AN ABSTRACT OF THE THESIS OF

Juma M. Katundu for the degree of Master of Science in Entomology presented on August 25, 1986.

Title: Status, Distribution and Seasonal Variation of Filbert Aphid Resistance to Selected Insecticides in the Willamette Valley, Oregon

Abstract approved: ____________________
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Levels of resistance to six selected insecticides of eleven field populations of the filbert aphid *Myzocallis coryli* (Goetze) were determined by using the leaf-dip residue technique. Test insecticides included compounds widely used in commercial filbert orchards, namely, carbaryl, diazinon, endosulfan, phosalone, fenvalerate and oxydemetonmethyl. Aphid samples were collected within a 100-mile range from Eugene in the south to Wilsonville in the north of the Willamette Valley, Oregon. The filbert orchards were characterized by different levels of insecticide exposure, age and management conditions. The tests were conducted to detect seasonality of resistance during the different phases of the population in the summer, fall and early spring months of 1985-1986.

Toxicological responses of various filbert aphid populations exhibited significantly different resistance to tested insecticides. All populations exhibited lethal concentration ($Lc_{50}$) values of 0.0013 g AI/l to 0.1507 g AI/l of endosulfan which, when compared to the susceptible OSU population, were categorized as zero to moderate levels of resistance. With the exception of a high $Lc_{50}$ value of 1.7853 g AI/l exhibited by the Harnisch population, resistance to diazinon is still at low levels or non-existent in most populations of _M. coryli_ in the Willamette Valley. $Lc_{50}$ values of carbaryl varied from 0.0075 g AI/l to more than 1.2 g AI/l, indicating significant differences in tolerance among the filbert aphid populations to this insecticide. The majority of the populations were moderately resistant, but extremely high levels ( >1000-fold) of resistance were evident in populations collected from two orchards. $Lc_{50}$ values for these populations were well above the maximum range of recommended field dosages. Highest resistance levels of more than 1000-fold of fenvalerate also were noticed in filbert aphid populations from these orchards; $Lc_{50}$'s were more than the maximum field rate. Populations of _M. coryli_ from other orchards were non-resistant ($Lc_{50}$ value of 0.0003 g AI/l) to highly resistant ($Lc_{50}$ value of 0.0989 g AI/l) to fenvalerate. Selection for high resistance to fenvalerate after just a few seasons of use in commercial orchards was not expected. Although failure of field control of filbert aphids by phosalone has not been reported, several populations have developed high resistance to this insecticide. Filbert aphid populations from three orchards had $Lc_{50}$'s above the maximum recommended field dosage of 0.563 g AI/l of phosalone. The maximum $Lc_{50}$ values for the rest of the populations ranged from 0.0012 g AI/l to 0.2499 g AI/l and were categorized respectively, as non-resistant to highly resistant strains. From one series of experiments in early spring of 1986, the majority of filbert aphid populations indicated zero to moderate levels of resistance to oxydemetonmethyl. One population with $Lc_{50}$ value of 0.2135 g AI/l showed the highest tolerance to this insecticide.

The shallow slopes of the log dosage mortality curves indicated heterogeneity of responses of the various filbert aphid populations to the insecticides. These responses could be explained by the widespread use and rotational spraying patterns of the insecticides in commercial orchards.

The distribution of resistance was not a regional phenomenon. It was associated with, 1) the pattern of insecticide usage and 2) the proximity of the source of aphid population to more intensively managed commercial orchards.

The tendency for increased resistance to all insecticides in summer and fall populations of *M. coryli* was evident. However, as an exception, phosalone resistance of Lemert population was also high when treated in early spring. Seasonal variations in susceptibility of less than 10-fold to endosulfan, and 237-fold to diazinon were measured. Extrapolation of $Lc_{50}$ values beyond the range of tested concentrations resulted in variations in tolerance of more than 1000-fold among some populations treated with carbaryl, phosalone and fenvalerate.

Several factors which may influence the widespread expression and the seasonality of insecticide resistance have been discussed without giving a generalized explanation. Rather than considering these results quantitatively, what is vital from the present studies is the information on changes in susceptibility of *M. coryli* to those insecticides recommended to filbert growers in this area. Resistance monitoring is considered critical to effective insect control programs in commercial filbert orchards of the Willamette Valley, Oregon.

# STATUS, DISTRIBUTION AND SEASONAL VARIATION OF FILBERT APHID RESISTANCE TO SELECTED INSECTICIDES IN THE WILLAMETTE VALLEY, OREGON

by

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## INTRODUCTION

*Corylus avellana* L., the commercial filbert (hazelnut) is the most important nut crop in the Pacific Northwest, and its production is concentrated in the Willamette Valley of Oregon. This region alone contributes over 95 percent of the crop produced in the United States. The production area is increasing from year to year and the present estimates indicate an acreage of more than 14,000 hectares (Ali Niazee 1985). Like other agricultural systems, the filbert ecosystem has its own pest complex (Ali Niazee 1980, 1983b, 1985, Thompson and Every 1958). The four hazelnut insects that could be classified as major pests include the filbert worm *Melissopus latiferreanus* (Walsh), the filbert aphid, *Myzocallis coryli* (Goetze), the filbert leafroller *Archips rosanus* L. and the oblique banded leafroller, *Choristoneura rosaceana* (Harris). Among these insects *M. latiferreanus* is the most important pest causing more than 30 percent nut damage in untreated orchards (Ali Niazee 1985). Like with most indirect pests, it has been difficult to estimate the loss caused by the filbert aphid. However with high populations that generally develop in commercial orchards

(Calkin et al. 1985, Messing 1982), significant deleterious effects on filbert production should be expected. Feeding on leaves by aphids depletes plant nutrients, resulting in reduced plant vigor, low nut quality and poor yields (Jones 1960, Painter and Jones 1958). In addition to the feeding damage on infested trees, the aphid also secretes honeydew which causes heavy growth of sooty molds on the leaves, and inferior nut appearance (El-Haideri 1959, Painter and Jones 1958).

Due to the presence of the pest complex described above and the need to reduce crop losses, extensive use of several classes of insecticides is prevalent in all commercial orchards. Before 1960, DDT and endosulfan were the most commonly used insecticides in filbert orchards. Since the early 1960s carbaryl has become the most important pesticide. Numerous combination sprays of carbaryl, endosulfan, diazinon and other insecticides have been applied each season for nearly 30 years to control pests (Ali Niazee 1977, Jones 1958). The excessive use of some non-selective insecticides, particularly carbaryl, seems to be one of the reasons for the prevalence of M. coryli in the filbert ecosystem, partly because of the detrimental effects of the chemicals on natural enemies (Ali Niazee 1977, Calkin et al. 1985, Messing 1982). Also, the continuous pesticide pressure in virtually all commercial orchards would make development of resistance in this multivoltine, monophagous species highly probable (Ali Niazee 1977). Thus as speculated, the inadequacy of carbaryl for filbert aphid control was reported by a number of growers during the late 1960s and early 1970s (Ali Niazee 1983). In 1983, the first documentation of resistance to this insecticide in the filbert aphid was reported by Ali Niazee (1983b).

The detection of resistance of the aphid to carbaryl has for the first time confirmed the potential for resistance development against other chemicals as well, thereby stimulating the need to emphasize a resistance management approach in the total insect pest management program (IPM) in the Pacific Northwest (Calkin et al. 1985). In response, detection and monitoring of resistance levels in filbert aphid populations over large areas in the Willamette Valley constituted the primary objective of the present study. The results of the investigations should provide up-to-date information on the proportion of the aphid population that is resistant, the level and geographical distribution of resistance and the number of insecticides or chemical classes to which cross- or multiple-resistance occurs in the field. Another goal of these investigations is to determine the seasonal variation of resistance (Bass and Rawson 1960, Dittrich 1963, Bramsby-Williams and Armstrong 1964, Brazzel and Lindquist 1960, Follet 1984). This is considered vital not only in comparisons and interpretation of results of resistance studies, but also in the practical application and assessment of the effectiveness of chemical control measures during the various aphid population phases, as influenced by the growth stages of the plant and the different environmental conditions in the field.

# LITERATURE REVIEW

## The Filbert Aphid

The filbert aphid, *M. coryli* is found throughout the filbert-growing regions of the world (Ali Niazee 1980, El-Haideri 1959). It was probably introduced along with filbert varieties in the 1880s but was recorded for the first time as a filbert pest in this region in the 1920s (Ali Niazee 1983b, 1985). At present it is one of the most important indirect pests of filberts in the Willamette Valley. El-Haideri (1959) conducted a comprehensive study of the biology of *M. coryli* in this region. The filbert aphid lays its eggs on the filbert tree. Oviposition begins in October and most of the eggs can be found on two and three year old twigs or branches. The overwintering eggs hatch in March when the filbert leaf-buds are about to open. This early spring form, the fundatrix or stem mothers, are found in large numbers during April, but their population declines during May. During late April and May the stem mothers produce the summer forms or viviparae. Peak populations occur between May and early July, and then are followed by a sharp decline in late July and August (El-Haideri 1959, Messing 1982). In fall, the sexual generation of males and females appear in and generally feed on the underside of the old or very old leaves. The adult ovipara (egg-laying females) mate and begin oviposition in the middle of October. The eggs overwinter until next spring.

This species is monophagous, feeding only on filberts, and can complete up to a total of 10 generations per year in the Willamette Valley (El-Haideri 1959). M. coryli is most commonly attacked by several predators and parasites (Ali Niazee 1983a, 1985; Messing 1982) and these are partly responsible for the population decline during the summer months. However the reduction of aphid population obtained due to natural control seldom reaches significant levels not to warrant chemical control measures in commercial filbert orchards. In order to develop action thresholds, further studies which emphasized the ecology and sampling of filbert aphids were carried out under the IPM project at Oregon State University (Calkin et al. 1985). In this study aphids were found to prefer the top portion of the canopy as the overall population in a tree increases. The significance of this preference as it occurred at a time when insecticide applications were being made is yet to be determined, whether it is influenced by the position of new foliage growth or a behavioral response to the chemical treatments (Ali Niazee 1983b, Croft and Hoyt 1983) is also unknown.

## Chemical Control

Until the advent of DDT in the 1940s the major insect pests of filberts were controlled by lead arsenate. DDT was widely used in the 1950s, however during the 1960s carbaryl, diazinon, endosulfan, malathion, parathion and azinphosmethyl became the main chemicals used in the filbert ecosystem in the Pacific Northwest (Jones 1960). DDT however continued to be recommended for control of sporadic pests until 1969 when it was withdrawn from the market. Since then more chemicals have been added to the filbert spray program for control of the filbert aphid and other major insects in the system (Table 1). Phosalone was introduced in 1972. The most recent chemical, fenvalerate, was included in the spray program in 1983. Although malathion and parathion were registered much earlier, oxydemetonmethyl has been the standard chemical for aphid control since 1978 (Ali Niazee 1985). As already indicated, the rest of the insecticides were used mainly to control other major filbert insects and provided varying effectiveness in controlling the filbert aphid (Calkin et al. 1985). Good aphid control has been achieved by application of diazinon, phosalone and endosulfan. Phosalone had another advantage in that it was less toxic to natural enemies of the filbert aphid (Calkin et al. 1985, Messing 1982). The disruptive nature of carbaryl on the predators and parasite complex causes the filbert aphid to be more persistent and thereby exposed to continuous pesticides pressure during the different stages of development in the entire growing season and from year to year.

## Resistance Problem

Resistance is an acquired character of a population. It is a preadaptive phenomenon by which a strain of insects develops the ability to tolerate doses of toxicants which would prove lethal to the majority of individuals in a normal population of the same species (Anonymous, 1957). Since 1914 when Melander first described resistance of San Jose scale to lime sulfur, many more cases have been documented. Through 1980, 428 cases of resistance have been reported in insects and related arthropods (Georghiou 1983). Of the 428 species, 60 percent are agricultural pests and a number of the others affect human health. Just over 10 species of those arthropods known to have developed resistant strains are beneficial, and consist mainly of predatory mites on deciduous fruit trees (Ware 1980, Croft and Stickler, 1983). With the rapid increase in cases of resistance to chlorinated hydrocarbons, organophosphates, carbamates, and recently pyrethroid insecticides (Georghiou and Mellon 1983), entomologists have been interested in a greater understanding of the mechanisms and the factors influencing the development of resistance in the entire arthropod complex so that a strategy of countermeasures could be formulated (Brown 1981).

In studying the biochemistry and physiology of resistance Oppenoorth and Welling (1976) have emphasized the importance of genetics for an understanding of resistance mechanisms. Resistance could be monogenic or dependent on a single gene (Ballantyne and Harrison 1967, Brown 1967, Busvine et al. 1963, Lichtwardt 1964), or it could be polygenic inheritance, in which a number of genes are involved in the development of resistance (Georghiou 1971, Sawicki and Farnham 1967). According to Chadwick (1955) and Winteringham (1969), any genetically controlled alterations in the physiological processes that determine the penetration, distribution or target site interaction of an insecticide would cause resistance. Of major importance however are altered sites of action, increased detoxification and reduced penetration (Georghiou 1972, Oppenoorth and Welling 1976). Thus one mechanism of resistance could be due to the presence of a gene that enables the insect to biochemically detoxify an insecticide by hydrolysis, oxidation, dehydrochlorination, glutathione (GSH) conjugation and other enzymatically enhanced reactions (Georghiou and Saito 1983, Plapp 1976). Another resistance mechanism may be a gene (eg. Kdr), that provides an alternative pathway to one blocked by a pesticide (Oppenoorth 1967, Oppenoorth and Welling 1976), or changes the sensitivity of vital enzymes like AChE or of the nervous system (Casida et al. 1983). In some other instances the mechanism of resistance may be strictly behavioral in that the insect can detect a pesticide and respond by avoiding it (Georghiou 1972, Pluthero and Singh 1984). Thus where the behavioral and physiological adaptations occur in concert (e.g. Ali Niazee 1983b), the insect will survive insecticides more effectively by limiting exposure, and by tolerating cases of unavoidable contacts with insecticides, respectively.

After significant advances were made in the knowledge of genetics, physiology and biochemistry of resistance, further efforts were needed to study the risk and dynamics of resistance in a target population. Thus credit for the available knowledge of the dynamics of resistance has always been given to population geneticists who approached resistance as an evolutionary phenomenon (Crow 1952, 1957, 1966; Georghiou 1965, 1972; Georghiou and Taylor 1977; Plapp 1976) and to numerous other researchers who examined the development, stability and regression of resistance in various pest species (Brown 1971, 1976; Georghiou 1964, 1965, 1972; Georghiou and Taylor 1976; Keiding 1963, 1967; Sawicki et al. 1980, Dunn and Kempton 1966, Abedi and Brown 1960, Beranek 1974, Lewallen 1960, Bauernfeind and Chapman 1985).

In view of the extremely variable nature of the development of resistance, Georghiou (1980) and Georghiou and Taylor (1976) attempted to systematically list and provide examples of field case histories where genetic, biological and operational factors in concert could determine the degree of selection pressure and evolution of resistance in a given ecological situation. Today by utilizing computer technology, modeling has become yet another tool in understanding at least theoretically the influence of known and simulated presumptive factors in the evolution and dynamics of resistance (Comins 1977; Georghiou and Taylor 1976, 1977a,b; Plapp et al. 1979, Kable and Jeffery 1979; Taylor and Georghiou 1979, 1982; Tabashnik and Croft 1983). Taylor and Headley (1973) and Hueth and Regev (1974) dealt with modeling of economic aspects of resistance development.

## Resistance Management

With the knowledge acquired so far it has become evident that although potential for resistance is universal, it is not beyond management. Whereas the genetic and biological factors may not themselves be subject to control, manipulation of operational and managerial factors may reduce levels of pesticide exposure as well as influence some ecological factors like isolation which may determine the degree of selection pressure (Georghiou and Taylor 1977a,b). Thus Keiding (1967) and Comins (1977) have recommended several tactics for delaying or avoiding development of resistance by selective use of pesticides. This involves use of chemicals with short residual life, selection directed at a single life stage, and timely localized application leaving certain generations or part of the population in refugia untreated. The principle being that the temporal and spatial distribution of pesticide application may subject the target species to less pressure to develop resistance, while also allowing resistant populations to revert to susceptibility due to increased chances of gene recombinations and immigration of non-resistant populations between generations (Dunn and Kempton 1966, Sawicki et al. 1980, Keiding 1963, Georghiou 1964).

The concept of changing pesticide-use patterns as a resistance-delaying tactic was further examined by Georghiou (1983), Georghiou at al. (1983), Lagune (1983) and lately discussed by Dover and Croft (1984). One suggestion was the use of mixtures or synergists as alternative means of preventing development of resistance in existing chemicals. Needham and Sawicki (1971), Priester and Georghiou (1980) and Sparks and Hammond (1983) have suggested piperonyl butoxide (Pb) and Pb/sesamex combination to increase toxicity of methoprene and difluobenzuron to resistant house flies, respectively. Plapp (1976) has, for example, indicated that combining synergists with pyrethrins would inhibit oxidative mechanisms of detoxification which allow the pest to survive. Yet the wrong choice of mixtures may contribute to cross-resistance (O'Brien 1967, Winteringham and Hewlett 1964). Georghiou (1980) discussed the principles of alternations of insecticides as a prophylactic countermeasure which employs temporal reduction of selection pressure and takes advantage of the principle of reversion of induced resistance. It has been suggested that rotating compounds with different modes of action and with different pathways of metabolic detoxification would maintain resistance genes for any one mechanism at low levels in the population (Cutright 1959, Georghiou 1982, 1983; Ozaki et al. 1983). During the early stages of selection, resistance tends to be unstable due to lower fitness of the resistant genotypes (Georghiou 1983). However, like mixtures, wrong sequential use of chemicals in the spray program may induce multiple or cross-resistance (Farnham and Sawicki 1976). A variation of this approach is the use of negatively correlated cross-resistant insecticides where tolerance to one product is associated with increased susceptibility to another product, and vice versa (Georghiou 1965, Ogita 1964).

In addition to these alternatives, another common approach has been replacing a problem chemical with products having no cross- or multiple resistance which encourages reversion to susceptibility. A crucial limitation to this approach is the availability of effective replacement chemicals in the market and their relative costs.

