5 indicates that some concentrations of esfenvalerate gave synergistic response with moderate and high concentrations of the both MCAs. However, additive interactions occurred at the lower concentrations of MCAs with most joint effects significantly higher than that of mixture components acting alone. At the lowest and moderate concentration of MCAs, the joint larval mortality was proportional to the concentration of esfenvalerate. Synergism or additivity was less pronounced when MCAs were applied at higher concentrations. That is, the mortality apparently decreased or did not significantly changed between Dipel concentrations (a.i.) of 1.0 and 2.0 MIU/l and MVP concentrations (a.i.) of 250 and 500 ppm. In general, combination effects were more potentiating at moderate test concentrations of both insecticides. However, the joint mortality in most combinations was significantly different from that of most active component alone. Experiments with surface-treated diet indicated that all the combination were additive. Yet, there was an increase of above 15% in observed mortalities over expected ones at 0.5 ppm of the chemical, suggesting a potentiating trend.

Data in Table 3.8 and 3.9 indicate that esfenvalerate like permethrin was more toxic to newly laid egg than to blackhead eggs. At both stages of eggs, marginal or real synergism of joint ovo-larval mortality was observed with the combination having 0.5 ppm of esfenvalerate. In this case and that of experiments with diet, at 1 ppm of esfenvalerate, however, this effect was masked by the highest mortality (100%) caused by the mixtures.

Interaction between MCAs and Diflubenzuron

Results (Tables 3.6, 3.7 and 3.8) indicate that diflubenzuron alone did not produce appreciable mortality of codling moth neonates when applied to apple- or diet surface. Nevertheless, diflubenzuron produced a significant mortality of 0-1, 3 and 5-7 day old codling moth eggs even at the lowest test concentration (Tables 3.6, 3.8 and 3.9). When both eggs and apples were treated with diflubenzuron, there were additive interactions of joint ovo-larval mortality at all test concentrations. This effect was significantly enhanced further by combining either Dipel or MVP with these concentrations. The combinations never produced 100% mortality, however, joint ovo-larval mortality of newly laid eggs was as great as that of full (field recommended) rate of diflubenzuron (110 ppm). Experiments with surface treated artificial diet produced similar results of larval mortality (Table 3.7).

Table 3.8: Combined Eggs and First-Instar Larval (Ovo-larval) Mortality of Codling Moth, when Newly Laid Eggs and Neonate Larvae were exposed to Microbial and Chemical Insecticide Mixtures.

For all interactions and control, n = 120 (four replications). Chi Square = 2.71 and 3.84 at df=1 respectively for alpha = 0.1 and 0.05). *, significant at P= 0.1, **, significant at P= 0.05 and ***, significant at P= 0.01. Values followed by different letters are significantly different at 95 % confidence interval.

Insecticide/ MCA	Concentration Chemical insecticide (ppm)	Dipel (MIU/L.)	MVP (ppm)	Eggs Failed to hatch (%)	S.E		Observed Ovo-larval mortality (%)	S.E.		Expected Ovo-larval mortality (%)	Cotoxicity Factor (%)	Chi-square Value		Conclusion
Dipel	-	1	-	0.0			24.0	2.8	c	-	-	-		-
	-	2	-	0.0			27.0	4.4	c	-	-	-		-
	-	4	-	0.0			38.3	4.2	a	-	-	-		-
MVP	-	-	250	0.0			24.7	3.4	c	-	-	-		-
	-	-	500	0.0			33.2	4.2	b	-	-	-		-
Azinphos-methyl	25	-	-	5.6	0.4	c	74.8	2.9	e	-	-	-		-
	50	-	-	11.1	2.4	b	85.0	3.2	d	-	-	-		-
	250	-	-	24.1	3.0	a	100.0	0.0	a	-	-	-		-
	25	1	-	6.9	1.1	c	87.2	2.0	cd	81.59	6.92	0.39		Additivity
	50	1	-	9.9	2.2	bc	97.7	1.9	ab	89.05	9.65	0.83		Additivity
	25	-	250	7.2	1.4	bc	84.6	3.6	d	83.14	1.76	0.03		Additivity
	50	-	250	12.0	1.9	b	92.7	2.7	bc	89.97	3.03	0.08		Additivity
Phosmet	100	-	-	9.4	1.5	bc	59.1	2.9	e	-	-	-		-
	150	-	-	14.1	1.5	b	82.0	5.1	c	-	-	-		-
	600	-	-	36.5	3.8	a	100.0	0.0	a	-	-	-		-
	100	1	-	6.2	0.9	c	77.5	3.7	cd	70.17	10.45	0.77		Additivity
	150	1	-	16.0	2.2	b	90.2	3.3	b	86.83	3.83	0.13		Additivity
	100	-	250	8.2	1.5	bc	69.3	2.8	d	72.68	-4.67	0.16		Additivity
	150	-	250	13.7	2.3	b	88.4	3.1	b	87.94	0.55	0.00		Additivity
Carbaryl	60	-	-	6.0	1.1	b	67.6	4.1	c	-	-	-		-
	90	-	-	7.9	2.0	b	83.9	5.2	b	-	-	-		-
	300	-	-	17.1	2.9	a	100.0	0.0	a	-	-	-		-
	60	1	-	6.1	1.3	b	91.6	3.0	b	88.26	3.75	0.12		Additivity
	90	1	-	8.7	1.8	b	100.0	0.0	a	93.84	6.56	0.40		Additivity
	60	-	250	5.1	1.5	b	87.4	3.9	b	89.25	-2.06	0.04		Additivity
	90	-	250	8.3	1.1	b	100.0	0.0	a	94.36	5.98	0.34		Additivity
Dimilin	22	-	-	67.5	4.5	c	72.6	4.8	c	-	-	-		-
	55	-	-	75.9	5.9	b	80.6	3.3	bc	-	-	-		-
	110	-	-	90.6	4.4	a	96.0	2.6	a	-	-	-		-
	22	1	-	63.5	5.8	cd	87.3	2.9	b	80.03	9.07	0.66		Additivity
	55	2	-	64.1	4.3	cd	96.1	3.4	a	83.13	15.63	2.03		Additivity
	22	-	250	60.3	3.7	d	85.1	4.3	b	81.71	4.10	0.14		Additivity
	55	-	250	78.1	3.6	b	97.6	1.4	a	87.00	12.23	1.30		Additivity
Esfen-valerate	0.5	-	-	5.9	1.1	b	69.4	4.5	c	-	-	-		-
	1.0	-	-	9.3	1.2	b	85.6	3.7	b	-	-	-		-
	12.0	-	-	38.8	4.0	a	100.0	0.0	a	-	-	-		-
	0.5	1	-	8.0	2.2	b	100.0	0.0	a	76.78	30.25	7.03	***	Synergism
	1.0	1	-	10.1	1.6	b	100.0	0.0	a	89.04	12.31	1.35		Additivity
	0.5	-	250	6.9	2.0	b	100.0	0.0	a	79.57	25.68	5.25	**	Additivity
	1.0	-	250	9.2	1.8	b	100.0	0.0	a	90.36	10.67	1.03		Additivity
Permethri	1	-	-	9.1	0.9	b	73.1	5.8	c	-	-	-		-
	2	-	-	11.4	1.6	b	82.5	4.2	b	-	-	-		-
	12	-	-	30.4	4.0	a	100.0	0.0	a	-	-	-		-
	1	1	-	9.5	1.5	b	100.0	0.0	a	79.53	25.73	5.27	**	Synergism
	2	1	-	12.9	2.4	b	100.0	0.0	a	86.74	15.29	2.03		Additivity
	1	-	250	7.7	1.3	b	100.0	0.0	a	81.99	21.96	3.95	**	Synergism
	2	-	250	12.5	2.6	b	100.0	0.0	a	88.33	13.21	1.54		Additivity

Table 3.9: Combined Eggs and First-Instar Larval (Ovo-larval) Mortality of Codling Moth, when Blackhead Stage Eggs and Neonate Larvae were exposed to Microbial and Chemical Insecticide Mixtures.

For all interactions and control, n = 120 (four replications). Chi Square = 2.71 and 3.84 at df =1 respectively for alpha = 0.1 and 0.05). *, significant at P= 0.1, **, significant at P= 0.05 and ***, significant at P= 0.01. Values followed by different letters are significantly different at 95 % confidence interval.

Insecticide/ MCA	Concentration (PPM)			Eggs Failed to hatch		Observed Ovo-larval Mortality		Expected Ovo-larval mortality	Cotoxicity Factor	Chi-square		Conclusion
	Chemical insecticide	Dipel MIU/l	MVP	(%)	S.E.	(%)	S.E.	(%)	(%)			
Dipel	-	1	-	0.00		23.08	3.4 c	-	-	-		-
	-	2	-	0.00		30.08	4.7 b	-	-	-		-
	-	4	-	0.00		39.59	3.6 a	-	-	-		-
MVP	-	-	250	0.00		28.27	3.2 b	-	-	-		-
	-	-	500	0.00		37.98	4.2 a	-	-	-		-
Azinphos-methyl	25	-	-	26.65	2.2 c	80.32	3.2 b	-	-	-		-
	50	-	-	41.40	3.6 b	89.27	5.1 b	-	-	-		-
	250	-	-	88.71	4.1 a	100.00	0.0 a	-	-	-		-
	25	1	-	30.23	3.1 c	100.00	0.0 a	84.86	17.84	2.71	*	Synergism
	50	1	-	40.44	3.6 b	100.00	0.0 a	91.75	9.00	0.74		Additivity
	25	-	250	29.13	3.8 c	95.69	2.1 ab	85.88	11.42	1.12		Additivity
	50	-	250	38.72	2.8 b	100.00	0.0 a	92.30	8.34	0.64		Additivity
Phosmet	100	-	-	21.57	1.5 d	75.97	3.6 c	-	-	-		-
	150	-	-	40.44	4.5 b	91.94	2.0 b	-	-	-		-
	600	-	-	91.04	3.7 a	100.00	0.0 a	-	-	-		-
	100	1	-	26.17	2.3 cd	91.49	3.0 b	81.52	12.23	1.22		Additivity
	150	1	-	36.07	1.6 b	100.00	0.0 a	93.80	6.61	0.41		Additivity
	100	-	250	23.26	1.5 d	87.70	1.7 b	82.76	5.97	0.29		Additivity
	150	-	250	33.30	2.1 bc	97.43	1.4 a	94.22	3.41	0.11		Additivity
Carbaryl	60	-	-	25.47	1.9 bc	80.84	4.1 c	-	-	-		-
	90	-	-	37.66	3.7 b	92.85	3.5 b	-	-	-		-
	300	-	-	67.27	4.3 a	100.00	0.0 a	-	-	-		-
	60	1	-	18.63	1.5 c	100.00	0.0 a	85.26	17.28	2.55		Additivity
	90	1	-	33.14	2.3 b	100.00	0.0 a	94.50	5.82	0.32		Additivity
	60	-	250	21.77	1.6 c	100.00	0.0 ab	86.26	15.93	2.19		Additivity
	90	-	250	34.11	4.0 b	100.00	0.0 a	94.87	5.41	0.28		Additivity
Dimilin	22	-	-	6.16	0.9 cd	12.42	1.3 d	-	-	-		-
	55	-	-	10.22	1.3 b	18.83	2.1 cd	-	-	-		-
	110	-	-	15.41	1.0 a	22.76	2.9 c	-	-	-		-
	22	1	-	8.15	2.7 bc	47.15	3.8 b	38.76	21.63	1.81		Additivity
	55	1	-	7.65	0.9 bc	54.00	1.9 ab	47.09	14.66	1.01		Additivity
	22	-	250	4.43	0.8 d	46.80	4.2 b	45.68	2.45	0.03		Additivity
	55	-	250	8.64	2.2 bc	59.60	2.0 a	49.66	20.02	1.99		Additivity
Esfenval-erate	0.5	-	-	1.74	0.8 b	66.87	2.4 c	-	-	-		-
	1.0	-	-	5.74	1.7 b	80.23	3.1 b	-	-	-		-
	12.0	-	-	25.68	2.1 a	100.00	0.0 a	-	-	-		-
	0.5	1	-	3.21	0.8 b	100.00	0.0 a	74.52	34.19	8.71	***	Synergism
	1.0	1	-	5.90	0.5 b	100.00	0.0 a	84.79	17.93	2.73	*	Synergism
	0.5	-	250	3.18	1.1 b	100.00	0.0 a	76.24	31.17	7.41	***	Synergism
	1.0	-	250	6.03	1.5 b	100.00	0.0 a	85.82	16.52	2.34		Additivity
Permethrin	1	-	-	4.52	0.8 b	71.57	1.9 c	-	-	-		-
	2	-	-	7.07	1.1 b	84.90	4.1 b	-	-	-		-
	12	-	-	20.93	2.4 a	100.00	0.0 a	-	-	-		-
	1	1	-	5.95	1.2 b	100.00	0.0 a	78.13	27.99	6.12	**	Synergism
	2	1	-	5.76	0.9 b	100.00	0.0 a	88.39	13.14	1.53		Additivity
	1	-	250	3.55	0.4 b	100.00	0.0 a	79.61	25.62	5.23	**	Synergism
	2	-	250	7.39	1.6 b	100.00	0.0 a	89.17	12.15	1.32		Additivity

Discussion

The findings of the present studies (Table 3.1-3.9) indicate that natural and genetically-engineered insecticides based on *Bacillus thuringiensis* are incapable of producing high levels of toxicity to *Cydia pomonella* (L.) neonates when surface-applied to apple or artificial diet, thus, Dipel and MVP are ineffective for the control of codling moth. This is because of the fact that codling moth neonates feed only for a short period before entering apple (Tadic 1963, Jaques *et al.* 1987) and as such do not acquire lethal doses of these insecticides. These findings tend to corroborate those of Roehrich (1963), Andermatt (1988), and Bajwa and AliNiazee (1995).

As the neonate codling moth feed for a very short period before entering the apple, maintenance of effective concentrations of insecticides on the surface of apple is quite critical. This is particularly important for microbial insecticides such as *B. thuringiensis*, where mode of entry is through ingestion only. Results (Tables 3.1-3.6) of the present studies show that the lowest concentration of either Dipel or MVP combined with chemical insecticides were not capable of producing appreciable effects. This suggests that when feeding externally, the larvae might not have acquired amounts of the bacterial spores and/or δ-endotoxin sufficient enough to supplement/potentiate the combined mortality. However, higher rates of MCAs (Dipel or MVP) combined with low to medium rates of chemical insecticides usually gave highly additive (CTF = 10-20) or synergistic (CTF $\geq$ 21) joint mortality, indicating acquisition of sufficient quantity of microbial control agent (s) to produce an effect. Morris (1972, 1975) found similar results against several forest insects. He observed that lower concentration of *B. thuringiensis* with different insecticides gave subadditive or antagonistic interaction, and moderate to higher rates of *B. thuringiensis* obtain a supplemented or potentiated combined mortality.

Results of the present tests (Tables 3.1-3.6) suggest that the combination effects observed were influenced by a variety of factors acting in concert with each other, e.g., type of bacterial or insecticidal formulation and their concentration, codling

moth stage and duration of exposure, method of treatment, and susceptibility of larvae to either agent. The mixtures that showed the greatest synergism were pyrethroids at low to moderate test concentrations in combination with moderate to high concentrations of Dipel or MVP. At the lowest concentration of Dipel, the additive effect was weak with organophosphate insecticides and diflubenzuron, but moderate with pyrethroid insecticides and carbaryl. This moderate additive effect, however, was not usually observed with the lowest concentration of MVP. Low doses of pyrethroids are known to cause stimulatory effect on growth and sporulation of *B. thuringiensis* (Habib & Garcia1981, Morris 1972 & 1977). Carbaryl reportedly had high compatibility with *B. thuringiensis* (Morris 1977) and, in general, interacted synergistically with this bacteria against several lepidopterous larvae (McEwen *et al.* 1960, Chen 1974, Richter & Fuxa 1984). Most combinations of azinphosmethyl, phosmet, carbaryl and diflubenzuron with moderate to high concentrations of either Dipel or MVP showed the additive effect whether the neonate larvae were fed on a surface-treated diet or apples, and when both eggs and larvae were exposed. In other words, an additive effect always resulted from combining Dipel at 1.0 and 2.00 MIU/l (a.i.) or MVP at 250 and 500 ppm (a.i.) with all test concentrations of azinphosmethyl, phosmet, carbaryl and diflubenzuron. With an increase of MCA concentrations from moderate to high (Dipel, 1.0 to 2.00 MIU/l a.i. or MVP, 250 to 500 ppm a.i.), the additive effect apparently weakened in all cases. Mixtures with highest concentrations of most chemical insecticides at all concentrations of Dipel and MVP produced an effect similar to or less than their effects when tested alone.

The synergistic and additive interactions observed in the present studies, may have been facilitated by the general compatibility of *Bacillus thuringiensis* spores or δ-endotoxins with chemical insecticides. Compatibility of the most agricultural chemicals and spores and/or δ-endotoxins of *B. thuringiensis* has already been established (Benz 1971, Chen 1974, Morris 1977). Morris (1974) reported that the integrity of δ-endotoxin was not usually affected by the low doses of most insecticides, however, the same insecticide at high doses could greatly reduce its size. His results

indicated that the size reduction was attributed to the presence of toxic emulsifiers and other surfactants in the insecticide formulations. He suggested that wettable powders were less harmful than emulcifiable concentrates. Salama *et al.* (1984) reported that low concentrations of pyrethroids such as permethrin, fenvalerate and cypermethrin had generally no effects on sporulation of *Bacillus thuringiensis* and were compatible with δ-endotoxin while Habib and Garcia (1981), and Morris (1972, 1977) reported that lower concentrations of pyrethroids stimulated germination and reproduction of this pathogen. Several authors (Chen 1974, Habib & Garcia1981, Jaques & Morris 1981) reported that low concentrations of carbaryl and several organophosphorous compounds including phosmet had a stimulating effect on spore germination but no effect on cell multiplication. A high compatibility of *B. thuringiensis* and diflubenzuron (Dimilin) has already been demonstrated by Morris (1977). Baicu and Hussein (1984) reported that low concentrations of pyrethroids namely fenvalerate, deltamethrin, cypermethrin and permethrin synergized *B. thuringiensis* in a laboratory tests against noctuid, *Mamestra brassicae*. It has been suggested that synergism may be due to physiological stress, reduction of phagocytic hemocytes caused by the chemicals, or inhibition of the insect's detoxification system by the microorganism (Benz 1971, Vail *et al.* 1972, Boman 1981).

At higher doses of both bacterial and chemical insecticides (Table 3.1-3.6), the joint mortality of most mixtures was marginally antagonistic (P = 0.1), subadditive (effect less than or the same as that of most active component in the mixture) or not significantly different from the combinations with lower concentrations of either microbial or chemical components. High concentrations of chemical insecticides might diminish the bacterial pathogenicity, or incompatibility of some chemicals with entomopathogens may produce an antagonism which increases with the concentration of the chemicals (Habib & Garcia1981). Sometimes, pathogen is partially inhibited by the toxicant but in turn detoxifies the latter (Benz 1971). These explanations might be true for a formulation based on spores of *B. thuringiensis* such as Dipel (which contains spores besides δ-endotoxin of *Bacillus thuringiensis*). Nevertheless, in the

present studies, both MCAs produced almost similar responses with a given chemical insecticides. This analogy suggests that something common (i. e., δ-endotoxin) may be responsible for the observed joint interactions. Habib & Garcia(1981) suggested that the action of MCAs could be lost due to the fast mortality caused by the high concentrations of the chemicals. However, another possible explanation is that higher concentrations of the bacterial endotoxin and the neurotoxic chemical insecticides would cause rapid knockdown and inhibit the neonates from consuming enough bacterial spores and/or δ-endotoxins from the external surface of apples to cause high mortality. Studies by Morris (1975a) supported this possibility. He observed decreasing incidence of septicemia with increasing dosage of chemical insecticides in similar type of studies against spruce budworm, *Choristoneura fumiferana*, and white-marked tussock moth, *Orgyia leucostigmata*.

In the present study, most carbaryl concentrations combined with all concentrations of microbial control agents produced moderate to strong additive effect (Table 3.3). This may be due to the fact that carbaryl would have acted as a weak contact insecticide against codling moth neonates, and as such it might not have interfered with external feeding as compared to that of organophosphorous insecticides (Table 3.1 and 3.3). Carbaryl had reportedly shown weak contact action against some insects (Mansour *et al.* 1966). Synergistic effect of carbaryl with *B. thuringiensis* against some lepidopterous larvae when they were continuously maintained on treated artificial diet until pupation was reported earlier (Benz 1971, Jaques & Morris 1981, Richter & Fuxa 1984). In the present studies and elsewhere (Salama *et al.* 1984), where lepidopterous larvae were exposed to the mixture for a short period of time, an additive effect was noticed. However, in lower or sublethal concentrations, larval behavior, movement or feeding habits was affected (Mohamed 1983a). For example, some insecticides have been demonstrated to act as irritant to increase activity of lepidopteran species (Streibert and Dittrich 1977, Salisberg *et al.* 1980). Such affects may influence activity and behavior of larval codling moth causing change in external feeding and/or duration of external stay on the surface-treated apple

or diet. Surprisingly, in the present studies, it was found that azinphosmethyl and carbaryl at a concentration of 10-25 ppm and 30-60 ppm, respectively, can increase wandering time and induce significant surface feeding of apple in the codling moth neonates (Bajwa, unpublished). Low doses of some insecticides are known to cause hyperphagia (excessive feeding), and higher sublethal doses, anorexia (decreased feeding) in other insects (Haynes 1988).

Azinphosmethyl, phosmet, carbaryl, esfenvalerate and permethrin at different test concentrations were toxic to both newly laid and blackhead eggs of codling moth. This toxic effect supplemented those exerted on first instar larvae. Larvae which hatched from treated eggs died after contacting and/or feeding on the residue of the insecticides or their mixtures with MCAs on the apple surface. At lower rates, these insecticides were primarily effective as larvicides whereas at high concentrations they were considerably ovicidal (Table 3.1- 3.9). Several authors made similar observations (Hamilton *et al.* 1954, Hagley 1976, Tolstova & Atanov 1976, Thwaite 1986). Matvievskij (1967) observed that carbaryl (Sevin) at 100 - 200 ppm reduced the emergence of larvae by 50-70 % and killed most of the surviving larvae within 6-7 days. In the present studies, blackhead eggs were found to be more susceptible than newly laid eggs when treated with organophosphate and carbaryl. These results parallel those of Smith and Salkeld (1966), and Thwaite (1984), who noticed a reduced hatch as the age of eggs at treatment increased. The increased susceptibility of blackhead eggs has usually been correlated with increased amounts of acetylcholine in late stage eggs (Pree & Hagely 1977). Conversely, pyrethroid insecticides esfenvalerate and permethrin, were found to be more toxic to the newly laid eggs of codling moth than to the blackhead eggs. These findings tend to confirm those of Pree and Hagely (1977) who indicated that newly laid codling moth eggs were more susceptible than older eggs. Salkeld and Potter (1953) reported similar results using allethrin against eggs of three different species of insect.

There was no significant difference between egg mortalities produced by chemical insecticides alone or in combination with either MCAs. The larvae hatched from the eggs treated at 0-24 hours or blackhead stage produced significantly higher

mortality at all test concentrations compared with that of untreated eggs. When these larvae were exposed to the mixtures, the joint effect was additive in case of organophosphate insecticides, carbaryl, diflubenzuron and most combinations with higher rates of pyrethroids, producing a significantly higher combined ovo-larvicidal activities (egg and larval mortalities) than those of each mixture component tested alone. Most combinations with the lower rates of either pyrethroids were synergistic in producing combined ovo-larvicidal activity against both newly laid or blackhead eggs. These results indicate that exposure of eggs at different stages to low rates of chemical insecticides alone or in combination with MCAs (Dipel, MVP), made the larva hatching from these eggs more susceptible to insecticide-MCA mixtures. This effect is more attributable to the low doses of chemical insecticides than to the MCAs. This effect could be either additive (all combinations with azinphosmethyl, carbaryl and diflubenzuron) or synergistic (some combination with pyrethroids). As a general rule, all test combinations produced better results when treated at blackhead egg stage and using Dipel.

In summary, three types of interactions were observed in the present research: additivity, in which the amount of observed mortality is not significantly different from the expected; synergism, in which observed mortality is significantly greater than expected; and antagonism, in which observed mortality is significantly less than expected (Benz 1971, McVay *et al.* 1977, Richter & Fuxa 1984). Often the interactions were better with Dipel than MVP. This may be because of the nature of the formulation. Dipel contains spores besides two different types of delta-endotoxins. Such a combination has been proved to be highly synergistic and very effective against other lepidopterous species (Somerville *et al.* 1970, Salama *et al.* 1981). The pyrethroids potentiated the effect of microbial insecticides. On other hand, carbaryl, azinphosmethyl, phosmet and diflubenzuron had an additive effect. The pyrethroids affect the peripheral and central nervous system resulting in rapid paralysis (Salama *et al.* 1984). According to O'Brien (1967) and Narahashi (1985), pyrethroids may also affect sodium and potassium permeability of insect cells and nitrogen metabolism. The endotoxin of *B. thuringiensis* cause rapid paralysis of midgut and selective

permeability of midgut epithelium (Knowles 1994). Therefore, the stress placed on the target insect must be high and may account for high potentiation of *B. thuringiensis*-based formulations by pyrethroids. The use of low concentrations of chemical insecticides such as pyrethroids (permethrin and esfenvalerate), organophosphates (azinphosmethyl and phosmet), carbaryl and diflubenzuron combined with moderate to high concentrations of *B. thuringiensis*-based formulations such as Dipel and MVP appeared suitable as a means to controlling codling moth. Any of these combinations would reduce the amount of chemical toxicant necessary for codling moth control. Although, the combinations other than those with pyrethroids had mortalities not significantly greater than expected (an additive effect), these combinations did produce up to 100% larval or combined ovo-larval mortality (egg and larval mortality). These chemical insecticides namely azinphosmethyl, phosmet, carbaryl and diflubenzuron, however, significantly enhanced the activity of *B. thuringiensis*-based insecticides in some combinations. These results indicate that application of mixtures of chemical and microbial insecticides is a feasible method to reduce the quantity of chemical insecticides used in a codling moth management program when total substitution by a microbial insecticide is not possible. At the time of treatment in the field, all phases of codling moth are present because of extended flight period. As eggs in all stages of development are affected by the MCA - chemical insecticide mixtures, the timing of spray to achieve maximum control may become less critical (Pree & Hagley 1977).

Chapter 4

Sublethal Effects of Microbial and Chemical Insecticides on Survival, Development and Reproduction of Codling moth, *Cydia pomonella* (L.)

Abstract

The codling moth when exposed at larval or adult stage to sublethal rates of azinphosmethyl, phosmet, carbaryl, esfenvalerate and permethrin manifested various short- and long-term effects with varying degree of intensity usually stronger with pyrethroids. When adult females were exposed to sublethal concentrations, diflubenzuron and microbial insecticides (Dipel and MVP) did not show adulticidal activity or any long-term effects on codling moth biology. Sublethal concentrations of chemical insecticides namely azinphosmethyl, phosmet, carbaryl, permethrin and esfenvalerate caused pronounced deleterious effects on the adult survival and oviposition. The exposure to both pyrethroid, esfenvalerate and permethrin, caused a small increase in sterility.

The exposure of neonate codling moth larvae to sublethal concentrations of most insecticides adversely affected their initial survival. Dipel, MVP and diflubenzuron had no effect on larval development and survival to pupal stage and beyond. Organophosphate azinphosmethyl and phosmet, carbamate carbaryl and pyrethroids permethrin and esfenvalerate had a severe impact on larval survival and pupal formation. Generally, larval survival was reduced with increasing concentrations. Carbaryl, esfenvalerate and permethrin affected the pupal survival and subsequent eclosion of adults. Esfenvalerate and permethrin considerably extended the duration of larval period. None of microbial and chemical insecticides significantly extended/contracted the pupal development period and adult longevity. Microbial insecticide, diflubenzuron, azinphosmethyl, phosmet and carbaryl had no effect on pupal weight, egg production and fecundity of the adults that survived insecticidal exposure as larvae. Larval contact with sublethal concentrations of esfenvalerate or permethrin resulted in reduction of pupal weight and subsequent egg deposition. Survivor adults were lighter and smaller in size. Fecundity of these moth, however, was not affected.

Introduction

A pest management program based on reduced rates of chemical insecticides mixed with microbial agents such as the *Bacillus thuringiensis* Berliner may not be implemented unless their sublethal effects on the biology and/or population dynamics of associated arthropods in the target ecosystem are thoroughly studied. As the residual activity of microbial insecticides is generally short-lived (Gardner & Hornby 1987, Ali & Young 1993, Nyouki & Fuxa 1994), these arthropods may be exposed, for an extended period, to the sublethal levels of chemical insecticides. Such an exposure may either have harmful or beneficial effects on the biology of pest and natural enemies leading to an added control or resurgence/permanence of the pests in the ecosystem. Sublethal effects result when insufficient molecules to cause death reach the sites of insecticidal action (Moriarty 1969, Haynes 1988). Insect exposure to sublethal rates of insecticides has been shown to cause latent toxicity, enzyme induction, hyperphagia, feeding deterrence, stimulatory and inhibitory effects on reproduction, knockdown, autotomy of contaminated body appendages, disruption of pheromone communication, and altered behavior and physiology (Moriarty 1969, Kumar & Chapman 1983, Smirnoff 1983, Stewart & Philogene 1983, Chen *et al.* 1985, Alford & Holmes 1986, Messing & Croft 1990, Moore & Tabashnik 1989, Moore *et al.* 1992). Moriarty (1969) and Haynes (1988) have reviewed the sublethal effects of synthetic insecticides on insect biology and insect behavior, respectively. They suggested that insecticidal effects on insects should include mortality resulting from the direct toxic effect of an insecticide and deleterious sublethal effects.

Sublethal rates of insecticides are considered to have long-term effects on the biology of insects (Moriarty 1969, Esaac *et al.* 1976, Stewart & Philogene 1983, Alford & Holmes 1986). For instance, larval exposure to low concentrations of an insecticide may produce a favorable/unfavorable effect on larval and pupal development and subsequently on adult longevity, oviposition and fecundity (Smirnoff 1983, Stewart & Philogene 1983). The unfavorable effects may reduce the

reproductive ability of a pest population, whereas favorable effects may ensure the survival of a vigorous population. Certain insecticides at sublethal doses stimulate or depress general locomotory behavior such as walking or flight (Haynes 1988). However, field use of lower/sublethal concentrations is believed to reduce or delay the development of pesticide resistance (Gist & Pless 1985). Accordingly, sublethal rates may have rather substantial effects on population dynamics, dispersal and insecticide resistance of the target and non-target insects in a given system.

In a crop spray program, many target sites do not receive the desired deposition of the applied insecticidal compounds (Stewart & Philogene 1983, Wieser 1985, Alford & Holmes 1986), and as such, the target insects encounter or are treated with sublethal levels of insecticides. Insects exposed to these sublethal dosages may display a variety of symptoms as listed above. It has been recently suggested that the sublethal effects (e.g. reduction in reproductive potential, antifeedant and repellent activities) of some insecticides (mainly pyrethroids) are important components of crop protection in different agricultural crops (Ruscoe 1977, Highwood 1979, Tan 1981, Kumar & Chapman 1983). As yet, little quantitative data on the extent and significance of these effects on insects is available (Kumar & Chapman 1983). This kind of information is particularly scarce for codling moth, *Cydia pomonella* (L.). It is, therefore, essential to study sublethal effects of commonly used insecticides on the biology of codling moth. This information is, also, required to determine feasibility of using mixtures of low or sublethal rates of microbial control agents (MCAs) and chemical insecticides against codling moth.

The present study was conducted to determine the effect of exposure to sublethal concentrations of the candidate microbial and chemical insecticides on survival, development and reproduction of the codling moth. In the present study, I define sublethal effects as *effects on surviving individuals of an insecticide exposure at any concentration/dose (hereinafter referred as sublethal concentration/dose with reference to surviving individuals). Hence, this term encompasses any abnormal effect -physiologic, morphologic, physiomorphic- and/or latent mortality observed at any subsequent stage in their life cycle*. It is difficult to study sublethal effects of the

insecticides on population dynamics of codling moth in the field. Therefore, laboratory experiments were designed in a way to simulate certain field conditions and to test these effects. Influence of sublethal rates on population dynamics of other associated arthropods will be discussed in chapter 6.

Materials and Methods

Codling Moth Rearing:

Laboratory culture of the codling moth was established and reared from larvae/pupae collected from the field in 1990. Batches of larvae from the same orchard were added annually to maintain genetic diversity and vigor in the colony (Riedl *et al.* 1985). The culture was maintained on thinning apples under control conditions (16 L / 8 D photoperiod and 24 ± 1°C). Newly emerged adults (0-24 hours old) were held in oviposition cages until death. They were supplied with 5 % sucrose solution as food on a dental wick. Wax paper was provided for oviposition. Generally eggs was stored for a short period as needed at 10°C to help synchronize hatching. To ensure emergence of sufficient larvae on the day of an experiment, eggs that were about to hatch, that is , those that had the blackhead stage, were held at 5-10 °C until the required day.

Chemical and Microbial Insecticides:

The chemical insecticides tested represented various classes comprising the organophosphorous compounds, azinphosmethyl (Guthion® 50WP) and phosmet (Imidan® 50WP); pyrethroids, esfenvalerate (Asana® XL) and permethrin (Ambush® 25.6%); carbamate, carbaryl (Sevin® 50WP) and the insect growth regulator, diflubenzuron (Dimilin® 25WP). Two formulations based on *Bacillus thuringiensis* were used in the experiment. The formulation Dipel® 2X (Abbott Laboratories), based on the natural strain of *B. thuringiensis* subsp. *Kurstaki*, is rated at 32,000 International Units of potency per mg (IU/mg). The other formulation MVP® (Mycogen Corporation) is a product of the CellCap technology based on a single δ-endotoxin gene of *Bacillus thuringiensis* subsp. *kurstaki* genetically engineered into *Pseudomonas fluorescens* Migula, the cells of which are killed at the end of the bacterial growth phase (Feitelson *et al.* 1990). The insecticides were obtained from

different manufacturers as technical material or from a freshly prepared batch of formulated material.

Since the sublethal effects may occur at insecticide concentrations which kill as high as 90 % of target population (Dumbre & Hower 1976), concentrations below and above LC50 were chosen for the present studies. Other reason for this choice was the chemical components of the best *B. thuringiensis*-insecticide mixtures (Chapter 3), which alone rendered greater than 50 % mortality. The solution of each insecticide was formulated in the water on the basis of weight per volume of active ingredient. A fresh solution was prepared for each replication. A control group treated with water only was included in each replication of an experiment with a chemical and microbial insecticides.

Adult Bioassay:

Effects of a 24 h exposure to residue of different pesticides (microbial and chemical) on codling moth adult survival, longevity, oviposition (number of eggs laid per female) and fecundity (number of viable eggs laid per female), were examined. Fresh foliage from apple trees were collected and brought to the laboratory, and dipped for 20 seconds in constantly stirred aqueous solution of different concentrations of candidate insecticides (Howell & Maitlen 1983). Control leaves were treated with water only. The treated leaves were left to dry for 30 - 60 minutes at room temperature. After the foliage was completely dried, it was placed in petri-dishes (9 cm diameter) with a wet filter paper. In each petri-dish 3-4 leaves were arranged to fully cover its base. Two pairs of codling moth adults (0-12 hours old, two each of male and female) were placed in each petri-dish, and there were 10 petri-dishes per treatment. This procedure was replicated four times. Petri-dishes were held for 24 hours in a rearing room at 24 $\pm$ 1 °C, 75% RH, and a photoperiod of 18L:6D. Alive moths (both active and inactive) that survived the 24 hours acute exposure to pesticide residues on apple leaves were transferred to translucent plastic cups (10 cm diameter by 5 cm high), used as oviposition chamber. Each oviposition chamber had only one pair of surviving adults for longevity and oviposition

observations. Moths were provided with cotton saturated with 5% sucrose solution as food. Mortality was recorded every 24 hours. The number of eggs deposited and percent egg hatch were determined by examining the cups under a microscope 10-15 days after the eggs had been deposited.

Larval Bioassay:

Thinning apples and artificial diet cubes (2.2 cm^3) were surface-treated with sublethal concentration of each insecticide by dipping in the solution. The neonatal larvae < 6 h old were place singly with a fine brush on individual treated apples (approximately equal in size and weight) or diet cubes. Each test consists of 40 cups of artificial diet or immature apple, replicated four times. These cups were held at 24 $\pm$ 1 °C, 60-65% RH, and a photoperiod of 16L:8D. Larval mortality was examined 7 days after treatment. All alive larvae both from surface-treated apple and diet experiments were carefully transferred to plastic cups (30-ml) approximately half-filled with fresh untreated artificial diet. On seventh day after this transfer, each plastic cup was provided with a small piece of corrugated cardboard to accommodate pupation. The development of the codling moth was followed through the adult stage, and abnormalities and mortalities were recorded and compared with those of the untreated control. The duration of the larval period were calculated as interval between larval eclosion from the eggs and the spinning of the pupal cocoon. When the pupae was formed, they were removed from the diet, lid of the container or corrugated cardboard with tweezers and carefully weighed on a balance. Each pupa was then returned to a separate translucent plastic cup. On eclosion, the moths were held in pairs in a oviposition cage (one liter ice cream carton lined with wax paper) for longevity and oviposition observations. The number of eggs deposited and percent egg hatch were determined by examining wax paper under a microscope 10-15 days after the eggs had been deposited.

Statistical Methods:

The data were analyzed using analysis of variance (ANOVA) with Fisher's Protected Least Significant Difference (FPLSD) (Petersen 1985) to separate treatment means at P = 0.05 level. In order to see effect of exposure on the fertility of codling moth adult, sterility index (SI) (Richmond *et al.* 1978, Robb & Parrella 1984) was calculated as follow:

$$SI = 100 - \left[\frac{N_t}{Nc} \times 100\right]$$

where N_t is number of treatment eggs hatching and N_c is number of control eggs hatching. A negative value of sterility index was expressed as fertility index: a percentage increment of egg hatch in a given treatment over egg hatch in the untreated control.

Results

Sublethal Effects on Codling Moth Adults

Data (Table 4.1) indicate that microbial insecticides, Dipel and MVP and insect growth regulator, diflubenzuron, did not have any adulticidal activity. No adverse effects on the survival, longevity, oviposition and fecundity of codling moth were observed. On the other hand, sublethal concentrations of chemical insecticides namely azinphosmethyl, phosmet, carbaryl, permethrin and esfenvalerate caused pronounced deleterious effects on the codling moth adult survival and oviposition. All concentrations except the lowest rates for phosmet, esfenvalerate and permethrin significantly decreased the adult survival over control. The adult longevity, however, was not effected significantly (Table 4.1). Interestingly, some moths which showed knockdown response (particularly with pyrethroid insecticides) at the end of 24 hours exposure period, recovered fully within the next 24 - 48 hours and did produced progeny. Apparently, the moths that survived first 24 hours after removal from the treated leaves, had no effect on their longevity.

Generally, the 24 h exposure to both pyrethroids, esfenvalerate and permethrin, caused a small increase in sterility (Table 4.1). These effects were highly influenced by the concentrations of insecticide used. In some cases there was an increase in fertility. For example, carbaryl and azinphosmethyl at lower concentrations, and phosmet at the highest concentration increased the fertility slightly. However, the sterility and fertility indices were not large enough to draw any statistically significant conclusion.

Sublethal Effects on Codling Moth When Larvae Exposed to Pesticides

Effects on Survival:

Results of experiments with treated apple and artificial diet are given separately in Table 2 and 3. Data show that exposure of neonate larvae to sublethal concentrations adversely affected their initial survival. Larval survival to the pupal

Table 4.1: Sublethal effects on codling moth adult female when exposed to insecticides residues on apple leaves.

Insecticide	Concentration (ppm)	Female survival after 24 h (%)	S.E.		Adult longevity (Days)	S.E.	Mean number of eggs per female survivor No.	S.E.		Hatchability (%)	S.E.	Sterility index	Fertility index
Control	-	92.50	(2.2)	ab	5.49	(0.5)	54.96	(4.2)	ab	74.28	(4.5)	0.00	0.00
Dipel	1 MIU/l	90.50	(3.3)	a-d	5.16	(0.8)	48.04	(5.3)	b-e	69.83	(6.1)	5.97	0.00
	2 MIU/l	93.75	(2.1)	a	6.01	(1.2)	58.83	(4.1)	a	76.01	(3.9)	0.00	2.70
MVP	250.00	91.25	(3.7)	abc	5.68	(1.1)	50.05	(4.2)	abc	80.16	(4.5)	0.00	7.97
	500.00	95.00	(1.8)	a	4.77	(0.8)	48.58	(3.7)	b-e	69.11	(3.8)	6.89	0.00
Azinphosmethyl	25.00	86.25	(4.3)	cde	6.32	(0.7)	39.78	(3.9)	f-i	75.62	(4.3)	0.00	2.50
	50.00	68.75	(4.2)	f	7.86	(1.3)	33.55	(4.1)	ijk	84.71	(5.1)	0.00	13.94
	75.00	40.00	(3.1)	h	4.57	(0.8)	30.83	(3.1)	jk	69.87	(2.9)	6.09	0.00
Phosmet	50.00	90.00	(3.9)	a-d	4.97	(0.9)	45.04	(3.3)	c-g	71.81	(3.7)	3.36	0.00
	100.00	72.50	(4.8)	f	5.79	(1.1)	37.05	(4.5)	hij	72.87	(4.2)	1.59	0.00
	150.00	48.75	(3.2)	g	4.98	(1.2)	39.07	(4.5)	f-i	83.25	(3.5)	0.00	12.47
Carbaryl	60.00	86.50	(5.1)	cde	4.78	(1.2)	37.23	(3.9)	hij	77.66	(4.2)	0.00	4.74
	90.00	82.50	(3.8)	e	4.50	(0.6)	41.59	(4.7)	e-h	85.64	(5.3)	0.00	15.69
	180.00	72.25	(2.8)	f	6.00	(1.5)	27.63	(2.1)	k	70.21	(3.6)	4.63	0.00
Diflubenzuron	22.00	91.25	(3.1)	abc	4.86	(0.8)	52.00	(4.7)	abc	78.63	(4.8)	0.00	5.92
	55.00	93.75	(4.7)	a	6.47	(0.9)	57.46	(5.1)	a	74.74	(5.3)	0.00	0.85
	110.00	95.25	(2.5)	a	7.49	(0.5)	48.58	(4.1)	b-e	70.90	(3.5)	4.53	0.00
Esfenvalerate	2.50	88.75	(3.7)	bcd	4.70	(1.1)	47.03	(4.7)	c-f	73.42	(2.9)	1.16	0.00
	5.00	85.00	(4.0)	de	5.64	(0.7)	45.36	(3.5)	c-g	64.63	(5.8)	12.99	0.00
	10.00	70.00	(3.9)	f	5.86	(0.8)	36.98	(3.1)	hij	63.64	(4.5)	14.32	0.00
Permethrin	2.50	90.00	(3.9)	a-d	5.47	(1.2)	46.44	(2.8)	c-g	74.36	(3.5)	-0.11	0.00
	5.00	86.50	(4.8)	cde	4.54	(1.1)	43.78	(4.2)	d-h	68.46	(2.4)	7.84	0.00
	10.00	72.50	(3.7)	f	5.36	(0.8)	39.28	(3.7)	f-i	66.67	(4.8)	10.13	0.00

Means within insecticide groupings followed by the same letter are not significantly different (P = 0.05; FPLSD).

stage and beyond, however, was not affected by microbial insecticides and diflubenzuron. Thus, once the neonate larvae survived initial exposure to microbial insecticides or diflubenzuron, no long-term impact was observed. However, with most other treatments, significantly reduced number of larvae transformed to pupal stage and at even higher rates, little or no survival occurred (usually concentration causing more than 75 % initial mortalities). This reduction in pupation was not significantly different at the lowest concentrations of most insecticides in case of experiments with apple, and carbaryl in case of experiments with diet. It was noticed that larvae wandered freely on the fruit or diet surface before attempting to enter. At lower rates, numerous larvae enter the treated fruit or diet cubes and the initial mortality was low, whereas the higher rates caused greater initial mortalities. Some surviving larvae attempted to enter the fruit or diet cube but died prior to successful penetration. There was no difference in the overall results of these trials based on larval diet substrates (artificial diet or apples) used.

Pupal survival to adult stage was affected ($P = 0.05$) in treatments with higher rates of azinphosmethyl, phosmet, carbaryl, and pyrethroids (Table 3 & 4). In experiments with apples, at higher concentrations of phosmet (150 ppm), carbaryl (90 ppm), esfenvalerate (2 ppm) and permethrin (4 ppm), none of the pupae survived to adult stage. These levels of insecticides as well as azinphosmethyl at 50 ppm, esfenvalerate at 1 ppm and permethrin at 2 ppm produced similar results in diet experiments.

In experiments with apple, none of the treatments produced significant mortality of adults within 24 h of eclosion from surviving pupae (Table 4.2). In experiments with artificial diet, the consequences of insecticide exposure were more conspicuous in term of causing significant pupal and adult mortality ($P = 0.05$) for higher concentrations of insecticides like carbaryl , esfenvalerate and permethrin (Table 4.3) than that of control. At the lowest concentrations of these insecticides,

Table 4.2: The effect of sublethal concentrations of insecticides on the survival of codling moth, when neonatal larvae were exposed to treated apples.

Insecticides	Conc. (ppm)	Larval survival 7 days after treatment (%) S.E.	Larvae pupated (%) S.E.	Pupae surviving to adult stage (%) S.E.	Adult mortality after 24 hours* (%)
Control	0	86.25 (2.7) a	68.84 (3.4) a	81.05 (3.4) a	0.00
Dipel	0.5 MIU/l	76.88 (3.4) ab	68.29 (4.2) a	77.38 (4.9) a	0.00
	1.0 MIU/l	65.63 (3.9) bc	73.33 (3.5) a	83.12 (4.1) a	0.00
	2.0 MIU/l	57.50 (5.2) c	67.39 (5.1) a	87.10 (3.5) a	0.00
	4.0 MIU/l	55.00 (4.7) c	63.63 (4.4) a	73.21 (3.9) a	0.00
MVP	0	86.25 (2.7) a	68.84 (3.4) a	81.05 (3.4) a	0.00
	125	77.50 (3.2) a	73.39 (5.3) a	86.82 (3.6) a	0.00
	250	60.63 (4.3) b	72.16 (2.6) a	74.29 (5.7) a	0.00
	500	57.50 (5.5) b	69.56 (4.1) a	82.81 (2.6) a	0.00
	750	42.50 (2.2) c	70.58 (3.4) a	85.42 (4.1) a	2.44
Azinphos-methyl	0	88.38 (5.1) a	77.86 (2.6) a	85.32 (4.5) ab	2.15
	5	76.88 (3.6) b	80.49 (4.2) a	76.66 (2.5) b	0.00
	10	62.50 (4.5) c	74.00 (1.9) ab	90.54 (3.9) a	0.00
	25	36.25 (1.8) d	65.24 (2.7) b	82.05 (5.4) ab	0.00
	50	27.50 (2.4) e	34.09 (1.2) c	80.00* (4.7) ab	0.00
Phosmet	0	88.38 (5.1) a	77.86 (2.6) a	85.32 (4.5) a	2.15
	25	65.63 (3.7) b	74.29 (3.8) ab	87.17 (3.7) a	0.00
	50	52.50 (3.2) c	67.00 (4.1) b	79.31 (4.0) a	0.00
	100	37.50 (2.7) d	43.33 (1.1) c	80.76 (3.1) a	4.76
	150	25.63 (2.9) e	19.51* (0.9) d	-	-
Carbaryl	0	86.25 (3.1) a	71.74 (3.3) a	77.78 (3.1) ab	1.30
	15	75.63 (3.4) b	73.55 (6.1) a	75.28 (2.3) ab	0.00
	30	67.50 (5.1) b	68.52 (3.9) ab	82.73 (4.3) a	0.00
	60	31.25 (2.8) c	58.22 (4.6) bc	67.92 (2.1) b	4.76
	90	20.63 (2.6) d	45.00* (2.4) c	-	-
Diflubenzuron	0	84.38 (2.4) a	75.55 (3.4) a	86.27 (3.9) a	1.14
	11	88.75 (3.6) a	72.54 (5.5) a	79.61 (4.2) a	0.00
	22	91.25 (4.1) a	80.14 (4.5) a	83.76 (3.8) a	0.00
	55	88.13 (2.7) a	67.98 (1.8) a	82.29 (5.4) a	1.26
	110	78.13 (2.3) a	68.80 (3.4) a	76.74 (4.5) a	3.03
Esfenvalerate	0.00	88.75 (3.5) a	73.94 (3.1) a	80.00 (3.1) a	0.00
	0.25	68.75 (3.6) b	67.27 (2.8) ab	77.03 (3.6) ab	1.75
	0.50	59.38 (2.8) c	60.61 (6.9) b	73.68 (2.1) ab	2.38
	1.00	47.50 (3.7) d	45.59 (2.9) c	65.21 (5.3) b	4.17
	2.00	31.25 (2.4) e	16.00* (1.8) d	-	-
Permethrin	0.00	88.75 (3.5) a	73.94 (3.1) a	80.00 (3.1) a	0.00
	0.50	73.75 (4.1) b	70.34 (2.9) a	75.90 (5.1) a	0.00
	1.00	55.00 (3.2) c	58.29 (4.3) b	61.63 (1.7) b	5.71
	2.00	38.75 (2.5) d	29.03 (1.6) c	72.22* (4.5) ab	0.00
	4.00	23.75 (1.5) e	18.42* (1.5) d	-	-

Means within insecticide groupings followed by the same letter are not significantly different (P = 0.05; Fisher's Protected LSD). *, result based on 4-16 individuals per treatment only, rest > 16 individuals per treatment.

Table 4.3: The effect of sublethal concentrations of insecticides on the survival of Codling moth, when neonatal larvae were exposed to treated artificial diet.

Insecticides	Concen-tration (ppm)	Larval survival 7 days after treatment (%)	S.E.		Larvae pupated (%)	S.E.		Pupae surviving to adult stage (%)	S.E.		Adult mortality after 24 hrs.* (%)	S.E.
Control	0	81.88	(3.1)	a	74.81	(3.5)	a	77.55	(3.7)	ab	0.00	
Dipel	1.00 MIU/l	69.38	(3.9)	b	77.48	(2.9)	a	82.55	(1.8)	a	0.00	
	2.00 MIU/l	53.75	(4.8)	c	68.60	(3.8)	a	76.27	(5.9)	ab	0.00	
	3.00 MIU/l	47.50	(4.5)	cd	73.68	(5.1)	a	80.35	(2.8)	a	0.00	
	4.00 MIU/l	41.25	(3.2)	d	66.67	(4.8)	a	68.18	(3.8)	b	0.00	
MVP	0	81.88	(3.1)	a	74.81	(3.5)	a	77.55	(3.7)	ab	0.00	
	125	86.25	(3.5)	a	78.26	(2.5)	a	71.29	(3.8)	b	0.00	
	250	60.63	(4.5)	b	70.10	(4.5)	a	82.35	(2.4)	a	0.00	
	500	48.75	(5.4)	b	67.95	(3.8)	a	81.13	(4.4)	a	4.80	(2.4)
	750	34.38	(3.7)	c	76.36	(4.4)	a	71.42	(2.7)	b	0.00	
Azinphos-methyl	0	86.25	(2.4)	a	84.78	(3.9)	ab	71.79	(3.9)	a	0.00	
	5	65.63	(4.3)	b	88.57	(3.3)	a	69.89	(4.2)	a	0.00	
	10	55.00	(3.1)	c	79.55	(2.5)	b	77.14	(3.6)	a	0.00	
	25	29.38	(1.1)	d	68.09	(4.1)	c	68.75	(2.6)	a	5.00	(4.3)
	50	14.38	(3.4)	e	21.74*	(1.7)	d	-			-	
Phosmet	0	86.25	(2.4)	a	84.78	(3.9)	a	71.79	(2.4)	ab	0.00	
	25	61.25	(3.3)	b	69.39	(4.1)	b	76.47	(3.8)	a	0.00	
	50	43.75	(4.7)	c	62.86	(3.6)	b	70.45	(4.3)	ab	0.00	
	100	31.88	(3.6)	d	50.98	(4.9)	c	65.38	(2.7)	b	11.76	(5.7)
	150	16.25	(1.8)	e	15.38*	(1.2)	d	-			-	
Carbaryl	0	82.50	(3.1)	a	79.55	(4.3)	a	82.85	(3.0)	a	0.00	
	15	71.88	(2.3)	b	75.65	(2.8)	ab	80.45	(2.7)	a	0.00	
	30	59.38	(4.5)	c	68.42	(3.4)	b	73.85	(3.4)	ab	6.25	(3.5)
	60	28.75	(5.1)	d	39.13	(4.2)	c	70.77*	(2.1)	b	16.70	(8.3)
	90	13.75	(1.5)	e	22.73*	(1.3)	d	-			-	
Difluben-zuron	0	81.25	(4.5)	ab	83.08	(4.6)	a	69.44	(2.9)	a	0.00	
	11	73.13	(2.8)	b	76.92	(3.8)	a	74.44	(4.4)	a	0.00	
	22	80.00	(4.7)	ab	74.22	(5.1)	a	68.42	(2.3)	a	0.00	
	55	78.13	(4.1)	ab	83.20	(2.3)	a	71.15	(3.9)	a	0.00	
	110	84.38	(2.8)	a	79.26	(3.7)	a	66.35	(2.8)	a	0.00	
Esfenvalerate	0.00	85.00	(3.8)	a	87.50	(4.4)	a	84.87	(3.5)	a	0.00	
	0.25	63.75	(4.4)	b	60.78	(3.5)	b	80.64	(4.1)	a	10.09	(1.9)
	0.50	45.00	(2.7)	c	40.28	(4.1)	c	67.53	(3.2)	b	20.00	(7.1)
	1.00	38.13	(3.8)	c	19.67*	(2.1)	d	-			-	
	2.00	20.00	(2.9)	e	-			-			-	
Permethrin	0.00	85.00	(3.8)	a	87.50	(4.4)	a	84.87	(3.5)	a	0.00	
	0.50	66.25	(4.8)	b	75.47	(3.8)	b	74.73	(4.5)	b	8.33	(2.8)
	1.00	50.00	(1.9)	c	63.75	(4.7)	c	65.27	(2.9)	c	11.84	(3.9)
	2.00	29.38	(2.8)	d	34.04*	(1.6)	d	-			-	
	4.00	15.63	(3.2)	e	-			-			-	

Means within insecticide groupings followed by the same letter are not significantly different (P = 0.05; FPLSD). *, result based on 4-16 individuals per treatment only, rest > 16 individuals per treatment.

however, pupal and adult survival was decreased but not significantly different from control.

Overall, organophosphate chemicals namely azinphosmethyl and phosmet, carbamate carbaryl and pyrethroids permethrin and esfenvalerate had a severe impact on larval survival and pupal formation. Larval survival in general, was reduced with increasing concentrations. In both apple and diet experiments, esfenvalerate and permethrin at 2 ppm and 4 ppm, respectively, killed all larvae prior to pupation. In diet experiments, none of the pupae survived to adult stage at 1 ppm of esfenvalerate, 2 ppm of permethrin and 50 ppm of azinphosmethyl. Carbaryl, esfenvalerate and permethrin affected the pupal survival and the subsequent eclosion of adults. Therefore, only these (pyrethroid insecticides and carbaryl) chemical insecticides had significant adverse long-term effects on the survival of codling moth after surviving initial exposure at neonatal stage.

Effects on Development:

Data (Tables 4.4 and 4.5) show similar but more pronounced effects for surface-treated diet experiments in comparison to treated apples. The larvae exposed to microbial insecticides and diflubenzuron at all levels did not differ from controls in duration of larval development period. In both apple and diet experiments, larval development period was significantly prolonged ($P < 0.05$) at the highest concentrations of phosmet (150 ppm) and carbaryl (90 ppm). Later on, these concentrations fatally affected pupal survival to adult stage. Most concentrations of pyrethroids considerably extended ($P < 0.05$) the duration of larval period. None of the insecticide (both microbial and chemical) significantly extended / contracted the pupal development period. However, at higher concentrations of some chemical insecticides, there was a definite trend of curtailing the duration. In case of experiments with treated diet, carbaryl and pyrethroid insecticides produced deformed pupae (abnormal or irregular in shape), significantly different from control (Table

Table 4.4: The effect of sublethal concentrations of insecticides on the development of codling moth, when neonatal larvae exposed to teated apple.

Insecticides	Conc. PPM	Mean larval period (days) S.E.		Mean pupal period (days) S.E.	Deformed pupae* (%)	Adult longevity (days) S.E.	Deformed adults* (%)
Dipel	0.00	21.67 (1.2)	a	9.70 (0.8)	0.00	7.85 (1.1)	2.6
	1.00 MIU/l	22.51 (1.4)	a	10.50 (1.0)	0.00	8.60 (2.4)	0.0
	2.00 MIU/l	23.31 (2.0)	a	8.87 (1.2)	0.00	7.33 (1.5)	0.0
	3.00 MIU/l	20.53 (1.5)	a	9.38 (1.5)	0.00	6.36 (0.8)	1.9
	4.00 MIU/l	23.11 (0.9)	a	10.67 (1.8)	1.79	8.03 (2.1)	0.0
MVP	0.00	21.67 (1.2)	a	9.70 (0.8)	0.00	7.85 (1.1)	3.9
	125.00	20.78 (1.5)	a	10.50 (1.2)	0.00	7.54 (0.7)	0.0
	250.00	22.40 (2.0)	a	10.71 (1.4)	0.00	8.63 (1.8)	0.0
	500.00	23.68 (2.3)	a	9.83 (0.8)	0.00	8.58 (2.7)	5.7
	750.00	23.23 (0.8)	a	8.76 (1.0)	0.00	8.03 (0.9)	0.0
Azinphos-methyl	0.00	23.29 (1.3)	ab	9.82 (1.2)	0.00	7.31 (1.4)	0.0
	5.00	21.46 (0.9)	b	10.03 (0.7)	1.50	8.23 (0.6)	0.0
	10.00	22.79 (1.7)	ab	8.98 (1.3)	3.13	8.66 (1.9)	1.5
	25.00	23.65 (1.1)	ab	10.68 (2.4)	0.00	7.99 (2.1)	3.1
	50.00	28.66 (2.1)	a	9.35* (0.8)	0.00	6.37* (1.0)	0.0
Phosmet	0.00	23.29 (1.8)	c	9.82 (1.2)	0.00	7.31 (1.4)	0.0
	25.00	23.80 (1.1)	abc	10.35 (0.9)	0.00	6.91 (1.7)	0.0
	50.00	22.60 (2.4)	bc	8.82 (1.5)	0.00	8.08 (2.0)	0.0
	100.00	25.58 (0.8)	ab	8.63 (0.8)	0.00	6.75 (1.5)	4.8
	150.00	29.10 (1.3)	a	-	-	-	-
Carbaryl	0.00	21.91 (0.9)	a	10.53 (1.3)	0.00	7.99 (0.9)	1.3
	15.00	23.51 (1.6)	a	10.08 (1.1)	0.00	9.03 (3.1)	0.0
	30.00	21.22 (2.5)	a	9.78 (0.9)	1.47	8.76 (1.8)	0.0
	60.00	24.26 (1.2)	a	8.87 (1.0)	3.13	9.38 (0.3)	4.8
	90.00	-		-	-	-	-
Diflubenzuron	0.00	22.09 (1.3)	a	10.94 (1.4)	0.00	8.67 (0.5)	0.0
	22.00	23.06 (2.3)	a	9.74 (0.7)	0.00	7.70 (0.9)	0.0
	55.00	21.90 (0.7)	a	11.22 (2.4)	0.93	7.23 (1.1)	0.0
	110.00	20.07 (1.4)	a	10.78 (1.2)	1.09	8.01 (2.1)	0.0
Esfenvalerate	0.00	21.98 (1.3)	b	10.42 (1.4)	0.96 (1.4)	8.05 (1.2)	0.0
	0.25	24.07 (2.1)	ab	11.25 (1.2)	1.78 (1.5)	8.53 (2.0)	5.3
	0.50	25.37 (2.4)	a	10.15 (1.1)	2.78 (2.5)	9.00 (1.8)	2.4
	1.00	25.89 (0.9)	a	8.63 (0.8)	12.63 (4.5)	7.15 (0.8)	4.2
	2.00	27.45* (2.3)	a	-	-	-	-
Permethrin	0.00	21.98 (1.3)	c	10.42 (1.4)	0.00	8.05 (1.2)	0.0
	0.50	25.82 (2.2)	abc	9.57 (0.9)	0.00	7.80 (0.9)	3.2
	1.00	24.60 (1.6)	bc	9.08 (2.1)	0.96 (1.1)	7.53 (2.4)	5.7
	2.00	27.29 (1.4)	ab	8.84 (1.7)	7.14 (3.2)	6.87* (1.7)	7.7
	4.00	28.67* (2.1)	a	-	-	-	-

Means within insecticide groupings followed by the same letter are not significantly different (P = 0.05; Fisher's Protected LSD). *, result based on 4 - 16 individuals per treatment only, rest > 16 individuals per treatment.

