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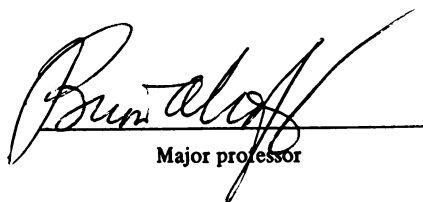
Spatial Distribution of Aphis pomi (Degeer)
and the Predator Aphidoletes aphidimyza
(Rondani) Relative to Apple Tree Growth

presented by

Duane Paul Jokinen

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SPATIAL DISTRIBUTION OF APHIS POMI (DEGEER)
AND THE
PREDATOR APHIDOLETES APHIDIMYZA (RONDANI)
RELATIVE TO GROWTH IN THE APPLE TREE

By

Duane Paul Jokinen

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ABSTRACT

SPATIAL DISTRIBUTION OF APHIS POMI (DEGEER) AND THE
PREDATOR APHIDOLETES APHIDIMYZA (RONDANI) RELATIVE
TO APPLE TREE GROWTH

By

Duane Paul Jokinen

Development of an integrated pest management (IPM) program for the apple aphid, Aphis pomi requires knowledge of host plant-pest-natural enemy relationships. In this study, growth of the apple trees and colonization by A. pomi and the cecidomyid predator Aphidoletes aphidimyza were measured on leaves by population surveys made in 1976 and 1977 in an orchard near Grand Rapids, Michigan. Stratified samples of these two species from terminals in the tree canopy (in three divisions: directional, level and inner-outer) were taken weekly. Host tree growth measurements including the number of terminal leaf primordia and leaves/terminal were also taken from each sample quadrant.

Analysis of data, using analysis of variance and linear regression indicated that A. pomi responded to actively growing terminals especially in the inner and upper quadrants of the apple crown. The distribution and relative abundance of A. aphidimyza, was closely coincidental with the aphid population distribution in the apple tree.

Duane Paul Jokinen

Results of these experiments are discussed in relation to the physiological characteristics of apple crown growth. The potential role of A. aphidimyza in an IPM program for the control of the apple aphid is discussed as well as several potential research objectives for further studies.

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Finally, I would like to acknowledge Drs. Dean Haynes and Thomas Edens for their contributions. By providing a source of intellectual challenge in a multitude of areas they have contributed significantly to my development.

Preface

The appendices included at the end of this thesis are to facilitate the reconstruction of the data summaries provided in this thesis as well as document other associated research efforts initiated on A. pomi and A. aphidimyza. They were generated from computer files made of the data taken in 1976 and 1977. These files are maintained on magnetic tape at Michigan State University Computer laboratory facility.

Throughout this thesis the term "apple canopy" is used to describe the upper foliage area of an individual tree. However, "canopy" is correctly defined as the upper most foliage level of a forest, and in retrospect "crown" would be a more appropriate term to designate this area of the tree.

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INTRODUCTION

Integrated pest management (IPM) systems for primary and secondary pests of apple utilize a variety of control tactics (Croft 1975, Huffaker and Croft 1976). Currently, biological control of primary pests is limited (Hagley 1974) and apple IPM systems use monitoring to predict activity of these species. For example, adult male codling moth (Laspeyresia pomonella Linn.) activity can be assessed using traps baited with synthetic sex pheromones and adult apple maggot (Rhagoletis pomonella Walsh) population activity can be assessed by bait and color attractants (Howitt and Conner 1964, Prokopy 1972). Population from these sampling tools when coupled with computer based phenology models (e.g. Riedl and Croft 1978, Welch et al. 1978) provide forecasts of critical temporal relationships between pest-plant stages which assist in the implementation of control procedures. As chemicals are the primary control method for these pests, improved timing of tactics eliminates unnecessary sprays, reduces costs and limits the amount of pesticides placed into the environment.

Secondary pests of apple, primarily the foliar feeding species such as Aphis pomi Degeer (the apple aphid) Panonychus ulmi (Koch) (the European red mite), and Typholobia pomaria McA. (the white apple leafhopper), often reach damaging population levels in the orchard. These species with intrinsically high reproductive rates can develop resistance

rapidly to most conventional pesticides. They are, therefore, difficult to control by chemical means alone, and IPM programs have stressed development of alternative cultural or biological controls.

Use for control of natural enemies attacking secondary pests becomes feasible when the pesticides applied for control of primary (or direct) fruit pests are minimally disruptive to these beneficial insects. This can be accomplished by the use of physiologically selective compounds or by minimizing the temporal and/or spatial contact of pesticides with these natural enemies. Distribution studies and sampling procedures for secondary pests and their natural enemies provide population estimates from which the potential for biological control or the need for chemical control can be determined. In this study, the spatial and temporal occurrences of A. pomi and the cecidomyiid predator Aphidoletes aphidimyza relative to growth features of the apple tree were investigated.

LITERATURE REVIEW

The Biology of *Aphis pomi*

The biological characteristics of *A. pomi* have been reported in several early publications (i.e. Baker and Turner 1916, Lathrop 1923 and 1928, Matheson 1919, Peterson 1918). The aphid overwinters as a diploid egg (black in color 0.5mm in length), primarily on shoots or one year old terminal growth in the apple canopy. Eclosion varies with latitude from the first week in April in Virginia (Baker and Turner 1916) to mid or late April in New York (Matheson 1919). Peterson (1916) correlated increased egg to nymph survival with increased humidity at the time of eclosion. In their study the average survival through egg hatch was roughly 25%.

A. pomi has four nymphal instars, the morphology of each is described in Baker and Turner (1916). The mature fifth instar female is wingless, parthenogenic, and viviparous. This stem mother produces nymphs that as adults are apterous (without wings) or alate (with wings). The ratio of apterous to alate forms varies throughout the summer; the environmental and biological factors regulating this process in aphids has been discussed in Lees (1961) and Johnson (1960, 1965, 1966). Alate production provides a ready source of migrant aphids throughout the season within and between orchards.

Lathrop (1923) estimated 5°C . (41°F) to be the development threshold for A. pomi. In 60 experiments during a single season, he followed the development of aphid nymphs, 24 hours old or less, to maturity and recorded first nymphal reproduction. From the max-min temperatures reported by Lathrop (1923), and using the method of Baskerville and Emin (1969) for calculating cumulative degree days, a mean generation development time is 230.0 degree days (Jokinen, unpublished analysis). Adult longevity was estimated to be 19.4 days (Standard Error = 4.6) for aphids in the second to 12th generations (Matheson 1919). The mean daily reproduction capability is 2.96 nymphs for the same generations (Matheson 1919). A total of 12-17 generations were observed in New York (Matheson 1919).

In late September haploid (XO) males and diploid females (XX) are produced in the orchards. Following mating oviposition of overwintering eggs occurs about 5 to 7 days later. Little information has been collected on the longevity of these adult forms, however, one early study (Baker and Turner 1916) indicated that it is ca. 25 days. Specht (personal comm.) noted the survival of both sexes of the aphid until November in Nova Scotia. Baker and Turner (1916) report a mean of 4.75 eggs laid per female. Westigard and Madsen (1964) reported that 90.9% of all eggs observed on 40 terminals were laid in the top 20.0 inches of the terminals.

Nutritional and varietal differences of the apple host in relation to infestations of A. pomi have been described. Takeda et. al. (1968) reported on the nutritional quality of leaves infested by A. pomi, and noted that leaves with high nitrogen content, low carbohydrate levels, and young leaves having particular amino acid contents were the most susceptible to aphid attack. Briggs and Alston (1968) noted resistance to A. pomi in the apple cultivars McIntosh, Baldwin, Northern Spy and Courtland. Wildbolz (1964) suggested that resistance or susceptibility in apple cultivars to A. pomi may be related to the changing practices of pruning and fertilization which influence growth patterns. He suggested that temporal differences between aphid egg eclosion in the spring and varietal variation in the initiation of tree growth could influence population levels.

Specht (1970, 1972) studied A. pomi populations on one year old trees in environmental cabinets. Growth and decline of aphid numbers correlated well with the growth activity of the trees. The distribution of aphids on terminal leaves varied throughout the study which he hypothesized was a result of the changing physiological condition of the leaves. Westgard and Madsen (1965) in studying three and ten year old apple trees in California, noted that the physiological condition of the tree foliage was a major factor in influencing aphid densities.

Damage to apple from aphid populations includes decreased terminal growth, extensive leaf curl, and copious honeydew accumulation on leaves and fruit (Oatman and Legner 1961). A. pomi, by intercellular penetration, feeds directly on the leaf phloem removing plant nutrients. Each nymphal instar makes a minimum of five feeding punctures (Heriot 1944). The collapse of surrounding cells and subsequent leaf curl reduces photosynthetic capabilities of the leaf. Quantification for the rate of plant nutrient removal has not been completed for A. pomi, however, a methodology for estimating such parameters has been developed for Drepanosiphum platanoides (schr.), the sycamore aphid (Dixon 1971).

Much of the previous literature on economic thresholds and control of A. pomi, as for many other orchard pests, emphasizes preventive or scheduled chemical control methods (Forsythe and Hall 1973, Glass and Chapman 1955, Pielou and Williams 1961). Madsen et. al. (1961) controlled damaging aphid populations (where aphid honeydew was found on fruit) when aphid densities greater than 5.0 were found on the seventh leaf of rapidly growing terminals. This indice was revised (Madsen et. al. 1975) and chemical control implemented when 50% of sampled leaves were infested; these samples contained the third, seventh, and fifteenth leaves from ca. 20 rapidly growing terminals.