TABLE 1. HISTORY OF INSECTICIDES USE IN FILBERT INSECT CONTROL IN THE WILLAMETTE VALLEY OF OREGON (1961-1985)

| Year | DDT | Endosulfan | Carbaryl | Malathion | Parathion | Diazinon | Systox | Guthion | Phosalone | Metasystox-R | Pydrin |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1961 | ● | o+++ | o++ | o | o | o+++ | | | | | |
| 1962 | ● | o+++ | o++ | o | o | o+++ | | | | | |
| 1963 | ● | o+++ | o++ | o | o | o+++ | | | | | |
| 1964 | ● | o+++ | o++ | o | o | o+++ | o | +++ | | | |
| 1965 | ● | o+++ | +++ | o | o | o+++ | o | +++ | | | |
| 1966 | ● | o+++ | +++ | o | o | o+++ | o | +++ | | | |
| 1967 | ● | o+++ | +++ | o | o | o+++ | o | +++ | | | |
| 1968 | ● | o+++ | +++ | o | o | o+++ | o | +++ | | | |
| 1969 | ● | o+++ | +++ | o | o | o+++ | o | +++ | | | |
| 1970 | | o+++ | +++ | o | o | o+++ | o | +++ | | | |
| 1971 | | o+++ | +++ | o | o | o+++ | o | +++ | | | |
| 1972 | | o+++ | +++ | o | o | o+++ | o | +++ | o+++ | | |
| 1973 | | o+++ | +++ | o | o | o+++ | o | +++ | o+++ | | |
| 1974 | | o+++ | +++ | o | o | o+++ | o | +++ | o+++ | | |
| 1975 | | o+++ | +++ | o | o | o+++ | o | +++ | o+++ | | |
| 1976 | | o+++ | +++ | o | o | o+++ | o | +++ | o+++ | | |
| 1977 | | o+++ | +++ | o | o | o+++ | o | +++ | o+++ | | |
| 1978 | | o+++ | +++ | o | o | o+++ | o | +++ | o+++ | o | |
| 1979 | | o+++ | +++ | o | o | o+++ | o | +++ | o+++ | o | |
| 1980 | | o+++ | +++ | o | o | o+++ | o | +++ | o+++ | o | |
| 1981 | | o+++ | +++ | o | o | o+++ | o | +++ | o+++ | o | |
| 1982 | | o+++ | +++ | o | o | o+++ | o | +++ | o+++ | o | |
| 1983 | | o+++ | +++ | o | o | o+++ | o | +++ | o+++ | o | +++ |
| 1984 | | o+++ | +++ | o | o | o+++ | o | +++ | o+++ | o | +++ |
| 1985 | | o+++ | +++ | o | o | o+++ | o | +++ | o+++ | o | +++ |

o = registered for filbert aphid control
\+ = registered for one or more of the major pest(s) control
● = registered for sporadic minor pests control

# METHODS AND MATERIALS

## Orchards

The aphids were collected from 10 orchards located between Eugene in the South and Wilsonville in the North of the Willamette Valley (Figure 1). This belt extends over 100 miles and covers the five counties of Lane, Benton, Linn, Marion and Clackamas.

The OSU strain was collected from scattered trees on the OSU campus and was selected for comparison because it represented at most limited pesticide use and was sufficiently isolated from commercial orchards. Abraham, a long abandoned orchard, was well isolated from other filbert orchards, and had no exposure to any of the test insecticides for the past 15 years. Castillo was an old orchard which in recent years received minimum management practices and no insecticide treatment for the past ten years. Buchanan and Lemert were relatively young orchards. Buchanan orchard was not sprayed since at least 1981. Lemert, on the other hand, was managed commercially and had received continuous insecticide exposure. The rest of the orchards, Bush, Twedt, Gray, Harnisch, Ferschweiller and Guiss, were commercially managed and had several years of intensive spraying.

Because of inadequate farm records, no accurate information on insecticide use before 1980 was available.

The approximate age of each orchard (Table 2), however, may reflect the degree of exposure to one or the other of the recommended chemicals in the filbert spray program. Thus the selected orchards would fairly represent different insecticide-use patterns and a diversity of management practices. Most of the sites however were not isolated enough to avoid the influence of the nearby orchards and surrounding crop systems.

## Aphids

Three series of population samples were bioassayed: Series A, collected from filbert orchards from June to second week of September 1985; Series B, collected from the third week of September to the second week of November 1985, and Series C, collected from the fourth week of March to the third week of April 1986. Those series represented the summer, fall and early spring forms, respectively.

Orchards in different geographical locations, and with different degrees of insecticide exposure, would provide a general or regional picture, as well as spread pattern, of resistance to selected insecticides. Aphids were collected on leaves picked from trees representing a random sample of the orchard and minimizing chances of collecting clonal colonies. Leaves were put in Zip-Loc[R] plastic bags in ice boxes and brought to the laboratory. The samples could be stored in the refrigerator at 10°C under high humidity for about one week to complete the bioassay.

## Insecticides

Commercial formulations of carbaryl (Sevin 50 WP, FMC), diazinon (Diazinon 50 WP, Ciba-Geigy), endosulfan (Thiodan 50 WP, FMC), fenvalerate (Pydrin 2·4 EC, Shell Dev. Co.), oxydemetonmethyl (Metasystox-R 25EC) and phosalone (Zolone 3 EC, Rhodia) were tested. Those compounds were selected to represent the four principal chemical classes; carbamates, chlorinated hydrocarbons, organophosphates and synthetic pyrethroids, that have been used most in the filbert spray program.

For all tests, serial dilutions of the selected pesticides in water were prepared, and a minimum of five concentrations for each insecticide was utilized in obtaining the mortality data. In the absence of baseline dosage-mortality data on the filbert aphid, tested concentrations were arbitrarily chosen to include 0.001, 0.01, 0.1, 1.0 and 10.0X the recommended field rate for each chemical (Table 3).

## Bioassay

From the 1960s experts began to take an interest in the standardization of test methods for detecting and measuring resistance in pests of agricultural importance so that the results obtained could be compared over a period of time or by different researchers (Busvine 1967, 1971; Winteringham 1969). In 1970 FAO began to draw up standard procedures for a number of key agricultural pests including a tentative method for measuring insecticide resistance of the peach-potato aphid (FAO 1970). Needham and Dunning (1965), Sawicki and Rice (1978), Sawicki et al. (1978), and many other workers have published their results on techniques for detecting resistance in Myzus persicae (Sulz). FAO method No. 17 was later proposed as the standard pesticide resistance detection method for adult aphids (FAO 1979). The FAO-recommended dip-test method was applied to detect resistance in the cereal and black bean aphids by Stribley et al. (1983). In showing filbert aphid resistance to carbaryl, Ali Niazee (1983b) used a leaf-dip test method which was less time consuming and did not require a Potter Tower apparatus.

A leaf-dip technique, based on slight modifications of the FAO (1979) and Ali Niazee (1983b) procedures, was used in the present study. Small whole leaves from filbert trees collected at the OSU Entomology Farm were dipped in the insecticide dilutions and allowed to air-dry for about 45 to 60 minutes in our laboratory. A glass cylinder 20-25 mm in diameter and height was attached with melted wax to each leaf, forming a chamber in which a batch of 20 3rd- and 4th-instar nymphs or adults of oviparae were placed. The inside of the glass cylinder was treated with fluon to prevent the aphids from escaping by climbing the walls. Three batches of 20 aphids were treated for each of the five test concentrations, giving a total sample size of 300 insects for each probit line. Two or three batches of 20 aphids confined on leaves treated with water alone were included as control to correct for natural mortality. The chambers containing the aphids were then placed on wet paper towels in plastic trays and held at 18-23°C under high humidity (more than 80% R.H.) for 24 hr before assessment of mortality was made. Treated aphids were considered dead if they did not move their legs or antennae when prodded with a soft camel's hair brush. If control mortality exceeded 20 percent, the results were discarded and an additional test was run. Probit analysis was made by using a computer program which corrected for control mortality. Resistance factors were determined by dividing the $Lc_{50}$'s of each orchard strain by the $Lc_{50}$ of the OSU strain. This technique could not be used to detect the behavioral resistance since the aphids were confined on the treated leaf surfaces.

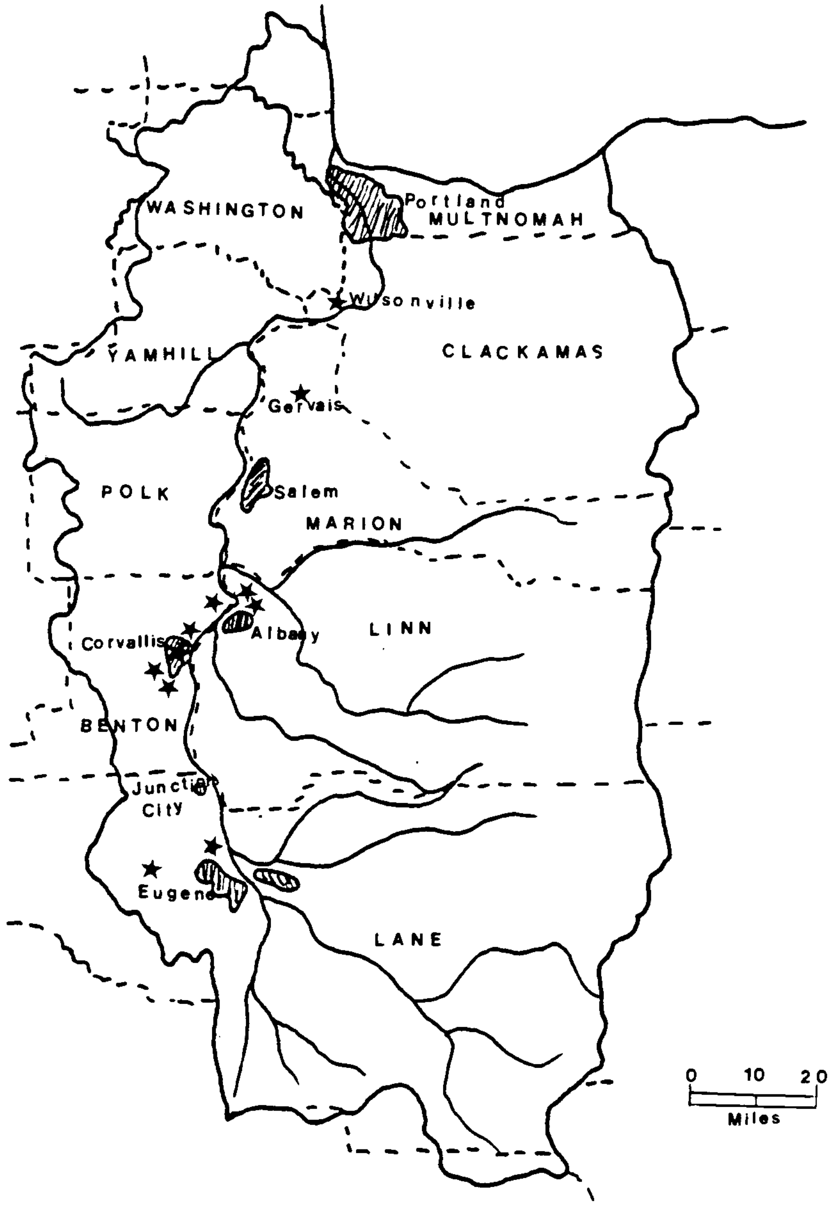



Figure 1. Map of the Willamette Valley, Oregon showing the locations from which sample populations of *Myzocallis coryli* Goetze were collected.

TABLE 2. CHARACTERIZATION OF SAMPLED FILBERT ORCHARDS IN THE WILLAMETTE VALLEY OF OREGON

| County | Locality | Orchard | Size (acres) | Age | Insecticides Use Pattern* | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Before | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 |
| Central Willamette Valley | | | | | | | | | | | |
| Benton | Corvallis | OSU | 6 trees | 6-60+ yrs | not known | | | | | | |
| | Corvallis | Buchanan | 10 | 12 yrs | D | - | - | - | - | - | - |
| | Corvallis | Castillo | 6 | 30-40 yrs | DM | - | - | - | - | - | - |
| | Corvallis | Twedt | 20 | 13 yrs | DCP | A | A | A | A | AF | F |
| Linn | Albany | Abraham | 20 | 60+ yrs | C | abandoned orchard since 1972 | | | | | |
| | Albany | Gray | 20 | 62 yrs | | | CD | C | D | ODF | ChF |
| | Albany | Harnisch | 9 | 15 yrs | | | ADO | O | D | OEDiF | - |
| South Willamette Valley | | | | | | | | | | | |
| Lane | Junction City | Lemert | 10 | 8 yrs | | | | CDE | CD | ACDO | CP |
| | Junction City | Bush | 30 | 15 yrs | CEDO | CO | EODA | OA | DF | CD | ChC |
| North Willamette Valley | | | | | | | | | | | |
| Marion | Gervais | Ferschweiller | 32 | 10-75 yrs | | | C | C | P | AF | F |
| Clackamas | Wilsonville | Guiss | 10 | 15-50 yrs | | C | OC | OCA | OCDi | OCDF | F |

* A=azinphosmethyl C=carbaryl D=diazinon Di=dimethoate E=endosulfan F=fenvalerate
O=oxydemetonmethyl P=phosalone M=malathion Ch=chlorpyrifos - = none

TABLE 3. INSECTICIDES USED IN DETERMINATION OF FILBERT APHID RESISTANCE

| Pesticide | Formulation | Field Rate: Formulation per 100 gals. water | Field Rate: Active ingredient g/l water |
|---|---|---|---|
| Carbamate | | | |
| carbaryl | Sevin, 50% WP | 2.0 lb. | 1.2 |
| Chlorinated hydrocarbon | | | |
| endosulfan | Thiodan, 50% WP | 1.0 lb. | 0.6 |
| Organophosphorus insecticides | | | |
| diazinon | Diazinon, 50% WP | 1.0 lb. | 0.6 |
| phosalone | Zolone, 3 EC | 1.0-1.5 pt. | 0.375-0.563 |
| oxydemetonmethyl | Metasystox-R, 25 EC | 0.5 pt. | 0.156 |
| Synthetic pyrethroid | | | |
| fenvalerate | Pydrin, 2.4 EC | 0.33-0.66 pt. | 0.0099-0.0198 |

# RESULTS

Based on 95% confidence interval around $Lc_{50}$ values, the significance of responses to insecticides among the filbert aphid populations could be compared. Ninety-five percent confidence intervals for $Lc_{95}$'s were found to be too wide and variable in some of the tests, and therefore unreliable in comparisons of resistance levels between populations. As summarized in Tables 4 and 5, differential responses to the tested insecticides were detected among filbert aphid populations from various orchards. The complete toxicological responses of filbert aphid populations to the tested insecticides are shown in Appendices A-1 to A-5. Failure of confidence intervals for $Lc_{50}$'s to overlap would indicate significant differences in response ($P \leq 0.05$). In the present discussions however, the level of resistance of each population was based on the resistance factor (RF) value as compared to a susceptible population collected at the campus of OSU and previously reported as a Standard Susceptible population (Ali Niazee 1983b). Taking the natural variation into consideration, a resistance level of 5-fold or less is categorized as susceptible. Again for the sake of simplicity, the resistance factor values are grouped into: low (5-20x), moderate (20-100x) and high (>100x). Similarly a seasonal change in response of individual populations to each insecticide is considered significant when, compared to the lowest $Lc_{50}$ value, the elevation is 5x or more.

The degrees of resistance exhibited by the various field populations of filbert aphid to the different insecticides in the three series of experiments are presented in Table 4 and Figures 2 to 6. Examining the data separately for each insecticide, the majority of the orchard populations exhibited no resistance (RF $<$ 5x) to moderate (RF 5-100x) levels of resistance to carbaryl. Filbert aphid populations from Buchanan and Bush orchards showed high resistance (RF 132x) and (RF 156x) respectively in series A experiments, and from Gray orchard (RF 148x) in series B experiments. Extremely high resistance to carbaryl was evident in populations from Twedt and Lemert orchards. $Lc_{50}$ values for those populations were well above the maximum range of recommended field dosages. The shallow slopes (Figure 2) of the curves would however indicate that the responses to carbaryl were very heterogeneous. Based on extrapolated $Lc_{50}$'s, the highest toxicity ratios calculated were ca. 4093-fold and 2.661 x $10^5$-fold for populations taken from Lemert and Twedt orchards, respectively.

Populations collected from Bush orchard in series A exhibited $Lc_{50}$ value of 0.1507 g AI/l of endosulfan, giving a moderate resistance factor of 50.2-fold. Moderate resistance levels were also obtained in series A from

Buchanan (RF 25.5x), Abraham (RF 27.5x) and Lemert (RF 41.4x). The resistance levels to endosulfan varied from zero to low (<5-20x) in both series B and C from all other orchards. The slopes for all populations were relatively steeper and less variable (Figure 3), suggesting a more homogeneous response of filbert aphids to endosulfan than other insecticides.

With the exception of populations collected from Harnisch which showed high resistance levels (RF 288x) in series A, and RF 286.5x in series B experiments, resistance to diazinon appears to be still at low levels or zero in most filbert aphid populations (Table 4 and Figure 4).

Results presented in Table 4 and Figure 5 indicate that responses of the filbert aphid populations to phosalone are highly variable. Although failure of field control of filbert aphids with phosalone has not been reported in the Willamette Valley, the present studies demonstrate that very high resistance to this insecticide does occur in some of the filbert-aphid populations in the region. In two out of the three series of experiments, Lemert populations required dosages higher than the maximum recommended field rate of phosalone to achieve a 50 percent mortality. $Lc_{50}$ values of 7.4 and 77.3 g AI/liter were extrapolated in series C and series B experiments, respectively. In spring tests (series C), filbert aphid populations from Ferschweiller orchard had $Lc_{50}$ of 3.44 g

AI/1 and resistance level was 3739-fold. Spring populations from Twedt orchards had their resistance level elevated to more than 1384-fold. In all instances of extreme resistance however, the slopes were very much flattened (Figure 5), suggesting heterogeneous response of those populations to phosalone. High resistance levels to phosalone were also exhibited in populations from Gray (RF 158.7x), Harnisch (RF 146.5x) and Guiss (RF 112.0x). Bush populations showed moderate resistance (RF 24.1-83.8x) to phosalone in all series of experiments. Whereas Abraham population was 23.2-fold resistant to phosalone, the resistance factors of populations from Buchanan and Castillo were low (RF $<$ 5-20x) in these experiments.

The resistance levels of the various filbert aphid populations to fenvalerate are shown in Table 4 and Ld-p lines illustrated in Figure 6. High levels of resistance to fenvalerate are present in populations from Harnisch (RF 367.5x) in series B, Ferschweiller (RF 392.2x) in series C, and Bush (RF 494.5x) in series B. Resistance to fenvalerate is highest in filbert aphid populations from Guiss and Twedt. From Guiss, resistance levels of 1188x in series A, and RF 11148x in series B were recorded. The level of resistance in Twedt populations has increased to RF 5357x in series B. That order of selection however was not found in the rest of the populations, which in general exhibited low-slightly moderate-levels of resistance to fenvalerate in the present study.

Oxydemetonmethyl was tested only against spring populations (series C) from nine orchards. The majority of the populations indicated zero to low levels of resistance (RF 3.4-16.9x) as shown in Table 5 and Figure 7. Harnisch population, with $Lc_{50}$ value of 0.0475 g AI/l had a moderate (RF 25x) resistance to oxydemetonmethyl. The most resistant strain was taken from Twedt which had $Lc_{50}$ of 0.2135 g AI/l and an increased tolerance of ca. 112-fold.