Table 4.5: The effect of sublethal concentrations of insecticdes on the development of codling moth, when neonatal larvae were exposed to treated artificial diet.

Insecticides	Concentration (ppm)	Mean larval period (days) S.E.		Mean pupal period (days) S.E.	Deformed pupae* (%) S.E.	Adult logevity (days) S.E.	Adult with deformed wings (%) S.E.
Control	Water	20.81 (1.1)	a	9.28 (1.3)	1.04	8.67 (1.2)	0.00
Dipel	0.5 MIU/l	22.88 (1.7)	a	11.13 (1.5)	0.00	7.47 (1.4)	0.00
	1.0 MIU/l	19.73 (0.8)	a	9.09 (1.6)	0.00	9.59 (2.1)	0.00
	2.0 MIU/l	23.18 (1.5)	a	8.68 (1.8)	1.72	8.39 (1.1)	0.00
	4.0 MIU/l	20.47 (2.1)	a	10.21 (0.7)	0.00	7.98 (0.9)	0.00
Control	Water	20.81 (1.1)	a	9.28 (1.3)	0.00	8.67 (1.2)	0.00
MVP	125	19.51 (2.1)	a	9.02 (1.1)	0.00	8.74 (0.6)	0.00
	250	22.96 (2.1)	a	8.97 (0.4)	0.00	7.68 (1.8)	2.17
	500	21.79 (1.4)	a	11.30 (1.3)	0.00	8.39 (2.1)	0.00
	750	23.47 (1.3)	a	9.56 (0.8)	2.38	8.44 (1.3)	0.00
Azinphos-	0	21.63 (1.6)	b	8.78 (0.7)	1.80	7.95 (1.1)	0.00
methyl	5	20.62 (2.2)	b	9.92 (2.1)	0.00	8.83 (1.4)	0.00
	10	21.71 (1.9)	b	9.63 (1.7)	0.00	9.29 (1.7)	0.00
	25	23.37 (1.5)	ab	8.48 (0.8)	3.13	8.71 (2.1)	4.54
	50	27.85* (2.4)	a	-	-	-	-
Phosmet	0	21.63 (1.6)	c	8.78 (0.7)	0.00	7.95 (1.1)	0.00
	25	21.08 (0.9)	c	8.66 (1.8)	0.00	8.18 (0.7)	0.00
	50	23.66 (0.4)	bc	9.50 (1.9)	0.00	8.43 (1.8)	0.00
	100	25.11 (2.1)	ab	7.96 (0.6)	0.00	8.45 (1.1)	7.14
	150	28.47* (1.4)	a	-	-	-	-
Carbaryl	0	20.86 (1.8)	b	10.66 (1.8)	1.25 (1.2)	8.70 (1.2)	1.28 (1.3)
	15	23.05 (1.2)	ab	11.07 (2.0)	0.00	7.93 (1.4)	0.00
	30	22.59 (0.7)	ab	10.74 (1.2)	3.61 (1.8)	8.59 (0.6)	5.83 (2.5)
	60	22.09 (1.7)	ab	8.51 (1.1)	11.11 (3.4)	9.12 (2.1)	16.67 (6.2)
	90	26.25 (0.5)	a	-	-	-	-
Diflubenzuron	0	22.08 (1.5)	a	10.85 (0.7)	0.00	8.17 (0.5)	0.00
	22	20.73 (1.2)	a	10.52 (0.8)	0.00	8.45 (1.1)	0.00
	55	19.98 (2.3)	a	11.56 (1.6)	0.00	10.09 (2.2)	0.00
	110	19.58 (0.8)	a	9.59 (1.8)	0.00	9.04 (0.7)	0.00
Esfenval-	0.00	22.36 (0.7)	c	9.97 (1.4)	1.88 (0.9)	8.46 (1.4)	0.00
erate	0.25	24.36 (2.1)	bc	7.97 (0.4)	11.00 (2.1)	7.35 (1.8)	10.28 (3.6)
	0.50	24.61 (0.7)	bc	7.21 (1.1)	16.33 (3.2)	7.89 (0.9)	16.67 (4.8)
	1.00	26.27 (3.3)	ab	-	-	-	-
	2.00	29.00* (1.4)	a	-	-	-	-
Permethrin	0.00	22.14 (1.9)	c	9.97 (1.4)	1.88 (0.9)	8.46 (1.4)	0.00
	0.50	23.15 (1.1)	bc	10.52 (1.7)	9.61 (3.5)	7.67 (2.7)	14.28 (6.1)
	1.00	27.53 (0.8)	ab	7.78 (1.0)	17.50 (2.2)	7.60 (1.1)	18.18 (5.7)
	2.00	30.31* (1.3)	a	-	-	-	-

Means within insecticide groupings followed by the same letter are not significantly different (P = 0.05; when neonatal Protected LSD). *, result based on 4 - 16 individuals per treatment only, rest > 16 individuals per treatment.

4.5). However, this effect was not confirmed by experiments with apples (Table 4.4).

The longevity of the adult females that survived insecticidal exposure as neonatal larvae was not significantly different from the control (Table 4.4 and 4.5). In case of experiments with treated diet, a small number of adults from the pyrethroid and carbaryl treatments had deformed wings (incapability to inflate their wings upon emergence)(Table 4.5). The deformed female adults were found to be capable of mating with normal males and ovipositioning under the laboratory conditions.

Effect on Weight Gain, Oviposition and Fecundity:

The results which were consistent for both apple and artificial-diet experiments (Table 4.6 and 4.7) showed that microbial insecticides and diflubenzuron did not affect the pupal weight of both sexes, egg production and fecundity of survivors. Larvae exposed to azinphosmethyl-treated apples at all levels did not differ from control in pupal weight (Table 4.6); however, female survivors at 25 ppm weighed significantly more than that of 50 ppm in experiments with apples. Generally, exposure to either phosmet or carbaryl did not produce any apparent effect on pupal weight of either sex. Also, azinphosmethyl, phosmet and carbaryl did not impair oviposition and fecundity. Adults from larvae treated with these insecticides tended to display greater reproductive potentials than the control, but this was not statistically significant (Tables 4.6 & 4.7). In the diet experiments, no observation could be made at the highest levels because none of the pupae survived to adult stage.

Exposure to most concentrations of pyrethroids, esfenvalerate and permethrin, produced severe long-term effects on codling moth weight-gain and oviposition (Table 4.6 and 4.7). Larval contacts with sublethal concentration of these insecticides resulted in reduction of pupal weight and subsequent egg deposition. Surviving pupae from all the treatments were lighter and smaller in size than the control. Fecundity of the moth, however, was not significantly affected in any of the treatments.

Table 4.6: Effect of sublethal concentrations of insecticides on weight gain, oviposition and fecundity when neonatal codling moth larvae were exposed to insecticide residue on apples.

Insecticides/ Concentrations		Mean pupal Weight Male (mg) S.E.		Female (mg) S.E.		Number of eggs Numbe S.E.		Egg Hatch (%) S.E.		Sterility index	Fertility index
Dipel	0.00	33.2 (1.9)	a	38.7 (2.7)	a	80.5 (4.8)	a	72.8 (3.2)		0.0	0.0
	1.00 MIU/l	32.5 (2.4)	a	37.9 (2.8)	a	69.3 (5.3)	a	70.9 (5.1)		2.6	0.0
	2.00 MIU/l	31.9 (2.7)	a	39.5 (1.2)	a	75.5 (6.4)	a	65.7 (3.6)		9.7	0.0
	3.00 MIU/l	33.0 (1.6)	a	38.4 (1.9)	a	70.3 (3.9)	a	70.4 (4.2)		3.3	0.0
	4.00 MIU/l	29.9 (3.1)	a	37.2 (1.5)	a	67.0 (4.5)	a	68.2 (4.4)		6.4	0.0
MVP	0.00	33.2 (1.9)	a	38.7 (2.7)	a	80.5 (4.8)	a	72.8 (3.2)		0.0	0.0
	125.00	30.3 (2.1)	a	38.2 (0.9)	a	69.0 (5.1)	a	72.7 (3.6)		0.2	0.0
	250.00	32.2 (1.2)	a	37.9 (2.5)	a	76.3 (4.5)	a	67.1 (5.4)		7.8	0.0
	500.00	31.9 (2.8)	a	37.4 (1.2)	ab	73.5 (7.3)	a	69.0 (5.3)		5.2	0.0
	750.00	33.3 (1.9)	a	35.5 (1.6)	b	65.1 (4.4)	a	73.3 (3.5)		0.0	0.7
Azinphos-methyl	0.00	32.6 (1.1)	a	39.3 (1.1)	ab	78.5 (3.7)	a	67.3 (4.6)		0.0	0.0
	5.00	33.2 (1.5)	a	39.4 (0.6)	ab	81.9 (3.1)	a	69.9 (4.1)		0.0	3.9
	10.00	32.2 (2.8)	a	38.2 (2.9)	ab	91.0 (5.3)	a	71.4 (6.6)		0.0	6.0
	25.00	31.2 (2.5)	a	41.0 (2.8)	a	96.8 (4.6)	a	74.7 (5.6)		0.0	6.5
	50.00	31.42 (1.2)	a	37.74 (0.7)	b	84.5 (3.8)	a	63.7 (4.8)		5.4	0.0
Phosmet	0.00	32.6 (1.1)	a	39.3 (1.1)	a	78.5 (3.7)	a	67.3 (4.1)		0.0	0.0
	25.00	32.0 (2.8)	a	40.1 (1.9)	a	76.5 (6.4)	a	63.6 (3.4)		5.6	0.0
	50.00	33.3 (1.8)	a	41.8 (2.8)	a	70.3 (4.3)	a	71.4 (6.1)		0.0	6.1
	100.00	30.6 (2.3)	a	38.9 (2.7)	a	87.8 (5.7)	a	62.0 (3.8)		7.8	0.0
Carbaryl	0.00	30.2 (0.9)	ab	39.5 (0.9)	ab	73.5 (4.5)	a	78.5 (4.7)		0.0	0.0
	15.00	31.9 (1.1)	a	37.4 (1.4)	b	78.8 (3.3)	a	75.3 (5.8)		4.1	0.0
	30.00	33.3 (2.4)	a	39.0 (2.7)	b	68.8 (6.3)	a	73.8 (4.8)		6.0	0.0
	60.00	27.9 (3.4)	b	41.6 (1.5)	a	86.5 (4.6)	a	84.8 (3.5)		0.0	8.1
Diflubenzuron	0.00	31.6 (2.7)	a	39.9 (1.1)	a	79.3 (3.1)	a	57.9 (3.2)		0.0	0.0
	22.00	33.0 (1.0)	a	38.6 (2.3)	a	63.5 (4.7)	a	62.5 (4.5)		0.0	8.0
	55.00	31.6 (1.8)	a	37.9 (3.1)	a	69.8 (5.1)	a	55.8 (6.1)		3.6	0.0
	110.00	29.9 (1.9)	a	39.5 (0.6)	a	77.8 (5.7)	a	60.9 (3.5)		0.0	5.2
Esfenvalerate	0.00	33.0 (1.1)	a	38.6 (2.2)	a	77.5 (3.5)	a	62.9 (3.8)		0.0	0.0
	0.25	29.2 (2.1)	ab	34.3 (0.7)	ab	69.8 (4.5)	ab	68.3 (5.9)		0.0	8.5
	0.50	27.4 (1.9)	b	31.9 (2.9)	b	59.8 (4.2)	bc	56.6 (4.7)		10.1	0.0
	1.00	27.2 (1.6)	b	33.1 (2.0)	ab	54.5 (3.8)	c	67.5 (4.5)		0.0	7.3
Permethrin	0.00	33.0 (1.1)	a	38.6 (1.0)	a	77.5 (3.5)	a	62.9 (3.8)		0.0	0.0
	0.50	29.9 (2.3)	ab	35.1 (1.8)	ab	67.2 (3.1)	ab	57.1 (5.1)		9.3	0.0
	1.00	28.1 (2.1)	ab	34.4 (2.3)	ab	63.3 (3.9)	b	68.5 (6.4)		0.0	8.3
	2.00	25.8 (1.1)	b	31.8 (1.4)	b	58.5 (6.3)	b	63.3 (4.7)		0.0	0.5

Means within insecticide groupings followed by the same letter are not significantly different (P = 0.05; FPLSD). *, result based on 4-16 individuals per treatment only, rest > 16 individuals per treatment.

Table 4.7: The effect of sublethal doses of insecticides on weight gain, oviposition and fecundity when neonatal codling moth larvae fed insecticides treated artificial diet.

Insecticides	Concen-tration (ppm)	Mean pupal weight Male (mg)	S.E.		Female (mg)	S.E.		Eggs Numb	S.E.		Egg hatch (%)	S.E.	Sterility index (%)	Fertility index (%)
Dipel	0	29.3	(2.9)	a	36.2	(2.8)	a	71.8	(4.5)	a	68.3	(4.1)	0.0	0.0
	1.00 MIU/l	28.4	(1.7)	a	35.3	(1.2)	a	63.0	(3.1)	a	72.6	(4.7)	0.0	6.4
	2.00 MIU/l	30.1	(1.0)	a	37.1	(2.1)	a	76.8	(5.1)	a	74.3	(5.8)	0.0	8.8
	3.00 MIU/l	29.2	(3.3)	a	35.1	(1.3)	a	63.5	(4.7)	a	64.3	(4.7)	5.9	0.0
	4.00 MIU/l	28.2	(1.4)	a	34.6	(1.8)	a	58.3	(4.3)	a	71.4	(3.5)	0.0	4.6
MVP	0	29.3	(2.9)	a	36.2	(2.8)	a	71.8	(4.5)	a	68.3	(4.1)	0.0	0.0
	125	30.1	(1.1)	a	35.6	(1.3)	a	74.5	(3.4)	a	64.5	(3.2)	5.5	0.0
	250	29.2	(2.7)	a	35.3	(2.5)	a	76.3	(4.6)	a	73.6	(4.6)	0.0	7.8
	500	28.8	(1.8)	a	34.1	(1.4)	a	64.8	(5.1)	a	67.7	(4.8)	0.8	0.0
	750	28.0	(2.7)	a	33.9	(2.2)	a	63.8	(3.5)	a	62.8	(5.1)	8.0	0.0
Azinphos-methyl	0	28.8	(1.6)	a	35.9	(1.9)	a	64.3	(4.3)	a	63.4	(3.5)	0.0	0.0
	5	30.7	(3.1)	a	34.7	(1.7)	a	67.5	(5.1)	a	68.2	(5.7)	0.0	7.5
	10	31.3	(2.9)	a	37.8	(2.3)	a	73.8	(4.6)	a	65.5	(4.3)	0.0	3.3
	25	31.1	(1.5)	a	38.2	(1.8)	a	79.3	(3.7)	a	72.1	(3.7)	0.0	13.7
	50	29.55	(2.1)	a	36.37*	(2.1)	a	-			-		-	-
Phosmet	0	28.8	(1.6)	a	35.9	(1.9)	a	64.3	(4.3)	a	63.4	(3.9)	0.0	0.0
	25	26.8	(1.7)	a	34.4	(1.1)	a	66.1	(5.2)	a	64.3	(4.2)	0.0	1.4
	50	27.4	(1.6)	a	35.5	(2.1)	a	58.5	(3.4)	a	68.3	(5.2)	0.0	7.7
	100	29.2	(2.5)	a	37.4	(1.6)	a	74.3	(6.1)	a	71.3	(3.6)	0.0	11.3
Carbaryl	0	27.7	(0.8)	b	34.9	(2.8)	a	68.8	(3.7)	a	60.0	(3.8)	0.0	0.0
	15	29.7	(1.1)	ab	36.6	(1.3)	a	70.6	(6.2)	a	64.9	(6.8)	0.0	8.2
	30	32.2	(2.6)	a	35.6	(3.8)	a	74.3	(4.2)	a	62.4	(3.6)	0.0	4.0
	60	30.9	(0.4)	ab	37.1	(2.5)	a	85.8	(5.1)	a	67.2	(5.3)	0.0	12.1
Diflubenzuron	0	30.0	(0.8)	a	37.5	(1.0)	a	76.5	(4.0)	a	81.3	(5.5)	0.0	0.0
	22	30.1	(2.5)	a	37.2	(1.8)	a	74.3	(4.2)	a	77.2	(6.1)	5.0	0.0
	55	28.8	(1.2)	a	36.2	(2.2)	a	66.3	(5.1)	a	81.7	(3.4)	0.0	0.6
	110	29.3	(1.7)	a	38.8	(2.1)	a	70.3	(4.7)	a	74.6	(4.2)	8.3	0.0
Esfenvalerate	0.00	31.9	(1.1)	a	38.2	(1.9)	a	77.5	(4.0)	a	80.2	(3.4)	0.0	0.0
	0.25	26.7	(2.3)	b	34.7	(2.1)	ab	65.1	(5.3)	ab	73.6	(5.5)	8.2	0.0
	0.50	24.0	(1.5)	b	33.7	(3.1)	b	58.2	(3.3)	b	76.6	(4.8)	4.5	0.0
	1.00	25.68	(2.2)	b	32.59	(2.5)	b	-			-		-	-
Permethrin	0.00	31.9	(1.1)	a	38.2	(1.9)	a	77.5	(3.7)	a	80.2	(3.4)	0.0	0.0
	0.50	27.2	(1.7)	ab	33.3	(1.4)	b	59.8	(4.1)	b	84.2	(4.2)	0.0	5.0
	1.00	24.8	(2.1)	b	30.7	(2.8)	b	55.0	(3.9)	b	74.4	(5.7)	7.2	0.0
	2.00	26.5	(2.7)	b	31.58*	(2.1)	b	-			-		-	-

Means within insecticide groupings followed by the same letter are not significantly different (P = 0.05; FPLSD). *, result based on 4-16 individuals per treatment only, rest > 16 individuals per treatment.

Discussion

Effects of Adult Exposure to Sublethal Concentrations

No significant degradation of the microbial and chemical insecticides was expected during 24 hours after treatment under the present laboratory conditions (Hameed & Allen 1976, Elliott & Anderson 1982, Reissig *et al.* 1985), therefore, the codling moth adults were exposed to a relatively uniform residue on the apple leaves. The reductions in oviposition and fecundity are considered to be sublethal effects because the longevity of the moths that survived the first 24 hours after treatment did not change. This reduction in oviposition may be attributed to mating disruption or metabolic cost incurred to detoxify the chemical absorbed or ingested. Sublethal rates of many chemical insecticides are thought to disrupt pheromonal communication and, hence, interfere with normal courtship behavior of several insect species (Haynes & Baker 1985, Haynes 1988). Metabolic cost may take a toll from the resources reserved for egg production. Enzyme induction, that is, production of increased quantity of an enzyme required to degrade toxic substance, is an expensive mechanism (Curtis and Barnes 1989). Decrease in reproduction have been reported for other species exposed to sublethal levels of some insecticides (Boles 1974, Zettler & LeCato 1974, Grosch 1975) but not consistent over several exposure rates.

When codling moth adults were exposed to residues on apple leaves, diflubenzuron (insect growth regulator) and Dipel and MVP (microbial insecticides) were found to be non-toxic. They did not show any long-term effect on adult longevity, oviposition and fecundity (Table 4.1). The results with diflubenzuron are consistent with the findings of other authors (Hoying & Riedl 1980, Elliott & Anderson 1982). *B. thuringiensis* is considered to be a potential larvicide without any toxicity for adult insects (Federici 1993). However, its sublethal effects on insect adults has never been studied.

It is important to note that pyrethroids not only killed the larvae (Tables 4.2, 4.3) and adults of codling moths at the rates tested, but they also reduced the number

of eggs produced by treated females (Table 4.1). Thus causing a substantial sublethal chronic effect in the progeny production. Sublethal levels of pyrethroids are known to significantly inhibit egg production by females in other insects including *Plutella xylostella* (Kumar & Chapman 1983, Moore *et al.* 1992), *Spodoptera frugiperda* (Gist & Pless 1985), *Sitophilus oryzae* and *S. granarius* (Nahal-El & Halfway 1973), but no such effects have been reported previously for codling moth.

Effects of Sublethal Concentrations when Neonate Larvae were Exposed

When neonate larvae were exposed to sublethal concentrations of insecticides, deleterious effect on larval and pupal development, and subsequently on adult oviposition were evident (Tables 4.2-4.7). Since consumption of any toxic material is limited by ethology of insect, it is difficult to know how much insecticide was consumed by each larva. Although only the larvae were exposed to the treated apples or diet, the complete toxic effect of these pesticides was not manifested until after the insect had become adult. This type of latent toxicity (Kalina 1950) is reported here for the codling moth for the first time. It is known that treating some insects larvae at an earlier stage gave more detrimental sublethal effects than treating at older stages (Esaac *et al.* 1972, 1975). It has been known that one time exposure of insect larvae to sublethal doses of chemical insecticides was capable of causing adverse/advantageous long-term effects on their subsequent biology (Esaac *et al.* 1972, Tan 1981, Kumar & Chapman 1983, Robb & Parrella 1984, Haynes 1988, Messing & AliNiazee 1988). Sublethal poisoning at the larval stage is known to manifest a variety of symptoms including depletion of glycogen, carbohydrate and fat reserves, qualitative changes in protein and lipid contents (Talton & Khan 1978, Turunen 1977) as well as effects on enzyme and endocrine systems (Esaac *et al.* 1972, Pratt 1975). These physiological alterations may result in long-term effects on the biology of treated insects.

Insect growth regulator diflubenzuron and microbial insecticides Dipel and MVP did not show any long-term effect on codling moth when exposed at neonatal stage (Table 4.2-4.7). This may be because these insecticides are stomach poisons. It

is known that codling moth larvae feed only for a short period before entering apple or diet cube (chapter 3) and as such may not have acquired sufficient doses to produce an effect. Similar effects have been observed with other lepidopterous insects for *B. thuringiensis* (Alford & Holmes 1986) and with codling moth for diflubenzuron (Hoying & Riedl 1980, Elliott & Anderson 1982). Some lepidopteran larvae were found to recover 24 hours long exposure to *B. thuringiensis*, when subsequently reared on untreated food (Somerville *et al.* 1970). Insect growth regulator, diflubenzuron is known for its momentary retention in the insect systems (Ishaaya 1992). This may be another possibility for not producing any long-term effects.

The treatment of neonatal larvae with azinphosmethyl, phosmet, carbaryl, esfenvalerate and permethrin caused a decrease in percentage pupation based on number of larvae survived seven days after pesticidal contact (Tables 4.2 & 4.3). Other authors found similar results with lower/sublethal concentrations of carbaryl and phosmet. Matvievskij (1967) observed that lower concentrations (100 - 150 ppm) of carbaryl killed most of the codling moth larvae in 6-7 days after exposure. Reed *et al.* (1985) noted a reduction in codling moth larval survival as the concentrations of phosmet increased from 25-100 ppm. However, neither of these studies were aimed at sublethal effects.

Pyrethroids and carbaryl caused other detrimental effects on pupal survival and subsequent adult eclosion (Tables 4.2 & 4.3). There was an apparent delayed or latent effect of these insecticides. Similar effects has been shown in other insect species (Esaac *et al.* 1972, Kumar & Chapman 1983, Gist & Pless 1985). In general, it is considered that the latent toxicity is due to storage of insecticides in the lipid tissues of insects in an unchanged form, which may be released during metamorphosis and cause immediate mortality or interference in the histogenesis resulting physiologic, morphologic or physiomorphic defects in the surviving adults. This phenomenon has been observed in *Drosophila melanogaster*, where stored insecticides was found to release from the body during pupal hitolysis (Moriarty 1968), nevertheless, there may be a number of factors and/or processes involved, therefore, other possibilities can not be excluded. In the present studies, tiny neonate codling moth larvae were exposed to

insecticidal chemicals for a short period of time. Therefore, they might not have acquired enough quantity of an insecticide to produce an effect as larvae grow in size and weight. It seems that exposure to sublethal concentration had radically changed the physiology of codling moth at molecular or cellular level, probably affecting the endocrine (hormone) or enzyme system permanently. Hence, adverse effects (as a result of metabolic cost) perpetuate and build up as larvae grow, the observed results of the present study appear to be in agreement with hormoligosis hypothesis, which predicts that sublethal poisoning is likely to reduce the general fitness of an insect and thus the reproductive capacity (Tamashiro & Sherman 1955). It is well documented that DDT can concentrate in the nuclei of insect cells and affect transcription of various genes (Ishaaya & Chefurka 1971, Mitsuhashi *et al.* 1970, Nelson 1970, William & Chung 1987). Quantitative and qualitative changes in proteins and lipids have been noticed in various insects as a result of larval exposure to low doses of insecticides (Brown 1963, Pratt 1975, Wongkobrat & Dahlman 1976).

Codling moth larvae which survived contact with pyrethroids (esfenvalerate, 0.25 - 0.50 ppm and permethrin, 0.50 - 1.00 ppm) showed a considerably extended ($P < 0.05$) duration of larval period (Tables 4.4 & 4.5). The exposure also resulted in reduction of pupal weight and subsequently the egg deposition (Tables 4.6 & 4.7). The surviving pupae from these treatments were lighter and smaller in size than from the control. The slower development of the treated larvae was probably the result of a decrease in food consumption (Turunen, 1977) and utilization (Talton and Khan 1978). These processes have not been investigated for codling moth, therefore, do deserve attention. Reduction in oviposition is possibly due to reduction of pupal weight. Tan (1981) found similar result with pyrethroid cypermethrin and permethrin against *Pieris brassicae*. Ross and Brown (1982) found that sublethal concentrations of fenvalerate and permethrin inhibited larval growth (decrease overall larval weight) of *Spodoptera frugiperda*. Moore (1980) discovered that some pyrethroids reduce the fecundity of the female *Anthonomus grandis grandis*. Gist and Pless (1985) found that 9 different pyrethroids inhibited growth of larvae, reduced the amount of feeding by larvae, and reduced mobility and fecundity of *Spodoptera frugiperda* adults. They

suggested that extension in larval development by pyrethroids was because they deter feeding, increasing larval time and decreasing final body weight.

Adults that developed from larvae which survived exposure to azinphosmethyl and carbaryl oviposited an increased number of eggs as insecticide concentration were increased (Table 4.7). Though the increment was statistically not significant, it was consistent with all treatments in both apple and diet experiments. As the fertility of the eggs laid by females from treated larvae in all cases was comparable to or higher than that of control; the mating appeared to be not affected. The increase in egg production may be explained in term of *hormologosis*, a phenomenon in which subharmful quantities of stress agents are stimulating on physiological processes (Luckey 1968). Reproductive potential of adult lepidoptera depends largely on the concentration of amino acids in larval hemolymph and the size of larval fat body. Thus, larval hemolymph is considered a major source of egg protein (Telfer 1965, Esaac 1975). Therefore, the protein egg reserves must be carried over from the larval stage because adult can not assimilate protein (Wigglesworth 1965). Esaac *et al.* (1972) found that some insecticidal chemicals affected protein synthesis by treated insects which in turn influenced egg production. He noted that sublethal doses of some insecticides e. g. carbaryl and organophosphate methyl parathion increased larval hemolymph protein and others, e. g. endrin decreased it. Increased egg production by lepidopterous insects exposed to insecticides has been observed in many species (Abdel-Salam & Nasr 1968, El-Sayed 1968, Esaac *et al.* 1972). However, in the present studies and elsewhere (Esaac *et al.* 1972) a given insecticides (e. g. phosmet in the present study) was found to cause both an increase and/or a decrease in number of eggs produced depending upon the dosage used.

Morphologic sublethal effect such as pupal deformities and wing deformity (incapability to inflate their wings upon emergence) in insect adults has been documented in the literature (Moriatry 1969, Bond & Upitis 1973, Kumar & Chapman 1983). In the present study, this phenomenon was seen with treatments having deleterious delayed/latent toxicity effect, thus yielding only a few pupae and adults (Tables 4.4 & 4.5). A comprehensive research on this sublethal effect is needed

because, deformed codling moth adults may add to population control since their inability to fly when disturbed make them more susceptible to natural calamities. In the present study it was observed that wing-deformed females could mate with normal males and oviposite like normal adults. In the field, however, these behaviors might not occur because of their inability to fly.

Codling moth larvae do not appear to be much affected by the sublethal exposures to commonly used insecticides like azinphosmethyl, phosmet, diflubenzuron and microbial insecticides (Dipel and MVP) (Tables 4.2-4.7). With these insecticides a consistent effect was not observed. Although higher concentrations of azinphosmethyl and phosmet produced some delayed/latent mortality (Tables 4.2-4.3), lack of other consistent effects and relative increase in oviposition at lower rate suggest that survivors of their sublethal exposures are not adversely affected.

Pyrethroid effects such as reduced pupation, lower pupal weight, and reduced oviposition, were possibly due to the their antifeedant property as observed with other lepidopterous larvae (Ross & Brown 1982, Kumar & Chapman 1983, Gist & Pless 1985). Effect on reproduction has potentially important implications in a pest management programs. A reduction in oviposition rate is highly desirable response to an insecticide. Similarly, the increased developmental times can disturb phenology of an insect, thus significantly reducing the number of generations per years as well as providing increased time for natural enemies for effective biological control. It seems that at lower concentrations synthetic pyrethroids alone or combined with microbial control agents such as *B. thuringiensis* and others can be effective for codling moth control because they retarded growth of larvae, reduced pupation, and impaired oviposition. These characteristics coupled with their great larvicidal potency might help prevent built-up of a large codling moth population in the field thus reducing overall economic damage.

Insect exposure to sublethal concentrations may either induce changes in individual's characteristic (s) (induction effect, e. g. increased oviposition), or select survivor (s) genetically predisposed for a particular characteristic (s) (selection effect, e. g. increased oviposition) (Messing & Croft 1990). At higher rates a selection effect

is usually expected (Terriere 1983). However, sublethal effects may occur at insecticides doses which kill as high as 90% of the target insect population (Dumbre & Hower 1976). In the present studies, an induction effect rather than a selection effect was observed; for instance, pyrethroids gave a consistent response at all levels of insecticides and the adverse effects were observed when either larval or adult stage was exposed. Insect generally responds rapidly once the insecticide has been accumulated in their body (Terriere 1983). An induction effect such as increased activity of enzymes can be detected in minutes in cell culture systems (Nebert *et al.* 1972). This kind of effect usually remains as long as the inducer is present and disappears as a rate function dependent upon the rate of metabolism and /or excretion of the inducer. Baeza-Squiban *et al.* (1988) found that pyrethroid like deltamethrin quickly accumulated in insect cells cultured *in vitro* and persist for a fairly long period of time. This could be a possibility for manifesting clear-cut long-term sublethal effects by pyrethroids than by organophosphorous insecticides in the present studies.

In synopsis, survivors of a treatment and their potential contributions to subsequent generations should be considered when determining efficacy of a control agent or method. In the field, sublethal exposure to insecticides may be caused because of spray drift and deposition irregularities (Wieser 1985, Alford & Holmes 1986). Study of sublethal effects is particularly important for an approach such as use of microbial-chemical insecticide mixture based on reduced rates of its components. Here, the comprehension of sublethal effects is direly needed because insects would be exposed to chemical component of the mixture for an extended period as compared to microbial component. Microbial insecticides based on *B. thuringiensis* generally have short (1- 4 days) residual activity (Gardner & Hornby 1987, Ali & Young 1993, Nyouki & Fuxa 1994) than most chemical insecticides (10 - 70 days) including pyrethroids, organophosphate and carbamate insecticides against a number of agricultural insect pests including codling moth (Hameed & Allen 1976). Codling moth when exposed at larval or adult stage to sublethal rates of azinphosmethyl, phosmet, carbaryl, esfenvalerate and permethrin manifested various short- and long-term effects with varying degree of intensity usually stronger with pyrethroids.

However, interpretation of sublethal effects is difficult; the more vigorous individuals may be selected through the insecticide exposure, and subsequent comparisons between treated and control individuals would, thus, be biased (Moriarty 1969). Present investigations were conducted under laboratory conditions and did not consider behavioral and many other potential biological effects of pesticides on codling moth. Seasonal and geographical variability in the codling moth populations, and environmental factors such as temperature may modify any effect reported in the present studies.

Chapter 5

Field Evaluation of Microbial-Chemical Insecticide Mixtures for the Control of Codling Moth, *Cydia pomonella* (L.)

Abstract

Chemical insecticides Guthion® 50WP (azinphosmethyl) and Imidan® 50WP (phosmet); pyrethroids, Asana® XL (esfenvalerate) and Ambush® 25.6% (permethrin) at field recommended rates effectively controlled codling moth damage in all seven field experiments conducted from 1991 to 1993. Field rates of Ultra-fine spray oil, SunSpray® (summer oil) and microbial insecticides (Dipel® 2X and MVP®) failed to control codling moth effectively. Increasing dosage and/or application frequency of the microbial insecticides, did not significantly increase their efficacy against codling moth.

All combinations of Guthion, Imidan, or Sevin with *B. thuringiensis*-based microbial insecticides gave little benefit in term of degree of protection from codling moth damage. When applied 2 times/generation, *B. thuringiensis*-diflubenzuron mixtures produced similar results. However, when applied 3 times/generation, Dipel (1.0X) + Dimilin (diflubenzuron) at 0.25X and 0.50X was as efficacious as the standard insecticides Guthion at normal (250ppm) and maximum field rates (300 ppm), respectively. Generally, mixtures with the lowest dose (0.1X) of pyrethroids produced synergistic interaction whereas those with higher rates (0.2, 0.25, and 0.5X) produced an additive joint action. Pyrethroids such as Asana (0.1X and 0.2X) and Ambush (0.1X) in combination with Dipel were among the treatments that provided the best control of codling moth in the field. With these mixtures, the overall codling moth damage was generally under acceptable limits of 1-2%, when codling moth infestation was < 23% in control. At 38-45% control fruit infestation, Dipel at lowest rate of Asana (0.1X) did not performed as good as Guthion at the maximum field rate of 300 ppm. The degree of protection by mixture, however, was equivalent to that of Guthion applied at normal rate of 250 ppm. An increase in dose of either microbial/chemical component in the mixture or number of mixture applications per generation (3 versus 2) generally resulted in better reduction of codling moth damage. The difference in effect, however, was unexpectedly small (statistically non-significant), suggesting that lower dosage of mixture components at lower frequency

of application was enough to give adequate protection against codling moth infestation. Other promising treatments such as Ambush (0.2X) + Dipel (1.0X) and Asana (0.25X) + Dipel (1.0X) consistently provided results statistically comparable to the standard treatments. Most interactions of pyrethroids with genetically engineered MVP were generally additive. Similarly, MVP - Dimilin mixtures were usually less effective than Dipel - Dimilin mixtures.

Introduction

The codling moth, *Cydia pomonella* (L.), is a major pest of deciduous tree fruit throughout the world (Putman 1963, Bajwa 1980, Riedl *et al.* 1985). High quality standards of modern fruit production do not tolerate more than 1-2 % of damaged apples or pear (Andermatt *et al.* 1988). At present, the control of this pest is principally achieved by two to six applications (depending on the number of generations in an area) of organic insecticides to produce blemish-free fruit. Application of these broad spectrum insecticides for the control of codling moth has resulted in several side effects such as destruction of useful natural enemies (Hagely & Laing 1989, Purcell & Granett 1986, Hardman & Gaul 1990) and development of resistance to pesticides (Varela *et al.* 1993, Knight *et al.* 1994) thus causing emergence of secondary insect pests and phytophagous mites as serious problems in the apple ecosystem (Bower & Kaldor 1980, Hardman & Gaul 1990, Croft & Riedl 1991). Low economic threshold and apparent resistance to chemical insecticides have led to increased application rates of commonly used organophosphate compounds (azinphosmethyl and phosmet) or their replacement with more potent pest control agent such as pyrethroids. Field use of pyrethroids or higher doses of organophosphate insecticides are known to have a devastating effect on pest natural enemies (Hull & Starner 1983, Hardman & Gaul 1990) and as such considered as a threat to integrated pest management programs of apple pests, which was developed over a period of 30 years (Croft & Hoyt 1983).

Several research efforts to develop alternative control techniques providing both pest suppression and reduction of the negative side effects of the pesticide approach have been undertaken. The techniques which showed some success include the use of reduced insecticide dosages (Bastiste 1972, Barnett *et al.* 1977), the use of insect growth regulators (Westigard 1979, Burts 1983, Westigard & Gut 1986, Moffitt *et al.* 1988), mating disruption (Moffitt *et al.* 1978, Moffitt & Westigard 1984, Howell *et al.* 1992, Barnes *et al.* 1992), biological control with viruses (Falcon *et al.*

1968, Huber & Wundermann, 1978, Jaques *et al.* 1981, Glen & Payne 1983), release of sterile adults (Proverbs *et al.* 1966), and utilization of low dosage mixtures of microbial and chemical insecticides (Karadzhov 1973a, Tomova and Ragelova 1977). Although there is repeated mention of using microbial-chemical insecticide mixtures against codling moth in some papers, this technique has never been evaluated in the orchard ecosystem of the United States. Our laboratory studies (Chapter 3) indicated that some combinations of chemical and *Bacillus thuringiensis*-based insecticides were efficacious against this pests. However, reliable assessment required testing in the field environment (Jaques 1981).

The present study was performed to assess effectiveness of mixtures of *B. thuringiensis*-based and chemical insecticides against codling moth in comparison with conventional insecticides and insect growth regulator, diflubenzuron. The effectiveness was measured by assessing fruit infestation rates at harvest.

Materials and Methods

Study Orchards:

Field trials were conducted at Lewis Brown Farm, Oregon State University, Corvallis. In 1990 and 1991, preliminary studies were conducted at Entomology Farm, Oregon State University, Corvallis, Oregon. Entomology Farm had mixed varietal apple plantation surrounded by cherry and hazelnut trees with no regular spray program for the apple pests. Lewis Brown Farm is a well managed horticultural orchard with blocks of different varieties of apple, pear, cherry, hazelnut and small fruits. The present experiments were conducted on two blocks of 10 year old *Red Delicious* apple trees planted with a spacing of 6 m between rows and 4 m between trees. The trees were irrigated fortnightly by under-tree sprinklers. They were pruned annually, and the grass and weeds around the trees were mowed regularly. At this farm, there was a history of applying 3-4 sprays of Guthion and/or Sevin each year for the control of codling moth.

Spray Solutions:

The commercial product tested were organophosphate, Guthion® 50WP (azinphosmethyl) and Imidan® 50WP (phosmet) ; pyrethroids, Asana® XL (esfenvalerate) and Ambush® 25.6% (permethrin); carbamate, Sevin® 50WP (carbaryl); insect growth regulator, Dimilin® 25WP (diflubenzuron); ultra-fine spray oil, SunSpray® and microbial insecticides, Dipel® 2X (*B. thuringiensis*) and MVP® (genetically engineered *B. thuringiensis* product). The manufacturers recommend Dipel at 0.5 - 2 lb. (approximately 31 - 124 Million International Units (MIU) in 100 liters) and MVP at 3 - 4 quarts per acre (approximately 188 - 250 ml in 100 liters) for field use against codling moth. The concentrations of chemical and microbial insecticides applied alone or when mixed were expressed as 0.1X, 0.2X, 0.25X, 0.5X, and 1.0X of recommended orchard rates against codling moth (Northwest Insect Control Hand Book, Manufacturer's Label/Brochure, Crop Protection Chemical

Reference or current literature). Field recommended rates were used. Acquisition of efficacy information was necessary because the joint action of a mixture may be influenced by concentrations of each component and inherent susceptibility of larvae to these components (Benz 1971). If a population shows tolerance / resistance to an insecticide, adjustments/modification in proportion of mixture components may be warranted.

In 1991 trials, 1.0, 0.5, 0.25 and 0.1 X of field recommended rate of chemical insecticides, Guthion, Imidan and Ambush, alone and/or in combination with that of 1.0, 0.5, 0.25 and 0.1 X of Dipel® 2X were tested against codling moth in three different experiments. In 1992 and 1993, most chemical insecticides at 0.1 and 0.2X were tested alone or in combination with Dipel 2X® and MVP® . Ultra-fine spray oil SunSpray® was tested at 0.5 % and 1.0 % alone and in combination with Dipel 2X® and MVP® at 0.5%. In all experiments (1991-1993), other treatments included were water treated or/and untreated check, two standard treatments of Guthion at 250 and 300 ppm, and microbial and chemical insecticides at their full field recommended rates for comparison purposes. Maximum field rate of Guthion (300 ppm) was included to compare mixtures' efficacy with a treatment yielding maximum protection irrespective of population pressure.

Experimental Design and Spray Schedule:

The test design consisted of 4-5 single-tree replicates in randomized complete block. All treatments were applied to run off with a handgun sprayer at 300 psi, equivalent to approximately 3740 liters per hectare. The sprays were applied in the early morning or in the evening. Every other tree in a row was treated in a way that each study tree was surrounded by 4 unsprayed trees to buffer it from spray drift, and to promote a buildup of codling moth. Every other year, the treated trees were selected from those which were buffer trees in the previous year. Computerized codling moth phenology model , *Codmoth*, was used to schedule spray timing. The first spray was applied at 450 day-degrees followed by 2nd and 3rd sprays 21 days

later and at 1460 day-degrees, respectively. A fourth spray was applied 21 days after the third spray.

As the residual activity of *B. thuringiensis*-based insecticides is short-lived, the synergistic *B. thuringiensis*-insecticide mixtures can only provide high initial mortality for a short-period of time. A relatively long-term residual activity from chemical component of the mixture was expected with a period less than that of its full field recommended rate because of highly correlated insecticide dose-residual period relationship. A 21 day interval between sprays is based on residual activity of field recommended dosage of commonly used chemical insecticides (Guthion, Imidan) against codling moth neonate larvae which provide > 90 % mortality (Hameed & Allen 1976). It was hypothesized that 2 application per generation might not be sufficient to avail full benefits of *B. thuringiensis*-chemical insecticide mixtures. Considering high initial mortality of mixtures (chapter 3) and short residual activity of it microbial component, and relatively longer activity of its chemical component but less than that of full field rate, a shorter spray interval was designed for an experiment performed in 1993. In this experiment three sprays per generation were applied, that is, first spray at 450 day-degrees, 2nd and 3rd sprays 14 days and 28 days later respectively, a fourth spray at 1460 day-degrees, and fifth and sixth sprays 14 days and 28 days later respectively. Results of different experiments were compared to determine optimum frequency of applications for microbial-chemical insecticide mixtures.

Dynamics of Hibernating Population:

As the number of hibernating individuals of a species may predict its population density in the next season, it is essential to study impact of a pest control agent/method on dynamics of hibernating population. In 1992 and 1993, corrugated bands (5-6 cm wide cardboard pupation strips) were tied round the trunk of each experimental tree seven days after the last spray to trap codling moth larvae seeking cocooning site to determine whether *B. thuringiensis*-insecticide mixture was effective in reducing number of hibernating larvae. The strips were removed 14 days after

harvest, and the numbers of larval galleries and larvae were recorded. Some galleries were void of larvae because of predation.

Among apple trees of the same size, the more fruit it bears, the more attractive it appears to be to codling moth (Wildbloz 1958). Therefore, it is necessary to eliminate the influence of different crop size in the experimental units by relating the number of diapausing larvae in trap bands to the total apples on the corresponding experimental units (Huber and Dickler 1977). In the present study, the number of larvae per 1000 apples was used as an index figure for the size of the population.

Damage Assessment:

Efficacy of *B. thuringiensis*-chemical insecticide mixture was assessed by percentage fruit damage after the first generation of codling moth and in picked and dropped fruit at harvest. Overall damage at harvest was assessed based on total number of fruit on a treated tree. The codling moth injury was classified as *sting* (shallow feeding damage) and *entry* (deep feeding damage: tunnels to the core). *Stings* are indicative of larvae dying within a short time after entry into the apple whereas *entries* are caused by feeding in apple by surviving larvae. *Stings* are essentially the shallow damage (2-4 mm across, up to 2 - 5 mm deep) to the fruit by young larvae which died or left the fruit before penetrating towards seeds. *Entries* were caused by the codling moth larvae that had penetrated half way or more to the seeds. Superficial injury (minute sting: 1-2 mm or less across and less than 2 mm deep) to the fruit surface that would not result in downgrading was not included as injury.

In mid-season, all windfall fruit beneath the treated trees were checked for deep entries. At each experimental tree, 20 - 40 apples randomly selected from both around and up/down the tree, were examined *in-situ* to enumerate deep entries by larvae of the first generation codling moth. At harvest, all windfall fruit were collected from beneath the experimental trees and examined for deep damage only. Stings were not recorded because of the difficulty of distinguishing them from other damage in

windfalls. At harvest, 50-100 fruit/replicate from both around and up/down the tree were randomly picked and examined for stings and entries caused by codling moth.

Statistical Analysis:

The results for codling moth injury were expressed as percentage of fruit damage. Data was analyzed by analysis of variance and means were separated ($P = 0.05$) using Fisher's Protected Least Significant Difference (FPLSD). Damage percentage and number of hibernating larvae were transformed using a square root transformation ($\sqrt{X + 0.5}$) to accommodate zero values (Fowler and Cohen 1990). Back transformed means are listed in the Tables. Different parameters calculated from the observed data were: *stings as % of total harvested-fruit damage, percentage protection by a treatment, percentage reduction in diapausing larvae, expected protection from a mixture* and *Chi-square values*.

The expected protection (E) for a mixture was calculated as given below:

$$E = P_m + P_i\ (1 - P_m)$$

where P_m is the percentage protection from microbial component alone and P_i is the percentage protection from insecticide alone. Percentage protection (Px) for a given treatment was calculated as:

$$Px = \frac{Oc - Ot}{Oc} \times 100$$

where Oc is observed codling moth damage in control and Ot is observed codling moth damage in a given treatment. Chi-square test was used to determine the synergistic, antagonistic and additive interactions of mixture components. In order to define and explain a general trend of joint activity, we designated different interactions

as weakly synergistic or antagonistic (Chi-square 2.71, df = 1, P = 0.1), moderately synergistic or antagonistic (Chi-square = 3.84, df = 1, P = 0.05), and strongly synergistic or antagonistic (Chi-square = 6.63, df = 1, P = 0.01).

Results

1991 Trials

Results presented in Tables 5.1-5.3 show that field recommended rates of Imidan 50WP (120 gm/100 l.), Ambush 25.6% (16 ml/100 l.) and Guthion 50WP (50 gm/100 l.) provided excellent control of codling moth. These chemical insecticides at reduced rates (0.1X, 0.25X, 0.5X field rates) significantly ($P < 0.05$) lowered the percentage of apple damage. Microbial insecticide, Dipel at 1.0 X provided significant reduction ($P = 0.05$) of codling moth damage in two of three experiments with 13.95% and 20.37% protection. At lower dosages of 0.1, 0.25 and 0.5 X, this insecticide completely failed to reduce any damage.

Some Dipel-Ambush mixtures (Dipel 1.0X + Ambush 0.1X and Dipel 0.5X + Ambush 0.5X) reduced damage similar to that of full rate of Ambush applied alone (Table 5.1). Interaction between Dipel at 1.0X and Ambush at 0.1X was moderately synergistic, resulting in a significant reduction of codling moth damage when compared to the chemical and microbial components applied alone. Other mixtures resulted in an additive effect. Among these, only Dipel 0.25X + Ambush 0.25X provided significantly more protection than that of corresponding dosages of mixture components alone.

Different combinations of Dipel and organophosphates Guthion and Imidan were additive (Tables 5.2 & 5.3). None of the Dipel-Guthion and Dipel-Imidan combinations provided protection from codling moth damage as good as Guthion/Imidan alone applied at full rate (the standard treatments). However, combinations with Dipel at 1.0X and either Guthion or Imidan at 0.1X performed better (slightly potentiating) than did the same rates of Dipel, Guthion and Imidan applied alone.

Table 5.1: The effectiveness of Dipel-azinphosmethyl (Guthion) mixtures against Codling moth on apples in 1991.

Treatment	Insecticide Rate/100 liters		Damage at harvest		Protection by treatment	Expected protection	Chi-square	Conclusion
	Microbial	Chemical	(%)		(%)	(%)		
Control	-	-	21.56	abc		-	-	-
Dipel 2X	100 MIU	-	16.01	cd	25.75	-	-	-
Dipel 2X	050 MIU	-	18.72	bc	13.17	-	-	-
Dipel 2X	025 MIU	-	22.84	ab	0.00	-	-	-
Dipel 2X	010 MIU	-	25.51	a	0.00	-	-	-
Guthion 50WP	-	50.0 gms	0.24	i	98.89	-	-	-
Guthion 50WP	-	25.0 gms	2.31	h	89.28	-	-	-
Guthion 50WP	-	12.5 gms	8.11	fg	62.38	-	-	-
Guthion 50WP	-	05.0 gms	11.21	ef	48.01	-	-	-
Guthion, Dipel	100 MIU	05.0 gms	5.95	g	72.40	61.39	1.97	Additive
Guthion, Dipel	050 MIU	25.0 gms	2.48	h	88.52	90.69	0.05	Additive
Guthion, Dipel	025 MIU	12.5 gms	6.79	g	68.51	62.38	0.60	Additive
Guthion, Dipel	010 MIU	05.0 gms	13.05	de	39.49	48.01	1.51	Additive

Square root transformation was performed for analysis of variance. All means are back-transformed. Treatment means in each column followed by the same letter are not significantly different (P= 0.05)

1992 Trials

Two experiments were performed at different sites during 1992 season. I attempted to select and continue evaluation of promising mixture treatments.

Trial 1:

The results of this experiment are given in Table 5.4. Mid- (after first generations) and end-season (at harvest) assessment of codling moth damage indicated that organophosphate, Guthion 50WP at 50 and 60 gm/100 liters (standard rates) gave excellent control of the codling moth. This rate reduced deep-entry damage in harvested fruit by 100 % and the hibernating larvae by 95 %. Other treatments such as insect growth regulator, Dimilin (44 gm/100 l.) and pyrethroid, Asana (30 ml/100 l.) and Ambush (16 ml/100 l.) also provided excellent control. In these treatments, sting damage mainly contributed to the total damage. Carbamate, Sevin (120 gm/100 l.) provided good control of first generation codling moth, but did not effectively protect crop subsequently. The reduced rates of the chemicals insecticides significantly lessened codling moth damage and hibernating larvae. These rates were capable of reducing deep entries better than sting damage indicating an earlier mortality of the larvae.

At harvest, summer oil SunSpray at 0.5 and 1.0 % concentrations provided a 44.20 % and 44.81 % reduction in codling moth damage, respectively (Table 5.4). Also, these rates failed to give satisfactorily control of first generation damage. A similarity in the percentage reduction of hibernating larvae and degree of protection observed in these treatments suggested that SunSpray had no long-term post-exposure effects on codling moth larvae. And as such, SunSpray at 0.5 - 1.0 % was ineffective in controlling codling damage.

The season-long assessment of codling moth damage indicated that Dipel and MVP at 1.0X provided larval control statistically better than water-treated and untreated controls with degree of protection comparable to that of 0.1X rates of most

Table 5.2: The effectiveness of Dipel-phosmet (Imidan) mixtures against Codling moth on apples in 1991.

Treatment	Insecticide Rate/100 liters		Damage at harvest (%)		Protection by treatment (%)	Expected protection (%)	Chi-square	Conclusion
	Microbial	Chemical						
Control	-	-	11.54	ab		-	-	-
Dipel 2X	100 MIU	-	7.93	cd	31.28	-	-	-
Dipel 2X	050 MIU	-	10.81	ab	6.33	-	-	-
Dipel 2X	025 MIU	-	12.24	a	0.00	-	-	-
Dipel 2X	010 MIU	-	9.21	abc	20.19	-	-	-
Imidan 50WP	-	120 gms	0.31	i	97.31	-	-	-
Imidan 50WP	-	060 gms	2.14	h	81.46	-	-	-
Imidan 50WP	-	030 gms	5.10	fg	55.81	-	-	-
Imidan 50WP	-	012 gms	7.39	cd	35.95	-	-	-
Dipel, Imidan	100 MIU	012 gms	3.75	g	67.48	55.98	2.36	Additive
Dipel, Imidan	050 MIU	060 gms	1.73	h	84.98	82.63	0.07	Additive
Dipel, Imidan	025 MIU	030 gms	6.36	def	44.89	55.81	2.14	Additive
Dipel, Imidan	010 MIU	012 gms	5.82	ef	49.55	48.88	0.01	Additive

Square root transformation was performed for analysis of variance. All means are back-transformed. Treatment means in each column followed by the same letter are not significantly different (P= 0.05)

chemical insecticides. At harvest, these microbial insecticides significantly reduced deep-entry damage without affecting shallow-entry damage. Usually, the reduction in hibernating larvae by a treatment was similar to its degree of protection. It appeared therefore, that microbial insecticides, Dipel and MVP, by themselves were ineffective for the control of codling moth.

The mixtures of reduced rate of Guthion (5 gm/100 l.) with Dipel (100 MIU/100 l.) or MVP (250 ml/100 l.) were additive in controlling codling moth. However, they were ineffective in reducing damage below tolerable level. Sevin at 0.1X in combination with either microbial insecticides produced less than additive results. The protection was as good as Sevin component (0.1X) applied alone. Therefore, Sevin at 0.1X, moderately antagonized the effect of *B. thuringiensis*-based microbial insecticides and as such efficacy of their mixtures fell short of expected protection.

Data in Table 5.4 show that pyrethroid insecticides (Ambush and Asana) did better in combination with Dipel than MVP. The difference, however, was not statistically significant. Dipel (100MIU/100 l. water) in combination with Asana and Ambush at 2.5 ppm and 4.0 ppm respectively produced synergistic effects in controlling codling moth damage. These combinations did better than their components applied alone for the control of first generation damage as well as the shallow (sting) and deep damage at harvest. The mixtures provided protection as great as Asana/Ambush applied at full rate and the standard Guthion treatments. In the mixture treated trees, the reduction in diapausing larvae approximated reduction in codling moth damage. Both pyrethroids at 0.1X augmented the efficacy of MVP, but none of the combination was synergistic. However, these combinations significantly reduced first generation damage, stings and deep damage at harvest and number of hibernating larvae than that of control and mixture components applied alone. Asana + MVP did better than Ambush + MVP and was rated as effective as Asana at 1.0X and Guthion at 1.0X. Among the most efficacious mixtures were Asana (0.1X) + Dipel (1.0X), Ambush (0.1X) + Dipel (1.0X) and Asana (0.1X) + MVP(1.0X). These

Table 5.3: The effectiveness of Dipel-permethrin (Ambush) mixtures against Codling moth on apples in 1991.

Treatment	Insecticide Rate/100 liters		Damage at harvest (%)		Protection by treatment (%)	Expected protection (%)	Chi-square	Conclusion
	Microbial	Chemical						
Control	-	-	15.18	a		-	-	-
Dipel	100 MIU	-	9.62	bc	36.62	-	-	-
Dipel	050 MIU	-	12.38	ab	18.43	-	-	-
Dipel	025 MIU	-	15.03	a	0.97	-	-	-
Dipel	010 MIU	-	13.56	ab	10.66	-	-	-
Ambush 25.6%	-	16.0 mls	0.00	h	100.00	-	-	-
Ambush 25.6%	-	08.0 mls	1.78	fg	88.27	-	-	-
Ambush 25.6%	-	04.0 mls	4.21	de	72.28	-	-	-
Ambush 25.6%	-	01.6 mls	6.40	cd	57.86	-	-	-
Dipel, Ambush	100 MIU	01.6 mls	0.78	gh	94.86	73.29	6.36*	Synergism
Dipel, Ambush	050 MIU	08.0 mls	0.00	h	100.00	89.37	1.26	Additivity
Dipel, Ambush	025 MIU	04.0 mls	2.80	ef	81.55	82.15	0.00	Additivity
Dipel, Ambush	010 MIU	01.6 mls	5.36	d	64.70	69.85	0.38	Additivity

Square root transformation was performed for analysis of variance. All means are back-transformed. Treatment means in each column followed by the same letter are not significantly different (P= 0.05)
*= significant at P= 0.05.

mixtures provided protection against codling moth similar to full pyrethroid rate and either of the standard treatments throughout the season.

Data (Table 5.4) show that Dimilin at 0.25X alone and along with either microbial insecticides significantly reduced first generation damage, and shallow- and deep-entry damage at harvest. Dimilin combined with Dipel considerably lowered deep entry damage ($P = 0.05$) than that with MVP. In synopsis, Dimilin at 0.25 X synergized Dipel, but, in combination with MVP yielded additive protection only. In these synergistic combinations, reduction in the diapausing larvae was inexplicably less than reduction in the codling moth damage. The degree of protection of the most promising mixtures did not parallel that of the standard treatments or full rate of Dimilin.

None of SunSpray-microbial insecticide combinations gave better results than the SunSpray mixture component applied alone (Table 5.4). Overall, the interactions between SunSpray and Dipel or MVP were antagonistic, significantly lowered observed protection than expected protection.

Trial 2:

Results of this trial given in Table 5.5, show that standard Guthion treatments (50 and 60 gm/ 100 l.) gave an excellent control of codling moth throughout the season. Dipel (1.0X) with Guthion (0.1X), Asana (0.1X), Sevin (0.1X) or Dimilin (0.25X) reduced mid-season damage comparable to the standard treatments. Similar results were obtained from mixtures of MVP (1.0X) and reduced rates of all chemical insecticides except Dimilin. At harvest, only two mixture treatments, Dipel (1.0X) + Asana (0.1X) and Dipel (1.0X) + Dimilin (0.25X), provided better control of shallow, deep, and total fruit damage. The latter treatment, however, was not as efficacious as the standard Guthion treatments. The overall damage in this treatment was higher because of high occurrence of codling moth damage in the windfall fruit. In summary, Dipel (1.0X) + Asana (0.1X) was as effective as the standard treatments in controlling

Table: 5.4: The effectiveness of microbial and chemical insecticides, and their mixtures in control of the codling moth on apples in 1992 (Trial No. 1). (Part 1 & 2).

