

AN ABSTRACT OF THE THESIS OF

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Title: Effects of Early Season Immigration on  
Acaricide Resistance of Tetranychus urticae Koch on  
Strawberry in the California Pajaro and Salinas Valley

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In the Pajaro Valley near Watsonville, California, twospotted spider mite (Tetranychus urticae Koch) populations were surveyed in 1983 and '84 to detect the influence of immigrants from nursery plants or surrounding vegetation on subsequent resistance development to cyhexatin and formetanate in strawberry fields. Susceptible mites (cyhexatin LC50 = 0.0039 % a.i.; formetanate LC50 = 0.0018 % a.i.) from strawberry nurseries initially colonize newly planted fruiting fields, having survived in diapause on transplants in cold storage (average 0.068 mites/plant) and subsequent transplanting (average 0.0051 mites/plant) in fruiting fields. At some sites these mites are subsequently outnumbered by immigration of resistant mites (average cyhexatin LC50 = 0.064 % a.i.; average formetanate LC50 = 0.086 % a.i.) which overwinter on surrounding

vegetation. At other sites, however, susceptible mites appear to predominate until the first acaricide sprays are applied. Immigration of mites from January through March was documented under four different alternate host plant settings surrounding individual fields. At three sites resistance was influenced by heavy immigration of resistant mites from surrounding vegetation in 1984 which resulted in average LC50's of 0.077 % a.i. and 0.037 % a.i. for cyhexatin and formetanate for all sites, respectively, by mid-March. At one isolated 1984 site without significant immigration of resistant mites, LC50's of only 0.0035 % a.i. and 0.0074 % a.i. occurred for cyhexatin and formetanate, respectively by the same time period. At high immigration sites (i.e. Lewis, Bachan and Eaton), average peak densities of active mites were 6.48 mites per plant near adjacent heavily mite-infested vegetation and 0.136 mites per plant opposite from mite-infested vegetation. At one site not experiencing high immigration rates (Smith), peak active mite densities were only 0.0312 mites per plant near adjacent lightly mite-infested weeds and 0.000 mites per plant away from mite-infested weeds. In 1983 heavy winter rainfall (8.5-fold higher than same period in 1984) slowed resistance development in T. urticae at strawberry sites by reducing survival of overwintering or early immigrant populations. Alterations of some crop production practices to improve management of immigrant T. urticae and their subsequent effects on acaricide resistance management are discussed.

Effects of Early Season Immigration on Acaricide  
Resistance of Tetranychus urticae Koch on Strawberry  
in the California Pajaro and Salinas Valleys

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Effects of Early Season Immigration on Acaricide  
Resistance of Tetranychus urticae Koch on Strawberry  
in the California Pajaro and Salinas Valleys

1.0 INTRODUCTION

In the California Pajaro and Salinas Valleys, the twospotted spider mite (Tetranychus urticae Koch) is a major pest of strawberries, causing cell damage, substantially decreasing photosynthetic output and reducing fruit production (W. W. Allen, 1974, Wyman, et al., 1979, Sances, et al., 1982, Oatman, et al., 1982). A long, dry growing season maximizes the formidable reproductive potential of this pest. Growers respond to high pest levels with 4 - 8 acaricide applications per year to keep fruit production high. Historically, acaricide resistance in T. urticae has occurred to all organochlorine, cyclodiene, organophosphate, carbamate and inorganic acaricides registered on the crop. In addition, resistance to chlorfensulfide, ovex, tetradifon, azobenzene, selenium, quinomethionate, binapacryl, chlordimeform, and some of the pyrethroids has also occurred in this species (Georghiou and Mellon, 1983).

Cyhexatin, an organotin acaricide, has been used to control spider mites since 1974 in the Pajaro Valley. It has favorable characteristics for use in IPM systems in that it is fairly selective, with little toxicity towards phytoseiid predators and other nontarget organisms. Average number of annual applications rose from 2.1 in 1974 to 5.2 in 1979, (see Appendix C for spray records) when cyhexatin resistance was first documented (R. D. Nelson, unpub). Average annual applications fell to 4.2 in 1982, then to 3.2 in 1983, (probably because of high mortality of overwintering mites from unusually heavy

rainfall). In 1984, average annual applications rose to 5.8 because of the dry preceding winter. Cyhexatin remains generally efficacious in the valley and is the acaricide of choice among strawberry growers. However, control failures have been mounting as cyhexatin resistance has become more widespread.

Since 1981 formetanate, a carbamate acaricide, has been used to control spider mite infestations on strawberries. Marked increases in formetanate resistance were first documented for T. urticae in 1982 (R. D. Nelson, unpub. data). The California registration use label suggests growers restrict applications to two per year because of resistance development. Since then, its use has dropped from an annual average of 1.7 applications in 1981 to 0.5 applications during 1983 and 0.8 applications in 1984. Formetanate remains efficacious for some growers, and plays an important role in acaricide resistance management.

Inheritance of resistance in T. urticae to cyhexatin and formetanate has recently been characterized by Croft, et al. 1984. Backcross experiments indicated that formetanate resistance appears to be dominant and monofactorily determined, whereas cyhexatin resistance may be intermediate to recessive and polyfactorily determined. Therefore, cyhexatin resistance may be unstable and resistance management tactics may prolong the effective useful life of this selective compound.

In the Pajaro Valley, strawberry production is predominantly based on an annual planting system, which is unique in the United States. At the end of each growing season, plantings are disked under. Some fields are immediately replanted with strawberry, while other fields are rotated to vegetable or cover crops. Soil is



broadcast fumigated with methyl bromide in preparation for new strawberry plantings. Since these cultural practices completely eradicate the previous season's within-field mite populations, new strawberry plantings in the Pajaro Valley are initially colonized by low levels of susceptible mites originating from unsprayed nursery agroecosystems. The environment surrounding new plantings also may possess mite-infested vegetation, where susceptible or resistant mite populations overwinter and subsequently immigrate into new plantings. Mites immigrating from the surrounding vegetation may subsequently overwhelm susceptible nursery mite colonists.

In recent years, attention has been focused on management of acaricide resistance to prolong the useful lifespan of selective acaricides. Genetic, biological, and operational factors have been shown to influence the development of resistance in arthropods (Comins, 1977b, Georgiou and Taylor, 1977a,b, Tabashnik and Croft, 1983). Growers control operational factors, which are the chemical and cultural (physical) inputs into the agroecosystem. Aspects of chemical inputs include the nature of the pesticide, previous history of pesticide use, residue persistence, formulation as well as application methods, frequency and timing. Crop production inputs include all aspects, such as irrigation, pruning, host-free periods, disking and field preparation. Growers have no control over genetic factors affecting resistance including the frequency, number and functional dominance of alleles coding for resistance in the pest, as well as interactions between alleles. Cross-resistance may occur when applications of other pesticides with similar modes of action cause selection of resistance alleles. Resistance will normally revert in the absence of selection pressure,

until the resistance alleles have become integrated with fitness factors of the susceptible population. Growers also have little control over biological factors including biotic and behavioral aspects such as generation time, reproductive potential, and mating preferences (monogamy vs. polygamy). Mobility, dispersal behavior, host plant range (monophagy/polyphagy) and fortuitous survival (e.g. ability to overwinter) are some of the behavioral factors affecting resistance. Ecological factors, such as trophic level interactions (e.g. biological control), and immigration (Comins, 1977, Tabashnik and Croft, 1983) also play an important role in the development of resistance. Immigration of mites appear to be one ecological factor that growers can have some influence upon as it affects resistance.

Recently, immigration of mites into agroecosystems has been given more attention, largely as a result of population dynamics research (Allen and Browne, 1972, Allen, 1974, 1981, Brandenburg and Kennedy, 1982, Boykin and Campbell, 1984, Hoy, 1984) on agricultural crops. Also, resistance modelling efforts which attempt to simulate the dynamics of mite populations and their resistance status (Taylor and Georgiou, 1979, Tabashnik and Croft, 1983, 1985) have also stimulated this interest. Immigrating mites can drastically influence resistance by diluting or concentrating the frequency of resistance genes in reproducing populations. Through unrestrained reproduction, early colonizers will impart a given level of resistance (i.e. susceptible or resistant) to subsequent generations in that agroecosystem. If a population has some acaricide resistance prior to acaricide application, the resistance will in all likelihood increase when acaricide applications select for resistant individuals, and

subsequent immigration will have less effect on the subsequent resistance episode. Conversely, resistant populations, in the absence of acaricide applications, may be diluted by large influxes of susceptible individuals. In the third scenario, if early colonizers have acaricide susceptibility, subsequent immigration of resistant individuals may drastically increase the resistance levels in that population when acaricide applications select for the resistant individual. Finally, resistance may develop from a susceptible population subjected to acaricide applications when the extremely infrequent "preadapted" individual survives and produces resistant offspring, which then recolonize the field.

This research project documented the influence of T. urticae immigration into newly-planted strawberry fields on resistance of mite populations. The extent and status of resistance in mites originating on nursery plants or from vegetation surrounding field sites were determined initially. This research focused on the influence of mites coming from nurseries or surrounding host plants on resistance levels developed in spider mites occurring in newly planted strawberry fields, until the first acaricide sprays were applied. My assumption was that novel resistance management tactics for this species might be developed with increased understanding of spider mite immigration.

Driscoll Strawberry Associates, Inc. cooperated in providing access to research sites and laboratory space. All research and descriptions reported herein pertain directly to agronomic practices utilized by Driscoll growers and may not be entirely applicable statewide (i.e., Univ. Calif. growers). Thanks are extended to Howard Tao, Henry Harney, Clint Miller Farms and Salinas

Berry Farms for their support and cooperation.

## 2.0 BACKGROUND

In order to understand the immigration events and resistance problems which are the basis of this research, it is necessary to know something about California strawberry culture. The following section briefly describes these practices in more detail.

### 2.1 Strawberry Production

California strawberries are primarily grown for sale as fresh fruit for worldwide markets. These markets demand that fruit be of a certain size, free of blemishes and ship well. Strawberry cultivars have been specifically developed for the Pajaro and Salinas Valleys to meet these demands. Within the past ten years, production of varieties has switched from using a two or three year production cycle to an annual cycle. A few growers still rotate plantings through a two-year cycle, but this is increasingly rare. One factor in stimulating change to a one-year cycle has been increasing resistance and the need to implement resistance management tactics for mites. A primary economic consideration was the fact that first-year plants produce higher yields and larger berries than second- or third-year plants. Reduced populations of the cyclamen mite, Steneotarsonemus pallidus (Banks), and reduced incidence of viral diseases are additional advantages to annual plantings.

Pajaro Valley growers often plant several varieties with different fruiting periods to spread out production. This takes advantage of the long dry weather period of this region which typically runs from April to October or November. Increasingly common "summer-planted" varieties

are planted adjacent to "winter-planted" varieties. This may exacerbate resistance induction, because the overlapping growing season eliminates the host-free period associated with strict annual winter planting and allows resistant mites to move into new plantings. The planting period for "summer-planted" and "winter-planted" cultivars is September and December, respectively (see Fig. 7). Following is a brief description of the winter planted cycle, beginning with picking and ending with new planting.

## 2.2 "Winter-planted" Strawberry Production Cycle

New plantings begin producing fruit by early March, but rainfall often ruins this crop for the fresh market. Commercial picking begins in April and continues until late fall. Old strawberry plantings are disked under in the autumn after sustained heavy rainfall because the crop is again ruined for the fresh market. Disking may occur anytime from September until December depending upon the weather and the growers' schedule. Fumigation with a methyl bromide/chloropicrin mixture follows if the area is to be immediately replanted with strawberries. Disking and fumigation eliminate mite populations inside field boundaries. Since within-field populations are eliminated by these measures, the only way that the next planting can be infested is by immigration sources outside of the new field (i.e. nursery sources or surrounding host plants). If the field is rotated out of strawberries, no fumigation occurs and diskings may be minimal, allowing mite populations a considerable amount of dispersal time. From December to January, new plants are transplanted into prepared fields. These plants have been grown at strawberry nurseries located in northern California.

### 2.3 Nursery Practices

Strawberry cultivars are planted in Shasta County nurseries and grown under conditions promoting vigorous vegetative growth. Strawberry runners (stolons) produce genetically identical "daughter" plants. By October or November of each year, these daughter plants are mature enough to transplant, and the entire plant population is mechanically mowed, harvested, bagged and trimmed. Manual trimming of leaves, runners and lower roots occurs in a trim shed. Cold storage of the plants follows. Plants designated for commercial growing areas are chilled just above freezing for 2-4 weeks, depending upon accumulated chill units (during warmer nursery years, more artificial chilling is required for development of sufficient amounts of plant fruiting hormones). Some plants are kept in cold storage until late spring and shipped back to nurseries for planting. This new vegetative crop of "mother" plants gives rise to next year's commercial "daughter" plants.

The nurseries occur in two geographical areas-- "high altitude" and "low altitude" locations-- to take advantage of unique growing conditions in each area. Historically, high altitude locations have had much higher spider mite populations than the low altitude locations. For a summary characterization of nursery sites, see Table 1 in the Methods section below.

To prevent the development of resistant mites (which might not be effectively controlled by sprays used in commercial fruit production plantings), no acaricides commonly used in the fruiting fields are used at nurseries. Nursery mite populations are primarily controlled by natural regulators (weather, predators, plant nutrition, etc.) and cultural controls (digging,

trimming, cold storage, etc.). Recently, attempts have been made to mass-rear a phytoseiid predator of T. urticae, Phytoseiulus persimilis A. and H., in greenhouses for release at nursery locations to further reduce spider mite populations (R. D. Nelson, personal communications).

#### 2.4 Mite Immigration in Relation to Strawberry Production

Low densities of T. urticae colonizing transplanted strawberries in the early season originate from the unsprayed nursery plant sources. These populations are then influenced by immigration of overwintering (but primarily nondiapause) individuals coming from the surrounding environment. The number of mites infesting vegetation surrounding strawberry fields in turn depends upon the types of cultural practices and strawberry growing practices utilized during the previous and current growing season. For instance, if a field is disked and fumigated immediately after picking ends, mite populations on strawberry plants have less opportunity to colonize surrounding plants. As noted earlier, immigration of resistant mites can originate from summer-planted plots immediately adjacent to winter-planted. This is especially true when summer plantings are pruned in late January or early February and infested strawberry leaves are blown into new winter plantings, facilitating dispersal of (diapause and nondiapause) resistant mites. With no host-free period, greatly increased survival of resistant mites from the previous planting may occur.

### 3.0 OBJECTIVES

The primary objective of this research was to understand the dynamics of resistance as influenced by early-season immigration of T. urticae into newly planted strawberry fields from several alternate host plant settings. More specifically, goals were to:

- 1) measure the numbers and resistance status of diapausing nursery mite populations which begin reproducing on transplants in Pajaro Valley strawberry fields in early season
- 2) determine the resistance status and rates of immigration of mites from different surrounding alternate hosts into newly planted strawberry fields in early season
- 3) determine acaricide resistance status within strawberry field populations of T. urticae originating from these various external source populations from time of first leaf growth to the first acaricide application of the season.



#### 4.0 METHODS

##### 4.1 Resistance Status: Acaricide Resistance Bioassay Description

Acaricide resistance bioassays are a means of assessing the resistance status of a mite population. While useful for resistance monitoring, they also can be useful in determining the origin of immigrating mites, within certain limits. Since the resistance status of all mite populations sampled during this research was determined with an acaricide resistance bioassay, a discussion of this technique will precede a description of population sampling methods. The bioassay technique described below was similar for all mite populations, regardless of origin or when the technique was used.

###### 4.1.1 Mite Collection and Leaf Disk Preparation

Mite populations were collected from infested plants encountered during sampling of strawberry fields, vegetation surrounding field sites and nursery plants. Infested leaves were placed in plastic bags, tied off and cooled in an ice chest. When brought to the laboratory, mites were refrigerated at about 15 degrees C. If the number and density of adult females was sufficient, mites were loaded onto leaf disks and sprayed within 48 hrs. of collection. More often, mites from infested leaves were colonized on uninfested bean plants inside mite-proof environmental chambers. All mite colonies were kept on Henderson Bush beans grown in vermiculite. Within 5 weeks, resulting mite colonies were bioassayed. All 1984 bioassays were produced from colonized mite samples as a standard procedure because of newly-available mite-proof chambers. To prepare a mite colony for spraying, leaf disks were cut and adult females were placed upon disks.

Eighteen millimeter bean leaf disks were cut from young primary leaves using a standard core sampler. On average, plants in which germination had occurred less than a week beforehand were utilized to insure that the leaf disk could withstand the feeding damage of 12 to 15 adult female T. urticae for 72 hours. When nutrients are removed from a leaf disk, T. urticae tends to disperse. To maximize the flatness of leaf disks, similar sections were cut from the leaves, avoiding midribs, large veins, and pockets formed by veins. The flattest possible leaf surface was chosen to minimize drowning and escape of mites.

Leaf disks were individually placed on two moistened cotton balls (large, unsterilized Curity® brand) situated in plastic, 35 ml. medicine cups filled to within 0.5 cm of the brim with tap water. The lower leaf surface was oriented upwards on the cotton. Leaf disks were gently pressed onto the top of the cotton, so that the surface of the leaf disk was brought into contact with the moist cotton, effectively sealing the underside to mite entry.

Forty leaf disks received 12 to 15 "healthy" adult female mites each. Mites were transferred with a small aspirator, constructed with a 10 micrometer micropipette and a mite-proof filter connected to surgical tubing. The aspirator was operated with gentle inhalations pulling mites from the colonized leaf into the mite collection chamber, which was opened to tap the mites out onto the leaf disk. Thirty-six leaf disks were loaded for four replications at each of nine concentrations. Four disks were loaded as controls. The whole bioassay was placed onto cafeteria trays and stored overnight (to allow resumption of normal behavioral activity) at 22 degrees C with sixteen hour photoperiod. Before acaricide spraying, injured, dead and abnormal

individuals were removed. Mites which escaped from the leaf disk were disregarded. The number of healthy individuals on each disk were tabulated on a standard data sheet just prior to spraying.

#### 4.1.2 Compound Formulation and Mixing

Since formulated compounds are the toxicant source used by the grower in the field, they were also used in this acaricide resistance bioassay technique. Cyhexatin was tested as a 50 % wettable powder (Plictran®), while formetanate was tested as a 92 % soluble powder (Carzol®). Fresh acaricide solutions (100 ml) were mixed just prior to spraying for each series of bioassays. Wettable and soluble powders were measured out on a Mettler analytical balance and poured into 125 ml. Ehrlenmeyer flasks. Nine concentrations ranging from ten times the field rate to 2% of the field rate were chosen as standard serial dilutions. Ideal bioassay concentrations resulted in a range of no mortality at lower concentrations to complete mortality at higher concentrations. A 100 ml. graduated cylinder and Pipetteman pipette gun were used to make the dilutions. Leaf Act 80® (phosphoric acid emulsion) was added to all formetanate solutions as was used in the field at a 1:800 ratio (Leaf Act 80® : toxicant + water :: 1 : 800). Leaf Act 80® lowers the pH of the solution to about 4.5 which gives maximum efficacy in the field, by slowing degradation of the residual active ingredient. Plastic-coated magnetic stirring bars were added to each flask, mixing the solution vigorously for one minute immediately prior to spraying. Each solution was visually checked for uniform suspension of wettable powder (cyhexatin) or completely dissolved soluble powder (formetanate) prior to spraying.

#### 4.1.3 Spray Apparatus

All bioassays in the Pajaro Valley were conducted with a Binks® air brush mounted to a ring stand with nozzle opening 15 cm. above the counter height. This sprayer was pressure-activated using an air compressor delivering 138,000 Newtons / sq. m.. An electrical rheostat controlled a solenoid which opened and shut to allow a constant burst (0.25 sec. for formetanate, 0.5 sec. for cyhexatin) of air pressure to the spray nozzle. Rubber tubing (20 cm.) with one end placed over the air brush intake tube and the other into the solution, delivered toxicant to the air brush nozzle. By pressing the rheostat switch, a quantity of spray material approaching "runoff" was delivered to the leaf disk and spider mites.

Fall nursery mite bioassays were accomplished in Corvallis with a slightly modified spray apparatus. All other bioassays were conducted at the Driscoll Strawberry Associates, Inc. research facilities in Watsonville in the Pajaro Valley. A small air pump delivering 138,000 Newtons / sq. m. was attached to a Binks® air brush without the rheostat. A glass funnel attached to the intake hose of the spray nozzle received about 10 mls of thoroughly mixed toxicant solution. Leaf disks were passed underneath the spray "cone" for a similar duration and quantity of spray as above. Without the rheostat, the quantity of toxicant delivered to each leaf disk can only be standardized with experience. A dissecting microscope was often used to check for uniform droplet size and spacing on the leaf disk. The automated technique was more desirable for standardization purposes, but no significant changes in cyhexatin mortality were found at field rate dosages of 0.5, 1.0 and 2.0 sec. spray duration during initial technique

testing in Watsonville (R. D. Nelson and R. W. Miller, unpublished data). For cyhexatin, most important was that "runoff" be approached, and that leaf disks be air-dried afterwards. For formetanate, most important was avoidance of excessive pooling of the toxicant on the leaf disk without sufficient draining or drying. Hall and Reichard (1978) showed that droplet size had almost no effect on mortality when concentration of toxicant remained constant using a similar technique in formetanate resistance bioassays conducted on T. urticae. Hence, formetanate droplet size was not regarded as an important variable in these bioassays.

#### 4.1.4 Mortality Definition

Some discussion of mortality is necessary to illustrate the limits of the acaricide resistance bioassay. The definition of bioassay mortality has always been a subjective and illusive concept, inherent in a variety of techniques used by researchers. Many definitions exist and many are unique for each species. Inability of the test organism to reproduce is a functional definition (also subjective) carrying the most meaning in population dynamics, but this can occur at sublethal dosages. Sublethal dosages are not observable in bioassay techniques, hence most researchers use some modification of the "prod-response" method, which involves touching the organism with a suitable instrument and observing the organism's response. The organism is recorded alive if it responds according to predefined bioassay criteria or dead if it does not respond. No aspect of reproductive capability is obtained. Hence mortality as defined above is only a relative measure of susceptibility or resistance.

Each compound was assessed somewhat differently

because each has unique acaricidal properties. Formetanate is a fast-acting carbamate compound, causing maximum mortality in susceptible mites in less than 24 hrs. Hence formetanate mortality was assessed 24 hrs. after spraying. Cyhexatin is a relatively slow-acting organotin compound, requiring 48 hrs. to produce maximum mortality in susceptible mites. Partially cyhexatin-resistant strains often survive longer periods before succumbing to toxicant, but are readily distinguished from susceptible mites 48 hrs. after spraying. Hence to distinguish susceptible mites from resistant mites, cyhexatin mortality was assessed 48 hrs. after spraying.

Living T. urticae were defined as follows:  
Vigorous movement of one or more appendages on a prostrate mite. Nervous discharges and slow flexing of appendages often occur in "dead" mites, hence care was taken to identify "vigorous" movement when observing a prostrate mite (on its back). A second round of prodding helped to distinguish nervous discharges from sustained movement, since nervous discharges did not occur after the first round of prodding. Upright mites scurry when prodded. Shriveled or dessicated mites usually did not respond to prodding.

The leaf disk technique was suitable for bioassays of up to 48 hrs. After 48 hrs., mites began to leave the disk in significant numbers. Mites which have moved off the leaf disk were tallied as "escaped" mites and disregarded in the analysis. Standard data forms contain two columns for total mite count, one for before spraying and one for time of mortality observation (adjusted total) which was corrected for escaped mites. Average escaped mites were less than 5 % of total mites bioassayed in all tests. Percent mortality was recorded

for each concentration and these data were subsequently analyzed to obtain a regression line.

#### 4.1.5 Analysis of Acaricide Resistance Bioassay Data and Susceptible Definition

Mortality data resulting from this bioassay were processed on a computerized probit analysis program (part of the software available on an OSU departmental computer). The output file lists slope, correlation coefficient, and lethal concentration (commonly abbreviated as LC) values with confidence intervals. Full summary tables with this information are in Appendices A and D, Tables 12 - 13 (mites collected at strawberry nurseries), and 17 - 18 (mites collected in the Pajaro and Salinas Valleys).

Since mite populations were never sprayed with acaricides while at the nursery, they were the most susceptible strain available. A susceptible baseline average was computed from 6-8 nursery mite bioassays from which resistance ratios (resistant LC50 / susceptible LC50) were calculated. Resistance ratios are useful for categorizing levels of resistance and standardizing analysis of bioassay data for different compounds. Commonly, LC50 and LC95 values are used for comparisons. LC50 values possess maximum statistical accuracy and were converted to resistance ratios in these analyses. (LC95 values are listed in the tables in the appendix, but will not be discussed, as confidence intervals at this region are usually considerably wider.)

While no widely accepted standards for discrimination of resistance levels exist, a 5-fold discrimination level was chosen as a conservative estimate for this technique since reproducibility tests

run on this technique consistently yielded 2-3 fold variation. Hence, for purposes of analysis, a mite population with a level of resistance greater than five times the average susceptible nursery strain was considered "resistant". Any population less than five times this value was regarded as "susceptible". Acaricide resistance bioassay data was used to discern susceptible nursery mites from more resistant strains present in the fruiting field. The 95 % confidence intervals for LC50's were summarized for cyhexatin and formetanate on 4-cycle semilog graphs.

#### 4.2 Nursery Mites: Nursery Sampling Sites and Acaricide Resistance Bioassay

The Driscoll strawberry nurseries previously alluded to in the background section (Sec. 2.0) are located in Shasta and Tehama Counties, California. Relative densities of *T. urticae* populations were sampled at three sites to document mite population levels at these sites late in the growing season, just before harvesting. These sites are characterized in Table 1.

Ninety-nine percent of the transplants planted at Pajaro Valley field sites originated from two of these nurseries. Less than one percent of Mills nursery plants went to Pajaro Valley field sites in 1983, hence sampling was primarily directed to the Carpenter and Tierney nurseries. The Carpenter and Tierney nurseries are geographically and biologically identical, since they are separated by only several hundred yards. Each site has conifer forests and isolated residences on the perimeters. It was anticipated that complete acaricide susceptibility exists at the Carpenter and Tierney nurseries. None of the weeds surrounding these sites harbored appreciable numbers of mites.



Table 1.

1982-'83 strawberry nursery site characterization summary: Origin of transplants monitored for mite immigration at fruiting field sites and subsequently examined in the laboratory for diapausing mites.