In studying the seasonal variations in susceptibility of the filbert aphid populations to various insecticides one may choose to consider either the resistance factor (RF) values (Figures 14 to 18) or comparisons of changes of $Lc_{50}$ values of individual insecticides for each orchard population (Table 4). Perhaps it is better to use both criteria because comparisons of RF values alone could be misleading due to natural variations of the $Lc_{50}$ values of the susceptible population.

Apparently changes in susceptibility to carbaryl were not significant in populations from Castillo, Abraham and Ferschweiller orchards. Less than 10x tolerance to this chemical was noted in samples from Harnisch, Guiss and Bush populations. Compared to the lowest $Lc_{50}$, Buchanan population was 14x more tolerant in summer, while Gray population exhibited 31-fold increase in resistance in fall. A change of 3,619x shown by the population from Twedt orchard, and 1514x increase of resistance to carbaryl of Lemert population in summer is difficult to explain. However, as indicated above, these values were based on extrapolated $Lc_{50}$'s, which were far above the range of tested dosages. However, it should be noted that certain populations of summer aphid do migrate short distances, thus immigration of resistant aphids cannot be overlooked.

Relatively small variations in susceptibility of filbert aphid populations to endosulfan occurred in these experiments. The highest change was ca. 8.7x increase in tolerance to this insecticide of Buchanan population during summer. Small (<10x) to moderate (10-<100x) changes of tolerance to diazinon were shown in all tested populations except that from Castillo which produced surprisingly higher tolerance (237x) in the spring population.

Variations in tolerance of higher magnitude were exhibited in four out of ten of the tested filbert aphid populations to fenvalerate. In contrast to other insecticides, tolerance to fenvalerate seems to increase in fall populations. Thus in series B experiments, Twedt populations were ca. 382x more tolerant to fenvalerate than in series A. $Lc_{50}$ values increased by ca. 465x in aphids collected from Guiss, and there was an increase of 164x in tolerance to fenvalerate of Bush population. Populations from Ferschweiller orchard were not bioassayed in the fall.

Results obtained in spring experiments however showed 126-fold tolerance of these populations to fenvalerate.

Levels of seasonal variation in response to phosalone of filbert aphids collected from all orchards were considered to be significant. However there were differences in the degree of variation of susceptibility to this insecticide among populations of the various orchards. Lemert populations for example, had their tolerance to phosalone raised 7576x in fall, and 727x in spring as compared to the $Lc_{50}$ value obtained in summer. The $Lc_{50}$ value of phosalone to Ferschweiller was increased 304x in spring as compared to summer populations. High variations in susceptibility were also shown in populations from Castillo 47x tolerant in summer compared to the lowest $Lc_{50}$ in fall, Gray populations exhibited more than 70x increases in tolerance in summer and fall as compared to spring. Whereas the highest variation of tolerance to phosalone of Bush population was ca. 49x, Guiss population was ca. 33x more tolerant, during summer experiments.

TABLE 4. INSECTICIDE SUSCEPTIBILITY OF ELEVEN POPULATIONS OF THE FILBERT APHID IN THE WILLAMETTE VALLEY OF OREGON

| Orchard | CARBARYL | | | DIAZINON | | | ENDOSULFAN | | | FENVALERATE | | | PHOSALONE | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $LC_{50}$ (gAI/1) | Slope | RF[1] | $LC_{50}$ (gAI/1) | Slope | RF[1] | $LC_{50}$ (gAI/1) | Slope | RF[1] | $LC_{50}$ | Slope | RF[1] | $LC_{50}$ (gAI/1) | Slope | RF[1] |
| | | | | | | | SERIES A | | | | | | | | |
| OSU | 0.0027 | 0.94 | 1.0 | 0.0062 | 1.15 | 1.0 | 0.0030 | 1.03 | 1.0 | 0.0005 | 1.12 | 1.0 | 0.0017 | 1.4 | 1.0 |
| Buchanan | 0.0357 | 0.77 | 13.2 | 0.0078 | 0.98 | 1.2 | 0.0765 | 0.63 | 25.5 | 0.0037 | 0.73 | 7.4 | 0.0094 | 0.55 | 5.5 |
| Castillo | 0.0401 | 1.51 | 14.9 | 0.0003 | 0.52 | 0.05 | 0.0128 | 0.94 | 4.3 | 0.0083 | 0.78 | 16.6 | 0.0007 | 1.22 | 0.4 |
| Twedt | >1.2 | 0.28 | 266091.8[a] | -- | -- | -- | -- | -- | -- | 0.0028 | 0.67 | 5.6 | -- | -- | -- |
| Abraham | 0.0145 | 1.20 | 5.4 | 0.0829 | 1.29 | 13.4 | 0.0825 | 0.85 | 27.5 | 0.0099 | 0.69 | 19.8 | 0.0395 | 0.97 | 23.4 |
| Gray | 0.0124 | 0.37 | 4.6 | 0.0495 | 0.83 | 8.0 | 0.0543 | 0.74 | 18.1 | 0.0015 | 1.14 | 3.0 | 0.2416 | 0.94 | 142.1 |
| Harnisch | 0.0039 | 0.95 | 1.4 | 1.7853 | 0.83 | 288.0 | 0.0017 | 1.2 | 0.6 | 0.0099 | 0.62 | 19.8 | 0.0064 | 1.5 | 3.8 |
| Fersch. | 0.0396 | 0.35 | 14.7 | 0.0043 | 1.08 | 0.7 | 0.0082 | 1.23 | 2.7 | 0.0014 | 0.68 | 2.8 | 0.0113 | 1.22 | 6.6 |
| Guiss | 0.1361 | 0.45 | 50.4 | 0.0175 | 0.85 | 2.8 | 0.0110 | 0.61 | 3.7 | >0.0198 | 0.35 | 1198.0[a] | 0.1904 | 0.57 | 112.0 |
| Bush | 0.4201 | 0.44 | 155.6 | 0.0516 | 0.49 | 8.3 | 0.1507 | 0.51 | 50.2 | 0.0011 | 0.99 | 2.2 | 0.1425 | 0.68 | 83.8 |
| Lemert | >1.2 | 0.31 | 4090.0[a] | 0.5200 | 0.63 | 8.4 | 0.1243 | 0.58 | 41.4 | 0.0012 | 1.07 | 2.4 | 0.0102 | 1.29 | 6.0 |
| | | | | | | | SERIES B | | | | | | | | |
| OSU | 0.0026 | 0.9 | 1.0 | 0.0014 | 0.87 | 1 | 0.0094 | 0.97 | 1.0 | 0.0002 | 1.01 | 1.0 | 0.0016 | 0.56 | 1.0 |
| Buchanan | 0.0531 | 0.73 | 20.4 | 0.0020 | 0.82 | 1.4 | 0.0088 | 0.92 | 0.9 | 0.0005 | 1.11 | 2.5 | 0.0002 | 0.4 | 0.1 |
| Castillo | 0.0095 | 1.41 | 3.7 | 0.0048 | 1.17 | 6.2 | 0.0060 | 1.19 | 0.6 | 0.0050 | 0.43 | 25.0 | 0.0027 | 1.07 | 1.7 |
| Twedt | 0.1985 | 1.04 | 76.3 | 0.0137 | 1.23 | 9.6 | 0.0073 | 0.71 | 0.8 | >0.0198 | 0.3 | 5360.0[a] | 0.0705 | 0.5 | 44.8 |
| Abraham | 0.0243 | 1.21 | 9.3 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Gray | 0.3842 | 1.16 | 147.8 | 0.0087 | 1.26 | 6.1 | 0.0329 | 1.64 | 3.5 | 0.0087 | 0.38 | 43.5 | 0.2499 | 0.7 | 158.7 |
| Harnisch | 0.0354 | 1.24 | 13.6 | 0.4097 | 1.04 | 286.5 | 0.0017 | 0.59 | 0.2 | 0.0735 | 0.51 | 367.5 | 0.2307 | 1.21 | 146.5 |
| Guiss | 0.0901 | 0.97 | 34.7 | 0.0051 | 1.08 | 3.4 | 0.0132 | 1.16 | 1.4 | >0.0198 | 0.28 | 11148.0[a] | 0.0485 | 0.68 | 30.8 |
| Bush | 0.1304 | 0.73 | 50.2 | 0.0044 | 0.76 | 3.1 | 0.0291 | 1.07 | 3.1 | 0.0989 | 0.84 | 494.5 | 0.038 | 1.46 | 24.1 |
| Lemert | 0.0073 | 0.59 | 2.8 | 0.0346 | 1.05 | 24.2 | 0.0309 | 0.85 | 3.3 | 0.0003 | 0.53 | 1.5 | >0.563 | 0.25 | 49069.0[a] |
| | | | | | | | SERIES C | | | | | | | | |
| OSU | 0.0085 | 0.94 | 1.0 | 0.0024 | 0.87 | 1.0 | 0.0047 | 1.04 | 1.0 | 0.0005 | 0.55 | 1.0 | 0.0009 | 0.85 | 1.0 |
| Buchanan | 0.0256 | 0.79 | 3.0 | 0.0181 | 0.72 | 7.7 | 0.0140 | 1.42 | 3.0 | 0.0022 | 0.74 | 4.9 | 0.0012 | 0.97 | 1.3 |
| Castillo | 0.0395 | 1.32 | 4.6 | 0.0711 | 0.82 | 30.1 | 0.0513 | 0.82 | 10.8 | 0.0018 | 0.76 | 4.0 | 0.0116 | 0.73 | 12.6 |
| Twedt | >1.2 | 1.27 | 1510.5[a] | 0.0033 | 1.22 | 1.4 | 0.0021 | 0.63 | 0.4 | 0.0300 | 0.37 | 66.7 | >0.563 | 0.39 | 1384.8[a] |
| Gray | 0.1147 | 0.71 | 13.5 | 0.0121 | 0.57 | 5.1 | 0.0085 | 1.2 | 1.8 | 0.0042 | 0.58 | 9.3 | 0.0033 | 0.65 | 3.6 |
| Harnisch | 0.244 | 1.23 | 2.9 | 0.0429 | 0.78 | 18.2 | 0.0018 | 0.9 | 0.4 | 0.0109 | 0.42 | 24.2 | 0.036 | 0.98 | 39.8 |
| Fersch. | 0.0084 | 1.05 | 1.0 | 0.0291 | 0.9 | 12.3 | 0.0013 | 1.24 | 2.7 | >0.0198 | 0.39 | 392.2 | >0.563 | 0.46 | 3739.2[a] |
| Guiss | 0.0174 | 1.18 | 2.0 | 0.0031 | 0.99 | 1.3 | 0.0024 | 0.86 | 0.5 | 0.0048 | 0.93 | 10.7 | 0.0058 | 1.63 | 6.4 |
| Bush | 0.0554 | 1.26 | 6.5 | 0.0015 | 0.87 | 0.6 | 0.033 | 0.86 | 7.1 | 0.0006 | 0.75 | 1.2 | 0.0029 | 0.74 | 24.9 |
| Lemert | 0.1200 | 0.79 | 14.1 | 0.0286 | 0.74 | 12.1 | 0.0382 | 1.57 | 8.1 | 0.0008 | 0.75 | 1.7 | >0.563 | 0.31 | 8058.8[a] |

[1]Resistance Factor = $\frac{LC_{50} \text{ of orchard population}}{LC_{50} \text{ of OSU population}}$

[a] Based on extrapolated $LC_{50}$ values.

TABLE 5. RESPONSES OF FIELD POPULATIONS OF FILBERT APHID TO OXYDEMETONMETHYL

| Orchard | $LC_{50}$ (gAI/l) | 95%CI (gAI/L) | $LC_{95}$ (gAI/L) | 95%CI (gAI/L) | Slope | $r^2$ | RF | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | $LC_{50}$ | $LC_{95}$ |
| OSU | 0.0019 | .0018-.0019[a] | 0.0767 | .0757-.0778 | 1.02 | .96 | 1.0 | 1.0 |
| Buchanan | 0.0130 | .0121-.0140 | 10.8630 | 7.4634-15.8110 | .56 | .92 | 6.8 | 141.6 |
| Castillo | 0.0121 | .0116-.0127 | 2.6326 | 2.3979-2.8903 | .70 | .96 | 6.4 | 34.3 |
| Twedt | 0.2135 | .1992-.2258 | 150.0316 | 1.8970-11866 | .58 | .80 | 112.4 | 1956.1 |
| Gray | -- | -- | -- | -- | -- | -- | -- | -- |
| Harnisch | 0.0475 | .0445-.0506 | 33.3933 | 12.9998-85.7788 | .58 | .80 | 25.0 | 435.4 |
| Ferschweiller | 0.0244 | .0228-.0263 | 24.8892 | 11.2729-54.9524 | .55 | .84 | 12.8 | 324.5 |
| Guiss | 0.0231 | .0223-.0239 | 2.1865 | 2.0661-2.3139 | .83 | .99 | 12.2 | 28.5 |
| Bush | 0.0321 | .0307-.0335 | 5.8058 | 5.0625-6.6582 | .73 | .92 | 16.9 | 75.7 |
| Lemert | 0.0064 | .0060-.0068 | 3.8095 | 3.2526-4.4618 | .59 | .96 | 3.4 | 49.7 |

a) Failure of confidence intervals (CI) to overlap indicates significant differences in response ($P \leq 0.05$).

TABLE 6. A SUMMARY OF THE DISTRIBUTION OF RESISTANCE AND NUMBER OF YEARS OF INSECTICIDE EXPOSURE TO TEN FILBERT APHID POPULATIONS IN THE WILLAMETTE VALLEY, OREGON

| County | Locality | Orchard | Insecticides* | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Carbaryl | Diazinon | Endosulfan | Phosalone | Fenvalerate | Oxydemeton-methyl |
| Central Willamette Valley | | | | | | | | |
| Benton | Corvallis | Buchanan | H(0) | L(1) | M(0) | L(0) | L(0) | L(0) |
| | Corvallis | Castillo | L(0) | M(1) | L(0) | L(0) | M(0) | L(0) |
| | Corvallis | Twedt | H(?) | L(?) | L(0) | H(1) | H(2) | H(0) |
| Linn | Albany | Abraham | L(?) | L(0) | M(0) | M(0) | L(0) | - |
| | Albany | Gray | H(2) | L(3) | L(0) | H(0) | L(2) | L(1) |
| | Albany | Harnisch | L(0) | H(2) | N(1) | H(0) | H(1) | M(3) |
| South Willamette Valley | | | | | | | | |
| Lane | Junction City | Lemert | H(4) | M(2) | M(1) | H(1) | N(0) | N(1) |
| | Junction City | Bush | H(4) | L(4) | M(2) | M(0) | H(1) | L(4) |
| North Willamette Valley | | | | | | | | |
| Marion | Gervais | Ferschweiller | L(2) | L(0) | N(0) | H(1) | H(2) | L(0) |
| Clackamas | Wilsonville | Guiss | M(5) | N(1) | N(0) | H(0) | H(2) | L(4) |

* Resistance categories: L = low M = moderate H = high N = non-resistant
Number of years of insecticide usage shown in parentheses. ? = not remembered

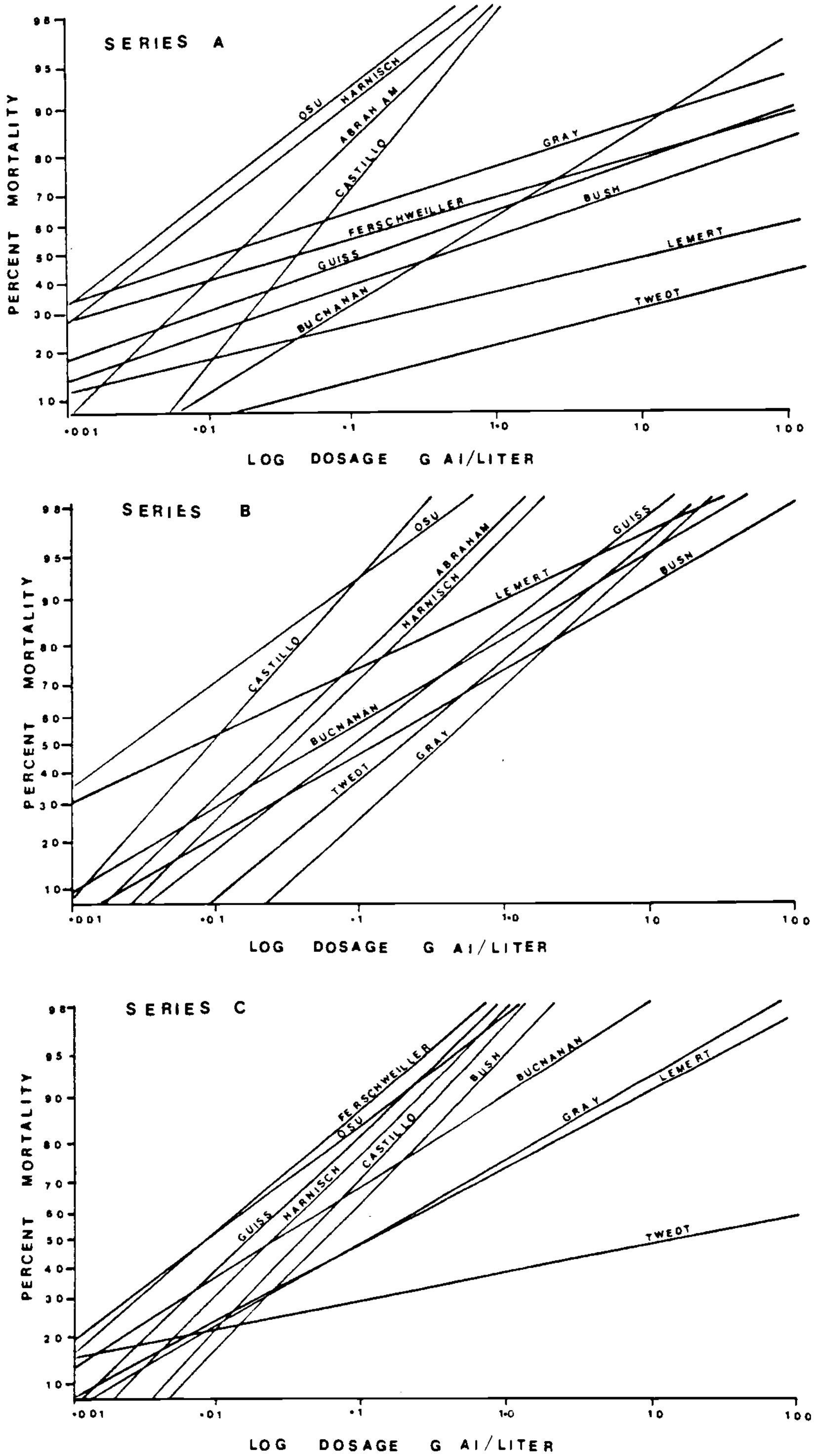



Figure 2. Log dosage concentration and percent mortality lines for different filbert aphid populations exposed to carbaryl.