Square root transformation was performed for analysis of variance. All means are back-transformed. Treatment means in each column followed by the same letter are not significantly different (P= 0.05). *, **, ***: significant based on chi-square value at P = 0.1, P = 0.05 and P = 0.01, respectively. Reduction in damage and diapausing larvae is based on comparison with control.

Table 5.4 (Part 1): The effectiveness of microbial and chemical insecticides, and their mixtures in control of the Codling moth on apples in 1992 (Trial No. 1). (Table continued on the next page).

Treatment	Insecticide Rate/100 litres		Fruit Damage (%)				Total damage at harvest (%)
	Microbial	Chemical	Mid-season (After 2 appl.)	Windfall fruit at harvest	Picked fruit: Stings	Picked fruit: Entries	
Control	Water		8.0 a	42.4 b	5.1 ab	15.3 a	21.8 a
Control	Untreated		6.7 a	58.6 a	4.3 abc	14.7 a	22.9 a
Dipel 2X	100 MIU	-	5.0 b	51.7 ab	2.4 ef	8.7 cde	13.0 b
MVP	250 mls	-	1.6 cd	40.0 bc	2.1 efg	7.3 ef	11.3 bcd
Guthion 50WP (Azinphosmethyl)		60 gms	0.3 fg	4.5 kl	0.5 ij	0.0 n	0.7 i
Guthion 50WP	-	50 gms	0.0 g	7.6 h-l	1.0 hi	0.3 mn	1.7 hi
Guthion 50WP	-	05 gms	3.5 bc	26.2 d	3.0 cde	10.7 b	14.5 b
Dipel, Guthion 50WP	100 MIU	05 gms	2.0 bc	14.7 e-h	2.5 def	5.4 gh	8.4 d
MVP, Guthion 50WP	250 mls	05 gms	1.3 de	16.3 efg	1.3 ghi	8.0 def	9.7 cd
Asana XL (Esfenvalerate)		30 mls	0.5 efg	6.7 i-l	1.1 ghi	0.3 mn	1.6 hi
Asana XL	-	03 mls	3.3 bc	25.7 d	3.9 bcd	4.7 hi	9.6 cd
Dipel, Asana XL	100 MIU	03 mls	0.0 g	3.3 l	1.2 ghi	0.3 mn	1.7 hi
MVP, Asana XL	250 mls	03 mls	0.0 g	10.5 g-k	1.0 hi	0.7 lm	2.1 gh
Ambush 25.6% (Permethrin)		16 mls	0.0 g	11.9 g-j	1.0 hi	0.1 n	1.5 hi
Ambush 25.6%	-	1.6 mls	1.9 cd	26.0 d	5.7 ab	5.1 gh	12.3 bc
Dipel, Ambush 25.6%	100 MIU	1.6 mls	1.2 def	4.5 kl	1.5 fgh	0.3 mn	1.9 ghi
MVP, Ambush 25.6%	250 mls	1.6 mls	0.0 g	5.3 j-l	1.8 e-h	1.0 kl	3.0 fgh
Sevin 50W (Carbaryl)		120 gms	0.0 g	8.3 g-l	1.5 fgh	3.3 ij	5.1 e
Sevin 50W	-	012 gms	1.7 cde	32.2 cd	2.0 efg	7.3 ef	11.2 cd
Dipel, Sevin 50W	100 MIU	012 gms	3.5 bc	26.7 d	1.5 fgh	7.3 ef	10.3 cd
MVP, Sevin 50W	250 mls	012 gms	0.0 g	14.3 e-h	6.0 a	4.4 hi	10.7 cd
Dimilin 25W (Diflubenzuron)		44 gms	1.7 cde	14.2 e-i	0.0 j	0.7 lm	1.7 hi
Dimilin 25W	-	11 gms	3.3 bc	32.1 cd	2.1 efg	9.3 bcd	12.7 bc
Dipel, Dimilin 25W	100 MIU	11 gms	1.7 cde	14.9 e-h	1.2 ghi	1.5 k	3.5 efg
MVP, Dimilin 25W	250 mls	11 gms	1.7 cde	27.9 cd	1.0 hi	2.5 j	4.9 ef
SunSpray (Summer Oil)		1.0 liter	3.5 bc	33.3 cd	1.0 hi	10.0 bc	12.7 bc
SunSpray		0.5 liter	5.0 b	22.9 def	1.1 ghi	10.1 bc	13.1 bc
Dipel, SunSpray	100 MIU	0.5 liter	5.0 b	25.0 de	1.0 hi	9.7 bcd	12.0 bc
MVP, SunSpray	250 mls	0.5 liter	3.0 bc	30.0 cd	1.2 ghi	6.7 fg	10.2 cd

Table 5.4 (Part 2): The effectiveness of microbial and chemical insecticides, and their mixtures in control of the Codling moth on apples in 1992 (Trial No. 1). (Table continued from the previous page).

Treatment	Insecticide rate/100 liters		Sting as % of harvested fruit damage		Diapausing larvae trapped		Protection over Control (%)	Expected protection (%)	Chi-square	Conclusion
	Microbial	Chemical			No. collected/ 1000 apples	Reduction (%)				
Control	Water		24.8	ijk	-	-	-	-	-	-
Control	Untreated		22.5	jkl	37.4	-	-	-	-	-
Dipel 2X	100 MIU	-	21.7	kl	24.9	33.4	43.3	-	-	-
MVP	250 mls	-	22.3	jkl	27.9	25.4	50.8	-	-	-
Guthion 50WP		60 gms	100.0	a	2.0	94.7	97.1	-	-	-
Guthion 50WP	-	50 gms	74.9	cd	4.1	89.0	92.4	-	-	-
Guthion 50WP	-	05 gms	22.0	kl	21.0	43.8	37.0	-	-	-
Dipel, Guthion	100 MIU	05 gms	31.7	h	9.8	73.7	63.5	64.3	0.0	Additivity
MVP, Guthion	250 mls	05 gms	13.5	mn	13.0	65.3	57.5	69.0	1.9	Additivity
Asana XL		30 mls	81.2	bc	3.5	90.6	93.0	-	-	-
Asana XL	-	03 mls	45.5	g	14.1	62.2	58.3	-	-	-
Dipel, Asana	100 MIU	03 mls	77.6	c	4.2	88.7	92.8	76.4	3.51*	Synergism
MVP, Asana	250 mls	03 mls	59.9	ef	6.7	82.1	91.0	79.5	1.7	Additivity
Ambush 25.6%		16 mls	91.0	ab	3.3	91.3	93.4	-	-	-
Ambush 25.6%	-	1.6 mls	52.6	fg	17.6	53.0	46.4	-	-	-
Dipel, Ambush	100 MIU	1.6 mls	85.3	bc	5.8	84.6	91.6	69.6	6.93***	Synergism
MVP, Ambush	250 mls	1.6 mls	64.4	de	8.1	78.4	86.9	73.6	2.4	Additivity
Sevin 50W (Carbaryl)		120 gms	31.1	hi	7.1	81.1	77.7	-	-	-
Sevin 50W	-	012 gms	21.4	kl	20.5	45.3	51.3	-	-	-
Dipel, Sevin	100 MIU	012 gms	17.0	lm	12.3	67.2	55.1	72.4	4.12**	Antagonism
MVP, Sevin	250 mls	012 gms	57.4	ef	18.0	51.9	53.2	76.1	6.85***	Antagonism
Dimilin 25W		44 gms	0.0	p	6.3	83.2	92.8	-	-	-
Dimilin 25W	-	11 gms	18.4	lm	21.0	43.8	44.9	-	-	-
Dipel, Dimilin	100 MIU	11 gms	44.4	g	7.6	79.6	84.8	68.8	3.74*	Synergism
MVP, Dimilin	250 mls	11 gms	28.7	hij	16.4	56.1	78.7	72.9	0.5	Additivity
SunSpray (Summer Oil)		1.0 liter	9.1	o	21.7	42.0	44.8	-	-	-
SunSpray		0.5 liter	9.8	no	19.8	47.1	44.2	-	-	-
Dipel, SunSpray	100 MIU	0.5 liter	9.4	no	16.2	56.7	47.9	68.4	6.16**	Antagonism
MVP, SunSpray	250 mls	0.5 liter	15.3	m	22.4	40.0	55.5	72.6	4.02**	Antagonism

mid- and end-season codling moth damage. In addition, Dipel + Dimilin and MVP + Asana produced promising results.

1993 Trials

Two different trials (Table 5.6 & 5.7) were conducted in different locations at Lewis Brown Farm, Corvallis, Oregon. The objectives of these experiments were (1) the continued evaluation of promising mixture treatments (trial 1 & 2), (2) adjusting mixture-component ratios for increased efficacy (trial 1) and (3) determining optimum frequency of mixture application (trial 2).

Trial 1:

The average control damage of 38.16 % in this trial was 1.7 - 3.46 times higher than all experiments carried out during 1991-1993 (Tables 5.1-5.7). Results in Table 5.6 indicate that standard Guthion treatments and all other chemical insecticides (1.0X) except Dimilin (1.0X) gave an excellent season-long control of codling moth. Highest rate of Dipel (1.5X) significantly reduced codling moth damage of first and later generations with average efficacy as great as that of 0.1X rates of chemical insecticides. Similarly, both Dipel and MVP at 1.0X and 0.5X generally failed to control codling moth. Reduced rates of chemical insecticides significantly lowered codling moth damage throughout the season. Often, higher reduced-rate (0.2X or 0.5X) of a chemical insecticide offered better protection than the lower reduced-rates (0.1X or 0.25X). However, their degree of protection (in the rage of 43 - 77%) was not economically acceptable. All chemical insecticide treatments (full or reduced) significantly curtailed deep damage to fruit. The higher incidence of stings compared to entries in these treatments indicates an early death of the larvae. First generation codling moth damage was significantly decreased at reduced rates of all chemical insecticides alone and in combination with either Dipel or MVP. All mixtures with

Table 5.5: The effectiveness of microbial-chemical insecticides mixtures in controlling the Codling moth on apples in 1992 (Trial No. 2).

Treatment	Insecticide rate/100 liters		Fruit Damage (%)				Total damage at harvest (%)	Sting as % of harvested fruit damage	% protection over Control
	Microbial	Chemical	Mid-season (After 2 appl.)	Windfall fruit at harvest	Picked fruit				
					Stings	Entries			
Control	-	-	4.5 a	13.8 a	4.1 a	6.9 a	12.8 a	31.8 c	-
Guthion 50WP	-	60 gms	0.5 c	3.8 b	0.0 d	0.0 e	0.4 f	0.0 d	96.9
Guthion 50WP	-	50 gms	0.3 c	0.0 c	0.0 d	0.0 e	0.0 f	0.0 d	100.0
Dipel, Guthion 50W	100 MIU	05 gms	0.6 c	3.4 b	1.9 bc	1.1 bcd	3.3 bc	57.9 ab	74.3
MVP, Guthion 50W	250 mls	05 gms	0.8 c	3.2 b	2.0 bc	2.0 b	4.5 b	44.4 bc	65.1
Dipel, Asana XL	100 MIU	03 mls	0.5 c	2.5 b	0.5 cd	0.1 de	0.7 ef	72.9 a	94.5
MVP, Asana XL	250 mls	03 mls	0.0 c	2.1 b	1.2 bc	0.8 b-e	2.2 cd	53.2 b	83.1
Dipel, Sevin 50W	100 MIU	012 gms	1.8 bc	3.5 b	1.9 bc	1.4 bc	3.7 bc	52.9 b	71.3
MVP, Sevin 50W	250 mls	012 gms	0.8 c	2.3 b	2.0 b	2.0 b	4.4 b	46.4 bc	66.0
Dipel, Dimilin 25W	100 MIU	11 gms	2.0 bc	5.4 b	0.5 cd	0.3 cde	1.4 de	34.7 c	88.7
MVP, Dimilin 25W	250 mls	11 gms	2.5 b	4.3 b	1.8 bc	1.5 b	4.1 b	45.5 bc	68.2

Square root transformation was performed for analysis of variance. All means are back-transformed. Treatment means in each column followed by the same letter are not significantly different (P= 0.05).

Guthion and Asana, and most mixtures with Dimilin and Sevin provided control of first generation codling moth equal to the standard Guthion treatments. Data (Table 5.6) show that Guthion at 0.1 and 0.2X alone and in combination with either microbial insecticides (1.0X), provided similar protection from codling moth damage. Among mixture treatments, all interactions were additive. An increase in Guthion or Dipel rate in the mixture did not significantly improve its efficacy. Number of hibernating larvae in a mixture treatment was similar to that of its chemical component applied alone. In general, reduction in diapausing larvae equaled reduction in codling moth damage.

Results in Table 5.6 show that Asana at 0.1 and 0.2X in combination with microbial insecticides gave better results than each component applied alone. At a given rate of Asana, mixtures with Dipel performed better than mixtures with MVP. These microbial insecticides in combination with higher rate of Asana (0.2X) gave higher level of protection, yet, with MVP non-significant from that with lower Asana rate (0.1X). Apparently, Dipel (1.0) + Asana (0.2) yielded season-long protection comparable to that of standard treatment Guthion at maximum field rate (300 ppm). The most promising mixture of 1992, i.e. Dipel (1.0X) + Asana (0.1X), performed as good as Guthion at 250 ppm. Interestingly, in Dipel (1.0X) + Asana (0.1X) treated trees, 100 % reduction in hibernating larvae occurred compared to 92.97 % reduction in codling moth damage. And as such, complete control of codling moth was achieved by this treatment. MVP (1.0X) + Asana (0.2X) being as effective as Dipel (1.0X) + Asana (0.1X), gave significantly lower degree of protection than either of the standard treatments. Mixtures of both microbial insecticides with lower Asana rate (0.1X) were marginally to moderately synergistic, whereas, with higher Asana rate (0.2X) only additive interactions were espied. Most mixtures equaled in reduction of hibernating larvae and codling moth damage to fruit.

Sevin (0.2X) in combination with both microbial insecticides (Dipel and MVP at 1.0X) provided significantly better control than that when applied alone (Table 5.6). The interactions were additive. Both mixtures were better in controlling shallow

Table 5.6 (Part 1): The effectiveness of microbial and chemical insecticide, and their mixtures against Codling moth on apples in 1993 (Trial No. 1).

(Table continued on the next page)

Treatment	Insecticide rate/100 liters		Fruit Damage (%)						Total damage
			Mid-season	Windfall fruit	Picked fruit				at harvest
	Microbial	Chemical	(After 2 appl.)	at harvest	Stings		Entries		(%)
Control	-	-	8.5 a	8.3 a	5.7	c-f	31.1	a	38.2 ab
Dipel 2X	50 MIU	-	3.8 c	5.6 bcd	9.6	ab	26.8	a	37.1 b
Dipel 2X	100 MIU	-	1.3 d	6.5 ab	8.6	bc	17.3	b	26.5 d
Dipel 2X	150 MIU	-	2.4 cd	5.6 bcd	7.8	bcd	16.6	b	24.8 d
MVP	125 mls	-	5.5 b	3.9 c-f	13.9	a	31.1	a	45.4 a
MVP	250 mls	-	8.0 ab	5.8 bc	3.5	e-i	25.6	a	29.5 cd
Guthion 50WP	-	60 gms	0.0 f	0.4 mn	0.8	l	0.1	p	0.9 q
Guthion 50WP	-	50 gms	1.5 d	1.5 i-l	0.9	kl	0.9	n-p	1.9 pq
Guthion 50WP	-	10 gms	2.6 cd	0.4 mn	3.6	e-i	8.3	c-f	11.9 f-i
Guthion 50WP	-	05 gms	4.0 bc	1.5 i-l	7.0	bcd	11.8	c	18.9 e
Dipel, Guthion	100 MIU	05 gms	0.7 df	1.8 i-l	6.4	b-e	9.2	cde	15.7 ef
Dipel, Guthion	100 MIU	10 gms	1.1 df	2.1 g-k	3.2	f-j	4.9	hij	8.2 jkl
Dipel, Guthion	150 MIU	10 gms	1.3 d	2.5 f-j	1.4	i-l	5.9	fgh	7.4 jkl
MVP, Guthion	250 mls	10 gms	1.5 d	1.9 h-l	3.0	g-l	6.5	e-g	9.8 h-k
Asana XL	-	30 mls	0.7 df	1.0 k-n	1.1	jkl	0.3	p	1.5 pq
Asana XL	-	06 mls	1.9 cd	0.7 l-n	4.9	d-g	3.2	i-l	8.1 jkl
Asana XL	-	03 mls	1.3 d	1.8 i-l	3.6	e-h	8.1	d-g	11.8 f-i
Dipel, Asana	100 MIU	06 mls	0.3 df	0.7 l-n	1.1	jkl	0.2	p	1.4 q
Dipel, Asana	100 MIU	03 mls	0.0 f	1.4 j-m	2.5	g-l	0.6	op	3.1 op
MVP, Asana	250 mls	06 mls	0.5 df	3.4 e-h	1.7	h-l	2.0	l-o	4.0 mno
MVP, Asana	250 mls	03 mls	0.9 df	1.5 i-l	1.7	h-l	2.8	j-m	4.6 mn
Sevin 50W	-	120 gms	0.0 f	0.8 k-n	1.6	h-l	0.5	p	2.2 opq
Sevin 50W	-	024 gms	5.7 b	3.9 c-f	8.4	bc	5.2	g-j	14.0 fg
Dipel, Sevin	100 MIU	024 gms	3.2 c	0.9 k-n	2.3	g-l	4.3	h-k	6.7 klm
MVP, Sevin	250 mls	024 gms	1.4 d	1.4 j-n	3.3	f-j	5.4	f-i	8.9 ijk
Dimilin 25W	-	44 gms	0.0 f	0.4 n	1.8	h-l	2.0	l-o	3.8 nop
Dimilin 25W	-	22 gms	0.7 df	2.7 f-j	2.8	g-k	9.9	cd	12.9 fgh
Dimilin 25W	-	11 gms	1.7 d	1.9 h-k	2.4	g-l	17.3	b	19.9 e
Dipel, Dimilin	100 MIU	22 gms	2.7 cd	3.6 efg	1.1	jkl	4.3	h-k	5.8 lmn
Dipel, Dimilin	150 MIU	11 gms	0.0 f	2.9 e-i	1.6	h-l	6.4	e-g	8.2 jkl
MVP, Dimilin	250 mls	22 gms	4.6 bc	4.6 b-e	1.9	h-l	6.0	fgh	8.6 i-l
MVP, Dimilin	250 mls	11 gms	2.7 cd	3.8 def	1.9	h-l	7.8	d-g	10.1 g-j

Square root transformation was performed for analysis of variance. All means are back-transformed. Treatment means in each column followed by the same letter are not significantly different (P= 0.05). *, **, *** : significant based on chi-square value at P = 0.1, P = 0.05 and 0.01 respectively. Reduction in damage and diapausing larvae is based on comparison with the control.

Table 5.6 (Part 2): The effectiveness of microbial and chemical insecticide, and their mixtures against Codling moth on apples in 1993. Trial No. 1.

(Table continued from the previous page)

Treatment	Insecticide rate/100 liters		Sting as % of harvested-fruit damage	Diapausing larvae trapped		Protection by treatment (%)	Expected protection (%)	Chi-square	Conclusion
	Microbial	Chemical		Number collected/ 1000 apples	Reduction (%)				
Control	-	-	15.6 no	49.8	-	-	-	-	-
Dipel 2X	50 MIU	-	26.3 jkl	43.4	12.9	0.0	-	-	-
Dipel 2X	100 MIU	-	33.2 hij	35.4	28.9	24.6	-	-	-
Dipel 2X	150 MIU	-	21.8 lm	38.2	23.4	29.5	-	-	-
MVP	125 mls	-	30.9 ijk	52.8	0.0	0.0	-	-	-
MVP	250 mls	-	12.1 o	41.9	15.9	21.6	-	-	-
Guthion 50WP		60 gms	87.6 a	1.0	98.0	97.3	-	-	-
Guthion	-	50 gms	51.9 de	3.7	92.7	94.4	-	-	-
Guthion	-	10 gms	30.0 jk	13.3	73.4	65.4	-	-	-
Guthion 50WP	-	05 gms	37.2 hi	32.3	35.2	46.3	-	-	-
Dipel, Guthion	100 MIU	05 gms	41.0 fgh	20.8	58.3	53.5	59.5	0.6	Additivity
Dipel, Guthion	100 MIU	10 gms	39.3 gh	6.6	86.7	76.6	73.9	0.1	Additivity
Dipel, Guthion	150 MIU	10 gms	19.5 mn	20.2	59.5	78.1	75.6	0.1	Additivity
MVP, Guthion	250 mls	10 gms	31.2 ijk	16.8	66.3	73.7	72.9	0.0	Additivity
Asana XL	-	30 mls	76.2 ab	2.2	95.6	95.6	-	-	-
Asana XL	-	06 mls	60.2 cd	7.6	84.8	76.8	-	-	-
Asana XL	-	03 mls	31.1 ijk	7.8	84.3	65.1	-	-	-
Dipel, Asana	100 MIU	06 mls	83.3 ab	1.2	97.7	96.0	82.5	2.2	Additivity
Dipel, Asana	100 MIU	03 mls	80.6 ab	0.0	100.0	93.0	73.7	4.5**	Synergism
MVP, Asana	250 mls	06 mls	45.9 efg	5.2	89.6	88.7	81.8	0.6	Additivity
MVP, Asana	250 mls	03 mls	37.7 hi	3.7	92.7	87.9	72.6	3.2*	Synergism
Sevin 50W	-	120 gms	75.3 b	2.5	95.0	93.6	-	-	-
Sevin 50W	-	024 gms	62.0 c	13.7	72.5	63.4	-	-	-
Dipel, Sevin	100 MIU	024 gms	35.2 hi	6.5	87.0	81.1	72.4	1.1	Additivity
MVP, Sevin	250 mls	024 gms	37.8 hi	8.9	82.2	75.6	69.2	0.6	Additivity
Dimilin 25W	-	44 gms	48.1 ef	13.9	72.0	88.6	-	-	-
Dimilin 25W	-	22 gms	21.7 lm	28.2	43.4	63.1	-	-	-
Dimilin 25W	-	11 gms	12.4 o	33.1	33.5	43.7	-	-	-
Dipel, Dimilin	100 MIU	22 gms	20.7 lmn	13.9	72.2	83.9	72.2	1.9	Additivity
Dipel, Dimilin	150 MIU	11 gms	19.4 mn	25.8	48.3	76.2	60.3	4.2**	Synergism
MVP, Dimilin	250 mls	22 gms	24.5 klm	20.9	58.0	76.9	71.1	0.5	Additivity
MVP, Dimilin	250 mls	11 gms	19.6 mn	31.1	37.6	71.8	55.8	4.5**	Synergism

Square root transformation was performed for analysis of variance. All means are back-transformed. Treatment means in each column followed by the same letter are not significantly different (P= 0.05). *, **, *** : significant based on chi-square value at P = 0.1, P = 0.05 and 0.01 respectively. Reduction in damage and diapausing larvae is based on comparison with the control.

damage than deep damage to the fruit and as such were ineffective in lowering number of hibernating larvae in the trap bands. Dimilin provided moderately synergistic and additive interactions with Dipel and MVP at lower rate (0.25X) and higher rate (0.5X), respectively (Table 5.6). None of the treatments gave protection as good as the standard treatments. Reduce rates and their mixtures with microbial insecticides produced more deep entries than shallow damage. Mixtures of Dimilin with both microbial insecticides curtailed the hibernating larvae in trap bands, however, the reduction was not significantly different from the Dimilin mixture-component applied alone.

Trials 2:

The main objective of these experiments was to determine the optimum frequency of mixture application for an effective and environmentally acceptable codling moth control with *B. thuringiensis*-chemical insecticide mixture. In these experiments, results of mixtures applied two and three times per generation were compared with each other, with their mixture components applied at the same frequency and with standard treatments of Guthion (1.0X) applied at standard timing.

Data (Table 5.7) show that standard treatments, Guthion at 50 and 60 grams/100 l., provided excellent protection from codling moth. Microbial insecticides, Dipel and MVP (1.0X), significantly reduced total codling moth damage with a low level of protection (23.71 - 26.32%) when applied three time per generation. Guthion at 0.1X alone provided similar reduction when applied two or three times per generation. Increasing frequency of applications from two to three per generation enhanced 11.7 and 11.2 % efficacy of mixtures of Dipel and MVP with Guthion (0.1X), respectively. The degree of protection, however, was not equivalent to the standard treatments.

Data (Table 5.7) show that Asana (0.1X) when applied three times/generation significantly reduced total codling moth damage with level of protection considerably higher than Guthion (0.1X), Sevin (0.2X) and Dimilin (0.5X) applied at the same

Table 5.7: The effectiveness of microbial-chemical insecticide mixtures at different application frequency against Codling moth on apples in 1993 (Trial No. 2).

Treatment	Insecticide Rate/100 liters		Applications/ generation	Fruit Damage (%)				Total damage at harvest (%)	Sting as % of harvested fruit damage	Protection (%) by treatment	Protection (%) increase over 2 sprays
	Microbial	Chemical		Windfall fruit at harvest	Picked fruit Stings	Picked fruit Entries	Picked fruit				
Control	-	-	-	12.4 a	4.6 a	10.7 a	15.4 a	17.2 a	30.2 i	-	-
Guthion 50WP (Azinphosmethyl)		60 gm	2	0.3 h	0.2 jk	0.0 j	0.2 j	0.3 i	100 a	98.5	-
Guthion 50WP	-	50 gm	2	2.7 cd	0.5 ijk	0.0 j	0.5 ij	0.6 hi	100 a	96.4	-
Dipel 2X	100 MIU	-	3	5.6 b	3.9 abc	8.5 ab	12.3 b	13.2 b	31.4 hi	23.7	-
MVP	250 ml	-	3	6.4 b	5.2 a	5.2 bc	10.4 b	11.4 b	50.1 efg	26.3	-
Guthion	-	10 gm	3	3.3 c	3.5 c	2.3 de	5.8 c	6.2 c	60.4 de	63.6	-2.8
Dipel, Guthion 50WP	100 MIU	10 gm	3	1.2 gh	1.6 efg	0.9 g-i	2.5 efg	2.2 fg	65.7 cd	87.3	11.7
MVP, Guthion 50WP	250 ml	10 gm	3	1.6 efg	1.4 fgh	1.5 efg	2.9 ef	3.1 e	48.8 fg	82.0	12.2
Asana XL (Esfenvalerate)		03 ml	3	3.2 cd	2.2 de	1.5 efg	3.7 de	4.0 de	60.2 de	76.4	3.9
Dipel, Asana XL	100 MIU	03 ml	2	1.4 fg	0.9 hij	0.4 ij	1.3 ghi	1.4 gh	69.9 c	91.6	-
Dipel, Asana XL	100 MIU	03 ml	3	1.0 gh	0.2 k	0.0 j	0.2 j	0.2 i	100 a	98.6	7.6
MVP, Asana XL	250 ml	03 ml	2	1.2 gh	1.9 def	0.5 hij	2.5 efg	2.6 efg	78.1 b	84.9	-
MVP, Asana XL	250 ml	03 ml	3	1.0 gh	0.9 hij	0.3 ij	1.2 hi	1.3 gh	73.4 b	92.6	9.1
Sevin 50W (Carbaryl)		24 gm	3	0.8 gh	2.6 d	3.5 cd	6.2 c	6.3 c	42.9 g	62.9	-1.0
Dipel, Sevin 50W	100 MIU	24 gm	3	1.4 fg	1.5 fgh	1.3 e-h	2.8 ef	2.9 ef	52.7 ef	83.0	2.3
MVP, Sevin 50W	250 ml	24 gm	3	2.3 def	1.7 efg	1.9 ef	3.6 de	3.9 de	46.4 fg	76.7	1.5
Dimilin 25W (Diflubenzuron)		11 gm	3	2.5 cde	1.5 fgh	3.9 c	5.3 cd	5.6 cd	27.6 i	66.7	52.8
Dipel, Dimilin 25W	150 MIU	11 gm	3	0.6 gh	0.7 ijk	1.0 f-i	1.7 fgh	1.7 gh	41.1 gh	89.7	48.8
Dipel, Dimilin 25W	100 MIU	22 gm	3	0.9 gh	0.4 ijk	0.4 ij	0.8 hij	0.8 hi	52.6 ef	95.0	31.7
MVP, Dimilin 25W	250 ml	22 gm	3	0.6 gh	0.8 h-k	2.3 de	3.1 e	3.2 ef	26.7 i	80.8	13.7

Square root transformation was performed for analysis of variance. All means are back-transformed. Treatment means in each column followed by the same letter are not significantly different (P= 0.05). For Guthion, Sevin and Dimilin, the protection (%) increase over 2 sprays was calculated based on average of percentage protection by the treatment (2 application/Codling moth generation) in all other experiments (1991-1993).

frequency. Nevertheless, the protection was not as good as the standard treatments. Mixture treatment, Dipel (1.0X) + Asana (0.1X), controlled codling moth damage significantly better when applied three times/generation with a level of protection equivalent to the standard Guthion treatment applied at 300 ppm (maximum recommended rate). The same mixture when applied two times/generation produced results similar to the standard Guthion treatment applied at the lower rate of 250 ppm. Increased application of MVP (1.0X) mixed with Asana (0.1X) decreased damage to fruit comparable to the standard Guthion treatment applied at 250 ppm. The reduction, however, was not statistically different from that of two applications/generation. In general, mixtures of both Dipel and MVP with Asana when applied three times/generation did not substantially increase the protection from codling moth damage compared with that of two applications per generation.

Increasing application of Dimilin (0.25X) from two to three times/generation resulted in enhanced fruit protection from codling moth by 52.82% (Table 5.7). Mixtures, Dipel (1.5X) + Dimilin (0.25X) and Dipel (1.0X) + Dimilin (0.50X), at higher application rate (three times/generation) provided the overall protection as good as standard Guthion treatments at 250 and 300 ppm, respectively. In these treatments, shallow-entry and deep-entry damage almost equally contributed to the over-all codling moth damage. At higher frequency of application, MVP (1.0X) + Dimilin (0.50X) was less effective in controlling codling moth damage compared to mixtures with Dipel. In summary, one mixture, Dipel (1.0X) + Dimilin (0.50X), when applied 3 times / generation provided the best results with over-all protection from codling moth damage comparable to the standard Guthion treatment (300 ppm).

Discussion

In the present studies, total damage to dropped and on-tree apples at mid- and end-season was considered to evaluate efficacy of the test treatments. This was necessary because apples that have been severely damaged by extensive feeding of codling moth larvae, especially early in the season, have greater tendency to drop prematurely than do nondamage or shallow-damage fruit (Jaques *et al.* 1981). Other criterion was reduction in diapausing larvae by a treatment compared with its degree of protection. A substantial reduction in diapausing larvae (as a result of sublethal effect or delayed mortality) by a treatment is a highly desirable response, because this can affect population density of codling moth in the years to come.

Most chemical insecticides at field recommended rates effectively controlled codling moth damage in all seven field experiments conducted during 1991-1993 (Tables 5.1-5.7). Sevin (120 gm/100 l.) and Dimilin (44 gm/100 l.) performed better in one season than other (Tables 5.4 and 5.6). However, insecticides treatments of Guthion (at 50 mg/100 l. and 60 gm/100 l.), Imidan (120 gm/100 l.), Asana (30 ml/100 l.), and Ambush (16 ml/100 l.) gave excellent season-long control of codling moth (Tables 5.1-5.7). The efficacy of these chemical insecticides in protecting apples against codling moth larvae was similar to those documented in the literature (Hoyt *et al.* 1978, Hall 1979, Hagley & Chiba 1980, Anderson & Elliott 1982, Westigard & Gut 1986). This suggested that population of codling moth used in this study was sufficiently susceptible to the chemical insecticides mentioned above. Small percentage of codling moth damage in most chemical insecticide-treated trees was due to shallow entry of codling moth rather than deep entry. This indicates the higher frequency of larval death after entering apples on chemical-treated trees than on trees treated otherwise. The finding that ultra-fine spray oil SunSpray® at 0.5 and 1.0% failed to control codling moth effectively was supported by a recent laboratory study which showed a low toxicity of this material to codling moth eggs and neonate (Riedl *et al.* 1995).

Increasing dosage or application frequency of microbial insecticides, Dipel® 2X and MVP®, did not significantly increase their efficacy against codling moth (Tables 5.6 and 5.7). When applied 2-3 times/generation, these microbial insecticides at 1.0X or 1.5X provided no more than 50% protection and, usually, the results were not consistent from trial-to-trial (Tables 5.1-5.7). These results as supported by other studies (Videnova & Ismail 1985, de Reede *et al.* 1985, Andermatt *et al.* 1988) suggest that *B. thuringiensis* was ineffective against codling moth in the field. The high proportion of injury to apple picked or dropped from microbial insecticide-treated trees was due to deep entry of larvae indicating that larvae might survive or recover fully the residual contact of these insecticides. Our sublethal studies (Chapter 4) corroborated these findings.

Because of unacceptable levels of codling moth damage in 1992 in the *B. thuringiensis*-Sevin mixtures (Tables 5.4 and 5.5), the rate of Sevin was increased (0.2X) in 1993 (Tables 5.6 and 5.7). This increased efficacy of the mixtures, but overall protection remained below the standard. Sogoyan and Slobodyanyuk (1981) reported similar results when mixture of Sevin and *B. thuringiensis* var. *galleriae* were used against *Cydia pomonella* and *Galleria mellonella*. Mixtures with reduced rates (0.1, 0.25 and 0.5X) of both microbial and organophosphate insecticides produced no better results than that of their chemical component applied alone (Tables 5.1 and 5.2). When so-called field recommended rates (usual efficacy < 50 %) of microbial insecticides were combined with reduced rates of both organophosphate Guthion and Imidan, better season-long control of codling moth was observed than that of mixture components applied alone (Tables 5.1, 5.2, 5.4-5.7). An increase in the dose rate (from 0.1 to 0.2X) or number of application (from 2 to 3 times/generation) improved the efficacy of these mixtures (Tables 5.6 and 5.7). The degree of protection, however, was not as good as any standard treatment (Tables 5.1, 5.2, 5.4-5.7). These findings matched those of Tkachev *et al.* (1977), Kleimenova (1970), and Niemczyk and Dawydko (1970) but contrasted those of Batalova (1970) and G'onev (1975). It is important to note that these scientists used mixtures of different *B. thuringiensis*

varieties/subspecies with organophosphate insecticides which were not employed in the present studies.

Results of the present efficacy tests indicate a potential use of mixtures of Dipel 2X (1.0X) with low rates of pyrethroids (0.1-0.2X) or Dimilin (0.25-0.50X) in the codling moth management (Tables 5.3-5.7). Damage was significantly less in trees treated with these mixtures than in trees treated with corresponding dosages of mixture components alone indicating enhancement of effectiveness of the biological component of the mixture (Tables 5.3-5.7). Mixture with the lowest dose (0.1X) of pyrethroid produced synergistic interaction whereas those with higher rates (0.2, 0.25, and 0.5X) produced an additive joint action (Tables 5.3, 5.4 and 5.7). Pyrethroid such as Asana (0.1X and 0.2X) and Ambush (0.1X) in combination with Dipel were among the treatments that provided the best control of codling moth in the field (Tables 5.3-5.7). Surprisingly, the efficacy of these mixtures were statistically similar to, but numerically always less than that produced by standard treatment Guthion at maximum field rate (Tables 5.3-5.7). For example, application of a promising mixture, Asana (0.1X) + Dipel (1.0X), reduced average damage by 92.96 + 0.6 % in all experiments compared to the non-treated trees whereas use of the standard treatment, Guthion (300 ppm), reduced average damage by 97.48 + 0.5% in the corresponding experiments (Tables 5.3-5.7). Therefore, the efficacy of these mixtures was generally considered less than that of Guthion used at maximum recommended rate. However, the degree of protection by these mixtures remained consistent in all trials performed in three year duration. With most *B. thuringiensis*-pyrethroid mixtures, the overall damage was generally under acceptable limits of 1-2% (Andermatt *et al.* 1988) when codling moth infestation was < 23 % (Tables 5.3, 5.4, 5.5 and 5.7). At 38 - 45 % control fruit infestation, Dipel at the lowest rate of Asana (0.1X) did not performed as good as Guthion at the maximum field rate of 300 ppm (Table 5.6). It seems that poor effect of this mixture was due to the extremely high population density in the test orchard during three years. However, the degree of protection by the mixture was equivalent to that of Guthion at the normal field rate of 250 ppm (Table 5.6). Other promising treatments such as Ambush (0.1X) + Dipel (1.0X) and Asana (0.2X) +

Dipel (1.0X) consistently provided results statistically comparable to the standard treatments (Tables 5.3, 5.4 and 5.6). These results broadly confirm our laboratory findings (chapter 3). Several authors made similar observations with *B. thuringiensis*-pyrethroid mixtures against different lepidopterous pests. Hardman and Gaul (1990) found mixtures of *B. thuringiensis* (1.0X) and permethrin (0.1X) as efficacious as full rate of pyrethroids against winter moth, *Operophtera brumata*, on apple. Jaques (1988) observed that *B. thuringiensis*-permethrin mixtures could provide acceptable control of *Pieris rapae* (L.) and *Trichoplusia ni* (Hubner) on cabbage without scarifying crop quantity and quality. Lama (1990) reported similar results using *B. thuringiensis*-pyrethroid mixtures against three lepidopterous species, viz. *Pieris brassicae*, *Mamestra brassicae* and *Plutella xylostella*, on cabbage.

Interaction of pyrethroids with genetically engineered MVP were generally additive, but, at relatively higher infestation (38% vs. 22 % or less), a mixture with lowest dose of pyrethroids showed marginal synergism (Tables 5.4 and 5.6). This mixture did not performed as good as synergistic Dipel-pyrethroid mixture. An increase in pyrethroid rates (from 0.1 - 0.2X) in the mixture or number of application (from 2 - 3 times/generation) resulted in enhanced efficacy against codling moth (Tables 5.6 and 5.7). MVP-Dimilin mixtures were usually less effective than Dipel-Dimilin mixtures (Tables 5.4-5.7). Better results with Dipel-pyrethroid/Dimilin mixtures than MVP-pyrethroid/Dimilin mixtures may be because of the nature of *B. thuringiensis* formulations. Dipel contains spores besides two different types of δ-endotoxins whereas MVP has only one type of δ-endotoxin. Spore-endotoxin combination has been proved to be highly synergistic and very effective against many lepidopterous species (Somerville 1970, Salama *et al.* 1981). Apparently mixtures with Dipel should place higher stress on the target insect than mixtures with MVP. Other reason for better results with Dipel-pyrethroid/Dimilin mixtures may be due to better persistence of Dipel on apple foliage than that of MVP. A mixture with synergistically interactive components having longer residual activity would obviously be more effective. Nyouki and Fuxa (1994) found significantly better overall

persistence of insecticidal activity of Dipel than that of MVP when *Pseudoplusia includens* (Walker) was fed on treated cotton, soybean, or tomato foliage in a greenhouse. They concluded that the presence of a living spore and second δ-endotoxin (Dipel) might contribute to increased persistence over that of a single δ-endotoxin (MVP). Previously, research of Griego and Spence (1978) has shown that spore-crystal (delta-endotoxin) aggregates can delay inactivation by ultraviolet, near ultraviolet and visible light. To sum up, results of present study indicate that some MVP-pyrethroid mixtures can be utilized effectively against codling moth in areas where its population pressure is low (average infestation 22 % or less). However, these mixtures are not as effective as Dipel-pyrethroid mixtures.

In general, Dipel (1.0X) + pyrethroid (0.1-0.2X) mixtures were highly effective in controlling codling moth damage all through the season (Tables 5.4-5.7). Overall fruit damage was mostly under the acceptable limits of 1-2 %. In general, sting damage largely contributed to the total damage in these treatments, thus indicating early mortality of the larvae exposed to mixture before entry into apple. Reduction in deep-entry damage to apples is particularly important because feeding of larvae deep in the pulp of apple makes the fruit non-marketable. Shallow damage, if confined to skin, is less severe often resulting in a lower grade of the fruit as fresh-market product (Jaques *et al.*1987).

An increase in dose of either microbial/chemical component in the mixture or number of mixture applications per generation resulted in better reduction of codling moth damage (Tables 5.1-5.3, 5.6 and 5.7). However, the difference in effect was unexpectedly small (statistically non-significant) with all conventional insecticides, suggesting that lower dosage of mixture components at lower frequency of application was enough to give adequate protection against codling moth infestation. Some mixtures such as combinations of Dipel with higher dosage of pyrethroids (0.2X Asana or 0.5X Ambush) may not be permissible from environmental point of view (Chapt. 6). This is because, for a slightly increased effect such as observed in the present studies, a big perturbation in the apple ecosystem can not be accepted. In case of

mixtures of Dipel with insect growth regulator Dimilin, increased application rate (3 vs. 2 per generation) resulted in 31.67 to 48.85 % increase in their efficacy (Table 5.7). When applied 3 times/generation, Dipel (1.0X) in combination with Dimilin at 0.25X and 0.5X was as efficacious as the standard insecticide Guthion at normal (250 ppm) and maximum field rates (300 ppm), respectively (Table 5.7). Studies performed elsewhere found combination of *B. thuringiensis* with diflubenzuron (Dimilin) was effective against different lepidopterous larvae (Novotny and Svestka 1986, Soria *et al.* 1988). In the present studies, a single treated tree was surrounded by four buffer trees and, therefore, a large part of the moth population was not subject to any control measures. Many adults were available to invade study trees. Such a situation can provide a severe test for the treatments, and it is, therefore, possible that in commercial situations or if larger areas are treated, the mixtures with lower rates of chemical insecticides would perform better.

In the spraying program with all chemical insecticides, reduction of diapausing larvae was comparable to reduction of the number of injured fruit (Tables 5.4 and 5.6). Similarly, the reduction of diapausing larvae by most mixtures was as good as the reduction of damage in windfall and harvested fruit (Tables 5.4 and 5.6). Dipel-pyrethroid mixtures significantly reduced the number of hibernating larvae below that of corresponding dosage of their components. The reduction equaled that of the standard treatments. Sometimes, Dipel - pyrethroid mixtures reduced numbers of diapausing larvae in trap bands more than fruit damage. For example, in 1993, no larvae was found in trap bands from Dipel (1.0X) + Asana (0.1X) treated trees (Table 5.6). This shows that most larvae which were able to penetrate an apple yielded to the delayed effect of mixture later in their life. This may result in an additive control in the field by curtailing hibernating codling moth population, thus affecting population dynamics in the following years. Such an effect may be more prominent if a larger area are treated. However, this effect was not observed in 1992, which suggests that some larvae can avoid or survive exposure to the mixture.

As some oils can act as an ultraviolet photostabilizer [Flint (ed.)1991], it was hypothesized that ultra-fine spray oil admixed with *B. thuringiensis* can improve its

residual activity against lepidopteran larvae. Results of the present study show that summer oil did not increase efficacy of *B. thuringiensis*-based insecticides against codling moth (Table 5.4). It may be due to the fact that *B. thuringiensis* is incapable of producing high levels of mortality for *C. pomonella* larvae under laboratory (Chapter 3) and field conditions (Tables 5.1-5.7). Therefore, spray oil may or may not have improved the residual activity of *B. thuringiensis*, it did not potentiate toxicity of *B. thuringiensis* against codling moth neonate larvae. Inserra *et al.* (1987) encountered similar results with mixture of *B. thuringiensis* and mineral oil against tortricid *Cacoecimorpha pronubana* (Hbn.) on rose and gerbera crops.

In synopsis, broadspectrum organophosphates (Guthion and Imidan) and pyrethroids (Asana and Ambush) were found to offer better control of codling moth than the more selective materials, Dimilin, summer oil and *B. thuringiensis*-based microbial insecticides. The overall results of the present tests indicate that *B. thuringiensis* plus low doses of pyrethroids or Dimilin can possibly be used against codling moth as an alternative to high doses of chemical pesticides and that the protective efficacy of such combinations may extend beyond the year of application. Among different mixtures, Dipel (1.0X) in combination with reduced rates of insect growth regulator, Dimilin (0.25-0.50X), or pyrethroids, Asana (0.1-0.2X) and Ambush (0.1X), can provide effective control of codling moth. The results of the these mixtures varied from year to year slightly but they all gave about the same degree of protection each time. Standard application rate (2 times/generation) and timing were found to be appropriate for Dipel-pyrethroid mixtures. Dipel-Dimilin mixtures were only suitable when applied 3 times/generation: first application at 450 and 1450 day-degrees for the first and second generations respectively, and second and third each at 14 days interval. At lower codling moth infestation (11 - 23 %), all Dipel-pyrethroid mixtures were as effective as the standard insecticide Guthion at 250 and 300 ppm. At higher infestation (38-45 %), Dipel with Asana at 0.2X was the most promising mixture, though, with lower rate of 0.1X, it controlled codling moth damage equaled to that of Guthion at 250 ppm. None of the hibernating larvae was entrapped in the latter treatment, suggesting 100 % control.

Chapter 6

Effects of Chemical and Microbial Insecticides, and their Mixtures on Phytophagous Mites and Predatory Fauna of Apple Ecosystem

Abstract

Microbial insecticides (Dipel 2X® and MVP®), diflubenzuron (Dimilin®) and summer oil (SunSpray®) were generally harmless (0 - <25% mortality or predator population reduction in orchard tests) to phytoseiids, *Z. mali*, predatory insects and spiders. These insecticides in their tested dosages (0.1-0.2/0.5, 1.0X) had slight or no effects on tetranychid mite, European Red Mite [*Panonychus ulmi* (Koch)] and Yellow Spider Mite [*Eotetranychus carpini borealis* (Ewing)]. Field rates of organophosphate azinphosmethyl (Guthion®) and phosmet (Imidan®) and carbamate carbaryl (Sevin®) were found to be slightly to moderately harmful (25 - 75% mortality) to *Typhlodromus pyri*, other phytoseiids, and some spiders and predatory insects. However, these insecticides caused less severe problem with European Red Mite (ERM) and Yellow Spider Mite (YSM) than pyrethroids. These organophosphates and carbaryl at 0.1-0.2X standard rates, applied alone or when mixed with microbial insecticides were selective to most arthropod predators. Field rates of esfenvalerate (Asana®) and permethrin (Ambush®) were found to be harmful (>75% mortality) to arthropod predators including araneids, acarids and predatory insects. Reduction of dosage to one-tenth of field rate provided selectivity to most predatory insects, spiders and *Zetzellia mali* (Ewing). This rate allowed some survival of *T. Pyri* and other phytoseiids, but not enough to provide adequate biological control. Generally, both pyrethroids at all test rates (0.1-1.0X), applied alone or mixed with microbial insecticides, caused an outbreak of phytophagous mites, ERM and YSM. However, significantly lower counts of ERM and YSM were associated with 0.1X standard rate, applied alone or when mixed with microbial insecticides mixtures, than those with corresponding 0.2X-0.5X and full-rate pyrethroid treatments.

T. pyri alone and mixed with a number of other phytoseiid species (such as *Amblyseius aberrans, T. arboreus, A. andersoni*) and *Z. mali* were found to be effective in controlling phytophagous mites. Control of phytophagous mites in experiments where *Z. mali* population was nearly lacking, was comparable to those

experiments where 3.1-7.14 /10 leaves of this predators was present. This predator alone even at 35.5/10 leaves could not control ERM, YSM or *Brevipalpus* spp. This suggests that mixed population of phytoseiids predominated by *T. pyri* alone or with *Z. mali* can provide effective biological control of ERM and YSM in Willamette valley.

It is concluded that mixtures of *Bacillus thuringiensis* formulations (Dipel 2X and MVP) and reduced rates of azinphosmethyl, phosmet, carbaryl, summer oil and diflubenzuron were selective to most arthropod predators and can be utilized in an apple pest management program. Mixtures of *Bacillus thuringiensis* formulations (Dipel 2X and MVP) and 0.1X standard rate of esfenvalerate and permethrin were less disruptive of predator/prey interaction than corresponding 0.2X and 1.0X standard rate. Hence, use of these mixtures compared with full rate of pyrethroids may improve the prospects for biological control of insect and mite pests in apple orchards.

Introduction

Apple orchard is a multiple-pest agroecosystem where at least one pest is a candidate for biological control. Integration of biological and chemical control tactics is the only rational approach available in such an ecosystem (Hull *et al.* 1985). Chemical control of primary pests in apples generally results in outbreaks of various secondary insect pests and phytophagous mites, which is attributed to the use of pesticides that suppress the natural enemies (Hoyt *et al.* 1978, Bostanian & Belanger 1985, Hardman *et al.* 1991). Therefore, apple integrated pest management (IPM) programs in Oregon and elsewhere are highly focused on selective methods for controlling key pests such as codling moth that allow biological control agents to survive (Westigard *et al.* 1986, Croft & AliNiazee 1996). Biological control is effective in keeping the populations of secondary pests below economic damaging level. The dominant pest problem in apple orchards is the emergence of spider mites as a serious threat following the application of broad-spectrum insecticides targeted for control of the key pests (Johnson & Wilson 1995). Strategically, the selection of a new pest control method or technique for inclusion in apple IPM programs has been largely based on its efficacy against the key pests and their effects on predacious mites and other beneficial arthropods.

Arthropod predators are important in the integrated management of codling moth and other apple pests (Falcon & Huber 1991). Different studies have shown that anthocorids, mirids, earwigs, lacewings, coccinelids, carabids, spiders and predatory mites are important predators of the apple insect and mite pests (Hoyt 1969, Jaynes & Marucci 1947, MacLellan 1962, Glen 1975, Wearing 1975, Glen & Milson 1978, Hagely *et al.* 1982, Hagely & Allen 1988). MacLellan (1963) reported that on average general predators caused about 56% mortality of codling moth from the time eggs were laid until the larvae became established in the fruit. Anthocorids, mirids, earwigs and predatory mites are known to prey upon codling moth and other lepidopterous eggs and hatching larvae (Jaynes & Marucci 1947, MacLellan 1962,

Glen 1975, 1977), whereas carabids, earwigs and spiders prey on mature codling moth larvae (fifth instar larvae) on the ground undertree bark (Wearing 1975, Glen & Milson 1978, Hagely *et al.* 1982, Hagely & Allen 1988). Earwigs are effective in controlling the woolly aphid, *Eriosoma lanigerum*, in Europe (Gruys 1980a, 1980b, 1982). Predatory anthocorid (*Anthocorus* species, *Orius* species), mirids (*Blepharidopterus* spp., *Malacoris* spp., *Phytocoris* spp.), coccinelids (*Adalia* spp., *Coccinella* spp. *Hippodamia* spp., *Stethorus* spp., and others), and lacewings (chrysopids and hemerobiids) are known to be predators of the European Red Mite, *Panonychus ulmi* (Falcon & Huber, 1991). Unfortunately, most general predators in apple ecosystem are susceptible to orchard pesticides belonging to different chemical groups (Hull & Starner 1983, Hardman & Gaul 1990). Some predators, however, are either tolerant to or have developed resistance against pesticides at concentration used in orchards (Asquith & Hull, 1973, Tanigoshi *et al.* 1983) . The general predators which survive chemical treatments in commercial orchards are an important source of natural control of different apple pests (Tanigoshi *et al.* 1983).

Predatory mites (Acari), particularly phytoseiids and *Zetzellia mali* (Stigmaeidae) are important biological control agents of phytophagous mites (White & Laing 1977, Croft & MacRae 1992a & b, Croft 1994). The successful establishment of predatory mites in apple orchard depends, in part, on their ability to survive applications of pesticides for the control of other pests and diseases. Phytoseiids have ability to acquire resistance to certain organophosphate and carbamate insecticides (Croft 1982, Hadam *et al.* 1986, Hardman *et al.* 1991, Hassan *et al.* 1987, Frisch 1988). In New Zealand, Markwick (1986) developed a strain resistant to pyrethroid insecticides such as cypermethrin, deltamethrin and fenvalerate. In France, Vidal and Kreiter (1995) have recently found a strain of *T. pyri* highly resistant (1,282-fold) to fenvalerate. Elsewhere, phytoseiids are extremely susceptible to pyrethroids (AliNiazee & Craham 1980, Riedl & Hoying 1980, Baillod & Guignard 1985, Hassan *et al.* 1987, Hardman & Gaul 1990, Hardman *et al.* 1991, Zacharda & Hluch 1991). Nevertheless, pyrethroids provide excellent control of many agricultural pests in the field (Ruscoe 1977). They provide better protection of fruit and foliage than other insecticides from

apple pests, such as codling moth (Hoyt *et al.* 1978), winter moth, *Operophtera brumata* (L.) (AliNiazee 1986), white apple leafhopper, *Typhlocyba pomaria* McAtee (Hull & Starner 1983), *Platynota idaeusalis* (Walker) (Hull *et al.* 1985), spotted tentiform leafminer (TLM), *Phyllonorycter blancardella* (F.) (Sanford 1984), and different fruit stinging mirids (Sanford 1985). Greater protection was especially noticeable when the pest were partly resistant to organophosphates. Development of management tactics that can maximize ecological selectivity of these insecticides may be one way to incorporate them into current apple pest control programs (Hull & Beers 1985). Hull and Knight (1989) suggested that tactics such as proper timing and reduced dosages might be developed for pyrethroids to minimize their detrimental effects on natural enemies while providing adequate control of primary pests.

Three species of phytophagous mites are commonly found on apple in Willamette Valley. These are the two tetranychid species, the European red mite, *Panonychus ulmi* (Koch), and the yellow spider mite, *Eotetranychus carpini borealis* (Ewing) and one eriophyid species, the apple rust mite, *Aculus schlechtendali* (Nalepa) (AliNiazee 1979, AliNiazee 1984). European red mite (ERM) is the most serious pest mite, and yellow spider mite (YSM) sometimes reaches damaging levels, particularly early in the season (AliNiazee 1984, AliNiazee & Westigard 1995). Apple rust mite (ARM) rarely causes measurable loss in apple orchard (Hagely *et al.* 1977, Hoyt 1995). Hadam *et al.* (1986) reported that three phytoseiids, *Typhlodromus pyri* Scheuten, *Galendromus occidentalis* (Nesbitt) and *T. arboreus* Chant in a ratio of approximately 55:30:15 in the apple orchards of Willamette Valley of Oregon. In the valley, populations of *T. pyri* were found to be moderately resistant to azinphosmethyl (5- to 7-fold) and highly resistant to carbaryl (25- to 28-fold) and parathion (ca. 100-fold) (Hadam *et al.* 1986). *T. pyri* , the principal phytoseiid in the apple orchards of Willamette valley, is the major predator of spider mites (Tetranychidae) including European red mite and yellow spider mite (AliNiazee & Westigard 1995). This predator can survive for extended periods on alternative sources of food such as pollen, mildew, rust mites (*Aculus schlechtendali* Nalepa) and tydeid mites when spider mites are scarce (Overmeer 1985).

Role of spider in biological control of agricultural pests is less understood although the spiders form a major component of arthropod fauna in many agroecosystem (Mansour 1984 & 1987). In deciduous orchards, spiders constitute a large and frequent part of the predatory arthropod fauna of where they prey upon active stages of plant feeding mites, scale, apple suckers, aphids, and moths (Chant 1956, Putman 1967, MacLellan 1973, Dondale *et al.* 1979, Mansour 1986 & 1987). The reduction in crop damage may occur through actual spider predation and through pest abandonment of plant parts occupied by spiders (Riechert & Lockley 1984). Several authors have pointed out that insecticides used in various crops are detrimental to the spiders (Riechert & Lockley 1984).

Bacillus thuringiensis (Berliner) is an important microbial pest control agent usually effective against pest Lepidoptera in various agricultural and forest crops (Federici 1993, Knowles & Dow 1993, Knowles 1994). Different varieties and products of *B. thuringiensis* have proved to be selective to natural enemies including spiders, and predacious mites and insects (Croft & Flexner 1989, Bajwa 1993). However, natural and genetically engineered insecticides based on *B. thuringiensis* are ineffective for the control of codling moth (Bajwa & AliNiazee 1995). Some studies in Europe and former USSR have demonstrated that combining low rates of chemical insecticides especially organophosphate and carbamate compounds with *B. thuringiensis* can provide effective control of codling moth (G"onev 1975, Karadzhov 1973 & 1974, Malevez 1978, Tomova & Rangelova 1977), the key pest in most apple orchards. Likewise, our laboratory and field studies (chapter 3 and chapter 5) suggested that codling moth can be effectively controlled by some mixtures of *B. thuringiensis* and low rates of an insect growth regulator dimilin and pyrethroids esfenvalerate and permethrin. In apple orchards of Nova Scotia, mixtures of *B. thuringiensis* and pyrethroids have shown to be effective against the winter moth, *Operophtera brumata* (L.) (Hardman & Gaul 1990, Hardman *et al.* 1995). However, the impact of these mixtures and genetically engineered *B. thuringiensis* product like MVP, on beneficial arthropods and phytophagous mites has never been studied before. In apple and pear orchards, reduced dosages compared with standard rates of some

insecticides enable sufficient survival of arthropod predators and thus lessened disruption of tetranychid mite populations as was reported in several studies (Hoyt 1969, Madge 1972, Westigard 1972, Thwaite 1976, Hardman & Gaul 1990). *B. thuringiensis* commercial products are considered to be safe for most general predators including spiders (Bajwa 1993). Here, we hypothesized that reduced rates of chemical insecticides in combination with *B. thuringiensis* would interfere less with regulation of pest mites because of lower initial toxicity to the predators and reduced residual life.

Reported in this chapter are results of a four-year field study on impact of microbial-chemical insecticides mixtures in comparison with standard rates of different apple pesticides on some beneficial arthropods and pest mites. Besides, the impact of the chemical-microbial mixtures on the predator-prey interaction of different pest and phytoseiid mites was also evaluated. Other objective of this field study was to establish the effects of all test microbial and chemical insecticides, at full and reduced rates of application, on arthropod predators and phytophagous mites present in the study orchard. These studies were performed under the regime of regional codling moth control program based on four seasonal sprays per year of organophosphates and pyrethroids.

Materials and Methods

Study Orchards

All field trials were conducted at Lewis Brown Farm, Oregon State University, Corvallis, except for the preliminary studies conducted at Entomology Farm, Oregon State University, Corvallis, Oregon in 1990 and 1991. Entomology Farm had mixed varietal apple plantation surrounded by cherry and hazelnut trees with no regular spray program for the apple pests. Lewis Brown Farm is a well managed horticultural orchard with blocks of different varieties of apple, pear, cherry, hazelnut and small fruits. The present experiments were conducted on two blocks of 10 year old *Red Delicious* apple trees planted with a spacing of 6 m between rows and 4 m between trees. The trees were irrigated fortnightly by under-tree sprinklers. They were pruned annually, and the grass and weeds around the trees were mowed regularly. At this farm, there was a history of applying 3-4 alternate sprays of Guthion and Sevin each year for the control of codling moth.