Site	Nearest Town	Elevation Class	Historical Mite Population Density	Cyhexatin Resistance	Formetanate Resistance	% Origin of plants on commercial survey sites	
						1983	1984
Carpenter	MacArthur	high	high	none	none	95+	99+
Tierney	MacArthur	high	high	none	none	5	0
Mills	Red Bluff	low	low	none	20-fold	<1	0

#### 4.2.1 Nursery Mites: Fall Populations

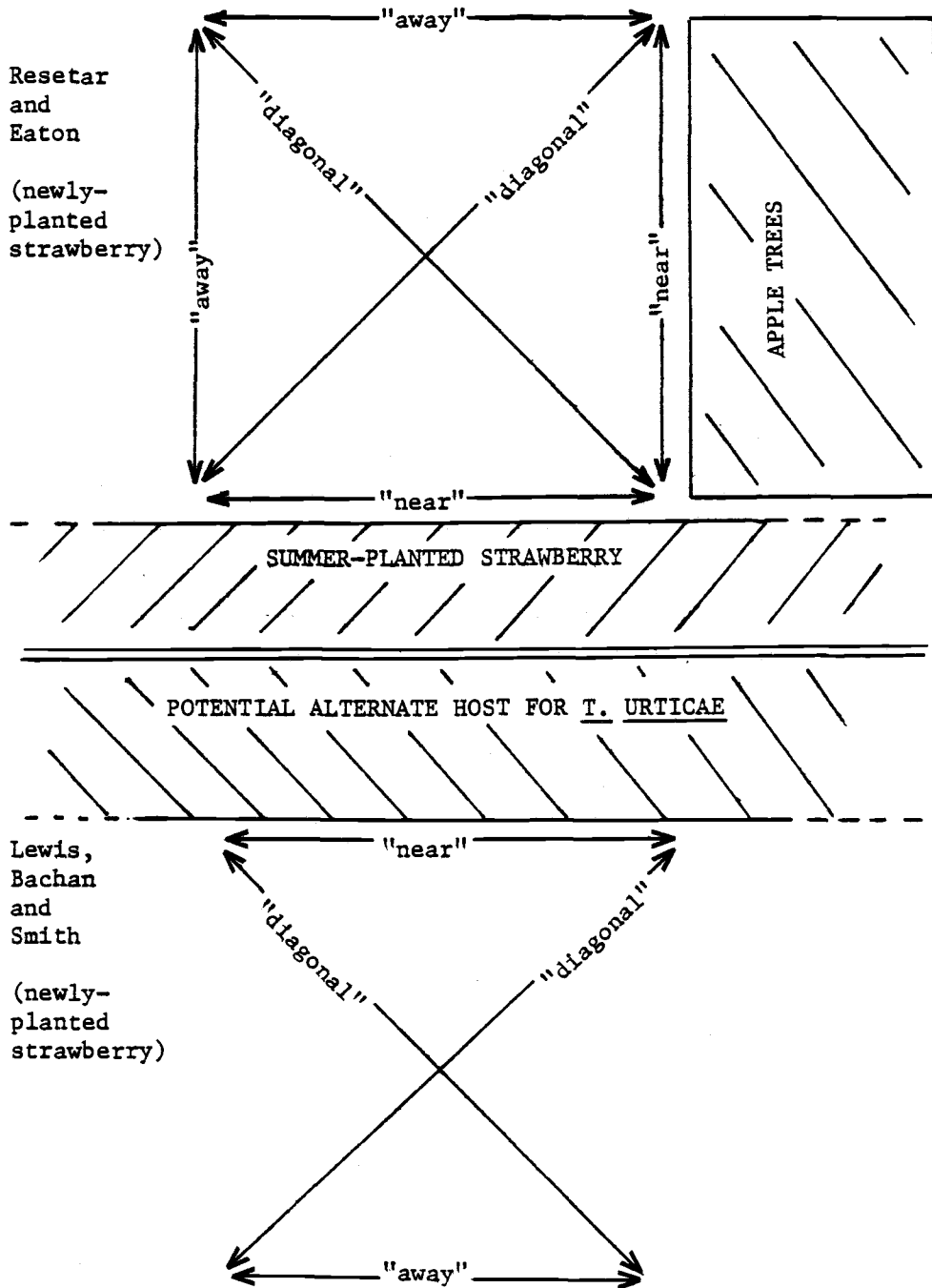
Mite population samples were taken by randomly collecting center strawberry leaflets from daughter plants along a pair of straight-line diagonal transects across the field at nursery sites. Leaflets from each transect were placed in separate plastic bags and cooled until counted under a dissecting microscope. Eggs, immatures and active adults were recorded separately in the fall of 1982, when the sample unit was three replicates of ten leaflets each. In 1983, only mites in diapause were counted at five replicates of ten leaflets, since it was then known that only the diapause phase survived cold storage, while active stages did not. Diapausing mites were readily distinguished from active mites by their solid orange (due to carotenoids) coloration. Mean mite densities for each site are recorded.

Acaricide resistance was also assessed for these populations. Mites from fall population samples were collected from diagonal transects described in the previous section (Fig. 1). Each colony was isolated and bioassays conducted (Section 4.1).

#### 4.2.2 Nursery Mites: Winter Populations

T. urticae nursery populations were sampled again for population and resistance levels in the winter by growing trimmed daughter plants from nursery locations in a trimshed or greenhouse. After several leaves had sprouted from the trimmed plants, leaves and plant crowns were examined for T. urticae. Plants intended for dissection were treated identically to those planted at field sites except that they were chilled several weeks longer. Upon removal from cold storage, plants were held

Figure 1. Transect orientation at fruiting field sites monitored for mite immigration, showing the pair of crisscrossing diagonal transects, the edge transects ("near" and "away" from adjacent mite infested vegetation) and adjacent plantings of strawberry and apple.



for one to four weeks in damp vermiculite at room temperature, isolated from external T. urticae sources. Emerging leaves were examined and plant crowns dissected under a dissecting microscope for emerging mites. Samples indicated relative numbers of diapausing females per plant which survived plant topping, digging, trimming and cold storage. Approximately 1700 plants from the Carpenter and/or Tierney nurseries were examined each year.

Populations of nursery mites in diapause were again estimated during initial strawberry field sampling described in section 4.4, "Immigration Patterns into Field Sites". As was the case for mites found during 1984 plant dissections, diapausing mites were colonized and subsequently bioassayed for acaricide resistance. When possible, nursery mites from winter population sampling were colonized, isolated in mite-proof chambers and bioassayed in Watsonville (Section 4.1).

#### 4.3 Surrounding Vegetation Mite Populations

Two types of vegetation surrounded newly planted strawberry field sites in the Pajaro Valley. Firstly, apples, second-year or summer-planted strawberry crops were adjacent to three of the four sample sites each year. Secondly, weedy annuals occurred in irrigation ditches, along roadsides, and especially under apple trees adjacent to field sites. The weedy annuals harboring T. urticae were collected and identified by Harry Agamalian, a weed science specialist at the University of California Cooperative Extension office in Salinas. Each potential host was examined for T. urticae with a ten-power hand lens at each field site. Species harboring T. urticae were recorded for each site (Table 2A). No quantitative sampling was undertaken of these alternate hosts for lack of a common

Table 2A.

List of weed species adjacent to fruiting field sites monitored for mite immigration. Also, tabulation of weed species harboring Tetranychus urticae adjacent to field sites.

		Letter Key to field sites	
L = Lewis	B = Bachan	R = Resetar	E = Eaton
			S = Smith
Scientific Name	Common Name	Plant Species Present at Site Perimeter	Harboring <u>T. urticae</u> at Site Perimeter
<u>Malva parviflora</u>	cheeseweed	L, B, R, E, S	L, B, S
<u>Urtica urens</u>	burning nettle	L, B, R, E, S	B, E, S
<u>Sonchus oleraceus</u>	sow thistle	B, R, E	B
<u>Senecio vulgaris</u>	common groundsel	B, R, E	B
<u>Stellaria media</u>	chickweed	B, R, E, S	B, S
<u>Capsella bursa-pastoris</u>	shepherd's purse	B, S	B, S
<u>Erodium moschatum</u>	whitestem filaree	B, R, E	B
<u>Oxalis cernua</u>	Bermuda buttercup	L, B, R, E	L, B
<u>Brassica campestris</u>	common yellow mustard	L, B, R, E, S	B
<u>Brassica incana</u>	short-pod mustard	B, R, E	B
<u>Hordeum leporinum</u>	wild barley	B, R, E	B
<u>Salix sp.</u>	willow	B, R	B

sampling unit that could be practically and evenly applied. However, acaricide resistance bioassays were performed on mites from surrounding vegetation and are described in the next section.

#### 4.3.1 Field Site and Surrounding Vegetation Bioassay Description

Four commercial strawberry plantings, each with a different type of surrounding vegetation, were chosen as field study sites. Vegetation surrounding each field site differed, yet was typical of the variety of agriculture and weed hosts occurring in the area. Table 2B and 2C describe 1983 and 1984 field site settings. In Table 2A, the species composition of weedy annuals and species infested with spider mites adjacent to field sites are summarized.

In order to understand the significance of each field site selection, it is necessary to discuss the individual circumstances of each site. Lewis, Bachan, Resetar, and Eaton sites were located within 10 km. of each other in the Pajaro Valley. The Lewis site was selected for its two-year strawberry planting rotation, which historically harbored large overwintering mite populations. Some mite-infested weedy annuals grew around the Lewis site, but the primary source of overwintering mites were in second year strawberry plants. The Bachan site had mature apples along one edge and row crops on the opposite edge. Mite infestations have historically been more severe near the apples trees, which have not received intensive acaricidal treatment. The Resetar site was 2 km long and narrow (50-80 m.), with mature apples along one edge and the Pajaro River on the opposite side. In previous years, mature apple trees grew on this narrow strip of land. Towards the end of

Table 2B.

Characterization of 1983 strawberry fruiting field sites examined for mite immigration and acaricide resistance in Tetranychus urticae.

Grower	Site	Location	Side A	Side B	Side C	Side D	Site history
Howard Tao	Lewis	Watsonville	2nd year strawb.	weeds	weeds	fallow	resistant strains heavy populations
Henry Harney	Bachan	Watsonville	mature apples	strawb. (planted in Dec.)	weeds	post- harvest celery	high-level resistance
Clint Miller Farms	Resetar	Watsonville	weeds	strawb. (planted in Sept.)	strawb. (planted in Dec.)	apples	previously an apple orchard
Salinas Berry Farms	Smith	Salinas	weeds (resi- dential)	fallow	strawb. (planted in Dec.)	fallow	low-level resistance or none

Table 2C.

Characterization of 1984 strawberry fruiting field sites examined for mite immigration and acaricide resistance in Tetranychus urticae.

Grower	Site	Location	Side A	Side B	Side C	Side D	Site history
Howard Tao	Lewis	Watsonville	2nd yr. strawb.	weeds	strawb. (planted in Dec.)	fallow	resistant strains heavy populations
Henry Harney	Bachan	Watsonville	mature apples	strawb. (planted in Dec.)	post- harvest celery	strawb. (planted in Dec.)	resistant strains
Clint Miller Farms	Eaton	Watsonville	strawb. (planted in Sept.)	mature apples	weeds	strawb. (planted in Dec.)	moderate-level resistance
Salinas Berry Farms	Smith	Salinas	strawb. (planted in Dec.)	strawb. (planted in Dec.)	strawb. (planted in Dec.)	weeds in old caul- iflower	low-level resistance or none



1982, the aging trees were removed and strawberries were planted for the first time. Adjacent to the Resetar lies the Eaton site, where strawberries were produced in 1982 and 1984. The area planted in late 1983 had been fallow for one season. The apple orchard bordering one side was the same as that bordering the Resetar. This apple orchard received intensive acaricidal treatment during this research. Summer-planted strawberries grew between the winter plantings and the Pajaro River. The Smith site was selected for its isolated location in the Salinas Valley, to serve as a low-level immigration site. In 1983, private residences bordered one edge of this site and weedy annuals were present under the fence which ran along the grower's property line. However, no mites were encountered on these weeds. In 1984, a piece of land immediately adjacent to the 1983 site was planted, and had only one patch of weeds (burning nettle) harboring T. urticae (see further discussion in results, section 5.3).

#### 4.3.2 Surrounding Vegetation: Acaricide Resistance Bioassays

Samples of mite populations on surrounding vegetation were collected and colonized in mite-proof cages at the Driscoll laboratory. The samples were taken from one plant species harboring the highest mite concentrations and subsequently bioassayed for acaricide resistance (Section 4.1).

#### 4.4 Immigration Patterns at Field Sites

##### 4.4.1 Immigration into Field Sites: Mite Immigration Observations

In the Pajaro Valley, field sampling was conducted in newly planted commercial strawberries from January 2nd

to March 15th, 1983 and December 19th, 1983 to March 12th, 1984, to document the influx of T. urticae from nursery plants and surrounding vegetation. Mite immigration undoubtedly occurs throughout the growing season (Allen and Browne, 1972, Allen and Coville, 1981), but early-season immigrants are hypothesized to have a significant role in the early resistance status of a field population (Tabashnik and Croft, 1983) since they will eventually colonize the entire field. With no prior information about the magnitude of these immigration events, the plant population sampled was made as large as was practically possible for one person, even though this quantity (200 to 300 plants per field site per week) may not have been large enough to accurately determine extremely low population densities. In order to document the earliest immigration, it was necessary to study immigration before much reproduction had occurred, and before acaricides had been applied, as this would obscure the immigration event. Later in the growing season, progeny of established "resident" populations are difficult, if not impossible, to distinguish from recent immigrants. For this reason research began as soon as possible after transplanting and ended when substantial mite immigration and/or reproduction had occurred or after acaricide spraying had begun.

Characterization of commercial strawberry planting sites in the previous section on surrounding vegetation are summarized in Tables 2A, 2B and 2C. All of the field sites chosen as a part of this research examined "winter-planted" varieties. Sampling consisted of a thorough visual examination of plants in a series of 48-plant transects. Each field site was approximately rectangular, with a pair of diagonal transects taken at each site (Fig. 1A). Opposing diagonal transects were taken to obtain an overall field population estimate. By

averaging diagonal transects, edge effects were somewhat smoothed out. In addition, data for diagonal transects were sequentially recorded so that immigrant mite density gradients near alternate T. urticae hosts could be analyzed. Another transect was taken within 10 meters of alternate T. urticae hosts to determine possible "edge" effects, along with an opposing transect from the opposite side of the site, 50-180 meters away (Fig. 1). Only one side of the Lewis, Bachan and Smith sites possessed potential alternate T. urticae hosts. Two sides of the Resetar and Eaton sites possessed potential alternate host plants for mites, hence another pair of transects were taken at these sites to sample for possible "edge" effects. Sample plants were chosen randomly along an approximately straight path, stepping over four to ten rows (beds) for each plant sampled. For each new sampling date, a slightly redirected path was chosen so that new plants were sampled each time. Each leaf on a sample plant was examined on the lower surface for T. urticae in a nondestructive manner. Any mud or sand clinging to the underside of a leaflet was gently flicked off to give a better view of any mites present. Four to six transects were completed at each site on a weekly basis (twice weekly on the Lewis site in 1983). In 1983, transects were sampled whenever weather allowed and continued until mid-March. In 1984, transects were sampled until growers applied acaricides at the site, because acaricide residues made further immigration documentation impossible.

Active adult females were recognized by size, "two-spotted" coloration and/or oviposition. Larvae, protonymphs and deutonymphs were collectively recorded as immatures and were recognized by size and shape. Eggs were counted with a ten power hand lens. Diapause females were recognized by their characteristic

orange-red coloration, and absence of oviposition. For each transect sampled, active adult females, immatures, eggs, diapausing females and "clean" plants were tabulated in a field notebook as abbreviations. After a field site became thoroughly infested, only adult mites and/or infested plants were recorded. Results of each plant sample were recorded sequentially so that the relative frequency of T. urticae along a particular portion of a transect could be subsequently analyzed. When a plant was infested with immatures or eggs, but not adult females, this was noted. During mite density analyses these cases were counted as one active adult female, since immatures generally do not immigrate, but exist as progeny of an active female immigrant which has subsequently disappeared from the plant.

#### 4.4.2 Immigration into Field Sites: Analysis of Mite Immigration Observations

Analysis of 1983 mite densities illustrates initial (first three weeks, during relatively dry weather) and subsequent (last seven weeks, during wet, inclement weather), active mite densities over an entire site. Because no increases in mite density or edge effects were recorded, all mean mite density along transects on a given sampling date were averaged to produce a mean mite density for the overall site.

Analysis of 1984 mite densities along edge transects illustrates "edge" effects between transects near and away from surrounding mite-infested vegetation. Mite densities along diagonal transects were analyzed to find an overall field mite density, averaging out some of the variability due to potential edge effects. Transect sample data were averaged as 4-plant sample units, averaged over two consecutive sampling dates at a site,

creating 12 replications of 8-plant sample units. Similar analysis was given to diagonal transect data, except that both diagonal transects for one date were utilized, doubling the sample unit to 16 plants. Analysis of variance tests (F-tests) were run to determine if significant ( $p = 0.01$ ) differences existed. Subsequently, Duncan's Multiple Range tests were run at the ( $p = 0.01$ ) level of significance to determine which transect means ("near", diagonal" to or "away" from adjacent mite-infested vegetation) were different from each other within field sites. Standard error and 95 % confidence intervals were recorded for each peak mite density. Mite densities were plotted on 4-cycle semilog graphs as numbers per plant on a log scale for transects "near", "diagonal to" and "away from" surrounding mite-infested vegetation, with 95 % confidence limits. All active mite density statistical analysis was run on the OSU Cyber mainframe with the Statistical Package for the Social Sciences (SPSS) software.

To illustrate within-transect mite density gradients at varying distances from surrounding mite-infested vegetation, peak mean density of active female mites from diagonal transects were subsequently evaluated as 8-plant sample units averaged over two consecutive sampling dates, creating 12 replications of 16-plant sample units, as above. Each successive sample unit was farther away than previous sample units from adjacent mite-infested vegetation. Mite densities were plotted on 4-cycle semilog graphs as numbers per plant (on the log scale) versus distance from surrounding mite-infested vegetation, with 95 % confidence limits. Regression analysis using a log transformation of mite density was subjected to 2-way analysis of variance, with coefficient of determination (R-squared) as a measure of reduction in variation of mite density (Y-axis) as explained by

distance (X-axis) from adjacent mite-infested vegetation (Neter, et al., 1983).

Increases in active females per plant observed over two consecutive sampling dates were graphically plotted on 4-cycle semilogos to demonstrate additional aspects of the immigration events at each field site, with 95 % confidence limits. Other aspects of immigration were analyzed by plotting the same data grouped as percent infested plants. Increases in percent infested plants observed over two consecutive sampling dates were plotted on a normal percentage scale, with 95 % confidence limits. Duncan's Multiple Range ( $p = 0.01$ ) tests were run to determine if significant differences existed between transect types (near, diagonal to, or away from adjacent mite-infested vegetation) within a field site. Additional immigration information was collected by the use of sticky plates, discussed in the next section.

#### 4.4.3 Immigration into Field Sites: Sticky Plates

In order to determine whether aerial mite movement was occurring, sticky plates were utilized to monitor airborne T. urticae immigrants (Boyle, 1957, Mitchell, 1970, Brandenburg, 1982). Eight 7.62 x 12.7 cm. plexiglass plates coated with silicon grease were suspended approximately one foot above the ground on pine stakes with a Tanglefoot ring about the stake base to prevent ambulatory mite movement up the stake. Collective surface area of each trap was 774 sq.-cm. Plates were collected and replaced weekly. A dissecting microscope was used to examine plates for spider mites. Between 8 - 20 traps were evenly distributed near site perimeters in 1983 and 5 - 6 traps were put out at each site in 1984. Since each trap oriented sticky plates in 4 directions, it was possible to record orientation of

each mite recovery. Orientation of mite recovery does not prove that an airborne mite came from a given direction or from surrounding vegetation, but adds valuable qualitative information.

#### 4.4.4 Immigration into Field Sites: Acaricide Resistance Bioassay

Mite-infested leaflets found at each field site were collected and transported to the laboratory where mites were colonized on isolated bean plants. Diapause and active phases were colonized separately, and bioassays run on these different sources. Diapause forms terminated diapause in the laboratory and produced active progeny. These active progeny were subsequently bioassayed as adults (Section 4.1). Cyhexatin and formetanate resistance levels were measured in 1984, while only formetanate resistance levels were measured in 1983.

#### 4.5 Environmental Monitoring

Temperature and rainfall were recorded with a thermograph and rain gauge at the Driscoll Strawberry research laboratory in Watsonville. Temperature records were used to calculate mite degree-days, according to developmental thresholds determined by Herbert (1981). (See also Carey and Bradley, 1982, Feldmann, 1981, Tanigoshi and Logan, 1979, Shih, et al., 1976, Laing, 1969, Lehr and Smith, 1957.) Degree-day data were calculated from 1983 temperature records to determine the maximum number of mite generations that could have occurred at the field sites during the survey period. Rainfall data were recorded for comparison of potential rain-induced mite mortality in 1983 versus 1984. Monthly rainfall totals were subsequently compared with probability data and normals calculated by NOAA

(Anonymous, 1981). Refer to Appendix E for tabulations of rainfall and rainfall probability.



## 5.0 RESULTS

### 5.1.1 Nursery Mites: Fall Populations

Mites were sampled at nursery sites just before digging occurred in late fall 1982 and 1983. Population sampling and resistance bioassay results for these populations are summarized (Tables 3A-D). A graphic summary of 95 % confidence limits for acaricide resistance bioassay LC50's for all mite strains tested in this research is given later in Sec. 5.3.1 (Figures 2A-B).

In fall of 1982, no distinction between active and diapausing nursery *T. urticae* populations was made as it was not yet known that only adult females in diapause survive cold storage on trimmed plants. Hence, the 1982 "Females" column in Table 3A-C includes both phases. Female mite densities were 8.9 and 11.3 females per leaflet in September for Carpenter and Tierney sites, respectively. In October, female densities had decreased to 6.3 females per leaflet at Carpenter and 4.2 females per leaflet at Tierney. On the Carpenter ranch, immature and egg densities decreased from 55.2 immatures per leaflet and 125.0 eggs per leaflet in September (Table 3A) to 17.2 and 2.0 per leaflet, respectively in October (Table 3B). Similarly, on the Tierney site, immature and egg densities decreased from 51.6 immatures per leaflet and 46.6 eggs per leaflet in September (Table 3A), to 25.4 and 3.0 per leaf, respectively in October (Table 3B). Cooler weather, shorter daylength and senescent host plants caused gradually increasing proportions of nursery mite populations to become entrained into diapause, as evidenced by the density decreases in immatures and eggs in late fall 1982 (Tables 3A-B).

Table 3A.

Mean density of mites counted on center strawberry leaflets (n = 30) at two nursery sites on September 16, 1982.

Regression results of acaricide resistance bioassays conducted on progeny of mites collected at nursery sites September 16, 1982.

Site	Females	Imma- tures	Eggs	Acaricide	LC50	Confidence (min,	Int. max)	Slope of Regress.	2 R	Resist. Ratio
Carpenter	8.9	55.2	125.0	cyhexatin	.0025	(.0025,	.0026)	5.04	.983	.356
				formetanate	.0014	(.00090,	.0023)	3.58	.973	.764
Tierney	11.3	51.6	46.6	cyhexatin	.0033	(.0025,	.0043)	1.80	.968	.840
				formetanate	.0017	(.0015,	.0018)	1.91	.605	.927

Table 3B.

Mean density of mites counted on center strawberry leaflets (n = 30) at two nursery sites on October 25, 1982.

Regression results of acaricide resistance bioassays conducted on progeny of mites collected at nursery sites October 25, 1982.

Site	Females	Imma- tures	Eggs	Acaricide	LC50	Confidence (min,	Int. max)	Slope of Regress.	2 R	Resist. Ratio
Carpenter	6.3	17.2	2.0	cyhexatin	.0016	(.0013,	.0020)	2.05	.869	.407
				cyhexatin	.0051	(.0044,	.0060)	3.13	.974	1.30
				formetanate	.0013	(.0011,	.0015)	5.76	.920	.709
				formetanate	.0013	(.0011,	.0015)	2.21	.912	.709
Tierney	4.2	25.4	3.0	cyhexatin	.0064	(.0058,	.0070)	2.23	.983	1.63
				formetanate	.0015	(.00054,	.0042)	2.16	.966	.818

Table 3C.

Mean density of mites counted on center strawberry leaflets (n = 30) at one nursery site on December 19, 1982.

Regression results of acaricide resistance bioassays conducted on progeny of mites collected at nursery site December 19, 1982.

Site	Females	Imma- tures	Eggs	Acaricide	LC50	Confidence (min,	Int. max)	Slope of Regress.	2 R	Resist. Ratio
Mills	0.0	0.0	0.0	cyhexatin	.0034	(.0028,	.0042)	7.12	.999	.865
				formetanate	.019	(.018,	.020)	1.69	.897	10.4
				formetanate	.0073	(.0068,	.0078)	1.75	.932	3.98

Table 3D.

Mean density of mites counted on center strawberry leaflets (n = 40) at one nursery site on October 1, 1983.

Regression results of acaricide resistance bioassays conducted on progeny of mites collected at nursery site October 1, 1983.

Source	Diapause Females	Acaricide	LC50	Confidence (min,	Int. max)	Slope of Regress.	2 R	Resist. Ratio
Carpenter progeny of formetanate survivors	1.9	cyhexatin	.0080	(.0078,	.0082)	2.57	.931	2.04
		formetanate	.0036	(.0032,	.0040)	1.67	.907	1.96
		formetanate	.050	(.048,	.053)	1.19	.914	27.3

In fall of 1983, only diapausing mite populations were assessed. On October 1st, 1983 (Table 3C), diapausing mite densities were 1.9 per leaflet. Since diapausing mites which seek protected overwintering sites in the plant crown are the eventual colonizers of field sites, density estimates of fall diapausing mite densities (Tables 3A-D) are not as important as subsequent winter diapausing mite density estimates (see sections 5.1.2-3).

Complete susceptibility in fall nursery T. urticae populations to cyhexatin and formetanate existed at Carpenter and Tierney sites, where more than 99 % of all transplanted strawberry plants originated (Tables 3A,B and D). Some formetanate resistance was found at the Mills site, possibly a result of cross-resistance from metasystox (an organophosphate) aphidicide applications earlier in 1982 (Table 3C). Some Mills plants were transplanted to a small section of the Resetar site, where no mites were recovered.

Elevated formetanate resistance levels at the Mills site raised the question whether formetanate resistance was present in susceptible mites at low levels. Thereafter, it led to a subsequent selection experiment where two formetanate bioassays were performed on Carpenter mites. Even though the first bioassay indicated typical susceptibility with a resistance ratio of 1.96, 3 mites out of a total of 212 mites survived applications at the field rate or higher. Progeny of these 3 females were subsequently colonized and bioassayed, resulting in a resistance ratio of 27.3 (Table 3D). These data emphasize either the high intrinsic propensity for formetanate resistance in this species or the fact that previous selections with other chemicals had conferred nursery mites with a low-level

cross-resistance to formetanate, even though it had never been applied at nursery sites.

#### 5.1.2 Nursery Mites: Winter Populations after Chilling

During winter 1983 and 1984, nursery mite densities were assessed at two different periods of the strawberry planting cycle, after chilling (but before transplanting), and after transplanting (see Sec. 5.1.3). In the first case, trimmed plants were taken from cold storage, grown indoors for a short period and subsequently examined for emerging T. urticae. Table 4 summarizes mean mites per trimmed plant and bioassay results of colonies produced from these mites collected before transplanting. A graphic summary of all 95 % confidence limits for acaricide resistance bioassay LC50's is given in Figures 2A-B (Sec. 5.3.1). As noted previously, these results indicate that only mites in diapause survive transplant chilling.

At high-elevation nurseries, densities of mites in diapause were relatively constant at 0.069 and 0.066 mites per plant in 1983 and 1984, respectively (Table 4). These similar mite densities indicate that even if larger densities of diapausing mites existed on intact nursery plants, the trimming process consistently removes all but a small fraction of the mite population. A few young leaves just emerging from the plant crown may escape the trimming process and harbor diapausing mites. The frequency of these overwintering sites may be relatively constant and probably is the factor limiting density levels of nursery mites on trimmed plants from year to year. Acaricide resistance bioassays were not conducted on these mite sources in 1983, but 1984 bioassay results at the Carpenter site indicated acaricide susceptibility

Table 4.