Biological and Environmental Factors Influencing
Aphis pomi

Assessment of mortality factors influencing the population dynamics of aphids is notably difficult due to their unique biological features. Specifically, overlapping viviparous generations, the telescoping of generations within individuals, varying production of alates, and their short developmental times limits the ability to separate or quantify the impact of mortality agents (van Emden 1963). Several studies, reviewed below, have contributed the identification and quantification of environmental or biological factors influencing A. pomi.

LeRoux (1959) evaluated the effect of frosts, heavy rainfall, and aestival temperatures greater than 90°F on aphid populations in Quebec. He indicated a single heavy frost in late May killed 96.5% of aphids populations in two separate orchards. Five rainfalls caused an average of 54.2% mortality. A three day period with maximum temperatures averaging 90.0°F in mid-June reduced populations an average of 71.5%.

The natural enemies of A. pomi have been studied in both Europe and the United States. Bonnemaïson (1972) identified two non-specific fungi attacking A. pomi in France--Entomophorales aphidus (Hoffman) and E. planchonina Cornu. Both required dense host populations and favorable

environmental conditions to reach epizootic proportions and exert biological control. The only known specific parasite of A. pomi is Trioxys angelicae Hal. (Hymenoptera: Braconidae) which is found in Europe and Asia Minor (Evenhuis 1963, Stary 1966, and Cierniewskii 1973). Parasitism of A. pomi in the U.S. has only been reported from California (Oatman and Legner 1961, Westigard and Madsen 1965) by an Aphidus sp. (Hymenoptera: Braconidae) that parasitized less than 1% of the aphids. Parasitism appears to be of minor significance in regulating A. pomi populations worldwide.

Apple aphid predation by species of the families Coccinellidae (Coleoptera), Chrysopidae (Neuroptera), and Syrphidae (Diptera) is well documented (Hodek 1966, Niemczyk 1977, Setti 1973, etc.). Although effective predators, these natural enemies often are general feeders and require large numbers of hosts to develop, have few generations per year, and often experience high mortality from orchard pesticides (Croft and Brown 1975). Thus, pesticides usually limit their effectiveness in controlling aphid populations in commercial orchards.

Setti (1973) evaluated the effectiveness of syrphid predation in Italian orchards and noted a complete absence of these predators where sprays were applied. The effectiveness of aphid control in non-sprayed orchards varied as the syrphid species were irregular in their occurrence and abundance. The presence of Chrysopa carnea (Steph)

(Chrysopidae) in orchards in Poland was related more to the occurrence of spider mite populations than either A. pomi or Dysaphis plantegina (Passerini) (the rosy apple aphid) populations (Niemczyza 1977). Further he concluded that the limited control of the apple aphids by C. carnea, in comparison with its effective control of field crop aphids, may be related to differences in the apple canopy microclimate, orchard pesticide use, and the high mobility of the adult predators allowing dispersal to other crops.

Holdsworth (1970) studied the predators of A. pomi in Ohio, citing the species Metasyrphus weidemanni Johnson (Diptera: Syrphidae), Leucopis sp. (Diptera: Chamaemyiidae), Anatis quindecimpunctata Oliver (Coleoptera: Coccinellidae), Chrysopa sanguinea (L.) and C. nigricornis Burmeister (Neuroptera: Chrysopidae) as occasional predators of A. pomi. Primary predators were Orius insidiosus Say (Hemiptera: Anthocorridae) and Aphidoletes cucumeris (Lintner) (Diptera: Cecidomyiidae). Holdsworth did not evaluate the control potential for any of these species.

In summary, the literature contains substantial biological information on A. pomi, the description of associated natural enemies, and some information of the environmental factors regulating aphid populations. Relationships between A. pomi and the apple host have been identified, however, detailed information on the spatial and temporal

distribution of A. pomi and its natural enemies are limited.

The Biology of Aphidoletes aphidimyza

Recent taxonomic revisions of the aphidophagous species in the family Cecidomyiidae (Harris 1966 and 1973, Gange 1973) have reduced species synonymy aiding in the identification of their biologies and prey hosts. Specifically, Aphidoletes aphidimyza (Rondani) is the accepted name for Cecidomya sp., Phaneobremia sp. and A. cucumeris which have been reported as predators of A. pomi (Bonnemaison 1972, Evenhuis 1961, and Holdsworth 1970). The prey range of A. aphidimyza is exclusively limited to aphids; a list of over 60 host species was provided by Harris (1973).

Utilization of A. aphidimyza for control of glasshouse aphids has been extensively developed in western and eastern Europe (Markkula 1973, Bondarenko 1975). This use of A. aphidimyza has required study of its life cycle to facilitate rearing and mass release of pupae and adults. Studies of aphid-A. aphidimyza interaction have contributed to improving glasshouse aphid control (El-Titi 1973 and 1974, Uygun 1971). The life cycle of this predator in glasshouse crops has been reviewed by Markkula et. al. (1976). Adams (1977) discussed limited aspects of its life cycle in Massachusetts apple orchards.

A. aphidimyza overwinters as pupae in the upper soil layer (1.0-2.5cm) beneath the host plant, emerging from May

to June in apple orchard of Massachusetts (Adams 1977). In glasshouses, emergent males live approximately 7.0 days and the females 9.25 days (El-Titi 1974). Following copulation the adult female lays 50-70 orange eggs ($0.3 \times 0.09\text{mm}$) singly or in clusters from the third to the ninth days. Egg development under laboratory conditions ($21.0^{\circ}\text{C} \pm 1^{\circ}$ and 85-95% RH) is about 2.5 days (Uygen 1971). Egg survival rates have not been determined, however, Uygun (1971) noted improved egg maturation when females had previously been provided with aphids and honeydew. El-Titi (1973) evaluated ovipositional responses to varying host densities in glasshouses. He reported that the mean number of eggs laid per female was proportional to the number of aphids per plant (Brassica oleracea).

There are reported to be three larval instars of A. aphidimyza which are orange in color and range from 0.4 to 3.4 in length (Harris 1973). Development of larvae at 21°C when supplied with 25.0 hosts per leaf averaged 4.0 days, survival was estimated to be roughly 75% and the mean number of aphids killed/larvae during development was 22.5 (Uygun 1971). In feeding the larvae inserts its mouthparts into interstitial membranes on the aphid's abdomen or legs. After injecting a paralyzing enzyme (phenoloxidase) from the salivary glands, the aphid gut contents are liquified and removed (Mayr 1975). The number of aphids consumed or killed per predator larvae varies with prey size and density.

Increasing the prey size (age) decreases the number of prey required for development; i.e. 5.4 Myzus persicae adults vs. 21.1 nymphs (at 21.0°C) (Uygun 1971). Several authors (Dunn 1949, George 1957, Nijveldt 1969) have reported that the number of aphids killed per larvae ranges from 5.0 to 100.0. Wildbert (1972) has studied larval searching and has related mortality to prey density. Larval mortality is also influenced by the ability of the adult females to effectively find hosts and oviposit eggs close to the colonies (El-Titi 1974). The final larval instar drops to the soil and forms a small (1.8 x 0.7mm) puparium; emergence of the adults in the laboratory occurs from 12 to 14 days later (Wildbert 1972). A total generation development time in the laboratory is 22.5 days at 21°C (Uygun 1971).

Populations of A. aphidimyza have been tested for tolerance to insecticides and acaricides (Adams 1977, Markkula and Tittanen 1976). Adams (1977) reported high egg mortality from the carbamate carbaryl and the organophosphate (OP) phosphamidon. Larval mortality was greatest from the OPS, phosphamidon and demeton-methyl and least from endosulfan. Differential mortality to the O-P azinphosmethly in population from an unsprayed orchard (highest) and from a commercial orchard (lowest) was also detected. Low mortality to six acaricides for a laboratory colony A. aphidimyza was reported by Markkula (1977).

In summary, the biology and life cycle of A. aphidimyza have been studied extensively. Most experiments were conducted primarily to facilitate use of the predator for biological control of glasshouse aphids. Detailed assessments of orchard populations feeding on A. pomi have not been made. This information is required to utilize A. aphidimyza more effectively as a biological control agent for aphids on apple.

METHODS

Sampling Procedures

Populations of A. pomi and A. aphidimyza were sampled weekly in a single orchard block during the summers of 1976 and 1977 at the Graham Experiment Station, near Grand Rapids, Michigan. The block sampled contained 40 Red Delicious trees. These trees were bound by a 30 tree block of Northern spys to the north and by a 60 tree block of Rome and Jonathan trees to the south.

Cultural practices used in the block were similar to those applied in commercial orchards. Pruning during the dormant season included the removal of the previous season's shoot growth in the inner portion of the tree and limited pruning of weakened or non-bearing limbs. Spray schedules and the pesticides applied for control of pests other than aphids for 1976 and 1977 are given in Table 1. The pesticides applied were selected on the basis of their minimal toxicity to populations of the European red mite predator Amblysius fallacis (Garman) (Croft 1976) and Aphidoletes aphidimyza (Adams 1977).