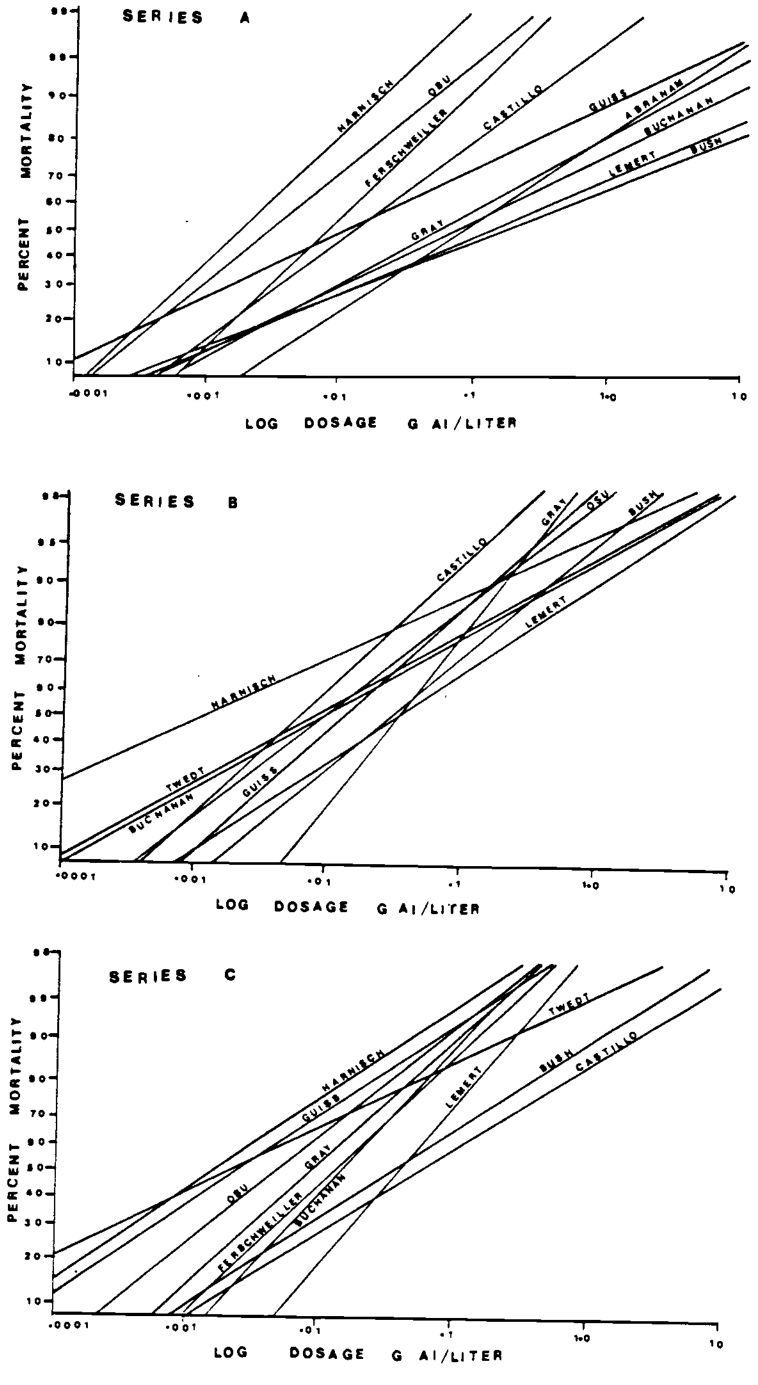



Figure 3. Log dosage concentration and percent mortality lines for different aphid populations exposed to endosulfan.

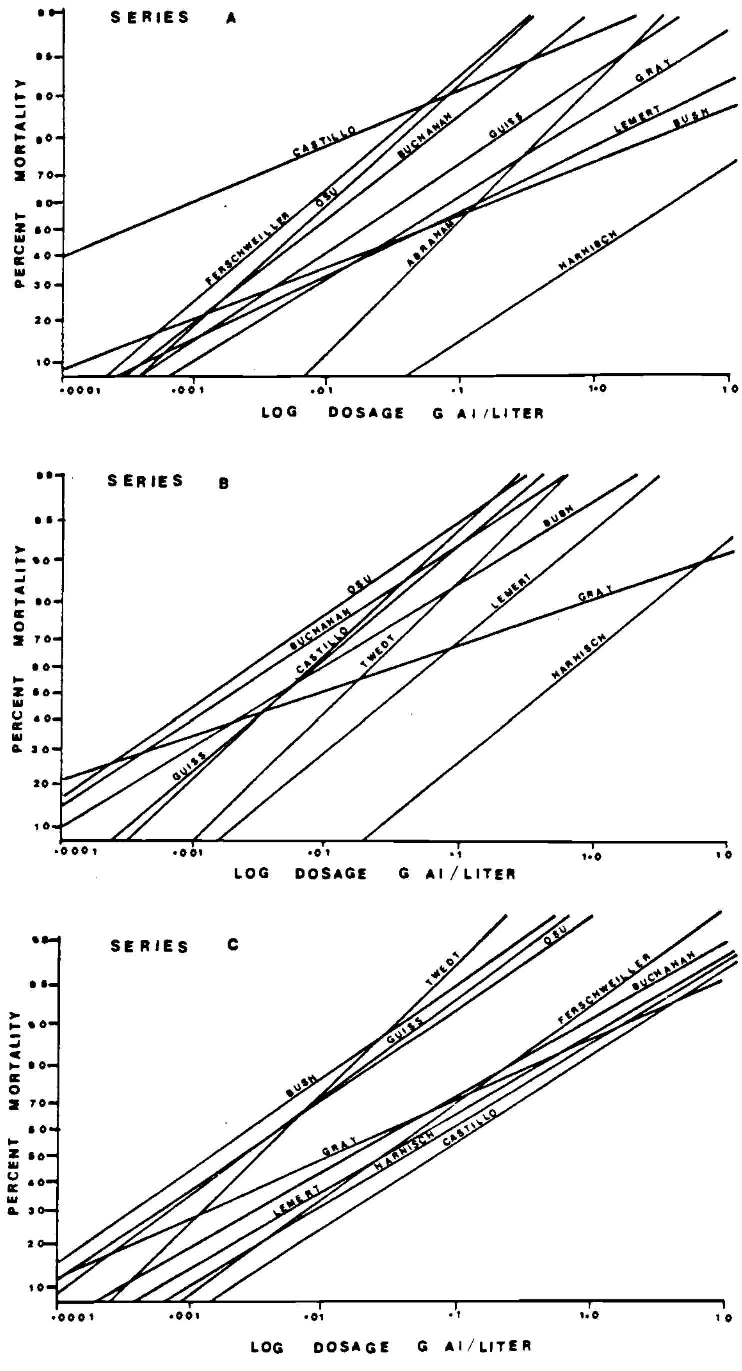



Figure 4. Log dosage concentration and percent mortality lines for different filbert aphid populations exposed to diazinon.

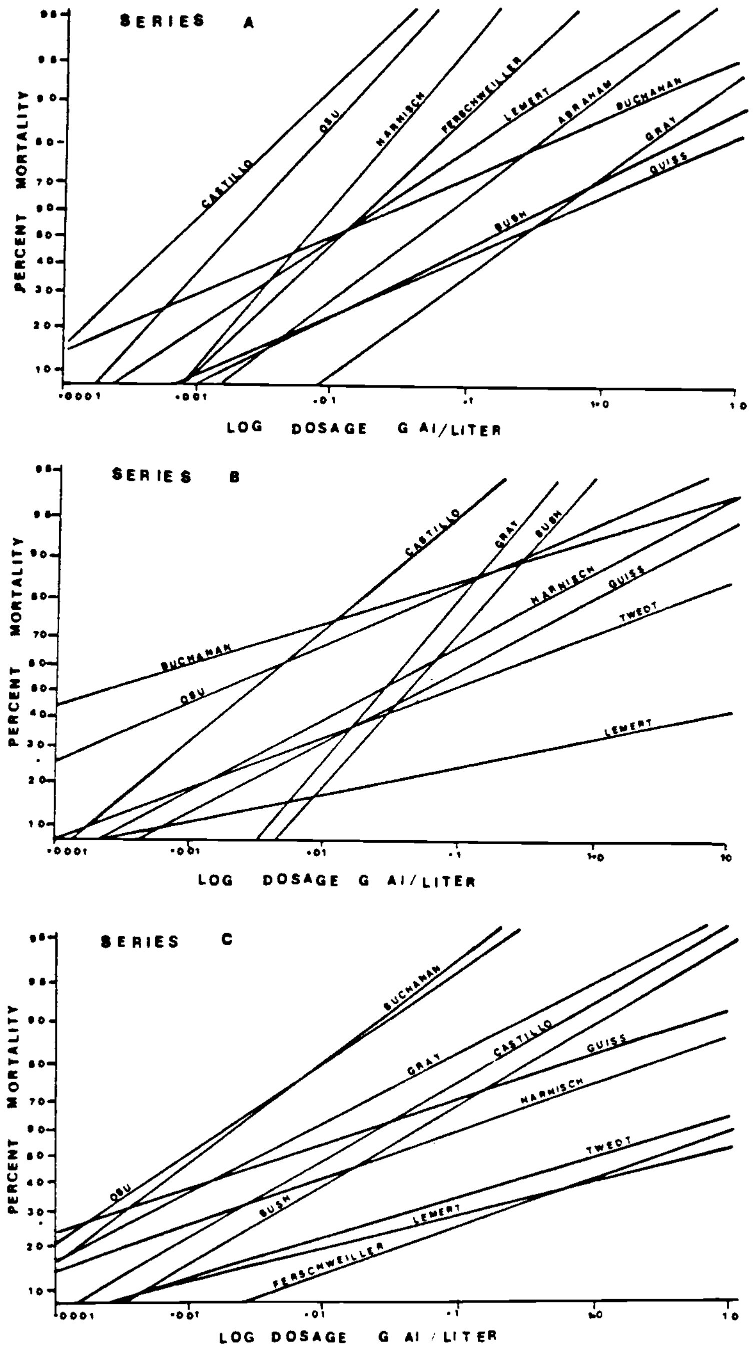



Figure 5. Log dosage concentration and percent mortality lines for different filbert aphid populations exposed to phosalone.

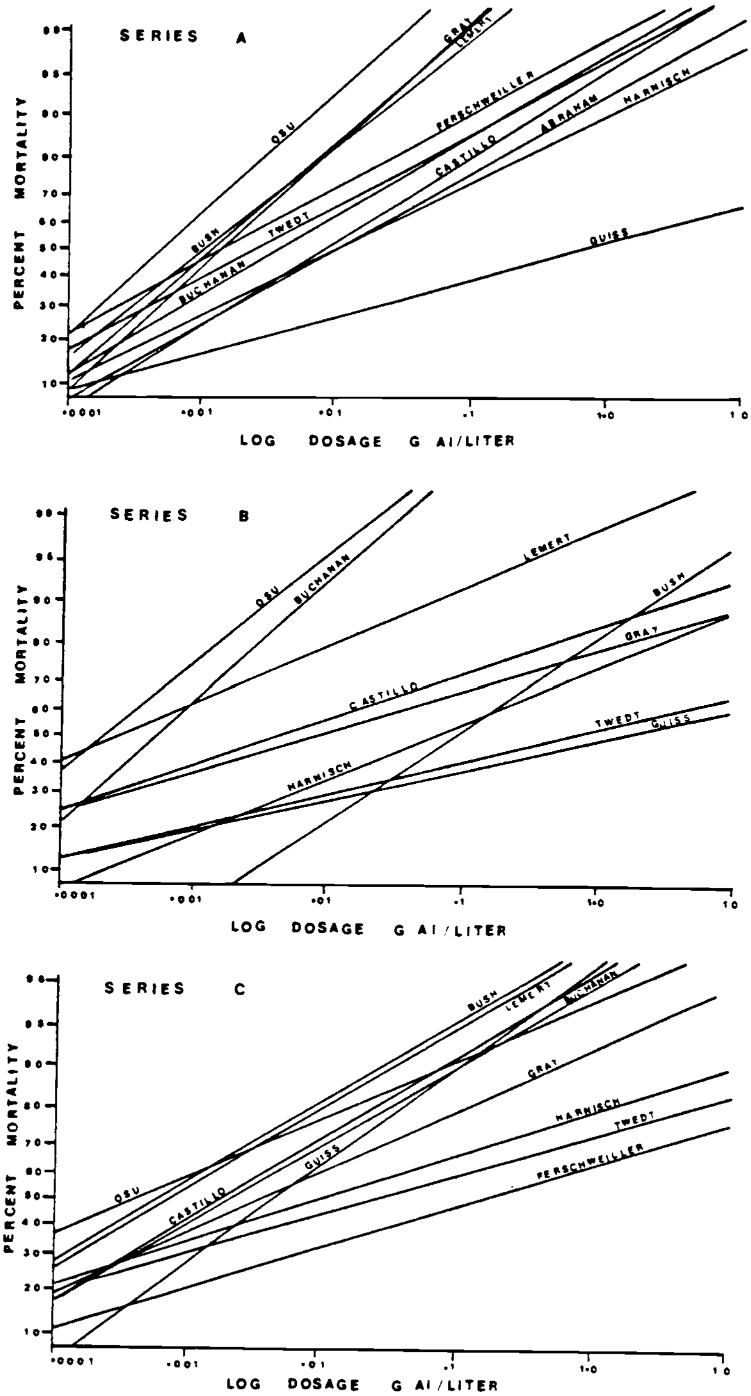



Figure 6. Log dosage concentration and percent mortality lines for different filbert aphid populations exposed to fenvalerate.

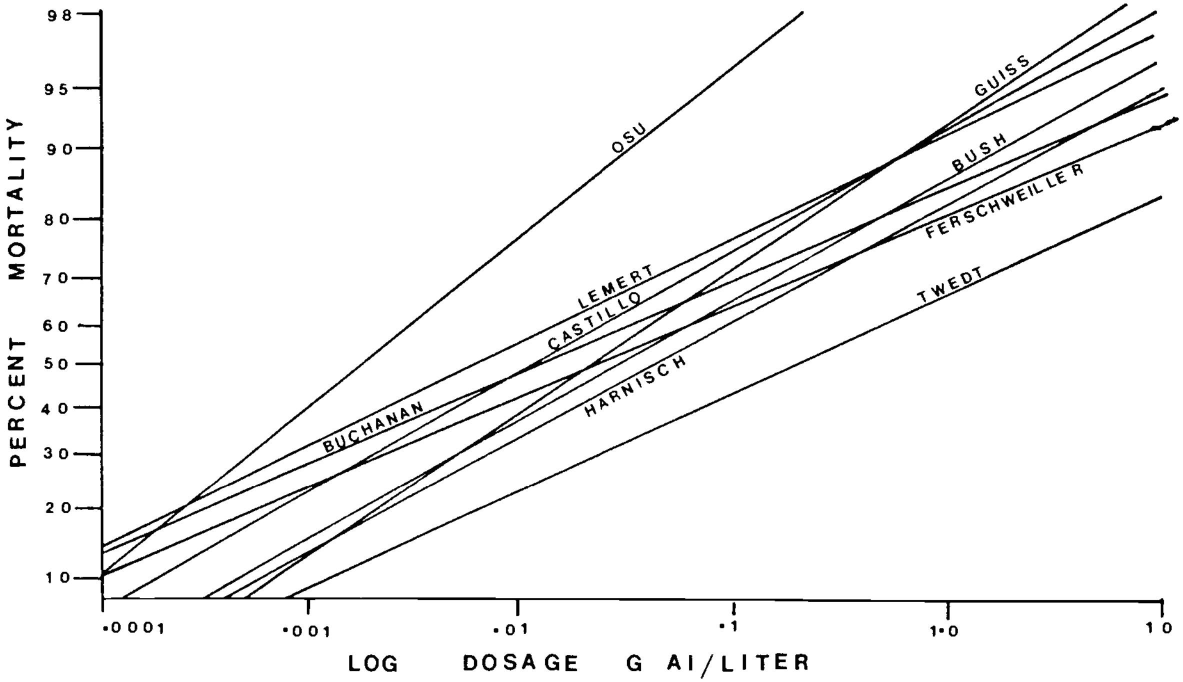



Figure 7. Log dosage concentration and percent mortality lines for different filbert aphid populations exposed to oxydemetonmethyl.

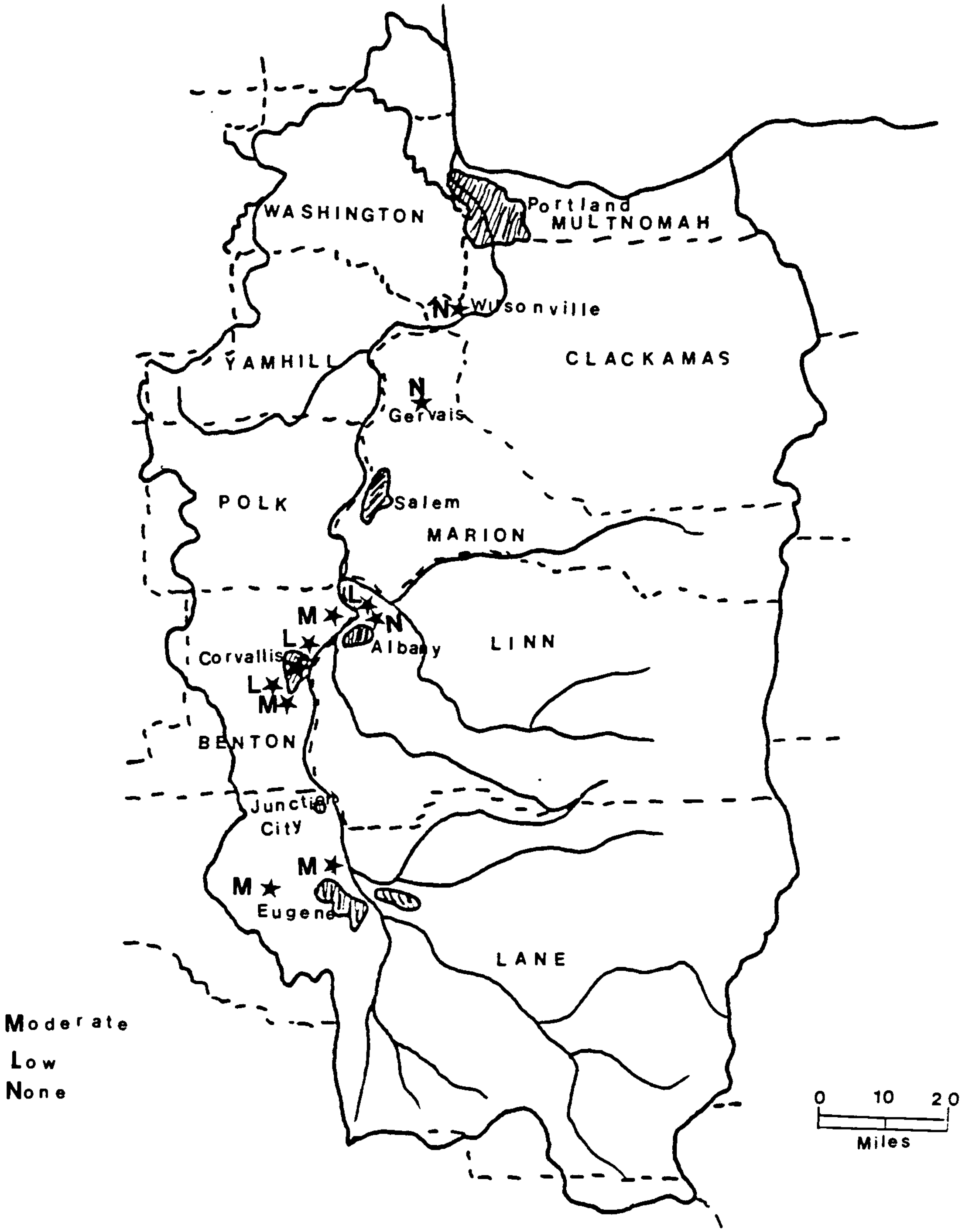



Figure 8. Map of the Willamette Valley, Oregon showing the distribution of filbert aphid resistance to endosulfan.