Spray Solutions

The commercial product used were organophosphate, Guthion® 50WP (azinphosmethyl) and Imidan® 50WP (phosmet); pyrethroids, Asana® XL (esfenvalerate) and Ambush® 25.6% (permethrin); carbamate, Sevin® 50WP (carbaryl); insect growth regulator, Dimilin® 25WP (diflubenzuron); ultra-fine spray oil, SunSpray® (summer oil) and microbial insecticides, Dipel® 2X (*B. thuringiensis*) and MVP® (genetically engineered *B. thuringiensis* product). The manufacturers recommend Dipel at 0.5 - 2 lb. (approximately 31 - 124 Million International Units (MIU) in 100 liters) and MVP at 3 - 4 quarts per acre (approximately 188 - 250 ml in 100 liters) for field use against codling moth. The concentrations of chemical and microbial insecticides applied alone or when mixed were expressed as 0.1X, 0.2X, 0.25X, 0.5X, and 1.0X of recommended orchard rates against codling moth (Northwest Insect Control Hand Book, Manufacturer's Label/Brochure, Crop

Protection Chemical Reference or current literature). Field recommended rates were used to acquire data on impact and relative toxicity of chemical and microbial insecticides to beneficial arthropods and pest mites.

In 1991 trials, 1.0, 0.5, 0.25 and 0.1 X of field recommended rate of chemical insecticides, Guthion, Phosmet and Ambush, alone and/or in combination with that of 1.0, 0.5, 0.25 and 0.1 X of Dipel® 2X were used in three different experiments. In 1992 and 1993, most chemical insecticides at 0.1 and 0.2 X were tested alone or in combination with Dipel® 2X and MVP®. Ultra-fine spray oil SunSpray® was tested at 0.5 % and 1.0 % alone and in mixture with Dipel and MVP at 0.5%. In all experiments (1990-1993), other treatments included were water treated or/and untreated check, standard treatment of Guthion at 250 ppm, and microbial and chemical insecticides at their full field recommended rates for comparison purposes.

Experimental Design and Spray Schedule

The test design consisted of 4-5 single-tree replicates in randomized complete block. Treatments were applied to control codling moth. All treatments were applied to run off with a handgun sprayer at 300 psi, equivalent to approximately 3740 liters per hectare. The sprays were applied in the early morning or in the evening. Every other tree in a row was treated in a way that each study tree was surrounded by 4 unsprayed trees to buffer it from spray drift, and to promote a buildup of natural fauna of all kinds of predators. Every other year, the treated trees were selected from those which were buffer trees in the previous year. Computerized codling moth model , *Codmoth*, was used to schedule spray timing. The first spray was applied at 450 day-degrees followed by 2nd and 3rd sprays 21 days later and at 1460 day-degrees, respectively. A fourth spray was applied 21 days after the third spray. In 1990, four sprays of each treatment were applied on May 22, June 12, July 23 and August 14; in 1991, on May 30, June 20, July 29 and August 19; in 1992, May 13, June 3, July 20 and August 11; and in 1993, May 20, June 10, July 24 and August 14.

In 1993, an experiment was performed to observe the effect of increased frequency of application (from 2 to 3 sprays/CM generation) of promising *B.*

thuringiensis- insecticide mixtures (chapter 5) on all predators and pest mites present in the study orchard. In this experiment three sprays per generation were applied, that is, two sprays at 14 days interval each after first spray at 450 day-degrees and fourth spray at 1460 day-degrees. Six spray program was applied on May 20, June 4, June 19, July 22, August 6 and August 21. The impact of increased frequency of applications on predators and pest mites were statistically analyzed to determine optimum number of sprays for promising microbial-chemical insecticide mixtures with minimum perturbation in the apple ecosystem.

Sampling Protocol

Mite Sampling:

All samples were made during the cooler early morning hours (7-9 am). Populations of mites were sampled by collecting 20 - 25 leaves per tree (Hoyt *et al.* 1978,AliNiazee 1984) sequentially from lower to upper region from the periphery of the tree (Croft & MacRae 1992). Leaves were placed in small brown paper bags stapled shut then rapped in plastic bags and stored in a cooler until returned to the laboratory. Then, leaves were stored at 4-6 ^{0}C until mites were counted, always within 6-7 days. Mites were brushed off the leaves (AliNiazee 1984, Westigard *et al.* 1986) using a mite brushing machine (Henderson & McBurnie 1943) and counted with the aid of a dissecting microscope. Both motile stages and eggs were counted except for rust mite, we counted only active forms of rust mites. Phytoseiid mites were mounted on slides for later identification. Mite densities were estimated as numbers per leaf or numbers per 10 leaves.

In 1990-1991experiment, leaves were collected twice from apple between 28 July or 30 July and 10 September, the seasonal period when predatory mites were most abundant in earlier studies (Putman 1970, Croft 1975, Woolhouse & Harmsen 1984, Amano and Chant 1990). In 1992-1993, five to six samplings were made from mid June to late August/mid September each year, with an average interval of 15 days

between sampling. Seasonal means of pest mites were compared with those of all natural enemies.

Insect Predators and Spider Sampling:

Sampling dates for insect predators and spiders were same as for mites. All samples were made during the cooler early morning hours (6-9 am), when arthropods were relatively inactive. On each sample date, predators were collected by tapping three limbs or lower branches per experimental tree three times with a bamboo stick over a 1-m^2 cloth tray (Jaques 1965, Hagely 1978, Dondale 1979, Mansour 1981). All dislodged arthropods were immediately preserved in alcohol for subsequent identification and counting. Predators found in the samples were recorded as to genus or species, but, for simplicity, some arthropods were grouped according to families and subfamilies, spiders, however, were lumped into the subclass Araneae.

Statistical Analysis

The data were transformed as root transformation, $(X + 0.5)^{0.5}$ where X is the number of mites per leaf from each tree, and subjected to analysis of variance (Zar 1984, pp. 241, 286-289). Means shown in the tables are back-transformed form means on square root scale. Separation of means was done with Fisher's Protected Least Significant Difference (FPLSD) (Petersen 1985). Generally, treatments were compared with each other and with control.

The collected data on the predators were pooled to assess the effect of insecticides and their mixtures on total predator population. In the event that predator population or their activities were significantly suppressed ($P<0.05$) in a treatment than that of control, field toxicities of that treatment to predators were evaluated based on categories recommended by International Organization of Biological Control (IOBC): Harmless (>25% mortality in orchard tests); slightly harmful (25-50%); moderately harmful (51-75%) and harmful (>75 %) (Hassan *et al.* 1987).

Results

Table 6.1-6.3 lists mites (Acari), predatory insects and spider species recorded on apple at the Entomology and Lewis Brown Farms, Oregon State University, Corvallis, Oregon from 1990-1993. During this study period, the most common arthropod species in the study orchards were: (1) various pest mites namely *Panonychus ulmi* (Koch), *Eotetranychus carpini borealis* (Ewing), and *Aculus schlechtendali* (Nalepa) (2) predatory mites namely *Typhlodromus pyri* Scheuten and *Zetzellia mali* (Ewing); (3) different araneid species including *Metaphidippus aeneolus*

Table 6.1: Common Acarids at Entomology and Lewis Brown Farms, Oregon State University, Corvallis, Oregon from 1990-1993.

Family	Species
Tetranychidae	*Panonychus ulmi* (Koch)
	Eotetranychus carpini borealis (Ewing)
	Tetranychus urticae Koch
	Brevipalpus sp.
	Bryobia sp.
Eriophyidae	*Aculus schlechtendali* (Nal.)
Phytoseiidae	*Typhlodromus pyri* Scheuten
	T. arboreus Chant
	Galendromus occidentalis (Nesbitt)
	Amblyseius andersoni (Chant)
	A. aberrans (Oude.)
Stigmaidae	*Zetzellia mali* (Ewing)
Erythraeidae	*Balaustium* spp.
Tarsonemidae	Tarsonemid spp.
Tydeidae	Tydeid spp.
Winterschmidtiidae	*Calvolia* spp.

Table 6.2: Common predatory insects at Entomology and Lewis Brown Farms, Oregon State University, Corvallis, Oregon from 1990-1993.

Order	Family/ Subfamily	Species	Life stage collected
Dermaptera	Forficulidae	*Forficula auricularia* L.	A, J.
Hemiptera	Anthocoridae	*Orius spp.*	A, J.
	Miridae		
	Subfamilies		
	1. Mirinae	*Phytocoris conspurcatus* Knight	A, J.
	2. Orthotylinae	*Heterotoma planicornis* (Scop.)	A, J.
		Diaphnocoris provancheri (Burque)	A, J.
	3. Dicyphinae	*Campyloneura virgula* (Herrick-Schaeffer)	A, J.
	4. Deraecorinae	*Deraecoris brevis* (Uhler)	A, J.
Neuroptera	Chrysopidae	*Chrysopa* spp.	E, A, J.
	Hemerobiidae	*Hemerobius* spp.	E, A, J.
Raphidiodea	Raphidiidae	Raphidiid sp.	A.
Diptera	Asilidae	Asilid spp.	A.
		Syrphid spp.	A.
Hymenoptera	Vespidae	Vespid sp.	A.
	Formicidae	Formicids	A.
Coleoptera	Coccinelidae	*Stethorus punctillum* Weise (69.11%)	A, J.
	(In the order	*Coccinela californica* Mann (8.89%)	A.
	of percentage	*Cycloneda polita* Csy. (6.86%)	A.
	occurrence)	*Adalia bipunctata* (L.) (5.62%)	A.
		Hippodamia convergens G.M. (3.43%)	A.
		Scymnus spp. ((2.34%)	A.
		Coccinella trifasciata (1.56%)	A.
		All others (2.19%)	A.
	Cantharidae	*Cantharid* sp.	A.

E: eggs, A: adult, J: juvenile

and Eris marginata(Salticidae), *Spirembolus mundus* and Micryphantinae (Linyphiidae), *Cheiracanthium inclusum* (Clubionidae), *Philodromus spectabilis* (Philodromidae) and *Theridion lawrencei* (Theridiidae); and (4) predatory insects,

Table 6.3: Spiders (Araneida) at Entomology and Lewis Brown Farms, Oregon State University, Corvallis, Oregon from 1990-1993.

Family	Subfamily/Species	Abundance (%)
Salticidae	**All species**	**33.48**
	Metaphidippus aeneolus	21.59
	Eris marginata	05.94
Linyphiidae		
	All species	**21.32**
	Spirembolus mundus	14.25
	Micryphantinae	05.63
Clubionidae	*Cheiracanthium inclusum*	**13.37**
Philodromidae	**All species**	**09.44**
	Philodromus spectabilis	08.04
	Philodromus rufus	01.05
Theridiidae	**All species**	**07.95**
	Theridion lawrencei	04.46
	Theridion differens	01.66
	Theridion californicus	01.01
Dictynidae	*Dictyna peragnatha*	**04.37**
Thomisidae	**All species**	**03.15**
	Xysticus locuples	02.27
Tetragnathidae	*Tetragnatha laboriosa*	**01.92**
Araneidae	**All species**	01.50
	Araneus diadematus	01.31
Miscellaneous	**All species**	**03.50**
(Anyphaenidae	*Anyphaena pacifica*	
Opilionidae	*Leuronychus parvulus*	
Oxyopidae)	*Oxyopes scalaris*	

Stethorus punctillum (Coccinelidae); *Heterotoma planicornis, Phytocoris conspurcatus, Campyloneura virgula* and *Diaphnocoris provancheri* (Miridae); *Orius* spp. (Anthocoridae) and *Forficula auricularia* (Forficulidae).

The relative abundance of different araneid and coccinelid species is given in Tables 6.2, 6.3 and 6.4. Population dynamics of these arthropods were highly variable from year to year. This may be because of competition, predator-prey interactions and climate that can affect population changes within and between years (Woolhouse & Harmsen 1984). In some treatments, the mite pest populations approached economic thresholds, 15-20 mites per leaf for tetranychids (Dover *et al.* 1979, Parella *et al.* 1981, Woolhouse and Harmsen 1984, Hardman *et al.* 1990) and 200-300 mites per leaf for eriophyids (Croft & Hoying 1977, Prokopy *et al.* 1980). However, apple foliage pests including white apple leafhopper, the spotted tentiform leaf miner, scale insects and different aphid species did not reach damaging levels. *Z. mali* and tydeids were virtually absent in 1993 (Bajwa unpublished).

These studies were performed to compare impact of different codling moth spray programs based on chemical insecticides, *B. thuringiensis* or *B. thuringiensis* + insecticide mixtures (as suggested in chapter 5) on beneficial arthropod and acarid fauna of apple orchards. In most experiments, four seasonal sprays of each treatment were applied. Spray timing was scheduled based on computerized codling moth model, *Codmoth*. The first spray was applied at 450 day-degrees followed by 2nd and 3rd sprays 21 days later and at 1460 day-degrees, respectively. A fourth spray was applied 21 days after the third spray.

1990 Trial

Although this trial was a preliminary study, it furnished useful information on some rare species and predator-prey interactions on apple. This year, *A. aberrans* was the most abundant phytoseiid species in the orchard.

Tables 6.5 and 6.6 show the mean counts of all predatory and pest mites. Data show that yellow spider mites (YSM), ERM and false spider mites in the Dipel alone and Dipel + Guthion *(azinphosmethyl)* mixture treatments (Dipel at 0.10 X, 0.25 X, and 1.00 X with Guthion at 0.10 X , 0.25 X, and 0.10 X, respectively) were statistically similar to that of control, but, significantly lower than that of azinphosmethyl applied at full-rate (1.00 X). In this orchard, *Calvolia* spp. and all phytoseiid species including *T. pyri* and *A. aberrans*, were substantially affected by half- and full-rate of azinphosmethyl. However, these doses did not show any unfavorable impact on tydeids and *Z. mali*. Interestingly, the latter was significantly more abundant on trees sprayed with azinphosmethyl at full-rates.

Table 6.4: Percentage abundance of some common spiders in apple at Lewis Brown Farm, Corvallis, Oregon, 1990-1991.

Spider species	1990	1991	1992	1993
Cheiracanthium inclusum	18.80	02.94	08.63	17.41
Eris marginata	08.54	29.41	01.18	10.30
Metaphidippus aeneolus	08.54	14.70	05.50	30.73
Philodromus spectabilis	05.98	04.71	16.67	05.75
Spirembolus mundus	09.40	18.53	39.60	03.79

1991 Trials

This year, three different experiments were conducted. Trial 1 was conducted at Entomology Farm, Oregon State University, Corvallis, and Trial 2 and 3 at Lewis Brown Farm. The most common spider species found in 1991 were *Eris marginata* (29.41%), *Spirembolus mundus* (18.53%), *Metaphidippus aeneolus* (14.70%), *Philodromus spectabilis* (4.71%), *Cheircanthium inclusum* (2.94 %), *Theridion lawrencei* (2.8 %), and *Xysticus locuples* (2.8) (Table 4).

Trial 1:

The most abundant phytoseiid species, *A. aberrans*, of 1990 was replaced by *T. pyri* this year. Data in Table 6.7 indicate that treatment mean counts for this predator in particular and total phytoseiids *(* including *T. pyri*) in general did not vary significantly in any treatment including 1.0X azinphosmethyl, however, their numbers were lower than that of control indicating some mortality. Similarly, levels of *Z. mali* and tydeids were not affected by any treatment. Counts of phytophagous mite *E. carpini borealis* were significantly higher in trees treated with full and half field-rate of azinphosmethyl ($P<0.05$). *Brevipalpus* spp. was significantly higher in trees treated with 1.0X azinphosmethyl ($P<0.05$). Dipel alone generally did not affect populations of most mite species.

In this orchard, activity of total number of predators was significantly higher in control than in any treatment (Table 6.8) ($P<0.05$). Most predators were numerically or statistically higher ($P<0.05$) in almost all mixture treatments than full-rate of azinphosmethyl (Table 8). Among different treatments, only full rate of azinphosmethyl significantly decreased ($P<0.05$) the mean count of mirid, *P. conspurcatus*. This insecticide alone at full-rate and in any combination with Dipel at reduced-rates significantly lowered ($P<0.05$) the number of most abundant predatory mirid, *C. virgula* and total spider numbers. However, azinphosmethyl at any dosage alone or in mixtures did not affect activities of two most abundant spider species, namely *Spirenbolus mundus* (Linyphiidae: Araneida), and *Eris marginata* (Salticidae: Araneida) on the treated trees.

Trial 2:

Data (Table 6.9) show that counts of motile ERM were generally lower with the Dipel mixtures than with full-rate of Imidan *(phosmet)*. However, none of the treatment affected ERM eggs, ARM, *Z. mali*, tydeid and *T. pyri* counts.

Table 6.5: Effects of seasonal applications of Dipel (Bt) and azinphosmethyl (Guthion), and their mixtures on some mite species in 1990.

Treatment	Insecticide rate/100 liters		Pest mites/leaf*			Miscellaneous mites/leaf*	
	Microbial	Chemical	*E. carpini*	*P. ulmi* (all stages)	*Brevipalpus* spp.	Tydeids	*Calvolia spp.*
Control	-	-	0.87 b	1.67 b	0.13 b	0.33 a	0.57 a
Dipel 2XL	100 MIU	-	1.00 b	2.67 ab	1.00 ab	0.37 a	0.26 bc
Guthion 50WP	-	50 gm	11.20 a	4.33 a	1.47 a	0.32 a	0.00 c
Dipel, Guthion	50 MIU	25 gm	13.70 a	2.33 ab	0.10 b	0.34 a	0.00 c
Dipel, Guthion	25 MIU	12.5 gm	1.47 b	1.33 b	0.17 b	0.30 a	0.33 ab
Dipel, Guthion	10 MIU	05 gm	2.30 b	1.33 b	0.69 ab	0.43 a	0.48 ab
Dipel, Guthion	100 MIU	05 gm	1.13 b	1.67 b	0.35 ab	0.46 a	0.41 ab

* Average mean counts per leaf of two samples taken on July 30 and August 21. Means in a column followed by same letter are not significantly different (P=0.05)

Table 6.6: Effects of seasonal applications of Dipel (Bt) and azinphosmethyl (Guthion) and their mixtures on predatory mites in 1990.

Treatment	Insecticide rate/100 liters		Predatory mites/10 leaves*				
			Stigmaids	Phytoseiids			
	Microbial	Chemical	*Z. mali*	*T. pyri*	*A. aberrans*	All others	Total
Control	-	-	2.50 b	8.84 a	12.34 ab	1.30 a	22.50 a
Dipel 2X	100 MIU	-	6.67 b	3.84 b	15.84 a	3.80 a	23.50 a
Guthion 50WP	-	50 gm	35.50 a	0.00 d	0.17 c	4.00 a	4.17 bc
Dipel, Guthion	50 MIU	25 gm	7.50 b	1.17 c	2.50 c	0.00 a	3.67 c
Dipel, Guthion	25 MIU	12.5 gm	4.34 b	0.50 cd	12.17 ab	0.80 a	13.50 ab
Dipel, Guthion	10 MIU	05 gm	3.17 b	1.00 cd	6.00 bc	1.30 a	8.34 bc
Dipel, Guthion	100 MIU	05 gm	5.00 b	4.00 b	8.50 ab	0.00 a	12.50 ab

* Average mean counts per leaf of two samples taken on July 30 and August 21.
Means in a column followed by same letter are not significantly different (P=0.05).

Data given in Table 6.10 show that activities of *Stethorus punctillum*, predatory mirids (*H. planicornis, D. brevis, C. virgula, D. provancheri*), lacewings, earwigs and araneids were not affected by any treatment viz. Dipel alone, full-rate of phosmet and Dipel-phosmet mixture treatments. Populations of these predators appeared to be tolerant of phosmet.

Trial 3:

Data (Table 6.11) show that counts of ERM (motile and eggs), ARM, and yellow spider mite were significantly higher with all mixture combinations and full-rate of permethrin than that of control. The abundance of these mites was positively correlated with an increase in amount of Ambush *(permethrin)* in the mixture; as the amount of permethrin was increases the number of mites in post-treatment counts increased also. It seems that this pesticide at 1.0 - 0.1 X rates was highly toxic to *T. pyri* and tydeids. However, Dipel was found to be harmless for all mite species.

Results given in Table 6.12 show that permethrin at full-rate and in mixture with Dipel at 0.5 and 0.25 was harmful (> 75% mortality or reduction in population) to most arthropod predators (predatory insects and spiders). At these rates, populations of most predatory insects and spiders were either statistically or numerically lower than those found in with 0.1X permethrin. This mixture had only slight effect on most predatory insects and spiders. It is evident that predatory insects and spiders survived low rate of this pyrethroid.

1992 Trial

Effects on Phytophagous Mites:

The mean numbers of ERM (motile mites + egg) during the study period are given in the Table 6.13. Counts reached maximum values in late-July or mid-August. Significant differences between the control and pyrethroid treatments became apparent

Table 6.7: Effects of seasonal applications of Dipel (Bt) and azinphosmethyl (Guthion), and their mixtures on phytophagous mites, tydeids and predatory mites in 1991.

Treatment	Insecticide rate/100 liters		Pest mites/leaf		Tydeids	Predatory mites/10 leaves			
	Microbial	Chemical	*E. carpini*	*Brevipalpus* spp.	per leaf	Stigmaid *Z. mali*	Phytoseiids *T. pyri*	Phytoseiids All others	Phytoseiids Total
Control	-	-	1.20 b	0.29 b	1.29 ab	6.1 b	11.1 a	4.2 a	15.3 a
Dipel 2X	100	-	0.93 b	0.48 ab	1.07 ab	1.7 c	9.2 a	3.2 a	12.4 a
Guthion 50WP	-	50	5.65 a	2.05 a	0.72 b	11.8 abc	6.0 a	1.5 c	7.5 a
Dipel, Guthion	50	25	5.25 a	1.71 ab	1.74 ab	7.9 abc	5.7 a	1.0 c	6.7 a
Dipel, Guthion	25	12.50	3.17 ab	0.35 ab	2.10 a	5.7 b	7.3 a	1.5 c	8.8 a
Dipel, Guthion	10	5	3.92 ab	0.93 ab	1.47 ab	18.1 a	6.3 a	2.9 ab	9.2 a
Dipel, Guthion	100	5	0.65 b	0.78 ab	1.08 ab	13.1 ab	9.0 a	1.9 bc	10.9 a

Average mean counts of two samples taken on August 5 and August 26.
Means in a column followed by same letter are not significantly different at P=0.05 level (FPLSD)

Table 6.8: Effects of seasonal applications of Dipel (Bt) and azinphosmethyl (Guthion) and their mixtures on generalist predators in 1991.

Treatment	Insecticide rate/100 liters		Predatory mirids			Araneida			Total predators	
	Microbia	Chemical	*C. virgula*	*P. conspurcatus*	Total	*S. mundus*	*E. marginata*	Total		
Control	-	-	9.20 a	6.11 a	15.31 a	1.25 ab	1.23 bc	8.96 a	24.27	a
Dipel 2X	100 MIU	-	5.20 bc	3.41 ab	8.61 bc	1.20 ab	1.56 ab	5.69 bc	14.30	b
Guthion 50W	-	50 gm	3.20 c	1.31 b	4.51 c	0.75 b	0.43 c	2.73 d	7.24	c
Dipel, Guthio	50 MIU	25 gm	4.63 bc	4.19 ab	8.82 bc	1.43 ab	0.61 c	4.47 bcd	13.29	bc
Dipel, Guthio	25 MIU	12.5 gm	5.98 b	1.48 b	7.46 bc	1.22 ab	1.73 ab	4.16 bcd	11.62	bc
Dipel, Guthio	10 MIU	05 gm	4.98 bc	3.97 ab	8.95 bc	1.45 a	2.23 a	6.21 ab	15.16	b
Dipel, Guthio	100 MIU	05 gm	5.42 bc	4.25 ab	9.67 b	1.11 ab	1.12 bc	4.87 bcd	14.54	b

Average mean counts of two samples taken on August 5 and August 26. Means in a column followed by same letter are not significantly different at P=0.05 level (Fisher's Protected Least Significant Difference).

($P<0.05$) after July 12 and between control and Sevin (*carbaryl*) (1.0X) after July 27. Afterwards, all pyrethroid treatments including reduced rates and mixtures had significantly more ERM than did the control trees. Exception to this was esfenvalerate applied at 5.0X (150 ml/100 l), which generally kept ERM population similar to that of control for the entire season. Counts of ERM were generally lower with the microbial insecticides- azinphosmethyl/carbaryl mixtures than with corresponding chemical insecticide treatments applied at their full rates. The full-rate treatments of permethrin, and esfenvalerate had significantly higher counts of ERM per leaf than control and their reduced rates (0.1X) applied alone or in combination with Dipel or MVP. Maximum numbers of ERM was observed in trees treated with full rate of either pyrethroids.

Full-rate of azinphosmethyl usually had higher counts of ERM than did the control during the study period, however, it was significantly different only on 26 August (Table 6.13). Conversely, throughout the season, neither the full rate of Dimilin *(diflubenzuron)* and summer oil, nor any of the microbial insecticides and reduced rates of azinphosmethyl (0.1X), carbaryl (0.1X) and summer oil (0.5X) alone or admixed with microbial insecticides had significantly more ERM than the control. Thus, reduced-rates of azinphosmethyl, carbaryl, diflubenzuron and summer oil alone or in combination with Dipel or MVP had no affect on ERM population when applied 4 times per season. The same was true for the full-rates of summer oil and diflubenzuron. All treatments including mixtures with reduced rates (0.1X) of permethrin and esfenvalerate caused significant ERM build up, yet experienced significantly lower abundance of tetranychid mites than full rates. That is, the ERM density was significantly higher in the full rate treatment trees than in the reduced rates ones.

Results given in Table 6.14 suggest that throughout the growing season, YSM populations were at low levels on trees treated with microbial insecticides, summer oil and diflubenzuron. Similar was generally true for trees treated with reduced rates of carbaryl and azinphosmethyl, and their mixtures with microbial insecticides. However, the seasonal mean densities were significantly higher ($P<0.05$) in trees treated with full

Table 6.9: Effects of seasonal applications of Dipel (Bt) and phosmet (Imidan), and their mixtures on phytophagous and predacious mites, and tydeids in 1991.

Treatment	Insecticide rate/100 liters		Phytophagous mites			Predatory mites		Tydeids
	Microbi	Chemical	*P. ulmi* (motile stages)	(eggs)	*A. schlectendali*	*Z. mali*	*T. pyri*	
Control	-	-	1.7 ab	6.7 a	89.2 a	3.1 bc	10.9 a	0.6 a
Dipel 2X	100 MIU	-	1.2 c	6.2 a	75.2 a	6.4 a	12.1 a	1.7 a
Imidan 50WP	-	120 gm	2.1 a	7.8 a	94.4 a	1.6 c	16.4 a	0.7 a
Dipel, Imidan	50 MIU	60 gm	1.3 c	7.3 a	80.5 a	5.9 ab	15.1 a	4.1 a
Dipel, Imidan	25 MIU	30 gm	1.4 bc	7.1 a	94.7 a	0.9 c	13.1 a	1.4 a
Dipel, Imidan	10 MIU	12 gm	1.2 c	8.7 a	83.7 a	1.4 c	13.8 a	0.6 a
Dipel, Imidan	100 MIU	12 gm	1.2 c	7.9 a	95.3 a	2.7 c	12.3 a	1.0 a

Average mean counts of two samples taken on August 4 and August 25. Means in a column followed by same letter are not significantly different at P=0.05 level (FPLSD).

Table 6.10: Effects of seasonal applications of Dipel (Bt) and phosmet (Imidan), and their mixtures on generalist predators in 1991.

Treatment	Insecticide rate/100 liters		Lacewings	Predatory Hemiptera				
	Microb. (MIU)	Chem. (gm)		*D. brevis*	*H. planicornis*	*C. virgula*	*D. provancheri*	Total
Control	-	-	1.9 ab	2.3 abc	0.9 a	0.4 a	0.7 a	4.3 ab
Dipel 2X	100	-	2.6 a	3.5 a	0.8 a	0.2 a	0.4 a	4.9 a
Imidan 50WP	-	120	0.6 bc	1.3 abc	0.6 a	0.6 a	0.4 a	3.0 bc
Dipel, Imidan	50	60	0.4 c	1.1 bc	1.8 a	1.0 a	0.2 a	4.0 ab
Dipel, Imidan	25	30	0.7 bc	0.8 c	0.2 a	0.4 a	0.2 a	1.5 c
Dipel, Imidan	10	12	0.6 bc	2.7 abc	1.3 a	0.4 a	1.0 a	5.4 a
Dipel, Imidan	100	12	2.8 a	3.1 ab	0.7 a	0.4 a	0.2 a	4.4 ab

Treatment	Insecticide rate/100 liters		*S. punctillum*	All Coccinelids	Earwig	All insect predators	Araneida	All Predators
	Microb.	Chem.						
Control	-	-	0.6 a	1.3 a	0.8 a	9.5 a	2.9 a	12.5 a
Dipel 2X	100	-	0.8 a	1.7 a	0.2 a	9.0 a	2.6 a	11.6 ab
Imidan 50WP	-	120	0.2 a	0.5 a	0.0 a	4.9 c	4.4 a	9.3 ab
Dipel, Imidan	50	60	0.2 a	0.5 a	0.2 a	5.5 bc	4.2 a	9.7 ab
Dipel, Imidan	25	30	0.4 a	0.8 a	0.6 a	4.0 c	4.2 a	8.2 b
Dipel, Imidan	10	12	0.6 a	1.3 a	0.4 a	7.9 ab	3.7 a	11.6 ab
Dipel, Imidan	100	12	0.6 a	1.4 a	0.5 a	7.1 ab	4.9 a	12.0 ab

Average mean counts of two samples taken on August 4 and August 25. Means in a column followed by same letter are not significantly different at P=0.05(FPLSD).

rates of azinphosmethyl on August 8 and with that of carbaryl on July 22, seasonal mean counts of this mite in both treatments remained similar to that of control throughout the other counts. Esfenvalerate and permethrin at full-rates caused a substantial buildup of YSM from the beginning of the season. Their respective mean seasonal counts were 24.0 and 27.6 per 10 leaves compared with 3.1 per 10 leaves in control. Reduced rates of these pyrethroids applied alone or when mixed with microbial insecticides generally increased YSM densities considerably higher ($P \leq 0.05$) than that of control but usually significantly lower than their full rates ($P \leq 0.05$).

The counts of ARM peaked on July 22 and did not vary significantly among the treatments until late August (Table 15). On 21 August, except for the carbaryl (1.0X), none of other treatments gave significantly higher counts of this species (Table 6.17). However, a comparison of seasonal mean densities in different treatments did not indicate ARM buildup. Hence, seasonal populations of this mite was unaffected by any test insecticides or its mixture with microbial insecticides.

Effects on Tydeids:

Results in Table 6.16 show that microbial insecticides applied alone and azinphosmethyl, carbaryl, diflubenzuron and summer oil applied alone or in combination with microbial insecticides had no effect on tydeid species. Only pyrethroids applied at full rates or reduced rates alone or in combination with microbial insecticides deleteriously affected seasonal average populations of these fungivore mites.

Effect on Predatory Mites:

Tables 6.17 and 6.18 represents the effect of different microbial and chemical insecticides and their mixtures on *T. pyri* and other phytoseiids during the study period of 6 June - 21 August, 1992. Insect growth regulator diflubenzuron, summer oil and

Table 6.11: Effects of seasonal applications of Dipel (Bt) and permethrin (Ambush), and their mixtures on tydeids and phytophagous and predatory mites in 1991.

Treatment	Insecticide rate/100 liters		Pest mites				Phytoseiid	Tydeids**
	Microbial	Chemical	*P. ulmi** (motile)	*P. ulmi** eggs	*E. carpini***	ARM*	*T. pyri***	
Control	-	-	2.7 d	26.6 d	5.9 d	70.4 d	5.3 a	3.2 a
Dipel 2X	100 MIU	-	2.2 d	29.0 d	6.0 d	68.9 d	7.7 a	4.1 a
Ambush 25.6%	-	16 ml	12.7 abc	100.2 abc	8.4 c	101.6 cd	0.0 b	0.0 b
Dipel, Ambush	50 MIU	8 ml	15.6 a	81.6 a	11.8 ab	142.4 ab	1.1 b	0.0 b
Dipel, Ambush	25 MIU	4 ml	13.7 ab	62.0 ab	14.7 a	171.9 a	0.0 b	0.0 b
Dipel, Ambush	10 MIU	1.6 ml	11.4 bc	56.7 bc	9.7 bc	120.2 bc	1.1 b	0.0 b
Dipel, Ambush	100 MIU	1.6 ml	9.8 c	66.6 c	8.4 c	75.0 d	2.3 b	1.1 b

*, mites/leaf, **, mites/10 leaves. Average mean counts of two samples taken on August 4 and August 25. Means in a column followed by same letter are not significantly different at P=0.05 level (FPLSD).

Table 6.12: Effects of seasonal applications of Dipel (Bt) and permethrin (Ambush 25.6%), and their mixtures on generalist predators in 1991.

Treatment	Insecticide rate/100 liters		Lacewings	Predatory Hemiptera			
	Microbial (MIU)	Chemical (ml)		*H. planicornis*	*D. brevis*	*D. provancheri*	Total
Control	-	-	0.20 a	0.36 a	2.67 a	0.90 ab	3.93 a
Dipel 2X	100	-	0.43 a	0.20 a	0.77 b	1.12 a	2.85 ab
Ambush 25.6%	-	16	0.00 a	0.20 a	0.00 c	0.33 b	0.53 c
Dipel, Ambush	50	8	0.00 a	0.20 a	0.00 c	0.00 b	0.50 c
Dipel, Ambush	25	4	0.11 a	0.20 a	0.00 c	0.00 b	0.43 c
Dipel, Ambush	10	1.60	0.61 a	0.43 a	0.62 b	0.36 b	2.47 ab
Dipel, Ambush	100	1.60	0.23 a	0.60 a	0.11 c	0.43 b	1.91 bc

Treatment	Insecticide rate/100 liters		*S. punctillum*	*F. auricularia*	Predatory insects	Araneida	Total predators
	Microbial (MIU)	Chemical (ml)					
Control	-	-	0.92 b	0.61 bc	7.12 a	1.47 abc	8.59 a
Dipel 2X	100	-	1.88 a	0.70 ab	7.50 a	0.61 bc	8.11 a
Ambush 25.6%	-	16	0.00 c	0.20 c	0.88 c	0.43 c	1.31 b
Dipel, Ambush	50	8	0.20 bc	0.20 c	0.50 c	1.48 abc	1.98 b
Dipel, Ambush	25	4	0.20 bc	0.00 c	0.60 c	0.90 bc	1.50 b
Dipel, Ambush	10	1.60	0.43 bc	1.42 a	5.70 ab	1.74 ab	7.44 a
Dipel, Ambush	100	1.60	0.61 bc	0.61 bc	3.10 bc	3.20 a	6.30 a

Average mean counts of two samples taken on August 4 and August 25. Means in a column followed by the same letter are not significantly different at P=0.05 level (FPLSD).

microbial insecticides Dipel and MVP, did not affected counts of *T. pyri* and other phytoseiids throughout the study period. Similar results were obtained for *Z. mali* (Table 6.19). It is, therefore, concluded that these insecticides were harmless to *Z. mali*, *T. pyri* and other phytoseiids. Azinphosmethyl and carbaryl at low rate (0.1 X) alone and admixed with Dipel and MVP (1.0X) were harmless also to *Z. mali*, *T. pyri* and other phytoseiids (Table 6.13 and 6.14). The full-rates of these insecticides did not show any adverse effect on *Z. mali* populations. However, these rates considerably reduced ($P<0.05$) seasonal mean counts of *T. pyri* and other phytoseiids, thus, both azinphosmethyl and carbaryl at full rate were slightly harmful to phytoseiids (25-50% mortality).

Both pyrethroid insecticides, Asana *(esfenvalerate)* and permethrin, at full-rate and reduced-rate alone or combined with Dipel and MVP significantly lowered ($P<0.05$) the mean numbers of *T. pyri* and other phytoseiids during most of the study period (June 20-August 21). In the first sample (June 20, 1992), the reduction in phytoseiid mites was statistically insignificant by most treatments with reduced rate (0.1X) of either pyrethroid. However, as the season progressed, the reduction in phytoseiids populations in various pyrethroid treatments (including full- and reduced-rates and mixtures) compared to that of control became more and more distinct. Both pyrethroids at full- and reduced rates applied alone or in combination with Dipel or MVP were harmful to *T. pyri* and other phytoseiids. However, all treatments with reduced rates of pyrethroids allowed survival of some predators which resulted in lower abundance of tetranychids mites than did the full rates (Tables 6.13 and 6.14). Both pyrethroid were found to be equally toxic to phytoseiids. Four seasonal sprays of 1.0X of these pesticides reduced the mean numbers of *T. pyri* to zero or near zero.

Data (Table 6.19) show that only full-rate of either pyrethroid was toxic to *Z. mali*. The reduced rates alone or in mixture with either microbial insecticides did not affect *Z. mali*. Rather, towards the end of the season (August 21, 1992), there were significantly higher ($P<0.05$) mean counts of this predator on trees treated with 0.1X

Table 6.13: Effects of seasonal applications of chemical and microbial insecticides and their mixtures on European red mite. Mean numbers (back-transformed) of ERM (motile + eggs) per leaf in sequential samples (20 leaves/replication) from late-June to late-August, 1992. (Mean number of eggs/leaf (back-transformed) are given in parenthesis).

Treatment	Insecticide rate/100 liters		Sampling date										Seasonal Mean	
	Microbial	Chemical	June 20		July 7		July 22		August 6		August 21			
Control	Untreated		1.24 bc	(0.50)	2.92 de	(1.63)	3.48 fg	(2.34)	1.45 j	(0.64)	2.33 f	(0.78)	2.28 f	(1.19)
Dipel 2X	100 MIU	-	2.33 bc	(1.80)	4.61 de	(4.18)	7.00 efg	(5.51)	3.28 ij	(1.99)	3.56 def	(1.86)	4.61 f	(3.38)
MVP	250 mls	-	1.15 bc	(0.87)	4.45 de	(3.34)	4.65 fg	(2.97)	4.01 hij	(3.72)	2.78 ef	(1.63)	3.97 f	(2.91)
Guthion 50WP (Azinphosmethyl)		50 gms	6.36 abc	(4.60)	9.98 c-e	(9.11)	15.68 b-f	(13.3)	13.74 f-i	(10.99)	5.80 def	(5.02)	11.30 def	(9.62)
Guthion 50WP	-	05 gms	1.45 bc	(0.93)	3.05 de	(1.96)	4.61 fg	(3.14)	3.87 hij	(3.30)	2.62 f	(1.90)	3.43 f	(2.53)
Dipel, Guthion 50WP	100 MIU	05 gms	4.40 abc	(3.51)	3.06 de	(2.54)	7.21 e-g	(6.28)	4.41 g-j	(3.04)	3.94 def	(1.98)	4.65 ef	(3.46)
MVP, Guthion 50WP	250 mls	05 gms	1.77 bc	(1.40)	2.17 e	(1.72)	4.41 fg	(3.86)	3.43 ij	(1.94)	2.75 ef	(1.22)	3.30 f	(2.18)
Asana XL (Esfenvalerate)		30 mls	17.84 ab	(8.46)	52.84 ab	(27.83)	79.53 a	(32.10)	74.93 ab	(45.40)	70.25 a	(40.00)	71.34 a	(36.25)
Asana XL	-	03 mls	9.16 ab	(5.15)	18.31 cd	(10.29)	31.66 b	(15.06)	50.18 bc	(31.09)	33.56 b	(18.43)	35.10 b	(18.64)
Dipel, Asana XL	100 MIU	03 mls	6.44 abc	(3.21)	19.12 c	(11.73)	23.77 bcd	(10.67)	33.83 cde	(21.87)	28.78 b	(15.88)	27.17 bc	(15.03)
MVP, Asana XL	250 mls	03 mls	7.04 abc	(4.10)	24.80 bc	(14.47)	31.12 b	(11.65)	43.54 cd	(28.80)	32.83 b	(16.15)	33.99 b	(17.77)
Ambush 25.6% (Permethrin)		16 mls	23.99 a	(11.9)	61.66 a	(37.73)	85.53 a	(42.85)	93.38 a	(57.27)	82.76 a	(48.90)	84.85 a	(46.69)
Ambush 25.6%	-	1.6 mls	7.21 abc	(5.06)	19.61 c	(9.47)	26.65 bc	(14.86)	25.30 def	(12.64)	25.52 bc	(12.99)	24.98 b-d	(12.49)
Dipel, Ambush 25.6%	100 MIU	1.6 mls	8.32 abc	(5.90)	20.05 bc	(12.11)	28.35 b	(13.42)	34.20 cde	(23.31)	32.60 b	(13.63)	29.06 bc	(15.62)
MVP, Ambush 25.6%	250 mls	1.6 mls	11.44 ab	(7.45)	27.72 bc	(15.00)	29.48 b	(11.96)	37.75 cde	(22.15)	31.74 b	(17.42)	32.00 b	(16.64)
Sevin 50W (Carbaryl)		120 gms	3.12 abc	(2.03)	9.73 c-e	(6.32)	19.71 b-e	(14.68)	16.00 e-h	(9.26)	12.27 cd	(7.00)	14.77 cde	(9.31)
Sevin 50W	-	012 gms	4.23 abc	(1.74)	3.40 de	(2.30)	8.88 d-g	(6.59)	5.23 g-j	(3.56)	4.13 def	(1.88)	5.34 ef	(3.58)
Dipel, Sevin 50W	100 MIU	012 gms	3.12 abc	(2.55)	4.64 de	(2.90)	5.58 fg	(5.39)	2.75 ij	(1.99)	3.24 def	(1.85)	3.68 f	(3.03)
MVP, Sevin 50W	250 mls	012 gms	1.66 bc	(1.47)	2.54 e	(1.85)	3.00 g	(1.30)	4.44 g-j	(4.30)	5.01 def	(2.61)	3.92 f	(2.70)
Dimilin 25W (Dimilin)	-	44 gms	3.91 abc	(1.93)	5.07 de	(3.30)	9.61 c-g	(8.70)	4.22 hij	(3.11)	3.03 def	(1.96)	5.48 ef	(4.27)
Dimilin 25W	-	11 gms	4.42 abc	(3.32)	4.70 de	(3.53)	5.05 fg	(3.97)	3.67 ij	(2.96)	5.65 def	(4.07)	4.77 ef	(3.61)
Dipel, Dimilin 25W	100 MIU	11 gms	1.83 bc	(1.01)	3.21 de	(1.78)	3.05 g	(2.30)	4.60 g-j	(3.53)	4.71 def	(3.61)	3.89 f	(2.80)
MVP, Dimilin 25W	250 mls	11 gms	1.59 bc	(0.92)	4.06 de	(2.86)	4.99 fg	(3. 79)	4.45 g-j	(2.60)	3.51 def	(1.56)	4.04 f	(2.45)
SunSpray (Summer Oil)		1.0 liter	0.80 c	(0.27)	1.82 e	(0.62)	3.64 fg	(2.95)	3.93 hij	(3.16)	3.67 def	(2.83)	3.27 f	(2.39)
SunSpray	-	0.5 liter	1.05 bc	(0.77)	3.46 de	(2.53)	7.13 efg	(6.50)	2.69 ij	(2.30)	3.13 def	(1.57)	4.10 f	(3.23)
Dipel, SunSpray	100 MIU	0.5 liter	3.85 abc	(3.47)	4.63 de	(3.17)	4.56 fg	(3.16)	2.92 ij	(1.42)	5.04 def	(2.75)	4.01 f	(2.63)
MVP, SunSpray	250 mls	0.5 liter	3.14 abc	(1.70)	2.95 de	(2.14)	3.74 fg	(2.56)	4.32 hij	(3.30)	5.40 def	(3.64)	4.10 f	(2.91)

Table 6.14: Effects of seasonal applications of chemical and microbial insecticides and their mixtures on yellow spider mites (YSM). Mean number (back-transformed) of individuals per 10 leaves in sequential samples (20 leaves/replication) from late-June to late-August, 1992. Seasonal average based on last four observations.

Treatment	Insecticides rate/100 liters		Sampling dates					Seasonal
	Microbial	Chemical	6/20/92	7/07/92	7/22/92	8/06/92	8/21/92	average
Control	Untreated		0.6 hij	5.7 hij	2.7 i-l	0.4 f	3.8 c-g	3.1 e-i
Dipel 2X	100 MIU		0.0 j	2.7 klm	4.6 f-i	1.0 ef	6.6 abc	3.7 e-h
MVP	250 mls	-	0.0 j	3.5 ijk	2.4 i-l	0.1 f	3.4 c-g	2.3 f-i
Guthion 50WP		50 gms	1.4 f-j	7.2 fgh	5.3 f-i	0.6 ef	3.9 c-g	4.3 ef
Guthion 50WP	-	05 gms	1.1 g-j	6.3 g-j	2.8 h-l	0.4 f	3.7 c-g	3.3 e-i
Dipel, Guthion	100 MIU	05 gms	3.0 d-g	8.0 fgh	3.7 h-k	0.9 ef	3.6 c-g	4.0 efg
MVP, Guthion	250 mls	05 gms	0.6 hij	5.7 hij	4.1 g-j	0.8 ef	2.6 f-i	3.3 e-i
Asana XL (Esfenvalerate)		30 mls	10.4 bc	24.0 ab	26.4 a	40.2 b	5.5 a-e	24.0 a
Asana XL	-	03 mls	4.6 de	19.1 bc	9.9 de	12.6 d	7.4 ab	12.2 c
Dipel, Asana	100 MIU	03 mls	2.9 d-g	9.7 e-h	9.9 de	18.6 c	5.8 a-d	11.0 cd
MVP, Asana	250 mls	03 mls	6.5 cd	11.3 efg	11.3 cd	10.5 d	2.5 f-i	8.9 d
Ambush 25.6% (Permethrin)		16 mls	17.1 a	29.5 a	20.6 ab	52.5 a	7.9 a	27.6 a
Ambush 25.6%	-	1.6 mls	4.3 ab	13.9 cd	11.1 bc	17.7 b	5.1 c-g	12.0 b
Dipel, Ambush	100 MIU	1.6 mls	15.4 de	18.4 cde	15.5 cd	33.1 c	3.9 a-f	17.7 c
MVP, Ambush	250 mls	1.6 mls	6.4 cd	11.7 c-f	9.8 de	21.8 c	2.0 hi	11.4 cd
Sevin 50W (Carbaryl)		120 gms	0.9 g-j	3.7 i-l	5.6 fgh	0.0 f	2.9 e-h	3.0 e-i
Sevin 50W	-	012 gms	1.3 f-j	6.3 i-l	7.8 ef	1.3 ef	3.5 d-h	4.7 e
Dipel, Sevin	100 MIU	012 gms	0.3 ij	5.7 hij	4.9 f-i	0.4 f	3.2 d-h	3.5 e-i
MVP, Sevin	250 mls	012 gms	1.4 f-j	6.6 f-i	4.4 f-i	1.3 ef	6.7 abc	4.8 e
Dimilin 25W (Diflubenzuron)		44 gms	2.2 e-i	3.7 ijk	5.3 f-i	2.1 e	0.0 f-i	3.4 e-i
Dimilin 25W	-	11 gms	2.5 e-h	2.0 lm	2.9 h-l	0.4 f	4.7 b-f	2.5 f-i
Dipel, Dimilin	100 MIU	11 gms	0.5 hij	3.0 i-l	3.8 h-k	0.4 f	4.9 a-f	3.0 e-i
MVP, Dimilin	250 mls	11 gms	0.3 ij	0.7 lm	2.8 h-l	0.4 f	3.4 d-h	1.8 hij
SunSpray (Summer Oil)		1.0 liter	1.2 g-j	2.2 klm	2.1 j-m	0.4 f	1.4 hi	1.5 ij
SunSpray	-	0.5 liter	1.3 f-j	3.2 i-l	1.1 lm	1.3 ef	2.8 e-i	2.1 ghi
Dipel, SunSpray	100 MIU	0.5 liter	0.9 g-j	2.0 lm	1.7 klm	0.9 f	0.9 ij	1.4 ij
MVP, SunSpray	250 mls	0.5 liter	0.3 ij	0.5 m	0.6 m	0.6 ef	0.0 j	0.4 j

Table 6.15: Effects of seasonal applications of chemical and microbial insecticides and their mixtures on apple rust mites (ARM) on apples. Mean number (back-transformed) of individuals per leaf in sequential samples (20 leaves/ replication) from late-June to late-August, 1992.

Treatment	Amount of insecticide per 100 liters		Sampling dates					Seasonal average
	Microbial	Chemical	6/20/92	7/07/92	7/22/92	8/06/92	8/21/92	
			n.s.	n.s.	n.s.	n.s.		
Control	Untreated		24.9	27.6	99.1	36.6	46.3 b-e	55.0 a-d
Dipel 2X	100 MIU		34.1	54.1	97.4	65.8	31.9 def	65.8 ab
MVP	250 mls	-	31.4	54.5	85.1	34.8	12.7 g	48.9 b-e
Guthion 50WP (Azinphosmethyl)		50 gms	35.9	57.0	86.5	27.0	49.4 b-e	60.0 abc
Guthion 50WP	-	05 gms	31.6	68.0	58.3	30.4	45.9 b-e	51.5 b-e
Dipel, Guthion	100 MIU	05 gms	27.9	45.8	65.5	37.6	26.7 efg	45.7 b-e
MVP, Guthion	250 mls	05 gms	18.9	37.2	37.5	28.3	41.7 c-f	38.1 def
Asana XL (Esfenvalerate)		30 mls	18.5	27.9	37.4	39.6	51.9 b-e	39.2 c-f
Asana XL	-	03 mls	19.0	32.1	33.6	24.4	75.2 ab	42.6 cde
Dipel, Asana	100 MIU	03 mls	24.9	17.1	25.8	25.2	21.1 fg	22.9 f
MVP, Asana	250 mls	03 mls	20.2	21.9	37.0	30.9	63.6 abc	38.9 def
Ambush 25.6% (Permethrin)		16 mls	28.0	45.4	92.0	51.8	67.6 abc	64.2 ab
Ambush 25.6%	-	1.6 mls	19.4	33.1	39.2	26.5	38.1 def	34.2 ef
Dipel, Ambush	100 MIU	1.6 mls	33.2	48.3	78.7	38.4	30.1 d-g	48.9 b-e
MVP, Ambush	250 mls	1.6 mls	24.3	41.5	62.3	34.4	48.2 b-e	46.6 b-e
Sevin 50W (Carbaryl)		120 gms	39.6	51.5	106.8	60.3	92.8 a	79.4 a
Sevin 50W	-	012 gms	24.8	31.7	33.4	22.9	34.4 def	32.4 ef
Dipel, Sevin	100 MIU	012 gms	37.2	56.3	92.3	32.6	32.6 def	56.5 a-d
MVP, Sevin	250 mls	012 gms	28.4	43.9	69.6	36.4	55.6 bcd	54.1 bcd
Dimilin 25W (Diflubenzuron)		44 gms	19.9	25.9	26.4	22.7	53.3 bcd	32.8 ef
Dimilin 25W	-	11 gms	31.9	59.8	67.8	61.5	57.7 a-d	64.9 ab
Dipel, Dimilin	100 MIU	11 gms	32.4	50.7	79.1	47.5	32.7 def	53.6 bcd
MVP, Dimilin	250 mls	11 gms	22.9	54.4	37.2	51.3	38.2 def	46.8 b-e
SunSpray (Summer Oil)		1.0 liter	30.0	70.5	47.2	29.7	49.9 b-e	50.2 b-e-
SunSpray	-	0.5 liter	37.9	54.1	82.2	27.8	38.5 c-f	51.4 b-e
Dipel, SunSpray	100 MIU	0.5 liter	27.2	51.7	56.9	46.4	31.3 d-g	47.3 b-e
MVP, SunSpray	250 mls	0.5 liter	24.1	43.8	52.6	22.8	31.3 d-g	39.3 c-f

Means in a column followed by same letter are not significantly different at P=0.05 (FPLSD). n.s.: non-significant. Seasonal average based on last four observations.

Table 6.16: Effects of seasonal applications of chemical and microbial insecticides, and their mixtures on tydeids on apples. Mean number (back-transformed) of individuals per leaf in sequential samples (20 leaves/replication) from late-June to late-August, 1992. (Seasonal average based on last four observations)

Treatment	Insecticide rate/100 liters		Sampling dates					Seasonal average
	Microbial	Chemical	6/20/92	7/07/9	7/22/9	8/06/92	8/21/92	
			n.s.	n.s.		n.s.		
Control	Untreated		0.8	0.6	1.9 bc	1.7	3.2 bc	1.8 b-d
Dipel 2XL	100 MIU		0.7	1.9	0.5 bc	1.3	1.9 b-f	1.4 b-e
MVP	250 mls	-	0.8	0.5	1.9 bc	2.1	1.7 b-f	1.5 b-d
Guthion 50WP		50 gms	0.2	0.3	0.5 bc	0.3	3.5 bc	0.9 c-g
Guthion 50WP	-	05 gms	0.9	3.1	1.7 bc	0.0	0.3 fg	1.1 b-e
Dipel, Guthion	100 MIU	05 gms	0.3	1.3	0.0 c	0.0	1.6 b-f	0.6 d-g
MVP, Guthion	250 mls	05 gms	0.4	1.2	0.6 bc	0.6	2.5 b-e	1.1 b-e
Asana XL		30 mls	0.0	0.0	0.0 c	0.0	0.0 g	0.0 h
Asana XL	-	03 mls	0.1	0.0	0.0 c	0.5	1.1 c-g	0.3 efg
Dipel, Asana	100 MIU	03 mls	0.1	0.0	0.0 c	0.3	0.0 g	0.1 gh
MVP, Asana	250 mls	03 mls	0.3	0.0	1.5 bc	0.0	0.3 fg	0.4 efg
Ambush 25.6%		16 mls	0.0	0.0	0.0 c	0.0	0.0 g	0.0 h
Ambush 25.6%		1.6 mls	0.1	0.0	0.0 c	0.3	1.2 c-g	0.4 efg
Dipel, Amb.	100 MIU	1.6 mls	0.1	0.0	1.9 bc	0.6	1.2 c-g	0.9 c-g
MVP, Amb.	250 mls	1.6 mls	0.4	0.0	0.0 c	0.0	0.3 fg	0.1 gh
Sevin 50W		120 gms	0.8	0.9	2.7 b	0.9	3.3 bc	1.8 bc
Sevin 50W	-	012 gms	2.5	2.6	8.6 a	1.8	3.3 bc	3.8 a
Dipel, Sevin	100 MIU	012 gms	0.6	1.1	1.1 bc	1.2	1.6 b-f	1.2 b-e
MVP, Sevin	250 mls	012 gms	1.0	1.3	2.5 b	1.7	3.0 bcd	2.1 b
Dimilin 25W		44 gms	0.8	1.7	1.1 bc	1.3	4.2 ab	1.9 bc
Dimilin 25W	-	11 gms	0.8	1.3	2.3 b	0.9	1.3 b-g	1.4 b-d
Dipel, Dimilin	100 MIU	11 gms	0.8	1.9	1.4 bc	0.7	4.3 a	1.9 bc
MVP, Dimilin	250 mls	11 gms	0.3	0.7	0.5 bc	0.5	0.9 d-g	0.6 d-g
SunSpray (Summer Oil)		1.0 liter	0.4	0.3	0.5 bc	1.3	2.2 b-e	1.0 c-f
SunSpray	-	0.5 liter	0.6	0.5	1.7 bc	1.1	1.6 b-f	1.2 b-e
Dipel, SunS.	100 MIU	0.5 liter	0.2	0.3	0.3 bc	0.5	1.9 b-f	0.7 d-g
MVP, SunS.	250 mls	0.5 liter	0.6	0.6	1.8 bc	0.6	3.9 ab	1.5 b-d

of pyrethroids alone or when mixed with microbial insecticides than in the control trees.

Effects on Predatory Insects:

Results (Table 6.20) indicate that seasonal activities of *Stethorus punctillum* Weise were not significantly affected by any treatment. However, full rates of esfenvalerate and permethrin curtailed the number of this predator by half the control population. Similar results were obtained for lace wings and mirids (Table 6.20). However, the difference between full rates of pyrethroids and other treatments became more distinct when seasonal mean of all predatory insects was taken. The seasonal mean values indicate that the activities of predatory insects were significantly diminished only on trees treated with full rates of pyrethroids ($P<0.05$) (Table 6.21). Their reduced rates (0.1X) when applied alone or in mixtures, however, did not have any effect on these predators.

Effects on Araneida:

In 1992, most common spider species were *Spirembolus mundus* (39.60 %), *Philodromus spectabilis* (16.7%), *Cheircanthium inclusum* (8.63 %), *Theridion lawrencei* (2.6%), *Metaphidippus aeneolus* (5.5%) and *Xysticus locuples* (5.7%) (Table 6.4). Seasonal mean numbers in Table 6.21 show that full rates of azinphosmethyl, carbaryl, esfenvalerate and permethrin significantly suppressed the spider population. The spider number from control trees was about 3 - 7 time larger than that from these treatments. In all other treatments, spiders densities were lowered, but not significantly different from control. Overall, diflubenzuron, summer oil and microbial insecticides whether applied at full or reduced rates had little effect on spiders. Same results were found for all mixture treatments.

Table 6.17: Effects of seasonal applications of chemical and microbial insecticides and their mixtures on phytoseiids. Mean numbers (back-transformed) of phytoseiids per 10 leaves in sequential samples (20 leaves/replication) from late-June to late-August, 1992. Seasonal mean based on last four observation.