Mean density of mites in diapause recovered from trimmed, chilled strawberry plants from nursery daughter plants. Similar plants from nurseries were transplanted at fruiting field sites monitored for mite immigration.

Regression results of acaricide resistance bioassays conducted on progeny of diapausing mites recovered from trimmed, chilled nursery plants.

Source	Year	Number of Mites Recovered	Number of Plants Examined	Mean Mites per Plant	Acar- icide	LC50	Conf. Interval (min max)	Slope of Regress.	2 R	Resist. Ratio
Carpenter	1983	20	393	0.051	(not assessed)					
Tierney	1983	102	1360	0.075	(not assessed)					
Mean	1983	122	1759	0.069						
Carpenter	1984	116	1763	0.066	cyhex.	.0033	(.0029, .0038)	3.01	.946	1.44
					formet.	.0056	(.0052, .0059)	.983	.928	1.80

with resistance ratios of 0.840 and 3.06 to cyhexatin and formetanate, respectively (Table 4).

During examination of new growth on trimmed, chilled plants which were grown for several weeks, mites were not found in the crown itself, but occasionally on older leaves (that were not trimmed) and most commonly on newly sprouted leaves. The brief growing period before examination of these plants probably allowed some mites to emerge from overwintering crevices in the crown onto these leaves, where diapause was terminated. As new young leaflets emerge from the crown, they are temporarily folded in half so that the top side of the leaflet surface forms a protected area in which mites begin to colonize the plant. Less frequently mites were found on fully opened leaves which expanded after the plants were brought out of chilling.

#### 5.1.3 Nursery Mites: Winter Populations after Transplanting

A second assessment of nursery mite densities and susceptibility to acaricides was undertaken at Pajaro Valley field sites after transplanting had occurred. Table 5 summarizes mean densities of diapausing mites per transplant and acaricide resistance bioassay results at each of the four field (study) sites. A graphic summary of all 95 % confidence limits for acaricide resistance bioassay LC50's is depicted in Figures 2A-B (Sec. 5.3.1). Densities of mites in diapause initially were very constant in newly planted fields in 1983, when no T. urticae were found in diapause on surrounding vegetation, with the exception of second year strawberry plantings at the Lewis site. Densities of nursery mites ranged from 0.0013 to 0.0033 mites per plant across all sites. The higher value at the Smith site in 1983

Table 5.  
Mean density of mites in diapause recovered from new strawberry transplants at fruiting field sites monitored for mite immigration.

Regression results of acaricide resistance bioassays conducted on progeny of diapausing mites recovered from new strawberry transplants at fruiting field sites monitored for immigration.

Source	Year	Number of Plants Examined	Mean Mites per Plant	Acaricide	LC50	Conf. Interval (min max)	Slope of Regress.	2 R	Resist. Ratio
Lewis	1983	1950	.0015	(not assessed)					
Bachan	1983	1250	.0013	formetanate	.0040	(.0037, .0043)	2.21	.993	2.18
Resetar	1983	1500	.0016	formetanate	.0028	(.0024, .0032)	2.61	.965	1.53
Smith	1983	1800	.0033	formetanate	.0028	(.0012 .0065)	2.37	.899	1.53
Lewis	1984	800	.0050	(not assessed)					
Bachan	1984	1200	.0183	cyhexatin	.084	(.077, .091)	1.09	.964	36.4
				formetanate	.032	(.030, .033)	1.49	.975	17.4
Eaton	1984	2500	.0056	cyhexatin	.0027	(.0023, .0033)	2.36	.996	.687
				formetanate	.020	(.019, .021)	1.08	.904	10.4
Smith	1984	2200	.0045	cyhexatin	.0077	(.0074, .0080)	2.36	.976	1.96
				formetanate	.0035	(.0033, .0037)	2.30	.922	1.91



probably reflects more effective sampling at this site or better mite survival rates, due to the well-drained soil there. Bioassay results indicate complete susceptibility in these mites, with formetanate resistance ratios of 1.53 each at Resetar and Smith sites, and 2.18 at the Bachan site (Table 5). Lewis site diapausing populations were not bioassayed in 1983.

Densities of diapausing mites were slightly higher in 1984, reflecting better sampling conditions and less weather-induced mortality (Table 5). Also, displacement of mites in diapause from surrounding vegetation into newly planted fields may have increased nursery mite density estimates at two of the sites. T. urticae are not known to immigrate by aerial means while in diapause as do active adult females, but observations indicate that diapause mite movement is facilitated by detached, windblown vegetation into newly planted strawberry fields. Densities of mites in diapause at the Bachan site were influenced by movement of mites from adjacent apple trees, as reflected by the resistance ratios of 36.4 and 17.4 to cyhexatin and formetanate, respectively. In late December, mite populations in diapause were observed on intact, senescent apple leaves. As apple leaf abscission occurred, wind blew some of these mite-infested leaves onto the field site, where piles of apple leaves were observed beside strawberry beds.

A 10.4-fold formetanate resistance ratio at the Eaton site in 1984 (Table 5) raises questions about the origin of these diapausing mites. It is possible that formetanate resistance may have been induced in this population before sampling began. It is more likely that mites in diapause were displaced from surrounding vegetation upon detached, windblown vegetation. Apple leaves were occasionally observed in new strawberry

plantings at the Eaton site as were strawberry leaves trimmed from adjacent summer plantings in late January (see Fig. 1, sec. 4.3.1).

Densities of diapausing mites of 0.0050 and 0.0045 mites per plant at Lewis and Smith sites, respectively, are probably closest to the true mean survivorship density of susceptible nursery mite populations. Annual densities of T. urticae in diapause at the Smith site varied the least of the field sites, from 0.0033 mites per plant in 1983 to 0.0045 mites per plant in '84 (Table 5). As noted earlier, this site also was the most isolated from surrounding mite-infested vegetation (Fig. 1, sec 4.3.1). Acaricide susceptibility occurred in Smith diapause mites (Table 5), but Lewis mites in diapause were not tested due to a shortage of mite-proof cages when these mites were recovered.

## 5.2 Surrounding Vegetation Mite Populations

Plants surrounding field sites which serve as alternate hosts for mite development and overwintering were not quantitatively sampled because of time constraints and lack of a common sampling unit for different plant hosts in either 1983 or 1984. However, colonies from these sources were started and bioassay results are reported in Table 6.

No mite populations were discovered during 1983 examinations of surrounding vegetation, except for high mite densities in second year strawberry plantings at the Lewis site, where resistance ratios of 8.91 and 7.09 occurred for cyhexatin and formetanate, respectively (Table 6). Less than one percent of these mites were in diapause during the sample period.

Table 6.

Regression results of acaricide resistance bioassays conducted on progeny of mites collected from mite-infested vegetation adjacent fruiting field sites.

Year	Site: Source	Acaricide	LC50	Confidence Int. (min max)	Slope	2 R	Resist. Ratio
1983	Lewis: 2nd yr. strawberry	cyhexatin	.035	(.033, .037)	1.95	.871	8.9
		formetanate	.013	(.012, .013)	2.19	.908	7.09
1984	Lewis: 2nd yr. strawberry	cyhexatin	.036	(.034, .037)	1.11	.900	9.16
		formetanate	.032	(.030, .033)	1.35	.940	17.3
1984	Bachan: apple leaves, weeds	cyhexatin	.143	(.131, .157)	1.09	.961	36.4
		formetanate	.029	(.028, .031)	1.53	.940	15.8
1984	Eaton: apple trees	cyhexatin	.050	(.046, .054)	.930	.955	12.7
1984	Eaton: burning nettle	formetanate	.016	(.015, .017)	1.88	.969	8.73
		cyhexatin	.024	(.023, .025)	1.76	.922	6.11
1984	Eaton: summer-planted strawberry	formetanate	.016	(.014, .016)	2.26	.982	8.73
		cyhexatin	.090	(.081, .101)	.902	.790	22.9
1984	Smith: burning nettle	formetanate	.021	(.019, .022)	1.22	.969	11.5
		cyhexatin	.040	(.039, .042)	1.11	.875	10.2
		formetanate	.404	(.361, .453)	.627	.786	220.

In 1984, mite populations were encountered in vegetation surrounding all 4 field sites (Table 6). Highest densities occurred at the Lewis site, where in many cases, hundreds of female T. urticae per plant were found. Bioassays of these mites indicated resistance ratios of 9.16 and 17.3 for cyhexatin and formetanate, respectively (Table 6). Approximately 20 % of these mites were in diapause during the sampling period.

At least ten plant species surrounding the Bachan site harbored low mite densities (Table 6). Occasional clusters of 5 - 10 mites were found on intact, senescent apple leaves. Nine weedy annuals growing under apple trees harbored some mites at low levels (Table 2C). Mites colonized from apple leaves and groundcover annuals were combined and bioassayed, resulting in resistance ratios of 36.4 and 15.8 for cyhexatin and formetanate, respectively. Most of the mites on apple leaves were in diapause, while almost all mites on weedy annuals were active in late December.

Apple leaves on trees adjacent to the Eaton site had fewer mites than did apples adjacent to the Bachan site, with occasional diapause forms present (Table 6). Bioassays indicated resistance ratios of 12.7 and 8.73 for cyhexatin and formetanate, respectively for these Eaton site mites. No mites were encountered in weedy annuals growing under these apples. Opposite the apples a small population of mites were encountered on burning nettle, with resistance ratios of 6.11 and 8.73 for cyhexatin and formetanate, respectively (Table 6). These weeds were disked under one month after sampling began. Summer plantings of strawberry harbored high mite densities, estimated by a grower sampling service at 10 females per leaflet in late January. When summer

plantings were trimmed during the 4th week of January, windblown strawberry leaves had some impact upon immigration into the field site (Section 5.3). Resistance levels of 22.9 and 11.5 were recorded from active mite populations collected from summer plantings (Table 6). Up to 20 % of these mites were in diapause during the second half of the sample period.

Active mite populations were encountered on several weedy annuals growing in postharvest cauliflower plantings adjacent to the Smith site (Table 6). These weeds were disked under 4 weeks after field sampling began. Resistance ratios of 10.2 and 220. were documented from this mite population for cyhexatin and formetanate, respectively. None of these mites were in diapause.

### 5.3 Immigration Patterns into Field Sites

Characterization of immigration of T. urticae at field sites from early January to mid-March, 1983 and late December to mid-March, 1984, is summarized by presentation of data as active female densities found on new transplants and acaricide bioassay LC50 resistance ratios in this section. Sections 5.3.2 through 5.3.6 more extensively develop results of 1984 between-transect mite density comparisons (Sec 5.3.2), within-transect mite density comparisons (Sec. 5.3.3), mite immigration patterns over time (Secs. 5.3.4 - 5.3.5) and sticky plate recoveries of airborne spider mites (Sec. 5.3.6) at each site, respectively. Only active female densities are dealt with in this section. (Refer to Appendix B for tables summarizing daily sample means for adult, immature and egg densities.) In Section 5.3.1, summaries of LC50 95 % confidence intervals for cyhexatin and formetanate resistance bioassays are plotted on 4-cycle semilog

graphs, showing acaricide resistance comparisons between all mite populations discussed throughout these results (Secs. 5.3 through 5.3.5).

High mite mortality and poor sampling conditions were caused by heavy, continuous rainfall during the last seven weeks of the 1983 sampling season (see 1983 results, Table 7A). This fact can be deduced from comparisons of 1983 and '84 immigrant mite data, where the only difference between the two sampling periods was 51.4 and 6.0 cm. of rain in '83 and '84, respectively (see precipitation data and rainfall probability tables, Appendix E). High mite densities accumulated (see Table 7B) in the absence of heavy rainfall in 1984, and low mite densities became even lower (see Table 7A) in 1983 after heavy rainfall occurred. If it is assumed for purposes of comparison that equal mite populations existed in 1982 and 1983 immediately prior to each field sampling season, a 98 % reduction of immigrant mite densities occurred due to heavy rainfall in 1983, compared with immigrant mite densities in 1984. Because of the effects of rainfall on the 1983 sampling season, results for immigration patterns at field sites are briefly summarized (Table 7A) as two cumulative sampling periods. (Refer to Appendix B for full tabulation of weekly sampling results from which the mean mite densities in Table 7A are calculated.) The first mean mite density reported for each site in Table 7A represents the first two and one-half weeks (Jan. 4-20) of field sampling, during which time 3.9 cm. of rain fell. The second mean mite density reported for each site in Table 7A represents the remaining seven weeks (Jan. 22 through Mar. 15) of field sampling, during which time 46.9 cm. of rain were recorded. Formetanate resistance was bioassayed when possible on 1983 colonies developed from active mite immigrants collected from all

**Table 7A.**

Peak mean density of active female mites observed on new strawberry transplants monitored at 1983 fruiting field sites for mite immigration.

Regression results of acaricide resistance bioassays conducted on progeny of active female mites recovered from new strawberry transplants at 1983 fruiting field sites monitored for mite immigration.

Site	Period	Number of Plants Examined	Active Female Density	LC50	Confidence (max	Int. min)	Slope	2 R	Resist. Ratio
Lewis	1/10-1/21 1/26-3/8	750 1200	0.059 0.016	.010	(.0098,	.011)	2.51	.849	5.45
Bachan	1/11-1/20 1/28-2/11 2/12-3/15	500 750 (no sampling due to flooding)	0.012 0.004	(not assessed)					
Resetar	1/9-1/17 1/25-2/21 2/22-3/15	300 1200 (no sampling due to flooding)	0.000 0.000	(not assessed)					
Smith	1/12 2/3-3/10	200 1600	0.000 0.000	(not assessed)					

Table 7B.

Peak mean density of active female mites observed on new strawberry transplants along transects near, diagonal to and away from adjacent mite-infested vegetation at 1984 fruiting field sites monitored for immigration.

Regression results of acaricide resistance bioassays conducted on progeny of active female mites recovered from new strawberry transplants at 1984 fruiting field sites monitored for mite immigration.

Site	Period	Transect	Number of Plants Examined	Active Females Per Plant	Acar- icide	Active Female LC50	Confidence (max	Int. min)	Slope	2 R	Resist. Ratio
Lewis	1/12-1/20	"near"	1/ 96	19.8	cyhex.	.033	(.031,	.034)	.983	.942	8.40
		"diag."	2/ 192	1.48	formet.	.045	(.042,	.048)	1.04	.964	24.6
		"away"	3/ 96	0.156							
Bachan	1/26-2/1	"near"	96	4.44	cyhex.	.075	(.069,	.082)	1.08	.865	19.1
		"diag."	192	1.02	formet.	.037	(.035,	.039)	1.17	.962	20.2
		"away"	96	0.167							
Eaton/ apple	1/31-2/7	"near"	96	1.16	cyhex.	.124	(.113,	.136)	.947	.843	31.6
		"diag."	192	0.203	formet.	.030	(.029,	.031)	1.31	.886	16.4
		"away"	96	0.0521							
Eaton/ summer- planted	1/31-2/7	"near"	96	0.500							
		"diag."	192	0.203	"	"	"	"	"	"	"
		"away"	96	0.167	"	"	"	"	"	"	"
Smith	2/8-2/16	"near"	96	0.0312	cyhex.	.0035	(.0031,	.0039)	1.60	.852	.891
		"diag."	192	0.0312	formet.	.0074	(.0069,	.0078)	.873	.851	4.04
		"away"	96	0.00							

1/ "near" = transect near mite-infested vegetation;

2/ "diag." = transects diagonal to adjacent mite-infested vegetation

3/ "away" = transect away from mite-infested vegetation



transects at a field site.

Only the Lewis and Bachan sites had any active female immigrants in 1983. An early mean T. urticae density of 0.059 decreased to 0.016 mites per plant over the remaining 7 weeks of the 1983 sampling period at the Lewis site. Formetanate bioassay results indicated resistance with a 5.45 resistance ratio (Table 7A). Together, these data indicate immigration initially occurred, but high mortality of colonizers increased when heavy rainfall began in late January. A similar mite density decrease occurred at the Bachan site (Table 7A), where the first 2.5 weeks resulted in a mean mite density of 0.012, which decreased to 0.004 mites per plant over the remaining 7 weeks. Poorly drained soil caused flooding of strawberry beds, especially on the southern third of this site, where total immersion of soil and plants occurred. Active mites were not colonized from this site. In contrast to Lewis and Bachan sites where immigration occurred at barely detectable levels, no active females were found at the Resetar or Smith sites (Table 7A) during winter sampling in 1983. The Resetar site, which had mature apples all along its 2 km length, was presumably an ideal area to document mite immigration. Lack of mite immigration at this site indicates that weather influenced immigration by causing mortality or delaying immigration of active T. urticae.

In 1984, lack of heavy rainfall (6.0 cm. or 0.5 cm per week) allowed mites to colonize field sites with little mortality, under near-perfect sampling conditions. Peak mean densities of active female mites near adjacent mite-infested vegetation (Table 7B, "near"), from the opposite side of the site (Table 7B, "away"), and from diagonal transects (Table 7B, "diag."), are reported in

Table 7. (Hereafter, descriptive terms "near", "diagonal" and "away" refer to the above transect types .) Listed to the right of each mite density entry are regression results of acaricide resistance bioassays for each fruiting field site (bioassay results refer to the field site as a whole, not to individual transects).

By the end of the 1984 sampling season, large density differences had developed along the respective transects at each field site. The most dramatic of these occurred at the Lewis site (Table 7B). High rates of immigration began during the 3rd week of the 1984 sampling period. By January 21st, active female densities had increased to 19.8 mites per plant near infested second year plantings, while it remained at 0.156 mites per plant 50 meters away from second year plantings. Mean diagonal mite density was 1.48 mites per plant. Acaricide resistance bioassays indicated resistance was present, with resistance ratios of 8.40 and 24.6 for cyhexatin and formetanate, respectively (Table 7B). (Acaricide resistance bioassays were conducted on mites collected from all transect-types and colonized together. Each field site was colonized separately.)

Because significant mite immigration with little oviposition had occurred at the Bachan site, active immigrant females were the predominant life stage when field sampling began December 20th. By February 1st, active mite densities had leveled off at 4.44 and 0.167 mites per plant near, and 100 meters away from infested vegetation, respectively. Mean diagonal mite density was 1.02 females per plant. Acaricide bioassays indicated resistance was present, with resistance ratios of 19.1 and 20.2 for cyhexatin and formetanate, respectively (Table 7B).

Low immigrant mite densities gradually accumulated at the Eaton site and leveled off around February 7th, when mean mite densities of 1.16 and 0.0521 mites per plant were present near infested apple trees, and 180 m. away from this infestation, respectively. Also at the Eaton site, an increase near infested summer plantings was observed. Peak mite densities were 0.500 and 0.167 mites per plant near infested summer plantings and 50 m. away from this infestation, respectively. Mean T. urticae density for diagonal transects was 0.203 mites per plant at the Eaton site (Table 7B). Acaricide bioassays indicated that active immigrants possessed acaricide resistance, with resistance ratios of 31.6 and 16.4, for cyhexatin and formetanate, respectively (Table 7B).

While active mites were encountered at the Smith site, it is very likely these mites originated at strawberry nurseries, having complete acaricide susceptibility with resistance ratios of .891 and 4.04 for cyhexatin and formetanate, respectively. (Recall that mites on weeds near this site had resistance ratios of 10.2 and 220. for cyhexatin and formetanate, respectively, Table 6.) Peak mite densities were 0.0312 mites per plant near adjacent mite-infested weeds and along diagonal transects, while no active mites were recovered during any sampling period from transects 50 m. away from this infestation (Table 7B). Since none of the mite densities were significantly different from each other (see Table 8), it would appear that active mites from the surrounding vegetation did not greatly impact upon the field site. Observations support this contention, as these plants remained in a healthy state of growth (hence mite dispersal was unlikely) until they were disked under during the 4th week of the sampling period. It cannot be stated, however, that immigration

of active mites from the surrounding environment did not occur at the Smith site, because one airborne, active female was recovered from sticky plates there (section 5.3.6).

#### 5.3.1 Acaricide Resistance Bioassay Summary: LC50 95 % Confidence Intervals

Confidence intervals (95 %) for acaricide resistance bioassay results reported previously in Section 5.1 through 5.3 are plotted on 4-cycle log graphs in Figures 2A-B, to illustrate relative differences between "susceptible" and "resistant" mite populations. The vertical line drawn at 0.0195 % a. i. for cyhexatin (Fig. 2A) and 0.0090 % a. i. for formetanate (Fig. 2B), represent values 5-fold greater than the mean LC50 value for susceptible mites, as defined previously. Note that no confidence intervals fall on this line and that intervals falling to the right have been interpreted as "resistant" and intervals falling to the left have been interpreted as "susceptible".

#### 5.3.2 Between-transect Mite Density Comparisons

As previously noted, differential active mite densities developed along transects "near" surrounding mite-infested vegetation compared to transects "away from" surrounding mite-infested vegetation. Between transect density gradients are reported in Table 8 and graphically summarized in Figure 3. Transect densities near surrounding infested vegetation, opposite from surrounding infested vegetation and diagonal averages are labeled "near", "away" and "diag.", respectively. Duncan's Multiple Range tests were run at the 0.01 level of significance for a Type I error to determine if significant differences existed between mite densities from each transect type. Also reported are 95 %

Figure 2A. Summary of  $LC_{50}$  confidence intervals (95 %) for cyhexatin resistance bioassays at nursery sites, fruiting field sites and vegetation adjacent to fruiting field sites monitored for mite immigration.

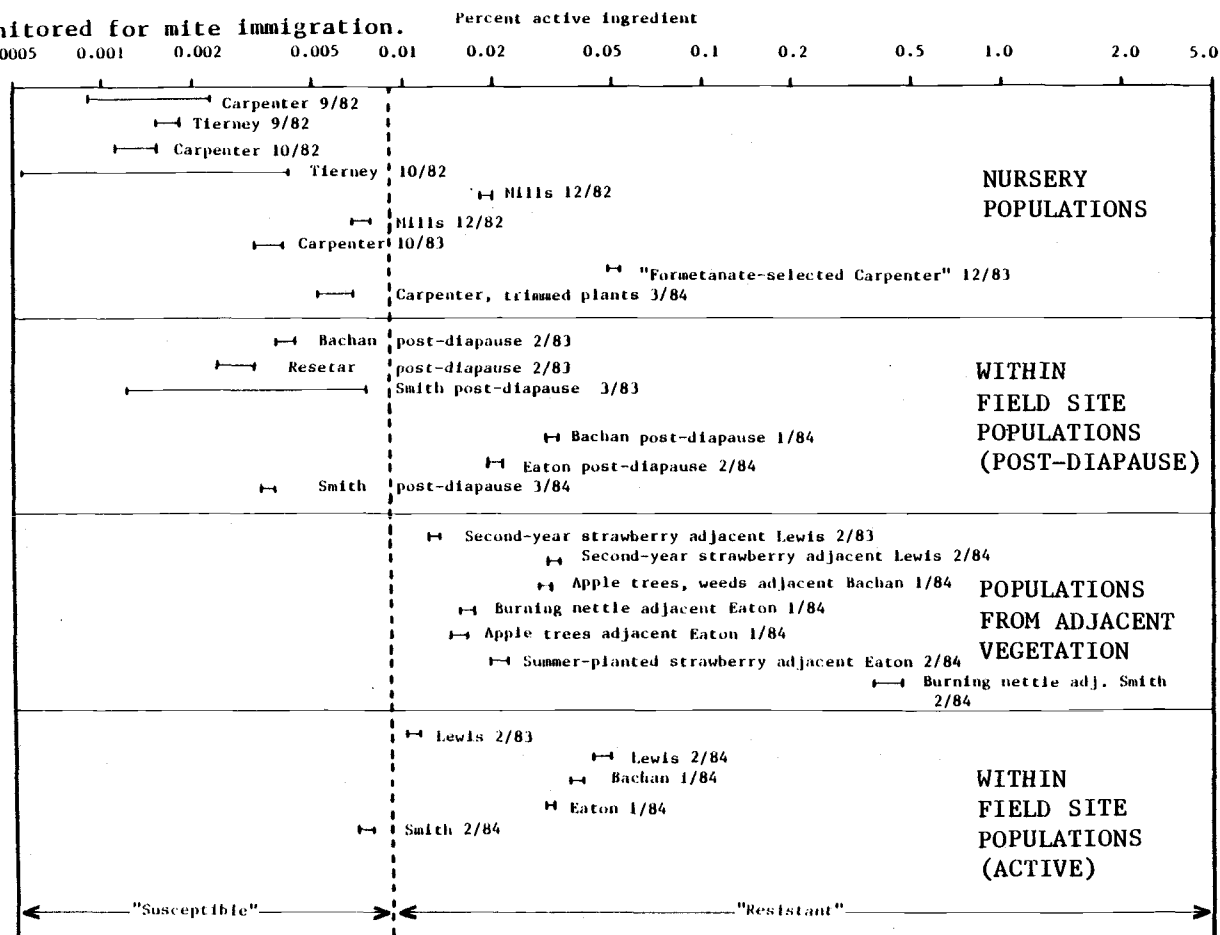


Figure 2B. Summary of LC<sub>50</sub> confidence intervals (95 %) for formetanate resistance bioassays at nursery sites, fruiting field sites and vegetation adjacent to fruiting field sites monitored for mite immigration.

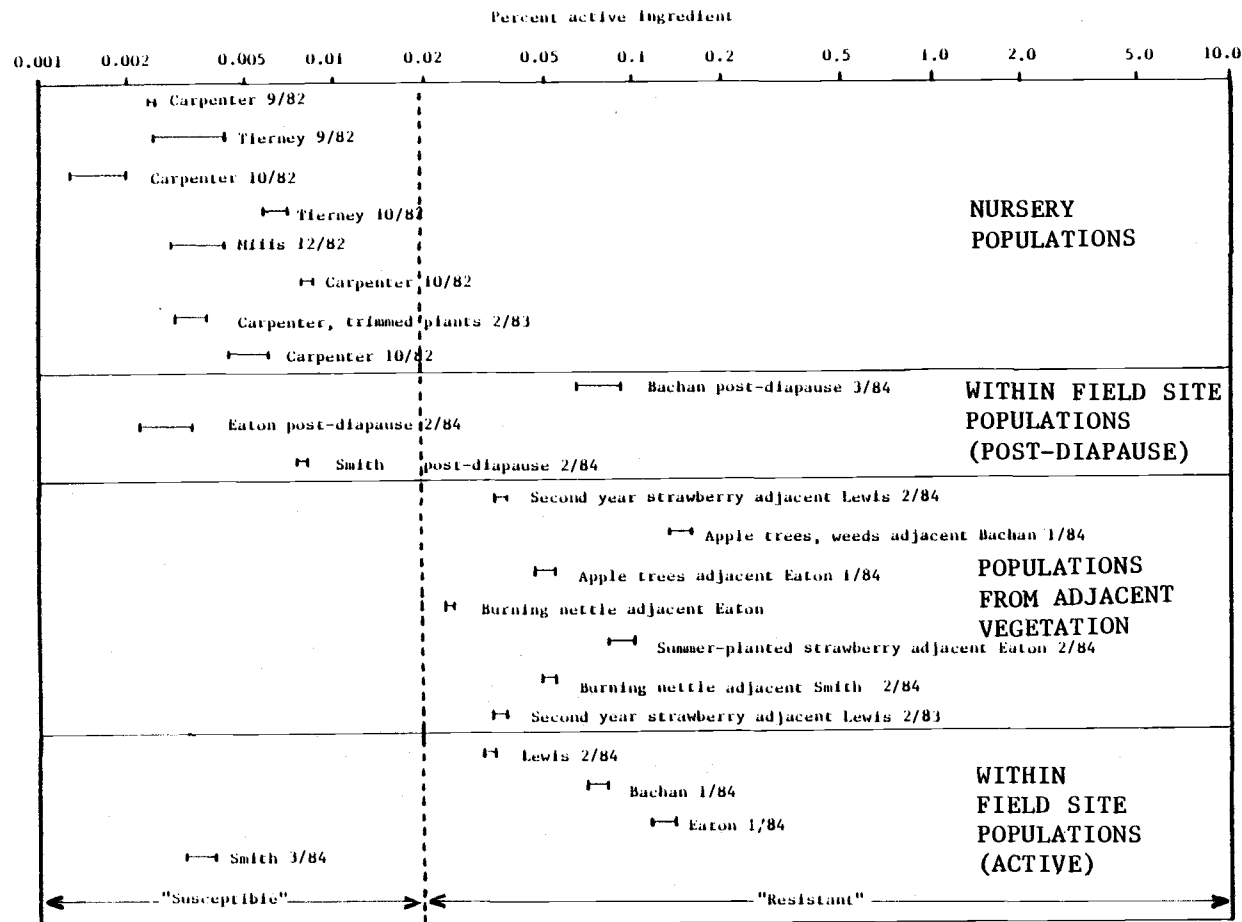


Table 8.