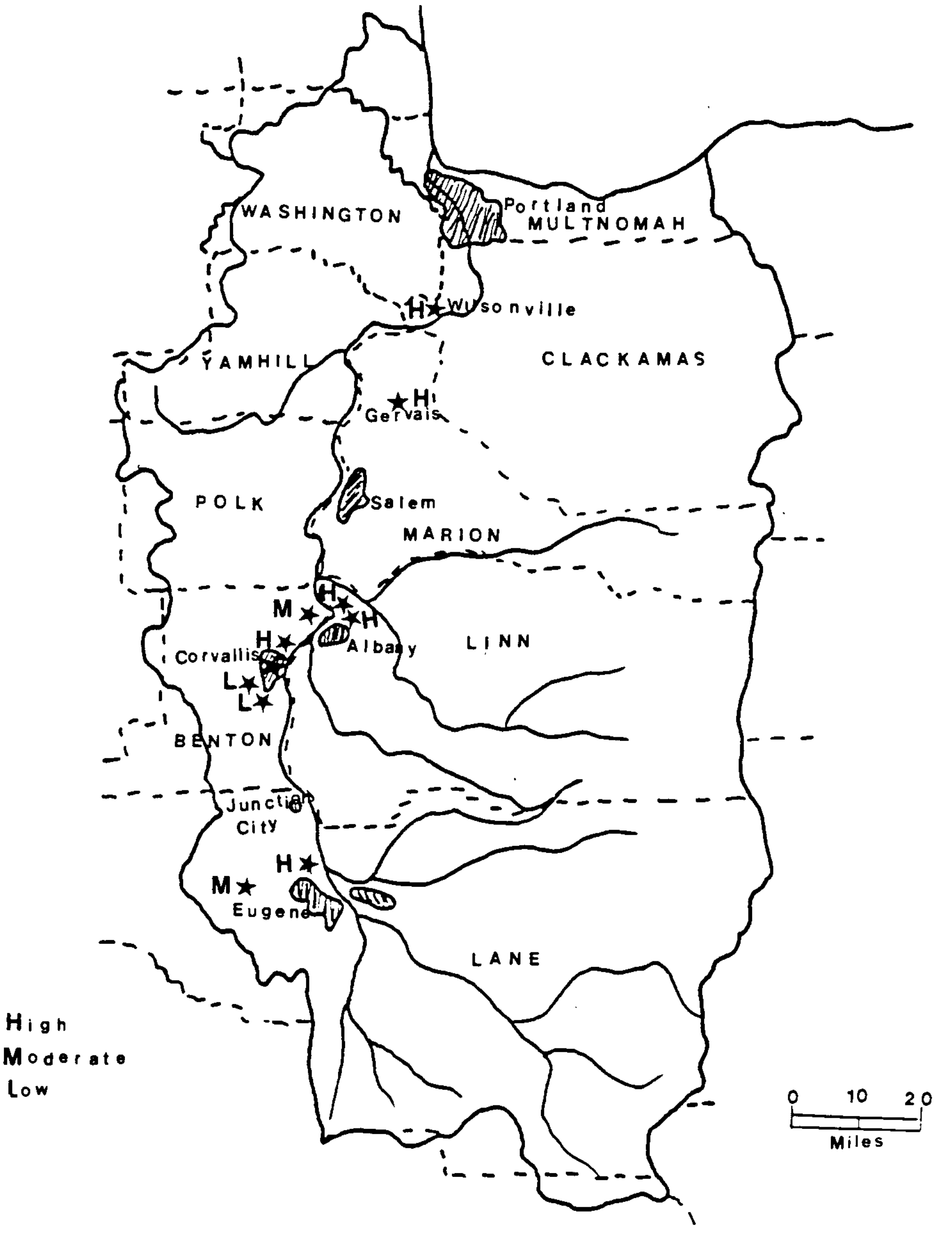



Figure 9. Map of the Willamette Valley, Oregon, showing the distribution of filbert aphid resistance to phosalone.

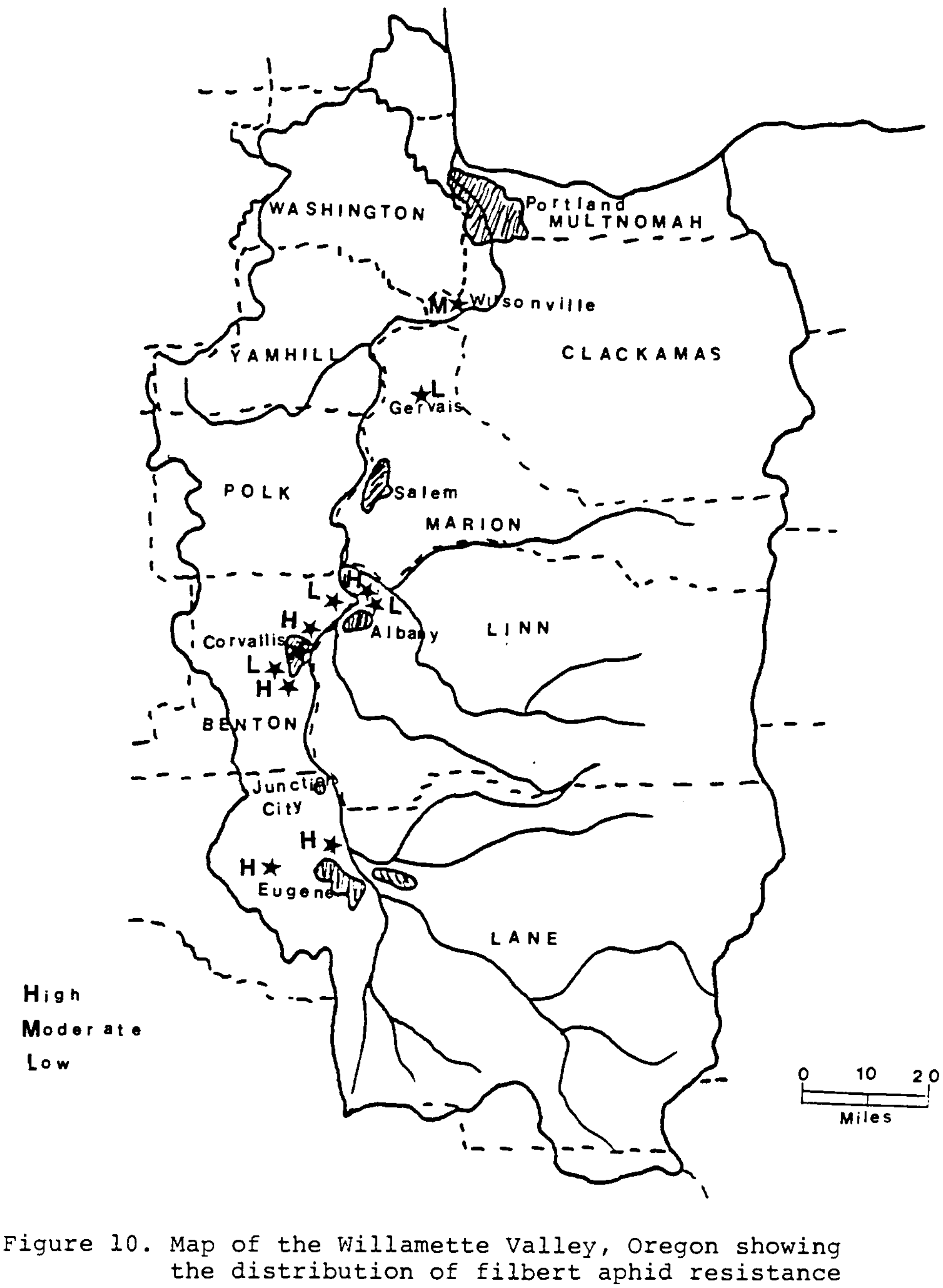



Figure 10. Map of the Willamette Valley, Oregon showing the distribution of filbert aphid resistance to carbaryl.

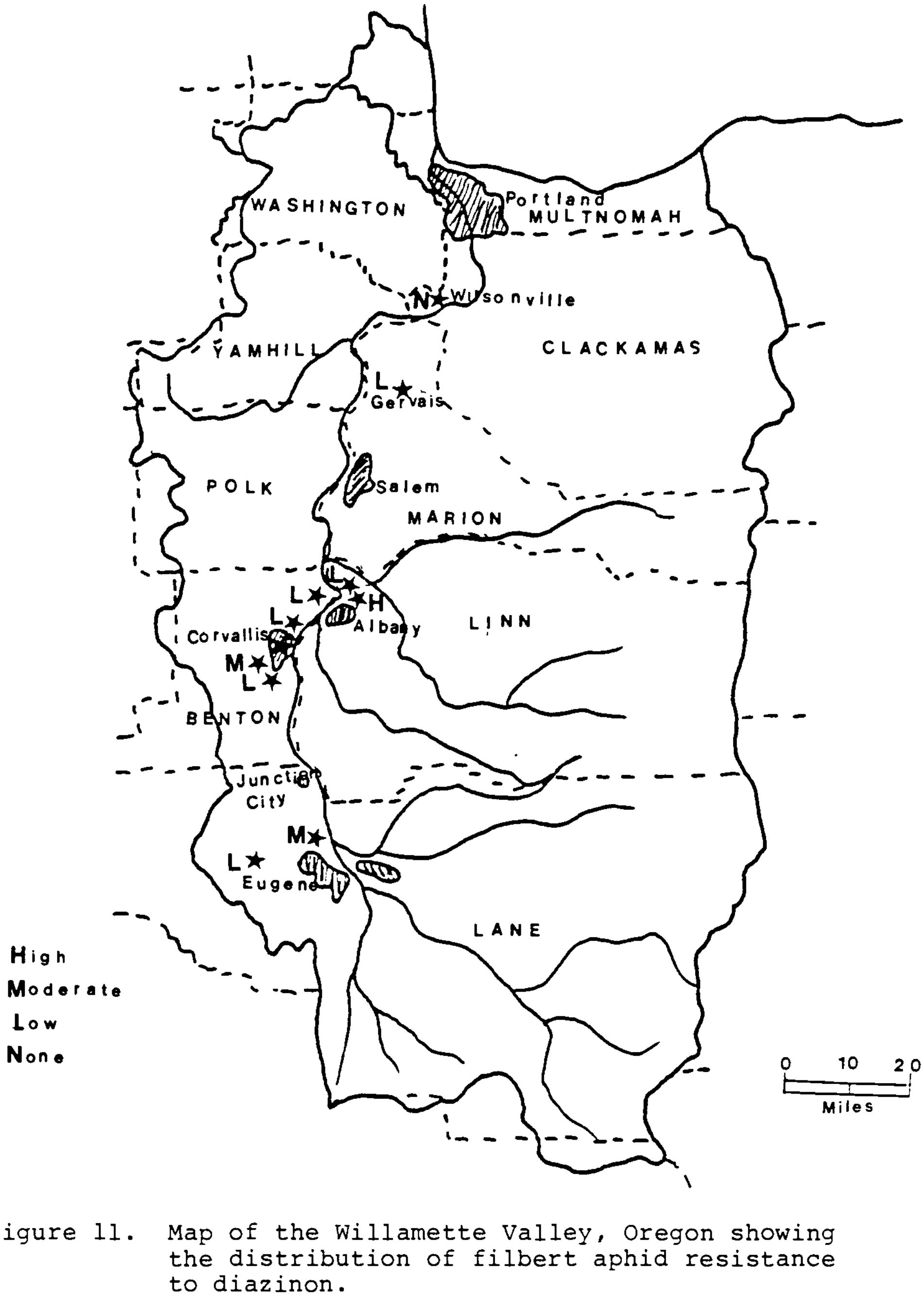



Figure 11. Map of the Willamette Valley, Oregon showing the distribution of filbert aphid resistance to diazinon.

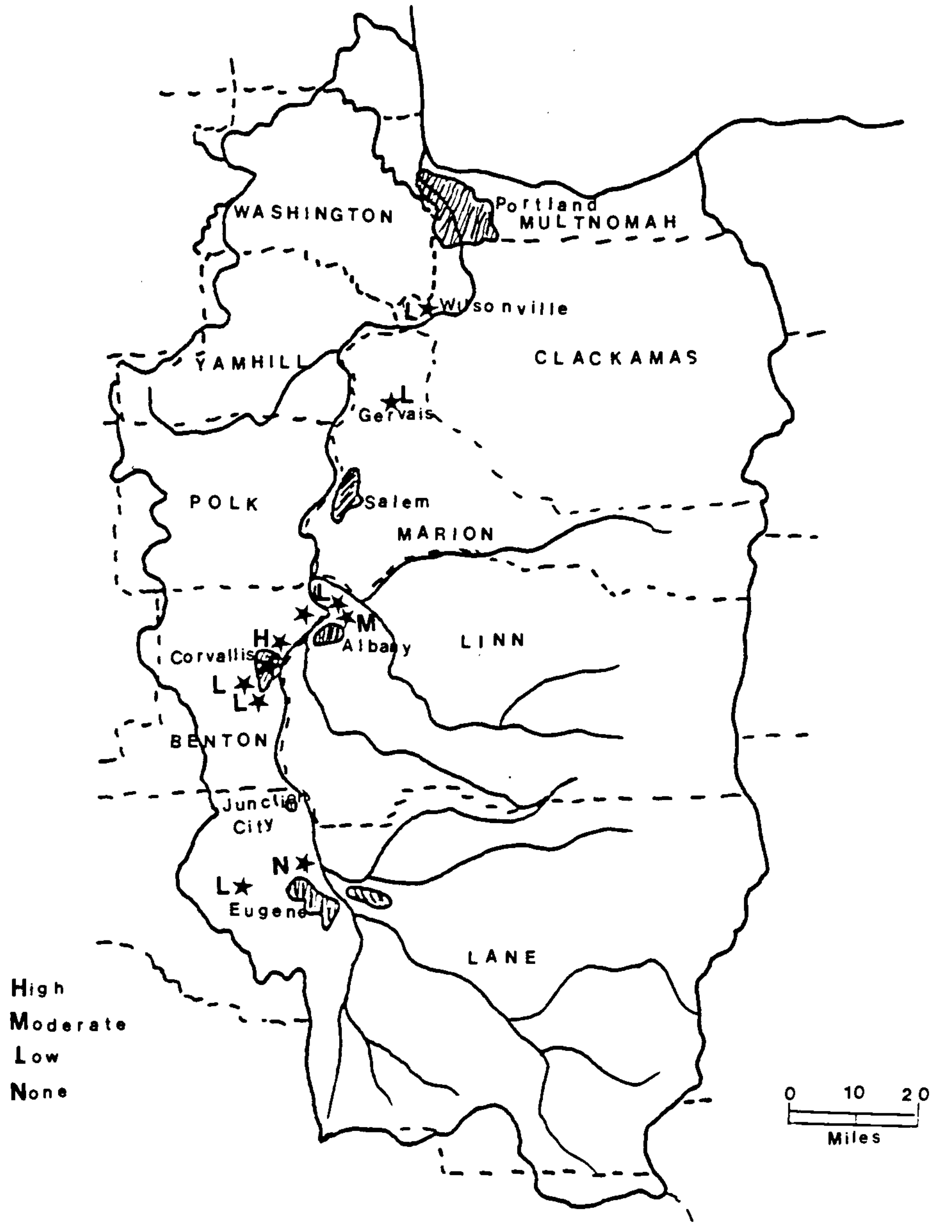



Figure 12. Map of the Willamette Valley, Oregon showing the distribution of filbert aphid resistance to oxydemetonmethyl.