The plant sample unit chosen was an entire terminal shoot. These were defined as terminals with axillary or terminal buds formed in the previous season with approximately 10 leaves or more (Vyvyan and Evans 1932). The base

Table 1. Spray schedule for Gibson experimental orchard block at Graham Experiment Station, Grand Rapids, Michigan 1976 and 1977.

1976

Date

Chemical compounds per 100/gal water

4-15	Benlate 2 oz. and 1 gal. Superior oil
4-19	Benlate 2 oz. and 1 gal. Superior oil
4-30	Cyprex $\frac{1}{2}$ lb.
5-07	Cyprex $\frac{1}{4}$ lb.
5-19	Cyprex $\frac{3}{8}$ lb. and $\frac{1}{2}$ lb. Guthion and 2 oz. Plictran
5-27	Cyprex $\frac{1}{4}$ lb.
6-02	Cyprex $\frac{1}{4}$ lb. and $\frac{1}{2}$ lb. Guthion
6-14	Cyprex $\frac{1}{4}$ lb. and $\frac{1}{2}$ lb. Guthion
6-29	Cyprex $\frac{1}{4}$ lb. and $\frac{1}{2}$ lb. Guthion
7-13	Cyprex $\frac{1}{4}$ lb. and $\frac{1}{2}$ lb. Guthion
7-26	Cyprex $\frac{1}{4}$ lb. and $\frac{1}{2}$ lb. Guthion
8-10	Cyprex $\frac{1}{4}$ lb. and $\frac{1}{2}$ lb. Guthion
8-24	Cyprex $\frac{1}{4}$ lb. and $\frac{1}{2}$ lb. Guthion

1977

Date

4-14	Cyprex $\frac{3}{8}$ lb. and 1 gal. Superior oil
4-19	Cyprex 1 $\frac{1}{2}$ lbs. and $\frac{1}{2}$ lb. Karathane and $\frac{1}{3}$ lb. Systox
4-25	Cyprex $\frac{1}{2}$ lb.
5-06	Cyprex $\frac{3}{8}$ lb. and 2 pts. flowable Sulfer
5-16	Cyprex $\frac{3}{8}$ lb. and $\frac{1}{2}$ bl. Guthion and $1\frac{1}{2}$ pts. Flowable Sulfer
5-25	Cyprex $\frac{3}{8}$ lb. and $\frac{1}{2}$ lb. Guthion
6-07	Cyprex $\frac{3}{8}$ lb. and $\frac{1}{2}$ lb. Guthion
6-24	Cyprex $\frac{3}{8}$ lb. and $\frac{1}{2}$ lb. Guthion
7-05	Cyprex $\frac{3}{8}$ lb. and $\frac{1}{2}$ lb. Guthion
7-19	Cyprex $\frac{3}{8}$ lb. and $\frac{1}{2}$ lb. Guthion
8-03	Cyprex $\frac{3}{8}$ lb. and $\frac{1}{2}$ lb. Guthion
8-17	Cyprex $\frac{3}{8}$ lb. and $\frac{1}{2}$ lb. Guthion
8-31	Cyprex $\frac{3}{8}$ lb. and $\frac{1}{2}$ lb. Guthion

of these terminals are demarcated by a whorl of leaves or by growth rings (Pool 1973). Secondary terminals, from axil leaf buds of the current season's growth were few in number and not sampled in this study.

From each terminal the number of leaves, leaf primordia, aphids, and cecidomyiids were recorded. Leaf primordia were defined as the number of unopened immature leaves clustered at the apex of the terminal. Visual counts of primordia ranged from 0-4, which corresponds to increasing terminal growth activity. The number of leaves per terminal was recorded from the top of the shoot to either the first growth rings or to the whorl of leaves.

During 1976 10 randomly selected trees in the orchard were chosen on June 3rd and in each a total of 20 terminals were tagged for repeated observation throughout the season. In each tree 5 actively growing terminals from 2 directional axis (N-S or E-W) and in lower and upper tree canopy levels were sampled per tree. In each axis terminals were selected from the inner most of the tree canopy to the outer periphery of the tree. The lower canopy ranged from 4 to 7 feet high and the upper canopy from 7 to 12 feet high. At each site on each date the number of leaf primordia, leaves and terminal length was recorded. Aphid and predator numbers on each leaf were recorded from the shoot apex to the base. Five of the 10 trees were sampled on alternate weeks.

The sampling design for 1977 was expanded and improved by randomly choosing up to 10 trees in the block on each sample date. In each tree, counts from 3 terminals located in the inside, middle and outer region of the canopy, in 4 directions and in the lower and upper tree canopy levels were sampled. As in 1976, the plant variables measured in 1977 included leaf primordia and leaves.

Aphid counts in each subsample included all stages found on leaf primordia, lower and upper leaf surfaces, petioles and on stems between leaves. While aphids were counted cecidomyiid larval locations were noted, and upon completion of the aphid counts, the entire terminal was again viewed to count cecidomyiid larvae.

Several factors influencing cecidomyiid larval population sampling should be noted. Because of first instar larval size and their tendencies to be hidden beneath larger aphids, primarily second and third instar larvae comprised the counts. Uygun (1971) has shown limited movement of larvae (from eclosion to third instar) from the site of oviposition, and as such the counts and distribution studies made in this study were considered to be representative of all instars even though counts of first instars were limited. Excessive apple leaf curl can also bias counting methods, however, in this study aphid densities were not exceedingly high and only few apple leaves were curled in 1976 or 1977.

Methods of Analysis

For data analysis the influence of tree growth on the pattern of insect infestation was compared in 1976 and 1977. Mean values per terminal for leaf primordia and leaves relative to canopy direction, canopy position (inside to outer periphery) and canopy level were compared on a degree day (dd) scale (Baskerville and Emin 1969, 5°C base threshold). Corresponding aphid and cecidomyiid densities per terminal in each of the quadrats were tested for significant differences on each sample date by analysis of variance (ANOVA). Prior to ANOVA, insect counts were transformed by $\log(X+1)$ counts. This is an adequate transformation for populations which follow a negative binomial distribution (Taylor 1970, Appendix F).

To determine the type of terminal growth preferred by aphids, 2 growth features were evaluated and compared. On each sample date aphid counts in classes of terminals separated first by leaf primordia (0-4) and then by 6 leaf classes (10 leaves/class) were tested by ANOVA. On dates where significant differences were detected, a modified least significant difference test was used to rank means. To compare growth characteristics between 1976 and 1977 leaf primordia and leaves per terminal for both years were plotted against dd and fit to log and power curves by least squares analysis.

RESULTS

In 1977 as estimated 279 ± 80.3 ($\bar{x} \pm \text{SE}$) terminals and 379 ± 141.6 terminals per tree were present in the lower and upper apple canopy quadrats in the study orchard respectively. From gross observations there appeared to be no difference between 1976 and 1977 in terminal growth densities in the orchard. The preliminary data taken in 1976 is described first to show the general features of tree growth and aphid population activity. Figures 1a-c summarize the 1976 data, showing means per terminal for leaf primordia, leaves and aphids in the various quadrats of the apple canopy.

Leaf primordia per terminal declined rapidly in early season in the upper and lower quadrants. However, the mean for the upper quadrat was initially greater than the lower quadrant by ca. 1.0 leaf primordia/terminal and remained greater through the season (Figure 1a). The appearance of new leaf primordia ceased at approximately 2400 dd in the lower quadrat, while in the upper quadrat at ca. 2800 dd. Leaf numbers were roughly equal in both canopies on the first sample date, thereafter leaves were added more rapidly in the upper quadrat (indicated by the slope in Figure 1b). The rate of leaf addition slowed at 1900 dd in the lower canopy and at 2550 dd in the upper canopy. Roughly 7.0 and 18.0 leaves were added per terminal in the lower and upper quadrats over the entire season.