Summary statistics for peak mean density of active female mites observed on new strawberry transplants along transects near, diagonal to and away from adjacent mite-infested vegetation at 1984 fruiting field sites, including Duncan's Multiple Range test, 95 % confidence intervals, and standard error.

Site	Adjacent Mite-infested Plant	Transect	Active Mite Density	DMRT (p = 0.01) 1/	95 % Confidence Intervals for Mean		Standard Error
Lewis	second year strawberry	"near" 2/	19.8	a	( 16.3	23.2)	1.57
		"diag." 3/	1.48	b	( 0.747	2.22)	0.335
		"away" 4/	0.156	b	( 0.0875	0.225)	0.0312
Bachan	apple	"near"	4.44	a	( 3.54	5.33)	0.406
		"diag."	1.02	b	( 0.607	1.44)	0.188
		"away"	0.167	b	( 0.0814	0.252)	0.0387
Eaton	apples	"near"	1.16	a	( 0.675	1.64)	0.219
		"diag."	0.203	b	( 0.0397	0.367)	0.0742
		"away"	0.0521	b	(-0.0109	0.115)	0.0286
Eaton	summer-planted strawberry	"near"	0.500	a	( 0.303	0.698)	0.0897
		"diag."	0.203	b	( 0.0397	0.367)	0.0742
		"away"	0.167	b	( 0.0962	0.237)	0.0320
Smith	burning nettle	"near"	0.0312	a	(-0.0047	0.0672)	0.0163
		"diag."	0.0312	a	(-0.0047	0.0672)	0.0163
		"away"	0.00	a	( 0	0)	0

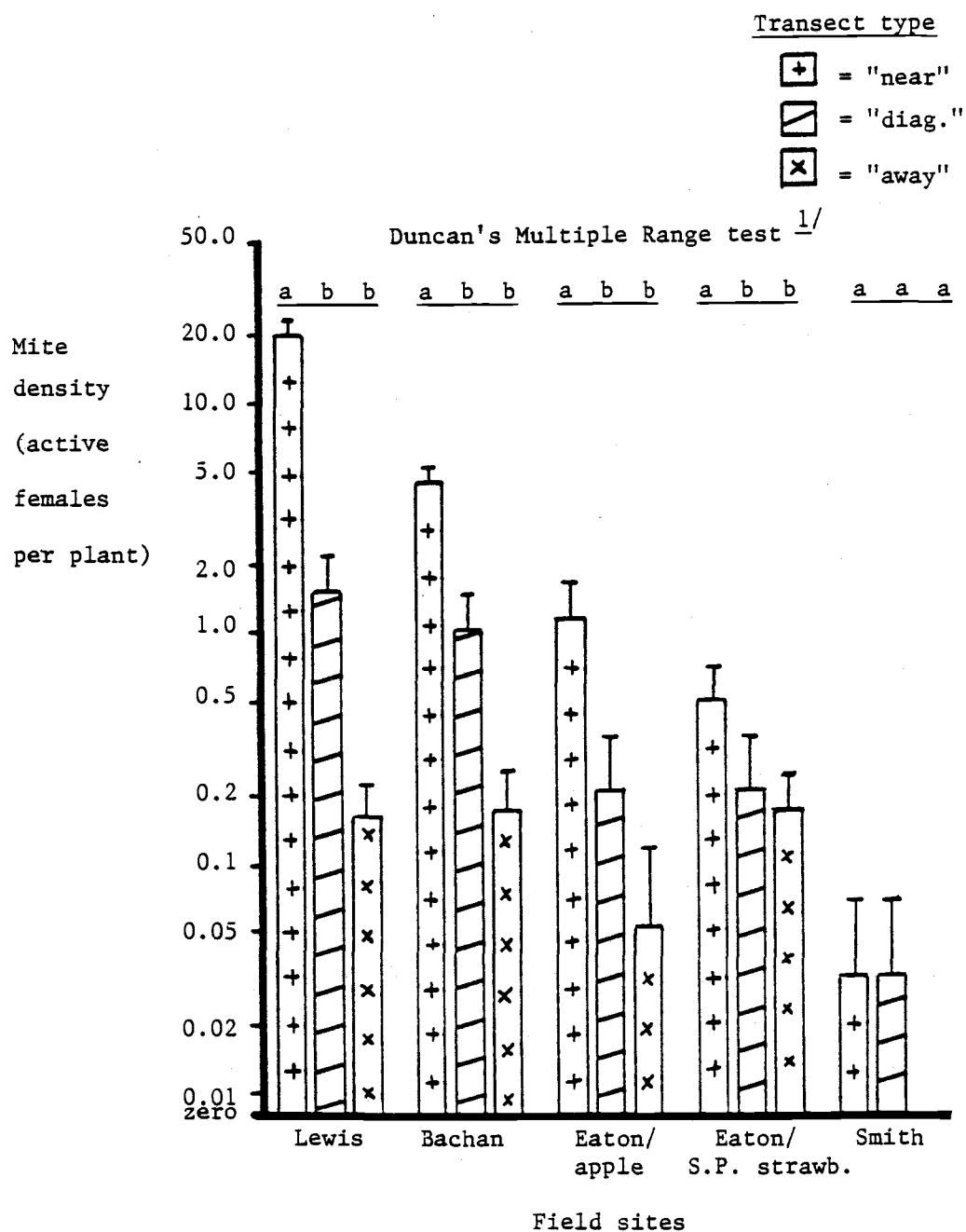
1/ Mite densities with common letters are not significantly different, Duncan's Multiple Range test

2/ "near" = transect near mite-infested vegetation;

3/ "diag." = transects diagonal to adjacent mite-infested vegetation

4/ "away" = transect away from mite-infested vegetation

Figure 3. Peak mean density of active female mites at 1984 fruiting field sites along transects "near", "diagonal" to and "away" from mite-infested vegetation. Field sites were monitored for mite immigration.



<sup>1/</sup> Bars with common letter and underlining are not significantly different at  $p = 0.01$ .



confidence intervals for mean mite densities and standard error.

At the Lewis site, Duncan's Multiple Range test indicated that significant differences did not exist between mite densities along transects away from and diagonal to second year strawberry, but these were significantly different from mite densities near second year strawberry (Table 8). At the Bachan site, mite densities along transects diagonal to and away from mite-infested apple trees were significantly different from mite densities near infested apple trees, but not from each other. At the Eaton site, mite densities along transects diagonal to and away from infested apple trees were also significantly different from mite densities near infested apple trees, but not from each other. Also at the Eaton site, mite densities along transects diagonal to and away from mite-infested summer-planted strawberry were significantly different from transects near infested summer-planted strawberry. Peak mite densities near, diagonal to and away from surrounding mite-infested weeds at the Smith site were not significantly different from each other (Table 8).

Active mite immigration did not appear to be normally distributed. Clusters of active adult females were often encountered on one plant surrounded by uninfested plants. Clumping effects may account for the relatively large standard errors reported in Table 8. Because diagonal transects encompassed areas near and away from surrounding mite infestations, their standard errors are proportionately larger. (Two large single-plant "outliers" were dropped from these and subsequent calculations for the Bachan site. The samples were recorded 2/1/84 as follows: one plant in the transect near apples had 67 active females, and a second

plant had 39 active females on a diagonal transect about 15 m from apple trees. These were dropped because they were over ten times larger than their respective means, distorting them. Their presence attests to the clumped distribution of short-range immigration events in T. urticae.)

### 5.3.3 Within-transect Mite Density Comparisons: Diagonals

As previously noted, mite density gradients which declined over increasing distances from surrounding mite-infested vegetation were evaluated as 16-plant sample units (as described in sec 4.4) from diagonal transect data for each field site. T. urticae densities are graphically summarized in Figures 4A-E as a function of number of active females per plant versus distance from adjacent mite-infested vegetation. In general, as distance from adjacent mite infestations increased, immigrant mite density decreased. Regression analysis with log transformation of mite density yielded a consistent pattern of declining mite density over increasing distance from adjacent infestations at Lewis (Fig. 4A), and Bachan (Fig. 4B) sites. These data are consistent showing a log-decline rate of dispersal for an organism having a non-active dispersal mechanism (Wolfenbarger, 1975, Pedgley, 1982). At the Eaton site, however the pattern was less evident because of lower mite density and the potential of interference or overlapping of the two mite sources with each other. This interference is manifested numerically as a secondary peak in mite density appearing towards the distal side of the field. Hence, the coefficient of determination (R-squared) values are relatively low at Eaton/apple (Fig. 4C) and Eaton/summer-planted (Fig. 4D) sites.

Figure 4A. Peak mean density of active female mites within diagonal transects at the 1984 Lewis site. Regression analysis ( $R^2 = 0.95$ ) with log transformation of mite density versus distance from adjacent mite-infested second-year strawberry.

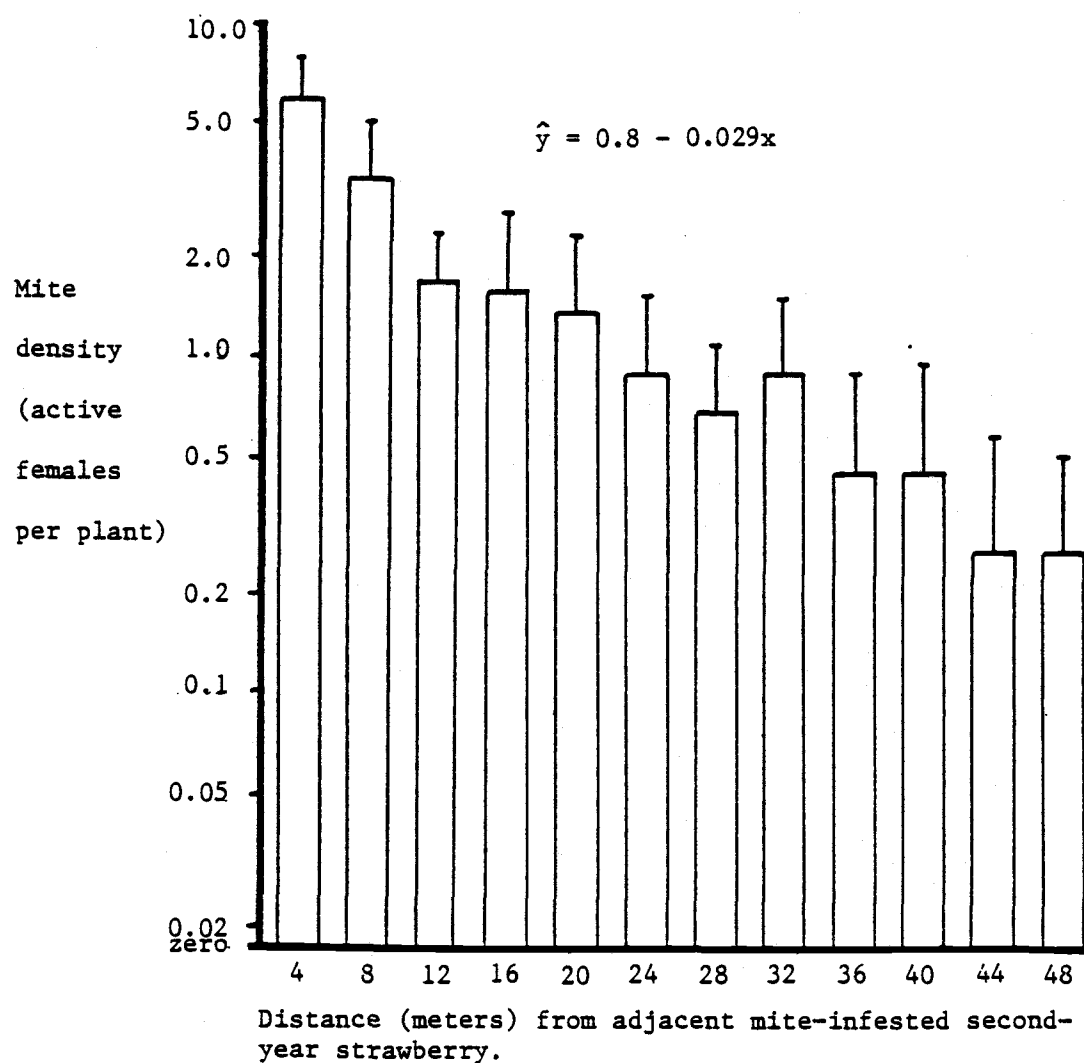


Figure 4B. Peak mean density of active female mites within diagonal transects at the 1984 Bachan site. Regression analysis ( $R^2 = 0.88$ ) with log transformation of mite density versus distance from adjacent mite-infested apple trees and groundcover weeds.

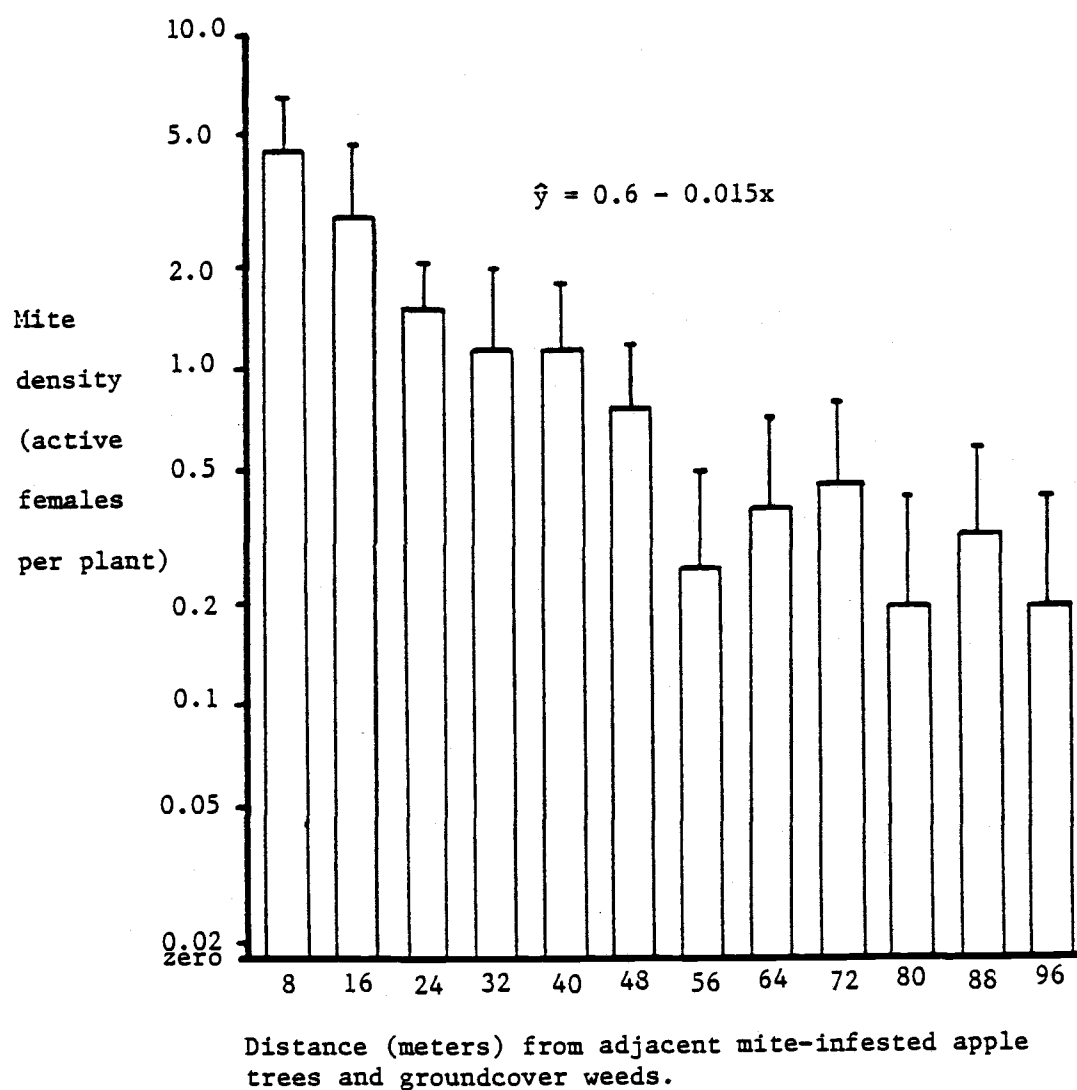


Figure 4C. Peak mean density of active female mites within diagonal transects at the 1984 Eaton/apple site. Regression analysis( $R^2 = 0.62$ ) with log transformation of mite density versus distance from adjacent mite-infested apple trees.

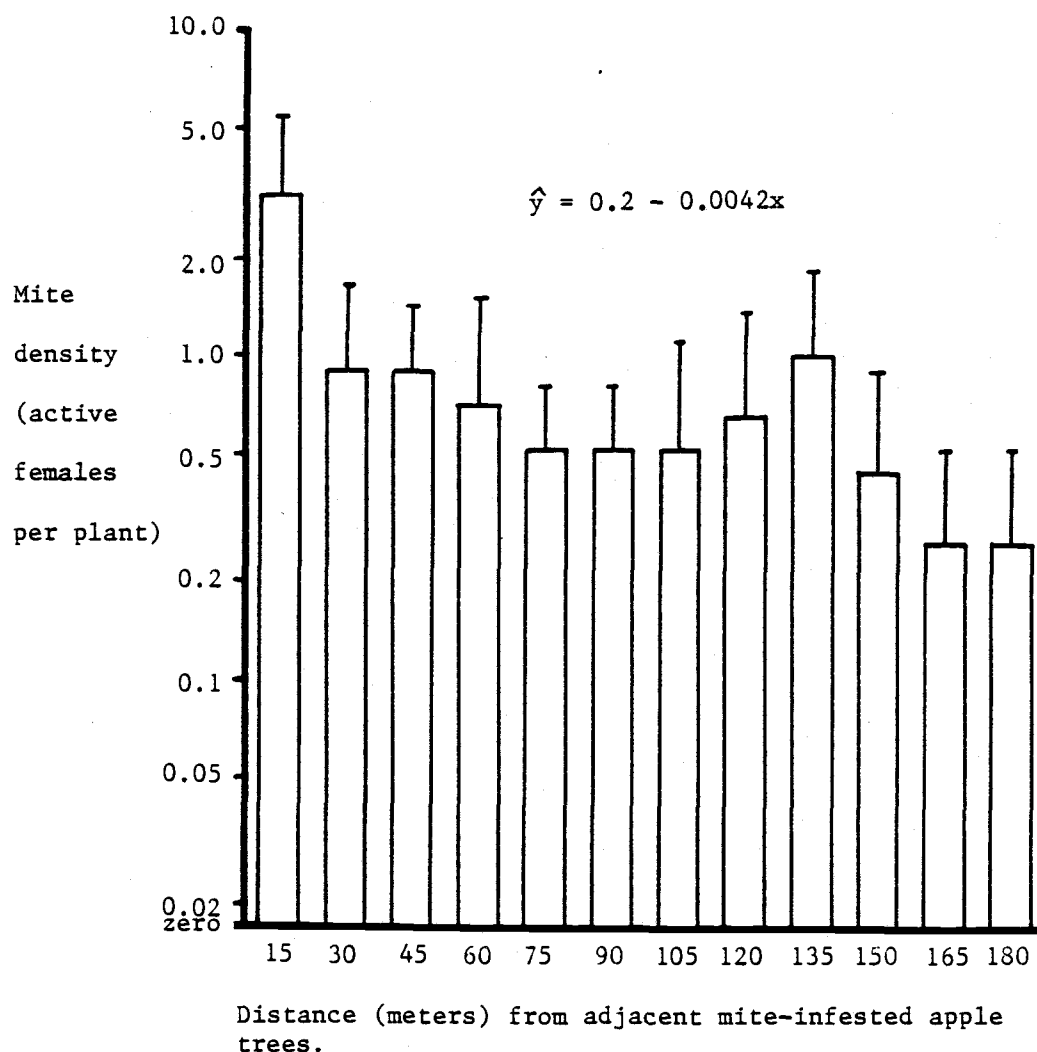


Figure 4D. Peak mean density of active female mites within diagonal transects at the 1984 Eaton/summer-planted strawberry site. Regression analysis ( $R^2 = 0.27$ ) with log transformation of mite density versus distance from adjacent mite-infested summer-planted strawberry.

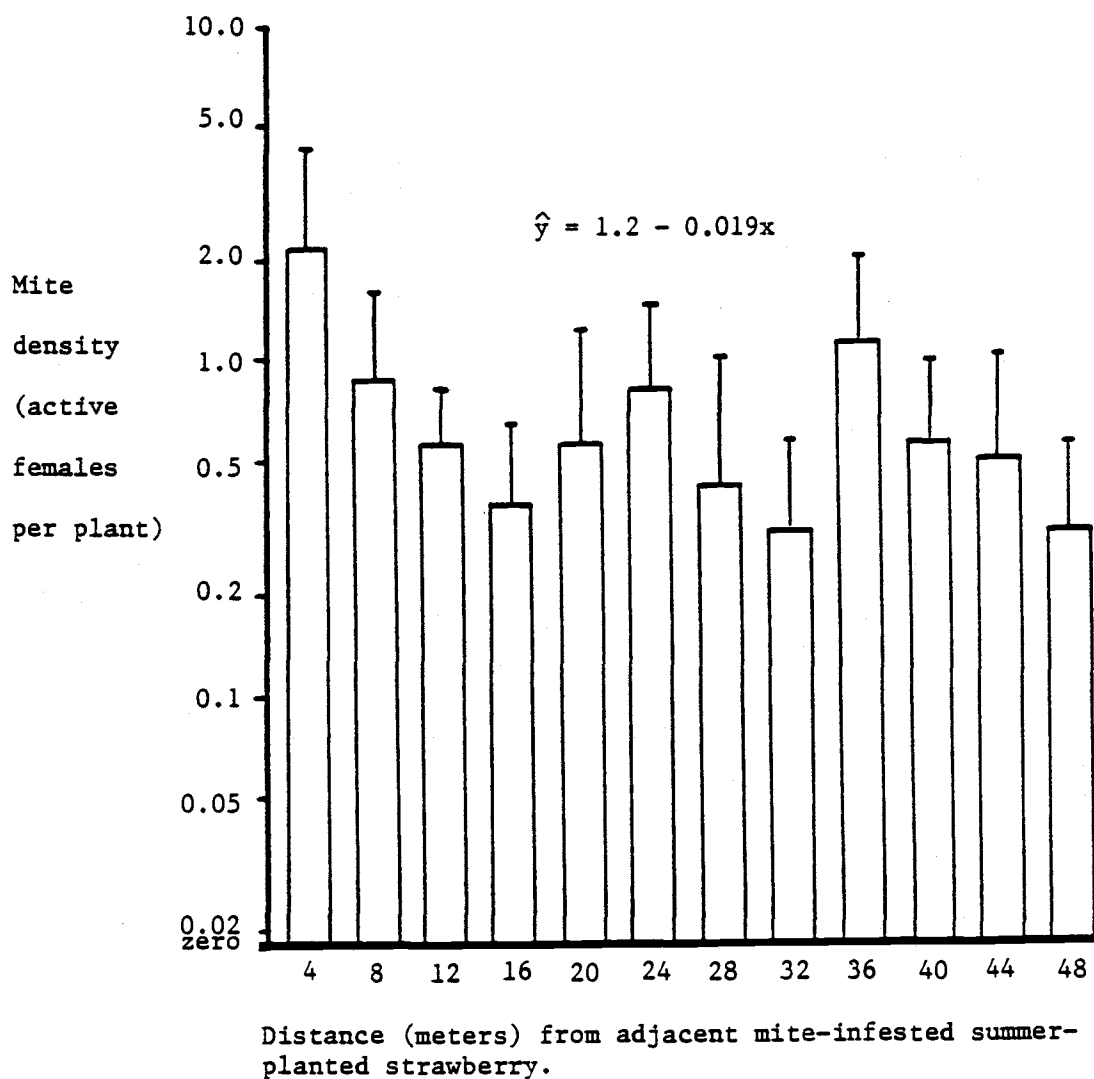
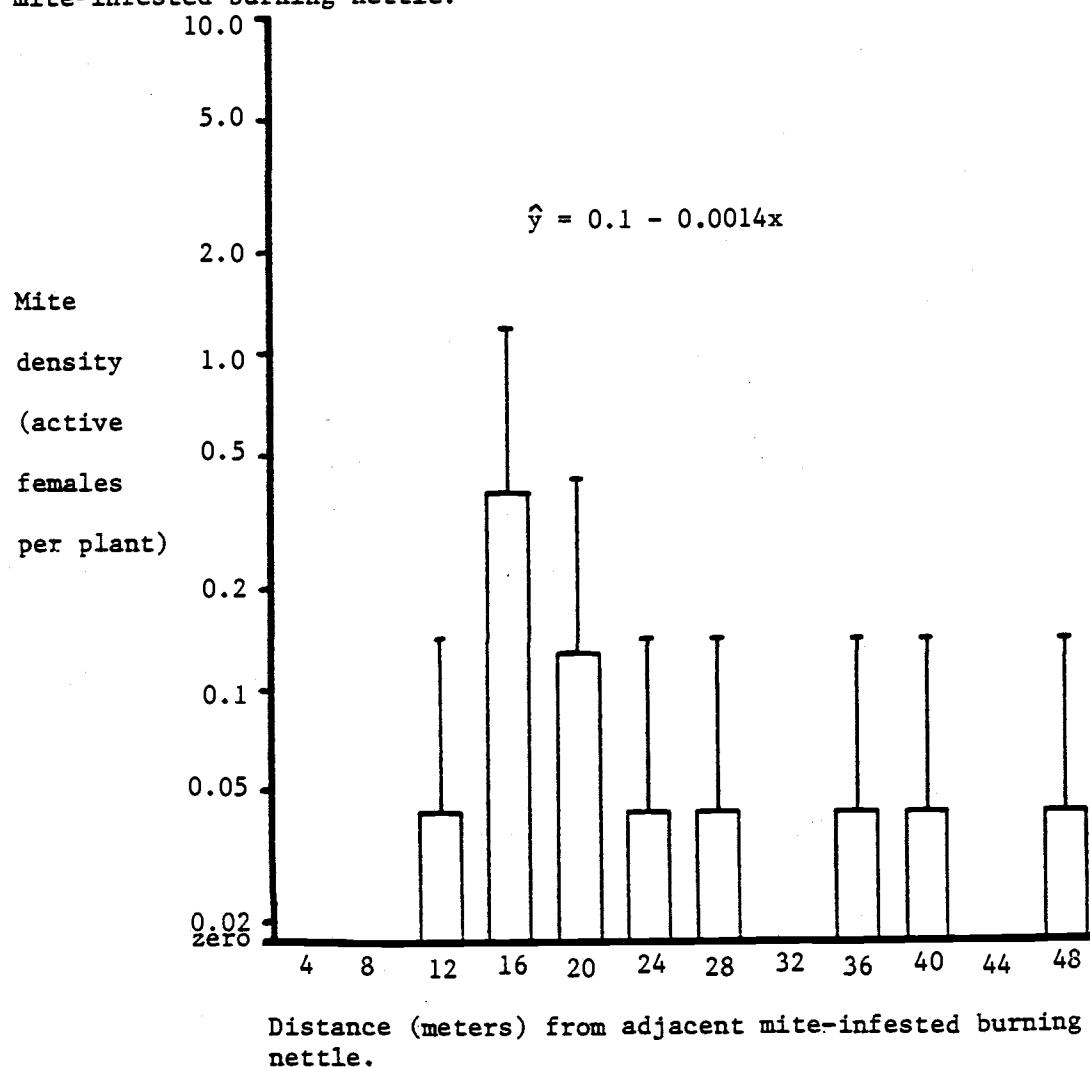


Figure 4E. Peak mean density of active female mites within diagonal transects at the 1984 Smith site. Regression analysis ( $R^2 = 0.04$ ) with log transformation of mite density versus distance from adjacent mite-infested burning nettle.