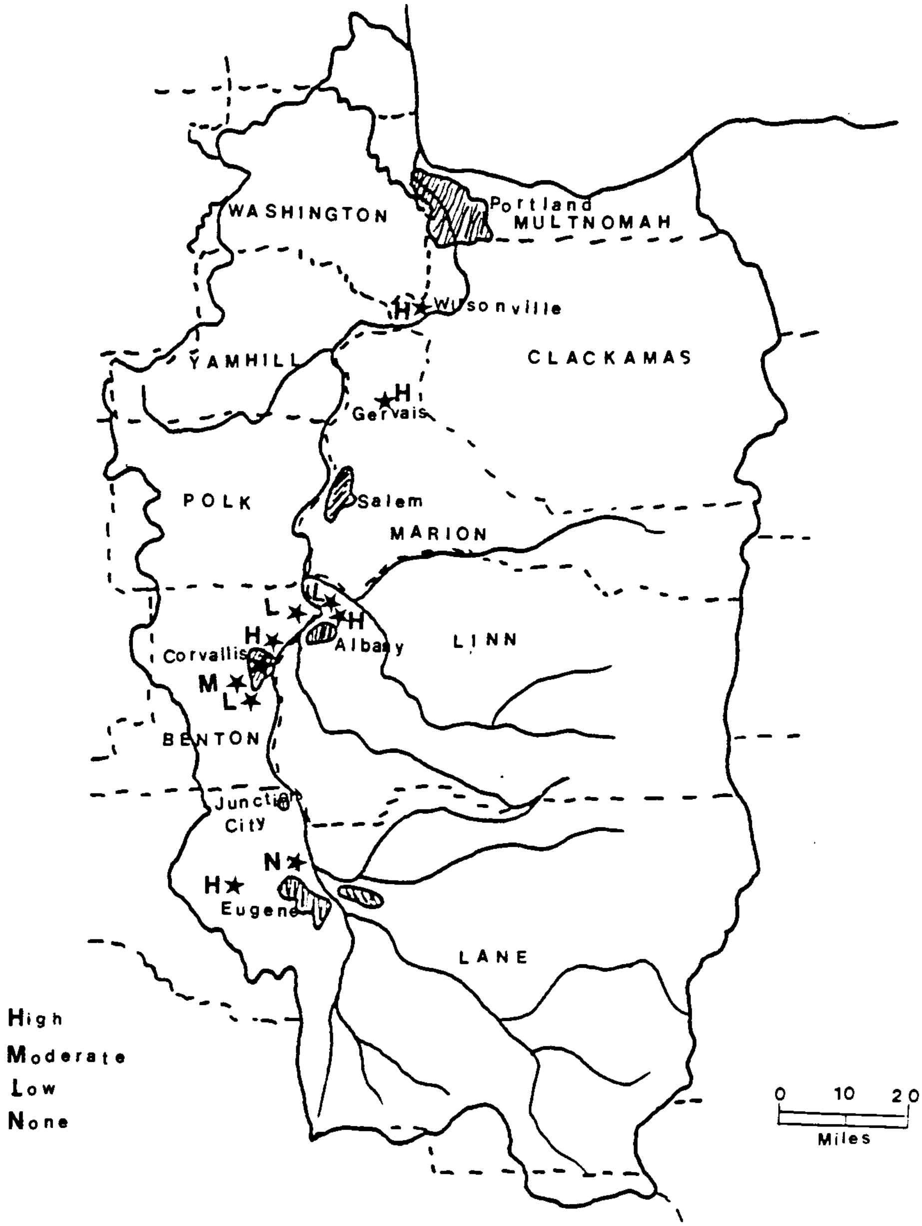



Figure 13. Map of the Willamette Valley, Oregon showing the distribution of filbert aphid resistance to fenvalerate.

Figure 14. Seasonal changes in susceptibility of filbert aphids to carbaryl.

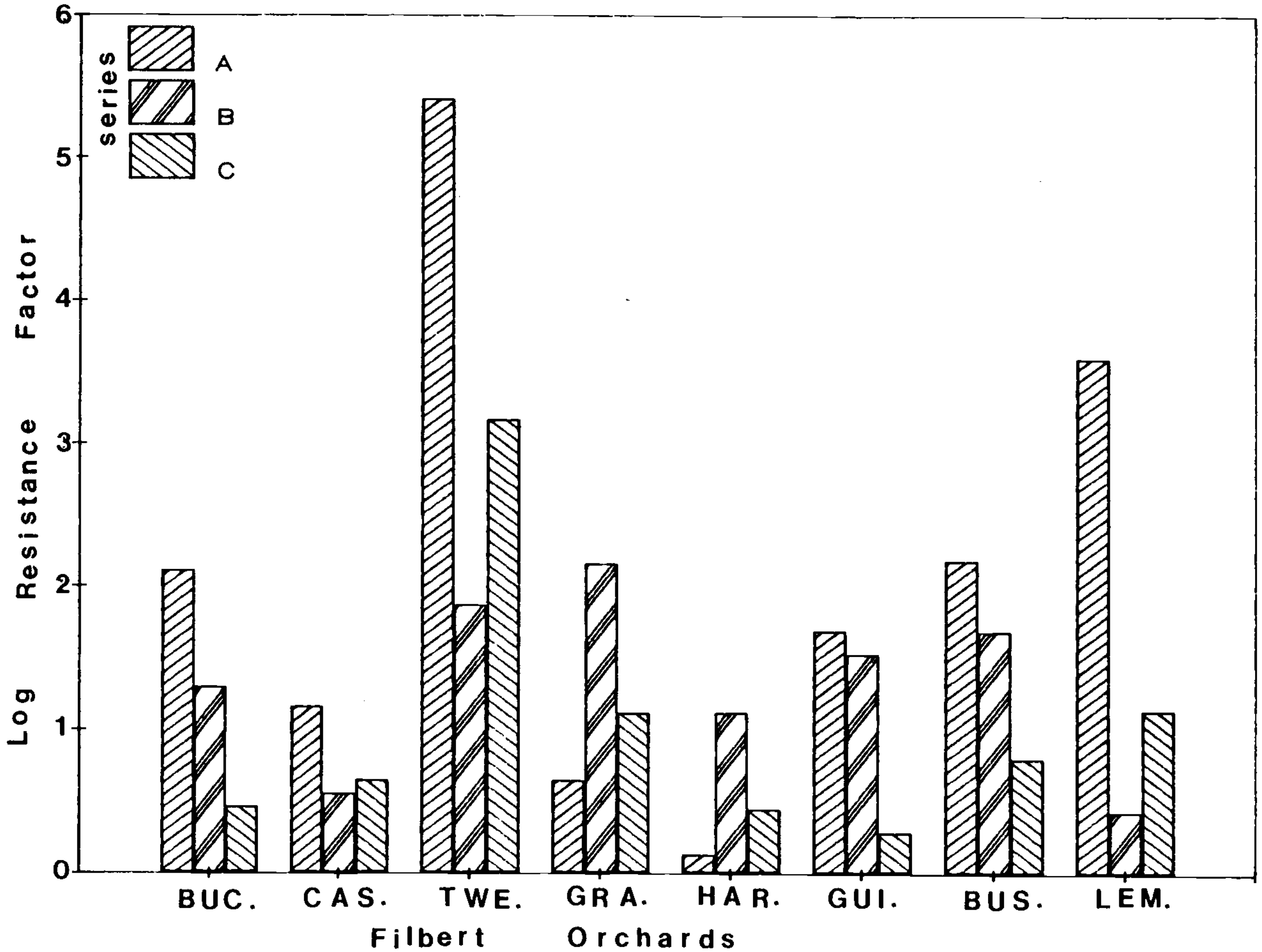


Figure 15. Seasonal changes in susceptibility of filbert aphids to diazinon.

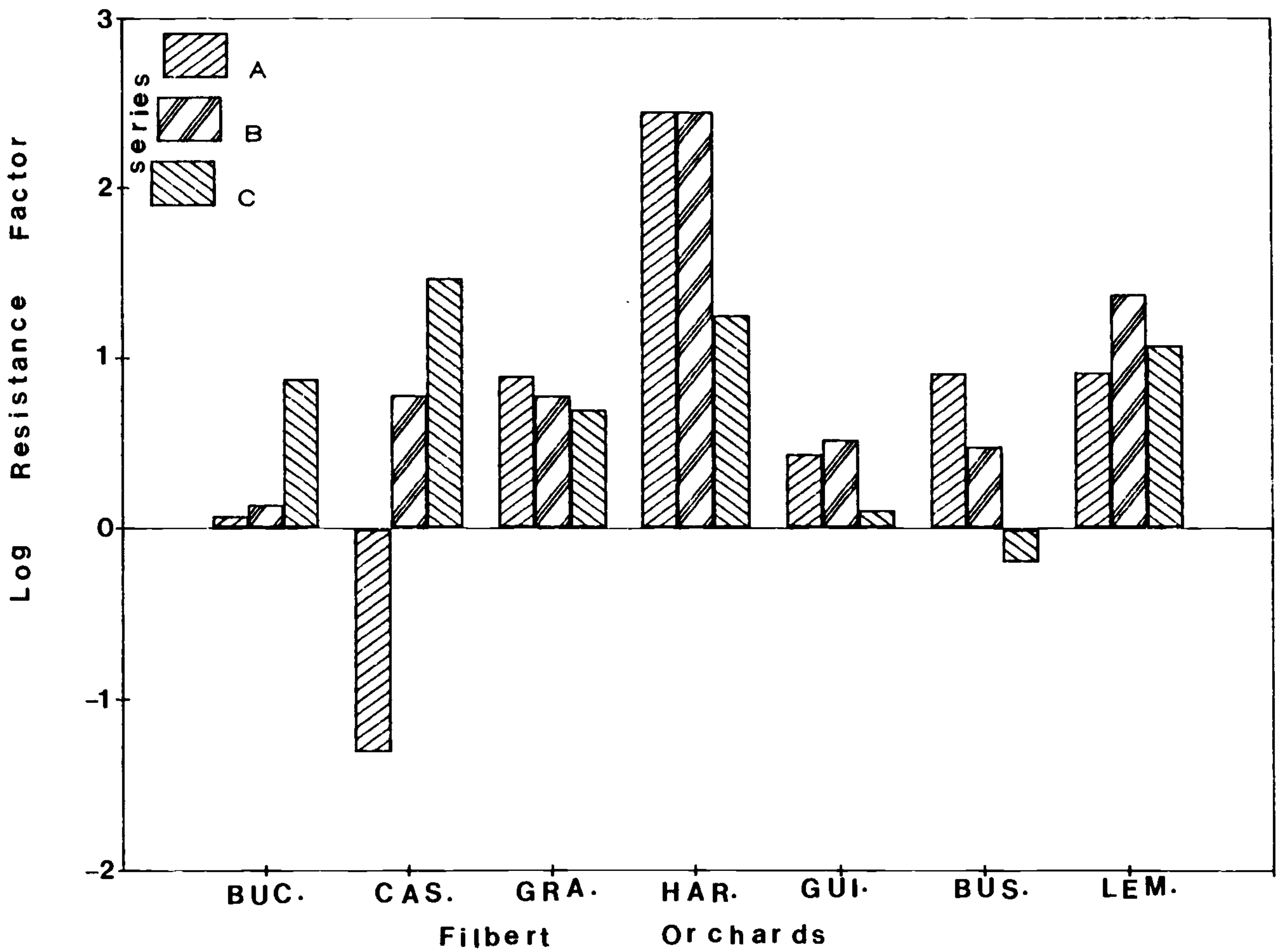


Figure 16. Seasonal changes in susceptibility of filbert aphids to endusulfan.

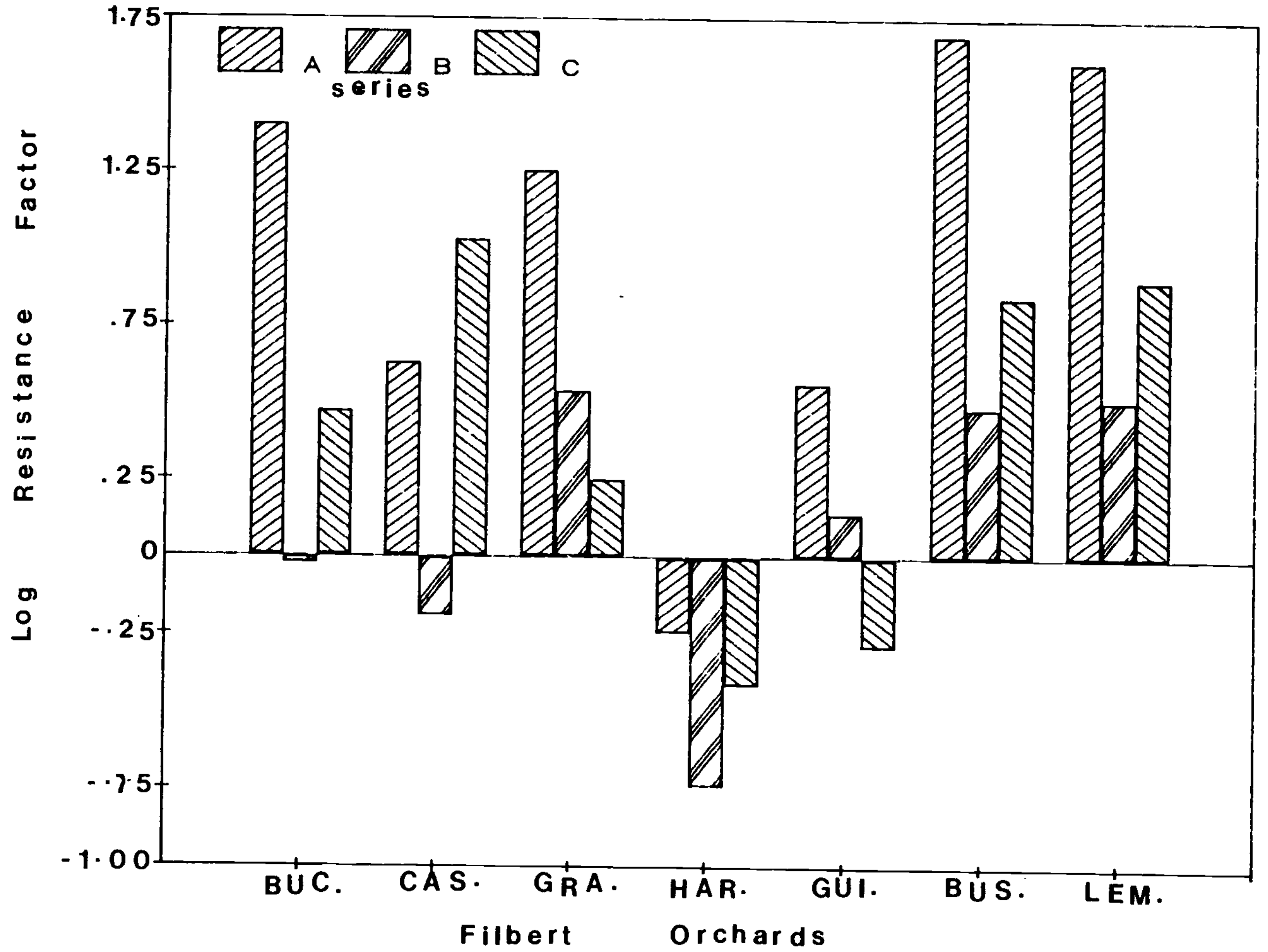


Figure 17. Seasonal changes in susceptibility of filbert aphids to phosalone.

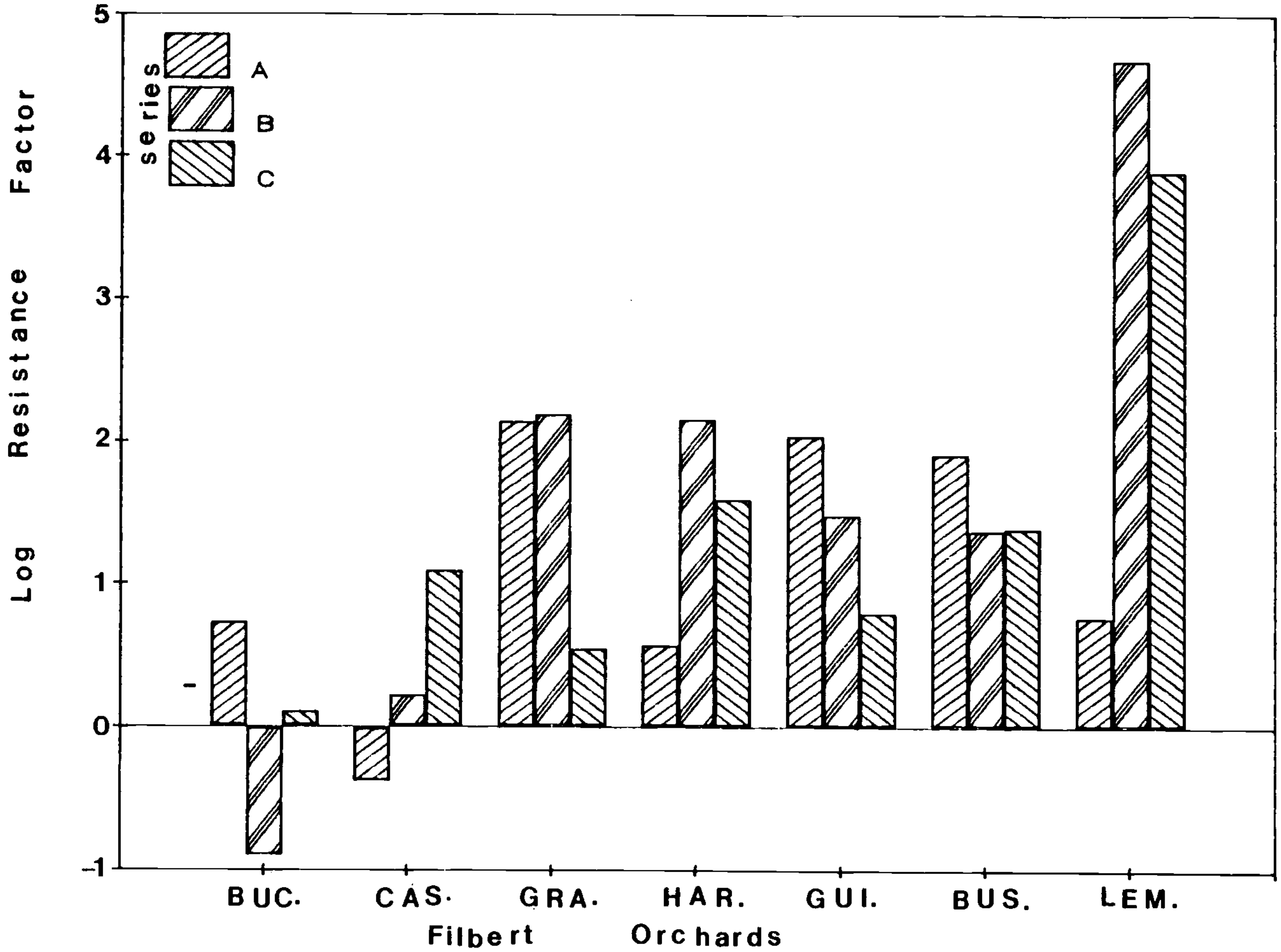
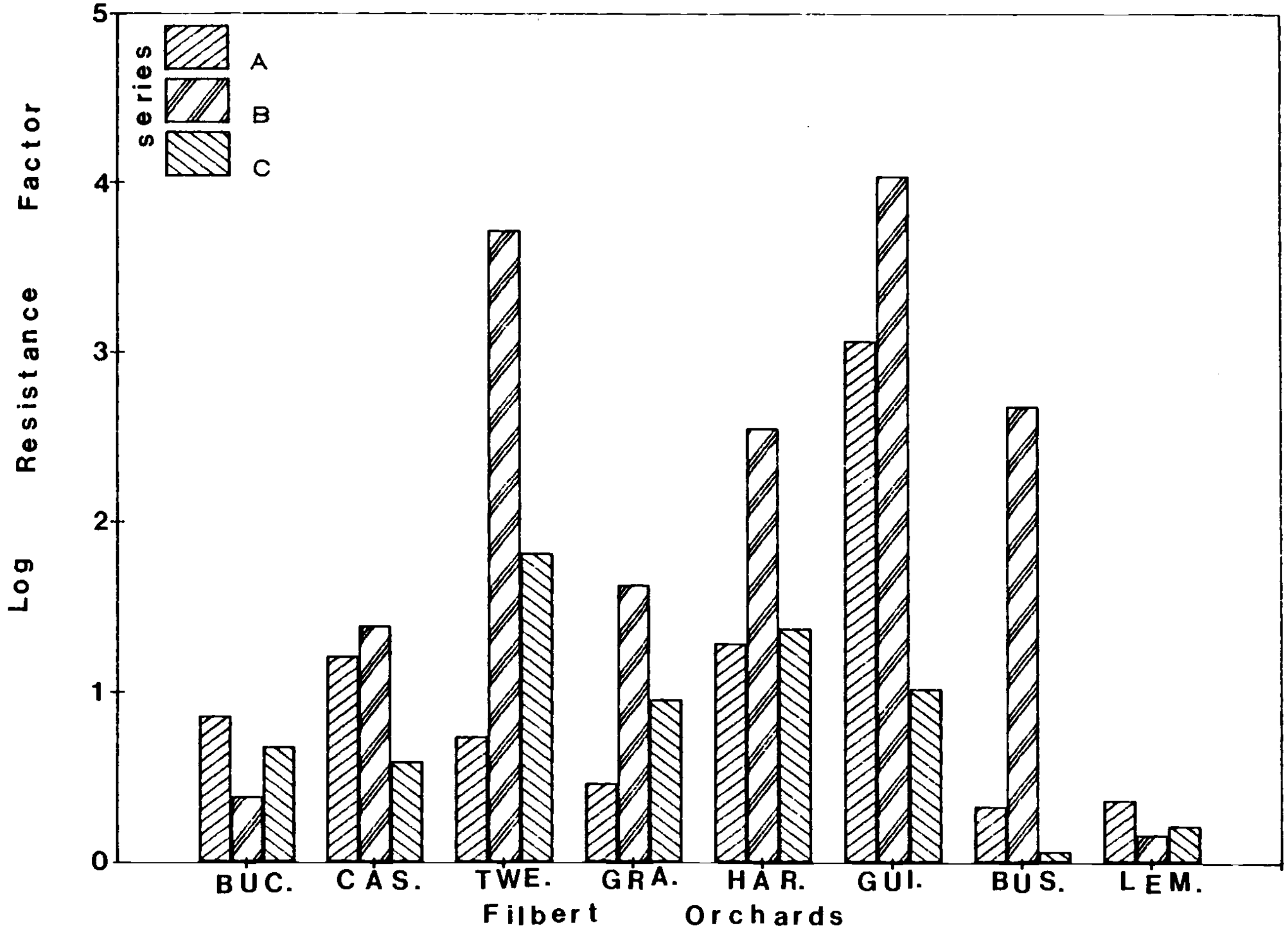