Treatment	Insecticide rate/100 liters		Sampling dates					Seasonal average
	Microbial	Chemical	6/20/92	7/07/92	7/22/92	8/06/92	8/21/92	
Control	Untreated		2.8 a-d	4.1 cd	5.9 ab	4.5 cde	5.2 bc	4.9 b-e
Dipel 2X	100 MIU	-	3.4 abc	2.4 def	2.0 e-g	4.9 cde	4.4 b-e	3.4 efg
MVP	250 mls	-	2.8 a-d	3.1 cde	3.0 c-f	5.6 cde	3.3 c-f	3.7 efg
Guthion 50WP	-	50 gms	2.4 b-f	3.0 cde	2.9 c-f	3.3 d-g	1.2 fg	2.6 fgh
Guthion 50WP	-	05 gms	4.9 a	6.6 adc	4.7 a-e	3.3 d-g	3.0 c-f	4.4 c-f
Dipel, Guthion	100 MIU	05 gms	4.2 a	5.7 a-d	5.3 a-d	7.0 abc	2.8 def	5.2 a-e
MVP, Guthion	250 mls	05 gms	2.7 a-d	3.3 cd	5.0 a-d	4.0 c-f	4.1 b-e	4.1 d-g
Asana XL	-	30 mls	0.0 g	0.0 g	0.0 h	0.0 h	0.3 g	0.1 j
Asana XL	-	03 mls	0.6 c-g	0.6 efg	0.4 h	1.0 ghi	0.0 g	0.5 ij
Dipel, Asana XL	100 MIU	03 mls	0.5 d-g	1.9 ef	0.7 gh	0.6 hi	0.6 g	0.9 i
MVP, Asana XL	250 mls	03 mls	0.3 f-g	0.7 efg	0.4 h	1.6 fgh	0.3 g	0.7 ij
Ambush 25.6%	-	16 mls	0.0 g	0.0 g	0.0 h	0.0 h	0.0 g	0.0 j
Ambush 25.6%	-	1.6 mls	1.0 b-g	1.4 ef	0.3 h	1.5 fgh	1.9 f	1.3 hi
Dipel, Ambush	100 MIU	1.6 mls	0.3 e-g	0.7 efg	0.0 h	1.9 fgh	1.2 fg	1.0 i
MVP, Ambush	250 mls	1.6 mls	0.6 c-g	0.4 efg	0.6 gh	2.1 fg	2.0 f	1.3 hi
Sevin 50W	-	120 gms	3.5 ab	2.6 c-f	2.0 e-g	3.0 d-g	2.0 f	2.4 gh
Sevin 50W	-	012 gms	3.3 abc	3.9 cd	3.6 a-f	4.9 cde	6.1 ab	4.6 cde
Dipel, Sevin	100 MIU	012 gms	2.5 b-f	3.4 cd	6.7 a	6.2 bcd	8.3 a	6.1 a-d
MVP, Sevin	250 mls	012 gms	4.1 a	6.5 a-d	5.7 abc	2.6 e-h	4.3 b-e	4.8 b-e
Dimilin 25W	-	44 gms	3.0 a-d	3.0 cde	2.8 c-f	4.9 cde	3.3 c-f	3.5 efg
Dimilin 25W	-	11 gms	4.4 a	6.1 a-d	3.9 a-f	3.6 d-g	3.3 c-f	4.2 c-g
Dipel, Dimilin	100 MIU	11 gms	3.9 ab	5.3 b-d	2.9 c-f	3.4 d-g	6.3 ab	4.5 c-f
MVP, Dimilin	250 mls	11 gms	3.2 abc	5.8 a-d	3.1 b-f	2.6 e-h	5.2 bcd	4.2 d-g
SunSpray (Summer Oil)		1.0 liter	5.8 a	11.5 a	4.3 a-e	10.3 ab	4.6 b-e	7.6 a
SunSpray	-	0.5 liter	4.7 a	9.5 ab	4.0 a-f	7.7 abc	5.0 bcd	6.5 abc
Dipel, SunSpray	100 MIU	0.5 liter	3.6 ab	5.8 a-d	6.5 a	11.6 a	4.7 b-e	7.1 ab
MVP, SunSpray	250 mls	0.5 liter	4.3 a	4.9 cd	2.6 d-g	6.9 bc	5.9 ab	5.1 b-e

Table 6.18: Effects of seasonal applications of chemical and microbial insecticides and their mixtures on *T. pyri* Mean number (back-transformed) of individuals per 10 leaves in sequential samples (20 leaves/replication) from early-July to late-August, 1992.

Treatment	Insecticide rate/100 liters		Sampling dates				Seasonal Mean
	Microbial	Chemical	7/07/92	7/22/92	8/06/92	8/21/92	
Control	Untreated		2.2 cde	3.6 ab	3.0 b-e	2.8 a-d	2.9 b-e
Dipel 2X	100 MIU		1.4 ef	1.4 cde	3.5 bc	2.8 a-d	2.2 def
MVP	250 mls	-	1.9 cde	1.3 de	4.3 abc	2.2 b-e	2.4 def
Guthion 50WP	-	50 gms	1.6 def	1.0 ef	1.6 d-g	0.4 fgh	1.2 ghi
Guthion 50WP	-	05 gms	4.3 abc	2.3 a-e	2.5 c-f	1.6 b-f	2.7 c-f
Dipel, Guthion 50WP	100 MIU	05 gms	3.6 a-d	2.8 a-e	5.3 abc	1.9 b-e	3.4 a-d
MVP, Guthion 50WP	250 mls	05 gms	2.3 cde	2.4 a-e	3.2 b-e	2.8 abc	2.7 c-f
Asana XL	-	30 mls	0.0 g	0.0 f	0.0 h	0.2 gh	0.1 kl
Asana XL	-	03 mls	0.6 efg	0.4 f	1.0 e-h	0.0 h	0.5 ijk
Dipel, Asana XL	100 MIU	03 mls	1.2 efg	0.7 ef	0.3 gh	0.2 gh	0.6 ij
MVP, Asana XL	250 mls	03 mls	0.5 fg	0.4 f	0.8 efg	0.0 h	0.4 jkl
Ambush 25.6%	-	16 mls	0.0 g	0.0 f	0.0 h	0.0 h	0.0 l
Ambush 25.6%	-	1.6 mls	1.3 ef	0.3 f	1.4 efg	1.2 d-g	1.0 hi
Dipel, Ambush 25.6%	100 MIU	1.6 mls	0.7 efg	0.0 f	1.6 d-g	1.1 efg	0.8 hij
MVP, Ambush 25.6%	250 mls	1.6 mls	0.4 fg	0.6 ef	2.1 c-f	1.6 c-f	1.2 ghi
Sevin 50W	-	120 gms	1.6 def	1.4 cde	2.3 c-f	1.0 efg	1.6 fgh
Sevin 50W	-	012 gms	2.0 cde	1.9 b-e	4.0 bc	2.6 a-e	2.6 c-f
Dipel, Sevin 50W	100 MIU	012 gms	1.1 efg	3.2 a-d	4.3 abc	4.6 a	3.3 a-e
MVP, Sevin 50W	250 mls	012 gms	3.6 a-d	3.3 abc	1.3 efg	2.2 b-e	2.6 def
Dimilin 25W	-	44 gms	2.2 cde	2.4 a-e	3.5 bc	1.4 c-g	2.4 def
Dimilin 25W	-	11 gms	3.6 a-d	2.6 a-e	1.9 c-f	1.1 d-g	2.3 def
Dipel, Dimilin 25W	100 MIU	11 gms	2.3 cde	1.6 b-e	1.4 efg	3.3 ab	2.1 efg
MVP, Dimilin 25W	250 mls	11 gms	2.9 b-e	1.8 b-e	2.3 c-f	2.8 a-d	2.4 def
SunSpray (Summer Oil)	-	1.0 liter	6.0 a	2.3 a-e	5.8 ab	2.9 abc	4.3 ab
SunSpray	-	0.5 liter	5.9 ab	2.3 a-e	5.3 abc	2.3 a-e	4.0 abc
Dipel, SunSpray	100 MIU	0.5 liter	4.2 abc	4.3 a	7.6 a	1.9 b-e	4.5 a
MVP, SunSpray	250 mls	0.5 liter	3.0 b-e	1.3 de	3.6 bc	3.2 abc	2.8 cde

Means followed by same letter are not significantly different at P=0.05 level (FPLSD)

Table 6.19: Effects of seasonal applications of chemical and microbial insecticides and their mixtures on *Z. mali* Mean number (back-transformed) of individuals per 10 leaves in sequential samples (20 leaves/replication) from June to August, 1992. Seasonal average based on last four observations.

Treatment	Insecticide amount per 100 liters		Sampling dates					Seasonal
	Microbial	Chemical	6/20/92	7/07/92	7/22/92	8/06/92	8/21/92	average
Control	Untreated		2.2 abc	6.9 a-e	8.5 abc	7.5 ab	2.2 fgh	5.4 ab
Dipel 2X	100 MIU		2.8 abc	6.7 a-e	6.3 bcd	4.7 a-e	5.6 b-e	5.0 ab
MVP	250 mls	-	1.6 bcd	5.4 b-f	6.3 bcd	2.1 ef	3.8 d-g	3.6 b
Guthion 50WP		50 gms	2.2 a-d	7.4 a-e	2.5 efg	5.5 abc	3.1 e-h	3.8 ab
Guthion 50WP	-	05 gms	2.8 abc	7.2 a-e	6.7 bcd	5.7 abc	1.6 gh	4.4 ab
Dipel, Guthion	100 MIU	05 gms	3.2 ab	9.9 abc	7.4 abc	4.4 a-e	3.5 e-h	5.4 ab
MVP, Guthion	250 mls	05 gms	1.7 bcd	7.2 a-e	4.1 c-g	3.4 c-f	4.2 c-f	3.9 ab
Asana XL (Esfenvalerate)		30 mls	0.3 ef	0.0 g	1.5 g	1.2 f	1.3 h	0.6 d
Asana XL	-	03 mls	1.9 a-d	4.8 c-f	7.2 abc	4.0 b-e	7.6 abc	5.1 ab
Dipel, Asana	100 MIU	03 mls	1.5 bcd	5.2 c-f	2.9 d-g	4.2 b-e	7.2 a-d	4.0 ab
MVP, Asana	250 mls	03 mls	3.9 a	10.3 abc	12.5 a	3.3 c-f	9.6 a	8.3 a
Ambush 25.6% (Permethrin)		16 mls	0.0 f	0.4 g	1.4 g	1.6 f	0.9 h	0.7 cd
Ambush 25.6%	-	1.6 mls	2.8 abc	7.2 a-e	7.9 abc	3.4 c-f	6.7 a-d	5.5 ab
Dipel, Ambush	100 MIU	1.6 mls	1.3 cde	4.5 def	5.1 b-f	3.6 b-f	5.3 b-e	3.7 ab
MVP, Ambush	250 mls	1.6 mls	2.5 abc	5.5 b-f	4.7 c-f	2.3 def	5.0 c-f	3.5 b
Sevin 50W (Carbaryl)		120 gms	2.8 abc	8.6 a-d	5.8 b-e	8.3 a	5.3 b-e	6.2 ab
Sevin 50W	-	012 gms	2.0 a-d	5.6 b-f	6.8 bc	4.0 b-e	5.9 a-e	4.7 ab
Dipel, Sevin	100 MIU	012 gms	3.8 a	11.6 ab	6.2 bcd	2.2 def	4.2 c-f	5.4 ab
MVP, Sevin	250 mls	012 gms	2.8 abc	7.5 a-e	7.0 bc	3.7 b-f	5.9 a-e	5.2 ab
Dimilin 25W (Diflubenzuron)		44 gms	1.7 bcd	5.2 c-f	6.6 bcd	4.0 b-e	7.7 abc	5.0 ab
Dimilin 25W	-	11 gms	1.2 cde	3.4 ef	9.4 ab	5.4 abc	3.7 efg	4.6 ab
Dipel, Dimilin	100 MIU	11 gms	0.7 def	2.1 fg	8.1 abc	5.3 a-d	3.9 d-g	4.0 ab
MVP, Dimilin	250 mls	11 gms	1.4 cde	3.3 ef	4.9 b-f	4.0 b-e	2.9 e-h	2.9 bc
SunSpray (Summer Oil)		1.0 liter	1.2 c-f	4.0 def	4.8 c-f	2.5 c-f	7.2 a-d	3.8 ab
SunSpray	-	0.5 liter	1.3 cde	3.4 ef	6.0 b-e	5.0 a-e	5.8 a-e	4.1 ab
Dipel, SunSpray	100 MIU	0.5 liter	1.5 bcd	5.2 c-f	2.2 fg	3.3 c-f	4.7 c-f	3.0 bc
MVP, SunSpray	250 mls	0.5 liter	3.6 a	13.4 a	5.1 b-f	3.7 c-f	9.1 ab	7.1 ab

Table 6.20: Effects of seasonal applications of chemical and microbial insecticides and their mixtures on some predatory insects. Mean numbers (back-transformed) of individuals per sample in sequential samples during growing season of 1992. (Monthly value = average of two samples taken biweekly. Mean = seasonal mean counts).

Treatment	Amount of insecticides per 100 liters		*S. punctillum*				Lace wings				Mirids			
	Microbial	Chemical	June	July	Aug.	Mean	June	July	Aug.	Mean	June	July	Aug.	Mean
Control	Untreated		1.6 abc	0.0	1.4	1.0	1.9	0.9 a	0.0	0.9	4.5 a	0.0	1.3	1.9
Dipel 2X (Bacterial)	100 MIU	-	0.0 e	0.9	1.4	0.8	0.9	0.5 ab	0.0	0.5	3.0 abc	0.9	1.1	1.6
MVP (Bacterial)	250 mls	-	0.3 de	0.6	0.6	0.5	2.3	0.0 b	0.0	0.8	1.8 a-e	0.0	0.3	0.7
Guthion 50WP (Azinphosmethyl)		50 gms	3.3 a	1.2	0.0	1.5	0.9	0.0 b	0.0	0.3	2.5 a-d	0.0	0.3	0.9
Guthion 50WP	-	05 gms	1.3 bcd	0.3	1.4	1.0	1.9	0.0 b	0.3	0.7	0.3 ef	0.9	1.0	0.7
Dipel, Guthion 50WP	100 MIU	05 gms	2.0 ab	0.6	0.6	1.1	1.3	0.6 ab	0.0	0.6	0.0 f	0.0	0.6	0.2
MVP, Guthion 50WP	250 mls	05 gms	1.4 bcd	0.0	0.3	0.6	0.9	0.0 b	0.3	0.4	1.3 b-f	1.3	0.3	1.0
Asana XL (Esfenvalerate)		30 mls	1.4 bcd	0.3	0.6	0.7	0.8	0.0 b	0.3	0.4	0.0 f	1.0	1.1	0.7
Asana XL	-	03 mls	2.0 ab	0.7	0.8	1.2	2.1	0.0 b	0.0	0.7	2.1 a-d	0.0	0.9	1.0
Dipel, Asana XL	100 MIU	03 mls	0.9 b-e	0.6	1.1	0.9	1.3	0.6 ab	0.4	0.8	2.2 a-d	0.0	0.6	1.0
MVP, Asana XL	250 mls	03 mls	2.5 ab	1.1	1.2	1.6	1.8	0.0 b	0.3	0.7	1.3 b-f	2.1	1.4	1.6
Ambush 25.6% (Permethrin)		16 mls	1.1 bcd	0.0	0.6	0.6	1.3	0.0 b	0.3	0.5	1.2 b-f	0.0	0.3	0.5
Ambush 25.6%	-	1.6 mls	0.5 cde	0.5	0.5	0.5	0.5	0.5 ab	0.5	0.5	2.4 a-d	1.4	0.3	1.4
Dipel, Ambush 25.6%	100 MIU	1.6 mls	0.6 b-e	0.0	2.9	1.2	2.4	0.9 a	0.9	1.4	0.0 f	1.9	3.1	1.7
MVP, Ambush 25.6%	250 mls	1.6 mls	0.6 b-e	0.3	2.9	1.3	0.9	0.0 b	1.2	0.7	0.7 def	0.7	2.5	1.3
Sevin 50W (Carbaryl)	-	120 gms	1.1 bcd	0.6	0.9	0.9	1.9	0.3 b	0.5	0.9	1.1 b-f	0.6	1.4	1.0
Sevin 50W	-	012 gms	0.5 cde	0.5	2.1	1.0	2.0	0.6 ab	0.3	1.0	0.6 def	1.1	0.5	0.7
Dipel, Sevin 50W	100 MIU	012 gms	1.4 bcd	0.7	0.7	0.9	1.1	1.3 a	0.3	0.9	2.6 a-d	0.6	0.6	1.3
MVP, Sevin 50W	250 mls	012 gms	0.0 e	1.3	2.2	1.2	0.5	0.7 ab	0.0	0.4	3.3 ab	1.6	0.5	1.8
Dimilin 25W (Diflubenzuron)		44 gms	0.0 e	0.7	1.9	0.9	1.1	0.6 ab	0.0	0.6	2.6 a-d	0.5	0.6	1.3
Dimilin 25W	-	11 gms	1.0 b-e	0.7	0.5	0.7	0.9	0.9 a	0.0	0.6	0.9 c-f	0.9	1.1	0.9
Dipel, Dimilin 25W	100 MIU	11 gms	0.7 b-e	0.0	0.9	0.5	0.9	0.0 b	0.0	0.3	2.5 a-d	0.6	0.0	1.0
MVP, Dimilin 25W	250 mls	11 gms	1.0 b-e	0.6	0.6	0.7	1.4	0.3 b	0.0	0.6	2.2 a-d	0.3	0.3	0.9
SunSpray (Summer Oil)	-	1.0 liter	1.3 bcd	0.0	0.0	0.4	0.7	0.0 b	0.0	0.2	2.3 a-d	1.3	1.0	1.5
SunSpray	-	0.5 liter	0.9 b-e	0.3	0.7	0.6	1.1	0.6 ab	0.0	0.6	0.6 def	0.9	1.1	0.9
Dipel, SunSpray	100 MIU	0.5 liter	1.0 b-e	0.0	0.3	0.4	3.0	0.6 ab	0.3	1.3	2.1 a-e	0.9	0.0	1.0
MVP, SunSpray	250 mls	0.5 liter	1.9 ab	1.5	0.7	1.4	1.9	0.0 b	0.0	0.6	1.4 b-f	0.9	0.3	0.9

Monthly value = average of two samples taken biweekly. Mean = Seasonal mean counts.

1993 Trials

The results of these trials are summarized in Tables 6.22-6.36. Data show that chemical insecticides at full rates and at one-tenth and/or one-fifth of full rates alone or in mixtures with Dipel (1.0 or 1.5X) or MVP (0.5 or 1.0X), had substantial effect on phytophagous and predatory fauna.

Trial 1

Effects on Phytophagous Mites:

The mean densities of ERM (motile mites + egg) and eggs counts (in parenthesis) are given in the Table 6.22. The mean ERM densities in different treatments reached highest in early - mid August. In the first sampling (June 24), only two treatments namely esfenvalerate (1.0X) and mixture of esfenvalerate (0.2X) and Dipel (1.0X) had significantly higher ERM populations. Afterwards, all esfenvalerate treatments including reduced rates (0.1X & 0.2X) and mixtures had significantly more ERM than did the control. Full rates of esfenvalerate had highest densities of ERM throughout the season except on August 8, when 0.2X of this pyrethroid had more mites than in any other treatment. Generally, there was no significant difference in mite abundance on trees treated with esfenvalerate at full rate and at 0.2X applied alone or in combination with *B. thuringiensis*. However, ERM buildup on tree treated with esfenvalerate at 0.1X alone or admixed with microbial insecticides was considerably lower ($P \leq 0.05$) than that of higher rates. Overall, all treatments including Dipel and MVP mixtures with 0.1and 0.2X of esfenvalerate caused outbreak of this mite. This pyrethroid at 0.1X alone and in mixtures resulted in significantly lower abundance of ERM than did its 0.2 X and 1.0X.

Starting July 8, full-rates of azinphosmethyl and carbaryl usually had higher counts of ERM than did the control (Table 6.22). However, throughout the season, neither the full rate of diflubenzuron nor any rates of the microbial insecticides had

Table 6.21: Effects of seasonal applications of chemical and microbial insecticides and their mixtures on total predatory insects and spiders. Mean numbers (back-transformed) of individuals per sample in sequential samples during the growing season of 1992. Monthly value = average of two samples taken biweekly.

Treatment	Insecticide rate/100 liters		Total insect predators				Spiders			
	Microbial	Chemical	June	July	August	Mean	June	July	Aug.	Mean
Control	Untreated		7.3	1.2	7.0 abc	4.9 a-d	5.5	3.4	2.5	3.7 a
Dipel 2X (Bacterial)	100 MIU	-	5.3	3.1	3.4 b-e	4.3 b-f	2.2	5.2	2.4	3.2 ab
MVP (Bacterial)	250 mls	-	4.2	1.7	2.6 c-f	2.9 efg	2.8	1.1	1.7	1.8 a-e
Guthion 50WP (Azinphosmethyl)		50 gms	7.2	0.0	3.8 b-e	3.5 d-g	0.9	0.9	0.9	0.9 de
Guthion 50WP	-	05 gms	4.4	0.6	1.9 ef	2.6 fg	2.6	1.3	4.0	2.5 abc
Dipel, Guthion	100 MIU	05 gms	2.6	2.3	2.1 def	2.5 fg	1.7	1.6	1.3	1.5 a-e
MVP, Guthion	250 mls	05 gms	5.3	3.3	3.1 b-f	4.1 b-f	1.9	2.2	3.3	2.5 abc
Asana XL (Esfenvalerate)		30 mls	2.2	2.2	2.3 def	2.2 g	0.6	0.9	1.3	0.9 cde
Asana XL	-	03 mls	6.3	0.7	1.7 ef	2.9 efg	0.5	1.3	4.9	1.9 a-e
Dipel, Asana	100 MIU	03 mls	4.4	1.3	2.1 def	2.6 fg	0.6	0.6	3.4	1.3 b-e
MVP, Asana	250 mls	03 mls	5.6	3.1	2.9 c-f	3.9 c-g	2.0	0.9	3.0	1.9 a-e
Ambush 25.6% (Permethrin)		16 mls	4.4	0.6	1.9 ef	2.3 g	0.5	0.6	0.5	0.5 e
Ambush 25.6%	-	1.6 mls	8.0	3.1	6.4 a-d	6.0 ab	1.3	0.5	1.9	1.2 b-e
Dipel, Ambush	100 MIU	1.6 mls	5.2	3.4	11.0 a	7.0 a	0.9	1.6	3.3	1.8 a-e
MVP, Ambush	250 mls	1.6 mls	5.6	4.1	7.5 ab	5.6 abc	1.6	0.9	2.6	1.7 a-e
Sevin 50W (Carbaryl)		120 gms	9.0	4.2	4.0 b-e	5.9 ab	0.9	1.2	1.6	1.2 b-e
Sevin 50W	-	012 gms	3.7	5.3	4.7 b-e	4.7 b-e	2.3	2.6	1.9	2.3 a-d
Dipel, Sevin	100 MIU	012 gms	4.5	3.6	1.5 ef	3.8 c-g	2.8	2.5	3.1	2.8 abc
MVP, Sevin	250 mls	012 gms	2.9	4.4	3.3 b-e	3.0 d-g	1.9	0.3	2.6	1.5 b-e
Dimilin 25W (Diflubenzuron)		44 gms	6.0	3.2	3.6 b-e	4.4 b-e	2.7	2.0	1.4	2.0 a-e
Dimilin 25W	-	11 gms	3.5	3.0	1.9 ef	3.1 d-g	2.4	1.1	1.5	1.7 a-e
Dipel, Dimilin	100 MIU	11 gms	4.9	2.5	1.2 ef	3.0 d-g	2.0	1.3	1.2	1.5 b-e
MVP, Dimilin	250 mls	11 gms	5.6	3.3	1.6 ef	3.5 d-g	2.6	2.0	2.2	2.3 a-d
SunSpray (Summer Oil)		1.0 liter	6.4	1.8	0.3 f	3.3 d-g	3.0	0.9	1.7	1.8 a-e
SunSpray	-	0.5 liter	3.2	3.8	1.9 ef	3.8 c-g	1.9	2.3	1.6	2.0 a-e
Dipel, SunSpray	100 MIU	0.5 liter	5.2	3.0	2.2 def	3.5 d-g	2.7	2.6	1.1	2.1 a-e
MVP, SunSpray	250 mls	0.5 liter	5.8	2.6	1.1 ef	3.4 d-g	1.7	4.7	0.5	2.0 a-e

Table 6.22: Effects of seasonal applications of chemical and microbial insecticides and their mixtures on European red mite (ERM). Mean numbers (back-transformed) of ERM (motile + eggs) per leaf in sequential samples during growing season of 1992. (Mean number of eggs/leaf (back-transformed) are given in parenthesis).

Treatment	Insecticide rate/100 liters		Sampling date						Seasonal Mean
	Microbial	Chemical	June 24	July 8	July 24	August 8	August 23	September 7	
Control	-	-	1.8 c-f (1.4)	0.7 ij (0.7)	1.5 f (1.4)	3.2 e (3.1)	0.8 e (0.6)	2.3 ij (1.5)	1.7 e (1.5)
Dipel 2X (Bacterial)	50 MIU	-	5.4 c-f (4.7)	3.5 g-j (3.4)	6.9 ef (6.2)	2.9 e (2.3)	4.2 de (3.8)	2.6 ij (1.9)	4.2 de (3.9)
Dipel 2X	100 MIU	-	2.5 def (2.3)	5.7 f-j (4.8)	2.2 f (1.9)	5.7 e (4.4)	4.7 de (3.5)	2.4 ij (1.6)	3.9 de (3.1)
Dipel 2X	150 MIU	-	2.2 def (1.9)	4.0 f-j (3.5)	4.0 f (3.7)	3.8 e (3.4)	5.5 de (4.5)	3.1 ij (2.4)	3.8 de (3.2)
MVP (Bacterial)	125 mls	-	3.9 c-f (3.7)	0.4 j (0.4)	4.5 ef (3.9)	3.4 e (2.6)	8.9 de (7.6)	2.5 ij (1.4)	3.9 de (3.3)
MVP	250 mls	-	3.0 c-f (2.9)	5.2 f-j (4.5)	4.8 ef (4.2)	5.4 e (2.9)	10.1 de (8.7)	1.2 j (0.6)	4.9 de (4.1)
Guthion 50WP (Azinphosmethyl)		50 gms	10.0 bcd (8.6)	27.9 cde (25.2)	16.5 e (14.0)	33.4 d (29.1)	46.8 c (41.9)	45.5 bc (43.1)	31.0 c (27.0)
Guthion 50WP	-	10 gms	8.1 b-e (6.5)	10.6 e-h (9.3)	9.9 ef (8.1)	11.2 de (10.2)	11.2 de (9.0)	6.0 g-j (4.4)	12.5 d (7.9)
Guthion 50WP	-	05 gms	6.5 b-f (6.3)	4.6 f-j (3.1)	4.0 f (1.8)	6.1 e (5.5)	5.2 de (4.8)	2.3 ij (1.8)	4.8 de (3.9)
Dipel, Guthion	100 MIU	10 gms	4.1 c-f (3.1)	8.3 f-j (5.7)	6.4 ef (4.4)	8.7 de (7.1)	6.4 de (4.6)	11.6 e-i (10.5)	7.6 de (5.9)
Dipel, Guthion	100 MIU	05 gms	3.0 c-f (2.4)	6.2 f-j (5.6)	7.4 ef (5.1)	9.6 de (8.9)	7.6 de (2.4)	3.5 ij (3.1)	6.2 de (4.6)
MVP, Guthion	250 mls	10 gms	6.5 b-f (5.6)	7.1 f-j (6.0)	9.0 ef (7.8)	14.3 de (12.7)	10.4 de (8.2)	3.6 ij (2.2)	8.7 de (7.1)
Asana XL (Esfenvalerate)		30 mls	31.7 a (29.3)	63.2 ab (50.0)	146.2 ab (128.9)	183.8 b (105.2)	332.5 a (251.4)	136.5 a (119.8)	149.0 a (126.5)
Asana XL	-	06 mls	10.9 bc (9.9)	40.9 bcd (37.1)	121.5 b (96.6)	304.8 a (253.3)	242.8 a (202.4)	55.7 b (43.0)	129.5 a (110.7)
Asana XL	-	03 mls	8.8 b-e (8.2)	13.1 efg (12.4)	64.6 cd (57.3)	102.6 c (87.8)	129.3 ab (113.3)	21.1 def (17.9)	56.6 b (49.6)
Dipel, Asana	100 MIU	06 mls	16.8 ab (14.0)	77.6 a (70.7)	172.8 a (128.9)	223.0 ab (206.4)	274.2 a (216.3)	28.4 cde (20.4)	132.2 a (121.1)
MVP, Asana	250 mls	06 mls	8.0 b-f (7.5)	51.1 abc (47.4)	141.7 ab (113.3)	256.0 ab (217.5)	263.0 a (221.2)	43.7 bc (27.6)	127.3 a (116.5)
Dipel, Asana	100 MIU	03 mls	8.6 b-e (6.9)	14.2 efg (10.2)	61.1 cd (46.0)	106.4 c (86.2)	110.8 b (88.5)	41.2 bcd (34.4)	57.0 b (45.4)
MVP, Asana	250 mls	03 mls	6.8 b-f (5.8)	9.7 e-j (7.2)	40.3 d (31.6)	77.6 c (60.8)	81.4 bc (63.6)	69.0 b (63.1)	47.5 bc (38.7)
Sevin 50W (Carbaryl)		120 gms	1.2 f (0.6)	18.7 def (16.3)	73.4 c (60.8)	96.2 c (77.3)	84.0 bc (77.2)	16.2 e-h (10.4)	48.3 bc (40.4)
Sevin 50W	-	024 gms	7.7 b-f (5.9)	9.5 e-j (7.8)	4.4 ef (3.5)	10.0 de (7.5)	9.4 de (7.9)	5.6 f-j (2.3)	7.8 de (5.8)
Dipel, Sevin	100 MIU	024 gms	5.4 c-f (3.5)	5.9 f-j (4.9)	6.9 ef (5.1)	14.0 de (10.8)	14.6 d (11.7)	10.3 f-i (7.0)	9.5 de (7.2)
MVP, Sevin	250 mls	024 gms	7.7 b-f (6.9)	7.4 f-j (6.5)	5.8 ef (4.9)	8.7 de (6.3)	11.7 de (9.4)	6.6 f-j (4.5)	8.0 de (6.4)
Dimilin 25W (Diflubenzuron)		44 gms	3.0 c-f (1.6)	10.5 e-i (8.1)	6.2 ef (5.0)	12.7 de (9.5)	12.1 de (10.2)	5.0 hij (3.9)	8.2 de (6.4)
Dimilin 25W	-	22 gms	1.5 ef (1.3)	7.3 f-j (6.9)	5.8 ef (5.3)	9.2 de (7.8)	7.0 de (6.3)	1.8 ij (1.1)	5.4 de (4.8)
Dimilin 25W	-	11 gms	5.5 c-f (4.9)	10.0 e-i (8.6)	9.0 ef (7.8)	10.3 de (8.7)	9.8 de (8.2)	6.0 g-j (3.7)	8.4 de (7.0)
Dipel, Dimilin 25W	100 MIU	22 gms	4.6 c-f (4.2)	6.8 f-j (5.1)	10.6 ef (7.2)	9.5 de (8.4)	8.1 de (6.8)	3.8 ij (2.2)	7.2 de (5.7)
Dipel, Dimilin 25W	100 MIU	11 gms	4.4 c-f (3.9)	0.9 hij (0.6)	8.7 ef (6.4)	4.0 e (2.9)	3.4 de (2.9)	2.4 ij (1.6)	3.9 de (3.1)
MVP, Dimilin 25W	250 mls	22 gms	3.9 c-f (2.4)	5.8 f-j (4.2)	6.3 ef (5.1)	8.9 de (7.2)	2.2 e (0.9)	3.7 ij (2.8)	5.0 de (3.8)

Table 6.23: Effects of seasonal applications of chemical and microbial insecticides and their mixtures on yellow spider mite (YSM). Mean numbers (back-transformed) of YSM per leaf in sequential samples (20 leaves/replication) from late-June to early-September, 1993.

Treatment	Insecticide rate/100 liters		Sampling date						Seasonal Mean
	Microbial	Chemical	June 24	July 8	July 24	August 8	August 23	September 7	
Control	-	-	3.7 ef	0.6 e	1.1 g	0.3 d	1.9 ef	4.2 cd	2.4 i
Dipel 2X (Bacterial)	50 MIU	-	14.9 b-e	6.8 cde	7.8 d-g	4.3 cd	0.6 f	2.1 cd	7.1 ghi
Dipel 2X	100 MIU	-	14.3 b-e	11.1 cde	4.4 efg	9.3 cd	5.6 def	2.0 cd	8.1 ghi
Dipel 2X	150 MIU	-	6.0 def	3.6 cde	1.2 g	4.6 cd	0.9 f	1.3 cd	3.3 i
MVP (Bacterial)	125 mls	-	11.9 c-f	0.3 e	4.0 fg	3.6 cd	4.1 ef	2.6 cd	4.6 i
MVP	250 mls	-	13.4 b-f	5.9 cde	3.6 fg	6.8 cd	3.3 ef	1.3 cd	5.9 hi
Guthion 50WP (Azinphosmethyl)		50 gms	17.8 bcd	15.6 cde	36.6 c	55.3 b	78.8 bc	18.5 c	37.1 de
Guthion 50WP	-	10 gms	6.5 def	8.7 cde	16.4 c-g	43.1 bc	17.8 def	12.2 c	27.5 ef
Guthion 50WP	-	05 gms	22.9 abc	6.9 cde	22.3 c-g	13.4 cd	10.8 def	10.3 c	15.5 f-h
Dipel, Guthion	100 MIU	10 gms	11.2 c-f	3.3 cde	27.5 cd	33.8 bcd	20.6 c-f	3.0 cd	18.9 fg
Dipel, Guthion	100 MIU	05 gms	6.0 def	2.1 de	5.9 d-g	3.0 cd	5.5 def	0.3 d	4.5 i
MVP, Guthion	250 mls	10 gms	10.9 c-f	0.3 e	3.6 fg	42.7 bc	31.3 cde	1.9 cd	24.8 ef
Asana XL (Esfenvalerate)		30 mls	20.1 bcd	123.6 a	168.6 b	156.8 a	171.4 a	11.6 c	132.5 a
Asana XL	-	06 mls	22.2 bc	22.4 bcd	101.0 b	194.1 a	17.5 def	99.9 a	80.4 bc
Asana XL	-	03 mls	32.7 ab	10.8 cde	33.0 c	91.5 ab	43.8 cd	2.4 cd	37.8 de
Dipel, Asana	100 MIU	06 mls	47.0 a	53.8 b	259.5 a	87.9 ab	162.1 ab	58.3 b	115.7 a
MVP, Asana	250 mls	06 mls	14.7 b-e	28.5 bc	162.5 b	208.4 a	130.3 ab	54.9 b	101.2 ab
MVP, Asana	250 mls	03 mls	35.8 ab	29.6 bc	99.9 b	79.0 b	89.8 b	20.2 c	59.1 d
Dipel, Asana	100 MIU	03 mls	20.0 bcd	19.0 b-e	34.7 c	105.2 a	66.2 bc	14.7 c	43.3 d
Sevin 50W (Carbaryl)		120 gms	16.9 bcd	19.5 b-e	9.7 c-g	158.8 a	75.3 bc	10.4 c	60.5 cd
Sevin 50W	-	024 gms	5.8 def	10.8 cde	16.6 c-g	23.0 bcd	16.1 def	9.7 c	13.7 f-h
Dipel, Sevin	100 MIU	024 gms	9.7 c-f	8.5 cde	27.1 cd	34.2 bcd	20.2 c-f	17.1 c	19.5 fg
MVP, Sevin	250 mls	024 gms	11.2 c-f	14.0 cde	20.4 c-g	15.7 cd	34.4 cde	11.8 c	17.9 fg
Dimilin 25W (Diflubenzuron)		44 gms	9.6 c-f	12.2 cde	26.0 cde	21.6 bcd	19.8 c-f	2.7 cd	15.7 f-h
Dimilin 25W	-	22 gms	2.5 f	9.6 cde	7.8 d-g	3.0 cd	1.9 ef	3.0 cd	4.7 i
Dimilin 25W	-	11 gms	16.5 bcd	18.8 cde	5.0 efg	2.0 cd	11.4 def	1.9 cd	10.5 ghi
Dipel, Dimilin 25W	100 MIU	22 gms	10.2 c-f	6.4 cde	8.3 c-g	3.2 cd	4.7 ef	5.0 cd	7.3 ghi
Dipel, Dimilin 25W	100 MIU	11 gms	10.1 c-f	1.1 de	6.6 d-g	2.5 cd	1.3 f	1.6 cd	4.0 i
MVP, Dimilin 25W	250 mls	22 gms	14.0 b-e	6.6 cde	4.5 efg	5.1 cd	0.8 f	2.0 cd	5.5 hi

significantly more ERM than the control. In general, the same was true for reduced rates of azinphosmethyl (0.2X & 0.1X), carbaryl (0.2X) and diflubenzuron (0.1X & 0.2X) alone or admixed with microbial insecticides. However, the mite densities in these treatments were always slightly higher than that of control from beginning through end of the season. Similarly, the seasonal mean ERM counts in these treatments were slightly higher than those of control and microbial insecticides. Accordingly, 1.0X of diflubenzuron and 0.1-0.2X reduced rates of azinphosmethyl, carbaryl and diflubenzuron alone or in combination with Dipel or MVP had slight or no affect on ERM population when applied two times per codling moth generation. Counts of ERM were generally lower with the microbial insecticides-azinphosmethyl/carbaryl mixtures than with corresponding chemical insecticide treatments applied at their full rates and all esfenvalerate treatments. Microbial insecticides, Dipel at 0.5 - 1.5X and MVP at 0.5-1.0X had no effect on ERM populations.

Results with YSM was similar to that of ERM. Microbial insecticides at different rates and diflubenzuron at 1.0X had no effect on YSM population throughout the growing season (Table 6.23). Similar results were obtained for carbaryl (0.2X) and azinphosmethyl (0.1X), and their mixtures with microbial insecticides. Azinphosmethyl at 0.2X alone and in mixtures did not show any effect until early part of August, when YSM population in most treatments reached the maximum (Table 6.23). The counts of this mites rapidly built up on trees treated with full rates of azinphosmethyl and carbaryl after July 8 and July 24, respectively. In general, pyrethroid esfenvalerate at full-rates and at 0.1X and 0.2X alone or in mixtures caused a outbreak of this mite throughout the season. Like with ERM, YSM population abundance on trees treated with this pyrethroid at 0.1X alone or admixed with microbial insecticides usually was not as large as that of trees treated with higher rates (1.0X and 0.2X applied alone or in mixtures) ($P \leq 0.05$).

Data (Table 6.24) show that apple rust mite (ARM) counts were maximum early in the season (late June - mid July in different treatments), although the ARM population varied from treatment to treatment, and did not show a definite trend.

Table 6.24: Effects of seasonal applications of chemical and microbial insecticides and their mixtures on apple rust mite (ARM). Mean number (back-transformed) of ARM (per leaf in sequential samples (20 leaves/replication) from late-June to early-September, 1993.

Treatment	Insecticide rate/100 liters		Sampling date						Seasonal Mean
	Microbial	Chemical	June 24	July 8	July 24	August 8	August 23	September 7	
Control	-	-	323.90 abc	63.41 f-h	28.80 gh	38.75 def	21.50 efg	15.65 b-f	82.0 e-i
Dipel 2X (Bacterial)	50 MIU	-	141.00 e-h	107.63 c-f	74.03 c-f	66.53 b-e	20.14 efg	3.11 def	68.7 ghi
Dipel 2X	100 MIU	-	403.95 ab	212.58 a	46.18 fgh	38.17 def	44.27 d-g	4.75 c-f	125.0 a-d
Dipel 2X	150 MIU	-	223.16 cde	113.39 b-f	41.98 fgh	26.72 def	16.02 fg	4.59 c-f	71.0 f-i
MVP (Bacterial)	125 mls	-	340.57 abc	24.23 h	22.00 h	27.46 def	10.88 g	4.59 c-f	71.6 f-i
MVP	250 mls	-	209.96 c-f	137.57 a-e	109.81 bcd	60.52 b-f	9.50 g	2.58 ef	88.3 d-h
Guthion 50WP (Azinphosmethyl)		50 gms	350.90 abc	130.69 a-e	140.79 abc	116.23 ab	90.07 a-d	41.27 ab	145.0 ab
Guthion 50WP	-	10 gms	181.77 d-g	171.01 a-d	178.77 ab	46.06 c-f	48.90 c-f	11.18 b-f	106.3 a-g
Guthion 50WP	-	05 gms	317.89 abc	163.70 a-d	225.36 a	81.66 a-d	59.60 cde	1.96 f	141.7 abc
Dipel, Guthion	100 MIU	10 gms	95.70 gh	221.45 a	166.47 ab	78.89 a-d	52.24 cde	37.37 ab	108.7 a-f
Dipel, Guthion	100 MIU	05 gms	136.12 e-h	34.17 h	72.87 c-f	29.97 def	24.28 efg	14.74 b-f	52.0 i
MVP, Guthion	250 mls	10 gms	452.33 a	63.41 f-h	96.51 b-f	25.63 def	8.77 g	3.86 def	108.4 a-f
Asana XL (Esfenvalerate)		30 mls	161.54 e-h	105.81 c-f	109.51 bcd	56.48 b-f	59.57 cde	10.34 b-f	83.9 e-i
Asana XL	-	06 mls	96.16 gh	41.14 gh	132.43 abc	60.58 b-f	86.47 bcd	25.14 bc	73.7 f-i
Asana XL	-	03 mls	260.11 b-e	190.91 abc	140.61 abc	147.91 a	115.03 abc	31.62 ab	147.7 a
Dipel, Asana	100 MIU	06 mls	82.38 h	99.52 d-g	138.63 abc	115.84 ab	140.33 ab	71.51 a	108.0 a-f
Dipel, Asana	100 MIU	03 mls	106.83 fgh	185.29 abc	107.11 b-e	118.70 ab	169.63 a	36.20 ab	120.6 a-e
Sevin 50W (Carbaryl)		120 gms	77.40 h	41.03 gh	132.92 abc	80.02 a-d	96.82 a-d	19.75 b-e	74.7 f-i
Sevin 50W	-	024 gms	178.29 d-g	73.62 e-h	40.54 fgh	119.46 ab	12.64 g	16.72 b-f	73.5 f-i
Dipel, Sevin	100 MIU	024 gms	143.64 e-h	134.77 a-e	22.50 h	38.19 def	8.62 fg	14.14 b-f	60.3 hi
MVP, Sevin	250 mls	024 gms	205.11 c-f	95.07 d-g	63.34 d-h	77.22 a-d	37.36 d-g	31.74 ab	85.0 d-i
Dimilin 25W (Diflubenzuron)		44 gms	73.24 h	135.56 a-e	216.34 a	106.98 abc	58.31 cde	19.34 b-f	101.6 b-g
Dimilin 25W	-	22 gms	95.63 gh	160.31 a-d	85.42 c-f	38.21 def	17.80 efg	16.93 b-f	69.0 ghi
Dimilin 25W	-	11 gms	192.43 d-g	204.00 ab	105.59 b-e	18.69 f	52.00 c-f	22.39 bcd	99.2 c-g
Dipel, Dimilin 25W	100 MIU	11 gms	148.17 e-h	191.98 abc	62.79 d-h	30.40 def	38.67 d-g	14.70 b-f	81.1 e-i
MVP, Dimilin 25W	100 MIU	22 gms	152.72 e-h	73.57 e-h	58.36 d-h	21.05 ef	26.95 efg	12.49 b-f	57.5 hi

Table 6.25: Effects of seasonal applications of chemical and microbial insecticides and their mixtures on all phytoseiids. Mean number (back-transformed) of individuals per 10 leaves in sequential samples (20 leaves/replication) from late- June to early-September, 1993.

Treatment	Insecticide rate/100 liters		Sampling date												Seasonal mean	
	Microbial	Chemical	June 24		July 8		July 24		August 8		August 23		September 7			
Control	-	-	9.6	a-d	6.6	b-f	9.3	abc	6.5	b-f	9.3	ab	8.3	abc	8.3	ab
Dipel 2X (Bacterial)	50 MIU	-	6.4	cde	7.5	b-e	7.6	bcd	5.4	d-g	5.3	b-e	7.1	a-e	6.6	ab
Dipel 2X	100 MIU	-	10.6	abc	9.2	abc	5.5	cde	4.3	fg	3.9	c-g	4.7	d-g	6.4	ab
Dipel 2X	150 MIU	-	8.6	bcd	10.3	ab	5.6	cde	6.0	c-g	7.6	abc	4.8	d-g	7.1	ab
MVP (Bacterial)	125 mls	-	13.3	ab	4.2	d-j	5.3	cde	4.0	g	5.9	a-e	5.2	c-g	6.3	ab
MVP	250 mls	-	10.0	abc	10.3	ab	6.4	b-e	9.0	ab	9.4	ab	4.7	d-g	8.3	ab
Guthion 50WP (Azinphosmethyl)		50 gms	3.4	e-h	2.9	f-j	4.5	de	3.9	g	3.4	e-h	3.0	fgh	3.5	cd
Guthion 50WP	-	10 gms	5.5	c-f	5.5	b-g	5.7	cde	7.4	bcd	4.3	c-f	5.6	c-g	5.7	bc
Guthion 50WP	-	05 gms	7.6	cde	3.7	e-j	4.8	de	5.6	d-g	9.8	a	5.9	cde	6.2	b
Dipel, Guthion	100 MIU	10 gms	5.2	c-f	5.6	b-g	7.3	bcd	4.4	fg	7.1	a-d	6.3	cde	6.0	b
Dipel, Guthion	100 MIU	05 gms	9.4	a-d	4.9	c-h	4.7	de	6.5	b-f	5.5	a-e	4.2	efg	5.9	b
MVP, Guthion	250 mls	10 gms	15.1	a	5.2	b-h	4.9	cde	4.4	fg	6.2	a-e	6.3	cde	7.0	ab
Asana XL (Esfenvalerate)		30 mls	0.7	gh	0.0	l	0.0	g	0.2	i	0.0	j	0.5	i	0.2	g
Asana XL	-	06 mls	0.0	h	0.0	l	0.3	g	0.3	i	0.5	j	0.9	i	0.3	g
Asana XL	-	03 mls	4.7	d-g	1.6	i-l	0.6	fg	0.9	hi	2.1	f-i	1.0	hi	1.8	def
Dipel, Asana	100 MIU	06 mls	3.1	e-h	1.4	jkl	0.3	g	0.0	i	0.6	ij	0.3	i	0.9	efg
MVP, Asana	250 mls	06 mls	0.9	gh	0.3	kl	0.3	g	0.3	i	0.9	ij	1.3	hi	0.6	fg
MVP, Asana	250 mls	03 mls	3.4	e-h	1.5	i-l	2.8	ef	2.0	h	1.0	hij	1.6	hi	2.1	de
Dipel, Asana	100 MIU	03 mls	5.8	c-f	1.7	h-l	4.0	de	0.8	hi	1.4	g-j	3.0	fgh	2.8	d
Sevin 50W (Carbaryl)		120 gms	1.9	fgh	2.5	g-k	1.3	fg	0.7	i	3.7	d-g	2.9	gh	2.2	de
Sevin 50W	-	024 gms	8.1	bcd	9.5	abc	10.6	ab	4.9	d-g	7.1	a-d	10.1	ab	8.4	ab
Dipel, Sevin	100 MIU	024 gms	6.3	cde	6.0	b-g	11.1	ab	5.4	d-g	5.4	b-e	7.4	a-e	6.9	ab
MVP, Sevin	250 mls	024 gms	7.0	cde	8.7	b-e	14.9	a	7.0	b-e	6.0	a-e	10.8	a	9.1	a
Dimilin 25W (Diflubenzuron)		44 gms	5.7	c-f	6.6	b-f	6.4	b-e	5.4	d-g	6.3	a-e	5.6	c-g	6.0	b
Dimilin 25W	-	22 gms	6.4	cde	9.6	abc	6.5	bcd	8.6	abc	6.4	a-e	7.5	a-d	7.5	ab
Dimilin 25W	-	11 gms	6.8	cde	4.7	c-i	5.8	cde	10.6	a	6.0	a-e	4.6	d-g	6.4	ab
Dipel, Dimilin 25W	100 MIU	22 gms	5.2	c-f	6.7	b-f	6.3	b-e	5.0	d-g	4.3	c-f	6.4	b-e	5.7	bc
Dipel, Dimilin 25W	100 MIU	11 gms	7.0	cde	15.6	a	7.4	bcd	4.7	e-g	5.2	b-e	5.8	c-f	7.6	ab
MVP, Dimilin 25W	250 mls	22 gms	5.5	cf	6.5	b-f	4.5	de	4.0	g	7.7	abc	5.9	cde	5.7	bc

Comparison of seasonal mean densities in different treatments indicates a significant ARM buildup on trees treated with full rate of azinphosmethyl. The same was true with 0.2X of azinphosmethyl and 0.1X of esfenvalerate, both applied alone or when mixed with microbial insecticides.

Effect on Predatory Mites:

During 1993, *Z. mali* population was scarce. Table 6.25 and 6.26 represent the effect of different microbial and chemical insecticides and their mixtures on *T. pyri* and other phytoseiids during the study period of 24 June - 7 September, 1993. Insect growth regulator diflubenzuron and microbial insecticides Dipel and MVP did not affected counts of *T. pyri* and other phytoseiids throughout the study period. The seasonal abundance of *T. pyri* and other phytoseiids on trees treated with these insecticides at full- or reduced-rates, was as great as that of control. It is, therefore, assumed that these insecticides were harmless to *T. pyri* and other phytoseiids.

Azinphosmethyl and carbaryl at low rate (0.1 X) alone and admixed with Dipel and MVP (1.0X) were harmless to *T. pyri* and other phytoseiids (Tables 6.25 & 6.26) . These insecticides at 1.0X, however, were detrimental. Azinphosmethyl curtailed 44% of *T. pyri* and 42% of total phytoseiid populations as compared with that of control. Carbaryl was slightly more toxic with corresponding 30% and 26% reduction. Hence, according to IOBC (Hassan *et al.* 1987), both azinphosmethyl and carbaryl at full rate were moderately harmful to *T. pyri* and total phytoseiid populations (Hassan *et al.* 1987).

Esfenvalerate at full- and reduced-rate alone or combined with Dipel and MVP significantly ($P<0.05$) lessened the mean numbers of *T. pyri* and other phytoseiids during most of the study period. There was more survival of *T. pyri* and other phytoseiids on trees treated with esfenvalerate at 0.1X alone or in combination with microbial insecticides. This insecticide at higher rates of 1.0X and 0.2X proved to be equally toxic to phytoseiids in general and *T. pyri* in particular. Correspondingly,

Table 6.26: Effects of seasonal applications of chemical and microbial insecticides and their mixtures on *T. pyri.* Mean number (back-transformed) of individuals per 10 leaves in sequential samples (20 leaves/ replication) from late-June to early-September, 1993.

Treatment	Insecticide rate/100 liters		Sampling date						Seasonal Mean
	Microbial	Chemical	June 24	July 8	July 24	August 8	Aug. 23	Sept. 7	
Control	-	-	7.2 abc	5.0 a-e	6.3 bcd	5.7 ab	3.8 a-d	5.0 bcd	5.5 abc
Dipel 2X (Bacterial)	50 MIU	-	3.9 c-h	7.0 a-d	4.0 def	3.8 b-e	4.0 a-d	3.3 c-g	4.3 a-e
Dipel 2X	100 MIU	-	5.4 b-e	6.0 a-d	4.3 c-f	3.3 c-f	1.6 d-h	2.7 e-h	4.2 a-f
Dipel 2X	150 MIU	-	6.3 a-d	8.6 ab	3.6 def	3.6 cde	2.8 a-f	2.0 ghi	4.3 a-e
MVP (Bacterial)	125 mls	-	9.7 a	3.6 d-g	3.7 def	3.6 cde	2.4 c-g	2.9 d-h	3.6 b-f
MVP	250 mls	-	8.0 ab	8.3 ab	4.5 def	6.2 a	4.8 ab	3.5 c-g	5.7 ab
Guthion 50WP (Azinphosmethyl)		50 gms	2.4 e-i	0.8 hi	3.2 efg	1.9 fgh	2.6 b-g	2.4 e-i	2.4 e-i
Guthion 50WP	-	10 gms	4.5 b-g	4.3 c-h	4.7 c-f	3.3 c-f	2.7 a-f	3.3 c-g	2.8 d-i
Guthion 50WP	-	05 gms	4.2 b-h	3.6 d-g	3.7 def	3.5 c-f	3.8 a-d	2.9 d-h	3.2 b-h
Dipel, Guthion	100 MIU	10 gms	5.9 a-d	3.7 d-g	4.2 c-f	4.9 abc	2.5 c-g	3.1 d-h	3.5 b-g
Dipel, Guthion	100 MIU	05 gms	2.2 f-i	4.5 b-f	4.8 c-f	3.0 d-g	1.5 f-i	3.3 c-g	3.2 b-h
MVP, Guthion	250 mls	10 gms	4.9 b-f	5.0 a-e	4.0 def	4.2 a-e	4.0 a-d	3.7 b-f	3.5 b-f
Asana XL (Esfenvalerate)		30 mls	0.2 j	0.0 i	0.0 i	0.1 i	0.0 j	0.3 jk	0.1 m
Asana XL	-	06 mls	0.0 j	0.0 i	0.3 i	0.3 i	0.5 hij	0.0 k	0.2 lm
Asana XL	-	03 mls	1.9 ghi	1.6 f-i	0.9 hi	0.6 hi	1.0 g-j	1.0 ijk	1.3 i-l
Dipel, Asana	100 MIU	06 mls	2.3 e-i	0.5 hi	0.3 i	0.0 i	0.3 ij	0.3 jk	0.7 j-m
MVP, Asana	250 mls	06 mls	0.6 ij	0.3 hi	0.3 i	0.3 i	0.6 hij	1.0 ijk	0.5 klm
MVP, Asana	250 mls	03 mls	1.6 hij	1.4 ghi	2.1 fgh	1.6 gh	0.4 hij	1.3 hij	1.4 h-k
Dipel, Asana	100 MIU	03 mls	4.8 b-f	1.4 ghi	3.1 efg	0.5 hi	0.1 j	2.9 d-h	2.1 f-j
Sevin 50W (Carbaryl)		120 gms	1.7 ghi	2.3 e-h	1.3 ghi	0.7 hi	1.4 f-i	2.1 f-i	1.6 g-k
Sevin 50W	-	024 gms	6.7 a-d	6.8 a-d	8.6 ab	3.6 cde	5.0 a	6.0 ab	6.1 a
Dipel, Sevin	100 MIU	024 gms	5.0 b-f	4.5 b-f	7.4 abc	2.5 efg	4.4 abc	5.4 bc	4.9 a-d
MVP, Sevin	250 mls	024 gms	5.6 a-d	3.6 d-g	10.7 a	4.7 a-d	3.5 a-e	9.0 a	6.2 a
Dimilin 25W (Diflubenzuron)		44 gms	3.2 d-h	5.0 a-e	3.8 def	3.4 c-f	2.2 d-g	3.6 b-g	3.5 b-f
Dimilin 25W	-	22 gms	4.3 b-h	7.9 abc	5.0 b-e	4.1 a-e	2.2 d-g	4.3 b-e	4.7 a-d
Dimilin 25W	-	11 gms	3.9 c-h	4.0 c-g	4.5 c-f	5.0 abc	4.0 a-d	3.1 c-g	4.1 a-f
Dipel, Dimilin 25W	100 MIU	22 gms	3.4 d-h	5.3 a-e	4.3 c-f	3.6 cde	2.7 a-f	2.8 d-h	3.7 a-f
Dipel, Dimilin 25W	100 MIU	11 gms	4.5 b-g	8.9 a	5.6 b-e	3.0 d-g	4.0 a-d	4.0 b-f	5.0 a-d
MVP, Dimilin 25W	250 mls	22 gms	4.9 b-f	6.5 a-d	3.9 def	3.6 cde	2.5 c-g	3.3 c-g	4.2 a-f

Table 6.27: Effects of seasonal applications of chemical and microbial insecticides and their mixtures on *Stethorus punctillum* and earwigs. Mean numbers (back-transformed) of individuals per sample in sequential samples during the growing season of 1993. (June and September populations based on one sample. July and August populations are averages of two samples taken biweekly. Mean = seasonal mean).

Treatment	Insecticide rate/100 liters		*S. punctillum*					Earwigs				
	Microbial	Chemical	June	July	Aug.	Sept.	Mean	June	July	Aug.	Sept.	Mean
Control	-	-	0.6	0.4	0.7	0.8	0.6 b-f	0.9	1.2	0.8	0.3	0.8 abc
Dipel 2X (Bacterial)	50 MIU	-	0.6	1.0	0.2	1.1	0.6 b-f	1.0	1.6	0.4	0.0	0.7 a-d
Dipel 2X	100 MIU	-	1.1	0.0	0.6	0.3	0.4 d-g	0.8	1.5	0.6	0.0	0.7 a-d
MVP (Bacterial)	125 mls	-	0.9	0.5	0.8	0.3	0.6 b-f	0.5	1.2	0.1	0.0	0.4 bcd
MVP	250 mls	-	0.3	0.3	0.6	0.3	0.3 d-g	0.4	0.8	0.4	0.3	0.5 a-d
Guthion 50WP (Azinphosmethyl)		50 gms	0.3	0.7	0.4	0.2	0.3 d-g	0.4	0.4	0.3	0.3	0.3 bcd
Guthion 50WP	-	10 gms	0.7	0.1	0.4	0.7	0.3 d-g	0.5	1.1	1.3	0.3	1.0 a
Guthion 50WP	-	05 gms	1.0	0.4	0.6	0.0	0.5 c-f	1.7	1.0	0.2	2.3	0.8 ab
Dipel, Guthion	100 MIU	10 gms	0.9	0.4	0.7	0.0	0.4 c-g	0.4	0.8	1.1	0.0	0.7 a-d
Dipel, Guthion	100 MIU	05 gms	1.9	0.7	1.4	1.3	1.1 abc	0.4	0.6	0.3	0.3	0.4 bcd
MVP, Guthion	250 mls	10 gms	1.6	0.7	1.9	1.0	1.1 ab	0.8	0.7	0.6	0.9	0.8 abc
Asana XL (Esfenvalerate)		30 mls	0.3	0.0	0.0	0.3	0.0 g	0.4	0.6	0.0	0.0	0.2 d
Asana XL	-	06 mls	0.7	0.2	0.1	0.0	0.2 fg	0.6	0.9	0.7	0.3	0.7 a-d
Asana XL	-	03 mls	0.6	0.3	0.3	0.0	0.2 efg	1.9	2.2	0.4	0.6	1.0 a-d
Dipel, Asana	100 MIU	06 mls	0.0	0.3	0.4	0.7	0.2 fg	0.2	0.4	0.7	0.0	0.4 a-d
Dipel, Asana	100 MIU	03 mls	0.3	0.3	0.4	0.3	0.2 efg	0.8	1.2	0.7	0.3	0.8 abc
Sevin 50W (Carbaryl)		120 gms	1.7	0.7	0.8	0.0	0.7 b-f	0.9	1.0	0.0	0.0	0.3 bcd
Sevin 50W	-	024 gms	1.2	1.0	0.9	0.8	1.0 bc	0.6	0.8	0.4	0.3	0.5 a-d
Dipel, Sevin	100 MIU	024 gms	1.0	1.1	1.2	0.6	1.0 abc	0.7	1.0	0.9	0.3	0.8 ab
MVP, Sevin	250 mls	024 gms	0.7	1.1	1.5	1.3	1.2 ab	0.5	1.1	0.4	0.3	0.6 a-d
Dimilin 25W (Diflubenzuron)		44 gms	1.4	0.3	0.2	0.3	0.4 d-g	0.6	1.1	0.2	0.3	0.5 a-d
Dimilin 25W	-	22 gms	1.1	1.5	0.6	1.0	0.8 b-e	0.4	0.6	0.0	0.3	0.3 cd
Dimilin 25W	-	11 gms	1.1	2.1	3.1	2.7	1.9 a	0.9	0.7	1.2	0.3	0.8 abc
Dipel, Dimilin	100 MIU	11 gms	2.2	1.9	2.1	4.0	2.0 a	0.7	0.9	0.5	0.6	0.7 a-d
MVP, Dimilin	100 MIU	22 gms	1.4	0.2	1.3	1.9	0.9 bcd	0.4	0.7	0.6	0.0	0.4 a-d

mixing of microbial insecticides with one-tenth to one-fifth of full rate of esfenvalerate did not mitigate its toxicity against phytoseiid species. Considering the IOBC criterion to categorize toxicity of insecticides against predators in the field (Hassan *et al.* 1987), the one-tenth rate of esfenvalerate was moderately harmful (51 - 75% mortality in orchard tests) to phytoseiids, and the one-fifth-full field rates very harmful (>75% mortality).