Regression analysis was run on mite densities along diagonal transects at the Smith site (Fig. 4E) for comparison purposes, even though preliminary analysis of variance tests indicated no significant differences existed along these transects. As expected, the regression explained almost none of the variation ( $R\text{-squared} = 0.04$ ), lending support to the assertion that this site was not affected by immigrant mites from surrounding vegetation. Since mite densities were highest near surrounding mite-infested vegetation at all Pajaro Valley sites (Figs. 4A-D), it may be inferred that a large percentage of mite immigration occurs over relatively short distances.

#### 5.3.4 Immigration Patterns over Time: Active Female Densities

Active female densities observed over each sampling period are graphically summarized in Figures 5A-E for transects near surrounding mite-infested vegetation, diagonal to, and away from surrounding infestations (between-transect density comparisons) for each field site. These data have also been graphically summarized as percent infested sample plants observed at each sampling period (see sec. 5.3.5).

Surrounding mite-infested vegetation had a noted "edge" effect on accumulating mite densities. When field sampling began (December 19-22), only two transects possessed significant active mite densities (Bachan, 3.73 mites per plant near apple trees -- Fig. 5B -- and Lewis, 0.167 mites per plant near second year strawberry -- Fig. 5A). All other transects had mite densities at or near zero during the first week of sampling. By the end of January, significant mite densities had accumulated at all Pajaro Valley field sites.



Figure 5A. Increase in mean density (active female mites) over two sampling periods (time) along transects "near", "diagonal" to and "away" from adjacent mite-infested second-year strawberry at the 1984 Lewis site, with Duncan's Multiple Range separation test for transect comparisons. <sup>1/</sup> Bars with common letters and underlining are not significantly different at  $p = 0.01$ .

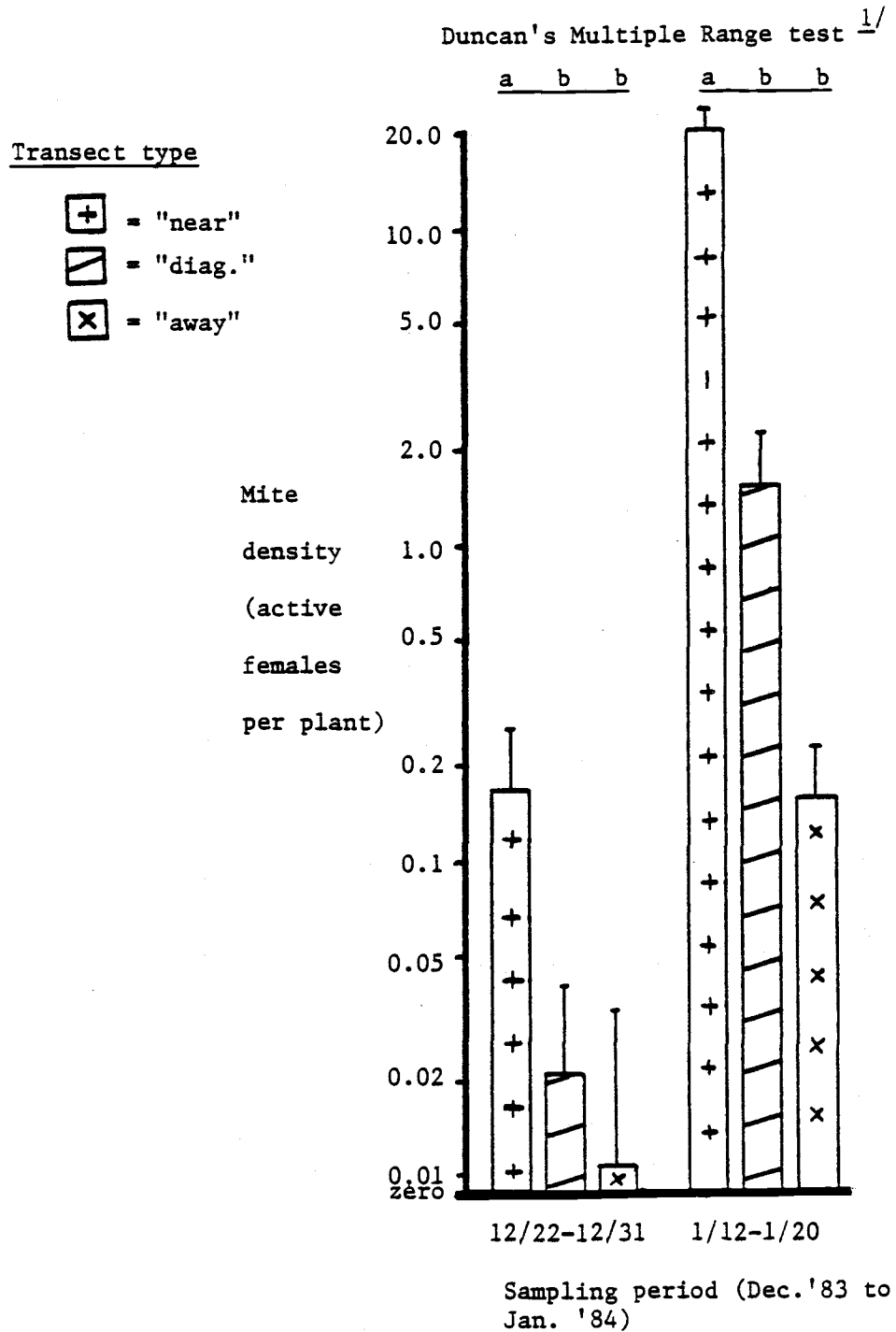


Figure 5B. Increase in mean density (active female mites) over three sampling periods (time) along transects "near", "diagonal" to and "away" from adjacent mite-infested apple trees and groundcover weeds at the 1984 Bachan site, with Duncan's Multiple Range separation test for transect comparisons.

1/ Bars with common letters and underlining are not significantly different at  $p = 0.01$ .

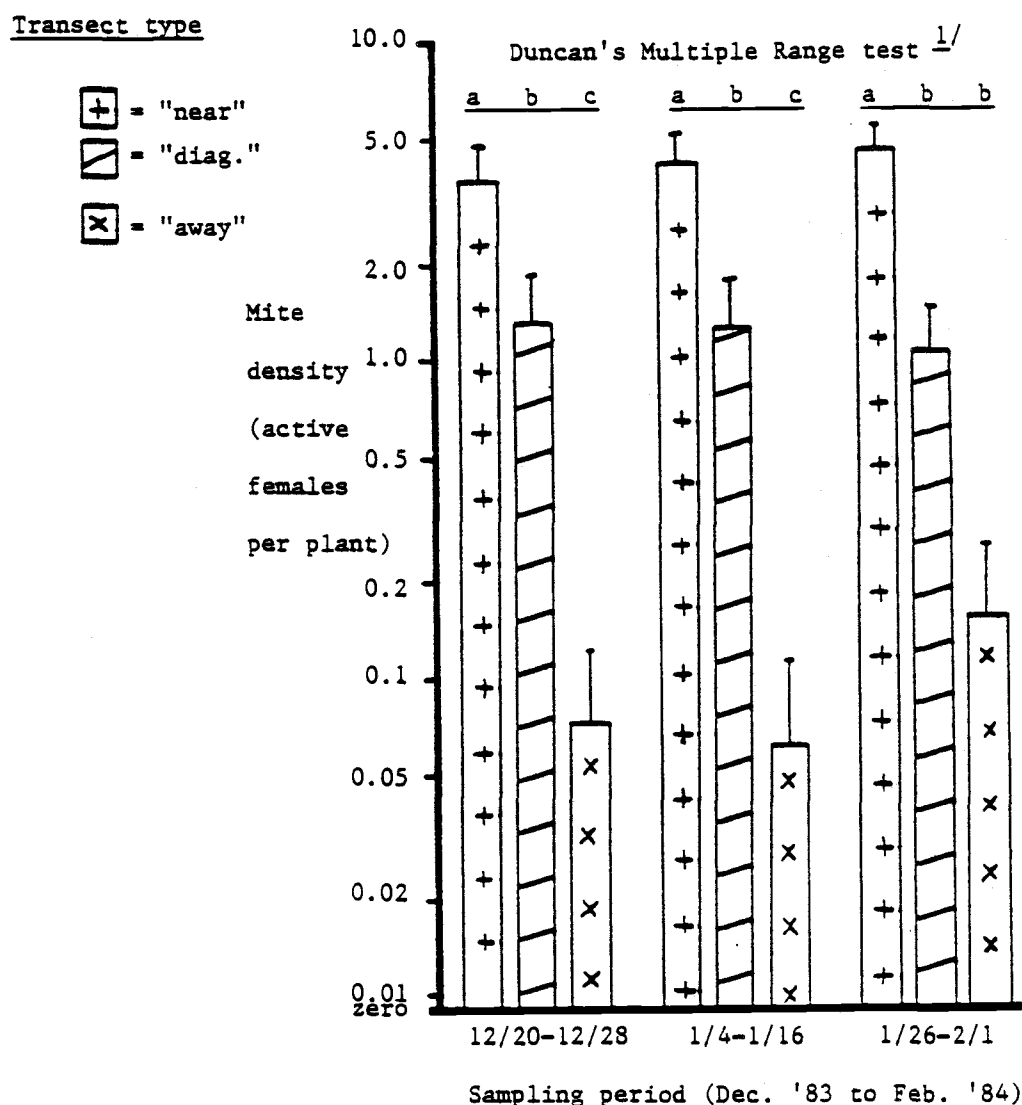


Figure 5C. Increase in mean density (active female mites) over four sampling periods (time) along transects "near", "diagonal" to and "away" from adjacent mite-infested apple trees at the 1984 Eaton/apple site, with Duncan's Multiple Range separation test for transect comparisons.

1/ Bars with common letters and underlining are not significantly different at  $p = 0.01$ .

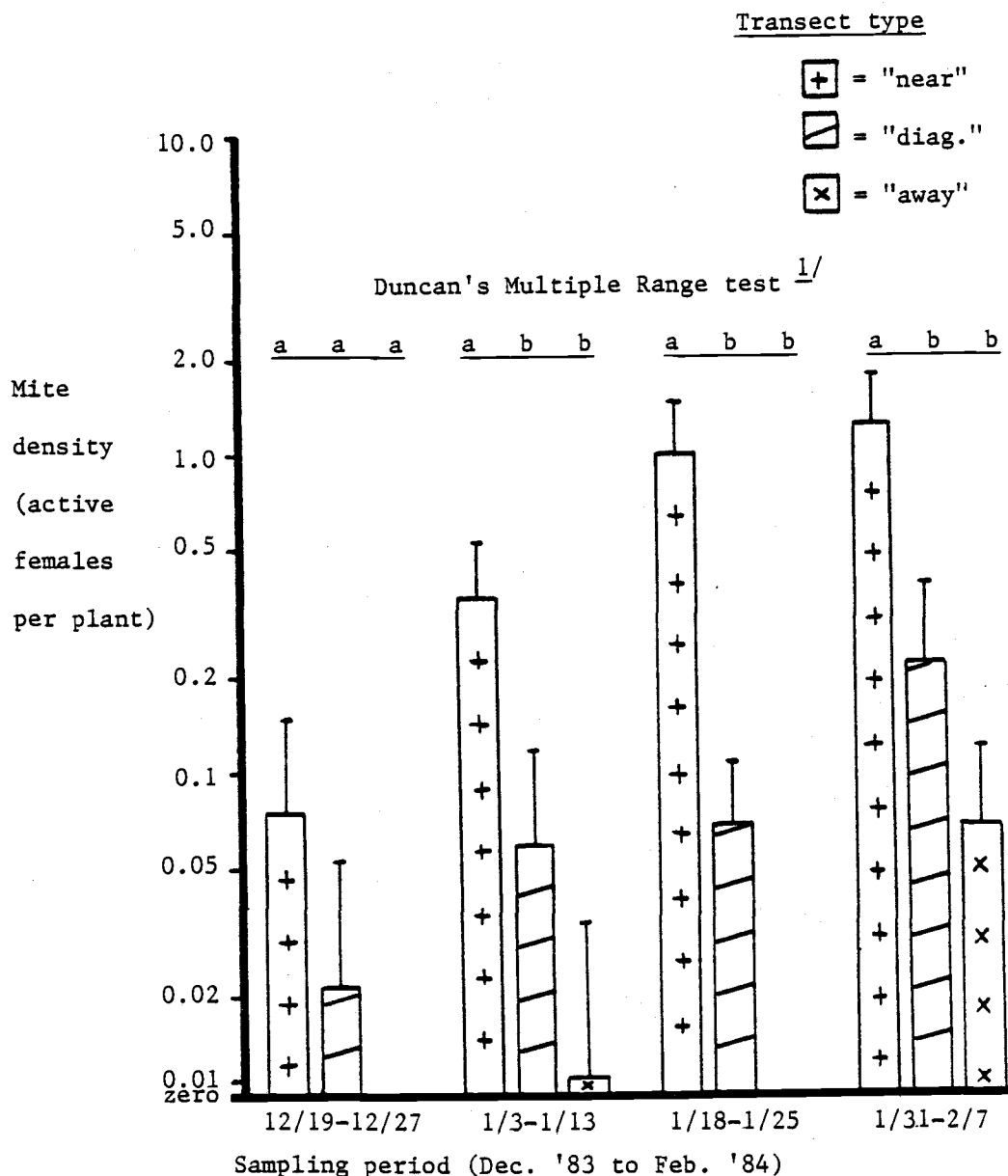


Figure 5D. Increase in mean density (active female mites) over four sampling periods (time) along transects "near", "diagonal" to and "away" from adjacent mite-infested summer-planted strawberry at the 1984 Eaton/summer-planted strawberry site, with Duncan's Multiple Range separation test for transect comparisons.

1/ Bars with common letters and underlining are not significantly different at  $p = 0.01$ .

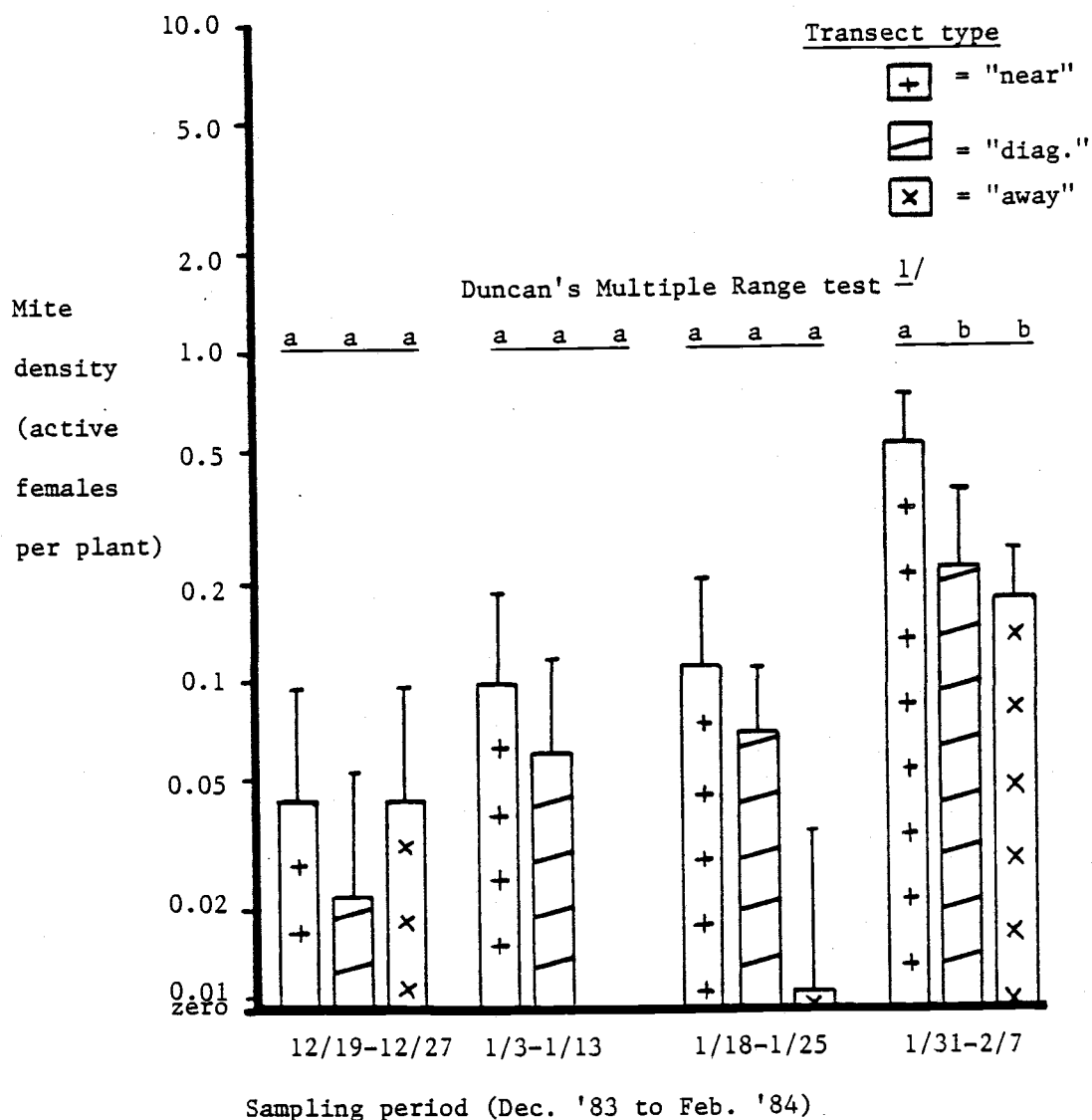
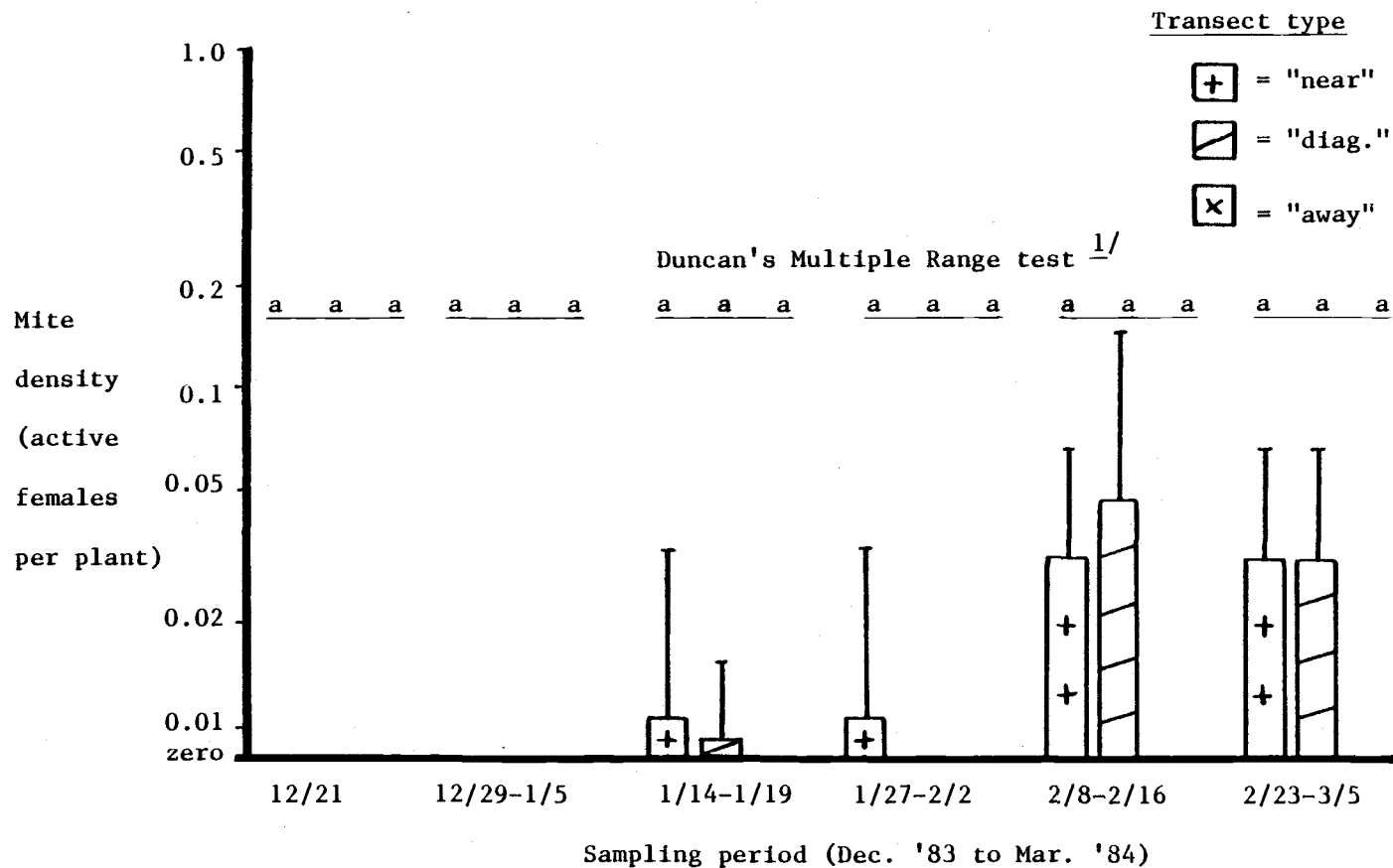


Figure 5E. Increase in mean density (active female mites) over six sampling periods (time) along transects "near", "diagonal" to and "away" from adjacent mite-infested burning nettle at the 1984 Smith site, with Duncan's Multiple Range separation test for transect comparisons.



<sup>1/</sup> Bars with common letters and underlining are not significantly different at  $p = 0.01$ .

The most notable increase occurred at the Lewis site, where active female densities near surrounding infestations in second year strawberry plants increased from 0.167 to 19.8 mites per plant over a 13-day span. During this same span, mite densities along transects away from infested second year strawberry rose from 0.0104 to 0.156 mites per plant, while mite densities along diagonal transects increased from 0.0208 to 1.48 mites per plant (Fig. 5A). A steady increase occurred at the Bachan site, where active female densities near surrounding mite-infested apple trees and groundcover weeds increased from 3.73 to 4.07 to 4.44 mites per plant over three sampling periods, respectively. Mite densities along transects away from infested apple trees rose from 0.0729 to 0.167 mites per plant, while mite densities along diagonal transects remained approximately unchanged, at 1.31, 1.26 and 1.02 mites per plant over the three sampling periods, respectively (Fig. 5B). Two edge effects were apparent at the Eaton site, where active female densities along transects near surrounding mite-infested apple trees and near surrounding mite-infested summer plantings of strawberry increased from 0.0729 to 1.16 mites per plant and from 0.0417 to 0.500 mites per plant, respectively. Away from mite-infested apple trees and summer-plantings of strawberry, mite densities increased from zero to 0.0625 mites per plant and from 0.0417 to 0.167 mites per plant, respectively, while diagonal transect mite densities at the Eaton site rose from 0.0208 to 0.203 mites per plant (Figs. 5C-D).

Small, but measurable increases occurred at the Smith site, where active female densities along diagonal transects and transects near adjacent mite-infested weeds each increased from zero to 0.0312 mites per plant. No active mites were encountered during sampling along

transects away from surrounding mite-infested weeds (Fig. 5E).

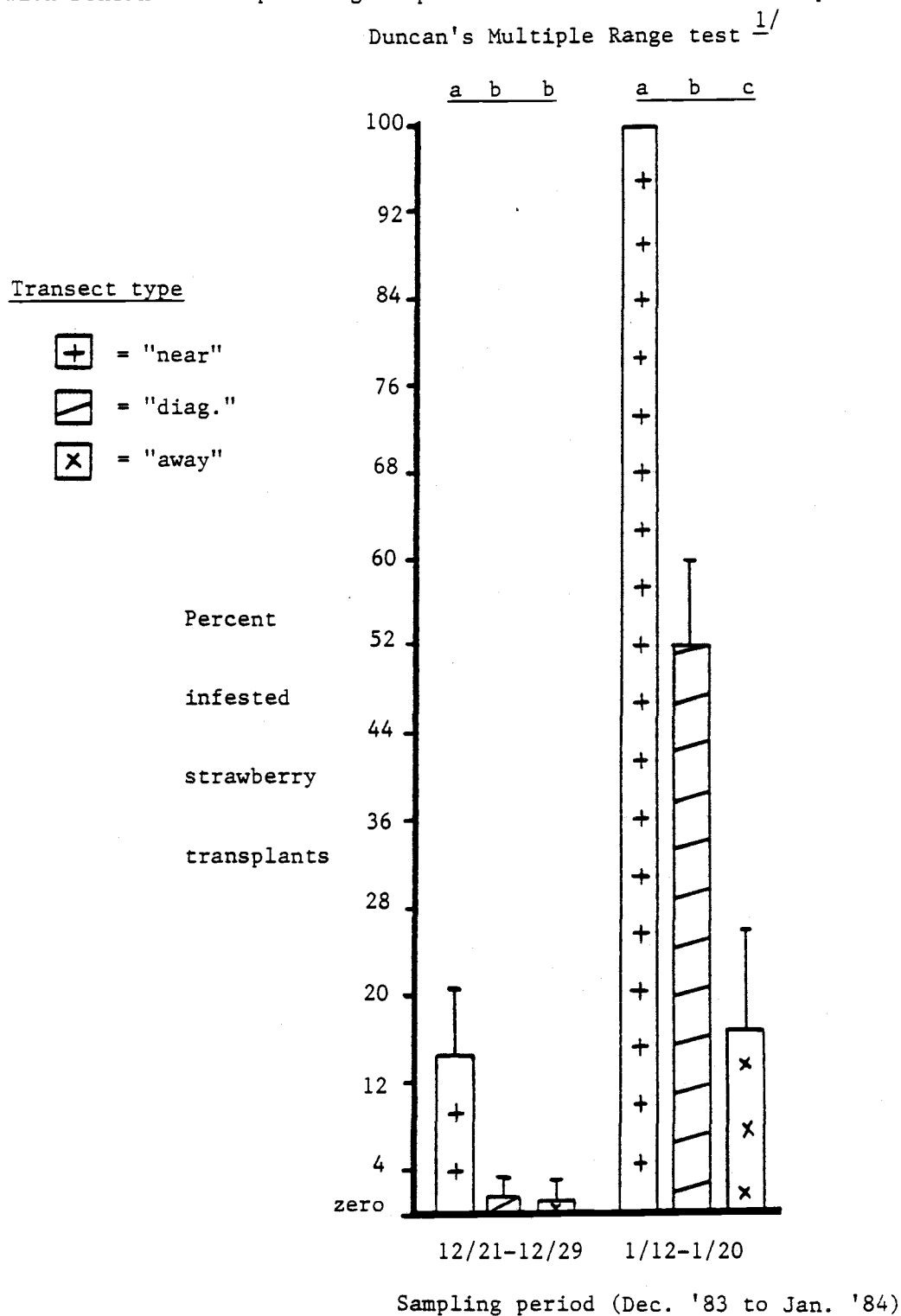
#### 5.3.5 Immigration Patterns over Time: Percent Infested Sample Plants

Figures 6A-E illustrate percent infested sample plants observed during each sampling period for transects near surrounding mite-infested vegetation, diagonal to, and away from surrounding infestations for each field site. Several additional aspects of the immigration events are observed when the percentage of infested plants are followed over time. By comparing female densities with percent infested plants, an idea of the distribution in each immigration event may be obtained.