Figure 18. Seasonal changes in susceptibility of filbert aphids to fenvalerate



# DISCUSSION

Populations of the filbert aphid in the Willamette Valley showed increased tolerance to all groups of insecticides tested although the numerical magnitude varied considerably from one individual compound to another, and between orchards. The extreme degree of resistance (RF $>$ 1000x) found to carbaryl, fenvalerate and phosalone was unexpected and should be interpreted with caution. Highest resistance to diazinon was a 288-fold increase, to endosulfan (RF 50.2x) and to oxydemetonmethyl (RF 112x). Despite the high resistance factors, the $Lc_{50}$ values for each insecticide obtained in some seasons and the majority of orchards, were generally well below the recommended field rates. Previous field efficacy trials showed that phosalone was effective against the filbert aphid. The responses obtained from this study would therefore suggest that the effectiveness of phosalone in the field could in part be due to its selectivity in sparing natural enemies to exert their regulatory influence on the filbert aphid populations. Higher levels of tolerance to phosalone could also be a problem of cross- or multiple resistance from use of one or the other of the closely related organophosphorus insecticides, i.e. azinphosmethyl, diazinon, oxydemeton-methyl and dimethoate. It is difficult to explain the higher resistance to fenvalerate that has been exhibited from several orchards in just less than three years of registration. In the field however this compound has not been particularly effective in controlling the filbert aphid. Perhaps it is this inherent tolerance that has increased the rate of selection for high resistance after just one or two seasons of exposure to fenvalerate. These results may further suggest that the factors or mechanisms responsible for the resistance of the organophosphorus and other groups of insecticides used earlier might as well be responsible for the present fenvalerate resistance.

The flattened slopes in the highly resistant populations were expected. Considering the insecticide use pattern in different orchards, the progress in selection to homogeneous resistance in filbert aphid populations could not be rapid. Most orchardists use more than one insecticide in one season separately or in mixtures. In some orchards alternating or rotational insecticide use pattern is also practiced and this could be one reason for heterogeneity found in all cases of resistance in this region.

The most interesting finding of this study was the marked variation in susceptibility to a particular insecticide between strains collected from different localities (Table 6 and Figures 8 to 13). What has become apparent however is that orchards whose filbert aphid populations exhibited highest tolerances were also those receiving relatively more intensive insecticide applications. But attempts to collect filbert aphids from Abraham, the abandoned and most isolated orchard in these experiments, were without success. Therefore, the data obtained from this orchard were not adequate for comparison purposes.

Field application of insecticides against the filbert leafroller and aphids is usually done during April to May, and cover spray(s) for control of the filbert worm in mid-July to late August. The fact that Myzocallis coryli Goetze is a single-host aphid leads to speculation that very few individuals can escape exposure to insecticides in commercial orchards. However, because of parthenogenesis and high reproductive rate, it is possible from a few surviving individuals to have rapid build up of large populations in later generations. In summer months the filbert aphid population is also experiencing high temperatures, crowding and poor food quality of mature leaves. Again, the possession of wings in all generations except oviparae is an obvious adaptation for dispersal of the filbert aphid (Sluss 1967, Gilbert 1982). The prevailing environmental conditions in summer will most likely cause the filbert aphid to fly to adjacent trees, or possibly be transported farther distances under favorable wind situations. Migration in the filbert aphid therefore occurs during or after exposure to intensive selection by commercial insecticides spraying. In the absence of any physical barrier along the Willamette Valley, the commercial orchards may be considered almost contiguous. Hence the aphids could move easily from one locality to another by wind and sometimes by using scattered volunteer trees to bridge the apparent gaps in their short-distance flights. The tendency of the filbert aphid to migrate either in order to spread the chance of survival in space, or as an attempt to find and colonize filbert trees that are nutritionally above average in quality, will result in distribution and considerable increase of the frequency of genes for insecticide resistance in this region. The frequency, as in fenvalerate -- or phosalone -- resistance, may rise quickly when the population is exposed to the chemical, resulting in a higher resistance expression in very short time.

The high resistance levels to phosalone of some populations not treated in recent years could be due to previously unrecorded exposure to this chemical. The present results could also be influenced by the fact that these sources are surrounded by filberts and other fruit trees which receive extensive sprays of phosalone or other related compounds. In contrast to phosalone, the reason for the slow development and spread of resistance to diazinon, which is widely used as an aphicide, is not known. The exceptional susceptibility of the filbert aphid to endosulfan could be due to its mode of action which may not involve the inhibition of cholinesterase associated with organophosphorus compounds and carbamates. Because too few orchards were sampled, the absence of high levels of resistance to carbaryl in Ferschweiller and Guiss populations may not reflect a true picture of resistance to this chemical in the North Willamette Valley. The occurrence of low to high levels of resistance to all insecticides, except fenvalerate, in Lemert (a young orchard) populations was an example of the influence of adjacent, intensively sprayed filberts and other fruit tree orchards. In general, there was no regional pattern of distribution of resistance.

Pronounced variation in susceptibility of the filbert aphid to test insecticides was also exhibited between seasons (Figures 14 to 18). Although no clear pattern was observed, the tendency for increased tolerance in the summer and fall populations was evident in all insecticides except phosalone in Lemert populations (Table 4 and Figure 11), where spring resistance was considerably high. Migration of populations from other orchards may in one way explain the seasonal variation in susceptibility and the widespread resistance of the filbert aphid to various insecticides in the Willamette Valley. Except for the early spring (stem-mother) population which emerges from eggs, in any particular orchard, the summer forms and oviparae (fall forms) are probably a mixed population composed of phenotypically or genetically different strains with regards to resistance.

The seasonality of insecticide resistance of the filbert aphid could also be caused by the changes in the physiological conditions of population development. Changes in the filbert tree phenology may affect the nutrition of the aphids and the level of insecticide exposure in the orchard. Thus despite attempts to collect samples not less than two weeks after insecticide application, some part of the aphid population in the orchard, particularly in summer and fall, may experience a degree of sublethal effects of insecticide residues from previous field treatment. According to some authors this would render the insects more susceptible to exposure to test insecticide in the laboratory. But in the present report the converse appears to be true. It seems that field exposure to insecticides would possibly eliminate most of the susceptible phenotypes in the orchard before samples are taken for laboratory bioassay. That could explain the general trend, with few exceptions, of increasing LD50 values of insecticides in tests conducted against late summer and fall generations as compared to the filbert aphid populations collected in early spring.

In these experiments one would also be interested to find what effect aging has on the variability of resistance levels in the filbert aphid populations to insecticides. If age were an important factor one would expect highly variable responses or shallower slopes of the dosage/mortality lines in Series B experiments in which discrimination of age by wing-bud size could not be done because only males are winged. Also, in contrast to other generations, fall forms feed largely on old senescing filbert leaves, and it is the only active stage that has higher risk of exposure to freezing temperatures in late October and November. However, the positive responses to resistance of this population phase suggests the existence of more important mechanisms of resistance that influence the levels of enzyme-systems and the biochemistry of the filbert aphid during the season.

That highest resistance levels were not obtained in early spring populations could indicate that seasonal variation in resistance is not influenced by interbreeding with resistant male genotypes. Instead, genetical variations of resistance in the parthenogenetic generations of the filbert aphid would presumably be caused by other genetic functions like mutations and chromosomal translocations (Blackman 1979) or by gene duplication leading to increased specific enzyme production (Devonshire and Sawicki 1979).

Comparison of the present results with the data obtained by Ali Niazee (1983b) on filbert aphid resistance to carbaryl raises yet another question of interpretation of tolerance levels when different populations are used as the susceptibility-types. Apparently the $Lc_{50}$ values for carbaryl obtained in the present experiments were within the susceptible (S) and intermediate resistance (IR) levels of previous work. Yet considerably large differences in $Lc_{50}$ values for the susceptible strains have made comparisons of tolerance ratios between the two sources of data less meaningful.

Some of the interesting findings and suggestions of the study are highlighted below. For practical resistance management of the filbert aphid, these conclusions may hopefully provide useful considerations in future resistance monitoring programs in the Willamette Valley.

1. Filbert aphids show various levels of resistance to all selected insecticides used in the filbert insects control program in the Willamette Valley of Oregon.

2. The data obtained indicate that filbert aphid resistance to the test insecticides is highly heterogeneous. Even in populations which may appear susceptible now, there is a potential problem that resistance frequencies may reach high levels in the immediate future.

3. Perhaps it is the use of mixtures of rotational patterns of insecticides application that has delayed the development of homogeneous, super-resistance of filbert aphids to some compounds in this region. The disadvantage of these practices however has been the occurrence of

multiple resistance to insecticides of filbert aphid populations from various orchards.

4. High inherent tolerance to fenvalerate or due to cross-resistance to other groups with similar resistance mechanisms could partly explain the rapid development of high levels of filbert aphid resistance to this pyrethroid insecticide.

5. No regional distribution of insecticide resistance was found on filbert aphids in the Willamette Valley. Highest resistance levels were mostly correlated to most intensive usage of insecticides.

6. Pronounced seasonal variations in susceptibility of filbert aphids to selected insecticides were noticed in these experiments.

7. Resistance expression however is subject to the influence of several environmental factors. Because of the multiplicity of factors involved, no generalized explanation can be given to the seasonal variations of the filbert aphid resistance to the various insecticides. More detailed investigations are necessary to study the influence of individual biological and environmental factors on insecticide resistance changes in the filbert aphids.

8. Finally, resistance monitoring is considered critical to resistance management. Whether the resistance monitoring program is for detection or documentation of insecticide resistance problem in filbert aphids,

consideration should be given to developing standard monitoring techniques. It is also important to establish susceptibility-types for reliable interpretation of insecticide resistance data which can be compared both in time and space. Use of synergists or biochemical methods such as electrophoresis may be essential to support and confirm bioassay results.

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# APPENDICES

TABLE A-1. RESPONSES OF FIELD POPULATIONS OF FILBERT APHID TO CARBARYL

| Orchard | $LC_{50}$ (gAI/1) | 95%CI (gAI/1) | $LC_{95}$ (gAI/1) | 95%CI (gAI/1) | Slope | $r^2$ | RF $LC_{50}$ | RF $LC_{95}$ |
|---|---|---|---|---|---|---|---|---|
| | | | | SERIES A | | | | |
| OSU | 0.0027 | .0027-.0027[a] | 0.1553 | .1541-.1564 | .94 | .72 | 1.0 | 1 |
| Buchanan | 0.3575 | .3318-.3851 | 50.2214 | 5.82 - 433.33 | .77 | .83 | 132.4 | 323.4 |
| Castillo | 0.0400 | .0400-.0401 | 0.4915 | .4902-.4928 | 1.51 | .81 | 14.9 | 3.2 |
| Twedt | 718.4478 | b | b | b | .28 | .85 | $2.66x10^5$ | -- |
| Abraham | 0.0145 | .0144-.0146 | 0.3400 | .3378-.3421 | 1.20 | .84 | 5.4 | 2.2 |
| Gray | 0.0124 | .0109-.0141 | 305.03 | b | .37 | .67 | 4.6 | $1.964x10^3$ |
| Harnisch | 0.0039 | .0038-.0039 | .2111 | .2095-.2127 | .95 | .86 | 1.4 | 1.4 |
| Ferschweiller | 0.0396 | .0343-.0458 | b | b | .35 | .77 | 14.7 | -- |
| Guiss | 0.1361 | .1191-.1555 | 649.5542 | b | .45 | .87 | 50.4 | $4.1826x10^3$ |
| Bush | 0.4201 | .3627-.4866 | b | b | .44 | .85 | 155.6 | -- |
| Lemert | 11.0501 | 4.4433-27.4805 | b | b | .31 | .76 | $4.09x10^3$ | -- |
| | | | | SERIES B | | | | |
| OSU | 0.0026 | .0026-.0026 | .1782 | .1767-.1797 | .90 | .75 | 1.0 | 1 |
| Buchanan | 0.0531 | .0514-.0549 | 9.5799 | 7.9460-11.5499 | .73 | .87 | 20.4 | 53.8 |
| Catillo | 0.0095 | .0094-.0095 | .1381 | .1378-.1385 | 1.41 | .81 | 3.7 | <1 |
| Twedt | 0.1985 | .1959-.2011 | 7.5536 | 7.1394-7.9917 | 1.04 | .95 | 76.3 | 42.4 |
| Abraham | 0.0243 | .0242-.0245 | 0.5582 | .5538-.5628 | 1.21 | .96 | 9.3 | 3.1 |
| Gray | 0.3842 | .3805-.3879 | 10.0480 | 9.3890-10.7531 | 1.16 | .84 | 147.8 | 56.4 |
| Harnisch | 0.0354 | .0353-.0356 | 0.7513 | .7464-.7564 | 1.24 | .94 | 13.6 | 4.2 |
| Ferschweiller | -- | -- | -- | -- | -- | -- | -- | -- |
| Guiss | 0.0901 | .0887-.0915 | 4.4897 | 4.2982-4.6897 | .97 | .96 | 34.7 | 25.2 |
| Bush | 0.1304 | .1257-.1352 | 23.1170 | 14.9016-35.8616 | .73 | .88 | 50.2 | 129.7 |
| Lemert | 0.0073 | .0090-.0077 | 4.7017 | 3.7288-5.9285 | .59 | .998 | 2.8 | 26.4 |
| | | | | SERIES C | | | | |
| OSU | 0.0085 | .0084-.0086 | 0.4889 | .4829-.4951 | .94 | .98 | | |
| Buchanan | 0.0256 | .0251-.0262 | 3.1901 | 3.0024-3.3895 | .79 | .97 | 3.0 | 6.5 |
| Castillo | 0.0395 | .0394-.0396 | 0.7027 | .6991-.7063 | 1.32 | .83 | 4.6 | 1.4 |
| Twedt | 12.8396 | 3.4833-47.3268 | b | b | 1.27 | .94 | 1510.5 | -- |
| Gray | 0.1147 | .1105-.1192 | 23.2554 | 14.6712-36.8624 | .71 | .89 | 13.5 | 47.6 |
| Harnisch | 0.0244 | .0243-.0245 | 0.5244 | .5211-.5278 | 1.23 | .91 | 2.9 | 1.1 |
| Ferschweiller | 0.0084 | .0084-.0085 | 0.3054 | .3030-.3079 | 1.05 | .85 | 1.0 | <1 |
| Guiss | 0.0174 | .0173-.0175 | 0.4247 | .4218-.4277 | 1.18 | .76 | 2.0 | <1 |
| Bush | 0.0554 | .0551-.0556 | 1.1251 | 1.1175-1.1327 | 1.26 | .98 | 6.5 | 2.3 |
| Lemert | 0.1200 | .1164-.1238 | 14.8402 | 11.6595-18.8885 | .79 | .89 | 14.1 | 30.4 |

a) Failure of confidence intervals (CI) to overlap indicates significant differences in response ($P \leq 0.05$).
b) Response variable for reliable regression.