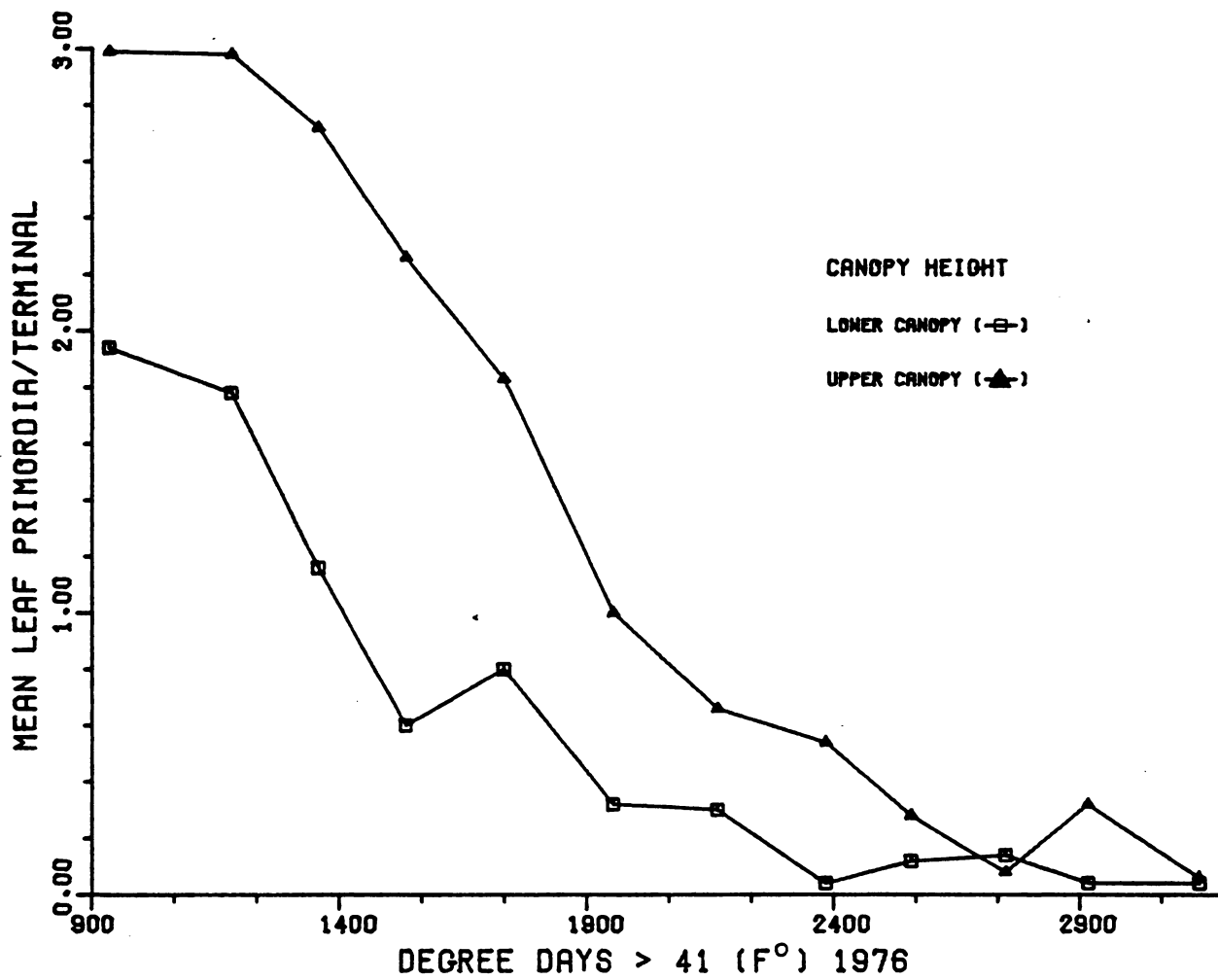


Figure 1a. LEAF PRIMORDIA MEANS IN CANOPY LEVELS (1976).

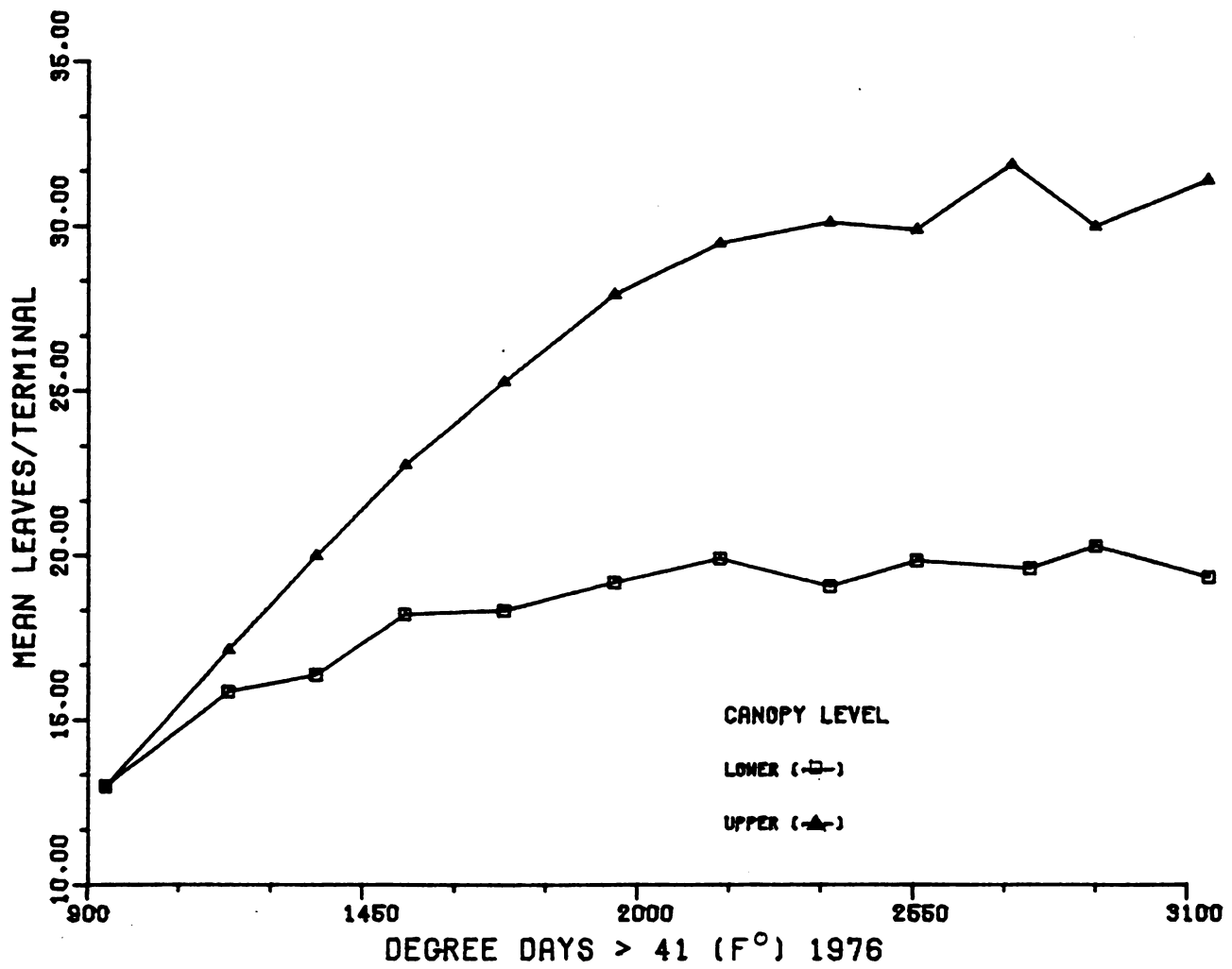


Figure 1b. LEAF MEANS IN CANOPY LEVEL (1976).

Aphid densities in 1976, were greater in the upper quadrat of the tree at all sample dates (Figure 1c). A single peak of the population was observed at 1400 dd. At peak density the mean number of aphids/terminal in the lower quadrat was 186.54 and in the upper quadrat 433.02. (Figure 1c).

Figures 2a-f illustrate the 1977 mean densities per terminal for leaf primordia and leaves from 3 stratified sample types. Means per terminal in the lower and upper canopy levels, in the inner, middle, and outer canopy positions, and in the four directional axis are depicted. These three stratifications are also used in the presentation of the spatial distributions of both A. pomi and A. aphidimyza (Figures 3a-f).

The mean number of leaf primordia per terminal greatest in the upper quadrat of the tree until 22 dd; thereafter, the upper and lower levels were about equal in numbers (Figure 2a). The decline of upper canopy leaf primordia began 200 dd later than in the lower canopy. Decreasing numbers of leaf primordia were recorded from the inner to outer periphery of the apple tree (Figure 2b) at all sample dates in 1977. Little difference was noted in the number of leaves/terminal for each directional component (Figure 2c).

Leaf addition to terminals was most rapid during early season in all canopy division (Figure 2d-f). Lower canopy growth, as observed through increase in mean leaf numbers,