As noted previously, clumping is evident when comparing these two types of presentations, especially at Pajaro Valley sites (see Sec. 6.0 for further discussion of clumped distribution of T. urticae). For instance, Bachan diagonal transects during the period Dec. 20-28 had 1.13 mites per plant (Fig. 5B), yet only 44 % of these plants were infested (Fig. 6B). Hence, for each plant which was infested, approximately 2.6 mites were found. Similarly clumped distributions may be found at Lewis (diagonal transects from 1/12 - 1/20) and Eaton sites (transects near infested apple trees from 1/31 - 2/7).

As noted previously, dramatic mite immigration occurred at the Lewis site, where infestations of new plantings near second year strawberry plants increased from 14.6 to 100 % over a 13-day span (Fig 6A). Percent infested plants away from second year strawberry plantings at the Lewis site increased from 1.04 to 16.7 %, while percent infested plants along diagonal transects

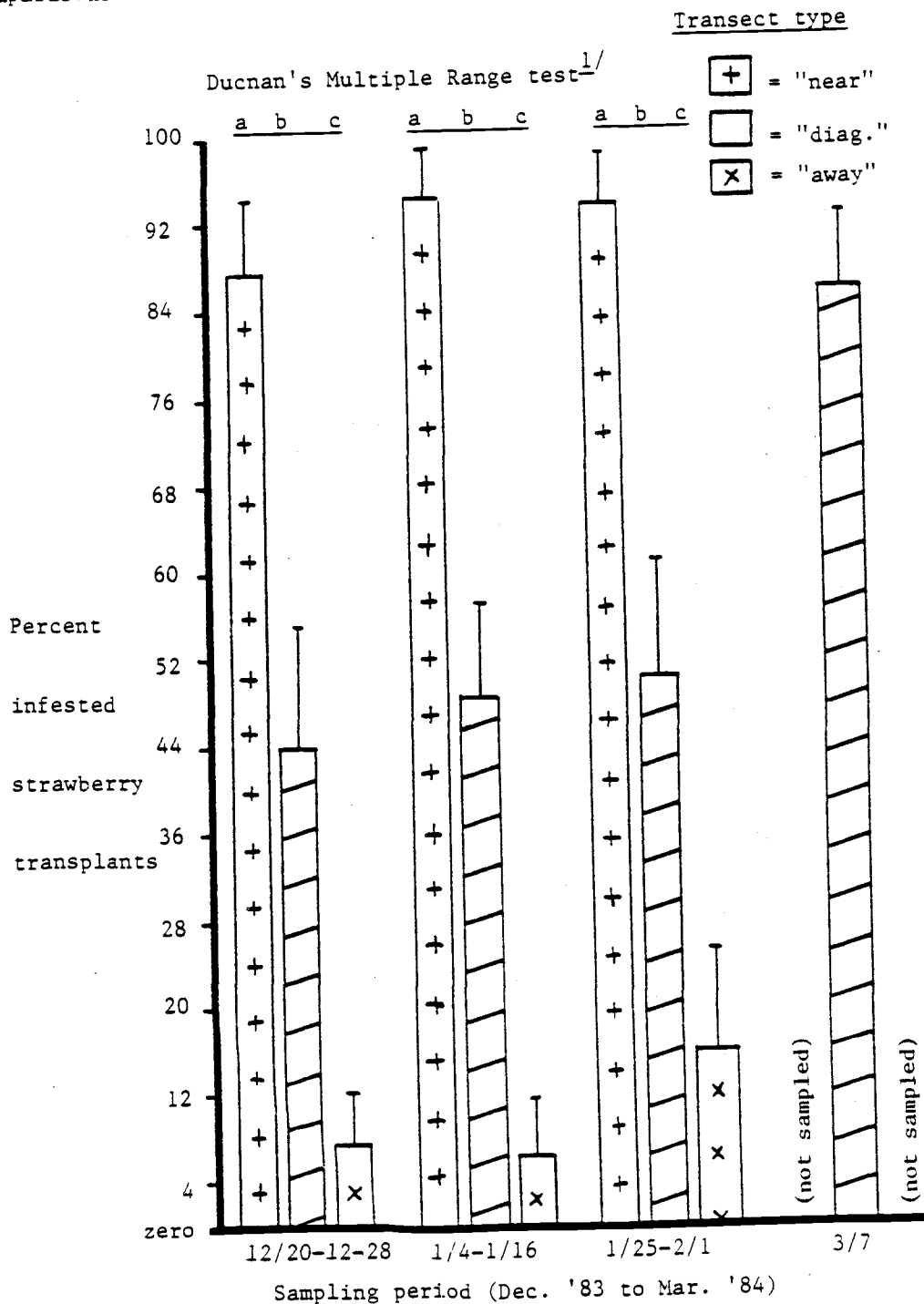
Figure 6A. Increase in mean percent infested plants over two sampling periods (time) along transects "near", "diagonal" to and "away" from adjacent mite-infested second-year strawberry at the 1984 Lewis site, with Duncan's Multiple Range separation test for transect comparisons.



<sup>1/</sup> Bars with common lettering and underlining are not significantly different at  $p = 0.01$ .

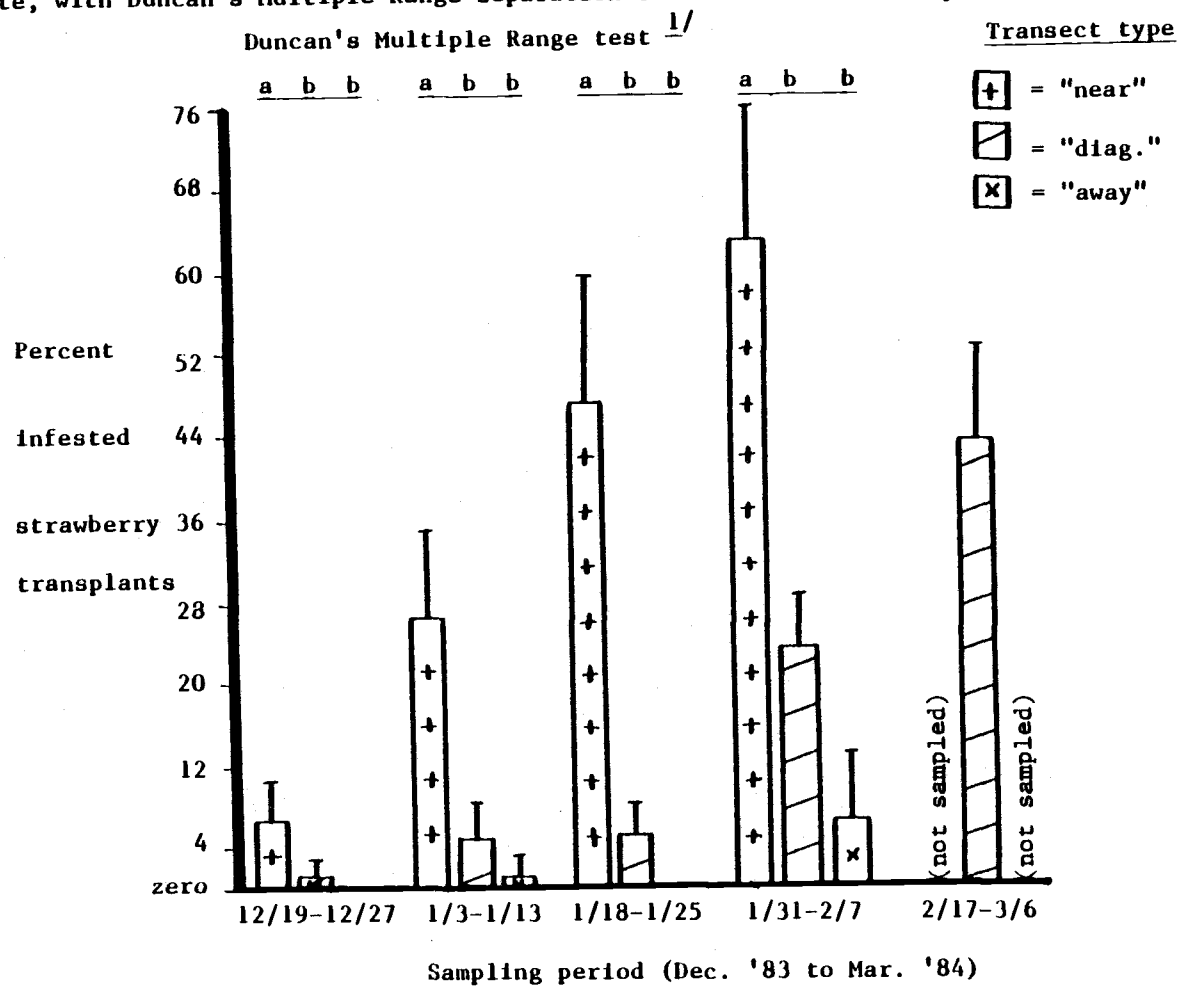


Figure 6B. Increase in mean percent infested plants over three sampling periods (time) along transects "near", "diagonal" to and "away" from adjacent mite-infested apple trees and groundcover weeds at the 1984 Bachan site, with Duncan's Multiple Range separation test for transect comparisons.



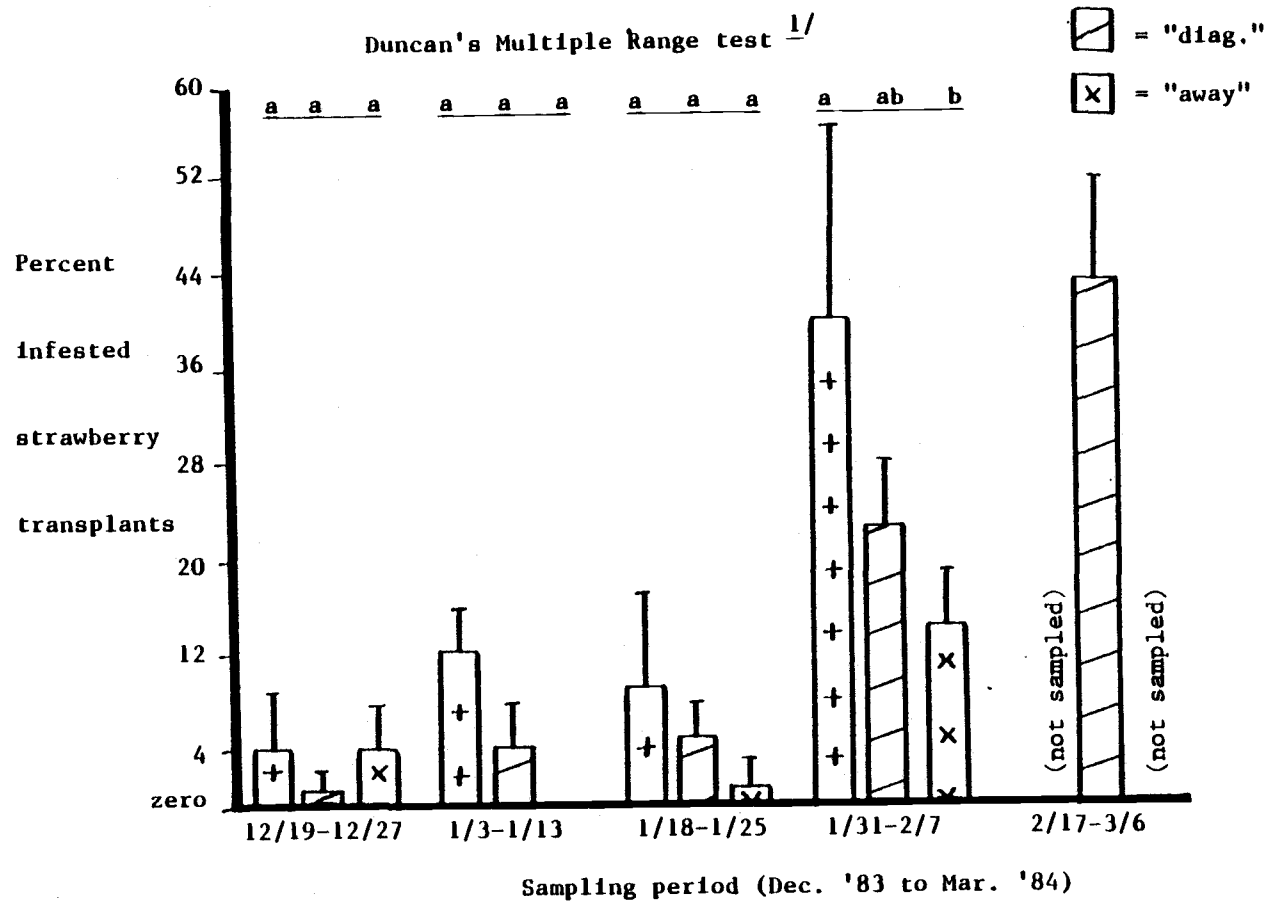
<sup>1/</sup> Bars with common lettering and underlining are not significantly different at  $p = 0.01$ .

Figure 6C. Increase in mean percent infested plants over five sampling periods (time) along transects "near", "diagonal" to and "away" from adjacent mite-infested apple trees at the 1984 Eaton/ apple site, with Duncan's Multiple Range separation test for transect comparisons.



<sup>1/</sup> Bars with common lettering and underlining are not significantly different at  $p = 0.01$ .

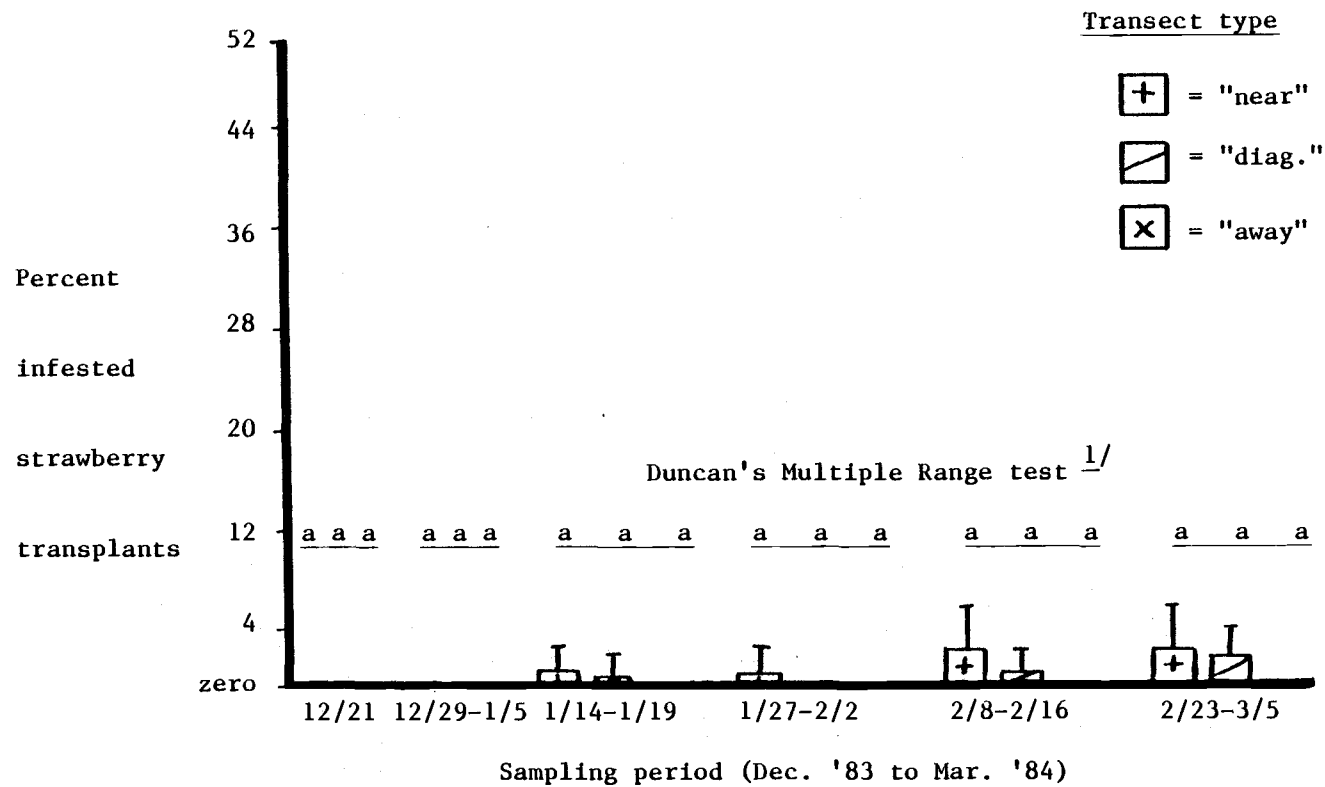
Figure 6D. Increase in mean percent infested plants over five sampling periods (time) along transects "near", "diagonal" to and "away" from adjacent mite-infested summer-planted strawberry at the Eaton/S.P. strawb. site, with Duncan's Multiple Range separation test for transect comparisons..



<sup>1/</sup> Bars with common lettering and underlining are not significantly different at  $p = 0.01$ .

Figure 6E. Increase in mean percent infested plants over six sampling periods (time) along transects "near", "diagonal" to and "away" from adjacent mite-infested burning nettle at the 1984 Smith site, with Duncan's Multiple Range separation test for transect comparisons.

1/ Bars with common lettering and underlining are not significantly different at  $p = 0.01$ .



rose from 1.56 to 52.1 % (Fig. 6A). Substantial T. urticae infestations were already present at the Bachan site, when field sampling began December 20th. Percent infested plants from diagonal transects at this site rose steadily from 44.3 to 85.4 % over the course of the sampling season. Percent infested plants away from infested apple trees at the Bachan site rose from 7.29 to 15.6 %, while the relatively mite-saturated transect near infested apple trees remained constant with 87.5, 94.8 and 93.8 % infested plants (Fig. 6B). An increase in the percentage of infested plants occurred in transects near apples at the Eaton site, where percent infested plants rose from 6.25 to 62.5 % by the time sampling was discontinued, while away from apple trees, percent infested plants increased from zero to 6.25 % (Fig. 6C). More subtle increases occurred in transects near summer-planted strawberry at this site, where infested plants increased from 4.17 to 39.6 %, compared to an increase in infested plants away from summer plantings from 4.17 to 14.6 % (Fig. 6D). Percent infested plants along diagonal transects at the Eaton site rose from 1.04 to 43.2 % (Figs 6C-D). Percent infested plants increased slightly at the Smith site, from zero in the early samples to 3.12 % near infested weeds and 2.60 % along diagonal transects by the the end of the sampling season. No active mites were found along transects away from mite-infested weeds during the sampling season (Fig. 6E).

#### 5.3.6 Immigration Patterns into Field Sites: Sticky Plate Recoveries

T. urticae may enter a newly planted strawberry field by one (or a combination) of three modes of transport: aerial dispersal, walking or while inhabiting detached vegetation which is blown onto the

site. Data on recovery of mites from sticky plates, which are summarized in Table 9A-B, is an indication of aerial mite immigration at a field site. Absence of mites on sticky plates implies either an absence of aerial mite immigration, or that if aerial mite immigration was occurring, it was at a frequency too low to be detected with this technique.

No mites were recovered at the Smith or Resetar sites in 1983 (Table 9A), despite larger numbers of traps employed at these sites. Four active adult females were recovered from plates at the Lewis site and one active female was recovered from a plate at the Bachan site (Table 9A). In 1984, active adult females were recovered from all four sites (Table 9B). Six active adult females and one deutonymph were recovered from plates at the Lewis site. Three active adult females, one diapausing female, and one protonymph were recovered from sticky plates at the Bachan site. Three active adult females and one deutonymph were recovered from sticky plates at the Eaton site. One active female was recovered from a plate at the Smith site.

Aerial immigration (as represented by a single mite) onto the isolated Smith site (Table 9B) was recorded February 2nd, after surrounding mite-infested vegetation had been disked under. Little is known about potential distances T. urticae can successfully immigrate, but the closest mite-infested vegetation (commercial strawberry plantings) when this mite was recovered were almost three kilometers away. Since mites caught on sticky plates die shortly afterwards, acaricide resistance could not be assessed.

One diapausing adult female (out of a total of 4 active mites) was recovered from sticky plates at a

Table 9A.

T. urticae recovered on sticky plates employed at 1983 fruiting field sites monitored for mite immigration. Each entry represents one mite recovery.

Site	Number of Plates Examined per Week	Recovery Dates	Location Near:	Orientation Towards:	Stage or Phase Recovered
Lewis	64	1/13	fallow	fallow area	active adult female
		1/13	fallow	fallow area	active adult female
		2/9	2nd yr. strawb.	2nd yr. strawb.	active adult female
		2/15	2nd yr. strawb.	2nd yr. strawb.	active adult female
Bachan	80	1/14	Pajaro River	Pajaro River	active adult female
Resetar	88	(no mites recovered)			
Smith	160	(no mites recovered)			

Table 9B.

*T. urticae* recovered on sticky plates employed at 1984 fruiting field sites monitored for mite immigration. Each entry represents one mite recovery.

Site	Number of Plates Examined per Week	Recovery Dates	Location Near:	Orientation Towards:	Stage or Phase Recovered
Lewis	48	1/12/84	2nd yr. strawb.	2nd yr. strawberry	deutonymph
		"	2nd yr. strawb.	Lewis Road (rasp.)	active adult female
		1/20/84	2nd yr. strawb.	Lewis Road (rasp.)	active adult female
		"	2nd yr. strawb.	Lewis Road (rasp.)	active adult female
		"	2nd yr. strawb.	2nd yr. strawberry	active adult female
		2/3/84	1st yr. strawb.	Lewis Road (rasp.)	active adult female
Bachan	40	"	2nd yr. strawb.	2nd yr. strawb.	active adult female
		12/28/83	apple trees	Riverside Hwy.	active adult female
		"	apple trees	apple trees	active adult female
		"	apple trees	apple trees	active adult female
		"	apple trees	apple trees	protonymph
Eaton	40	1/18/84	apple trees	apple trees	diapause female
		1/3/84	S.P./apple tree	apple trees	active adult female
		"	S.P. strawberry	S.P. strawberry	deutonymph
		1/19/84	S.P. strawberry	S.P. strawberry	active adult female
Smith	48	3/6/84	S.P. strawberry	S.P. strawberry	active adult female
		2/2/84	fallow	fallow	active adult female



Bachan site trap (Table 9B) less than 10 meters from the nearest mite-infested apple trees. Mites in diapause do not aerially disperse as a "normal" behavior, but if they are on aging, senescent vegetation, these mites will seek sheltered overwintering sites on the ground (see next section for more discussion). The mite in diapause recovered from a sticky plate at the Bachan site (Table 9B) may have been blown onto the sticky plate while exhibiting this type of behavior. Other diapausing mites may have been displaced onto this site in a similar fashion, since the density of mites in diapause recovered from plant sampling at the Bachan site (see sec. 5.1.3, Table 5) was 3.5-fold higher than at other sites (probably due to the close proximity of abscising apple leaves infested with diapausing mites, which then blew into the field) and acaricide bioassays indicated resistance in these mites.

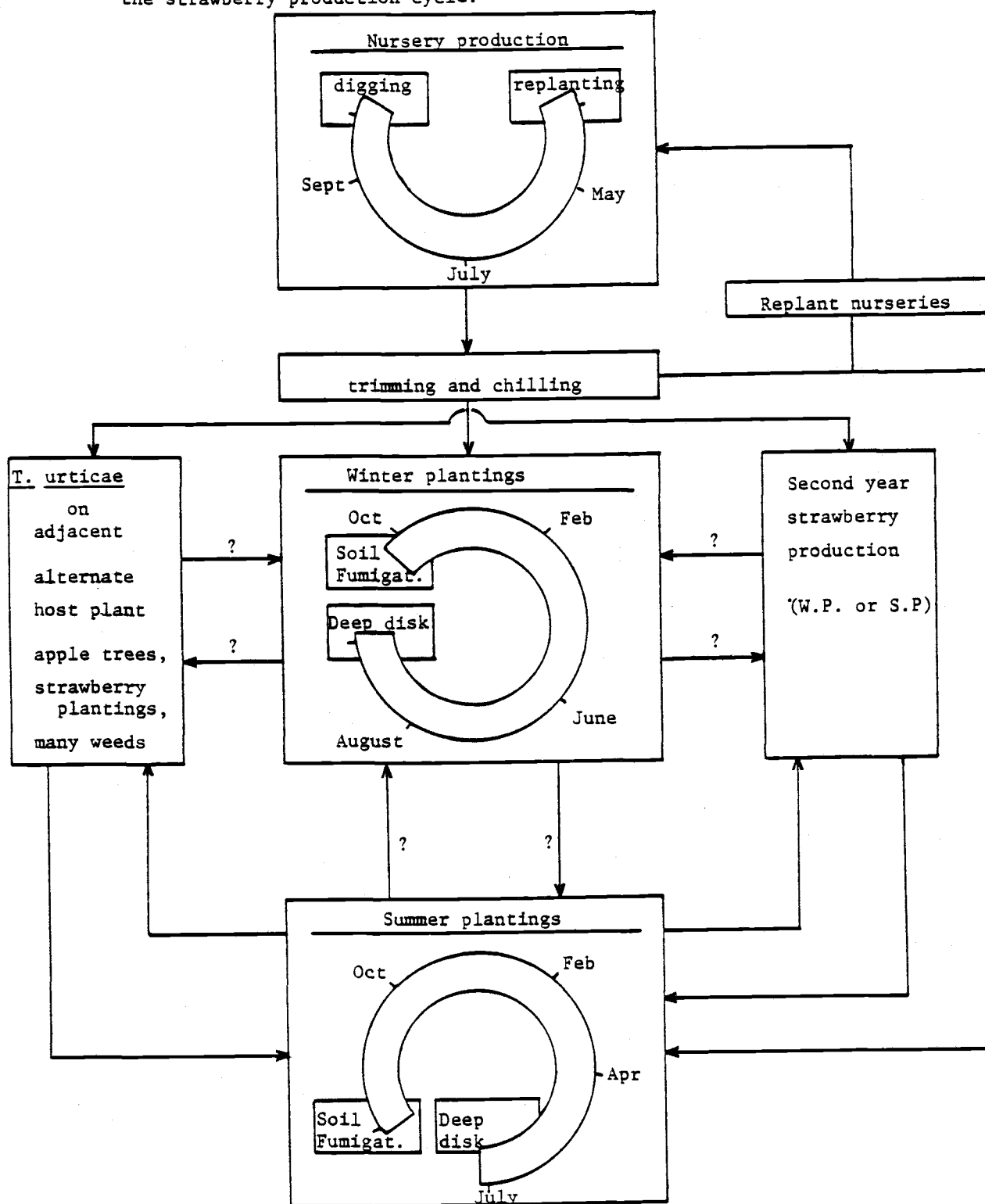
In 1984, 10 of 16 mite recoveries were oriented towards surrounding mite-infested vegetation. While orientation of mites recovered from sticky plates does not prove aerial mite immigration from a given source or direction, the passive nature of airborne mite immigration means that prevailing wind currents dictate the direction in which mite immigration will occur. Hence when wind direction is coming from behind surrounding mite-infested vegetation towards field sites, it is likely that some airborne mites from these surrounding sources will be deposited on plants and sticky plates in field sites. Orientation of sticky plate recoveries towards surrounding mite-infested vegetation also lends support to the assertion that much mite immigration occurs over relatively short distances.