Effects on Predatory insects:

The effects of treatments on insect predators are summarized in Tables 6.27-6.29. Total number of most predators were usually higher on untreated trees (Table 6.29). In 1993, *Orius* spp. and *Heterotoma planicornis* were the most abundant Hemiptera, however, lace wing numbers were scare throughout the season (Table 6.28).

Data in Table 6.27 indicate that esfenvalerate usually affected seasonal mean activities of *Stethorus spp.*, mirids and *F. auricularia* on trees treated with full rate. However, 0.1X and 0.2X of this insecticides applied alone or in combination with microbial insecticides had no effect on these predator species. Among other treatments, full rates of azinphosmethyl and carbaryl significantly reduced densities of mirids without any side effect, whatsoever, on *H. planicornis*.

Data in Table 6.29 indicates that the density of total predatory insects was significantly less only on trees treated with full rate of esfenvalerate. In other treatments, the counts were as great as that of control. Microbial insecticides and diflubenzuron at different dosage were benign in their effect on predatory insects. Similarly was generally true with reduced rates (0.1X and/or 0.2X) of azinphosmethyl, carbaryl and diflubenzuron, whether applied alone or when mixed with Dipel/MVP.

Table 6.28: Effects of seasonal applications of chemical and microbial insecticides and their mixtures on predatory Hemiptera on apples. Mean number (back-transformed) of individuals per sample in sequential samples during the growing season of 1993. (June and September mean predator counts based on one sample, all others average of two samples taken biweekly)

Treatment	Insecticide rate/100 liters		*Orius spp.*					All mirids					*Heterotoma planicornis*				
	Microbial	Chemical	June	July	Aug.	Sept.	Seasonal mean	June	July	Aug.	Sept.	Seasonal mean	June	July	Aug.	Sept.	Seasonal mean
Control	-	-	1.3 a	2.0	1.9	2.3	1.9	4.1 a	1.9	1.7	1.4 a-d	2.2 ab	0.4	0.2	0.6	0.4	0.4 def
Dipel 2X	50 MIU	-	0.4 ab	1.0	0.7	0.7	0.7	2.0 abc	0.9	1.9	4.4 a	2.2 ab	1.0	0.0	0.7	1.3	0.8 b-f
Dipel 2X	100 MIU	-	0.5 ab	1.4	0.7	0.7	0.8	2.6 ab	2.8	2.2	1.1 bcd	2.1 ab	0.7	0.0	0.7	0.3	0.4 def
MVP	125 mls	-	0.5 ab	0.9	1.7	0.9	1.0	2.5 ab	2.2	1.1	1.1 bcd	1.7 bc	1.0	0.3	0.7	0.7	0.5 c-f
MVP	250 mls	-	0.9 ab	1.1	2.3	0.7	1.3	1.7 abc	1.6	1.5	1.9 abc	1.7 bc	1.0	1.3	0.3	0.3	0.8 b-f
Guthion 50WP (Azinphosmethyl)		50 gms	0.0 b	0.7	1.4	0.7	0.7	0.7 bc	0.6	1.8	0.7 cd	0.9 c	0.3	0.3	0.0	0.7	0.3 ef
Guthion 50WP	-	10 gms	1.3 ab	1.3	1.7	1.1	1.3	4.7 a	0.7	0.6	0.9 cd	1.5 bc	2.0	0.7	0.7	0.3	0.9 a-f
Guthion 50WP	-	05 gms	0.4 ab	0.7	1.5	0.7	0.8	1.7 abc	1.4	1.6	1.9 a-d	1.6 bc	1.0	1.0	0.7	1.3	1.0 a-e
Dipel, Guthion	100 MIU	10 gms	1.1 ab	0.7	1.3	1.2	1.0	0.6 bc	3.1	1.6	0.0 d	1.1 bc	0.7	1.7	0.0	0.0	0.6 b-f
Dipel, Guthion	100 MIU	05 gms	0.7 ab	1.0	1.5	1.0	1.1	2.8 ab	2.2	1.5	0.9 cd	1.8 ab	2.0	1.0	0.7	0.0	0.9 a-f
MVP, Guthion	250 mls	10 gms	0.9 ab	1.5	1.4	1.0	1.2	2.0 ab	1.5	1.9	1.5 a-d	1.7 bc	1.7	0.9	0.8	0.4	1.0 a-e
Asana XL (Esfenvalerate)		30 mls	1.1 ab	1.2	1.6	0.9	1.2	0.0 c	1.6	0.9	0.3 cd	0.6 c	0.0	0.7	0.3	0.3	0.3 ef
Asana XL	-	06 mls	0.5 ab	1.1	1.1	0.7	0.8	3.9 a	2.2	3.2	4.0 ab	3.3 a	3.0	0.3	1.3	0.0	1.2 abc
Asana XL	-	03 mls	0.7 ab	1.0	1.3	1.5	1.1	1.7 abc	1.4	4.0	0.3 cd	1.7 bc	1.7	1.7	2.0	0.0	1.3 ab
Dipel, Asana	100 MIU	06 mls	0.4 ab	1.5	1.0	1.2	1.0	2.3 ab	0.9	2.6	2.1 abc	1.9 ab	1.3	1.3	0.7	0.0	0.8 a-f
Dipel, Asana	100 MIU	03 mls	0.4 ab	1.2	1.4	0.7	0.9	1.7 abc	1.4	3.0	3.1 abc	2.3 ab	2.0	1.3	2.0	0.7	1.5 a
MVP, Asana	250 mls	06 mls	0.6 ab	1.2	1.3	1.0	1.0	1.9 abc	1.1	2.7	1.8 a-d	1.9 ab	1.6	1.1	1.5	0.4	1.2 abc
Sevin 50W (Carbaryl)		120 gms	1.0 ab	1.2	1.6	1.1	1.1	0.7 bc	1.2	0.5	1.4 a-d	0.9 c	1.0	0.0	0.3	0.7	0.5 c-f
Sevin 50W	-	024 gms	0.6 ab	1.2	1.7	1.2	1.2	2.5 ab	1.4	1.6	1.5 a-d	1.6 ab	1.4	0.9	1.0	0.4	0.9 a-f
Dipel, Sevin	100 MIU	024 gms	0.7 ab	1.1	1.3	0.9	1.0	2.2 ab	1.0	2.2	2.4 abc	1.9 ab	0.9	0.6	0.2	0.6	0.5 c-f
MVP, Sevin	250 mls	024 gms	0.5 ab	0.9	1.2	0.7	0.8	1.6 abc	1.2	1.6	1.5 a-d	1.4 bc	1.1	0.5	0.4	0.5	0.6 b-f
Dimilin 25W (Diflubenzuron)		44 gms	0.6 ab	1.0	1.2	0.7	0.9	1.1 bc	0.6	1.4	1.2 cd	1.1 bc	0.3	0.0	0.0	0.7	0.3 f
Dimilin 25W	-	22 gms	0.4 ab	0.7	0.9	1.0	0.7	0.9 bc	2.5	0.9	2.2 abc	1.5 bc	0.7	0.3	0.0	0.3	0.3 ef
Dimilin 25W	-	11 gms	0.4 ab	0.9	1.0	1.2	0.9	2.5 ab	2.5	1.9	0.9 cd	1.9 ab	1.7	1.3	0.7	0.7	1.1 a-d
Dipel, Dimilin	100 MIU	11 gms	0.4 ab	0.7	1.5	0.7	0.8	2.7 ab	1.3	1.1	1.1 bcd	1.5 bc	2.0	0.7	0.7	0.7	1.0 a-e
MVP, Dimilin	100 MIU	22 gms	0.8 ab	1.0	1.0	0.7	0.9	1.8 abc	1.7	2.0	1.3 a-d	1.6 ab	1.2	0.6	0.3	0.6	0.7 b-f

Table 6.29: Effects of seasonal applications of chemical and microbial insecticides and their mixtures on total insect predators. Mean numbers (back-transformed) of individuals per sample in sequential samples during the growing season of 1993. Monthly value = average of two samples taken biweekly.

Treatment	Insecticide rate/100 liters		Total predatory insects/sample					Spiders/sample				
	Microbial	Chemical	June	July	Aug.	Sept.	Seasonal mean	June	July	Aug	Sept.	Seasonal mean
Control	-	-	7.1	5.1	3.1	4.7	5.0 ab	2.0	3.7 ab	2.6	3.3	2.9 ab
Dipel 2X (Bacterial)	50 MIU	-	3.7	5.1	5.1	1.3	3.8 bc	1.7	1.2 a-d	1.3	2.7	1.7 abc
Dipel 2X	100 MIU	-	6.3	8.6	3.9	1.3	5.0 ab	1.4	1.1 bcd	1.9	2.7	1.8 abc
MVP (Bacterial)	125 mls	-	7.0	6.0	3.7	0.0	4.2 abc	0.5	1.3 a-d	1.6	4.7	2.0 abc
MVP	250 mls	-	4.4	4.7	3.5	0.0	3.1 bc	0.9	1.7 a-d	2.3	2.0	1.7 abc
Guthion 50WP (Azinphosmethyl)		50 gms	5.3	6.4	3.8	2.7	4.5 ab	0.5	0.7 d	1.2	1.3	0.9 c
Guthion 50WP	-	10 gms	5.0	2.2	4.4	2.3	3.5 bc	0.3	1.9 a-d	1.3	0.3	1.1 bc
Guthion 50WP	-	05 gms	5.0	6.5	7.3	4.0	5.7 a	0.5	0.3 d	2.0	1.7	1.2 bc
Dipel, Guthion	100 MIU	10 gms	4.4	7.2	5.5	2.3	4.9 ab	0.9	3.0 abc	1.3	0.7	1.5 abc
Dipel, Guthion	100 MIU	05 gms	4.9	5.6	5.2	2.8	4.6 ab	1.1	4.2 a	2.9	1.0	2.3 abc
MVP, Guthion	250 mls	10 gms	5.5	4.1	6.7	3.9	5.0 ab					
Asana XL (Esfenvalerate)		30 mls	1.9	1.1	3.7	0.7	1.8 c	0.0	0.3 d	1.9	0.3	0.6 c
Asana XL	-	06 mls	5.3	2.8	4.1	0.0	3.0 bc	0.3	1.1 a-d	1.1	2.0	1.1 bc
Asana XL	-	03 mls	6.3	2.8	3.2	1.7	3.5 bc	1.2	0.6 cd	2.4	1.7	1.5 abc
Dipel, Asana	100 MIU	06 mls	3.3	1.2	5.0	2.0	3.4 bc	1.1	0.0 d	2.0	0.7	1.2 bc
Dipel, Asana	100 MIU	03 mls	2.9	2.0	5.0	0.7	3.1 bc	0.9	1.7 a-d	2.7	1.3	1.6 abc
MVP, Asana	250 mls	06 mls	4.0	3.1	6.8	2.5	4.1 abc	0.4	0.8 cd	1.5	1.1	1.1 bc
Sevin 50W (Carbaryl)		120 gms	6.2	0.9	4.2	2.3	3.4 bc	2.6	3.6 ab	3.4	0.7	2.6 a
Sevin 50W	-	024 gms	5.5	2.0	3.1	3.7	3.6 bc	1.7	2.0 a-d	2.7	0.9	1.8 abc
Dipel, Sevin	100 MIU	024 gms	2.5	0.5	4.5	4.6	3.0 bc	1.4	3.1 abc	2.7	1.7	2.2 abc
MVP, Sevin	250 mls	024 gms	3.7	4.4	6.3	8.2	5.6 ab	0.8	1.1 a-d	1.4	1.0	1.4 abc
Dimilin 25W (Diflubenzuron)		44 gms	5.2	3.0	3.6	1.7	3.4 bc	0.9	1.6 a-d	2.0	1.0	1.5 abc
Dimilin 25W	-	22 gms	3.6	7.1	6.0	2.0	4.7 ab	0.3	1.1 bcd	1.5	1.7	1.2 bc
Dimilin 25W	-	11 gms	5.5	5.0	6.4	3.3	5.1 ab	0.3	1.6 a-d	2.3	1.7	1.6 abc
Dipel, Dimilin	100 MIU	11 gms	5.2	7.2	6.9	3.7	5.7 a	0.7	1.7 a-d	1.6	1.0	1.4 abc
MVP, Dimilin	100 MIU	22 gms	7.0	2.2	4.3	6.0	4.9 ab	2.1	1.4 a-d	1.8	1.7	1.8 abc

Effects on Araneida:

In 1993, the most common spider species were *Metaphidippus aeneolus* (30.73%), *Cheircanthium inclusum* (17.41%), *Eris marginata* (10.30%), *Spirembolus mundus* (3.79%), *Theridion lawrencei* (6%), *Philodromus spectabilis* (5.5%) and *Philodromus spectabilis* (5.75%) (Table 6.4) . Seasonal mean numbers in Table 6.29 show that azinphosmethyl at 1.0X and esfenvalerate at 1.0X and 0.2 X when applied alone significantly reduced the spider population below that of control. However, mixtures of 0.2X reduced dose of esfenvalerate with 1.0X of Dipel/MVP were safe for these predators. Carbaryl, diflubenzuron and microbial insecticides whether applied at full or reduced rates had no effect on spider activities on treated trees. The reduced rates of carbaryl (0.2X) and diflubenzuron (0.2-0.5X) mixed with microbial insecticides did not produce any ill effect on spider densities. The same was true for reduced rates of azinphosmethyl applied separate or in mixtures with microbial insecticides.

Trial 2

This experiment was performed on apple plantation located about 200 meters apart from that of Trial 1. In this trial, effect of different application frequencies (6 versus 4) on mites and beneficial arthropods were determined.

Effects on Phytophagous Mites:

Table 6.30 and 6.31 indicate that population of predominant phytophagous species, YSM and ERM, was negligible on the control trees. Azinphosmethyl at 1.0X, applied four times/season and Dipel-esfenvalerate mixtures applied 4 or 6 times/season induced significant buildup of ERM and YSM. Lower application frequency (4 times/season) of Dipel-esfenvalerate mixture resulted in essentially lower population

Table 6.30: Effect of different seasonal spraying rates (4 versus 6) of Dipel-chemical insecticide mixtures on the European red mite (ERM) in 1993 (Trial 2).

Treatment	Insecticide rate/100 liters		Sprays per season	Sampling date						Seasonal average
	Microbial	Chemical		June 25	July 9	July 25	August 9	August 24	September 8	
Control	-	-	-	0.2 c (0.2)	0.1 e (0.1)	1.2 c (1.2)	2.1 de (1.9)	2.5 e (2.3)	1.7 d (1.6)	1.3 d (1.3)
Guthion	-	50 gm	4	1.2 abc (1.1)	5.9 a (4.2)	5.3 bc (4.9)	14.1 bc (12.2)	12.1 cd (9.0)	11.9 c (11.2)	8.4 c (7.1)
Guthion, Dipel	100 MIU	10 gm	4	1.1 abc (0.9)	0.3 de (0.3)	0.4 c (0.3)	1.0 de (0.9)	3.8 de (3.2)	1.4 d (1.2)	1.3 d (1.1)
Guthion, Dipel	100 MIU	10 gm	6	1.8 ab (1.6)	1.8 bcd (1.8)	4.1 bc (3.6)	7.1 cde (6.4)	10.8 cd (9.9)	5.0 cd (4.5)	5.1 cd (4.6)
Asana, Dipel	100 MIU	03 ml	4	2.9 a (2.8)	3.2 ab (2.0)	18.8 a (12.8)	68.2 a (58.2)	135 a (76.0)	177 a (162.1)	67.5 a (52.3)
Asana, Dipel	100 MIU	03 ml	6	0.7 bc (0.6)	2.5 bc (2.2)	9.6 b (8.4)	22.6 b (19.6)	97 b (54.8)	112 b (110.6)	40.9 b (32.7)
Sevin, Dipel	100 MIU	24 gm	4	0.2 c (0.2)	0.7 cde (0.6)	0.4 c (0.2)	0.8 e (0.7)	8.3 cde (7.3)	1.8 d (1.4)	2.0 cd (1.7)
Sevin, MVP	100 MIU	24 gm	6	1.1 abc (1.1)	2.2 bc (1.8)	3.6 bc (2.8)	8.0 cd (6.6)	16.9 c (14.7)	5.4 cd (4.6)	6.2 cd (5.3)
Dimilin, Dipel	100 MIU	22 gm	4	0.9 bc (0.9)	0.6 cde (0.6)	0.4 c (0.4)	1.8 de (1.6)	2.8 e (2.6)	1.9 cd (1.7)	1.4 d (1.3)
Dimilin, Dipel	100 MIU	22 gm	6	1.5 abc (1.4)	1.7 bcd (1.6)	5.2 bc (4.7)	3.5 de (2.9)	7.6 cde (5.8)	4.5 cd (3.3)	4.0 cd (3.2

Eggs counts are given in parenthesis. Means in a column followed by same letter are not significantly different at P=0.05 level.

Table 6.31. Effect of different seasonal spraying rates (4 versus 6) of Dipel-chemical insecticide mixtures on yellow spider mite on apples.

Treatment	Insecticide rate/100 liters		Sprays per season	Sampling date						Seasonal average
	Microbial	Chemical		June 25	July 9	July 25	August 9	August 24	September 8	
Control	-	-	-	0.0	0.6	1.1 b	0.5 d	0.3 d	0.6 c	0.5 f
Guthion	-	50 gm	4	3.9	0.9	9.4 ab	7.1 ab	11.9 c	8.6 bc	6.3 c
Guthion, Dipel	100 MIU	10 gm	4	0.9	0.3	0.7 b	0.6 cd	0.5 d	1.6 c	0.7 f
Guthion, Dipel	100 MIU	10 gm	6	1.2	0.0	1.1 b	4.6 bc	7.6 c	2.9 c	2.4 de
Asana, Dipel	100 MIU	03 ml	4	1.1	1.8	17.7 a	13.9 a	89.4 a	45.1 a	19.5 a
Asana, Dipel	100 MIU	03 ml	6	3.8	2.7	11.7 ab	13.6 a	43.8 b	22.2 ab	13.6 b
Sevin, Dipel	100 MIU	24 gm	4	0.3	0.6	2.0 ab	1.0 cd	1.0 d	1.0 c	0.9 ef
Sevin, MVP	100 MIU	24 gm	6	1.9	0.9	1.7 b	5.5 bc	9.6 c	1.9 c	3.1 d
Dimilin, Dipel	100 MIU	11 gm	4	1.0	0.0	0.9 b	1.0 cd	0.0 d	1.9 c	0.7 f
Dimilin, Dipel	100 MIU	11 gm	6	0.3	0.7	0.3 b	0.6 cd	0.6 d	0.0 c	0.4 f

Means in a column followed by same letter are not significantly different at P=0.05 level.

densities of these mites. Their populations built up rapidly during the month of August in the both treatments. ERM population reached damaging levels beginning from early-August on trees sprayed at higher frequency and from mid-August on trees sprayed otherwise. In these treatments, YSM approached economic threshold late in the season only (Table 6.31). With this mite species, no significant difference was found at lower or higher frequency of application until late-August, when a sharp increase in the population occurred (Table 6.31). Afterwards, apparently higher YSM population was associated with higher application rate. Though higher application frequency of mixtures of Dipel with azinphosmethyl or carbaryl yielded numerically higher population densities of ERM and YSM, the results were statistically significant only for YSM. However, Dipel-diflubenzuron mixture applied four or six times/season had no affect on either species. Trees receiving higher application frequency (6 time/season) of Dipel-carbaryl/ diflubenzuron mixtures had level of ARM similar to that of control (Table 6.32). On the other hand, increased application frequency (6 time/season) of Dipel-azinphosmethyl/esfenvalerate mixture resulted in significant rise of this mite.

Effect on Tydeids:

Seasonal averages show that both lower and higher application rate of mixtures of Dipel with azinphosmethyl, carbaryl or diflubenzuron had no effect on tydeids (Table 6.33). However, Dipel-esfenvalerate mixture applied at either rate was harmful to this fungivore mite.

Effect on Predatory mites:

Data in Tables 6.34 and 6.35 show that increased application frequency of Dipel-esfenvalerate mixtures significantly reduced *T. pyri* and total phytoseiid populations on the treated trees. The same was generally true for the Dipel-carbaryl mixture against total phytoseiid with apparently no effect on *T. pyri*. These predator, however, were not affected by Dipel-azinphosmethyl/diflubenzuron mixtures at increased application rate (6 vs. 4 applications/season). Therefore, in this trial, Dipel-

azinphosmethyl /diflubenzuron mixtures applied 4 or 6 times per season were benign in their effects on phytoseiids.

Effect on Beneficial Arthropods:

Results given in Table 6.36 suggest that significantly lower populations ($P<0.05$) of predatory insects and spiders were associated with trees receiving more applications (6 seasonal) of Dipel-esfenvalerate mixture than that of control. However, at lower rate, there was no effect. Other mixtures applied four or six times did not affect these predators throughout the growing period.

Table 6.32. Effect of different seasonal spraying rate (4 versus 6) of Dipel-chemical insecticide mixtures on apple rust mite (ARM) in 1993 (Trial 2).

Treatment	Insecticide rate/100 liters		Sprays per season	Sampling date						Seasonal average
	Microbial	Chemical		June 25	July 9	July 25	August 9	August 24	September 8	
Control	-	-	-	7.1 d	14.6 d	14.3 cd	9.2 cd	2.4 cde	3.9 d	7.9 d
Guthion	-	50 gm	4	28.4 a	65.5 a	82.0 a	75.2 a	48.0 a	40.4 b	54.8 a
Guthion, Dipel	100 MIU	10 gm	4	19.0 abc	24.2 cd	6.6 d	21.3 bc	3.1 cde	8.6 cd	12.4 cd
Guthion, Dipel	100 MIU	10 gm	6	23.0 ab	28.2 bcd	18.3 cd	19.7 bc	5.3 bc	15.4 c	17.5 c
Asana, Dipel	100 MIU	03 ml	4	17.6 a-d	47.3 abc	63.4 ab	53.9 a	23.1 ab	89.6 a	45.5 a
Asana, Dipel	100 MIU	03 ml	6	9.7 bcd	28.9 bcd	33.3 bc	26.5 b	12.6 ab	64.7 a	26.7 b
Sevin, Dipel	100 MIU	24 gm	4	9.9 bcd	17.0 d	20.1 cd	28.4 b	0.9 de	4.2 d	11.2 de
Sevin, MVP	100 MIU	24 gm	6	8.0 cd	31.1 a-d	11.2 d	9.1 cd	0.6 e	3.5 d	8.4 d
Dimilin, Dipel	100 MIU	11 gm	4	19.2 abc	37.7 a-d	9.2 d	3.9 d	6.0 b	3.5 d	11.0 d
Dimilin, Dipel	100 MIU	11 gm	6	26.0 a	61.5 ab	14.7 cd	6.6 d	4.3 cde	3.2 d	15.1 cd

Means in a column followed by same letter are not significantly different at P=0.05 (FPLSD)

Table 6.33: Effect of different application rates (4 versus 6) of Dipel-chemical insecticides mixtures on tydeids in 1993 (Trial 2).

Treatment	Insecticide rate/100 liters		Sprays per season	Tydeids/10 leaves				Seasonal average
	Microbial	Chemical		June	July	August	September	
Control	-	-	-	0.0 b	1.9 c	3.3 bc	2.3 ab	1.2 ab
Guthion	-	50 gm	4	1.3 a	9.2 a	15.8 a	8.1 a	7.5 a
Guthion, Dipel	100 MIU	10 gm	4	0.0 b	1.7 c	3.9 bc	1.6 ab	1.1 ab
Guthion, Dipel	100 MIU	10 gm	6	0.0 b	6.7 a	8.0 ab	5.0 a	3.4 ab
Asana, Dipel	100 MIU	03 ml	4	0.0 b	0.5 c	0.6 cd	0.3 b	0.2 b
Asana, Dipel	100 MIU	03 ml	6	0.0 b	0.3 c	0.0 d	0.6 b	0.1 b
Sevin, Dipel	100 MIU	24 gm	4	0.7 ab	2.3 bc	1.9 cd	3.4 ab	1.3 ab
Sevin, MVP	100 MIU	24 gm	6	0.9 ab	2.1 bc	1.7 cd	4.4 ab	1.5 ab
Dimilin, Dipel	100 MIU	22 gm	4	0.0 b	2.5 bc	4.0 bc	5.8 a	2.2 ab
Dimilin, Dipel	100 MIU	22 gm	6	0.0 b	1.9 c	2.0 cd	2.9 ab	1.1 ab

Means in a column followed by same letter are not significantly different at P=0.05 (FPLSD)

Table 6.34: Effect of different seasonal spraying rate (4 versus 6) of Dipel-chemical insecticide mixtures on phytoseiids in 1993 (Trial 2).

Treatment	Insecticide rate/100 liters		Sprays per season	Sampling date						Seasonal average
	Microbial	Chemic		June 25	July 9	July 25	August 9	August 24	September 8	
Control	-	-	-	11.0 a	6.0 a	3.9 abc	5.3 a	7.4 a	5.7 abc	6.5 ab
Guthion	-	50 gm	4	3.6 bcd	2.9 ab	3.1 bc	1.8 abc	3.8 abc	3.4 c	3.1 d
Guthion, Dipel	100 MIU	10 gm	4	5.0 bc	4.3 ab	3.2 bc	2.7 ab	7.5 a	5.0 bc	4.6 bcd
Guthion, Dipel	100 MIU	10 gm	6	6.9 ab	7.9 a	5.9 a	2.6 ab	2.2 cd	5.3 abc	5.1 a-d
Asana, Dipel	100 MIU	03 ml	4	1.1 d	0.0 c	0.2 d	0.0 c	0.0 e	0.3 d	0.3 f
Asana, Dipel	100 MIU	03 ml	6	1.6 cd	0.9 bc	1.7 cd	1.2 bc	1.5 d	2.3 cd	1.5 e
Sevin, Dipel	100 MIU	24 gm	4	9.2 a	6.6 a	7.6 a	2.3 ab	5.3 ab	8.5 ab	6.6 ab
Sevin, MVP	100 MIU	24 gm	6	5.6 b	5.0 a	2.7 bc	3.0 ab	3.5 bc	4.0 bc	3.9 cd
Dimilin, Dipel	100 MIU	22 gm	4	10.3 a	6.6 a	5.3 a	4.6 a	5.2 ab	11.1 a	7.2 a
Dimilin, Dipel	100 MIU	22 gm	6	7.5 ab	7.0 a	5.0 ab	3.4 ab	4.3 abc	8.1 ab	5.9 abc

Means in a column followed by same letter are not significantly different at P=0.05 (FPLSD)

Table 6.35. Effect of different seasonal spraying rate (4 versus 6) of Dipel-chemical insecticide mixtures on *T. pyri.* in 1993 (Trial 2).

Treatment	Insecticide rate/100 liters		Sprays per season	Sampling date						Seasonal average
	Microbial	Chemic		June 25	July 9	July 25	August 9	August 24	September 8	
Control	-	-	-	5.0 a	4.4 a	1.8 bc	5.0 a	4.9 a	4.3 bc	4.2 abc
Guthion	-	50 gm	4	1.1 c	0.6 bc	2.6 ab	1.5 abc	3.5 a	3.4 bc	2.1 d
Guthion, Dipel	100 MIU	10 gm	4	3.6 ab	4.3 a	2.2 ab	1.9 abc	2.2 a	4.5 b	3.1 cd
Guthion, Dipel	100 MIU	10 gm	6	5.3 a	3.2 ab	2.6 ab	1.9 abc	2.2 ab	3.9 bc	3.2 cd
Asana, Dipel	100 MIU	03 ml	4	0.7 c	0.0 c	0.2 c	0.0 c	0.0 b	0.0 d	0.1 f
Asana, Dipel	100 MIU	03 ml	6	1.1 c	0.3 c	1.0 bc	0.7 c	0.0 b	1.4 c	0.8 e
Sevin, Dipel	100 MIU	24 gm	4	5.8 a	6.7 a	3.6 a	0.9 bc	1.9 b	4.5 b	3.9 bc
Sevin, MVP	100 MIU	24 gm	6	3.8 ab	3.5 ab	2.4 ab	2.0 abc	3.5 a	4.0 bc	3.2 cd
Dimilin, Dipel	100 MIU	11 gm	4	6.3 a	5.0 a	2.9 ab	3.9 ab	3.9 a	11.1 a	5.5 a
Dimilin, Dipel	100 MIU	11 gm	6	5.2 a	4.2 a	4.6 a	1.1 bc	4.0 a	8.1 ab	4.5 ab

Means in a column followed by same letter are not significantly different at P=0.05 (FPLSD)

Table 6.36. Effect of different application rates (4 versus 6) of Dipel-chemical insecticides mixtures on insect predators and spiders in 1993 (Trial 2).

Treatment	Insecticide rate/100 liters		Sprays per season	Total insect predators				Seasonal average	Spiders				Seasonal average
	Microbial	Chemical		June	July	August	September		June	July	August	Sept.	
Control	-	-	-	0.3 c	1.7	1.7	0.8 ab	1.5 ab	0.5	3.9	4.3	1.6	2.9 ab
Guthion	-	50 gm	4	2.3 a	0.3	0.3	0.4 bcd	0.8 cde	3.0	0.6	2.5	1.1	2.1 a-d
Guthion, Dipel	100 MIU	10 gm	4	1.6 ab	2.2	2.0	1.4 a	2.1 a	1.9	2.2	5.0	2.1	3.3 a
Guthion, Dipel	100 MIU	10 gm	6	1.9 a	0.6	1.3	0.7 bc	1.2 bcd	1.9	1.7	2.0	0.9	2.1 a-d
Asana, Dipel	100 MIU	03 ml	4	0.6 bc	1.0	1.0	0.4 bcd	0.9 b-e	0.9	1.9	1.7	0.9	1.7 bcd
Asana, Dipel	100 MIU	03 ml	6	0.3 c	0.4	0.3	0.1 d	0.4 e	0.9	0.9	0.6	0.1	0.8 d
Sevin, Dipel	100 MIU	24 gm	4	1.3 ab	1.3	1.7	0.9 ab	1.5 ab	1.4	1.2	3.3	1.1	2.3 abc
Sevin, MVP	100 MIU	24 gm	6	0.6 bc	1.0	1.3	0.6 bc	1.1 bcd	1.6	2.2	1.9	0.9	2.0 a-d
Dimilin, Dipel	100 MIU	22 gm	4	2.0 a	0.7	1.3	0.7 bc	1.2 bcd	1.7	3.1	1.2	1.1	2.1 a-d
Dimilin, Dipel	100 MIU	22 gm	6	0.3 c	1.4	1.0	0.6 bcd	1.1 bcd	0.6	4.9	1.2	0.9	2.2 a-d

Means in a column followed by same letter are not significantly different at P=0.05 (FPLSD)

Discussion

Outbreaks of spider mites following use of many broad spectrum pesticides especially pyrethroids is well documented in the literature (AliNiazee 1984, Kapetanakis *et al.* 1986, Bostanian & Belanger 1985, Hardman *et al.* 1988, Hull & Knight 1989, Hardman *et al.* 1991, Li & Harmsen 1992). The toxicity of pyrethroids and other non-selective pesticides to the predaceous phytoseiid mites have been established (Croft & Theiling 1987). The removal of phytoseiids by pesticides is considered to be responsible for the build up of spider mite populations in many areas (Hull & Knight 1989, Hardman *et al.* 1991). *T. pyri* is one of the most important natural enemies of spider mites in apple orchards of Willamette Valley of Oregon (Hadam *et al.* 1986). In the present studies, we theorized that if suppression of *T. pyri* is a major factor in promoting increase of tetranychid mites, then we should expect counts of ERM and YSM to be higher in treatments where pyrethroid or other non-selective compounds were applied, provided that the insecticide was not toxic to spider mites. This correlation was observed in all experiments conducted during four-year study period (1990-1993). A careful review of results of present studies (Tables 6.5-6.9, 6.11, 6.13, 6.17-6.19, 6.22, 6.25, 6.26, 6.30, 6.34, 6.35) indicates that both tetranychid species, ERM and YSM, generally show secondary effects, mediated through different levels of predation in sprayed versus control trees. These results corroborate reports of similar secondary effects of pesticides on tetranychids (e.g. Hall 1979, Hull *et al.* 1985, Hardman *et al.* 1988, Li & Harmsen 1992). Nevertheless, pyrethroid insecticides may produce some sort of sublethal effects on these tetranychids (Walker & Penman 1978, Hislop *et al.* 1981, Jones & Parella 1984, Li and Harmsen 1992).

Thoughout the study period (1990-93), tetranychid (ERM and YSM) counts in control trees were below the economic threshold levels (Tables 6.5, 6.7, 6.9, 6.11, 6.13, 6.14, 6.22, 6.23, 6.30, 6.31). Bacterial insecticides (0.5-1.5X), and diflubenzuron (0.25X-1.0X) had no effect on these mites. Use of *B. thuringiensis* and

diflubenzuron in apple orchards has proved to be non-disruptive to tetranychid populations (Jaques 1965, Westigard 1979, Riedl & Hoying 1980, Westigard & Gut 1986). Throughout the growing season, tetranychid mites in trees treated with summer oil at 1 and 0.5X were similar to that of control trees. These findings are in agreement with those of Lienk (1972), and Lawson and Weires (1991).

Results of present studies show that mixtures of summer oil and diflubenzuron with Dipel or MVP did not cause tetranychid build up in the treated trees (Tables 6.5, 6.7, 6.9, 6.11, 6.13, 6.14, 6.22, 6.23, 6.30, 6.31). One mixture treatment, Dipel (1.0X) plus diflubenzuron (0.25X), applied four or six times per season, did not disrupt predator-prey interaction in the apple orchards (Tables 6.30-6.35).

Bacterial insecticides + organophosphate/carbaryl mixtures were usually associated with lower counts of ERM and YSM than corresponding full-rate insecticides treatments. Generally, the counts of tetranychids in trees sprayed with reduced rates or mixtures were statistically similar to but always higher than that of control (Tables 6.22, 6.23, 6.30, 6.31). Nevertheless, in these treatments the rate of predator mortality (especially that of *T. pyri*) was low. Past studies did not suggest any sublethal effects of organophosphate and carbaryl on fecundity/reproductive potential of these tetranychids (Hall 1979, Penman *et al.* 1981). This slight disruption of prey regulation in these treatments may be because of sublethal effects on predators which may include reduced feeding on prey, reduced oviposition, and avoidance of sprayed surface (Walker & Penman 1978, Hislop *et al.* 1981, Penman *et al.* 1981), all of which can permit temporary escape of spider mites from effective biological control.

At the dosages (0.1-1.0X) tested, neither esfenvalerate nor permethrin showed any acaricidal activity on tetranychus mites. Seasonal applications of pyrethroids, rather, caused severe outbreak of tetranychid mites at all dosages tested, applied alone or when mixed with bacterial insecticides (Tables 6.11, 6.13, 6.14, 6.22, 6.23, 6.30, 6.31). However, lower counts of ERM and YSM were associated with lower rates (0.1X) and bacterial-pyrethroid mixtures than those with corresponding full-rate insecticides. Mixtures with one-tenth field rate of pyrethroids were less disruptive of phytoseiid/tetranychid interaction than those with higher rates (0.2/0.25, 0.5X).

Higher counts of ERM and YSM on trees receiving more applications (6 versus 4 seasonal codling moth sprays) of bacterial-pyrethroid mixtures suggest that these mixtures have an additive effect in suppressing natural enemies (especially *T. pyri*) (Tables 6.30 and 6.31).

Phytophagous mite outbreaks caused by the use of pyrethroids are well documented in the literature (AliNiazee 1984, Kapetanakis *et al.* 1985, Bostanian and Belanger 1985, Hardman *et al.* 1988, Hull & Knight 1989, Hardman *et al.* 1991, Li & Harmsen 1992). In the present studies, indeed, tetranychid mites, ERM and YSM, were found to be positively associated with pyrethroid dosage and frequency of applications (Tables 6.11, 6.13, 6.14, 6.22, 6.23, 6.30, 6.31). The results show a rate response from pyrethroids, i.e., the higher the rate of pyrethroid, the greater the resurgence of ERM and YSM. Hardman *et al.* (1991) observed similar response with ERM populations. Other field studies (Hoyt *et al.* 1978, Hall 1979, Iftner & Hall1989, Hull & Knight 1989) also indicated a direct relationship between application rates of pyrethroids fenvalerate and permethrin and populations of the ERM and the twospotted spider mites, *Tetranychus urticae* Koch, after treatment. Hull and Knight (1989) found rate related responses even in the absence of predators.

Although frequently 0.1X esfenvalerate and full rates of azinphosmethyl or carbaryl had similar number and species of mite predators, higher populations of spider mites were found in esfenvalerate treated trees (Table 6.22, 6.23). It is possible that this pyrethroid increase fecundity of spider mites either directly or indirectly by making the leaf tissues a more favorable food source (Hoyt *et al.* 1978, Riedl & Hoying 1980). Li and Harmsen (1992) noticed reproduction enhancing effect of pyrethroid PP321 on *T. urticae* in the field. Jones and Parrella (1984) found that the reproductive potential of citrus red mites, *Panonychus citri* (McGregor), was enhanced in the presence of permethrin residues.

Full and reduced dosages of microbial insecticides, Dipel and MVP, summer oil, phosmet and carbaryl had no effect on ARM (Table 6.9, 6.11, 6.15, 6.24). The same was true for mixtures of summer oil, carbaryl, diflubenzuron and phosmet with the microbials (Tables 6.15, 6.24, 6.32). There were variable results for full rates of

azinphosmethyl, diflubenzuron and pyrethroids from year to year (Tables 6.15, 6.24, 6.32). Because of this, no conclusion could be reached on the effect of field rates of these insecticides on this mite species. Both permethrin and esfenvalerate at 0.1X alone and/or admixed with either bacterial insecticides significantly increased ($P \leq 0.05$) this mite in 1991 (Table 6.11) and 1993 (Tables 6.24 and 6.32) experiments, respectively. However, in 1992, this rate of either pyrethroid did not affect ARM population (Table 6.15). This year, *Z. mali* was abundant and its populations in apple trees treated with 0.1X of either pyrethroid were unaffected. Possibly, this species kept ARM population under control. It is known that *Z. mali* favors the ARM as prey (White & Laing 1977). This predator in 1991 and 1993 was either absent or sparsely present on a few trees. The results pertaining to the effect of carbaryl, phosmet, *B. thuringiensis* (Dipel) and summer oil on ARM are in agreement with several past studies (Jaques 1965, Hardman & Gaul 1990). Effect of MVP and all mixtures on this eriophyid mite was studied first time. The data showed no effect on ARM. The present results regarding pyrethroids are in agreement with results of other pyrethroids such as cypermethrin which at one-tenth of field rate is known to cause high increase in ARM (Kapetanakis *et al.* 1986, Hardman and Gual 1990).

Lower population of *Brevipalpus spp.* on control trees with maximum predator populations as compared to that of full rates of azinphosmethyl with lower predator populations indicates that predators may play an important role in the regulation of this tenuipalpid (Tables 6.5 and 6.7). As there is not much work done on this group of mites, therefore, only a few predators are known for tenuipalpids (McMurtry 1984).

During the 4-year study period of 1990-1993, the control trees experienced lowest numbers of tetranychid and other phytophagous mites (Tables 6.5, 6.7, 6.9, 6.11, 6.13, 6.14, 6.22, 6.23), and rather high populations of predacious mites (Tables 6.6-6.8, 6.10, 6.12, 6.17-6.21, 6.25-6.29, 6.34-6.36). The trees treated with different insecticides had variable numbers of phytoseiids and predatory insects; where the predators were reduced due to pesticides, large numbers of tetranychid mites were found (Tables 6.11, 6.13,6.14, 6.22, 6.30, 6.31, 6.34). Phytoseiids were almost wiped out from the trees treated with full rates of pyrethroid esfenvalerate and permethrin

(Tables 6.11, 6.17, 6.18, 6.25, 6.26, 6.34, 6.35). The direct toxicity of permethrin and esfenvalerate on phytoseiids noticed in the present studies, is in agreement with the reported effects of pyrethroids on these predators by earlier workers (Hoyt *et al.* 1978, Zwick & Fields 1978, Hall 1979, Rock 1979, AliNiazee & Cranham 1980, Riedl & Hoying 1980, AliNiazee 1984, Hull *et al.* 1985a, Kapetanakis *et al.* 1986, Hardman *et al.* 1988, Li & Harmsen 1992, Hardman *et al.* 1995). However, effect of esfenvalerate on phytoseiids has never been studied before in apple ecosystem. In the present study, esfenvalerate and permethrin were found to be equally toxic to *T. pyri* and other phytoseiids (Tables 6.17 and 6.18). Reduction of dosage to one-tenth of field recommended rate allowed some survival of predators, but not enough to provide adequate biological control.

It is known that phytoseiids have ability to develop resistance against some pyrethroids (Stickler & Croft 1981, 1982, Croft *et al.* 1982). A pyrethroid-selected field strain of *T. pyri* was tolerated four times the recommended field rate of cypermethrin in the apple orchards of New Zealand (Markwick 1986). Effective control of phytophagous mites by *T. pyri* where multiple pyrethroid applications were used seasonally has been demonstrated (Markwick 1988). However, in the present study, better survival of *T. pyri* at low rate of both pyrethroids (esfenvalerate and permethrin) was probably attributed less to pyrethroid resistance than to low dosage applied. In any event, this study confirmed earlier findings that lower rates of pyrethroids applied alone or when mixed with bacterial insecticides allowed more phytoseiids to survive (Li & Harmsen 1992, Hardman & Gual 1990, Hardman *et al.* 1995), thus may proved to be compatible with integrated mite control.

Better survival of *T. pyri* populations on trees treated with 1.0X of organophosphate azinphosmethyl and phosmet, and the carbamate carbaryl (Tables 6.6, 6.7, 6.9, 6.11, 6.18, 6.26, 6.35) may suggest the development of low level resistance to organophosphates and carbaryl in this predatory mite species. The tetranychid mite counts on trees treated with these insecticides were usually significantly lower ($P \leq 0.05$) than that of pyrethroids applied at 0.2X or more (Tables 6.11, 6.13, 6.14, 6.22, 6.23, 6.30, 6.31). Moreover, improved survival of *T. pyri* on

trees treated with full and half field rate of phosmet corroborated the inference that its populations were organophosphate-resistant (Table 6.9). It is known that phosmet, azinphosmethyl and carbaryl are highly toxic to *T. pyri*, unless resistant to these compounds has been developed (Hassan *et al.* 1987, Baillod & Guignard 1985, Frisch 1988). *T. pyri* may be cross resistant to carbaryl as result of organophosphate selection (Croft 1989b). This is because of a common modified acetylcholinesterase mechanism (Hadam *et al.* 1986). The results of present study are largely in agreement with an early laboratory study in which local populations of *T. pyri* were found to be resistant to azinphosmethyl and carbaryl (Hadam *et al.*1986). However, the level of resistance found in the study was much higher than observed in the present field studies. Level of resistance may differ in two populations isolated from each other by space and/or time (spatiotemporal populations). Factors such as genetics, bionomics, physiology and orchard management practices play an important role in the maintenance of pesticide resistance in a field predator population (Croft 1989a). Moreover, once resistance develops in a population, some selection intensity (pesticide application) is required to maintain the resistance factor, otherwise, it will decrease over time.

Present results (Tables 6.6, 6.9 and 6.11) show that *Z. mali* was quite tolerant of full rates of azinphosmethyl, phosmet and carbaryl and one-tenth rate of pyrethroids. The same was true for all bacterial-chemical insecticide mixtures. Full rates of both pyrethroids, esfenvalerate and permethrin, were, however, harmful (>75% mortality) to this predator. Previous reports show that *Z. mali* is considerably tolerant of organophosphates (Montoyama *et al.* 1970, Croft & Brown 1975, White & Laing 1977) but, very susceptible to pyrethroids (Weires & Smith 1978, Hull & Starner 1983). More recently, Li and Harmsen (1992) found that pyrethroid PP 321 at 0.1X allowed significantly more *Z. mali* to survive than that at 0.2X and more.

In 1990, at Entomology Farm, the most abundant phytoseiid species was *A. aberrans* (Table 6.6). This species is usually associated with hazelnut trees in the Willamette Valley and its occurrence on apple is rare (Hadam *et al.* 1986). The apple plantation in the study orchard was in close proximity of hazelnut trees. Therefore, it is

considered that populations of *A. aberrans* might have been dispersed from hazelnut trees to the neighboring apple trees. The full and half rates of azinphosmethyl was highly toxic to this species and *T. pyri* as well (Table 6.6). However, the treated trees experienced a large population of *Z. mali* after marked reduction in these phytoseiids (Table 6). Phytoseiid are considered more susceptible to organophosphate, to which *Z. mali* has some tolerance (Laing 1977). In 1991, *T. pyri* was the most abundant species in the orchard (Table 7). This year, full rate of azinphosmethyl numerically reduced *T. pyri* and other phytoseiid populations but not statistically significant from that of control. The disagreement in the results of these years was probably caused by the presence of large number of *Z. mali* counts (35.5/10 leaf) on the treated tree which might have competed with phytoseiids (Hardman *et al.* 1995) and predated upon their eggs (Clements & Harmsen 1990), thus depleting their population. Often *Z. mali* and phytoseiids have different responses to many insecticides (White & Laing 1977).

Throughout the season, no building up of the predatory mites was noticed in tree treated with full rates of pyrethroids (Tables 6.17-19, 6.25 and 6.26). In other words, no dispersal from the neighboring buffers trees occurred, and even if it did, the immigrant died rather early. *T. pyri* adults females tend to avoid apple leaf surfaces bearing pyrethroid residues at sublethal level (Walker & Penman 1978, Hislop *et al.* 1981). Therefore, it is possible that the persistent effects of pyrethroid residues to *T. pyri* may extend somewhat beyond the period when they caused direct mortality. Ruscoe (1977) observed similar phenomenon against larvae of *Plutella xylostella*.

Bacterial insecticides (0.5-1.5X), summer oil (0.5-1.0X), and diflubenzuron (0.25X-1.0X) were generally harmless (0 - <25% mortality or predator population reduction in orchard tests, Hassan *et al.* 1986) to predatory insects (Tables 6.8, 6.9, 6.12, 6.20, 6.21, 6.27-29 and 6.36). Likewise, mixtures of bacterial insecticides and reduced rates of diflubenzuron (0.25 and 0.50X) or summer oil (0.50X) were non-toxic to these predators. The findings pertaining to impact of *B. thuringiensis* on predatory insects are essentially in agreement with most past studies conducted in apple or pear orchards in Oregon or else where (Jaques *et al.* 1965, Walters 1976b,

Westigard *et al.* 1986), in the laboratory (Wilkinson *et al.* 1975, Walters 1976a, Walters 1976b, Salama *et al.* 1982 , Herbert & Harper 1986) and in other agroecosystems (Umarov *et al.* 1975, Franz *et al.* 1980, Hassan *et al.* 1983, Salama and Zaki 1984). However, impacts of genetically engineered MVP on natural enemies have never been investigated before. Facts available on summer oils imply that they are usually less harmful to beneficial insects than other pesticides with longer residual activity (Davidson *et al.* 1991). Selectivity of diflubenzuron to predatory insects has already been established (Croft 1989a). In the present studies, mostly adults but a few larvae of predacious insects were detected on apple trees. Diflubenzuron, in some cases, may be toxic to the immature stages of predatory insects (Bower & Kaldor 1980, Anderson and Elliott 1982). Insect predators which are active as adults and tend to immigrate to crop habitats rather than develop in treated systems (Croft 1989f) usually are not affected by diflubenzuron. However, dose manipulation (reduced dose) may be use to mitigate ill effects on immature stages (Croft 1989f). Accordingly, use of *B. thuringiensis*-diflubenzuron mixtures may provide best possible solution to this problem, besides controlling codling moth comparable to that with full rate of diflubenzuron. Even at higher frequency of use (6 vs. 4 seasonal sprays), these mixtures were harmless to most predatory fauna.

Phosmet at 0.1-1.0X was selective for most predacious insects including *S. punctillum* and other coccinelids, lacewings, earwigs, *D. brevis*, mirid species *H. planicornis, C. virgula* and *D. provancheri* (Table 6.10). Similar results were obtained with mixtures of reduced rates (0.1and 0.25X) of this insecticide with *B. thuringiensis* (Dipel). When all predatory insects were taken collectively, higher doses (0.5 and 1.0X) were found to be slightly harmful (25-50% mortality) (Table 6.10). This is because an analogous but (statistically) insignificant effect caused by a treatment on each predatory species may be accumulated additively to produced a (statistically) significant effect at a group level (total number of predatory insects). Azinphosmethyl and carbaryl at 1.0X were generally moderately toxic to mirids except one species *H. planicornis* (Tables 6.8, 6.20 and 6.28). These compound were quite selective to other predatory insects such as *S. punctillum*, lacewings, earwigs and

Orius spp. (Table 6.8, 6.20, 6.21, 6.28, 6.29). Azinphosmethyl and carbaryl at 0.1 and 0.2X applied alone or in mixtures with either bacterial insecticides were harmless (>25% mortality) to all predacious insect species taken individually or collectively (Tables 6.8, 6.21, 6.29 and 6.36). It is well documented that most pest natural enemies in apple orchards have begun to adapt to long-term chemical selection with organophosphate (Croft 1989e). Widely used organophosphorous compounds such as azinphosmethyl is now considered selective pesticide due to resistance development in natural enemies (Croft and Theiling 1989). Insects resistant to organophosphate compounds may exhibit cross-resistance to carbaryl and other carbamate insecticides as well (Croft 1989e, 1989g).

In the present studies, 0.25, 0.5 and 1.0X rates of permethrin were harmful to several insect predators including *D. brevis, D. provancheri, F. auricularia* and *S. punctillum*. (Table 6.12). This insecticides was slightly harmful to lacewings at 0.25X and 0.10X, however, higher rates (0.5 and 1.0X) were devastating to this predator (Tables 6.12, 6.20 and 6.21). Generally, this insecticide at 0.1X applied alone or when mixed with bacterial insecticides was harmless or slightly harmful to most predatory insects. Other pyrethroid, esfenvalerate at 1.0X essentially gave similar results as that of permethrin (Tables 6.20, 6.21, 6.27-29 and 6.36). To sum up, the results of present study show that only 0.1X reduced rates of both pyrethroid permethrin and esfenvalerate, applied alone or in mixtures with Dipel or MVP, were somewhat selective to predacious insects. Field rates of these pyrethroids were essentially harmful to all insect predators except to the mirid, *H. planicornis*.

Croft and Theiling (1988, 1989) extensively reviewed side-effects of agricultural pesticides on arthropod natural enemies. They have summarized the results of most studies conducted from 1950 to 1986 in a database summary, the SELCTV. An overview of this database suggests that predatory Hemiptera and Neuroptera are tolerant of pyrethroids. Among the Hemiptera, mirids, nabids and lygaeids are somewhat tolerant, where as anthocorids are more susceptible. Among Neuroptera, chrysopids are found to be more tolerant than hemerobiid. However, coccinelids are moderately susceptible to pyrethroids. Hull and Starner (1983) found a high level of

organophosphate resistance and lower levels of pyrethroid resistance in *Stethorus* spp. populations from apple orchard in the eastern United States. In California, the common lacewing has developed low-level resistance to a wide range of conventional insecticides, including several carbamates, organophosphate, and pyrethroid permethrin (Crafton-Cardwell and Hoy 1985 & 1986). In Ontario, Canada, lacewings have been widely adapted to the pesticides regimes used on apple (Crafton-Cardwell and Hoy 1985). Tolerance for pyrethroids in predatory insects may be due to cross resistance developed to other pesticides, such as DDT and organophosphate (Pree *et al.* 1989).

In conclusion, results of the present studies suggest that bacterial preparations Dipel and MVP, insect growth regulator diflubenzuron, summer oils and mixtures of bacterial insecticides with reduced rate of organophosphates, azinphosmethyl and phosmet (0.10 and 0.20/0.25X) , carbaryl (0.10 and 0.20X), summer oils (0.50X) and diflubenzuron (0.25 and 0.50X) were selective to most predatory insects. Full rates of these organophosphates and carbaryl were relatively less selective and those of pyrethroids, esfenvalerate and permethrin, the least. Selectivity with pyrethroids, esfenvalerate and permethrin, could only be acquired if used at 0.1X and 0.20/0.25 of full field rates. The latter rate was less selective than former. These pyrethroids at 0.1X applied alone or when mixed with Dipel or MVP was usually harmless to slightly harmful to most insect predators.

Population estimation of families and main species of spiders shown in Table 6.3, demonstrate that the salticid *Metaphidippus aeneolus*, linyphiid *Spirembolus mundus*, clubionid *Cheiracanthium inclusum*, Philodromid *Philodromus spectabilis* and the salticid *Eris marginata* were the dominant species with average densities of 21.59, 14.25, 13.37, 8.04 and 5.94 %, respectively of total spiders collected from 1990-1993. Individuals of these species were collected in 50-60% of the samples and in all 4 years of the study.

Spiders were not susceptible to both natural and genetically engineered bacterial insecticides, Dipel and MVP, insect growth regulator diflubenzuron and summer oil (SunSpray) (Tables 6.8, 6.10, 6.12, 6.21, 6.29 and 6.36). The results for

B. thuringiensis (Dipel) confirm those of laboratory study by Mansour and Nentwig (1988) and field study by Jaques (1965). The effects of summer oil and diflubenzuron on spiders are not well documented, however, these compounds are considered to be more selective to arthropod natural enemies than conventional insecticides (Croft and van de Baan 1989, Davidson *et al.* 1991). The full rates of permethrin was found to be moderately (1991) to highly harmful (1992) and those of esfenvalerate moderately (1993) to highly harmful (1992) for spiders. Differences in species composition (Table 6.4) during the study period may explain the disparity in the results. It may be possible that *S. mundus*, the most abundant species in 1992, was susceptible to pyrethroids and *E. marginata* and *M. aeneolus*, most abundant species in 1991 and 1992, respectively, tolerant of pyrethroids. Spiders are thought to be tolerant of pyrethroids (Croft & Theiling 1989), however, Staubli *et al.* (1984) found permethrin highly harmful (>75% mortality) to spiders. Nevertheless, results of present studies show that pyrethroids at 0.1X, alone or when mixed with Dipel and MVP, were quite selective to spiders.

The full rate of azinphosmethyl was moderately toxic (50-75% mortality) to spiders (Tables 6.8, 6.21, 6.29, 6.36). However, these predators were not affected by reduced rates (0.5X-0.1X) of this organophosphate whether applied alone or in mixtures with bacterial insecticides. The organophosphate phosmet at all doses (1.0-0.1X) was quite selective to spiders (Table 6.10). Full rates of carbaryl did not affect spider population in 1993 (Table 6.29), however, it was moderately toxic in 1992 (Table 6.21). This disparity can be explained in term of species compositions in these years (Table 6.4). In 1992, 40% of total spider population was *Spirembolus mundus*, which represented only 3.8% of 1993 population. Whereas in 1993 *Metaphidippus aeneolus* was the most abundant species (31%), which represented only 5.5% of 1992 population. It seems that *S. mundus* was susceptible to full rate of carbaryl, whereas *M. aeneolus* was tolerant. Yet, the lower rates of carbaryl (1.0X and/or 0.2X) applied alone or when mixed with bacterial insecticides generally had no effect on spiders (Tables 6.21, 6.29 and 6.36).

In general, results of present studies are in agreement with those obtained on apple by Mansour *et al.* (1981) and cotton by Laster and Brazzel (1968), who stated

that spiders were fairly tolerant to organophosphate and carbamate insecticides, and those of Pfimmer (1964), Negm and Hensley (1969), and Mansour and Nentwig (1988). Mansour *et al.* (1981) found that when topically applied, azinphosmethyl at 20mg/g of body weight was non-toxic to *Chiracanthium mildei* L. (the most abundant in the apple orchard of Israel) than that of 30mg/g, which produced 100% mortality after two days. He noticed that field rates of this insecticides suppressed mixed spider population in the apple trees. Mansour and Nentwig (1988) found that field rates of most organophosphate and carbamate was moderately toxic to spiders species *Philodromus aureolus*, *Linyphia triangularis*, *Argyope argentata*, and *C. mildei*. Recently, pesticide resistance has been detected in many spider species found in agricultural crops. In Austria, Polesny (1990) found numerous species resistant to a number of pesticides. He reported that one species, *Philodromus aureolus*, was resistant to all test organophosphate and carbamate compounds. Earlier, Mansour and Nentwig (1988) reported that *Philodromus aureolus* was completely resistant to 30 pesticides including 16 insecticides, 4 acaricides, 1 herbicide and 9 fungicides.

Conclusion

Bacterial insecticides Dipel and MVP (0.5-1.5X rates), summer oil (0.5-1.0X), and diflubenzuron (0.25X-1.0X) were generally harmless (IOBC Evaluation Standard: 0 - <25% mortality or predator population reduction in orchard tests, Hassan *et al.* 1986) to phytoseiids, *Z. mali*, predatory insects and spiders. These insecticides in their tested dosages had slight or no effects on tetranychid European red mite and yellow spider mite as well as on tydeids. Mixtures of bacterial insecticides with summer oil and diflubenzuron were among the treatments least disruptive for predator/prey interaction.

Full rates of azinphosmethyl, phosmet, and carbaryl were found to be slightly to moderately harmful (25 - 75% mortality) to *T. pyri*, other phytoseiids, and some spiders and predatory insects. These insecticides at reduced rates (0.1-0.2X), applied alone or when mixed with bacterial insecticides, were selective to most arthropod predators. Full rates of esfenvalerate and permethrin were harmful (>75 % mortality) to most arthropod predators. However, reduced rates (0.1and 0.20/0.25X) of these pyrethroids were selective to most insect predators and spiders. Permethrin at 0.25X-0.50X and esfenvalerate at 0.2X were harmful to predatory mites, phytoseiids and *Z. mali*, and tydeids. Mixing Dipel or MVP with permethrin at 0.25-0.5X and esfenvalerate at 0.2X did not lessen their inherent toxicity against these mites. Yet, both pyrethroids at 0.1X applied 4 times/season alone or in combination with bacterial insecticides acted moderately allowing some *T. pyri* and other phytoseiids, and most insect predators and spiders to survive/continue their activities on the treated trees. Generally at this dosage and frequency of application, field toxicity of both pyrethroids to many predators was comparable to that of full field rates of organophosphate azinphosmethyl and phosmet and carbamate carbaryl. Despite, counts of tetranychid mites from these treatments were higher than that of full rates of organophosphate and carbaryl. Apparently, under similar pressure of predator populations, tetranychid counts should not significantly vary in different treatments. Such a disparity may

suggest some sort of sublethal effects of pyrethroids on predators/tetranychid populations, as has been documented in the literature (Walker & Penman 1978, Hislop *et al.* 1981, Penman *et al.* 1981, Jones & Parella 1984, Li and Harmsen 1992).