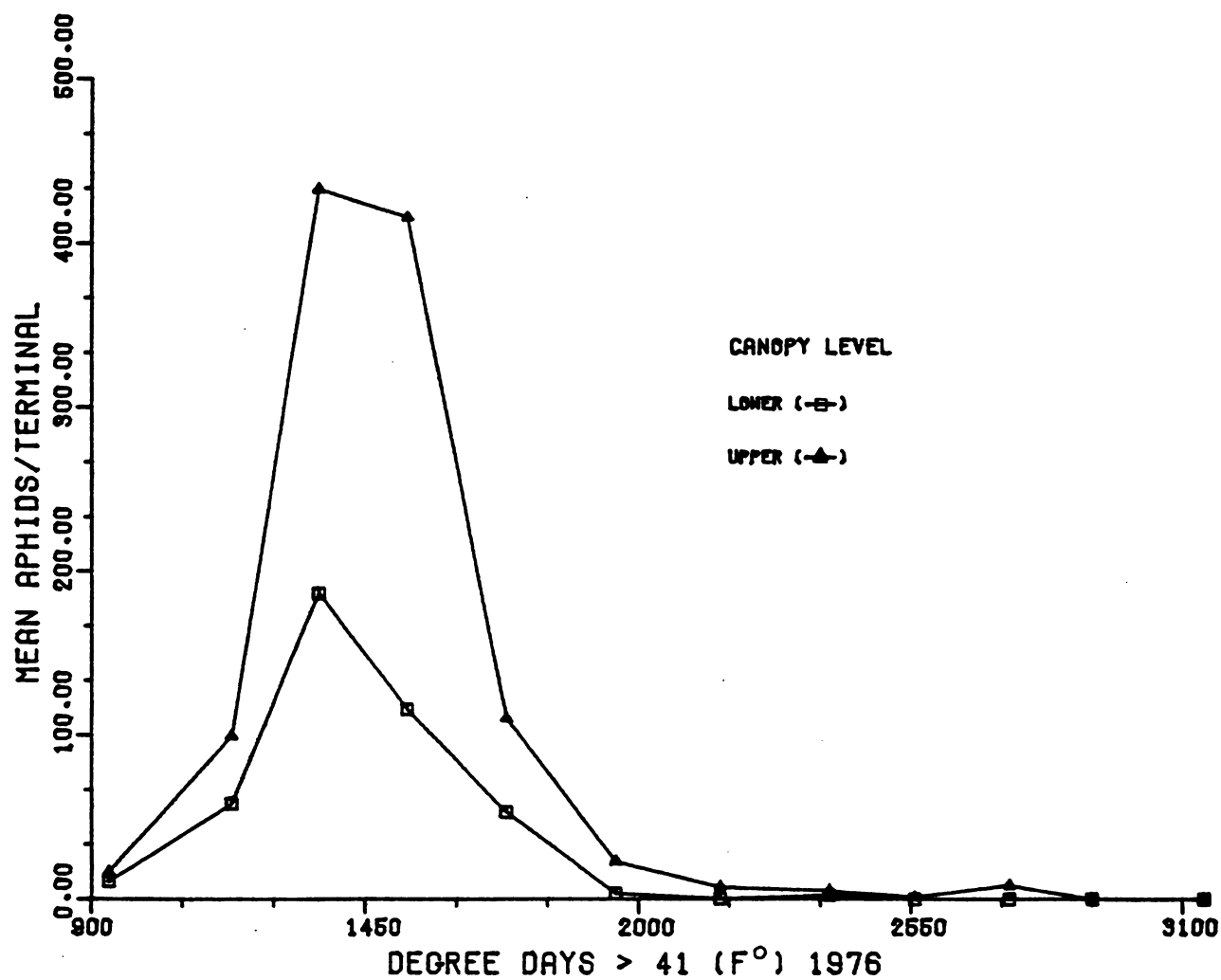


Figure 1c. APHID MEANS IN CANOPY LEVEL (1976)