## 6.0 DISCUSSION AND CONCLUSIONS

This research attempted to characterize mite immigration as it affects acaricide resistance and population buildup of T. urticae during several phases of the strawberry production cycle in the Pajaro and Salinas Valleys in California. Mite immigration, as it influences acaricide resistance has been discussed, as illustrated in Figure 7, by characterizing mite sources and acaricide resistance at several important steps of the production cycle. Two primary sources of immigrant mites are responsible for acaricide susceptibility or resistance in the Pajaro Valley. These are nursery mites originating on trimmed plants designated for transplanting at new field sites and mites overwintering on vegetation surrounding field sites in the Pajaro Valley. In Figure 7, three annual planting cycles are represented by partial rings. Nursery plant production begins in April or May and ends in October or November. Winter plantings of strawberry begin in November or December and end in October. Summer plantings of strawberry begin in September and end in June or July. Each arrow represents potential movement of T. urticae through various parts of the production cycle. Question marks represent potential mite immigration, which may or may not be realized in a particular year depending on many factors, including weather and grower production practices, to name a few.

Plant production begins at the nursery (Fig. 7). Tetranychus urticae infesting high-elevation nursery strawberry plants were uniformly susceptible to cyhexatin and formetanate (Table 3). The Mills site, a low elevation nursery, harbored mites with formetanate resistance, possibly due to previous selection with other chemicals or the high intrinsic propensity for

Figure 7. Conceptual diagram depicting movement of *T. urticae* through the strawberry production cycle.



Arrows depict potential movement of *T. urticae* through the production system. "?" indicates inputs which are potentially the most variable. Partial rings depict the cyclic nature of plantings and time plants are in the soil.

formetanate resistance<sup>1/</sup> in this species. Since less than 1 % of new transplants at field sites originated from the Mills nursery, and no mites were recovered from the field site planted with Mills nursery transplants, acaricide susceptibility was used (in addition to orange diapause coloration of nursery mites) to identify mites of nursery origin, in spite of formetanate resistance at the Mills site.

When mite density sampling was first begun at the nurseries, it was not known which mite stages survive trimming and chilling, which occurs October through December each year (Fig. 7), hence all mite stage densities were initially assessed (Table 3). Later, it was determined that only diapausing females survive plant trimming and chilling at -2.2 degrees C. Vaz Nunes and Veerman (1979a,b and 1982a,b) have documented various aspects of diapause in European strains of T. urticae. Stenseth (1965) found that active adult female mortality for T. urticae was greater than 99 % after 3 days at -15 degrees C, and 97 % after 40 days at -5 degrees C in European strains. However, 20 % of diapausing females survived 12 or more days at -15 degrees C. The mites which survive chilling have endured a stressful environment, with below-freezing temperatures, low relative humidity due to low temperatures, and continuous darkness. Stenseth (1965) noted that mite survival percentages at cold temperatures were greatly increased when relative humidity was kept high.

1/ The quick selection of formetanate-resistant genotypes from a previously susceptible nursery mite population indicates that future formetanate use in mite management programs on strawberry in the Pajaro Valley may be extremely limited, but it could remain valuable in an acaricide rotation program as one aspect of acaricide resistance management.

In October and November, plants are mechanically lifted out of the soil, bagged and transported to trimming and chilling facilities in the Pajaro Valley (see Fig. 7). After trimming of leaves, runners and roots occurred, diapausing mite populations were assessed and found to possess complete acaricide susceptibility (Table 4). Also, densities of diapausing mites on trimmed plants were found to be relatively constant (Table 4). The number of overwintering sites within the plant crown after trimming may be relatively constant and probably is the factor limiting density levels of diapause mites on trimmed plants from year to year. Diapausing mites emerge from protective overwintering crevices in the crown of the trimmed plant, move to developing leaflets, terminate diapause and begin to oviposit and feed there after an undetermined quantity of heat units have accumulated (Veerman, 1977). If it becomes desirable to increase the density levels of susceptible immigrant mites entering new sites on strawberry transplants, altered trimming and/or chilling practices may be necessary.

After the trimmed plants were chilled for several weeks, they were transplanted into recently fumigated soil at strawberry production sites (Fig. 7). At this time, the only mites on the transplants were nursery mites which had survived trimming and chilling. Because these mites were in diapause, while Pajaro Valley mites were mostly active, orange diapause coloration was used as a marker (secondary to susceptibility assessments with acaricide resistance bioassays) to determine if a mite originated from the nursery. Density levels of diapausing mites in newly planted field sites (Fig. 7) were found to be much lower, compared to trimmed plant mite densities, leading to the conclusion that significant mortality of mites in diapause (and/or rapid

termination of diapause) occurs after trimmed plants are transplanted at field sites (Table 5). The stressed cold storage survivors subsequently face traumatic environmental changes after transplanting, including a rapid temperature increase to 14-23 degrees C., and exposure to full sunlight, wind, rain, etcetera, with little leaf canopy for protection.

Again, mite populations in diapause at field sites were found to be susceptible to acaricides, with the exception of two sites where resistant diapausing mites on detached vegetation surrounding the field sites were blown into the field by wind (Table 5). Displacement<sup>2/</sup> of resistant mites in diapause infesting detached, windblown vegetation added to density estimates of diapausing mites at the Bachan and Eaton sites. This made identification of nursery mite immigrants, based on orange diapause coloration, an unreliable marker at these two sites in 1984. However, acaricide resistance bioassay was the primary method of determining nursery origin for all mite strains. Because mites in diapause at these sites were resistant, they could not have come entirely from nursery sites. Observations of detached, windblown vegetation were fairly frequent at both sites. Apple leaves (from adjacent apple trees) were found across the Bachan site in late December and strawberry trimmings (from adjacent summer plantings) over most of the Eaton site in late January.

2/ Documentation of "normal" behavior of diapause *T. urticae* commonly indicates that it drops to the ground to find overwintering sites in the soil or under bark or other debris (van de Vries, et al., 1972). Hence the word "displacement" indicates that aerial movements of *T. urticae* in diapause do not normally include immigration to new vegetative growth. The recovery of one diapausing mite from sticky plates near apple trees on the Bachan site indicates, however, that immigration of the diapause phase may occur, if only infrequently.

Detached, windblown mite-infested vegetation may enter newly planted strawberry sites and unfavorably influence acaricide resistance episodes there, as it did on the Bachan and Eaton sites in 1984. The growers' ability to control this input could reduce spider mite buildup and acaricide resistance problems at these sites. Control measures would include thorough cleanup of any loose leaves, runners and weeds at the site immediately after pruning. Cooperation may be sought from neighboring growers to better manage loose vegetation which may harbor resistant mite populations.

The second primary source of mite immigrants are on alternate host plants surrounding new strawberry plantings in the Pajaro Valley (see Fig. 7). Vegetation surrounding all field sites harbored resistant T. urticae at varying density levels (Table 6). Apple orchards and established plantings of strawberry are two primary overwintering sites for T. urticae. Various weed species also harbored resistant mites, but the role of specific weed species in early season mite immigration will require further study. The growers' ability to control mite infestations on vegetation surrounding new strawberry planting sites may favorably influence acaricide resistance episodes there. By decreasing the overwintering populations of resistant mites in the fall, less immigration of resistant mites will occur the following winter and spring. Paramount are cooperation and education of neighboring growers to focus upon management of this overwintering population. Prevalent grower attitudes tend to inhibit the implementation of this type of cooperation because growers with resistant mites are reluctant to blame his/her neighbor for mite problems or offer to help him/her with mite management. However, some form of intergrower cooperation will be necessary to implement

management of resistant overwintering T. urticae.

Other possible control measures include: strategic location, when possible, of planting sites where no alternate T. urticae hosts exist (i.e. apples, summer plantings and second-year plantings of strawberry); prompt, thorough destruction of old strawberry plantings, soil fumigation upon termination of the picking season, and management where possible (i.e. onsite weeds) of overwintering mite populations in the non-picking season without selecting for acaricide-resistant genotypes. (This would be facilitated by the use of an acaricide not used during the fruiting season. At present, however, no such alternative compound is presently registered on strawberry which remains efficacious). Conservation and augmentation of phytoseiid predators in perennial plant reservoirs surrounding field sites could also substantially reduce resistant overwintering mite populations (McMurtry, et al. 1978). A narrow strip of trap crop (e.g. Faba bean, corn, etc.) around the perimeter of new plantings could be another approach. Possible control measures will require further research to evaluate their effect upon overwintering mite populations.

Summer plantings and second-year plantings (see Fig. 7) in the Pajaro and Salinas Valleys also harbor resistant mites, which very probably will immigrate to new adjacent winter plantings (Table 6). Summer plantings or second year plantings of strawberry adjacent to winter plantings negates the impact of host-free control measures for all three production types, since the strawberry host plant is always present and acaricide pressure occurs in one of these varieties for 9 - 10 months each year. Many strawberry cultivars respond more



favorably to summer planting (e.g. most Univ. Calif. cultivars) and are likely to predominate in the Pajaro and Salinas Valleys in future years. Second-year plantings could soon completely disappear from the Pajaro Valley because annual plantings are more profitable. The exchange of resistant mites between summer, second-year and winter plantings of strawberry may be substantially reduced by separating the varieties geographically. Since little mite immigration was detected in the early season over 100 meters, a "safe" distance between these different types of plantings may be as short as several hundred yards.

Assessments of resistance levels taken on active mites sampled within new winter-planted field sites (Table 7) in the Pajaro and Salinas Valleys showed varying levels of resistance in early season (Fig. 7). Significant densities of resistant mites built up along 1984 sampling transects near adjacent mite-infested vegetation, while lower mite densities built up along transects away from infested vegetation at three Pajaro Valley sites (Table 8, and Figures 3 - 6). These immigrant mites influenced acaricide resistance status at these sites by producing enough resistant progeny to cause acaricide resistance to be present before the first acaricide sprays of the new growing season. This situation leaves growers with an increasing probability of mite control failure due to acaricide resistance. Significant active mite immigration did not occur at the isolated Smith site, as measured by field sampling (Table 8). Hence, acaricide resistance will not occur at this site as a result of early season immigration by resistant T. urticae.

Varying mite density levels accumulated at each 1984 field site and each mite density was associated with the

relative abundance of mites inhabiting surrounding vegetation. The Lewis site had extremely high density levels of resistant mites in adjacent second year strawberry plantings, hence experienced the highest density level of resistant immigrant mites (Fig. 5A). The Bachan site had moderate density levels of resistant mites in adjacent apple trees and groundcover weeds because of neglectful mite management in the apple trees (R. Nelson, personal communication) and experienced a relatively high density level of resistant immigrant mites (Fig. 5B). The apple trees appear to be an important reservoir for resistant T. urticae, since apples also receive cyhexatin applications for mite management purposes. The importance of the role of groundcover weeds needs further research, but it may be assumed that groundcover weeds contribute to the alternate host reservoir of resistant T. urticae. The Eaton site experienced lower densities of resistant immigrant mites, probably because adjacent resistant mite populations in apple trees (Fig. 5C) and summer plantings of strawberry (Fig. 5D) were somewhat better managed. A very low density of highly resistant mites in a small patch of burning nettle adjacent to Smith site strawberry plantings did not appear to affect the resistance scenario there, as all mites found at this site were susceptible (Table 7B). Because very low densities of mites existed adjacent to the Smith site, very low densities of immigrant mites developed there (Fig. 5E).

At Pajaro Valley sites where acaricide-resistant mites annually immigrate into new strawberry planting sites, modified crop production practices may greatly extend the effective use-life of cyhexatin and newly registered acaricides. The low intrinsic mite density which occurred at the Smith site indicates that acaricide

resistance may be avoided by planting, when possible, in isolated locations, as well as by carefully managing surrounding weed hosts. Possible resistance management strategies include a unilateral, valley-wide host-free period, more thorough monitoring of acaricide resistance in T. urticae populations on alternate hosts, and modified weed host control. Conservation and augmentation of phytoseiid predators could substantially reduce overwintering populations in perennial vegetation surrounding strawberry planting sites. Judicious use and rotation of acaricides based on mite density thresholds and resistance monitoring, could significantly delay development of cyhexatin resistance as well as development of future resistance to newly registered acaricides in T. urticae (Tabashnik and Croft, 1983).

The fact that similar mite density levels did not occur at these four sites, along with the finding that significant mite density gradients declined over distance at Pajaro Valley sites (Fig. 4), indicates that immigrant mite density is inversely proportional to the distance from the immigration source. This means that the majority of early season mite immigration occurs over short distances (probably 100 meters or less).

From observations of active immigrant mite densities at field sites, mite immigration appeared to be clumped (Table 8). Large "clusters" of active females were often found on a strawberry plant surrounded by uninfested plants. This is unequivocally differentiated from the clumped distribution found after several generations of reproducing spider mites have occurred on one plant, because immigrant mite clumping was present before eggs or immatures were present.

Established populations of T. urticae have been shown to have a clumped distribution (Nelson and Stafford, 1972). Clumped distributions of established T. urticae populations are probably due to limited mobility, limited movement of the "feeding" phase, numerous sibling matings and arrhenotokous reproduction. However, the factors responsible for a clumped distribution in an established, reproducing mite population may be quite different from the factors causing the apparent clumping of immigrant mite populations, which have not yet begun oviposition. The inferred clumping of immigrant mites (active females, Sec. 5.3.5) may be due to a number of uninvestigated possibilities, including mass aerial dispersal (i.e., they immigrate together). Masses of spider mites and webbing may be observed at the upper tips of chlorotic vegetation in greenhouses or even on weeds in a sprayed environment (e.g. personal observation of this phenomenon on morning glory in September 1983 at the Bachan site). This behavior is presumably adapted for wind dispersal as a resource becomes depleted or environmental conditions become unsuitable. Suski and Naegele, (1969a,b,) determined that active T. urticae, upon exhausted or chlorotic host plants exhibit a positive response to light (their "dispersal" phase) and indicated that the light responses of many invertebrates are "strongly influenced by water saturation of body tissues. When leaves are heavily damaged there occurs a decrease of relative humidity and a shortage of food supply." Thus lack of food and dessication were considered as the most probable factors in the change to the "dispersal" phase. Boyle (1957) performed greenhouse experiments on the dispersal phase of T. urticae, where he detected mites in the air at low to moderate wind speeds. Although no "dispersal" phase behavior of hundreds of massed mites was ever

observed adjacent to field sites in the early season, conceivably small numbers of active mites could aerially disperse en masse to an area within a field site, where the mites would then walk to and colonize the nearest strawberry plant. (A 1984 single sticky plate recovery of an adult female next to an immature mite is possible evidence for this hypothesis.)

Windborn movement of detached, mite-infested vegetation is a second factor which may help to explain the clumping effect of immigrating mite populations. If a mite-infested windborn leaf lands in the proximity of a young strawberry plant, the mites on that leaf are likely to exhibit nearly synchronized dispersal behavior since they are responding to similar cues just described (Smitley and Kennedy, 1985) for conditions triggering the dispersal phase. The nearest hostplant, therefore, is likely to be infested by mobile stages of mites dispersing from the leaf approximately at the same time. At the Bachan and Eaton sites detached, infested vegetation was readily observed moving into new strawberry plantings. Pruned, mite-infested vegetation from second-year plantings, although not observed firsthand, may also help to account for clumping of immigrant mites at the Lewis site. Infestation levels remained too low to infer that immigrants were clumped at the isolated Smith site.

In 1983, high mite mortality and poor sampling conditions were caused by heavy, continuous rainfall during the last seven weeks of the sampling season (late Jan. through mid-March), causing a 98 % reduction in estimates of immigrant mite density, as compared to 1984 mite density levels (Table 7A). Mite densities remained so low that no active mite immigration patterns were evident, after an initial period of sampling during

favorable weather. In a year with average winter rainfall, immigrant mite densities ranging somewhere between 1983 and 1984 estimates should occur. The function assumed by quantity of rainfall versus percent mite mortality is not known, but may not be linear. Hence, without further research, 1983 and 1984 immigrant mite density estimates may serve as the probable lower and upper "prediction limits" for future mite immigration events.

Immigration of resistant active mites into winter plantings (see Fig. 7) at the isolated Smith site cannot be entirely ruled out because one female mite was recovered on a sticky plate there (Table 9B). Early season aerial immigration of T. urticae into strawberries is not a well-researched subject, especially over long dispersal distances (i.e., kilometers), as must have occurred at the Smith site. Aerial dispersal of spider mites into strawberries has been documented (Allen and Browne 1972, Allen, 1974, Allen and Coville, 1981) later in the growing season, when the frequency of airborne mites is higher. Numerous studies have been done on aerial immigration of T. urticae into other crops (Stabler, 1914, Boyle, 1957, Hussey and Parr, 1963, Osman and Rasmy, 1976, Brandenburg and Kennedy, 1982b, Boykin and Campbell, 1984, Hoy, et al., in press), aerial dispersal in other mite species (Fleschner, et al., 1956, Mitchell, 1970, Nielson, 1958, Johnson and Croft, 1981, Hoy, et al., in press), and aerial dispersal in other minute, wingless arthropods (Washburn and Washburn, 1984).

In summary, it is apparent that resistant mites are able to overwinter at varying density levels on alternate host plants (i.e., apple, summer and second-year plantings of strawberry) where they or their progeny may

immigrate into a new strawberry planting, dramatically increasing acaricide resistance levels there. It is also apparent that at isolated sites, acaricide resistance will not occur as a result of early-season immigration of resistant mites, because susceptible immigrant mites originating from strawberry nurseries will be the only early season colonizers at the site.

Crop production practices may play an important role in future resistance management programs. The fact that density of immigrant mites decreases over distance from the mite source suggests that growers may be able to minimize mite immigration through resourceful management. Cooperation between growers and their neighboring growers, though difficult to implement, may enable effective management of overwintering resistant mite populations in the Pajaro Valley. This may, in turn, reduce the number of mite control failures due to acaricide resistance and the number of annual acaricide applications required for T. urticae in the valley.

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## 8.0 APPENDICES

# Appendix A

Table 10A. 1982 nursery mite population summary (leaflet count).

Source	Sample Date	# Leaflets Sampled	Average # Adults	Average # Immatures	Average # Eggs
Carpenter	9/16/82	30	8.9	55.2	125.0
Tierney	9/16/82	30	11.3	51.6	46.6
Carpenter	10/25/82	30	6.3	17.2	2.0
Tierney	10/25/82	30	4.2	25.4	3.0
Carpenter 2nd, 3rd Daughters	10/25/82	30	15.3	56.4	11.9
Mills	12/19/82	80	0.0	0.0	0.0

Table 10B. 1983 nursery mite population leaflet counts

Ranch/Plant Type	Date	Average Number Dormants	Average Number Predators	Average Number Actives	Average Number Immatures	Average Number Eggs
Carpenter* Senescent Mothers	10/1/83	19.4	0.10	----	----	----
Carpenter* Daughters	10/1/83	1.9	0.08	----	----	----
Mills Daughters	10/2/83	0.1	0.06	0.36	0.58	0.32

\* Samples are averages of 50 center leaflets.

<u>Table 11A. 1983 daughter plant dissection data summary</u>					
Nursery Source	Date Examined	# Plants Examined	# Days Grown	# Mites Recovered	Mites/Plant
Carpenter	2/4/83, 2/5/83, 2/20/83	393	7-13	20	0.051
Tierney	2/19/83- 3/19/83	1366	1-17	102	0.075
Total	2/4/83- 3/19/83	1760	1-17	122	0.069

<u>Table 11B. 1984 daughter plant dissection data summary</u>					
Nursery Source	Date Examined	# Plants Examined	# Days Grown	# Mites Recovered	Mites/Plant
Carpenter	12/30/83	302	11	19	0.063
Carpenter	1/24/84	319	27	40	0.125
Carpenter	2/7/84	559	24	21	0.038
Carpenter	2/21/84	583	15	36	0.062
Total		1763		116	0.066
Canal	12/30/83	125	11	0	0.0
Canal	1/13/84	265	25	0	0.0
Canal	1/24/84	260	27	2	0.0077
Canal	2/9/84	430	26	0	0.0
Total		1080		2	0.0019
Mills	2/9/84	597	26	0	0.0
Mills	2/25/84	540	19	0	0.0
Total		1137		0	0.0

Table 12A. 1982 formetanate bioassay data on susceptible* nursery mites										
Source	Assay Date	LC50	(CI Min, CI Max)		LC95	(CI Min, CI Max)		Slope	<sup>2</sup> R	R/S ratio LC50/LC95
*High elevation: "Susceptible" population										
Carpenter	8/15/82	.0038	(.0034, .0042)		.015	(.014, .017)		2.69	.839	2.07/1.82
Carpenter	10/2/82	.0014	(.00090, .0023)		.0041	(.0026, .0065)		3.58	.973	.764/.497
Carpenter	11/5/82	.0013	(.0011, .0015)		.0024	(.0020, .0029)		5.76	.920	.709/.291
Carpenter	11/20/82	.0013	(.0011, .0015)		.0073	(.0062, .0086)		2.21	.912	.709/.885
Tierney	10/2/82	.0017	(.0015, .0018)		.012	(.011, .013)		1.91	.605	.927/1/45
Tierney	11/20/82	.0015	(.00054, .0042)		.0087	(.0031, .024)		2.16	.966	.818/1.05
Average		.0018333			.008250			3.051666		
*Low elevation: significantly higher LC50 values										
Hackler	11/5/82	.0052	(.0050, .0054)		.012	(.011, .013)		4.48	.957	2.84/1.45
Mills	12/11/82	.019	(.018, .020)		.177	(.165, .189)		1.69	.897	10.4/21.5
Mills	12/19/82	.0073	(.0068, .0078)		.064	(.059, .069)		1.75	.932	3.98/8.12



Table 12B. 1983 formetanate bioassay data on nursery mites									
Source	Assay Date	LC50	(CI Min, CI Max)	LC95	(CI Min, CI Max)	Slope	<sup>2</sup> R	R/S ratio LC50/LC95	
Carpenter	10/22/83	.0036	(.0032, .0040)	.034	(.031, .038)	1.67	.907	1.96/4.12	
Mills	10/22/83	.0077	(.0071, .0081)	.037	(.034, .040)	2.41	.910	4.20/4.48	
Carpenter selection	12/30/83	.050	(.048, .053)	1.22	(1.12, 1.33)	1.19	.914	27.3/148.	
Carpenter (trimmed plant dissections)	3/11/84	.0056	(.0052, .0059)	.262	(.246, .280)	.983	.928	3.06/31.7	

Table 13A. 1982 cyhexatin bioassay data on susceptible nursery mites								
Source	Assay Date	LC50	(CI Min, CI Max)	LC95	(CI Min, CI Max)	Slope	<sup>2</sup> R	R/S ratio LC50/LC95
Carpenter	8/16/82	~.0014		~.0024	(not run: 100% kill @ 0.0025 % a.i.)			.356/.151
Carpenter	10/17/82	.0025	(.0025, .0026)	.0054	(.0052, .0056)	5.04	.983	.636/.340
Carpenter	11/24/82	.0016	(.0013, .0020)	.010	(.0080, .012)	2.05	.869	.407/.629
Carpenter	12/5/82	.0051	(.0044, .0060)	.017	(.015, .020)	3.13	.974	1.30/1.07
Tierney	11/3/82	.0033	(.0025, .0043)	.027	(.021, .036)	1.80	.968	.840/1.70
Tierney	12/5/82	.0064	(.0058, .0070)	.035	(.032, .038)	2.23	.983	1.63/2.20
Hackler	11/8/82	.0052	(.0038, .0071)	.011	(.0077, .015)	5.34	.964	1.32/.692
Mills	12/2/82	.0034	(.0028, .0042)	.0059	(.0048, .0071)	7.12	.999	.865/.371
Average		.0039286		.01590		3.815714		

Table 13B. 1983 cyhexatin bioassay data on susceptible nursery mites								
Source	Assay Date	LC50	(CI Min, CI Max)	LC95	(CI Min, CI Max)	Slope	<sup>2</sup> R	R/S ratio LC50/LC95
Carpenter	10/15/83	.0080	(.0078, .0082)	.035	(.034, .036)	2.57	.931	2.04/2.20
Mills	10/15/83	.010	(.010, .011)	.067	(.065, .069)	2.03	.920	2.55/4.21

Appendix B

Table 14A. 1983 survey site data: Mites / plant (avg. all transects)

Survey Site	Date Sampled	# Plants Examined	Diapausing Females	Active Females	Immatures	Eggs
Smith	1/12/83	200	0.005	0.000	0.000	0.000
Smith	2/3/83	300	0.010	0.000	0.000	0.000
Smith	2/10/83	300	0.000	0.000	0.000	0.000
Smith	2/16/83	300	0.000	0.000	0.000	0.000
Smith	2/23/83	250	0.004	0.000	0.024	0.012
Smith	3/4/83	250	0.000	0.000	0.000	0.000
Smith	3/10/83	200	0.005	0.000	0.000	0.000
Resetar	1/17/83	300	0.007	0.000	0.000	0.000
Resetar	1/25/83	300	0.000	0.000	0.000	0.000
Resetar	2/1/83	300	0.000	0.000	0.000	0.000
Resetar	2/14/83	300	0.000	0.000	0.000	0.000
Resetar	2/21/83	300	0.000	0.000	0.023	0.000

Table 14B. 1983 mite frequency summary

Site:	Lewis			Resetar			Smith			Bachan		
Type:	Diap.	Active	Imm.	Diap.	Active	Imm.	Diap.	Active	Imm.	Diap.	Active	Imm.
Period												
1/7 - 1/17	0.009	0.049	0.171	0.007	0.000	0.000	0.005	0.000	0.000	0.000	0.020	0.516
1/18 - 1/28	0.000	0.052	0.250	0.000	0.000	0.000	===	===	===	0.002	0.002	0.058
1/29 - 2/8	0.000	0.005	0.140	0.000	0.000	0.000	0.010	0.000	0.000	0.004	0.000	0.000
2/9 - 2/19	0.000	0.015	0.118	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.012	0.120
2/20 - 3/2	0.000	0.030	0.500	0.000	0.000	0.023	0.004	0.000	0.024	===	===	===
3/3 - 3/13	0.000	0.010	0.110	===	===	===	0.002	0.000	0.000	===	===	===

Table 14C. 1984 survey data: Mites / plant by transect

<u>Eaton site: Near summer planted strawberries</u>				
Date Sampled	Active Females	Diapausing Females	% Infested plants immatures & eggs	% Infested plants all stages
12/19/83	.06	.00	0	6
12/27/83	.02	.00	0	2
1/3/84	.02	.00	0	2
1/13/84	.14	.02	4	16
1/18/84	.16	.00	0	14
1/25/84	.04	.00	0	4
1/31/84	.74	.00	16	42
2/7/84	.34	.00	20	34