TABLE A-2. RESPONSES OF FIELD POPULATIONS OF FILBERT APHID TO DIAZINON

| Orchard | $LC_{50}$ (gAI/l) | 95%CI (gAI/l) | $LC_{95}$ (gAI/l) | 95%CI (gAI/l) | Slope | $r^2$ | RF $LC_{50}$ | RF $LC_{95}$ |
|---|---|---|---|---|---|---|---|---|
| | | | SERIES A | | | | | |
| OSU | 0.0062 | .0062-.0062[a] | 0.1665 | .1652-.1678 | 1.15 | .86 | 1 | 1 |
| Buchanan | 0.0078 | .0077-.0079 | 0.3721 | .3666-.3777 | .98 | .93 | 1.2 | 2.2 |
| Castillo | 0.0003 | .0003-.0003 | 0.4155 | .3918-.4408 | .52 | .87 | <1 | 2.5 |
| Twedt | -- | -- | -- | -- | -- | -- | -- | -- |
| Abraham | 0.0829 | .0824-.0834 | 1.5687 | 1.5543-1.5931 | 1.29 | .88 | 13.4 | 9.4 |
| Gray | 0.0495 | .0467-.0525 | 4.7574 | 3.8983-5.8057 | .83 | .87 | 8.0 | 28.6 |
| Harnisch | 1.7853 | 1.5413-2.0679 | 172.8935 | b | .83 | .83 | 288 | $1.038 \times 10^3$ |
| Ferschweiller | 0.0043 | .0043-.0044 | 0.1440 | .1422-.1459 | 1.08 | .82 | <1 | <1 |
| Guiss | 0.0175 | .0171-.0180 | 1.4946 | 1.4338-1.5579 | .85 | .84 | 2.8 | 9.0 |
| Bush | 0.0516 | .0455-.0584 | 115.6061 | b | .49 | .67 | 8.3 | 694.3 |
| Lemert | 0.0520 | .0478-.0564 | 20.6215 | 8.6207-49.3287 | .63 | .90 | 8.4 | 123.9 |
| | | | SERIES B | | | | | |
| OSU | 0.0014 | .0014-.0015 | 0.1097 | .1080-.1144 | .87 | .92 | 1 | 1 |
| Buchanan | 0.0020 | .0020-.0020 | 0.2065 | .2034-.2097 | .82 | .996 | 1.4 | 1.9 |
| Castillo | 0.0048 | .0048-.0048 | 0.1230 | .1221-.1238 | 1.17 | .81 | 6.2 | 1.1 |
| Twedt | 0.0136 | .0136-.0137 | 0.2984 | .2964-.3004 | 1.23 | .92 | 9.6 | 2.7 |
| Abraham | -- | -- | -- | -- | -- | -- | -- | -- |
| Gray | 0.0087 | .0077-.0097 | 47.0042 | 2.6011-849.4069 | 1.26 | .95 | 6.1 | 428.5 |
| Harnisch | 0.4097 | .4025-.4172 | 15.5332 | 13.0658-18.4666 | 1.04 | .92 | 286.5 | 141.6 |
| Ferschweiller | -- | -- | -- | -- | -- | -- | -- | -- |
| Guiss | 0.0051 | .0051-.0052 | 0.1711 | .1696-.1726 | 1.08 | .86 | 3.4 | 1.6 |
| Bush | 0.0044 | .0043-.0045 | 0.6329 | .6137-.6527 | .76 | .84 | 3.1 | 5.8 |
| Lemert | 0.0346 | .0342-.0351 | 1.2601 | 1.2377-1.2830 | 1.05 | .81 | 24.2 | 11.5 |
| | | | SERIES C | | | | | |
| OSU | 0.0024 | .0023-.0024 | 0.1855 | .1831-.1880 | .87 | .82 | | |
| Buchanan | 0.0181 | .0175-.0187 | 3.3956 | 3.1166-3.6995 | .72 | .92 | 7.7 | 18.3 |
| Castillo | 0.0711 | .0683-.0741 | 7.0579 | 6.0322-8.2579 | .82 | .99 | 30.1 | 38.0 |
| Twedt | 0.0033 | .0033-.0033 | 0.0725 | .0722-.0729 | 1.22 | .89 | 1.4 | 1 |
| Gray | 0.0121 | .0115-.0128 | 8.9337 | 6.7070-11.8998 | .57 | .93 | 5.1 | 48.2 |
| Harnisch | 0.0429 | .0416-.0443 | 5.6110 | 5.0548-6.2284 | .78 | .88 | 18.2 | 30.2 |
| Ferschweiller | 0.0291 | .0286-.0297 | 1.9375 | 1.8692-2.0083 | .90 | .91 | 12.3 | 10.4 |
| Guiss | 0.0031 | .0031-.0032 | 0.1451 | .1436-.1465 | .99 | .79 | 1.3 | <1 |
| Bush | 0.0015 | .0015-.0015 | 0.1118 | .1105-.1130 | .87 | .92 | <1 | <1 |
| Lemert | 0.0286 | .0277-.0295 | 4.8630 | 4.4051-5.3684 | .74 | .96 | 12.1 | 26.2 |

a) Failure of confidence intervals (CI) to overlap indicates significant differences in response ($P \leq 0.05$).
b) Response variable for reliable regression.

TABLE A-3. RESPONSES OF FIELD POPULATIONS OF FILBERT APHID TO ENDOSULFAN

| Orchard | LC50 (gAI/l) | 95%CI (gAI/l) | LC95 (gAI/l) | 95%CI (gAI/l) | Slope | $r^2$ | RF LC50 | RF LC95 |
|---|---|---|---|---|---|---|---|---|
| | | | | SERIES A | | | | |
| OSU | 0.0030 | .0030-.0030[a] | 0.1182 | .1172-.1193 | 1.03 | .73 | 1 | 1 |
| Buchanan | 0.0765 | .0692-.0847 | 32.7310 | 4.7976-223.3 | .63 | .79 | 25.5 | 276.9 |
| Castillo | 0.0128 | .0123-.0133 | 0.7153 | .6809-.7514 | .94 | .85 | 4.3 | 6.1 |
| Twedt | -- | -- | -- | -- | -- | -- | -- | -- |
| Abraham | 0.0825 | .0803-.0847 | 7.1892 | 6.4721-7.9858 | .85 | .98 | 27.5 | 60.8 |
| Gray | 0.0543 | .0440-.0670 | 9.2603 | 2.7235-31.4862 | .74 | .77 | 18.1 | 78.3 |
| Harnisch | 0.0017 | .0027-.0018 | 0.0408 | .0406-.0411 | 1.20 | .75 | <1 | <1 |
| Ferschweiller | 0.0082 | .0081-.0082 | 0.1783 | .1766-.1799 | 1.23 | .84 | 2.7 | 1.5 |
| Guiss | 0.0110 | .0104-.0116 | 5.7493 | 4.6828-7.0587 | .61 | .90 | 3.7 | 48.6 |
| Bush | 0.1507 | .1277-.1778 | 263.2409 | b | .51 | .98 | 50.2 | $2.227 \times 10^3$ |
| Lemert | 0.1243 | .1110-.1393 | 88.7816 | b | .58 | .95 | 41.4 | 751.11 |
| | | | | SERIES B | | | | |
| OSU | 0.0094 | .0093-.0096 | 0.4097 | .04025-.4172 | 1.00 | .97 | 1 | 1 |
| Buchanan | 0.0088 | .0086-.0091 | 1.6823 | 1.5961-1.7731 | .72 | .92 | <1 | 4.1 |
| Castillo | 0.0060 | .0060-.0061 | 0.1452 | .1442-.1462 | 1.19 | .84 | <1 | <1 |
| Twedt | 0.0073 | .0071-.0076 | 1.5334 | 1.4564-1.6144 | .71 | .94 | <1 | 3.7 |
| Abraham | -- | -- | -- | -- | -- | -- | -- | -- |
| Gray | 0.0330 | .0329-.0330 | 0.3310 | .3303-.3316 | 1.64 | .87 | 3.5 | <1 |
| Harnisch | 0.0012 | .0011-.0012 | 0.7066 | .6750-.7398 | .59 | .83 | <1 | 1.7 |
| Ferschweiller | -- | -- | -- | -- | -- | -- | -- | -- |
| Guiss | 0.0132 | .0131-.0133 | 0.3421 | .3394-.3449 | 1.16 | .97 | 1.4 | <1 |
| Bush | 0.0291 | .0288-.0295 | 0.9944 | .9789-1.0102 | 1.07 | .92 | 3.1 | 2.4 |
| Lemert | 0.0309 | .0301-.0317 | 2.6603 | 2.5284-2.7990 | .85 | .90 | 3.3 | 6.5 |
| | | | | SERIES C | | | | |
| OSU | 0.0047 | .0047-.0048 | 0.1825 | .1808-.1843 | 1.04 | .89 | | |
| Buchanan | 0.0140 | .0140-.0141 | 0.2018 | .2010-.2026 | 1.42 | .82 | 3.0 | 1.1 |
| Castillo | 0.0513 | .0498-.0529 | 5.2832 | 4.8199-5.7911 | .82 | .86 | 10.8 | 28.9 |
| Twedt | 0.0021 | .0020-.0022 | 0.8833 | .8428-.9257 | .63 | .96 | <1 | 4.8 |
| Gray | 0.0085 | .0084-.0085 | 0.2017 | .2002-.2031 | 1.20 | .90 | 1.8 | 1.1 |
| Harnisch | 0.0018 | .0018-.0018 | 0.1225 | .1208-.1242 | .90 | .81 | <1 | <1 |
| Ferschweiller | 0.0129 | .0128-.0123 | 0.2714 | .2697-.2732 | 1.24 | .84 | 2.7 | 1.5 |
| Guiss | 0.0024 | .0024-.0024 | 0.1919 | .1893-.1945 | .86 | .99 | <1 | 1.1 |
| Bush | 0.0333 | .0326-.0341 | 2.6909 | 2.5649-2.8230 | .86 | .92 | 7.0 | 14.7 |
| Lemert | 0.0382 | .0379-.0384 | 0.4278 | .4240-.4317 | 1.57 | .93 | 8.1 | 2.3 |

a) Failure of confidence intervals (CI) to overlap indicates significant differences in response ($P \leq 0.05$).
b) Response variable for reliable regression.

TABLE A-4. RESPONSES OF FIELD POPULATIONS OF FILBERT APHID TO PHOSALONE

| Orchard | $LC_{50}$ (gAI/l) | 95%CI (gAI/l) | $LC_{95}$ (gAI/l) | 95%CI (gAI/l) | Slope | $r^2$ | RF $LC_{50}$ | RF $LC_{95}$ |
|---|---|---|---|---|---|---|---|---|
| | | | | SERIES A | | | | |
| OSU | 0.0017 | .0017-.0017[a] | 0.0252 | .0252-.0253 | 1.40 | .71 | 1 | 1 |
| Buchanan | 0.0094 | .0086-.0103 | 9.2614 | 4.9062-17.4829 | .55 | .88 | 5.5 | 367.5 |
| Castillo | 0.0007 | .0007-.0007 | 0.0157 | .0157-.0158 | 1.22 | .78 | <1 | <1 |
| Twedt | -- | -- | -- | -- | -- | -- | -- | -- |
| Abraham | 0.0395 | .0389-.0402 | 1.9320 | 1.8752-1.9905 | .97 | .94 | 23.2 | 76.5 |
| Gray | 0.2416 | .2319-.2518 | 13.6766 | 9.6618-19.3598 | .94 | .99 | 142.1 | 542.7 |
| Harnisch | 0.0064 | .0063-.0064 | 0.0794 | .0787-.0802 | 1.50 | .84 | 3.8 | 3.2 |
| Ferschweiller | 0.0114 | .0112-.0115 | 0.2542 | .2500-.2586 | 1.22 | .94 | 6.6 | 10.1 |
| Guiss | 0.1904 | .1705-.2127 | 147.1371 | b | .57 | .91 | 112.0 | $5.839 \times 10^3$ |
| Bush | 0.1425 | .1308-.1552 | 35.9154 | 8.1389-158.4874 | .68 | .78 | 83.8 | $1.425 \times 10^3$ |
| Lemert | 0.0102 | .0101-.0103 | 0.1926 | .1899-.1954 | 1.29 | .88 | 6.0 | 7.6 |
| | | | | SERIES B | | | | |
| OSU | 0.0016 | .0015-.0017 | 1.344 | 1.2329-1.4651 | .56 | .97 | 1 | |
| Buchanan | 0.0002 | .0002-.0003 | 3.2264 | 2.6642-3.9072 | .40 | .95 | <1 | 2.4 |
| Castillo | 0.0027 | .0026-.0027 | 0.0903 | .0895-.0912 | 1.07 | .92 | 1.7 | <1 |
| Twedt | 0.0705 | .0653-.0763 | 147.1976 | b | .50 | .85 | 44.8 | 109.5 |
| Abraham | -- | -- | -- | -- | -- | -- | -- | -- |
| Gray | 0.2499 | .2401-.2600 | 55.5087 | 19.0945-161.3667 | .70 | .78 | 158.7 | 41.3 |
| Harnisch | 0.2307 | .2281-.2334 | 5.3175 | 5.0813-5.5647 | 1.21 | .89 | 146.5 | 4.0 |
| Ferschweiller | -- | -- | -- | -- | -- | -- | -- | -- |
| Guiss | 0.0485 | .0462-.0508 | 12.9453 | 9.4875-17.6634 | .68 | .89 | 30.8 | 9.6 |
| Bush | 0.0380 | .0378-.0382 | 0.5080 | .5061-.5099 | 1.46 | .83 | 24.1 | <1 |
| Lemert | 77.2780 | | | | .25 | .77 | $4.9 \times 10^4$ | -- |
| | | | | SERIES C | | | | |
| OSU | 0.0009 | .0009-.0009 | 0.0780 | .0770-.0790 | .85 | .93 | 1 | |
| Buchanan | 0.0012 | .0012-.0012 | 0.0641 | .0634-.0648 | .96 | .87 | 1.3 | <1 |
| Castillo | 0.0116 | .0111-.0122 | 2.0703 | 1.8913-2.2663 | .73 | .90 | 12.6 | 26.5 |
| Twedt | 1.2740 | 1.0699-1.5172 | b | b | .39 | .89 | 1384.8 | |
| Gray | 0.0033 | .0032-.0035 | 1.1706 | 1.1053-1.2397 | .65 | .96 | 3.6 | 15.0 |
| Harnisch | 0.0361 | .0325-.0400 | 242.2478 | b | .43 | .98 | 39.8 | 3105.74 |
| Ferschweiller | 3.4401 | 2.7597-4.2883 | b | b | .46 | .93 | 3739.2 | |
| Guiss | 0.0058 | .0053-.0064 | 41.0183 | 6.1560-273.31 | 1.63 | .99 | 6.3 | 525.9 |
| Bush | 0.0229 | .0221-.0227 | 3.7176 | 3.4218-4.0390 | .74 | .92 | 24.9 | 47.7 |
| Lemert | 7.4141 | 3.8714-14.1986 | b | b | .31 | .78 | 8058.8 | -- |

a) Failure of confidence intervals (CI) to overlap indicates significant differences in response ($P \leq 0.05$).
b) Response variable for reliable regression.

TABLE A-5. RESPONSES OF FIELD POPULATIONS OF FILBERT APHID TO FENVALERATE

| Orchard | $LC_{50}$ (gAI/l) | 95%CI (gAI/l) | $LC_{95}$ (gAI/l) | 95%CI (gAI/l) | Slope | $r^2$ | RF $LC_{50}$ | RF $LC_{95}$ |
|---|---|---|---|---|---|---|---|---|
| | | | SERIES A | | | | | |
| OSU | 0.0005 | .0005-.0005[a] | 0.0446 | .01400.0151 | 1.12 | .98 | 1 | 1 |
| Buchanan | 0.0037 | .0033-.0042 | 0.6464 | .5613-.7443 | .73 | .95 | 7.4 | 44.6 |
| Castillo | 0.0083 | .0079-.0088 | 1.0490 | .9817-1.1210 | .78 | .86 | 16.6 | 72.3 |
| Twedt | 0.0024 | .0021-.0027 | 0.6705 | .5740-.7834 | .67 | .97 | 5.6 | 46.2 |
| Abraham | 0.0099 | .0092-.0107 | 2.4115 | 2.1269-2.7341 | .69 | .93 | 19.8 | 166.3 |
| Gray | 0.0015 | .0014-.0015 | 0.0410 | .0398-.0423 | 1.14 | .88 | 3.0 | 2.8 |
| Harnisch | 0.0099 | .0079-.0125 | 4.5380 | 2.4805-8.3022 | .62 | .75 | 19.8 | 313.0 |
| Ferschweiller | 0.0014 | .0014-.0016 | 0.3616 | .3190-.4099 | .68 | .90 | 2.8 | 24.9 |
| Guiss | 0.5942 | .4580-.7709 | b | b | .35 | .92 | $1.20 \times 10^3$ | -- |
| Bush | 0.0011 | .0010-.0011 | 0.0495 | .0485-.0505 | .99 | .81 | 2.2 | 3.4 |
| Lemert | 0.0012 | .0012-.0013 | 0.0415 | .0399-.0431 | 1.07 | .86 | 2.4 | 2.9 |
| | | | SERIES B | | | | | |
| OSU | 0.0002 | .0002-.0002 | 0.009 | .0087-.0093 | 1.01 | .99 | 1 | 1 |
| Buchanan | 0.0005 | .0005-.0005 | 0.0152 | .0149-.0154 | 1.11 | .97 | 2.5 | 1.7 |
| Castillo | 0.0050 | .0042-.0059 | 32.7976 | 5.2895-203.3614 | .43 | .92 | 25.0 | $3.644 \times 10^3$ |
| Twedt | 1.0714 | .7728-1.4853 | b | b | .30 | .96 | $5.36 \times 10^3$ | -- |
| Abraham | -- | -- | -- | -- | -- | -- | -- | -- |
| Gray | 0.0087 | .0068-.0111 | 167.3603 | b | .38 | .74 | 43.5 | $1.8596 \times 10^4$ |
| Harnisch | 0.0735 | .0658-.0822 | 123.33 | b | .51 | .84 | 367.5 | $1.3703 \times 10^4$ |
| Ferschweiller | -- | -- | -- | -- | -- | -- | -- | -- |
| Guiss | 2.2296 | 1.4654-3.3924 | b | b | .28 | .86 | $1.11 \times 10^5$ | -- |
| Bush | 0.0989 | .0946-.1033 | 8.8640 | 7.4583-10.5346 | .84 | .95 | 494.5 | 984.9 |
| Lemert | 0.0003 | .0002-.0003 | 0.3615 | .3218-.4062 | .53 | .85 | 1.5 | 40.2 |
| | | | SERIES C | | | | | |
| OSU | 0.0005 | .0004-.0005 | 0.4422 | .3979-.4916 | .55 | .97 | | |
| Buchanan | 0.0022 | .0021-.0024 | 0.3652 | .3438-.3880 | .74 | .90 | 4.9 | <1 |
| Castillo | 0.0018 | .0017-.0019 | 0.2603 | .2437-.2780 | .76 | .95 | 4.0 | <1 |
| Twedt | 0.0300 | .0245-.0366 | 747.67 | b | .37 | .98 | 66.7 | 1690.8 |
| Gray | 0.0042 | .0038-.0046 | 2.9419 | 2.4578-3.5214 | .58 | .99 | 9.3 | 6.7 |
| Harnisch | 0.0109 | .0093-.0128 | 88.5256 | .8817-8888.46 | .42 | .79 | 24.2 | 200.2 |
| Ferschweiller | 0.1765 | .1468-.2122 | 2884.39 | b | .39 | .91 | 392.2 | 6522.8 |
| Guiss | 0.0048 | .0044-.0051 | 0.2831 | .2611-.3071 | .93 | .99 | 10.7 | <1 |
| Bush | 0.0006 | .0006-.0007 | 0.0991 | .0940-.1046 | .75 | .89 | 1.3 | <1 |
| Lemert | 0.0006 | .0007-.0008 | 0.1144 | .1083-.1208 | .75 | .92 | 1.7 | <1 |

a) Failure of confidence intervals (CI) to overlap indicates significant differences in response ($P \leq 0.05$).
b) Response variable for reliable regression.