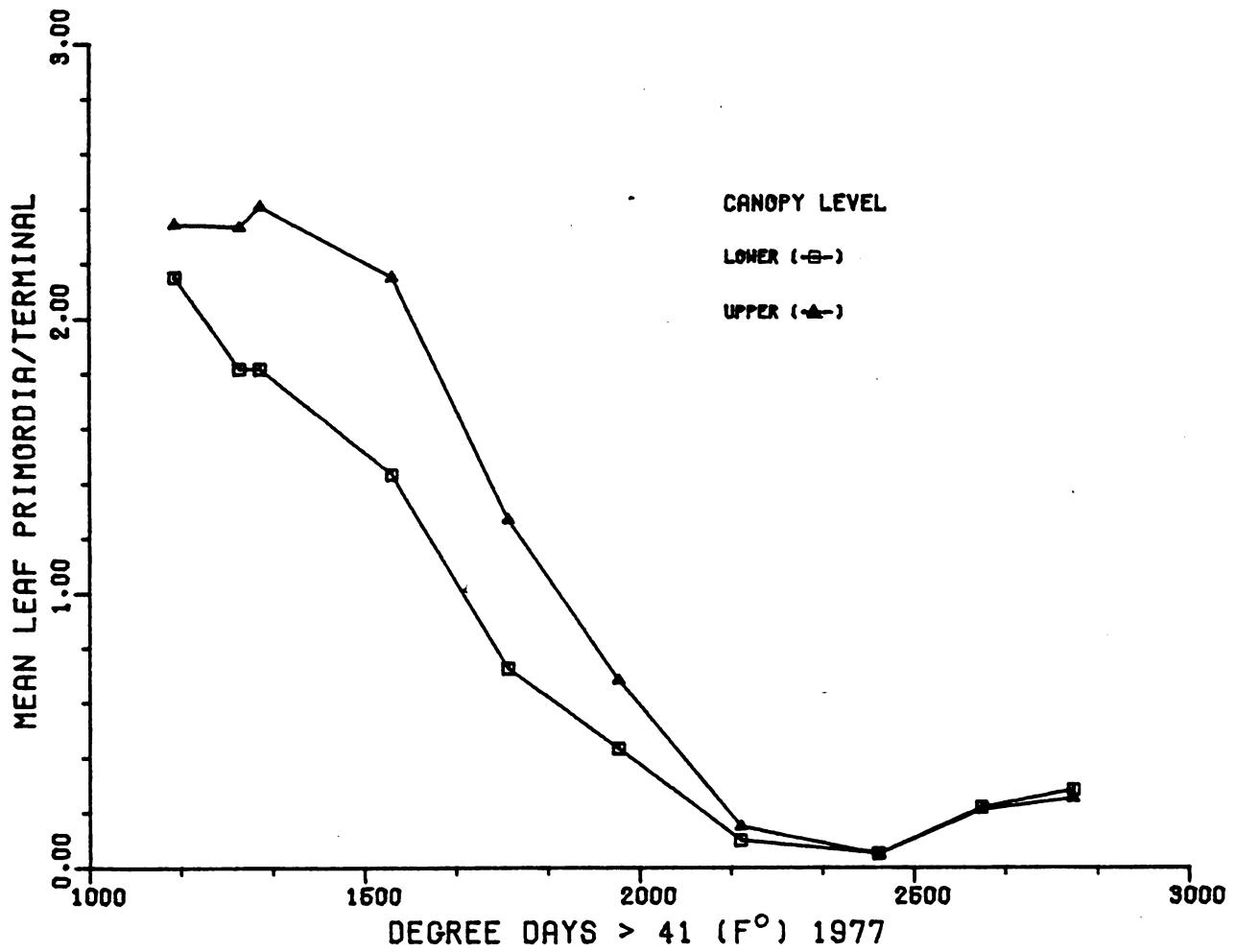


Figure 2a. LEAF PRIMORDIA MEANS IN CANOPY LEVELS

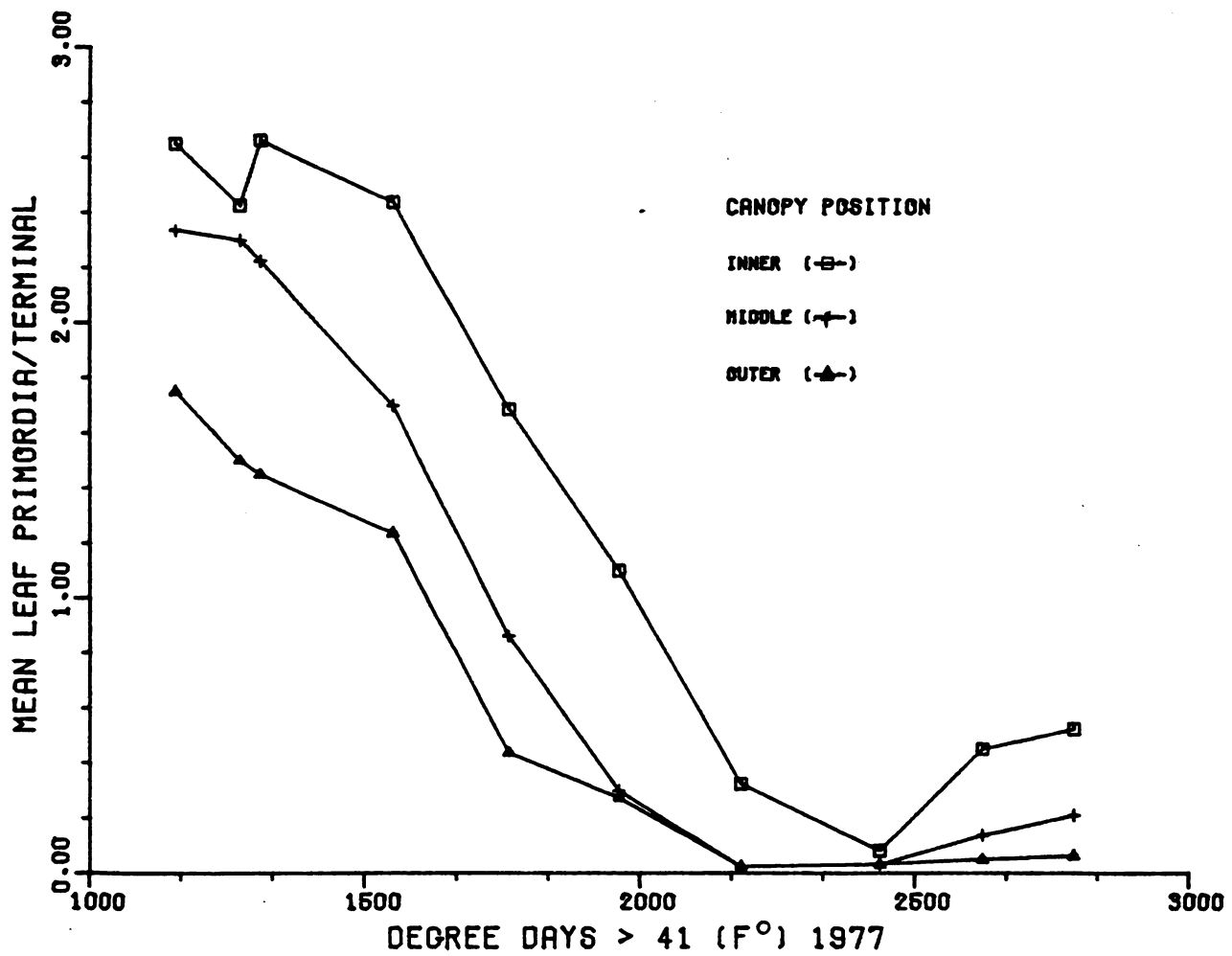


Figure 2b. LEAF PRIMORDIA MEANS IN CANOPY POSITION

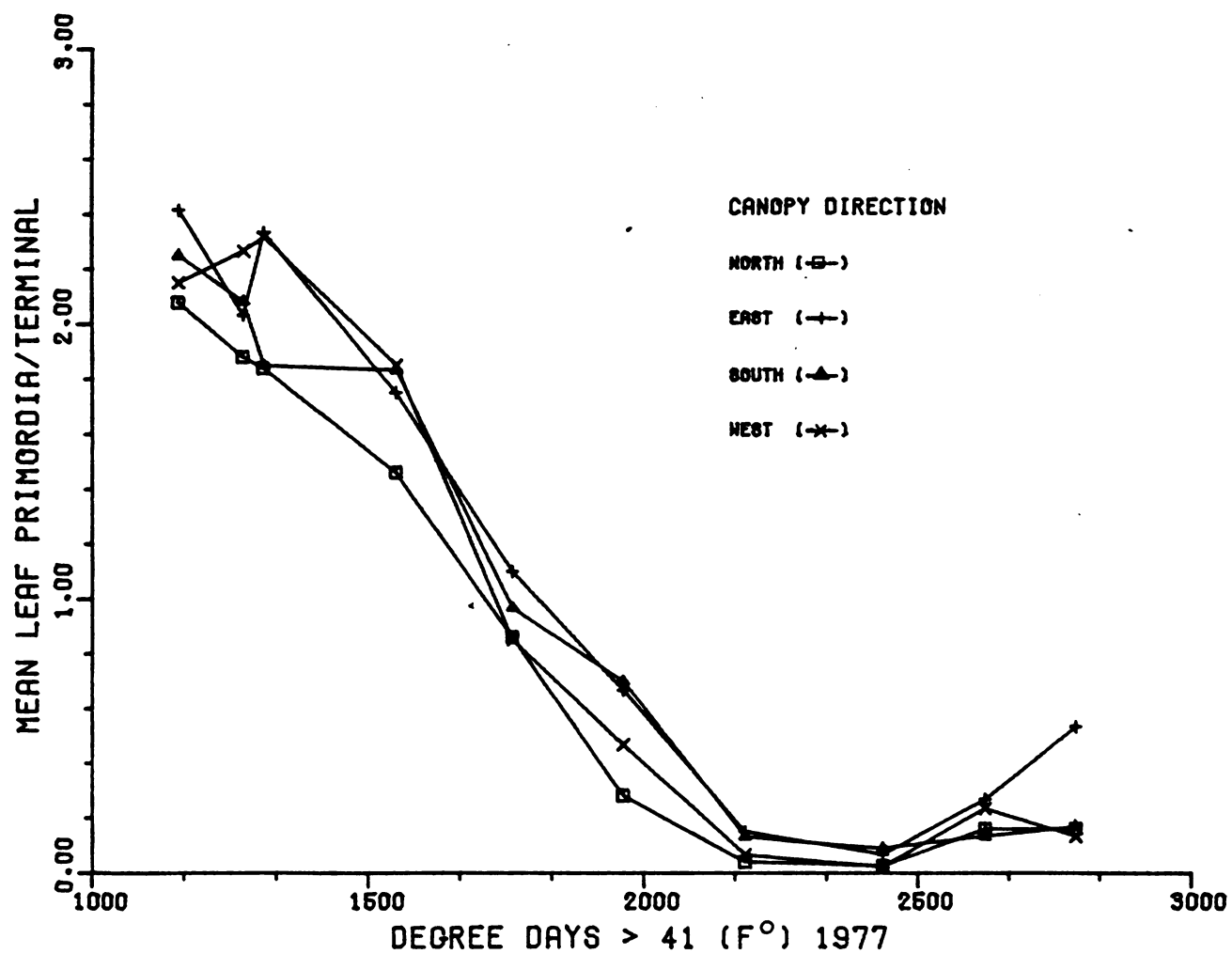


Figure 2c. LEAF PRIMORDIA MEANS IN CANOPY DIRECTIONS

terminated at roughly 1600 dd. Upper canopy growth continued until roughly 2500 dd (Figure 2d). The relative numbers of leaves added during the season in these two regions were 6.28 and 10.03 per terminal. The inner, middle, and outer canopy positions showed cessation of growth at 2700, 1900, and 1700 dd (Figure 2e), respectively. The numbers of leaves added in these positions over the growing season were 12.20, 7.40, and 3.76. As with leaf primordia, directional differences in leaf addition were not observed in 1977 (Figure 2f).

Figures 3a-f summarize the data on aphid and cecidomyiid population densities in all canopy divisions on each sample date. ANOVA procedures were used to test significant differences in populations within each division. Where differences ($\alpha=0.01$) existed the largest mean is starred (note: there were no significant differences in canopy directions) (see Table 2). Two population peaks were observed in 1977 for A. pomi and A. aphidimyza. In relation to the previously described growth patterns of the tree, there was a highly correlated aphid response. Four of the ten sample dates showed a significant difference in aphid means for lower and upper canopy divisions. These four dates also correspond with peaks of growth of the apple host in these levels and the magnitude of the peaks reflect the differences in growth activity. The first peak of aphid