<u>Eaton site: Near apples</u>				
Date Sampled	Active Females	Diapausing Females	% Infested plants immatures & eggs	% Infested plants all stages
12/19/83	.06	.04	4	10
12/27/83	.08	.00	0	6
1/3/84	.22	.00	4	18
1/13/84	.38	.00	10	32
1/18/84	1.00	.04	NA	50
1/25/84	.82	.00	10	42
1/31/84	.98	.00	46	60

<u>Eaton site: Southern edge (opposite S.P.)</u>				
Date Sampled	Active Females	Diapausing Females	% Infested plants immatures & eggs	% Infested plants all stages
12/19/83	.08	.06	0	8
12/27/83	.02	.00	0	2
1/3/84	.00	.00	0	0
1/13/84	.00	.02	0	2
1/18/84	.02	.00	0	2
1/25/84	.00	.00	0	0
1/31/84	.14	.00	10	20
2/7/84	.08	.00	6	10

<u>Eaton site: Diagonal 1</u>				
Date Sampled	Active Females	Diapausing Females	% Infested plants immatures & eggs	% Infested plants all stages
12/19/83	.00	.04	0	2
12/27/83	.02	.00	0	2
1/3/84	.02	.02	0	4
1/13/84	.10	.00	6	8
1/18/84	.04	.02	0	6
1/25/84	.08	.00	0	4
1/31/84	.36	.00	16	18
2/7/84	.68	.00	36	36
2/17/84	1.16	.00	38	38
3/6/84	NA	NA	NA	68

Date Sampled	Active Females	Eaton site: Diagonal 2		
		Diapausing Females	% Infested plants immatures & eggs	% Infested plants all stages
12/19/83	.00	.00	0	0
12/27/83	.02	.00	0	2
1/3/84	.02	.00	0	2
1/13/84	.06	.00	0	6
1/18/84	.02	.00	2	4
1/25/84	.06	.00	2	8
1/31/84	.14	.00	12	14
2/7/84	.08	.00	16	20
2/17/84	.68	.00	26	28
3/6/84	NA	NA	NA	38

Date Sampled	Active Females	Eaton site: Canal plants		
		Diapausing Females	% Infested plants immatures & eggs	% Infested plants all stages
12/19/83	.00	.00	0	0
12/27/83	.00	.00	0	0
1/3/84	.00	.00	0	0
1/13/84	.02	.00	0	2
1/18/84	.00	.00	0	0
1/25/84	.00	.00	0	0
1/31/84	.08	.00	6	8
2/7/84	.20	.00	4	4
2/17/84	.18	.02	4	4
3/6/84	.00	.00	0	0

Date Sampled	<u>Bachan site: Near adjacent apples</u>			
	Active Females	Diapausing Females	% Infested plants immatures & eggs	% Infested plants all stages
12/20/83	3.70	.02	0	88
12/28/83	3.52	.02	0	84
1/4/84	4.42	.06	4	92
1/16/84	3.80	.02	4	96
1/26/84	5.28	.02	6	96
2/1/84	3.94	.00	NA	90

Date Sampled	<u>Bachan site: Near adjacent fallow area</u>			
	Active Females	Diapausing Females	% Infested plants immatures & eggs	% Infested plants all stages
12/20/83	.04	.02	0	4
12/28/83	.10	.00	0	8
1/4/84	.04	.00	0	4
1/16/84	.06	.00	2	8
1/26/84	.12	.02	4	14
2/1/84	.06	.00	10	16

Date Sampled	<u>Bachan site: Diagonal 1</u>			
	Active Females	Diapausing Females	% Infested plants immatures & eggs	% Infested plants all stages
12/20/83	1.90	.02	0	60
12/28/83	1.14	.02	0	34
1/4/84	1.26	.02	0	50
1/16/84	1.06	.00	2	54
1/26/84	.78	.06	6	54
2/1/84	1.84	.00	58	58
3/7/84	NA	NA	NA	84



Date Sampled	Active Females	<u>Bachan site: Diagonal 2</u>		
		Diapausing Females	% Infested plants immatures & eggs	% Infested plants all stages
12/20/83	1.32	.02	2	54
12/28/83	.78	.02	0	24
1/4/84	1.58	.02	2	42
1/16/84	.90	.06	0	38
1/26/84	.98	.02	4	36
2/1/84	.90	.00	38	50
3/7/84	NA	NA	NA	86

Date Sampled	Active Females	<u>Lewis site: Diagonal 1</u>		
		Diapausing Females	% Infested plants immatures & eggs	% Infested plants all stages
12/22/83	.02	.00	0	2
12/31/83	.02	.00	0	2
1/12/84	.62	.00	2	40
1/20/84	1.34	.00	NR	56

Date Sampled	Active Females	<u>Lewis site: Diagonal 2</u>		
		Diapausing Females	% Infested plants immatures & eggs	% Infested plants all stages
12/22/83	.04	.04	0	4
12/31/83	.00	.00	0	0
1/12/84	1.34	.00	2	46
1/20/84	2.40	.00	NR	62

<u>Lewis site: Near adjacent 1st year strawberries</u>				
Date Sampled	Active Females	Diapausing Females	% Infested plants immatures & eggs	% Infested plants all stages
12/22/83	.00	.02	0	2
12/31/83	.02	.00	0	2
1/12/84	.08	.02	0	8
1/20/84	.22	.00	4	26

<u>Lewis site: Near adjacent 2nd year strawberries</u>				
Date Sampled	Active Females	Diapausing Females	% Infested plants immatures & eggs	% Infested plants all stages
12/22/83	.16	.00	0	14
12/31/83	.16	.00	0	14
1/12/84	18.24	.00	NR	100
1/20/84	20.84	.00	NR	100

<u>Smith site: Near cauliflower/disked area</u>				
Date Sampled	Active Females	Diapausing Females	% Infested plants immatures & eggs	% Infested plants all stages
12/21/83	.00	.00	0	0
12/29/83	.00	.00	0	0
1/5/84	.00	.00	0	0
1/14/84	.00	.00	0	0
1/19/84	.00	.00	2	2
1/27/84	.02	.00	2	2
2/2/84	.00	.00	0	0
2/8/84	.02	.00	6	6
2/16/84	.00	.00	0	0
2/23/84	.00	.00	0	0
3/5/84	.02	.00	6	6

<u>Smith site: Near adjacent 1st year strawberries</u>				
Date Sampled	Active Females	Diapausing Females	% Infested plants immatures & eggs	% Infested plants all stages
12/21/83	.00	.00	0	0
12/29/83	.00	.00	0	0
1/5/84	.00	.02	0	2
1/14/84	.00	.00	0	0
1/19/84	.00	.00	0	0
1/27/84	.00	.00	0	0
2/2/84	.00	.00	0	0
2/8/84	.00	.00	0	0
2/16/84	.00	.00	0	0
2/23/84	.00	.00	0	0
3/5/84	.00	.00	0	0

<u>Smith site: Diagonal 1</u>				
Date Sampled	Active Females	Diapausing Females	% Infested plants immatures & eggs	% Infested plants all stages
12/21/83	.00	.02	0	2
12/29/83	.00	.00	0	0
1/5/84	.00	.00	0	0
1/14/84	.00	.00	0	0
1/19/84	.00	.00	0	0
1/27/84	.00	.00	0	0
2/2/84	.00	.00	0	0
2/8/84	.00	.00	0	0
2/16/84	.18	.12	4	4
2/23/84	.00	.00	0	0
3/5/84	.06	.00	4	4

<u>Smith site: Diagonal 2</u>				
Date Sampled	Active Females	Diapausing Females	% Infested plants immatures & eggs	% Infested plants all stages
12/21/83	.00	.02	0	2
12/29/83	.00	.00	0	0
1/5/84	.00	.00	0	0
1/14/84	.00	.00	0	0
1/19/84	.02	.00	2	2
1/27/84	.00	.00	0	0
2/2/84	.00	.00	0	0
2/8/84	.00	.00	0	0
2/16/84	.00	.00	0	0
2/23/84	.02	.00	0	2
3/5/84	.00	.00	2	2

# Appendix C

Table 15A. Annual cyhexatin applications (1974-1983) on first year strawberries (Driscoll spray records)  
(NF = not farmed, - = not available)

Site	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	Total	Years Farmed	Avg. Spray/Yr.
Alexander	-	-	-	-	-	-	-	-	-	-	6 = 6	6	1	6.00
Aromas	NF	NF	NF	4	4	7	5	NF	5	NF	6 = 31	6	6	5.16
Bachan	3	3	4	8	6	6+?	NF	4	4	4	10 = 52+	10	10	5.20
Beach	1	NF	4	4	4	2+?	5	4	6	2	12 = 44+	10	10	4.40
Bern	-	-	-	-	-	-	-	-	-	-	7 = 7	7	1	7.00
Borina	NF	NF	5	2	4	3	3	NF	5	NF	5 = 27	7	7	3.86
Brown	NF	4	2	6	4	8	6	8	4	3	9 = 54	10	10	5.40
Cassin	-	-	-	-	-	-	-	-	-	-	4 = 4	4	1	4.00
Connell	3	2	4	4	5	4	7	1	4	2	- = 36	10	10	3.60
Eaton	2	NF	4	2	5	1+?	5	NF	4	NF	8 = 31	8	8	3.88
Eiskamp	NF	1	1	NF	3	7	3	3	NF	3	NF = 21	6	6	3.50
Escalon	NF	NF	NF	NF	5	10	6	6	5	2	- = 34	6	6	5.67
Fabdem	3	2	4	5	5	5	5	8	5	4	NF = 46	10	10	4.60
Fagundus	NF	NF	NF	NF	NF	NF	NF	NF	5	NF	NF = 5	1	1	5.00
Fennell	NF	NF	NF	4	4	4	3	5	2	4	NF = 26	7	7	3.71
Fly	NF	NF	NF	NF	NF	NF	NF	NF	5	NF	6 = 11	2	2	5.50
Fuji	NF	NF	NF	NF	NF	NF	2	3	2	2	- = 9	4	4	2.25
Guzman	-	-	-	-	-	-	-	-	-	-	7 = 7	7	1	7.00
Hackman	NF	NF	NF	5	5	5	4	4	4	4	4 = 35	8	8	4.38
Higaki	NF	3	5	6	8	NF	5	7	6	NF	NF = 40	7	7	5.71
Kalich	2	3	4	5	4	5	5	NF	3	NF	NF = 31	8	8	3.88

Table 15A (cont.) Annual cyhexatin applications (1974-1983) on first year strawberries (Driscoll spray records)  
(NF = not farmed, - = not available)

Site	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	Total	Years Farmed	Avg. Spray/Yr.
Kane	-	-	-	-	-	-	-	-	-	-	4	= 4	1	4.00
Kobara	3	2	5	5	5	7	6	3	4	??	-	= 40	9	4.44
Lettunich	2	3	3	6	6	7	5	6	NF	5	NF	= 43	9	4.78
Lewis	NF	NF	NF	NF	NF	6	5	4	3	4	??	= 22	5	4.40
Maemura	NF	NF	NF	NF	5	7	9	6	9	NF	NF	= 36	5	7.20
Marinovich	-	-	-	-	-	-	-	-	-	-	7	= 7	1	7.00
Murikami	2	2	4	5	3	3	6	6	2	1+?	NF	= 34+	10	3.40
Pidduck	NF	NF	NF	NF	4	5	3	3	4	3	7	= 29	7	4.14
Porter	3	2	4	5	4	7	5	3	5	2	6	= 46	11	4.18
Pratt	-	-	-	-	-	-	-	-	-	-	7	= 7	1	7.00
Resetar	NF	NF	NF	NF	NF	NF	NF	NF	NF	4	3	= 7	2	3.50
Sakai	2	2	3	4	6	4	6	7	6	6	7	= 53	11	4.81
Scurich	-	-	-	-	-	-	-	-	-	-	4	= 4	1	4.00
SMBF 500	1	1	2	5	5	3	4	2	2	2	3	= 30	11	2.73
SMBF 900	1	2	2	5	5	4	4	2	3	2	4	= 34	11	3.09
Sherwood	NF	NF	NF	NF	NF	NF	NF	4	5	3	3	= 15	4	3.75
Silliman	NF	4	NF	5	3	NF	4	NF	3	3	4	= 26	7	3.71
Smith	NF	NF	NF	NF	NF	NF	4	7	3	3	4	= 21	5	4.20
Stella	2	1	NF	4	2	5	2	5	NF	4	NF	= 25	8	3.13
Westco	NF	NF	NF	NF	NF	4	6	3	6	4	-	= 23	5	4.60
Total												916	223	4.11

Table 15B. Annual formetanate applications (1981-1983) on first year strawberries (Driscoll spray records) NF # not farmed

Site	1981	1982	1983	1984	Total	Number of Yrs. Farmed	Average Sprays/Yr.
Alexander	NF	NF	NF	0	0	1	0.00
Aromas	NF	1	NF	2	3	2	1.50
Bachan	3	1	0	1	5	4	1.25
Beach	0	0	0	0	0	4	0.00
Bern	NF	NF	NF	0	0	1	0.00
Borina	NF	0	NF	3	3	2	1.50
Brown	0	2	1	2	5	4	1.25
Cassin	-	-	-	1	1	1	1.00
Connell	4	0	0	-	4	3	1.33
Eaton	NF	0	NF	1	1	2	0.50
Eiskamp	3	NF	0	NF	3	2	1.50
Escalon	2	2	0	-	4	3	1.33
Fabdem	0	2	1	NF	3	3	1.00
Fagundus	NF	0	NF	NF	0	1	0.00
Fennell	3	1	2	NF	6	3	2.00
Fly	NF	0	NF	1	1	2	0.50
Fuji	0	0	0	-	0	3	0.00
Hackman	4	2	0	1	7	4	1.75
Higaki	1	0	NF	NF	1	2	0.50
Kalich	NF	0	NF	NF	0	1	0.00

Table 15B.(cont.) Annual formetanate applications (1981-1983) on first year strawberries (Driscoll spray records) NF # not farmed

Site	1981	1982	1983	1984	Total	Number of Yrs. Farmed	Average Sprays/Yr.
Kane	NF	NF	NF	1	1	1	1.00
Kobara	3	2	1	-	6	3	2.00
Lettunich	0	NF	0	NF	0	2	0.00
Lewis	6	2	1	-	9	3	3.00
Maemura	2	0	NF	NF	2	2	1.00
Marinovich	NF	2	0	0	2	3	0.67
Murikami	0	1	1	NF	2	3	0.67
Pidduck	0	0	0	0	0	4	0.00
Porter	4	3	2	2	11	4	2.75
Pratt	NF	NF	NF	0	0	1	0.00
Resetar	NF	NF	0	0	0	2	0.00
Riverside	NF	NF	NF	1	1	1	1.00
Sakai	0	0	0	0	0	4	0.00
Scurich	NF	NF	NF	0	0	1	0.00
SMBF 500	2	0	2	3	7	4	1.75
SMBF 900	2	0	2	2	6	4	1.50
Sherwood	3	2	0	0	5	4	1.25
Silliman	NF	2	0	1	3	3	1.00
Smith	0	2	0	0	2	4	0.50
Stella	0	NF	0	NF	0	2	0.00
Westco	0	0	0	-	0	3	0.00
Total					81	83	0.98



Appendix D

Table 16A. Formetanate bioassay data on Eaton mites

Source	Test Date	LC50	(CI Min, CI Max)	LC95	(CI Min, CI Max)	Slope	<sup>2</sup> R	R/S ratio LC50/LC95
adj. nettle	1/14/84	.016	(.014, .016)	.084	(.073, .096)	2.26	.982	8.73/10.2
adj. apples	1/29/84	.016	(.015, .017)	.121	(.114, .127)	1.88	.969	8.73/14.7
actives	1/29/84	.030	(.029, .031)	.541	(.510, .574)	1.31	.886	16.4/65.6
adj. S.P.	2/6/84	.021	(.019, .022)	.462	(.423, .504)	1.22	.968	11.5/56.0
post-diapause	2/6/84	.020	(.019, .021)	.684	(.637, .735)	1.08	.904	10.9/82.9

Table 16B. Formetanate bioassay data on Bachan mites

Source	Test Date	LC50	(CI Min, CI Max)	LC95	(CI Min, CI Max)	Slope	<sup>2</sup> R	R/S ratio LC50/LC95
post-diapause	2/20/83	.0040	(.0037, .0043)	.022	(.021, .024)	2.21	.993	2.18/2.67
actives	1/19/84	.037	(.035, .039)	.941	(.864, 1.02)	1.17	.962	20.2/114.
adj. apples	1/19/84	.029	(.028, .031)	.353	(.331, .377)	1.53	.940	15.8/42.8
post-diapause	2/29/84	.032	(.030, .033)	.411	(.393, .431)	1.48	.975	17.4/49.8

Table 16C. Formetanate bioassay data on Smith mites										
Source	Test Date	LC50	(CI Min, CI Max)		LC95	(CI Min, CI Max)		Slope	<sup>2</sup> R	R/S ratio LC50/LC95
post-diapause	3/5/83	.0028	(.0012,	.0065)	.014	(.0058,	.032)	2.37	.899	1.53/1.70
adj. nettle	1/29/84	.404	(.361,	.453)	170.	(.026,	1.1 x 10 <sup>7</sup> )	.627	.786	220./20,600
post-diapause	3/11/84	.0035	(.0033,	.0037)	.018	(.017,	.019)	2.30	.922	1.91/2.18
actives	2/29/84	.0074	(.0069,	.0078)	.563	(.523,	.606)	.873	.851	4.04/68.2

<u>Table 16D. Formetanate bioassay data on Lewis mites</u>										
Source	Test Date	LC50	(CI Min,	CI Max)	LC95	(CI Min,	CI Max)	Slope	<sup>2</sup> R	R/S ratio LC50/LC95
actives	2/13/83	.010	(.0098,	.011)	.047	(.044,	.050)	2.51	.849	5.45/5.70
adj. 2nd yr.	2/13/83	.013	(.012,	.013)	.072	(.069,	.075)	2.19	.908	7.09/8.73
actives	10/13/83	.029	(.028,	.030)	.449	(.429,	.471)	1.38	.973	15.8/54.4
adj. 2nd yr.	2/6/84	.032	(.031,	.033)	.527	(.503,	.551)	1.35	.940	17.8/63.9
actives	2/6/84	.045	(.042,	.048)	1.71	(1.53,	1.91)	1.04	.964	25.0/207.

<u>Table 16E. Formetanate bioassay data on Resetar mites</u>										
Source	Test Date	LC50	(CI Min,	CI Max)	LC95	(CI Min,	CI Max)	Slope	<sup>2</sup> R	R/S ratio LC50/LC95
post-diapause	2/20/83	.0028	(.0024,	.0032)	.012	(.010,	.014)	2.61	.965	1.53/1.45

Source	Test Date	LC50	(CI Min, CI Max)	LC95	(CI Min, CI Max)	Slope	<sup>2</sup> R	R/S ratio LC50/LC95
adj. apple	1/25/84	.050	(.046, .054)	2.92	(2.40, 3.56)	.930	.955	12.7/184.
adj. nettle	1/25/84	.024	(.023, .025)	.207	(.196, .218)	1.76	.922	6.11/13.0
actives	1/25/84	.124	(.113, .136)	6.77	(4.19, 10.9)	.947	.843	31.6/426.
post-diapause	2/2/84	.0027	(.0023, .0033)	.014	(.011, .016)	2.36	.996	.687/.881
adj. S.P.	2/2/84	.090	(.081, .101)	6.00	(3.41, 10.6)	.902	.790	22.9/377.

Source	Test Date	LC50	(CI Min, CI Max)	LC95	(CI Min, CI Max)	Slope	<sup>2</sup> R	R/S ratio LC50/LC95
actives	1/25/84	.075	(.069, .082)	2.48	(1.97, 3.14)	1.08	.865	19.1/156.
adj. apples	1/25/84	.143	(.131, .157)	4.65	(3.20, 6.75)	1.09	.961	36.4/292.
post-diapause	3/1/84	.084	(.077, .091)	2.89	(2.34, 3.57)	1.07	.964	21.4/182.

<u>Table 17C. Cyhexatin bioassay data on Smith mites</u>										
Source	Test Date	LC50	(CI Min,	CI Max)	LC95	(CI Min,	CI Max)	Slope	<sup>2</sup> R	R/S ratio LC50/LC95
adj. nettle	2/2/84	.040	(.039,	.042)	1.22	(1.13,	1.32)	1.11	.875	10.2/76.7
post-diapause	2/2/84	.0077	(.0074,	.0080)	.038	(.037,	.040)	2.36	.976	1.96/2.39
actives	3/1/84	.0035	(.0031,	.0039)	.037	(.033,	.042)	1.60	.852	.891/2.33

<u>Table 17D. Cyhexatin bioassay data on Lewis mites</u>										
Source	Test Date	LC50	(CI Min,	CI Max)	LC95	(CI Min,	CI Max)	Slope	<sup>2</sup> R	R/S ratio LC50/LC95
adj. 2nd yr.	2/17/83	.035	(.033,	.037)	.246	(.229,	.263)	1.95	.871	8.91/15.5
actives	2/22/84	.033	(.031,	.034)	1.54	(1.40,	1.68)	0.983	.942	8.40/96.9
adj. 2nd yr.	2/22/84	.036	(.034,	.037)	1.06	(.994,	1.13)	1.11	.900	9.16/66.7

Appendix E

Table 18. Degree-day data for *T. urticae*

Day of Month	November'82 Heat units	December'82 Heat units	January'83 Heat units	February'83 Heat units	March'83 Heat units
1	9.9	2.3	2.6	5.3	6.0
2	12.1	1.2	1.4	3.2	6.0
3	14.1	5.8	3.1	3.8	6.0
4	12.1	5.0	2.5	4.1	6.5
5	8.1	6.3	4.2	2.7	5.5
6	5.7	1.6	3.9	4.5	4.4
7	4.5	1.6	3.6	4.5	8.5
8	2.5	4.2	2.8	4.0	13.5
9	0.4	4.7	5.1	4.4	9.0
10	2.8	3.7	9.6	6.6	9.0
11	3.2	3.8	11.0	4.9	7.0
12	6.8	1.8	9.7	6.5	8.0
13	6.2	2.8	8.0	5.1	6.5
14	6.2	1.4	9.0	5.8	---
15	6.5	2.9	8.5	4.4	
16	6.6	3.6	4.5	6.8	
17	3.9	3.4	5.1	7.8	
18	5.5	3.9	1.6	3.5	
19	4.5	6.8	1.2	4.0	
20	3.6	2.2	1.0	7.2	
21	3.8	3.5	0.0	6.0	
22	2.5	4.6	2.6	10.2	
23	6.1	0.6	5.4	5.5	
24	6.3	0.8	4.4	3.0	
25	6.4	0.8	4.5	3.0	
26	5.6	0.3	7.5	7.0	
27	2.3	3.4	3.5	6.5	
28	6.5	4.5	2.8	6.0	
29	5.5	2.2	2.9	---	
30	4.4	1.3	4.5		
31	---	1.9	5.4		

Formulas used to determine generation time and degree-days (Herbert, 1981)  
 With a developmental threshold of 10 C (50 F),

@15 C(59.0 F), T#141.3 Days(C) for females; and  $141.3 / (15 - 10 \text{ C}) \# 28.26 \text{ days}$   
 @18 C(64.4 F), T#152.3 Days(C) for females; and  $152.3 / (18 - 10 \text{ C}) \# 19.04 \text{ days}$   
 @21 C(69.8 F), T#139.8 Days(C) for females; and  $139.8 / (21 - 10 \text{ C}) \# 12.71 \text{ days}$   
 converted to Fahrenheit:  $(59.0 \text{ F} - 50 \text{ F})(28.26 \text{ days}) \# 254.3 \text{ Degree-days(F)}$   
 $(64.4 \text{ F} - 50 \text{ F})(19.04 \text{ days}) \# 274.2 \text{ Degree-days(F)}$   
 $(69.8 \text{ F} - 50 \text{ F})(12.71 \text{ days}) \# 251.7 \text{ Degree-days(F)}$

Table 19. Maximum possible T. urticae generations (T # 254.3 days(F))  
 (for hypothetical oviposition on day of planting)  
 Site      thru Nov'82    thru Dec'82    thru Jan'83    thru Feb'83    thru Mar'83

Bachan	0.39	0.76	1.32	1.89	2.27
Lewis	0.25	0.61	1.17	1.75	2.13
Resetar	0.02	0.38	0.94	1.52	1.90
Smith	0.00	0.33	0.89	1.46	1.84

<u>Table 20A. 1982-83 Rainfall data</u>					
Day of Month	November'82 Rainfall	December'82 Rainfall	January'83 Rainfall	February'83 Rainfall	March'83 Rainfall
1		0.2			1.48
2		0.02			1.02
3				0.06	0.25
4					0.16
5					
6				1.8	
7					0.54
8	0.04			0.83	
9	0.29				
10	0.83				
11					
12				0.70	
13		0.08		0.37	1.51
14					
15					
16			0.20	0.11	
17		0.07			0.80
18	0.36			0.32	0.62
19	1.59		1.54	0.04	
20		0.04			0.97
21		1.00	0.02		0.23
22	0.03	1.4			0.1
23	0.70	0.60	3.26		1.03
24				0.75	0.31
25				0.08	
26				1.4	
27			2.21	0.6	0.76
28					
29	0.79		0.80		
30	1.8		0.18		
31					0.02
Total	6.43	3.41	8.21	7.06	9.80

Table 20B. 1983-84 Rainfall data					
Day of Month	November'83 Rainfall	December'83 Rainfall	January'84 Rainfall	February'84 Rainfall	March'84 Rainfall
1					
2				.04	
3		.82			
4					
5					
6					
7	.06				
8		.01			
9	.02	.39		.32	
10	.10			.09	
11	2.85	.73			
12				.03	.08
13	.80			.29	.62
14					.05
15					
16	.13		.03	.64	
17	.30	.09			
18	.35				
19					
20	1.30				
21			.18	.14	
22		.10			
23					
24	.50	.30			
25	.80	.20			
26		1.30			
27					
28					
29					
30		.67			
31					.16
Total	7.21	4.61	.21	1.55	.91



Table 21. Monthly rainfall probabilities at the Watsonville Waterworks (1849-1980)

Return exceedence period frequency	Probability of exceeding rainfall	Jan	Feb	Mar	Sep	Oct	Nov	Dec	Annual
---	.960	0.11	---	---	---	---	---	---	---
---	.950	0.25	0.00	0.00	0.00	0.00	0.00	0.00	---
---	.900	0.79	0.22	0.34	0.00	0.00	0.00	0.47	13.27
---	.800	1.59	1.06	1.02	0.00	0.03	0.49	1.29	---
2	.500	3.67	3.08	2.64	0.00	0.69	2.06	3.47	---
5	.200	6.54	5.70	4.74	0.43	1.78	4.57	6.59	20.66
10	.100	8.39	7.33	6.05	1.00	2.55	6.30	8.63	30.40
20	.050	10.11	8.82	7.24	1.69	3.29	7.96	10.54	---
25	.040	10.64	9.28	7.61	1.93	3.53	8.48	11.14	---
40	.025	11.74	10.21	8.36	2.45	4.02	9.58	12.37	---
50	.020	12.26	10.65	8.71	2.71	4.25	10.09	12.95	---
100	.010	13.82	11.96	9.71	3.53	4.97	11.67	14.71	---
200	.005	---	---	10.78	---	---	---	---	---