Thoughout the study period (1990-93), tetranychid counts in control trees were low. Seasonal application of permethrin and esfenvalerate caused severe outbreak of these mites at all dosages tested, applied alone or when mixed with bacterial insecticides. However, significantly lower counts of ERM and YSM were associated with one-tenth (applied 4 times/season alone or when mixed with bacterial insecticides) of field rate than those with corresponding one-fifth or full-rate pyrethroid treatments. Seasonal application of full rates of conventional insecticides, azinphosmethyl, phosmet and carbaryl, caused less severe problem with ERM and YSM than corresponding rates of pyrethroids. This may be partly due to organophosphate tolerance (Hardman *et al.* 1990) and organophosphate-carbaryl cross resistance (Hadam *et al.* 1986, Croft 1989e) in the *T. pyri* population and partly to the relatively short residual life of these insecticides compared with pyrethroids (Penman *et al.* 1981). Phytoseiid mites are highly sensitive to pyrethroid (fenvalerate) residues (Riedl & Hoying 1980, Penman *et al.* 1981).

In the present study, predators of tetranychid mites included *T. pyri*, other phytoseiids, *Z. mali*, mirids, *S. punctillum* and lacewings. Among these, *T. pyri*, other phytoseiids and *Z. mali* are important predators. *T. pyri* alone or mixed with *G. occidentalis* provides excellent control of phytophagous mites (*P. ulmi, A. schlechtendali* and *Tetranychus urticae* Koch) (Croft & MacRae 1992b). Moreover, *Z. mali* can contribute to the biological control of pest mites by *T. pyri* (Croft & MacRae 1992a, Croft 1994). Results of the present study show that *T. pyri* alone and mixed with a number of other phytoseiid species (such as *A. aberrans, T. arboreus, A. andersoni*) and *Z. mali* can provide effective control of these phytophagous mites. Control of phytophagous mites in experiments (1993) where *Z. mali* population was nearly lacking, was comparable to those experiments (1991-92) where 3.1-7.14 /10 leaves of this predators was present. This predator alone even at 35.5/10 leaves could not control ERM, YSM or *Brevipalpus* spp. This suggests that mixed population of

phytoseiids predominated by *T. pyri* alone or with *Z. mali* can provide effective biological of ERM and YSM in Willamette valley.

Chapter 7

Summary and Practical Implication

Integrated Summary

The present study was designed to determine the feasibility of introducing mixtures of *Bacillus thuringiensis*-based microbial and chemical insecticide as effective and safer alternatives to present codling moth management practices which depends almost exclusively on use of highly toxic organophosphate insecticides. The effectiveness of the mixtures of selected chemical and *B. thuringiensis*-based insecticides against codling moth was evaluated under laboratory (chapter 3) and field conditions (chapter 5). The synergistic, additive, or antagonistic effects of these mixtures on insect mortality (chapter 3) and sublethal effects on various biological parameters such as survival to adult and oviposional rates (chapter 4) were investigated in details. In addition, the field impacts of these mixtures on some non-target arthropods such as phytophagous and predatory mites, entomophagous insects and spiders was determined (chapter 6).

In laboratory, both natural and genetically-engineered microbial insecticides based on *B. thuringiensis* (Dipel 2X and MVP) were incapable of producing high levels of toxicity (> 60%) to codling moth neonates even at three to four times the recommended field rate (Tables 3.1-3.9). It was found that if this pathogen (natural or genetically engineered) has to be utilized for the control of codling moth, mixing it with low doses of some chemical insecticides is essential (Tables 3.1-3.9). However, not all these combinations are effective. A proper proportion of mixture components is an important determinant of efficacy against codling moth. Generally, higher rates of natural and genetically engineered insecticides bases on *B. thuringiensis* combined with low to medium rates of chemical insecticides gave highly additive or synergistic effect (Tables 3.1-3.9). Thus, moderate to higher *B. thuringiensis* concentration were required to obtain a supplemented or potentiated combined mortality. The mixtures that showed the greatest synergism were pyrethroids at low to moderate test concentrations in combination with moderate to high rates of Dipel or MVP (Tables 3.4, 3.5, 3.8 and 3.9). Most combinations of azinphosmethyl, phosmet, carbaryl and

diflubenzuron, with moderate to high concentrations of either Dipel or MVP showed additive effect (Tables 3.1-3.3, 3.6 and 3.7). However, mixtures with highest concentrations of most chemical insecticides at all concentrations of Dipel and MVP produced an effect similar to or less than their effects when tested alone (Tables 3.1-3.9). At highest doses of both microbial and chemical insecticides, the joint mortality of most mixtures was marginally antagonistic (P = 0.1), subadditive (effect less than or the same as that of most active component in the mixture) or not significantly different from the combinations with lower concentrations of either microbial or chemical components (Tables 3.1-3.9). Both microbial control agents (MCAs) produced almost similar responses with a given chemical insecticides.

There was no significant difference between egg mortalities produced by chemical insecticides alone or in combination with either MCAs (Tables 3.8 and 3.9). The larvae hatched from eggs treated at 0-24 h or blackhead stage produced significantly higher mortality at all test concentrations compared with that of untreated eggs (Tables 3.8 and 3.9). When these larvae were exposed to the mixtures, the joint effect was additive in case of organophosphate insecticides, carbaryl, diflubenzuron and most combinations with higher rates of pyrethroids, producing a significantly higher combined ovo-larvicidal activities (egg and larval mortality) than those of each mixture component tested alone (Tables 3.8 and 3.9). Most combinations with the lower rates of either pyrethroids were synergistic (Tables 3.8 and 3.9). The exposure of eggs at different stages to low rates of chemical insecticides alone or in combination with MCAs, caused the larvae hatching from these eggs to be more susceptible to insecticides-MCA mixtures. This effect was more attributable to the low doses of chemical insecticides than to the MCAs. This effect could be either additive (all combinations with azinphosmethyl, carbaryl and diflubenzuron) or synergistic (some combinations with pyrethroids) (Tables 3.8 and 3.9). As a general rule all test combinations produced better results when treated at blackhead eggs stage and when using Dipel (Tables 3.8 and 3.9).

Concluding the results of toxicological studies in the laboratory, three types of interactions between *B. thuringiensis* and chemical insecticides were observed:

additivity, in which the amount of observed mortality is not significantly different from the expected; synergism, in which observed mortality is significantly greater than expected; and antagonism, in which observed mortality is significantly less than expected . Often the interactions were better with Dipel than MVP. The pyrethroids potentiated (synergised) the effect of microbial insecticides. On the other hand, carbaryl, azinphosmethyl, phosmet and diflubenzuron had an additive effects. These insecticides, however, significantly enhanced the activity of *B. thuringiensis*-based insecticides in some combinations.

The pest control approach mentioned above is based on reduced rates of microbial and chemical insecticides. For such an approach, study of sublethal effects on insect biology is particularly important because exposure to sublethal concentrations may either have harmful or beneficial effects on the biology of pest and natural enemies leading to an added control or resurgence/permanence of the pests in the ecosystem. In the present study, codling moth when exposed at larval or adult stage to sublethal rates of azinphosmethyl, phosmet, carbaryl, esfenvalerate and permethrin manifested various short- and long-term effects with varying degree of intensity usually stronger with pyrethroids (Tables 4.1-4.7). Diflubenzuron and microbial insecticides (Dipel and MVP) had no adulticidal activity and long-term effects on codling moth biology (Tables 4.1-4.7). Sublethal concentrations of chemical insecticides namely azinphosmethyl, phosmet, carbaryl, permethrin and esfenvalerate caused pronounced deleterious effects on the adult survival, oviposition and fecundity (Table 4.1). However, adult longevity was not affected significantly (Table 4.1).

The exposure of neonate codling moth larvae to sublethal concentrations of most insecticides adversely affected their initial survival (Tables 4.2 and 4.3). Larval development and survival to pupal stage and beyond, however, was not affected by microbial insecticides and diflubenzuron (Tables 4.2-4.7). Organophosphate chemicals namely azinphosmethyl and phosmet, carbamate carbaryl and pyrethroids permethrin and esfenvalerate had a severe impact on larval survival and pupal formation (Table 4.2 and 4.3). Larval survival, in general, was reduced with increasing concentrations

(Tables 4.2 and 4.3). Carbaryl, esfenvalerate and permethrin affected the pupal survival and subsequent eclosion of adults (Tables 4.2 and 4.3). Only these insecticides had significant adverse long-term effects on the survival of codling moth after surviving initial exposure at neonatal stage. Most concentrations of pyrethroids considerably extended the duration of larval period (Tables 4.4 and 4.5). The pupal development period and adult longevity was not significantly extended /contracted by any test insecticides (microbial and chemicals) (Tables 4.4 and 4.5). Pupal weight, egg production and fecundity of the adults that survived insecticidal exposure as larvae, were not affected by microbial insecticide, diflubenzuron, azinphosmethyl, phosmet and carbaryl (Tables 4.6 and 4.7). On the other hand, pyrethroids produced severe long-term effects on codling weight-gain and oviposition. Larval contact with sublethal concentrations of pyrethroids resulted in reduction of pupal weight and subsequent egg deposition (Tables 4.6 and 4.7). Surviving adults were lighter and smaller in size (Tables 4.6 and 4.7). Fecundity of these moth, however, was not affected.

In the field test, most chemical insecticides Guthion® 50WP (azinphosmethyl) and Imidan® 50WP (phosmet); pyrethroids, Asana® XL (esfenvalerate) and Ambush® 25.6% (permethrin) at field recommended rates effectively controlled codling moth damage in all seven field experiments conducted during 1991-1993 (Tables 5.1-5.7). Carbamate, Sevin® 50WP (carbaryl); insect growth regulator, Dimilin® 25WP (diflubenzuron) performed better in one season than other (Tables 5.4 and 5.6). Insecticides treatments of Guthion at 50 mg/100 l. and 60mg/100l., Imidan (120 gm/100 l.), Asana (30 ml/100 l.), and Ambush (16 ml/100 l.) gave excellent season-long control of codling moth (Tables 5.1-5.7). However, ultra-fine spray oil, SunSpray® (summer oil) and microbial insecticides failed to control codling moth effectively (Tables 5.1-5.4 and 5.6). Increasing dosage and/or application frequency of microbial insecticides, Dipel® 2X (*B. thuringiensis*) and MVP® (genetically engineered *B. thuringiensis* product), did not significantly increase their efficacy against codling moth (Tables 5.6 and 5.7)

Results of the present field efficacy tests indicate a potential use of mixtures of Dipel with low rates of pyrethroids (0.1-0.2X) or Dimilin (0.25-0.50X) in the codling moth management (Tables 5.3-5.7). Standard application rate (2 times/generation) and timing were found to be appropriate for Dipel-pyrethroid mixtures (Tables 5.3-5.7). Dipel-Dimilin mixtures were only suitable when applied 3 times/generation (Tables 5.4-5.7). Generally, mixtures with the lowest dose (0.1X) of pyrethroids produced synergistic interaction whereas those with higher rates (0.2, 0.25, and 0.5X) produced an additive joint action (Tables 6.3, 6.4 and 6.6). Pyrethroids such as Asana (0.1X and 0.2X) and Ambush (0.1X) in combination with Dipel (1.0X) were among the treatments that provided the best control of codling moth in the field (Tables 5.3-5.7). With these mixtures, the overall codling moth damage was generally under acceptable limits of 1-2%, when codling moth infestation was < 23% in controls (Tables 5.3-5.5 and 5.7). At 38-45% control fruit infestation, Dipel at lowest rate of Asana (0.1X) did not performed as good as Guthion at the maximum field rate of 300 ppm (Table 5.6). The degree of protection by mixture, however, was equivalent to that of Guthion applied at normal rate of 250 ppm. An increase in dose of either microbial/chemical component in the mixture or number of mixture applications per generation (3 versus 2) generally resulted in better reduction of codling moth damage (Table 5.6 and 5.7). However, the difference in effect was unexpectedly small (statistically non-significant), suggesting that lower dosage of mixture components at lower frequency of application was enough to give adequate protection against codling moth infestation. Other promising treatments such as Ambush (0.1X) + Dipel (1.0X) and Asana (0.2X) + Dipel (1.0X) consistently provided results statistically comparable to the standard treatments (Tables 5.3, 5.4 and 5.6). Most interactions of pyrethroids with genetically engineered MVP were generally additive (Tables 5.4-5.7). Similarly, MVP-Dimilin mixtures were usually less effective than Dipel-Dimilin mixtures (Tables 5.4-5.7). Mixtures of Dipel with Dimilin at increased application rate (3 versus 2 per generation) resulted in 31.67 to 48.85% increase in their efficacy (Table 5.7). When applied 3 times/generation, Dipel (1.0X) in combination with Dimilin at 0.25X and 0.50X was as efficacious as the standard insecticides Guthion at normal (250ppm) and

maximum field rates (300 ppm), respectively (Table 5.7). All combinations of Guthion, Imidan, or Sevin with *B. thuringiensis*-based microbial insecticides gave little benefit in term of degree of protection from codling moth damage (Tables 5.1-5.7).

Bacterial insecticides (0.5-1.5X), summer oil (0.5-1.0X), and diflubenzuron (0.25X-1.0X) were generally harmless [IOBC Evaluation Standard: 0 - <25% mortality or predator population reduction in orchard tests (Hassan *et al.* 1987)] to phytoseiids, *Z. mali*, predatory insects and spiders. Results (Tables 6.5-6.36) of present studies show that bacterial insecticides (Dipel and MVP), diflubenzuron (Dimilin) and summer oil (SunSpray) are generally benign for most arthropod predators especially *T. pyri*, *Z. mali* and predatory mirids. These insecticides in their tested dosages had slight or no effects on tetranychid ERM and YSM (Tables 6.5, 6.7, 6.9, 6.11, 6.13, 6.14, 6.22, 6.23, 6.30 and 6.31). Full rates of pyrethroids, esfenvalerate and permethrin, were found to be harmful [> 75% mortality in orchard tests (Hassan *et al.* 1987)] to arthropod predators including araneids, acarids and predatory insects (Tables 6.12, 6.17-6.21, 6.25-6.29). Permethrin at 0.25X-1.0X and esfenvalerate at 0.2X and 1.0X were harmful (>75% mortality) to predatory mites, phytoseiids and *Z. mali* (6.11, 6.17-6.19, 6.25 and 6.26). Esfenvalerate and permethrin at 0.1X applied alone or in mixture with bacterial insecticides acted moderately allowing some *T. pyri* and other phytoseiids, and most insect predators and spiders to survive/continue their activities on the treated trees (Tables 6.11, 6.12, 6.17-6.21, 6.25-6.29 and 6.34-6.36). Generally at this dosage, field toxicity of these pyrethroids to many predators was comparable to that of full field rates of organophosphate azinphosmethyl and phosmet and carbamate carbaryl (Tables 6.17-6.21, 6.25-6.29 and 6.34-6.36). Full field rates of azinphosmethyl, phosmet and carbaryl were found to be slightly to moderately harmful (25 - 75% mortality) to *T. pyri*, other phytoseiids, and some spiders and predatory insects (Tables 6.5-6.10, 6.17-6.21, 6.25-6.29 and 6.34-6.36). These rates generally caused less severe problem with ERM and YSM than corresponding rates of pyrethroids (6.13, 6.14, 6.22, 6.23, 6.30 and 6.31). Both pyrethroids, esfenvalerate and permethrin, at all test rates (0.1-1.0X) caused an outbreak of these phytophagous mites (Tables 6.11, 6.13, 6.14, 6.22,

6.23, 6.30 and 6.31). However, significantly lower counts of ERM and YSM were associated with 0.1X standard rate, applied alone or when mixed with microbial insecticides mixtures, than those with corresponding 0.2X-0.5X and full-rate pyrethroid treatments (Tables 6.11, 6.13, 6.14, 6.22, 6.23, 6.30 and 6.31). During the study period (1990-93), tetranychid counts in control trees were below the economic threshold levels (Tables 6.5, 6.7, 6.9, 6.11, 6.13, 6.14, 6.22, 6.23, 6.30 and 6.31).

In the present study, predators of tetranychid mites included *T. pyri*, other phytoseiids, *Z. mali*, mirids, *Stethorus punctillum* and lace wings (Tables 6.5-6.10, 6.12, 6.17-6.21, 6.25-6.29 and 6.34-6.36). Among these, *T. pyri*, other phytoseiids and *Z. mali* were important predators. Results of the present study show that *T. pyri* alone and mixed with a number of other phytoseiid species (such as *A. aberrans, T. arboreus, A. andersoni*) and *Z. mali* can provide effective control of the phytophagous mites (Tables 6.5-6.7, 6.9, 6.13-6.19, 6.22-6.26 and 6.30, 3.31, 6.34 and 6.35). Control of phytophagous mites in experiments (1993) where *Z. mali* population was nearly lacking, was comparable to those experiments (1991-92) where 3.1-7.14 /10 leaves of this predators was present (Tables 6.7, 6.9, 6.13-6.19, 6.22-6.26 and 6.30-6.35). This predator alone even at 35.5/10 leaves could not control ERM, YSM or *Brevipalpus* spp (Table 6.6). This suggests that mixed population of phytoseiids predominated by *T. pyri* alone or with *Z. mali* can provide effective biological of ERM and YSM in Willamette valley.

Practical Implication

Based on results of present investigation it is concluded that there is a potential use of mixtures of *B. thuringiensis* with low rates of diflubenzuron (0.25-0.50X) or esfenvalerate and permethrin (0.1-0.2X) in the codling moth management program. However, *B. thuringiensis*-diflubenzuron mixtures were only suitable when applied 3 times/ generation: first application at 450 and 1450 day-degrees for the first and second generations respectively, and second and third each at 14 days interval (day-

degree values based on computerized codling moth phenology model, *Codmoth*). Neither microbial insecticides nor diflubenzuron had adulticidal activity or any deleterious sublethal effects on the biology of codling moth, therefore, control of this insect by *B. thuringiensis*-diflubenzuron mixtures was largely dependent on their direct toxicity to codling moth eggs and/or neonates. These mixtures were environmentally safe and did not cause outbreaks of phytophagous mites.

Whenever, organophosphate insecticides fail to control lepidopterous pests (codling moth, winter moth and leaf roller) and pyrethroids are required, use of *B. thuringiensis*-pyrethroid mixtures (with one-tenth the recommended rate of pyrethroid) should be considered as an alternative. These mixture can provide effective control of codling moth (chapter 1 & 5), winter moth, and leaf rollers (Hardman & Gaul 1990, Hardman *et al.* 1995). Most sublethal effects of these pyrethroid were deleterious for codling moth, hence, they may provide added control of codling moth in the field. Control of this insect by *B. thuringiensis*-pyrethroids mixtures, therefore, was dependent on their direct toxicity to codling moth neonates and deleterious sublethal effects of pyrethroids on codling moth biology. Nevertheless, these mixtures had both direct and indirect effects on individual components species of the predatory complex of apple ecosystem. Comparing with greater disruption caused by full rates of pyrethroids, these mixtures had partial effects on the complex resulting in improved survival of a number of predaceous fauna, thereby, leaving open the possibility of some form of IPM depending on predator control of pestiferous species. Generally, the level of disruption caused by these mixtures was not greater than that of full rates of conventional insecticides. e. g. azinphosmethyl, phosmet and carbaryl. Use of these mixtures resulted in significantly lower abundance of tetranychid phytophagous mites than full rates of pyrethroids ($P \leq 0.05$). Four or six seasonal sprays of these mixtures can provide effective control of codling moth, however, lower application frequency (4 sprays) was less disruptive for natural enemies in the apple ecosystem. As these mixtures contain only low dosage of pyrethroids, they can effectively minimize resistance development in a pest and simultaneously encourage resistance development in a natural enemies (Croft

1989a). It is concluded that *B. thuringiensis*-pyrethroid mixtures may prove to be compatible with mite IPM programs in apple orchards if the system can be modified to produce higher predator-prey ratios.

If introduction of pyrethroid-resistant *T. pyri* is followed by this modified spray program, better results can be achieved. Better prospects for biological control of phytophagous pest mites are expected, if pyrethroid resistant/tolerant *T. pyri* are released under the proposed sprays program to improve survival of *T. pyri*. Introductions of exotic insecticides-resistant phytoseiids have been successfully undertaken in various parts of the world (Croft 1989c). Recently, in France a strain of *T. pyri* was found to be resistant to the three main pesticide groups: carbamate, organophosphate, and pyrethroids (Vidal and Kreiter 1995). This strain was 1,282-fold resistant to fenvalerate, a close relative of esfenvalerate. This strain has been successfully introduced in many French vineyards (Valentin 1993).

Although the research presented here provides potential avenues for the careful introduction of the *B. thuringiensis*-pyrethroid mixtures into existing IPM programs for apple, more research is needed to determine their long range effects on the apple ecosystem. These mixtures may provide effective control of other apple pests like leafrollers, leafhoppers and leafminers. Their efficacy against winter moth has already been established (Hardman & Gaul 1990). Although *B. thuringiensis*-azinphosmethyl/phosmet mixtures were not effective against codling moth, they can be useful against winter moth and leafrollers in areas where populations of these pests are still susceptible to organophosphate. Presumably, this may be true for *B. thuringiensis*-carbaryl and MVP- organophosphate/carbaryl mixtures as well.

During the study period (1991-1993), climatic conditions were moderate, hence, effect of environmental factors like temperature, humidity and rainfall on the field efficacy of *B. thuringiensis*-chemical insecticide mixture could not be studied. *B. thuringiensis* is sensitive to sun light and high temperature (McGuire *et al.* 1994, Nyouki & Fuxa 1994), hence, the efficacy of the mixtures against codling moth may be substantially affected in areas with higher summer temperature. There is a need to perform experiments in different areas with varied climatic condition to thoroughly

examine the efficacy of *B. thuringiensis*-esfenvalerate/permethrin and *B. thuringiensis*-diflubenzuron mixtures against codling moth. Before actually putting this technique in place, some other studies are also warranted, which include: large plot trials, economic studies on the use of mixtures in comparison with conventional control methods, etc.

Also, it is suggested that *B. thuringiensis* mixtures with pyrethroids like bifenthrin and fenpropathrin should be studied in future. These compound have shown increased activity on apple aphids (especially the woolly apple aphids and the apple aphid) and spider mites and considerably less activity against some natural enemies (Croft 1989b). Reduced rate of these insecticides may not upset predator-prey balance by allowing some prey to survive as food for predatory mites. And, chances of development of resistance to pyrethroids in spider mite population will be minimized.

Bibliography

Abdel-Salam, F. A. and F. A. Nasr. 1968. The effect of some insecticides on the stages of the Egyptian cotton leafworm, *Prodenia litura* Fab. Zeit. Pfl. Krank. U. Pfl. Schutz, 75: 687-689.

Alford, A. R. and J. A. Holmes. 1986. Sublethal effects of carbaryl, aminocarb, fenitrothion, and *Bacillus thuringiensis* on the development and fecundity of spruce budworm (Lepidoptera: Tortricidae). J. Econ. Entomol. 79: 31-34.

Ali, A. and S. Y. Young. 1993. Effects of rate and spray volume of *Bacillus thuringiensis* var. *kurstaki* on activity against *Heliothis virescens* (Lepidoptera: Noctuidae) and persistence in cotton terminals. J. Econ. Entomol. 86: 735-738.

AliNiazee, M. T. 1979a. Role of a predatory mite, *Typhlodromus arboreus*, in biological control of spider mites on apples in western Oregon. *In* Proc. 4th internat. Congr. Acarology. 1974, Salfedan, Austria, 637-642.

AliNiazee, M. T. 1979b. Mite populations in western Oregon. pp. 71-76. *In* J. G. Rodriguez (ed.), Recent advances in Acarology, New York Academic Press.

AliNiazee, M. T. 1984. Effect of two synthetic pyrethroids on the predatory mite, *Typhlodromus arboreus*, in apple orchards of western Oregon. pp. 655-658. *In* D. A. Griffiths and C. E. Bowman (eds.), Acarology VI, Wiley New York.

AliNiazee, M. T. 1986. The European winter moth as a pest of filberts: damage and chemical control. J. Entomol. Soc. B. C. 83: 6-12.

AliNiazee, M. T. and J. E. Craham. 1980. Effect of four synthetic pyrethroids on a predatory mite, *Typhlodromus pyri*, and its prey *Panonychus ulmi*, on apples in southeast England. Environ. Entomol. 9: 436-439.

AliNiazee, M. T., and P. H. Westigard. 1995. Yellow Spider Mite. pp. 75-76. *In* J. R. Nechols, L. A. Andres, J. W. Beardsely, R. D. Goeden and C. G. Jackson (eds.), Biological control in the western United States. Univ. Calif. Press.

Amano, H. and D. A. Chant. 1990. Species diversity and seasonal dynamics of Acari on abandoned apple trees in southern Ontario, Canada. Exp. appl. Acarol. 8: 71-96.

Andermatt, M., E. Mani, Th. Wildbolz and P. Luthy. 1988. Susceptibility of *Cydia pomonella* to *Bacillus thuringiensis* under laboratory and field conditions. Entomol. Exp. Appl. 49: 291-295.

Anderson, D. W. and R. H. Elliott. 1982. Efficacy of diflubenzuron against the codling moth, *Laspeyresia pomonella* (Lepidoptera: Olethreutidae) and impact on orchard mites. Can. Entomol. 114: 733-737.

Andrews, R. E., R. M. Faust, H. Wabiko, k. C. Raymond, L. A. Bulla Jr. 1987. The biotechnology of *Bacillus thuringiensis*. CRC Critical Rev. in Biotechnology, 6(2): 163-200.

Anonymous, 1989. New *Bacillus thuringiensis* options. Ag Consultant. 45(6): 1, 4.

Aronson, A. I., W. Beckman, and P. Dunn. 1986. *Bacillus thuringiensis* and related insect pathogens. Microb. Rev. 50: 1-24.

Asquith, D. and L. A. Hull. 1973. *Stethorus punctum* and pest population responses to pesticide treatments on apple trees. J. Econ. Entomol. 66: 1197-1203.

Baeza-Squiban, A., C. Meinard and F. Marano. 1988. Metabolism of deltamethrin in two cell types *in vitro*. Pestic. Biochem. & Physiol. 32: 253-261.

Baeza-Squiban, A., M. Best-Belpomme and F. Marano. 1989. Cytotoxicity, accumulation, and metabolism of deltamethrin, a pyrethroid insecticides, in *Drosophila melanogaster* cells. Pestic. Biochem. & Physiol. 33: 201-212.

Baicu, T. and S. M. Hussein. 1984. Joint action of mixtures of insecticides with preparations of *Bacillus thuringiensis* Berliner against different insect pests. Buletinul de Protectia Plantelor No. 4: 55-62. [R. A. E. 1987. 75(8): 4300].

Baillod, M. and E. Guignard. 1984. Resistance de *Typhlodromus pyri* Scheuten (Acari: Phytoseiidae) a l'azinphos et lutte biologique contre les acariens phytophages en arboriculture. Revue Suisse Vitic. Arboric. Hortic. 16: 155-160.

Baillod, M. and E. Guignard. 1985. Typhlodromes, lutte biologique contre les acariens phytophages et programme de traitement. Reve Suisse Vitic. Arboric. Hortic. 17: 30-31.

Bajwa, M. I. 1980. Apple cultivation. Dept. Agricul., A. J. K., Pakistan. 72pp.

Bajwa, M. I. 1984. Codling moth. Kisht Zar 1(1): 9-14.

Bajwa, W. I. 1993. Effects of *Bacillus thuringiensis* Berliner on pests' natural enemies. pp. 67-68. *In* Proc. Grad. Conf. 93. Oreg. State Univ., Corvallis, Oregon.

Bajwa, W. I. and M. T. AliNiazee. 1995. Laboratory evaluation of *Bacillus thuringiensis* (Berliner) against neonate *Cydia pomonella* (L.) larvae. Abst. 45, Proc. Grad. Conf. 1995. Oreg. State Univ., Corvallis, Oregon.

Barnes, M. M. 1958. Technique for testing insecticide deposits with newly hatched codling moth larvae. J. Econ. Entomol. 51(4): 547-549.

Barnes, M. M. and H. R. Moffitt. 1963. Resistance to DDT in the adult codling moth and reference curves for Guthion and of carbaryl. J. Econ. Entomol. 56: 722-725.

Barnes, M. M., J. G. Millar, P. A. Kirsch and D. C. Hawks. 1992. Codling moth (Lepidoptera: Tortricidae) control by dissemination of synthetic female sex hormone. J. Econ. Entomol. 85(4): 1274-1277.

Barnett, W. W., C. S. Davis and G. A. Rowe. 1977. The California integrated pest management project for pears: summary and evaluation. 1973-1976. Univ. Calif. AESCE, 25 pp.

Bartlett, B. R. 1964. Integration of chemical and biological control. pp. 489-511. *In* P. DeBach (ed.), Biological control of insect pests and weeds. Reinhold Pub., New York.

Batalova, T. S. 1970. The biological method of control of the codling moth. Zashchita Rastenii. 15(8): 22-23. [R. A. E. 1973. vol.61(12)]

Batiste, W. C. 1972. Integrated control of codling moth on pears in California- effects of varying dosage of azinphosmethyl and oil with individual cover sprays. Environ. Entomol. 1(4): 503-508.

Benz, G. 1971. Synergism of micro-organism and chemical insecticides, pp. 327-355. *In* H.D. Burges and N.W. Hussey [eds.], Microbial control of insects and mites. Academic Press. London, New York. 861 pp.

Berry, R. E., A. F. Moldenke, J. C. Miller and J. G. Wernz. 1993. Toxicity of diflubenzuron in larvae of gypsy moth (Lepidoptera: Lymantriidae): effects of host plants. J. Econ. Entomol. 86(3): 809-814.

Berry, R. E, S. J. Yu and L. C. Terriere. 1980. Influence of host plants on insecticide metabolism and management of variegated cutworm. J. Econ. Entomol. 73: 771-774.

Bliss, C. I. 1939. The toxicity of poisons applied jointly. Ann. Appl. Biol. 26: 585-615.

Boles, H. P. 1974. The effects of sublethal dosages of pyrethrin on the mating efficiency of the rice weevil, *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae). J. Kans. Entomol. Soc. 47: 444-451.

Boman, H. G. 1981. Insect responses to microbial infections. pp. 769-784. *In* H. D. Burges [ed.], Microbial control of pests and plant diseases 1970-1980. Academic Press, London.

Bond, E. J. and E. Upitis. 1973. Response of three insects to sublethal doses of phosphine. J. Stored Prod. Res.: 307-313.

Bostanian, N. J., A. Belanger and I. Rivard. 1985. Residues of four synthetic pyrethroids and azinphosmethyl on apple foliage and their toxicity to *Amblyseius fallacis* (Acari: Phytoseiidae). Can. Entomol. 117: 143-152.

Bostanian, N. J. and A. Belanger 1985. The toxicity of three pyrethroids to *Amblyseius fallacis* (Garman) Acari. Phytoseiidae and their residues on apple foliage. Agric. Ecosys. & Environ. 14: 234-250.

Bower, C. C. and J. Kaldor. 1980. Selectivity of five insecticides for codling moth control: effects on the two spotted spider mites and its predators. Environ. Entomol. 9: 128-132.

Brain, P. and D. M. Glen. 1989. A model of the effect of codling moth granulosis virus on *Cydia pomonella*. Ann. appl. Biol. 115: 129-140.

Brattsten, L. B. 1986. Fate of ingested plant allelochemicals in herbivorous insects, pp. 211-256. *In* L. B. Brattsten and S. Ahmed (eds.), Molecular aspects of insect-plant associations. Plenum, New York.

Brattsten, L. B. 1986. Potential role of plant allelochemicals in the development of insecticide resistance, pp. 331-348. *In* P. Barbosa and D. K. Le Tourneau (eds.), Novel aspects of insect-plant interactions. Wiley, New York.

Brattsten, L. B., C. W. Holyoke Jr., J. R. Leeper, And K. F. Raffa. 1986. Insecticide resistance: challenge to pest management and basic research. Science 231: 1255-60.

Brown, A. W. A. 1963. Chemical injuries. *In* E. A. Steinhaus (ed.), Insect pathology 1: 65-131. Academic Press. New York.

Brunner, J. F., S. C. Hoyt and M. A. Wright. 1982. Codling moth control-a new tool for timing sprays. Washington State Univ. Coop. Ext. Bull. 1072.

Burges H. D. and E. M. Thompson. 1971. Standardization and the bioassay of microbial insecticides . pp. 591-622. *In* H.D. Burges and N.W. Hussey [eds.], Microbial control of insects and mites. Academic Press. London, New York.

Burov, D. , K. Rizvanov and I. Grigorov. 1967. The control of the codling moth with bacterial preparations. Rastit. Zasht.: 24-25 [R. A. E. 1970 Vol. 58:3372].

Burts, E. C. 1983. Effectiveness of a soft-pesticides program on pear pests. J. Econ. Entomol. 76: 936-941.

Bush, M. R., Y. A. I. Abdel-Aal and G. C. Rock. 1993. Parathion resistance and esterase activity in codling moth (Lepidoptera: Tortricidae) from North Carolina. J. Econ. Entomol. 86(3): 660-666.

Carlton, B. C. 1993. Development of improved bioinsecticides based on *Bacillus thuringiensis*. pp. 258-266. A. C. S. Symp. Ser. Am. Chem. Soc.

Chant, D. A. 1956. Predacious spiders in orchards in south-eastern England. J. Hort. Sci. 31: 35-46.

Chen, J. S., C. J. Lee, M. G. Yao and C. N. Sun 1985. Effect of pyrethroids on knockdown and lack of coordination responses of susceptible and resistant diamondback moth (Lepidoptera: Ypononeutidae). J. Econ. Entomol. 78: 1198-1202.

Chen, K. S., B. R. Funke, J. T. Schulz , F. I. Carlson, and I. Proshald. 1974. Effects of certain organophosphate and carbamate insecticides on *Bacillus thuringiensis*. J. Econ. Entomol. 67: 471-473.

Clements, D. R. and R. Harmsen. 1990. Predatory behavior and prey-stage preferences of stigmaeid and phytoseiid mites and their potential compatibility in biological control. Can. Entomol. 122: 321-328.

Creighton, C. S. and T. L. McFadden. 1974. Complimentary action of low rates of *Bacillus thuringiensis* and chlordimeform hydrochloride for control of caterpillar. J. Econ. Entomol. 67: 1902-1904.

Croft, B. A. 1975. Integrated control of apple mites. Coop. Ext. Ser. Mich. State Univ. Bull. E-825. 12 pp.

Croft, B. A. 1982. Arthropod resistance to insecticides: a key to pest control failures and successes in North American apple orchards. Entomol. Exp. Appl. 31: 88-110.

Croft, B. A. 1989a. Deciduous tree fruit species. pp. 503-528. *In* B. A. Croft, Arthropod biological control agents and pesticides. John Wiley & Sons, New York.

Croft, B. A., 1989b. Ecological selectivity. pp. 247-267. *In* B. A. Croft, Arthropod biological control agents and pesticides. John Wiley & Sons, New York.

Croft, B. A. 1989c. Endemic species. pp. 431-453. *In* B. A. Croft, Arthropod biological control agents and pesticides. John Wiley & Sons, New York.

Croft, B. A. 1989d. Introduced species. pp. 455-471. *In* B. A. Croft, Arthropod biological control agents and pesticides. John Wiley & Sons, New York.

Croft, B. A. 1989e. History, methods and constrains of genetic improvement. pp. 473-501. *In* B. A. Croft, Arthropod biological control agents and pesticides. John Wiley & Sons, New York.

Croft, B. A., 1989f. Pesticides resistance: documentation. pp. 357-381. *In* B. A. Croft, Arthropod biological control agents and pesticides. John Wiley & Sons, New York.

Croft, B. A., 1989g. Physiological selectivity. pp. 221-245. *In* B. A. Croft, Arthropod biological control agents and pesticides. John Wiley & Sons, New York.

Croft, B. A. 1989h. Toxicology and genetics. pp. 383-402. *In* B. A. Croft, Arthropod biological control agents and pesticides. John Wiley & Sons, New York.

Croft, B. A. 1994. Biological control of apple mites by a phytoseiid mite complex and *Zetzellia mali* (Acari: Stigmaeidae): long-term effects and impact of azinphosmethyl on colonization by *Amblyseius andersoni* (Acari: Phytoseiidae). Environ. Entomol. 23 (5): 1317-1325.

Croft, B. A. and A. W. A. Brown. 1975. Responses of arthropod natural enemies to insecticides. Ann. Rev. Entomol. 20: 285-335.

Croft, B. A., and C. A. Mullin. 1989. Physiology and toxicology. pp. 127-153. *In* B. A, Croft. Arthropod biological control agents and pesticides. John Wiley & Sons New York.

Croft, B. A., and D. R. Penman. 1989. Evaluating the IPM implementation process. *In* Pesticides: issues and options for New Zealand. Ministry for the Environment. New Zealand: 159-165.

Croft, B. A. and H. W. Riedl. 1991. Chemical control and resistance to pesticides of the codling moth, pp. 371-387. *In* L. P. S. van der Geest and H. H. Evenhuis (eds.), Tortricid pest: their biology, natural enemies and control. Elsevier, Amsterdam.

Croft, B. A., and I. V. MacRae. 1992a. Persistence of *Typhlodromus pyri* and *Metaseiulus occidentalis* (Acari: Phytoseiidae) on apple after inoculative release and competition with *Zetzella mali* (Acari: Stigmaeidae). Environ. Entomol. 21(5): 1168-1177.

Croft, B. A., and I. V. MacRae. 1992b. Biological control of apple mites by mixed populations of *Metaseiulus occidentalis* (Nesbitt) and *Typhlodromus pyri* Scheuten (Acari: Phytoseiidae). Environ. Entomol. 21(1): 202-209.

Croft, B. A. and K. M. Theiling. 1989. Pesticide effects on arthropod natural enemies: a database summary. pp. 17-46. *In* B. A. Croft, Arthropod biological control agents and pesticides. John Wiley & Sons New York.

Croft, B. A. and L. A. Hull. 1991. Tortricid pests of pome and stone fruits, chemical control and resistance to pesticides, pp. 473-486. *In* L. P. S. van der Geest and H. H. Evenhuis (eds.), Tortricid pest: their biology, natural enemies and control. Elsevier, Amsterdam.

Croft, B. A. and M. E. Whalon. 1982. Selective toxicity of pyrethroid insecticides to arthropod natural enemies and pests of agricultural crops. Entomophaga 27: 3-21.

Croft, B. A. and M. T. AliNiazee. 1983. Differential resistance to insecticides in *Typhlodromus arboreus* Chant and associated phytoseiids in apples in the Willamette Valley, Oregon. Environ. Entomol. 12: 1420-1423.

Croft, B. A. and M. T. AliNiazee. 1996. Biological control in deciduous tree fruit crops. *In* T. W. Fisher (Ed.), Principles and application of biological control. UC. Press (in press).

Croft, B. A. and R. Messing. 1989. Sublethal influences. pp. 157-183. *In* B. A. Croft, Arthropod biological control agents and pesticides. John Wiley & Sons New York.

Croft, B. A. and S. A. Hoying. 1977. Competitive displacement of *Panonychus ulmi* Koch. by *Aculus schlechtendali* Nal. in apple orchards. Can. Entomol. 109: 1025-1034.

Croft, B. A. and S. C. Hoyt. 1978. Considerations for the use of pyrethroid insecticides for deciduous fruit pest control in the USA Environ. Entomol. 7: 627-630.

Croft, B. A. and S. C. Hoyt (Eds.). 1983. Integrated management of insect pests of pome and stone fruits. Wiley, New York.

Croft, B. A., S. W. Wagner and J. G. Scott. 1982. Multiple and cross-resistance to insecticides in pyrethroid-resistant strains of the predatory mite, *Amblyseius fallacis*. Environ. Entomol. 11: 161-164.

Curtis, H. and N. S. Barnes. 1989. Biology. Worth Publisher, New York. 1192 pp.

Davidson, N. A., J. E. Dibble, M. L. Flint, P. J. Maner and A. Guye. 1991. Managing insects and mites with spray oils. Univ. Calif. Publication 3347.

De Reede, R. H., P. Gruys and F. Vaal. 1985. Leafrollers in apple IPM under regimes based on *Bacillus thuringiensis*, on diflubenzuron, or on epofenonane. Entomol. Exp. Appl. 37: 263-274.

Dolphin, R. E., M. L. Cleveland and T. E. Mouzin. 1967. Field tests with *Bacillus thuringiensis* Berliner in apple Orchard. Proc. Indiana Acad. Sci.: 265-269. [R. A. E. 1971. 59: 930].

Donadale, C. D., B. Parent and D. Pitre. 1979. A 6-year study of spiders (Araneae) in Quebec apple orchard. Can. Entomol. 111: 377-380.

Dover, M. J., B. A. Croft, S. M. Welch and R. L. Tummala. 1979. Biological control of *Panonychus ulmi* (Acari: Tetranychidae) by *Amblyseius fallacis* (Acari: Phytoseiidae) on apple: a prey-predator model. Environ. Entomol. 8: 282-292.

Dulmage, H. T. 1973. *Bacillus thuringiensis* U. S. assay standard. Report on adoption of a primary U. S. reference standard for assay of formulations containing the δ-endotoxin of *Bacillus thuringiensis* Bull. Entomol. Soc. Am. 19: 200-202.

Dulmage, H. T. 1981. Insecticide activity of isolates of *Bacillus thuringiensis* and their potential for pest control. p. 193-222. *In* H. D. Burges (ed.), Microbial control of pests and plant diseases 1970-1980. Academic Press, London.

Dulmage, H. T. , A. J. Martinez and T. Penna. 1976. Bioassay of *Bacillus thuringiensis* (Berliner) δ-endotoxin using tobacco budworm. U. S. Department of Agriculture Tech. Bull. 1528.

Dulmage, H. T. and E. Martinez 1973. The effects of continuous exposure to low concentrations of the delta endotoxin of *Bacillus thuringiensis* on the development of the tobacco budworm, *Heliothis virescens*. J. Invertebr. Pathol. 22: 14-22.

Dulmage, H. T., O. P. Boening, C. S. Rehnborg, and G. D. Hansen. 1971. A proposed standardized bioassay for the formulation of *Bacillus thuringiensis* based on the international unit. J. Invertebr. Pathol. 18: 240-245.

Dunbre, R. B. and A. A. Hower. 1976. Sublethal effects of insecticides on the alfalfa weevil parasites *Microctonus aethiops* and the influence of parasitism on host susceptibility. Environ. Entomol. 5: 311-315.

Dunkle, R. L. and B. S. Shasha. 1989. Response of starch-encapsulated *Bacillus thuringiensis* containing ultraviolet screens to sunlight. Environ. Entomol. 18: 1035-1041.

Dutcher, J. D. 1993. Recent examples of conservation of arthropod natural enemies in agriculture. pp. 101-108. *In* R. D. Lumsden and J. L. Vaughn (eds.), Pest management: biologically based techniques. Conf. Proc. Series, Amer. Chemical Soc. Wash. D. C.

Easterbrook, M. A. 1984. Effects of pesticides on the apple rust mite *Aculus schlechtendali* (Nal.) (Eriophyidae). J. Hort. Sci. 59: 51-55.

Elliott, R. H. and D. W. Anderson. 1982. Factors influencing the activity of diflubenzuron against the codling moth, *Laspeyresia pomonella*, (Lepidoptera: Olethreutidae) . Can. Entomol. 114: 259-268.

El-Sayed, G. E. N. 1968. Effect of sublethal doses of certain insecticides on the cotton leafworm, *Prodenia litura* Fab. M. Sc. Thesis, Cairo University.

English, L. and S. L. Slatin. 1992. Mode of action of delta-endotoxins from *Bacillus thuringiensis*: a comparison with other bacterial toxins. Insect Biochem. Mol. Biol. 22: 1-7.

Esaac, E. G., S. El-Gogary, M. S. Abdel-Fatah and A. Mahr Ali. 1972. Effect of carbaryl, methyl parathion, and endrin on egg production and percent pupation of the Egyptian cotton leafworm, *Spodoptera littoralis* (Boisd.). Z. ang. Ent. 71: 263-270.

Esaac, E. G., S. El-Gogary, M. S. Abdel-Fatah, A. Mahr Ali and Takla. 1975. Free amino acids and protein content in larval haemolymph of Egyptian cotton leafworm. *Spodoptera littoralis* (Boisd.). Z. ang. Ent. Vol. 79.

Esaac, E. G., S. El-Gogary and N. S. Takla. 1976. Biochemical changes caused by some insecticides in relation to egg production in the Egyptian cotton leafworm, *Spodoptera littoralis* (Boisd.). Z. ang. Ent. 80:40-45.

Falcon, L. A. 1971. Use of bacteria for microbial control. p. 67-95. *In* H. D. Burges and N. W. Hussey [eds.], Microbial control of insects and mites. Academic Press, New York.

Falcon, L. A. and J. Huber. 1991. Biological control of the codling moth. p. 355-369. *In* L. P. S. van der Geest and H. H. Evenhuis (eds.), Tortricid pest: their biology, natural enemies and control. Elsevier, Amsterdam.

Falcon, L. A., W. R. Kane and R. S. Bethell. 1968. Preliminary evaluation of a granulosis virus for control of the codling moth. J. Econ. Entomol. 61: 1208-1213.

Faust, R. M. and L. A. Bulla, Jr. 1982. Bacteria and their toxins as insecticide. pp.75-208. *In* E. Kurstak (ed.), Microbial and viral pesticides. Marcel Dekker, Inc. New York and Basel.

Federici, B. A. 1993. Insecticidal bacterial protein identify the midgut epithelium as a source of novel target sites for insect control. Arch. Insect Biochem. and Physiol. 22: 357-371.

Fedorinchik, N. S. 1977. Success from and outlook for use of microorganisms for the biological control of harmful insects and disease organisms of plants in the nonblack- soil zone. Trudy Vsesoyuznogo Nauchnoissledovatel'skogo Instituta Zashchity Rastenii No. 53: 19-92 [R. A. E. 1978 Vol. 66 no.11: 5641].

Fedorinchik, N. S. and R. S. Sogoyan . 1975. Microbial preparations for the control of tortricids in orchards on the Black Sea Coast of the Krashnodar region. [R. A. E. 1977. 65(11): 6151].

Feitelson, J. S., J. Payne and L. Kim.1992. *Bacillus thuringiensis*: insects and beyond. Bio/Technology 10: 271-275.

Feitelson, J. S., T. C. Quick and F. Gaertner, 1990. Alternative hosts for *Bacillus thuringiensis* delta-endotoxin genes. UCLA-Sym-Mol-Cell-Biol. New York, NY. Wiley-liss, Inc. 112: 561-571.

Finney, D. J. 1964. Probit analysis. Cambridge University, London.

Finney, D. J. 1978. Probit analysis. Cambridge University, London.

Fischer-Colbrie, P. 1978. Field tets using granulosis virus against codling moth (*Laspeyresia pomonella* L.). Mitteilugen aus der biologischen Bundesanstalt fur land-und Forstwirtschaft 180: 72-74.

Fischhoff, D. A. 1989. Applications of plant genetic engineering to crop protection. Phytophathol., 79: 38-40

Fischhoff, D. A., K. S. Bowdisch, F. J. Perlak, P. G. Marrone, S. H. McCormick, J. G. Niedermeyer, D. A. Dean, K. Kueano-Kretzmer, E. J. Mayer, D. E. Rochester, S. G. Rogess and R. T. Fraley. 1987. Insect tolerant transgenic tomato plants. Bio/Technology, 5: 807-813.

Flint, M. L. (ed.). 1991. Microbial insecticides. p 81. *In* Integrated pest management for apples and pears. Univ. Calif. Publication No. 3340. 214 pp.

Fowler, J. and Cohen, L. 1990. Practical statistics for field biology. Milton Keynes (England).

Franz, J. M., H. Bogenschutz, S. A. Hassan, P. Huang, E. Naton, H. Suter and B. Viggiani. 1980. Results of a joint pesticide test programme by the working group: pesticides and beneficial arthropods. Entomophaga 25: 231-236.

Frisch, T. 1988. The impact of New York apple orchard pest management practices on two beneficial mites. M. S. thesis, Cornell University, Ithaca.

Gardner, W. A. 1988. Enhanced activity of selected combinations of *Bacillus thuringiensis* and B-exotoxin against fall armyworm (Lepidoptera: Noctuidae) larvae. J. Econ. Entomol. 81(2): 463-469.

Gardner. W. A. and J. A. Hornby. 1978. Bioassay of the persistence of *Bacillus thuringiensis* on sorghum panicles. J. Entomol. Sci. 22: 210-211.

Gelernter, W. D. 1990a. MVP bioinsecticide: a bioengineered, bioencapsulated product for control of lepidopteran larvae. pp. 14. *In* D. E. Pinnock (ed.), Proceedings, 5th International Colloquium on Invertebrate Pathology and Microbial control, 20-24 August 1990. Adelaide, Australia.

Gelernter, W. D. 1990b. *Bacillus thuringiensis*, bioengineering and the future of bioinsecticides. Brighton Crop Protection Conference-Pests and Diseases. 7A-3: 617-624.

Gill, S. S., A. Elizabeth, A. Cowles and V. Patricia. 1992. The mode of action of *Bacillus thuringiensis* endotoxins. Annu. Rev. Entomol. 37: 615-636.

Gist, G. L. and C. D. Pless. 1985. Effects of synthetic pyrethroids on growth and development of the fall armyworm, *Spodoptera frugiperda*. Fla. Entomol. 68: 450-456

Glen, D. M. 1975. The effects of predators on eggs of codling moth, *Cydia pomonella*, in a cider-apple orchard in southwest England. Ann. appl. Biol. 80: 115-119.

Glen, D. M. and C. C. Payne. 1983. Production and field evaluation of codling moth granulosis virus for control of *Cydia pomonella* in the United Kingdom. Ann. Appl. Biol. 104: 87-98.

Glen, D. M. and J. Clark. 1985. Death of *Cydia pomonella* larvae and damage to apple fruit, after field application of codling moth granulosis virus. Entomol. exp. appl. 38: 93-96.

Glen, D. M. and N. F. Milson. 1978. Survival of mature larvae of codling moth (*Cydia pomonella*) on apple trees and ground. Ann. Appl. Biol. 90: 133-146.

G"onev, G. 1975. Integrated and biological control in apple and plum orchards in the Stara Zagora districts. Rastitelna Zashchita Vol. 23 (9): 31-34.

Grafton-Cardwell, E. E. and M. A. Hoy. 1985. Short-term effects of permethrin and fenvalerate on oviposition by *Chrysoperla carnea* (Neuroptera: Chrysopidae). J. Econ. Entomol. 78: 955-959.

Grafton-Cardwell, E. E. and M. A. Hoy. 1986. Selection of the common green lacewing for resistance to carbaryl. Calf. Agric. 40(9/10): 22-24.

Gratwick, M. 1964. Laboratory assessment of the toxicity of field-weathered deposits of insecticide to larvae of the codling moth, *Cydia pomonella* L. Bull. Entomol. Res. 55: 35.

Gratwick, M. and R. P. Tew. 1966. A comparison of the toxicity of various carbamate, organophosphorous and organochlorine compounds to codling moth. Proc. 3rd British. Insectic. and Fungic. Conference 1965, Brighton, 276-285.

Gratwick, M., J. M. Sillibourne and R. P. Tew. 1965. The toxicity of insecticides to larvae of the codling moth, *Cydia pomonella* L. Bull. Entomol. Res. 56: 367-388.

Griego, V. M. and K. D. Spence, 1978. Inactivation of *Bacillus thuringiensis* spores by ultraviolet and visible light. Appl. Environ. Microbiol. 35: 906-910.

Grosch, D. S. 1975. Reproductive performance of *Bracon hebetor* after sublethal doses of carbaryl. J. Econ. Entomol. 68: 659-662.

Gruy, P. 1980a. Development of an integrated control programs for orchards. pp. 5-10. *In* Integrated control of insects in Netherlands. PUDOC. Wageningen, Netherlands.

Gruy, P. 1980b. Solved and unsolved problems of integrated control in apple orchards. Illustrated by examples from the Netherlands. pp. 359-364. *In* Proc. Intern. Symp. on Integrated Control in Agricul. and Forestry (1979), Vienna, Austria.

Gruy, P. 1982. Hits and misses. The ecological approach to pest control in orchards. Ent. exp. appl. 31: 70-75.

Habib, M. E. and M. A. Garcia. 1981. Compatibility and synergism between *Bacillus thuringiensis* var. *Kurstaki* and two chemical insecticides. Z. Angew. Entomol. 91: 7-14.

Hadam, J. J., M. T. AliNiazee and B. A. Croft. 1986. Phytoseiid mites (Parasitiformes: phytoseiidae) of major crops in Willamette Valley, Oregon, and pesticide resistance in *Typhlodromus pyri*. Environ. Entomol. 15: 1255-1263.

Hagely, E. A. C. 1975a. Note on the ovicidal effect of three insecticides against codling moth (Lepidoptera: Tortricidae). Proc. Ent. Soc. Ont. 108: 69-77.

Hagely, E. A. C. 1975b. The arthropod fauna in unsprayed apple orchards in Ontario II. Some predacious species. Proc. Ent. Soc. Ont. 105: 28-40.

Hagely, E. A. C. 1978. Integrated pest management- insecticides and natural predator populations on apple. Proc. Ent. Soc. Ont. 109:9-22.

Hagely, E. A. C. and J. E. Laing. 1989. Effect of pesticides on parasitism of artificially distributed eggs of the codling moth, *Cydia pomonella* (Lepidoptera: Tortricidae) by *Trichogramma* spp. (Hymenoptera: Trichogrammatidae). Proc. Ent. Soc. Ont. 120: 25-33.

Hagely, E. A. C. and M. Chiba. 1980. Efficacy of phosmet and azinphosmethyl for control of major insect pests of apple in Ontario. Can. Entomol. 1075-1083.

Hagely, E. A. C. and W. R. Allen. 1988. Ground beetles (Coleoptera: Carabidae). As predators of codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae). Can. Entomol. 120: 917-925.

Hagely, E. A. C., L. G. Monteith, D. H. C. Herne and R. Trottier. 1977. Pest population buildup in apple orchards following omission of insecticide and acaricide sprays. Proc. Ent. Soc. Ont. 108: 7-11.

Hagely, E. A. C., N. J. Holliday and D. R. Barber. 1982. Laboratory studies of the food preferences of some orchard carabids (Coleoptera: Carabidae). Can. Entomol. 114: 431-437.

Hagely, E. A. C., R. Trottier, L. G. Monteith, D. H. C. Herne, A. Hikichi and A. Maitland. 1978. Pest management in Ontario apple orchards. Ministry of Supply and Services Canada. Ottawa. 21 pp.

Hall, R. F. 1979. Effects of synthetic pyrethroids on major insects and mite pests of apple. J. Econ. Entomol. 72: 441-446.

Hameed, S. F. and J. G. Allen. 1976. Toxicity and persistence of some organophosphorous insecticides and permethrin on apple fruits for the control of codling moth, *Laspeyresia pomonella* (L.). J. Hort. Science 51: 105-115.

Hamilton, D. W. and D. O. Hathaway. 1966. Codling moth, pp. 339-354. *In* C. V. Smith (ed.), Insect colonization and mass production. Academic Press, New York.

Hamilton, J. T. and F. I. Attia. 1977. Effects of mixtures of *Bacillus thuringiensis* and pesticides on *Plutella xylostella* and the parasite *Thyraella collaris*. J. Econ. Entomol. 70:146-148.

Hardman, J. M. and S. O. Gaul. 1990. Mixtures of *Bacillus thuringiensis* and pyrethroids control winter moth (Lepidoptera: Geometridae) in orchards without causing outbreaks of mites. J. Econ. Entomol. 83: 920-936.

Hardman, J. M., H. J. Herbert, K. H. Sanford and D. Hamilton. 1985. Effects of populations of European red mite, *Panonychus ulmi*, on the apple variety Red Delicious in Nova Scotia. Can. Entomol. 117: 1257-1265.

Hardman, J. M., R. E. L. Rogers and C. R. MacLellan. 1988. Advantages and disadvantages of using pyrethroids in Nova Scotia apple orchards. J. Econ. Entomol. 81: 1737-1749.

Hardman, J. M., R. E. L. Rogers, J. P. Nyrop and T. Frisch. 1991. Effect of pesticide applications on abundance of European red mite (Acari: Tetranychidae) and *Typhlodromus pyri* (Acari: Phytoseiidae) in Nova Scotian apple orchards. J. Econ. Entomol. 84(2): 570-580.

Hardman, J. M., R. F. Smith, and E. Bent. 1995. Effects of different integrated pest management programs on biological control of mites on apple by predatory mites in Nova Scotia. Environ. Entomol. 24: 125-142.

Hassan, S. A. 1983. Procedure for testing the side effects of pesticides on beneficial arthropods as being considered by the IOBC international working group "Pesticides and Beneficial Arthropods". Mitt. Deutch. Ges. F. Allgen. U. Angew. Entomol. 4: 86-88.

Hassan, S. A., A. Albert, F. Bigler. P. Blaisinger, H. Bogenschutz, E. Boller, J. Brun, P. Chiverton, P. Ewards, W. D. Englert, P. Haung, C. Inglesfield, E. Naton, P. A. Oomen, W. P. J. Overmeer, *et al.* 1987. Results of the third joint pesticides testing programme carried out by IOBC/WPRS-working group "Pesticides and beneficial organism". J. Appl. Ent. 103: 92-107.

Hassan, S. A., F. Bigler. H. Bogenschutz, E. Boller, J. Brun, P. Chiverton, P. Ewards, F. Mansour, E. Naton, P. A. Oomen, W. P. J. Overmeer, L. Polgar *et al.* 1988. Results of the fourth joint pesticides testing programme carried out by IOBC/WPRS-working group "Pesticides and beneficial organism". J. Appl. Ent. 105: 321-329.

Hathaway, D. O. 1967. Inexpensive cardboard trays for mass rearing codling moth. J. Econ. Entomol. 60: 888-889.

Haynes, K. F. 1988. Sublethal effects of neurotoxic insecticides on insect behavior. Annu. Rev. Entomol. 33: 149-168.

Haynes, K. F. and T. C. Baker 1985. Sublethal effects of permethrin on the chemical communication system of the pink bollworm moth, *Pectinophora gossypiella.* Arch. Insect Biochem. Physiol. 2: 283-293.

Heler, L. S. and F. W. Plapp, Jr. 1986. Use of oils in insect control. Southwest Entomol. 11: 1-8.

Henderson, H. F. 1970. Insecticides for codling moth control and their effect on other insects and mites of apple in British Columbia. J. Econ. Entomol. 63(5): 1521-1523.

Henderson, C. F. and H. V. McBurnie. 1943. Sampling techniques for determining populations of the citrus red mite and its predators. USDA Circular 671.

Herbert, D. A. and J.D. Harper. 1985. Bioassay of a Beta-exotoxin of *Bacillus thuringiensis* against *Heliothis zea* larvae. J. Invertebr. Pathol. 46: 247-250.

Herbert, H. J. 1981. Biology, life tables, and intrinsic rate of increase of the European red mite, *Panonychus ulmi* (Acarina: Tetranychidae). Can. Entomol. 113: 65-71.

Herbert, H. J. and K. H. Sanford. 1969. The influence of spray programs on the fauna of apple orchards in Nova Scotia. XIX. Apple rust mite, *Vasates schlechtendali*, a food source for predators. Can. Entomol. 101: 62-67.

Herne, D. C. and C. T. Lund. 1973. Influence of acaricides on seasonal populations of European red mite and predaceous mites on apple. Pesticide Res. Report. Canada Comm. on Pesticides Use in Agr., Agric. Canada, pp 14-17.

Herrnstadt, C., G. G. Soares, E. R. Wilcox and D. L. Edwards. 1986. A new strain of *Bacillus thuringiensis* with activity against coleopteran insects. Bio. Technology, 4: 305-308.