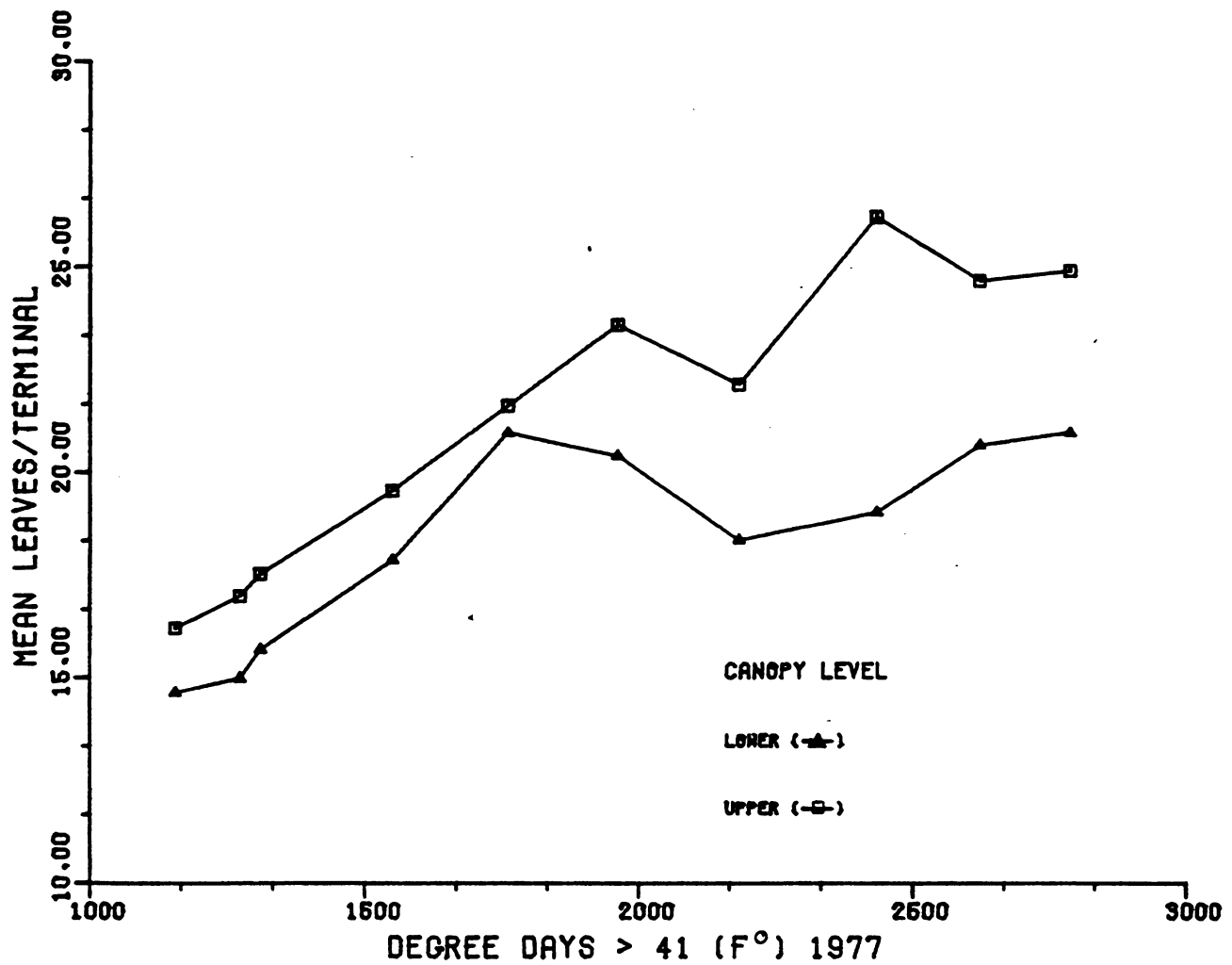


Figure 2d. LEAF MEANS IN CANOPY LEVELS

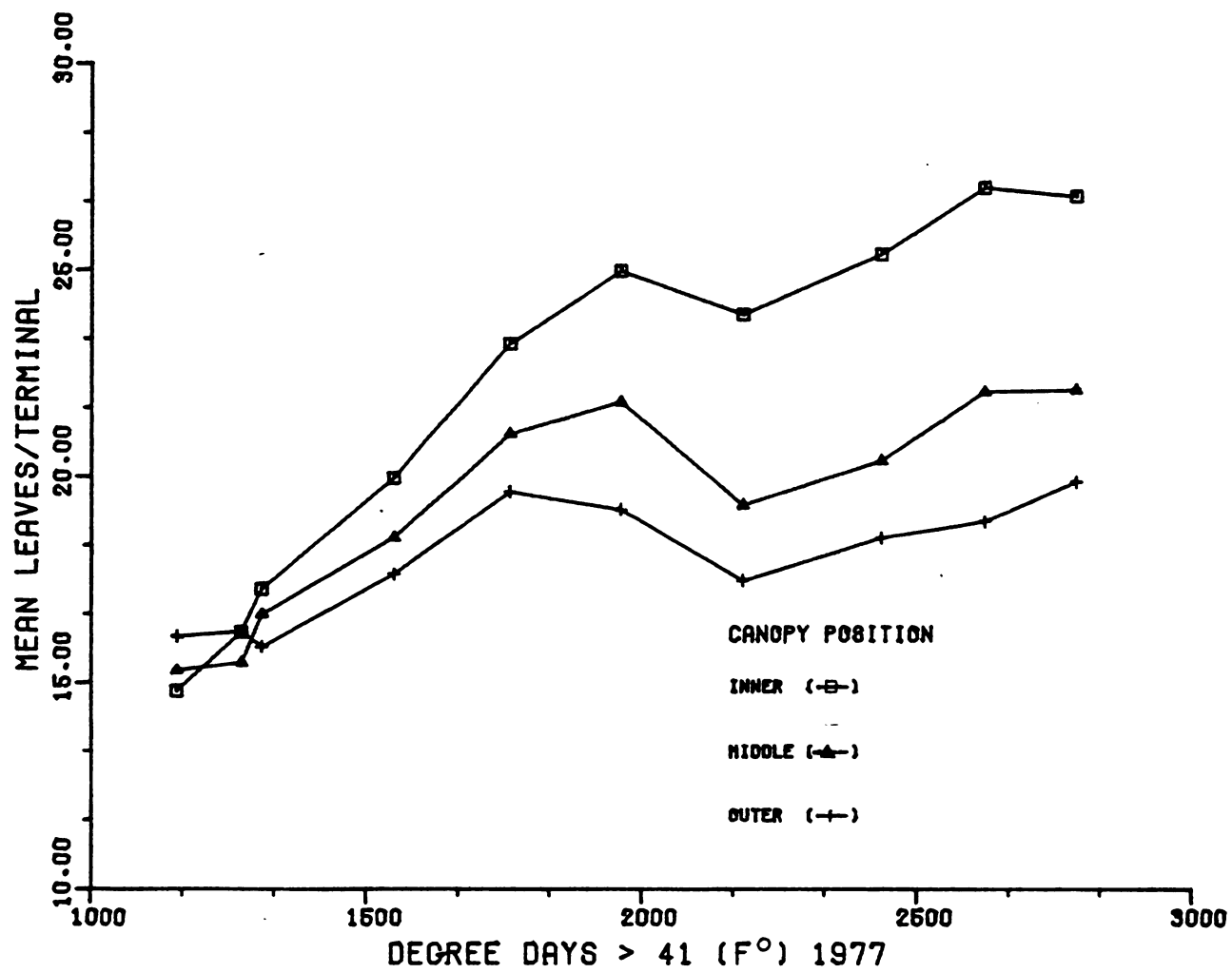


Figure 2e. LEAF MEANS IN CANOPY POSITION

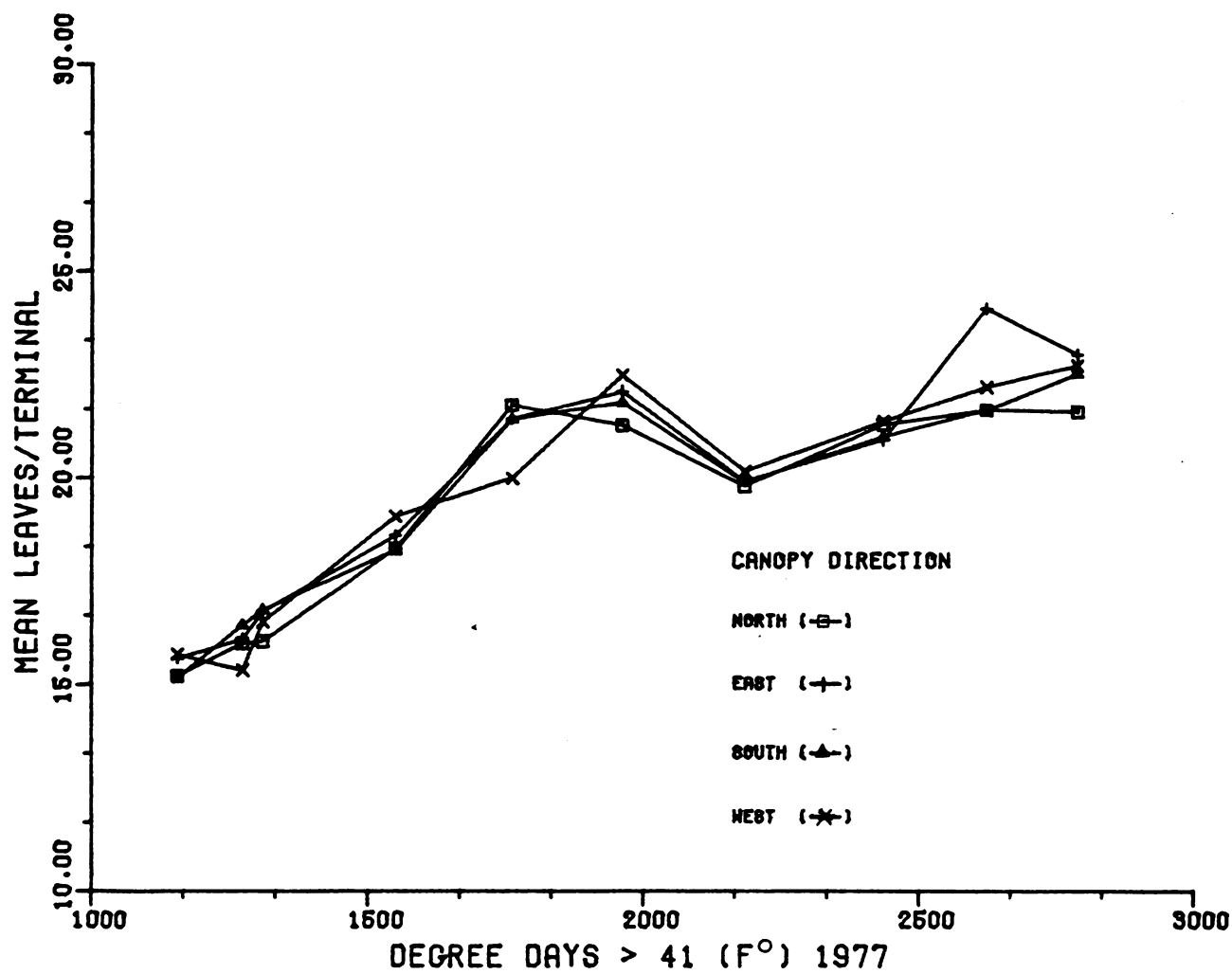


Figure 2f. LEAN MEANS IN CANOPY DIRECTIONS

Table 2. Results From the ANOVA for Determining Differences in Mean Aphid Densities in Three Canopy Divisions, 1977.

Date	DD	Grand ¹ Canopy Level			Canopy Direction			Canopy Position			
		Mean	DF	F	Sign.	F	DF	Sign.	F	DF	Sign.
6-03-77	1155	1.22	1	3.687	.056	3	1.496	.217	2	4.854	.009
6-10-77	1273	3.23	1	7.517	.007	3	2.376	.071	2	3.780	.686
6-15-77	1370	6.04	1	9.477	.002	3	.014	.998	2	.698	.498
6-22-77	1550	20.95	1	.000	.985	3	2.045	.019	2	2.144	.120
6-29-77	1761	45.34	1	.388	.562	3	1.034	.378	2	28.358	.001
7-06-77	1962	43.98	1	.211	.647	3	.801	.496	2	34.526	.001
7-13-77	2184	33.80	1	7.452	.007	3	.272	.846	2	11.617	.001
7-20-77	2436	71.00	1	7.124	.008	3	.475	.700	2	18.945	.001
7-27-77	2623	18.78	1	.108	.743	3	.499	.683	2	3.265	.040
8-03-77	2815	17.95	1	3.511	.062	3	.450	.718	2	3.237	.041

¹A. pomi per terminal for all samples

numbers showed means of 45.20 and 46.98 for both lower and upper canopies. The second peak showed the greatest number of aphids in the upper quadrat, 91.12 versus 42.55 aphids per terminal in the lower quadrat. This coincided with the same period of rapid growth in the upper tree canopy (Figure 3a and Figure 2a).