Highwood, D. P. 1979. Some indirect benefits of the use of pyrethroid insecticides. p. 3 61-369. Proc. 1979 Britian Crop Protect. Conf.: Pest and Disease.

Hislop, R. G., P. J. Auditore, B. L. Weeks and R. J. Prokopy. 1981. Repellency of pesticides to the mite predator *Amblyseius fallacis*. Prot. Ecol. 3: 253-257.

Hofte, H. and H. R. Whitely. 1989. Insecticidal crystal proteins of *Bacillus thuringiensis*. Microbiol. Rev. 53: 242-255.

Honek, A. and I. Novak. 1978. Effect of sublethal doses of intration 50 on reproduction in *Pyrrhocoris apterus* L. (Hemiptera: Pyrrhocoridae). Z. Angew. Entomol. 83:364-370.

Howell, J. F., 1983. Codling moth (Lepidoptera: Olethreutidae): determining the drawing range of virgin females. J. Econ. Entomol. 76: 436-439.

Howell, J. F. 1991. Reproductive biology. pp. 157-173. *In* L. P. S. van der Geest and H. H. Evenhuis (eds.), Tortricid pest: their biology, natural enemies and control. Elsevier, Amsterdam.

Howell, J. F., A. L. Knight, T. R. Unruth, D. F. Brown, J. L. Krysan, C. R. Sell and P. A. Kirsch. 1992. Control of codling moth in apple and pear with sex pheromones-mediated mating disruption. J. Econ. Entomol. 85(3): 918-925.

Howell, J. F. and J. C. Maitlen. 1983. Codling moth (Lepidoptera: Olethreutidae) susceptibility to azinphosmethyl. J. Econ. Entomol. 76: 912-915.

Howell, J. F. and L. D. White 1972. Codling moth (Lepidoptera: Olethreutidae) susceptibility to azinphosmethyl. J. Econ. Entomol. 76:912-915.

Hoying, S. A. and H. Riedl. 1980. Susceptibility of the codling moth to diflubenzuron. J. Econ. Entomol. 73: 556-560.

Hoyt, S. C. 1969. Integrated chemical control of insects and biological control of mites on apple in Washington. J. Econ. Entomol. 62: 74-86.

Hoyt, S. C. 1991. Biology, ecology and control of mites in Washington orchards. pp 147-156. *In* K. Williams (ed.), New directions in tree fruit pest management. Good. Fruit Grower, Yakima, Washington.

Hoyt, S. C. 1995. Mite complex on apple. pp. 63-66. *In* J. R. Nechols, L. A. Andres, J. W. Beardsely, R. D. Goeden and C. G. Jackson (eds.), Biological control in the western United States. Univ. Calif.

Hoyt, S. C., J. R. Leeper, G. C. Brown and B. A. Croft. 1983. Basic biology and management components for insect IPM. pp. 93-151. *In* B. A. Croft and S. C. Hoyt (Eds.), Integrated management of insect pests of pome and stone fruits. Wiley, New York.

Hoyt, S. C., P. H. Westigard and E. C. Burts. 1978. Effects of two synthetic pyrethroids on the control of codling moth, pear psylla and various mite species in northwest apple and pear orchards. J. Econ. Entomol. 71: 431-434.

Huber, J. and E. Dickler. 1976. The granulosis virus of the codling moth (*Laspeyresia pomonella*): testing its potency for biological control. Z. ang. Ent. 82: 143-147

Huber, J. and E. Dickler. 1977. Codling moth granulosis virus: Its efficacy in the field in comparison with organophosphorous insecticides. J. Econ. Entomol., 70, 557-561.

Huber, J. and H. Wundermann. 1978. Mist blower application of granulosis virus. Mitteilungen aus der Biologischen Bundesanstalt fur Land-und Forstwirt-schaft 180: 78-79.

Huber, J. and S. A. Hassan. 1991. Biological control of tortricid pests in pome and stone fruits. pp. 497-503. *In* L. P. S. van der Geest and H. H. Evenhuis (eds.), Tortricid pest: their biology, natural enemies and control. Elsevier, Amsterdam.

Hull, L. A. and A. L. Knight. 1989. Effect of late-season fenvalerate and flucythrinate applications on European red mite (Acari: Tetranychidae) and tufted apple bud moth (Lepidoptera: Tortricidae) populations on apple. J. Econ. Entomol. 82: 1174-1179.

Hull, L. A and E. H. Beers. 1985. Ecological selectivity: modifying chemical control practices to preserve natural enemies. *In* M. A. Hoy and D. C. Herzog (eds.),

biological control in agricultural integrated pest management systems. Proc. Conf., 4-6 June 1984, Lake Alfred, Fla. Academic, New York.

Hull, L. A. and V. R. Starner. 1983. Impact of four synthetic pyrethroids on a major natural enemies and pests of apple in Pennsylvania. J. Econ. Entomol. 76: 122-1 30.

Hull, L. A., E. H. Beers and R. L. Meagher, Jr. 1985a. Impact of selective use of the synthetic pyrethroid fenvalerate on apple pests and natural enemies in large-orchard trials. J. Econ. Entomol. 78: 163-168.

Hull, L. A., E. H. Beers and R. L. Meagher, Jr. 1985b. Integration of biological and chemical control tactics for apple pests through selective timing and choice of synthetic pyrethroids. J. Econ. Entomol. 78: 714-721.

Iftner, D. C. and F. R. Hall. 1983. Effects of fenvalerate and permethrin on *Tetranychus urticae* Koch (Acari: Tetranychidae) dispersal behavior. Environ. Entomol. 12: 1782-1786.

Iftner, D. C. and F. R. Hall. 1984. The effect of fenvalerate and permethrin residues on *Tetranychus urticae* Koch fecundity and rate of development. J. Agric. Entomol. 1: 91-200.

Ignoffo, C. M., and B. Gregory. 1972. Efforts of *Bacillus thuringiensis* B-exotoxin on larval maturation, adult longevity, fecundity, and egg viability in several species of Lepidoptera. Environ. Entomol. 1: 269-272.

Inserra, S., C. Calabretta and G. T. Garzia. 1987. Attack by *Cacoecimorpha pronubana* (Hbn.) on protected crops of gerbera and rose and possibilities of chemical and biological control. Difesa-delle-Piante, 10: 97-100.

Ishaaya, I. 1992. Insect resistance to benzoylphenylureas and other insect growth regulators, mechanisms and countermechanisms. Proc. A. C. S. Symp. Ser. Am. Chem. Soc. pp. 231-246.

Ishaaya, I. and W. Chefurka. 1971. Induction of RNA and protein-biosynthesis in the housefly microsomes after DDT treatment. *In* Proceedings International IUPAC Congress of Pesticides Chemistry, 2: 267-279.

Jaques, R. P. 1961. Control of some Lepidopterous pests of apple with commercial preparations of *Bacillus thuringiensis* Berliner. J. Insect Pathol. 3: 47-54.

Jaques, R. P. 1965. The effect of *Bacillus thuringiensis* Berliner on the Fauna of an apple orchard. Can. Entomol. 97(8): 795-802.

Jaques, R. P., 1988. Field tests on control of the imported cabbageworm (Lepidoptera: Pieridae) and the cabbage looper (Lepidoptera: Noctuidae) by mixtures of microbial and chemical insecticides. Can. Ent. 120:575-580.

Jaques, R. P., 1989. The potential of microbial insecticides in agriculture. Can. J. Plant Science. 69: 1.

Jaques, R. P., and D. R. Laing. 1989. Effectiveness of microbial and chemical insecticides in control of the Colorado potato beetle (Coleoptera: Chrysomelidae) on potatoes and tomatoes. Can. Ent. 121:1123-1131.

Jaques, R. P. and O. N. Morris. 1981. Compatibility of insect pathogens with other methods of pest control and with different crops. p. 695-715. In H. D. Burges (ed.) Microbial control of pests and plant diseases. 1970-1980. Academic Press , London.

Jaques, R. P., C. R. MacLellan, K. H. Sanford, M. D. Proverbs and E. A. C. Hagley. 1977. Preliminary orchard tests on control of codling moth larvae by a granulosis virus. Can. Entomol. 109(8):1079-1081.

Jaques, R. P., D. R. Laing and H. E. L. Maw. 1989. Efficacy of mixtures of microbial insecticides and permethrin against the imported cabbageworm (Lepidoptera: Pieridae). Can. Ent. 121:809-820.

Jaques, R. P., J. E. Laing, C. R. MacLellan, M. D. Proverbs. K. H. Sanford and R. Trottier. 1981. Apple orchard tests on the efficacy of the Granulosis Virus of the codling moth, *Laspeyresia pomonella* (Lepidoptera.: Olethreutidae). Entomophaga 26 (20): 111-118.

Jaques, R. P., J. E. Laing, D. R. Laing and D. S. K. Yu.1987. Effectiveness and persistence of the Granulosis virus of the Codling moth, *Cydia pomonella* (L.) (Lepidoptera: Olethreutidae) on apple. Canadian Entomologist. 119(8): 1063-1067.

Jaynes, H. A. and P. E. Marucci. 1947. Effect of artificial control practices on the parasites and predators of codling moth. J. Econ. Entomol. 40: 9-25.

Johnson M. W. and Wilson L. T. 1995. Integrated pest management: contributions of biological control to its implement. pp. 7-24. *In* J. R. Nechols, L. A. Andres, J. W. Beardsely, R. D. Goeden and C. G. Jackson (eds.), Biological control in the western United States, Univ. Calif. Publication No. 336.

Jones, V. P. and M. P. Parrella. 1984. The sublethal effects of selected insecticides on the life table parameters of *Panonychus citri* (Acari: Tetranychidae). Can. Entomol. 116: 1033-1040.

Kalina, B. F. 1950. Development and viability of *Drosophila melanogaster* on a medium containing DDT. Science 111: 39-40.

Kapetanakis, E. G. and J. E. Craham. 1983. Laboratory evaluation of resistance to pesticides in phytoseiid predators *Typhlodromus pyri* Scheuten (Acari: Phytoseiidae) from English apple orchards. Ann. Appl. Biol. 103: 389-400.

Kapetanakis, E. G., T. M. Warman and J. E. Craham. 1986. Effects of permethrin sprays on the mite fauna of apple orchards. Ann. Appl. Biol. 108: 21-32.

Karadzhov, S. 1973a. The efficacy of Entobakterin against *Cydia pomonella*. Rastitelna Zashchita 21(2): 26-29.

Karadzhov, S. 1973b. The problem of harmful Acarina on apple. Rastitelna Zashchita (1973) 21 (11): 21-26 [R.A. E. 1975. Vol. 63(12)].

Karadzhov, S. 1974. Effectiveness of Entobakterin (*Bacillus thuringiensis* var. *galleriae*) against the codling moth (*Carpocapsa pomonella* L.). Gradinarska I Lozxarska Nauka 11(4): 53-60.

Kazmierczak, R. F. G. W. George and A. L. Knight. 1993. Economic effects of resistance and withdrawal of organophosphate pesticides on an apple production system. J. Econ. Entomol. 86: 684-696.

Kennedy, G. G. and E. R. Oatman. 1976. *Bacillus thuringiensis* and pirimicarb: selective insecticides for use in pest management of broccoli. J. Econ. Entomol. 69: 767-772.

Kholopov, P. S. 1978. Use of Entobakterin. Zashchita Rastenii No. 5: 13 [R. A. E. 1979. 67(5): 2070].

Kleimenova, V. A. 1970. Integrated control of apple codling moth. Sadovodstvo 12:13-14. [Horticultural abstracts (1971): 415713].

Knight, A. L., J. F. Brunner and D. Alston. 1994. Survey of azinphosmethyl resistance in codling moth (Lepidoptera: Tortricidae) in Washington and Utah. J. Econ. Entomol. 87: 285-292.

Knowles, B. H. 1994. Mechanism of action of *Bacillus thuringiensis* insecticidal δ-endotoxin. Advances in Insect physiology, 24: 275- 308.

Knowles, B. H. and J. A. T. Dow. 1993. The crystal δ-endotoxins of *Bacillus thuringiensis*: models for their mechanism of action on insect gut. BioEssays 15: 469-476.

Korchagin, V. N., 1983. Protection of orchards against pests and diseases (during and after flowering). Zashchita Rastenii No. 5: 54-56. [R. A. E. 1984. 72(10):6459].

Kreiter, S., D. Cotton, N. Baleste and N. Le Scolan. 1994. First insecticides resistance in *Typhlodromus pyri* Scheuten (Acari: Phytoseiidae) strains from French vineyards. *In* D. Kropczynska (ed.), Proceedings, second symposium of European Association of Acarologists, 31 August-5 September 1992, Krynica Poland. Warsa University Press, Poland.

Kuenen, D. J. 1958. Influence of sublethal doses of DDT upon the multiplication rate of *Sitophilus granarius* (Coleoptera: Curculionidae). Entomol. Exp. Appl. 1: 147-152.

Kumar, K. and R. B. Chapman. 1983. Toxicity of insecticides to diamondback moth *Plutella xylostella* (L.). N. Z. J. Experimental Agric. 11: 77-81.

Kumar, K. and R. B. Chapman. 1984. Sublethal effects of insecticides on the diamond moth, *Plutella xylostella* (L.). Pestic. Sci. 15: 344-352.

Kumar, K. and R. B. Chapman. 1985. Repellency and antifeedant activity of pyrethroids to diamondback moth. Proc. 36th N. Z. Weed and Pest Control Conf.

Kurstak, E. and P. Tinjssen, 1982. Microbial and viral pesticides: mode of action, safety and future prospects. pp. 3-34. *In* E. Kurstak (ed.) Microbial and viral pesticides. Marcel Dekker, Inc. New York and Basel.

Laing, D. R. and R. P. Jaques. 1980. Codling moth: Techniques for rearing larvae and bioassaying granulosis virus. J. Econ. Entomol. 73: 851-853.

Lama, F. M. 1990. Effectiveness of thuricide and its mixtures. Zashchita-Rastenii No. 12:17.

Lambert, B. and M. Peferoen. 1992. Insecticidal promise of *Bacillus thuringiensis* facts and mysteries about a successful bioinsecticide. BioScience 42: 112-121.

Laster, M. L. and J. R. Brazzel. 1968. A comparison of predator populations in cotton under different control programs in Mississippi. J. Econ. Entomol. 61: 714-719.

Lawson, D. S. and R. W. Weires. 1991. Management of European red mite (Acari: Tetranychidae) and several aphid species on apple with petroleum oils and insecticidal soap. J. Econ. Entomol. 84: 1550-1557.

Legner, E. F. and E. R. Oatman. 1964. Spiders on apple in Wisconsin and their abundance in a natural and two artificial environments. Can. Entomol. 96: 1202-1207.

Li, S. Y. and R. Harmsen. 1992. Effects of low application rates of the pyrethroid PP321 on the apple orchard mite complex (Acari) in Ontario. Can. Entomol. 124: 381-390.

Lienk, S. E. 1972. European red mite control on apple with early season sprays. J. Econ. Entomol. 65: 1684-1686.

Lindroth, R. L. 1989. Differential esterase activity in *Papilio glaucus* subspecies: absence of cross-resistance between allelochemicals and insecticides. Pestic. Biochem. Physiol. 35: 185-191.

Lindroth, R. L., B. D. Anson and A. V. Weisbrod. 1990. Effects of protein and juglone on gypsy moth: growth performance and detoxification enzyme activity. J. Chem. Ecol. 16: 2533-2547.

Luckey, T. D. 1968. Insect hormoligosis. J. Econ. Entomol. 61: 7-12.

Luo, S. B., P. J. Yan , Chai, C. J., S. P. Laing, Y. M. Zhang , Y. Zhang, and G. K. Le. 1986. Control of pink bollworm, *Pectinophora gossypiella* with *Bacillus thuringiensis* in cotton fields. Chinese J. Biol. control. 2(4) 167-169 [R. A. E. 1987 Vol. 75(5): 2465].

Luthy, P. and H. R. Ebersold. 1981. *Bacillus thuringiensis* delta-endotoxin: histopathology and molecular mode of action. pp. 235-267. *In* E. W. Davidson (ed.), Pathogenesis of invertebrate microbial diseases. Allenheld, Osmun and Co., Totowa, New Jersey.

Luthy, P., J. Cordier, and H. Fischer. 1982. *Bacillus thuringiensis* as a Bacterial Insecticide: Basic considerations and application. pp. 35-74. *In* E. Kurstak [ed.]. Microbial and viral pesticides. Marcel Dekker, Inc. New York and Basel.

Lynch, R. E., L. C. Lewis and E. C. Berry. 1980. Application efficacy and field persistence of *Bacillus thuringiensis* when applied to corn for European corn borer control. J. Econ. Entomol. 73: 4-7.

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

MacLellan, C. R. 1962b. Predator populations and predation on the codling moth in an integrated control orchard. Mem. Ent. Soc. Can. No. 32: 41-54.

MacLellan, C. R. 1973. Natural enemies of the light brown apple moth, *Epiphyas postvittana*, in the Australian Capital Territory. Can. Entomol. 105: 681-700.

Madge, P. E. 1972. A cooperative programme of research into the management of pome fruit pests in southern Australia: II. Reducing rate of insecticide as a first step in integrated control. Abstr. 14, Int. Congr. Ent. 237.

Malevez, N. 1978. Test of integrated control against the codling moth *Laspeyrsia pomonella* L. (Lepidoptera: Olethreutidae) by means of *Bacillus thuringiensis* Parasitica 34 (1):11-19.

Mansour, F. 1984. A malathion-tolerant strain of the spider *Chiracanthium mildei* and its response to chlorpyrifos. Phytoparasitica 12: 163-166.

Mansour, F. 1987. Spiders in sprayed and unsprayed cotton fields in Israel their interactions with cotton pests and their importance as predators of the Egyptian cotton leaf worm, *Spodoptera littoratis*. Phytoparasitica. 15(1): 31-41.

Mansour, F. and W. H. Whitecomb. 1986. The spiders of citrus grove in Israel and their role as biocontrol agents of *Ceroplastes floridensis*. Entomophaga 31: 269-276.

Mansour, F. and W. Nentwig. 1988. Effects of agrochemical residues on four spider taxa: laboratory methods for pesticide tests with web-building spiders. Phytoparasitica. 16(4): 317-325.

Mansour, F., D. Rosen, H. N. Plaut and Shulov. 1980a. A survey of spider populations (Araneae) in sprayed and unsprayed apple orchards in Israel and their ability to feed on larvae of *Spodoptera littoralis* (Boisd.). Acta Oecol. App. 1: 189-197.

Mansour, F. , D. Rosen, A. Shulov, H. N. Plaut. 1980b. Evaluation of spiders as biological control agents of *Spodoptera littoralis* larvae on apples in Israel. Acta. Oecol., Oecol. Appl. 1: 225-232.

Mansour, F. , D. Rosen, H. N. Plaut and Shulov. 1981. Effect of commonly used pesticides on *Chiracanthium mildei* and other spiders occurring on apple. Phytoparasitica 9(2): 139-144.

Mansour, N. A, M. E. Eldefrawi, A. Toppozada and N. Zeid. 1966. Toxicological studies on the Egyptian cotton leafworm, *Prodenia litura*. VI. Potentiation and antagonism of organophosphorous and carbamate insecticides. J. Econ. Entomol. 59: 307-311.

Marco, E. and M. I. Orus. 1991. Long-term effects of trichlorfon on the cyanobacterium Anabaena PCC 7119. Agric. Ecosys. & Environ. 39: 257-266.

Markwick, N. P. 1986. Detecting variability and selecting for pesticide resistance in two species of phytoseiids mites. Entomophaga 31: 225-236.

Matvievskij, A. S. 1967. The action of sevin on codling moth. Hort. Abs. 38 (1968): 692.

McEwen, F. L. et. al. 1960. Field tests with Bacillus thuringiensis Berliner for control of four lepidopterous pests. J. Insect Pathol. 2: 152-164.

McGuire, M. R., B. S. Shasha, L. C. Lewis and T. C. Nelsen. Residual activity of granular starch-encapsulated *Bacillus thuringiensis*. J. Econ. Entomol. 87(3): 631-637.

McMurtry, J. A. 1984. A consideration of the role of predators in the control of Acarine pests. pp. 109-121. *In* D. A. Griffiths and C. E. Bowman (eds.), Acarology VI (Vol. 1). John Wiley & Sons, New York.

McVay, J., R. R. T. Gudausks, and J. D. Harper. 1977. Effect of *Bacillus thuringiensis*-nuclear polyhedrosis virus mixtures on *Trichoplusia ni* larvae. J. Invertebr. Pathol.29: 367-372.

Messing, R. H. and B. A. Croft. 1990. NERISK: an expert system to enhance the integration of pesticides with arthropod biological control. Acta-Hortic. 276: 15-19.

Messing, R. H. and M. T. AliNiazee. 1988. Hybridization and host suitability of two biotypes of *Trioxys pallidus* (Hymenoptera: Aphididae). Ann. Entomol. Soc. Am. 81: 6-9

Miles, J. R. W. 1964. A new colorimetric method for determination of residues of guthion and ethyl guthion and their oxygen analogs. J. Assoc. Agric. Chem. 47: 882-885.

Mitsushashi, J. and T. D. D. Grace and D. F. Waterhouse. 1970. Effects of insecticides on cultures of insect cells. Ent. exp. & appl. 13: 327-341.

Moar, W. J. and J. T. Trumble. 1987. Biologically derived insecticides for use against beet armyworm. Calif. Agric. Nov.-Dec. 1987: 13-15.

Moffitt, H. R. and L. D. White. 1972. Susceptibility of gamma-irradiated and unirradiated codling moths to azinphosmethyl, carbaryl and DDT. J. Econ. Entomol. 65:1008-1010.

Moffitt, H. R. and P. H. Westigard. 1984. Suppression of codling moth ((Lepidoptera: Tortricidae) population on pears in southern Oregon through mating disruption with sex pheromones. J. Econ. Entomol. 77: 1513-1519.

Moffitt, H. R., K. D. Mantey and G. Tamaki. 1983. Effect of chitin-synthesis inhibitors on oviposition by treated adults and on subsequent egg hatch of the codling moth, *Cydia pomonella* (Lepidoptera: Olethreutidae). Can. Entomol. 115: 1659-1662.

Moffitt, H. R., K. D. Mantey and G. Tamaki. 1984. Effects of residues of chitin-synthesis inhibitors on egg hatch and subsequent larval entry of codling moth, *Cydia pomonella* (Lepidoptera: Olethreutidae). Can. Entomol.116: 1057-1062.

Moffitt, H. R., P. H. Westigard and D. O. Hathaway. 1978. Pheromonal control of the codling moth and biological control of pear psylla. Proc. Oreg. State Univ. Hort. Soc. 70: 95-96.

Moffitt, H. R., P. H. Westigard and K. D. Mantey. 1988. Resistance to diflubenzuron in the codling moth (Lepidoptera: Tortricidae). J. Econ. Entomol. 81: 1511-1515.

Mohamed, A. I. , S. Y. Young and W. C. Yearian. 1983a. Effect of microbial: chemical pesticide mixtures on *Heliothis virescens*. Environ. Entomol. 12: 478-481.

Mohamed, A. I. , S. Y. Young and W. C. Yearian. 1983b. Susceptibility of *Heliothis virescens* (F.) (Lepidoptera: Noctuidae) larvae to microbial agent-chemical pesticide mixtures on cotton foliage. Environ. Entomol. 12: 1403-1405.

Montoyama, N. , G. C. Rock and W. C. Dauterman. 1970. Organophosphorous resistance in an apple orchard population of *Amblyseius fallacis*. J. Econ. Entomol. 63(5): 1439-1442.

Moore, R. F. 1980. Behavioral and biological effects of NRDC-161 (insecticide) as factors in control of boll weevil (*Anthonomus grandis grandis*). J. Econ. Entomol. 73: 265-267.

Moore, A., and B. E. Tabashnik. 1989. Leg autotomy of adult diamondback moth (Lepidoptera: Plutellidae) in response to tarsal contact with insecticide residues. J. Econ. Entomol. 82: 381-384.

Moore, A., B. E. Tabashnik and M. D. Rethwisch. 1992. Sublethal effects of fenvalerate on adults of diamondback moth (Lepidoptera: Plutellidae). J. Econ. Entomol. 85(5): 1624-1627.

Moriarty, F. 1968. The toxicity and sublethal effects of P, P'-DDT and dieldrin to *Aglais urticae* L. (Lepidoptera: Nymphalidae) and *Chorthippus brunneus* Thunberg (Saltatoria: Acrididae). Ann. appl. Biol. 62: 371-393.

Moriarty, F. 1969. The sublethal effects of synthetic insecticides on insects. Biol. Rev. 44: 321-357.

Morris, O. N. 1972. Susceptibility of some forest insects to mixture of commercial *Bacillus thuringiensis* and chemical insecticides, and sensitivity of pathogen to insecticides. Can. Entomol.104: 1419-1424.

Morris, O.N. 1974. Effect of some chemical insecticides on the germination and replication of commercial *Bacillus thuringiensis*. J. Invertebr. Pathol. 26: 199-204.

Morris, O. N. 1975a. Susceptibility of the spruce budworm, *Choristoneura fumiferana* and white marked tussock moth, *Orgyia leucostigmata* to *Bacillus thuringiensis*: chemical insecticide combinations. J. Invertebr. Pathol. 26: 193-198.

Morris, O. N. 1975b. Effect of some insecticides on the germination and replication of commercial *Bacillus thuringiensis*. J. Invertebr. Pathol. 26: 199-204.

Morris, O.N. 1976. A 2-year study of the efficacy of *Bacillus thuringiensis*-chitinase combinations in spruce budworm (*Choristoneura fumiferana*) control. Can. Entomol. 108: 225-233.

Morris, O.N. 1977. Compatibility of 27 chemical insecticides with *Bacillus thuringiensis* var. *kurstaki*. Can. Entomol. 109: 855-864.

Morris, O.N. 1980. Protection of *Bacillus thuringiensis* from inactivation by sunlight. Can. Entomol. 115: 1215-1227.

Morris, O. N. 1983. Protection of *Bacillus thuringiensis* from inactivation by sunlight. Can. Entomol. 115: 1215-1227.

Morris, O. N. 1986. Susceptibility of the bertha armyworm, *Mamestra configurata* (Lepidoptera: Noctuidae), to commercial formulation of *Bacillus thuringiensis* var. *Kurstaki*. Can. Entomol.118: 473-478.

Morris, O. N. 1988. Comparative toxicity of delta-endotoxin and thuringiensin of *Bacillus thuringiensis* and mixtures of the two for the bertha armyworm (Lepidoptera: Noctuidae). Can. Entomol. 81 (1): 135-141.

Morris, O.N. and J. A. Armstrong, 1975. Preliminary field trials with *Bacillus thuringiensis*-chemical insecticide combinations in the integrated control of the Spruce Budworm, Choristoneura fumiferana (Lepidoptera: Tortricidae). Can. Ent. 107:1281-1288.

Morris, O.N., J. A. Armstrong and M. J. Hildebrand. 1977. Aerial field trials with a new formulation of *Bacillus thuringiensis* against the spruce budworm, *Choristoneura fumiferana* (Clem.). Inf. Ref. CC. X. Chem. Control. Res. Inst. 144: 23.

Morris, O.N., M. Trottier, N. B. McLaughlin and V. Converse. 1994. Interaction of caffeine and related compounds with *Bacillus thuringiensis* ssp. *kurstaki* in Bertha armyworm (Lepidoptera: Noctuidae). J. Econ. Entomol. 87(3): 610-617.

Mosievskaya, L. M. and E. M. Makarov. 1974. The effect of bacterial preparations on the parasites of codling moth. Zashchita Rastenii. No. 11: 25 [R. A. E. 1976 Vol. 64(10)].

Nahal-El, A. K. M., and M. A. Halfway. 1973. Bull. Entomol. Soc. Egypt 7: 431-434.

Narahashi, T. 1985. Mechanisms of action of pyrethroids on sodium and calcium channel gating. *In* M. G. Ford (ed.), Neuropharmacology and pesticide action. pp. 36-60

Nebert, D. W., J. E. Gielen and F. M. Goujon. 1972. Genetic expression of aryl hydrocarbon hydroxylase induction. III changes in the binding of n-octylamine to cytochrome P-450. Molecul. Phormacol. 8: 651.

Negm, A. A. and S. D. Hensley. 1969. Effects of insecticides on ant and spider populations in Louisiana Sugarcane fields. J. Econ. Entomol. 62: 948-949.

Nelson, M. J. 1970. DDT: a study of its role as an inducer of protein synthesis at the macromolecular level. Ed. No. XVI. New York: John Wiley & Son.

Niemczyk, E. 1980. Applying bacterial preparations against orchard pests, pp. 416-419. *In* K. Russ and H. Berger (eds.), Proceedings, Internat. Symposium of IOBC/WPRS on Integrated Control in Agriculture and Forestry. Vienna, 8-12

October 1979. Publ. Internat. Organization of Biological control of Noxious Animals and plants, Vienna, Austria.

Niemczyk, E. and B. Dawydko. 1970a. The effectiveness of Thuricide 90TS in the control of the codling moth (*Carpocapsa pomonella* L.) in field conditions. Roczniki Nauk Rolniczych, Series E. 1(1): 149-156. [R. A. E. 1973 Vol. 61 No.2: 460].

Niemczyk, E. and B. Dawydko. 1970b. The effectiveness of Thuricide 90TS and Entobakterin-3 for the control of rose Tortricid (*Cacoecia rosana* L.), the small ermine moth (*Hyponomeuta malinellus* Zell.) and the apple leaf skeletoniser (*Simaethis pariana* Clerk.) Roczniki Nauk Rolniczych, Series E. 1(1) 103-117.

Niemczyk, E., R. Olszak, and M. Miszcak. 1976. The effectiveness of the bacterial preparation Dipel in controlling the codling moth (*Laspeyrsia pomonella* L.) and Leafrollers (Tortricidae) during summer period. [R. A. E. 1977. 65(8): 4467].

Nishimura, K. and T. Fujita. 1991. Insecticidal and sodium-current activities of pyrethroids and their quantitative structure-activity relationships. pp. 219-230. *In* E. Hodgson, R. M. Roe and N. Motoyama (eds.), Pesticides and the future: toxicological studies of risks and benefit. Vol. 2. North. Carolina State Univ. Raleigh. .

Novotny, J. and M. Svestka. 1986. Synergism of biological and chemical insecticides against larvae of the gypsi moth *Lymantria dispar* (L.). [R. A. E. 76(12): 9143].

Nyouki, F. F. R. and J. R. Fuxa. 1994. Persistence of natural and genetically engineered insecticides based on *Bacillus thuringiensis*. J. Entomol. Sci. 29(3): 347-356.

Nyouki, F. F. R., J. R. Fuxa and A. R. Richter. 1996. Spore-toxin interaction and sublethal effects of *Bacillus thuringiensis* in *Spodoptera frugiperda* and *Pseudoplusia includens* (Lepidotera: Noctuidae). J. Entomol. Sci. 31: 52-62.

O'Brien, R. D. 1967. Insecticides, action and metabolism. Academic Press, New York.

Overmeer, W. P. J. 1985. Alternative prey and other food resources, pp. 131-140. *In* W. Helle and M. W. Sabelis (eds.), Spider mites their biology, natural enemies and control, vol. 1B. Etsevier, Amsterdam, The Netherlands.

Parent, B. 1967. Population studies of phytophagous mites and predators of apple in southwestern Quebec. Can. Entomol. 99: 771-778.

Parrella, M. P., J. P. McCaffrey and R. L. Horsburgh. 1981. Population trends of selected phytophagous arthropods and predators under different pesticide programs in Virginia apple orchard. J. Econ. Entomol. 74: 492-498.

Peferoen, M. 1991. *Bacillus thuringiensis* in crop protection. Agro Food Industry Hi-Tech 6: 5-9.

Penman, D. R., and R. B. Chapman. 1980. Wooly apple aphids outbreak following use of fenvalerate in apples in Canterbury, New Zealand. J. Econ. Entomol. 73: 49-51.

Penman, D. R., R. B. Chapman and K. E. Jesson. 1981. Effects of fenvalerate and azinphosmethyl on two-spotted spider mite and phytoseiid mites. Ent. Exp. & Appl. 30: 91-97.

Petersen, R. G. 1985. Design and analysis of experiments. Marcel Dekker, New York.

Pfimmer, T. R. 1964. Populations of certain insects and spiders on cotton plants following insecticide applications. J. Econ. Entomol. 57: 640-644.

Pickel, C., R. S. Bethell and W. W. Coates. 1986. Codling moth management using degree days. Univ. Calif. Integr. Pest Manage. Publ. 4.

Polesny, F. 1990. Spiders-their importance and influence in agriculture. Pflanzenschutz-wien 4: 7-8.

Pratt, G. E. 1975. Inhibiting of juvenile hormone carboxyesterase of locust haemolymph by organophosphates *in vitro*. Insect Biochem. 5: 595-607.

Pree, D. J. and E. A. G. Hagley. 1977. Toxicity of some insecticides to eggs of the oriental fruit moth and codling moth. Proc. Ent. Soc. Ont. 108: 69-77.

Pree, D. J., D. E. Archibald and R. K. Morrison. 1989. Resistance to insecticides in the common green lacewing *Chrysopa carnea* (Stephens)(Neuroptera: Chrysopidae) in southern Ontario. J. Econ. Entomol. 82: 29-34.

Pristavko, V. P. 1967. On the use of *Bacillus thuringiensis* Berliner - insecticide combinations to control insect pests. pp. 26-75. *In* P. A. Van Der Laan (ed.), Insect Pathology and Microbial control. Proc. International Colloquium on Insect Pathology and Microbial control, Wageningen, The Netherlands.

Pristavko, V. P and N. V. Dovzhenok. 1974. Ascorbic acid influence on larval blood cell number and susceptibility to bacterial and fungal infection in the codling moth, *Laspeyresia pomonella* (Lepidoptera: Tortricidae). J. Invert. Path. 24: 165-168.

Prokopy, R. J., W. M. Coli and R. G. Hislop. 1980. Sampling methods and provisional economic threshold levels for major apple insects and mite pests in Massachusetts. Mass. Fruit Notes 45: 6-10.

Prokopy, R. J., W. M. Coli, G. E. Morin and R. Spitko. 1986. Synthetic pyrethroids: benefits versus biological costs in fruit management. Mass. Fruit Notes 51: 6-8.

Proverbs, M. D., J. R. Newton and D. M. Logan. 1966. Orchard assessment of the sterile male technique for control of the codling moth, *Carpocapsa pomonella* (L.) (Lepidoptera: Olethreutidae). Can. Entomol. 98: 90-95.

Purcell, M. and J. Granett. 1986. Differential age susceptibility of the codling moth (Lepidoptera: Tortricidae) to chitin synthesis inhibitors and thuringiensin. J. Econ. Entomol. 79: 1624-1626.

Putman, W. 1963. The codling moth, *Carpocapsa pomonella* (Lepidoptera: Tortricidae): a review with special reference to Ontario. Proc. Ent. Soc. Ont. 93(1962): 22-60.

Putman, W. L. 1967. Prevalence of spiders and their importance as predators in Ontario peach orchards. Can. Entomol. 99: 160-170.

Putman, W. L. 1970. Life history and behavior of *Balaustium putmani* (Acari: Erythraeidae). Ann. Ent. Soc. Am. 63: 76-81.

Reed, D. K., N. J. Tromley and G. A. Reed. 1985. Activity of avermectin B1 against codling moth (Lepidoptera: Olethreutidae). J. Econ. Entomol. 78: 1067-1071.

Reissig, W. H., B. H. Stanley, M. E. Valla, R. C. Seem and J. B. Bourke. 1983. Effects of surface residues of azinphosmethyl on apple maggot behavior, oviposition and mortality. Environ. Entomol. 12: 815-822.

Reissig, W. H., B. H. Stanley, W. L. Roelofs and M. R. Schwarz. 1985. Tests of synthetic apple volatile in traps as attractants for apple maggot flies in commercial apple orchards. Environ. Entomol. 14: 55-59.

Reissig, W. H., R. W. Weires, G. C. Forshey, W. L. Roclofs, R. C. Lamb and H. S. Aldwinckle, 1984. Insect management in disease-resistant dwarf and semi-dwarf apple trees. Environ. Entomol. 13: 1201-1207.

Richmond, J. A., A. B. DeMilo, H. A. Thomas and A. B. Bofkovec. 1978. Mortality and sterility of southern pine beetle treated with chemosterilants and growth regulators. J. Ga. Entomol. Sco. 13: 237-240.

Richter, A. R. and J. R. Fuxa. 1984. Pathogen-pathogen and insecticides interactions in velvetbean caterpillar (Lepidoptera: Noctuidae). J. Econ. Entomol. 77: 1559-1564.

Riddick, E. W. and N. J. Mills. 1994. Potential of adult carabids (Coleoptera: Carabidae) as predators of fifth-instar codling moth (Lepidoptera: Tortricidae) in apple orchards in California. Environ. Entomol. 23(5) 1338-1345.

Riechert, S. E. and T. Lockley. 1984. Spiders as biological control agents. A. Rev. Ent. 29: 299-320.

Riedl. H. 1991. Beneficial arthropods for pear pest management. pp. 101-118. *In* K. Williams (ed.), New directions in tree fruit pest management. Good Fruit Grower, Yakima, Washington.

Riedl, H. and S. A. Hoying. 1980. Impact of fenvalerate and diflubenzuron on target and non-target arthropod species on Barlett pears in northern California. J. Econ. Entomol. 73: 117-122.

Riedl. H. and W. Loher. 1984. Circadian control of oviposition in the codling moth, *Laspeyresia pomonella*, Lepidoptera: Olethreutidae. Ent. exp. & appl. 27: 38-49.

Riedl. H., A Seaman, and F. Henrie. 1985. Monitoring susceptibility to azinphosmethyl in field populations of the codling moth (Lepidoptera: Tortricidae) with pheromone traps. J. Econ. Entomol. 78: 692-699.

Riedl. H., J. Halaj, W. B. Kreowski, R. J. Hilton and P. H. Westigard. 1995. Laboratory evaluation of mineral oils for control of codling moth ((Lepidoptera: Tortricidae). J. Econ. Entomol. 88: 140-147.

Riedl. H., L. A Hanson and A. Seaman. 1986. Toxicological response of codling moth (Lepidoptera: Tortricidae) populations from California and New York to azinphosmethyl. Agri. Ecosys. & Environ. 16: 189-201.

Robb, K. L. and M. P. Parrella. 1984. Sublethal effects of two insect growth regulators applied to larvae of *Liriomyza trifolii* (Diptera: Agromyzidae). J. Econ. Entomol. 77: 1288-1292.

Robertson, J. L. And K. C. Smith. 1984. Joint action of pyrethroids with organophosphorous and carbamate insecticides applied to Western Spruce Budworm (Lepidoptera: Tortricidae). J. Econ. Entomol. 77 (1): 16-22.

Rock, G. C. 1979. Relative toxicity of two synthetic pyrethroids to a predator *Amblyseius fallacis* and its prey *Tetranychus urticae*. J. Econ. Entomol. 72: 293-294.

Rock, G. C. and P. L. Shaffer. 1983. Development rate of codling moth (Lepidoptera: Olethreutidae) reared on apple at four constant temperatures. Environ. Entomol. 12: 831-834.

Roehrich, R. 1964. A comparative study of the sensitivity of three Lepidoptera (Tortricoidea) to commercial preparations of *Bacillus thuringiensis* Berliner. J. Insect. Pathol. 6: 186-197.

Ross, D. C. and T. M. Brown. 1982. Inhibition of larval growth in *Spodoptera frugiperda* by sublethal dietary concentrations of insecticides . J. Agric. Food Chem. 30: 193-196.

Ruscoe, C. N. E. 1977. The NRDC pyrethroids as agricultural insecticides. Pestic. Sci. 8: 236-242.

Salama, H. S. and F. N. Zaki. 1984. Impact of *Bacillus thuringiensis* Berliner on the predator complex of *Spodoptera littoralis* (Boisd.) in cotton field. Z. ang. Ent. 97: 485-490.

Salama, H. S., F. N. Zaki and A. El-Sharaby. 1982. Effect of *Bacillus thuringiensis* Berl. on parasite and predators of the cotton leafworm *Spodoptera littoralis* (Boisd.). Z. ang. Ent. 94: 498-504.

Salama, H. S., M. S. Foda and A. El. Sharaby. 1981. Potency of spore-δ-endotoxin complexes of *Bacillus thuringiensis* against some cotton pests. Z. ang. Ent. 91: 388-398.

Salama, H. S., M. S. Foda, F. N. Zaki, and S. Moawad. 1984. Potency of combination of *Bacillus thuringiensis* and chemical insecticides on *Spodoptera littoralis* (Lepidoptera: Noctuidae) J. Econ. Entomol.77:885-890.

Salisberg, W, R. Newmann and G. Voss. 1980. Chlordimeform mode of toxic action in various developmental stages of *Spodoptera littoralis*. J. Econ. Entomol. 73: 193-196.

Salkeld, E. H. and C. Potter. 1953. The effect of age and stage of development of insect eggs on their resistance to insecticides Bull. Entomol. Res. 44: 527-589.

Smith, E. H. and E. H. Salkeld. 1966. The use and action of ovicides. Annu. Rev. Entomol. 11: 331-368.

Sanford, K. H. 1983. An overview of insecticide and miticide evaluation on apple and pear, pp. 31-37. *In* Annual report 1982, Agriculture Canada Research Station, Kentville, Nova Scotia.

Sanford, K. H. 1984. Overview of 1983 insecticide and miticide evaluation on apple and pear, pp. 61-69. *In* Annual report 1983, Agriculture Canada Research Station, Kentville, Nova Scotia.

Sanford, K. H. 1985. Overview of 1984 insecticide and miticide evaluation on apple and pear, pp. 59-65. *In* Annual report 1984, Agriculture Canada Research Station, Kentville, Nova Scotia.

Sanford, K. H. 1986. Overview of 1985 insecticide and miticide evaluation on apple and pear, pp. 85-92. *In* Annual report 1985, Agriculture Canada Research Station, Kentville, Nova Scotia.

Setyobudi, L. 1990. Seasonality of codling moth, *Cydia pomonella* L. (Lepidoptera: Olethreutidae) in the Willamette Valley of Oregon: Role of photoperiod and temperature. Ph.D. Thesis, Oreg. State Univ., Corvallis.

Shelton, A. M., J. L. Robertson and J. D. Tang. 1993. Resistance of diamondback moth (Lepidoptera: Plutellidae) to *Bacillus thuringiensis* subspecies in the field. J. Econ. Entomol. 86(3): 697-705.

Smirnoff, W. A. 1983. Residual effects of *Bacillus thuringiensis* and chemical insecticide treatments on spruce budworm (*Choristoneura fumiferana* Clemens). Crop Prot. 2: 225-230.

Smith, E. H. and E. H. Salkeld. 1966. The use and action of ovicides. Ann. Rev. Entomol. 11: 331-368.

Sogoyan, R.(1969). Tests of Entobakterin for control of the codling moth in the Black Sea area. Byull. Vses. nauchno-issled. Inst. Zashch. Rast.3 (11) pp.45-48.

Sogoyan, R. S. and G. A. Slobodyanyuk. 1980. Are bacterial-insecticide mixtures effective? Zashchita Rastenii No.7: 28 [R.A.E.1981 69(3)].

Somerville, H. J., Y. Tanada and E. M. Omi. 1970. Lethal effect of purified spore and crystalline endotoxin preparation of *Bacillus thuringiensis* on several lepidopterous insects. J. Invertebrate Pathol. 16: 241-248.

Soria, S., C. Herranz, C. F. Sanchez-Herrera, E. Obama and F. S. Herrera. 1988. Trial of effectiveness of chitin synthesis inhibiting biological and pyrethroid product against *Lymantria monacha* (L.) (lepidoptera: Lymantriidae), a dangerous

defoliator of *Pinus sylvestris* L. Boletin-de-SanidadVegtal, Plages, 14(1): 149-155.

Stewart, J. G. and B. J. R. Philogene. 1983. Sublethal effects of fenitrothion on the development of a parental generation of *Manduca sexta*. Entomol. Exp. Appl. 33:314-319.

Strapazzon, A. and L. Dalla Monta . 1986. *Bacillus thuringiensis* Berliner and traditional products in an apple orchard. Summer control of the fruit feeders and side-effects on mites. Atti Giornate Fitopatologiche.1: 41-51. (R.A.E.1988 76(3): 1110.

Streibert, H. P. and V. Dittrich. 1977. Toxicological response of insect eggs and larvae to saturated atmosphere of chlordimeform. J. Econ. Entomol. 70: 57-59.

Strickler, K. and B. A. Croft. 1981. Variation and azinphosmethyl resistance in populations of *Amblyseius fallacis*. Environ. Entomol. 10: 233-236.

Strickler, K. and B. A. Croft. 1982. Selection for permethrin resistance in the predatory mite *Amblyseius fallacis*. Entomologia exp. appl. 31: 339-345.

Staubli, A., M. Hachler, P. Antonin and C. Mittaz. 1984. Tests de novicite de divers pesticides envers les enemis naturels des principaux ravageurs de vergers de poiriers en Suisse romande. Revue suisse Vitic. Arboric. Hortic. 16: 279-286.

Sutter, G. R., A. D. Abrahamson, E. W. Hamilton and I. D. Bick. 1971. Compatibility of *Bacillus thuringiensis* var. *thuringiensis* and chemical insecticides. I. Effect of insecticides on bacterial replication rate. J. Econ. Entomol. 64: 1348-1350.

Talitskii, V. I. and V. S. Kondrya 1970. The effect of Entobakterin on the beneficial-insect fauna. Zoologicheskii Zhurnal 49(7): 992-1000. [R. A. E. 1972. 60: 4461].

Talton, M. T. and S. M. Khan. 1978. Effects of fenitrothion and aminocarb, at doses giving low mortality, on surviving eggs and larvae of the eucalypt-defoliating chrysomelid beetle *Paropsis atomaria* OI.I. methods, mortality and relative toxicity. Aust. J. Zool. 26: 121-126.

Tamashiro, M. and M. J. Sherman. 1955. Direct toxicity of insecticides to oriental fruit fly larvae and their internal parasites. J. Econ. Entomol. 48: 75-79.

Tan, K. 1981. Antifeeding effect of cypermethrin and permethrin at sublethal levels against *Pieris brassicae* larvae. Pestic. Sci. 12: 619-626.

Tanigoshi, L. K., S. C. Hoyt and B. A. Croft. 1983. Basic biology and management components for mite pests and their natural enemies. pp. 153-202. *In* B. A. Croft and S. C. Hoyt (Eds.), Integrated management of insect pests of pome and stone fruits. Wiley, New York.

Telenga, N. A. and N. P. Dyadechko. 1957. Manuscript Coll. C. I. L. B. on the population dynamics and biological control of the potato beetle (*Leptinotarsa decemlineata*), Hamburg, Cit. Muller-Kogler(1965).

Telfer, W. H. 1965. The mechanism and control of yolk formation. Ann. Rev. Ent. 10: 161-184.

Terriere, L. C. 1983. Enzyme induction, gene amplification and insect resistance to insecticides. pp. 265-297. *In* G. P. Georghiou and T. Saito (eds.), Pest resistance to insecticides. Plenum Press, New York.

Terriere, L. C. 1984. Induction of detoxification enzymes in insects. Ann. Rew. Entomol. 29: 71-88.

Theiling, K. M. 1987. The SELCTV database: the susceptibility of arthropod natural enemies of agricultural pests to pesticides. MS thesis, Oreg. State Univ. Corvallis, 170 pp.

Theiling, K. M. and B. A. Croft. 1988. Pesticide side effects on arthropod natural enemies: a database summary. Agric., Ecosys. Environ. 21: 191-218.

Thwaite, W. G. 1976. Effect of reduced dosage of azinphosmethyl on control of codling moth, *Cydia pomonella* (L.)., and light-brown apple moth, *Epiphyas postvittana* (Walk.), in an apple orchard. Z. Ang. Ent. 80: 94-102.

Thwaite, W. G. 1984. Laboratory evaluation of insecticides for the control of codling moth, *Cydia pomonella* (L.). in apples. Proc. 4th Aust. Appl. Ent. Res. Conf. Adelaide, S. A. pp 238-243.

Tkachev, V. M. 1986. Protection of apple. Zashchita Rastenii No. 5: 24-25. [R. A. E. 1989 Vol.77(10): 7673].

Tkachev, V. M. and L. Romanova. 1985. Economic effectiveness of biopreparations. Zashchita Rastenii No. 6: 10-12. [R. A. E. 1985. 73 (3):6930]

Tkachev, V. M., A. Yu. Karabash and Yu. I. Prikhodko. 1975. Entobakterin had no effect. Zashchita Rastenii No. 9: 11. [R. A. E. 1977. 65(1): 274].

Toba, H. H. and J. F. Howell. 1992. An improved system for mass-rearing codling moth. J. Entomol. Soc. B. C. 88: 22-27.

Tolstova, Yu. S. and N. M. Atanov. 1976. Ovicidal activity of insecticides and acaricides on the codling moth (*Laspeyresia pomonella* L.). Doklady Vsesoyuznoi Ordena Lenina Akademii Sel'skokhozyaistvennykh Nauk Imeni v. I. Lenina, No. 4, pp. 22-23.

Tomova, A. and I. Rangelova. 1977. Control of the codling moth by biological means. Rastitelna Zashchita No. 7: 25-26. [R. A. E. 1978 Vol. 66 (4):2057].

Tompkins, G. J., J. J. Linduska, J. M. Young and E. M. Dougherty. 1986. Effectiveness of microbial and chemical insecticides for controlling cabbage looper (Lepidoptera: Noctuidae) and imported cabbageworm (Lepidoptera: Pieridae) on collards in Maryland. J. Econ. Entomol. 79: 497-501.

Trudgill, P. W., R. Widdus and J. S. Rees. 1971. Effects of organochlorine insecticides on bacterial growth, respiration and viability. J. Gen. Microbiol. 69: 1-13.

Turunen, S. 1975. Effects of gamma-BHC on lipid digestion and utilization in *Pieris brassicae* (Lepidoptera: Pieridae) reared on an artificial diet. Ann. Zool. Fenn. 12: 275-279.

Turunen, S. 1977. Food utilization and esterase activity in Pieris brassicae during chronic exposure to lindane containing food. Ent. exp. & appl. 21: 254-260.

Umarov, S. A., Nilova, G. N. and T. D. Davlyatov. 1975. The effects of Entomobakterin and Dendrobacillin on beneficial arthropods. Zash. Rast. 3: 25-26.

Vaeck, M., A. Reynaerts, H. Hofte, S. Jansens, M. De Baukeleer, C. Dean, M. Zabeau, M. Van Montagu and J. Leemans. 1987. Transgenic plants protection from insect attack. Nature (London), 328: 33-37.

Vail, P. V., C. F. Sohoo, R. S. Seay, R. G. Killiner and W. W. Wolf. 1972. Microbial control of lepidopterous pests of fall lettuce in Arizona and effects of chemical and microbial pesticides on parasitoids. Environ. Entomol. 1: 780-785.

Vail, P. V., J. S. Tebbets, D. F. Hoffmann and a. M. Dandekar. 1992. Response of production and storage walnut pests to *Bacillus thuringiensis* insecticidal crystal protein fragments. Biological Control 1: 329-333.

Vail, P. V., R. E. Seay and J. DeBolt. 1980. Microbial and chemical control of the cabbage looper on fall lettuce. J. Econ. Entomol. 73: 72-75.

Vail, P. V., W. Barnett, D. C. Cowan, S. Sibbett, R. Beede and J. S. Tebbets. 1991. Codling moth (Lepidoptera) control on commercial walnuts with a granulosis virus. J. Econ. Entomol. 84: 1448-1453.

Valentin, G. 1993. Les typhlodromes. Des acariens utiles pour le vigneron. Vigneron Champenois 6: 24-49.

Van der Geest, L. P. S. 1971. Use of *Bacillus thuringiensis* for control of orchard pests. Z. Angew. Entomol. 69: 263-266.

Varela, L. and S. C. Welter, V. P. Jones, V. P. Jones, J. F. Brunner and H. Riedl. 1993. Monitoring and characterization of insecticide resistance in codling moth (Lepidoptera: Tortricidae) in four western states. J. Econ. Entomol. 86: 1-10.

Varela, L. and S. C. Welter 1990. Codling moth resistance in pear orchards in California. pp. 40-41. *In* research reports: 64th annual western orchard pest and disease management conference, Imperial Hotel, Portland, Oregon. January 10-12, 1990.

Vidal, C. and S. Kreiter. 1995. Resistance to a rang of insecticides in the predacious mite *Typhlodromus pyri* Scheuten (Acari: Phytoseiidae): inheritance and physiological mechanisms. J. Econ. Entomol. 88(5): 1097-1105.

Videnova, E. and Kh. Ismail. 1985. Application of the bacterial Dipel in the control of codling moth, (*Laspeyresia pomonella* L.) Pochvoznanie-Agrokhimiya-i Rastitelna-Zashchita 20:(5): 90-98.

Walker, J. T. S. and D. R. Penman. 1978. Integrated control of apple pests in New Zealand. 11. The influence of field applications of azinphosmethyl on predation of European red mite by *Typhlodromus pyri*. Proc. N. Z. Weed and Pest Control Conf. pp. 208-213.

Walters, P. J. 1976a. Susceptibility of three *Stethorus* spp. (Coleoptera: Coccinellidae) to selected chemical used in N. S. W. Apple orchards. J. Aust. Entomol. Soc. 15: 49-52.

Walters, P. J. 1976b. Effect of five acaricides on *Tetranychus urticae* (Koch) and it predator *Stethorus* spp. (Coleoptera: Coccinellidae) in an apple orchard. J. Aust. Entomol. Soc. 15: 53-56.

Wearing, C. H. 1975. Integrated control of apple pests in New Zealand. 3. Natural mortality of fifth instar larvae of the codling moth, Laspeyresia pomonella tagged with cobalt-58 in relation to their distribution. N. Z. J. Zool. 2: 151-168.

Wearing, C. H. 1979. Integrated control of apple pests in New Zealand.10. Population dynamics of codling moth in Nelson. N. Z. J. Zool. 6: 165-199.

Wearing, C. H. and W. P. Thomas. 1978. Integrated control of apple pests in New Zealand 13. Selective insect control using diflubenzuron and *Bacillus thuringiensis*. Proc. 31st N. Z. Weed and Pest control Conf. pp 221-235.

Weires, R. W. and G. L. Smith. 1978. Apple mite control in Hudson Valley. 1977 Insecticides and Acaricide Tests. Entomol. Soc. Am. Misc. Publ. 3: 42-43.

Welter, S. C., L. Varela and R. Freeman. 1991. Codling moth resistance to azinphosmethyl in California. Resist. Pest Manag. Newsl. 3: 12.

Westigard, P. H. 1973. The biology and effect of pesticides on *Deraecoris brevis piceatus* (Heteroptera: miridae). Can. Entomol. 105: 1105-1111.

Westigard, P. H. 1979. Codling moth: control on pears with diflubenzuron and effects on non-target pest and beneficial species. J. Econ. Entomol. 72: 552-554.

Westigard, P. H. and L. J. Gut 1986. Codling moth ((Lepidoptera: Tortricidae) control on pears with modified programs using growth regulators. J. Econ. Entomol. 79: 247-249.

Westigard, P. H., L. Gentner and B. A. Butt. 1976. Codling moth: eggs and first-instar mortality on pear with special reference to varietal susceptibility. Environ. Entomol. 5: 51-54.

Westigard, P. H., L. J. Gut and W. J. Liss. 1986. Selective control program for the pear pest complex in southern Oregon. J. Econ. Entomol. 79: 250-257.

Westigard, P. H., P. B. Lombard and D. W. Berry. 1979. Integrated pest management of insects and mites attacking pears in southern Oregon. Oreg. Agric. Exp. Stn. Bull. 634.

Wieser C. J. 1985. Techniques of foliate protection and population management: application technology. Proc. Spruce Budworms Res. Symposium, CANUSA.

Wigglesworth, V. B. 1965. The principles of insect physiology. Methuen and Co. Ltd. London.

Wildbolz, Th. 1958. Uber die orientierung des apfelwicklers bei der eiablage. Mitt. Schweiz. Ent. Ges. 31: 25-54.

Wilkinson, J. D., K. D. Biever. and C. M. Ignoffo. 1975. Entomophaga 20: 113-120.

Willett, M. and P. H. Westigard. 1988. Using horticultural spray oils to control orchard pests. Pacific Northwest Coop. Ext. Bull. 328. 8p.

Williams, C. S. and R. A. Chung. 1987. Ultrastructural effects of DDT on cells grown *in vitro*. J. Environ. Path. Toxicol. Oncol. 7: 35-58.

Williams, D. G. and G. M. McDonald. 1982. The duration and number of the immature stages of codling moth *Cydia pomonella* (L.) (Lepidoptera: Tortricidae). J. Aust. Ent. Soc. 21: 1-4.

White, N. D. G. and J. E. Laing. 1977. Field observations of *Zetzella mali* (Ewing) (Acarina: Stigmaeidae) in southern Ontario apple orchards. Proc. Ent. Soc. Ont. 108: 23-30.

Wong, S. W. and R. B. Chapman. 1979. Toxicity of synthetic pyrethroid insecticides to predaceous phytoseiid mites and their prey. Aust. J. Agric. Res. 30: 497-501.

Wongkobrat, A. and D. A. Dahlman. 1976. Larvae *Manduca sexta* haemolymph carboxyesterase activity during chronic exposure to insecticide-containing diets. J. Econ. Entomol. 69: 237-240.

Woolhouse, M. E. J. and R. Harmsen. 1984. The mite complex on the foliage of a pesticide-free apple orchard: population dynamics and habitat associations. Proc. Ent. Soc. Ont. 115: 1-11.

Yamamoto, T. and R. E. McLaughlin. 1981. Isolation of protein from the parasporal crystal of *Bacillus thuringiensis* var. *kurstaki* toxic to the mosquito larvae, *Aedes taeniorhynchus*. Biochem. Biophys. Res. Commun. 103: 414-421.

Yeh, R. , A. Whipp, and J. P. Trijau. 1986. Diamondback moth resistance to synthetic pyrethroids: how to overcome the problem with deltamethrin. *In* Diamondback Moth Management. Proc. First International Workshop, Taiwan. [R. A. E. 1987. 75(4): 1890].

Yokoyama, V. Y. and J. Pritchard. 1984. Effect of pesticides on mortality, fecundity, and egg viability of *Geocoris pallens* (Hemiptera: Lygaeidae). J. Econ. Entomol. 77: 876-879.

Zacharda, M. and M. Hluch. 1991. Long-term residual efficacy of commercial formulations of pesticides to *Typhlodromus pyri* Scheuten (Acari: Phytoseiidae) inhibiting commercial vineyards. Exp. Appl. Acarol. 13: 27-40.

Zar, J. H. 1984. Biostatistical analysis. Prentice-Hall, Englewood Cliffs, N. J. 718 pp.

Zettler, J. L. and G. L. Lecato. 1974. Sublethal doses of malathion and dichlorphos: effects on fecundity of the black carpet beetle. J. Econ. Entomol. 67: 19-21.

Zwick, R. W. and G. J. Fields. 1978. Field and laboratory evaluations of fenvalerate against several insect and mite pests of apple and pear in Oregon. J. Econ. Entomol. 71: 793-796.