Mean aphid densities in the three canopy positions were not significantly different on the first four sample dates. On the remaining dates (Table 2), significant differences between canopy positions occurred, with the highest aphid densities found in the inner canopy position followed by progressively fewer aphids in the middle and outer periphery of the apple canopy (Figure 3b). Directional differences shown in Figure 3c were not significant.

A. aphidimyza populations showed two peaks which were closely synchronized with the temporal, spatial, and numerical distribution of its prey. Predator populations for the lower and upper canopies peaked at ca. 1900 dd and at 2400 dd (Figure 3d) respectively. The means for the first peak were roughly equal at 0.33 and 0.28 cecidomyiid larvae per terminal. The second peak showed greater numbers in the upper canopy than the lower at 1.35 and 0.85 larvae per terminal respectively. Of the three canopy positions the inner canopy contained the largest number of predators for six of the ten sample dates, similar to the aphid densities described (Figures 3b and 3e). Directional differences in

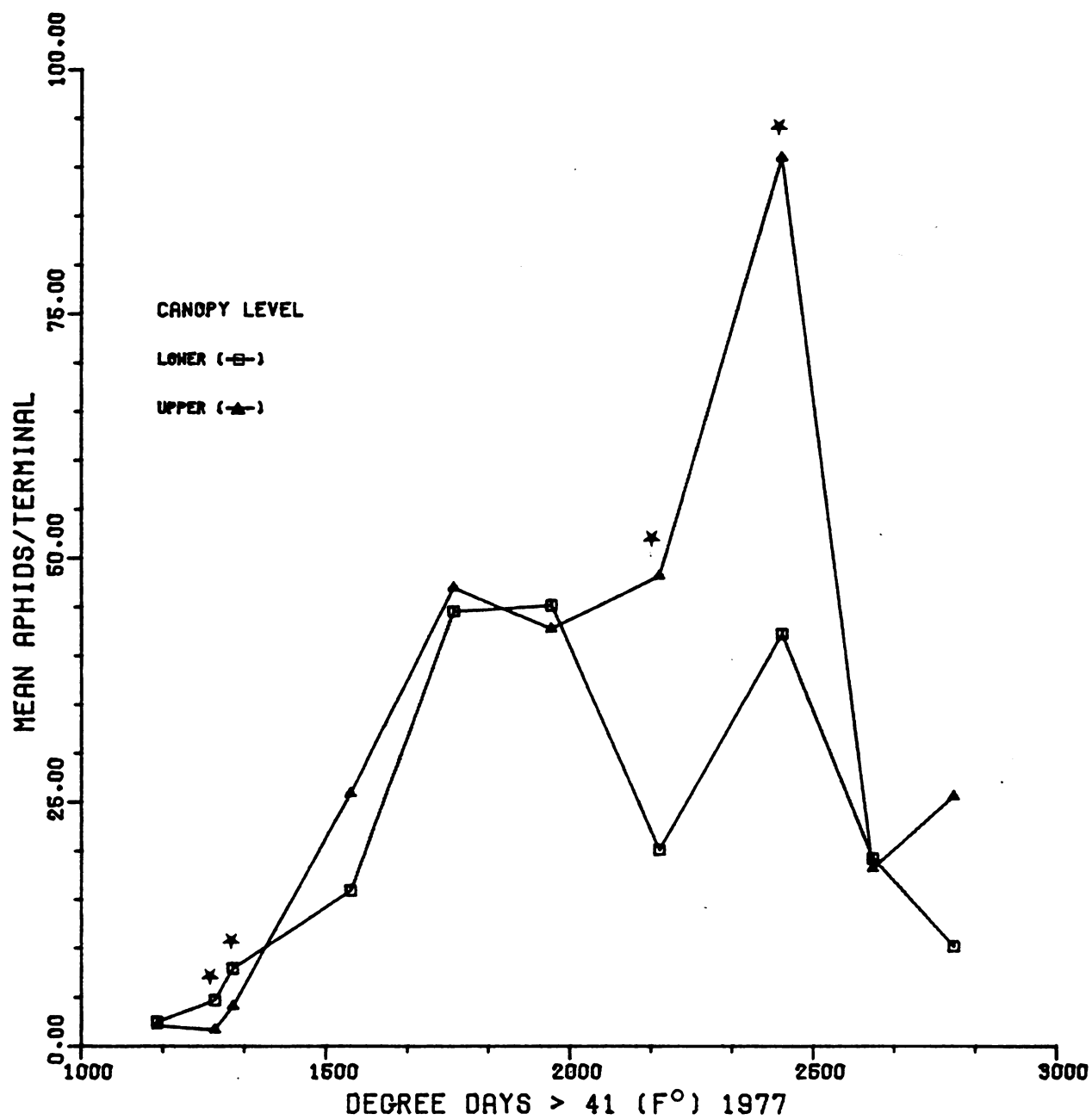


Figure 3a. APHID MEANS IN CANOPY LEVELS

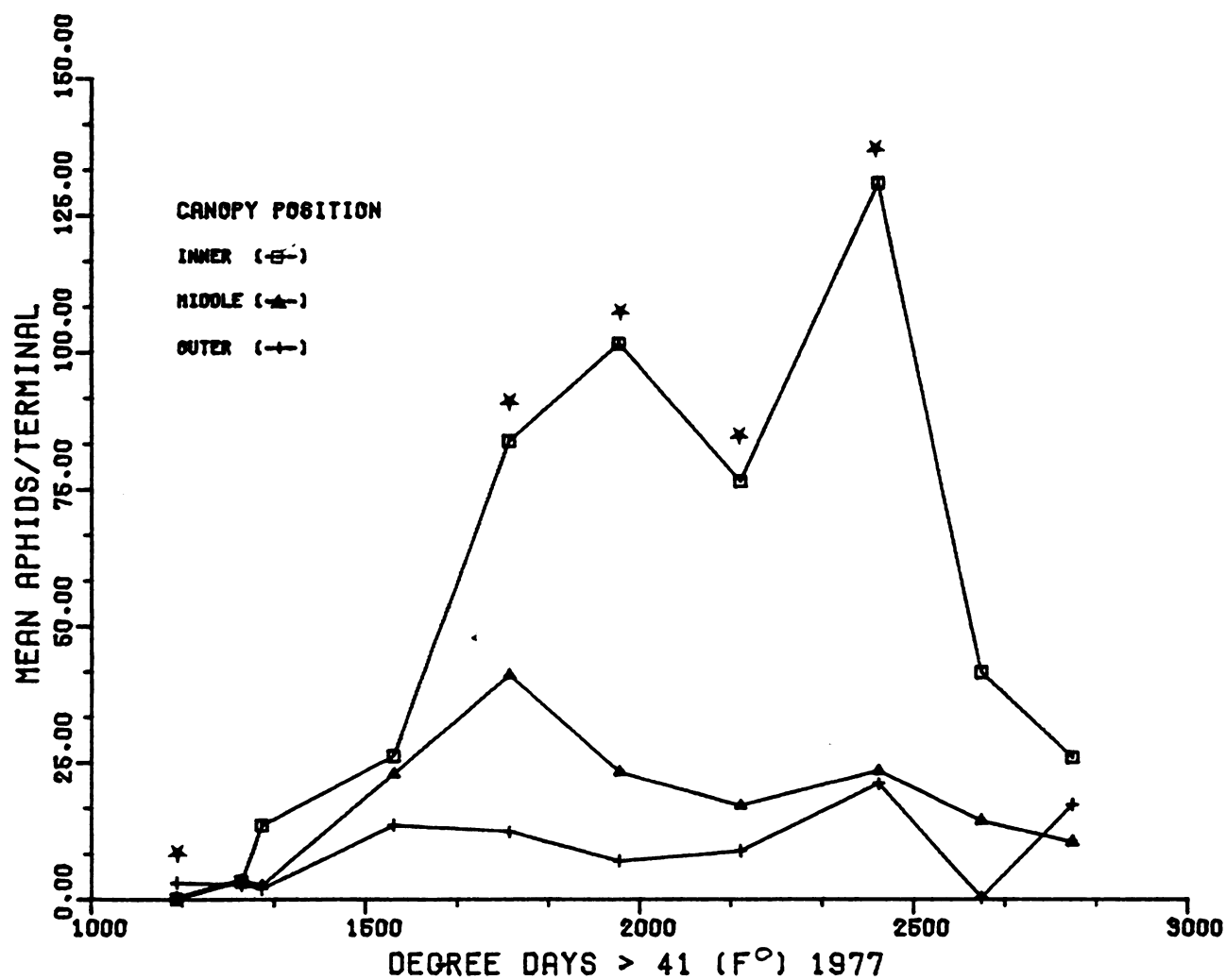


Figure 3b. APHID MEANS IN CANOPY POSITION

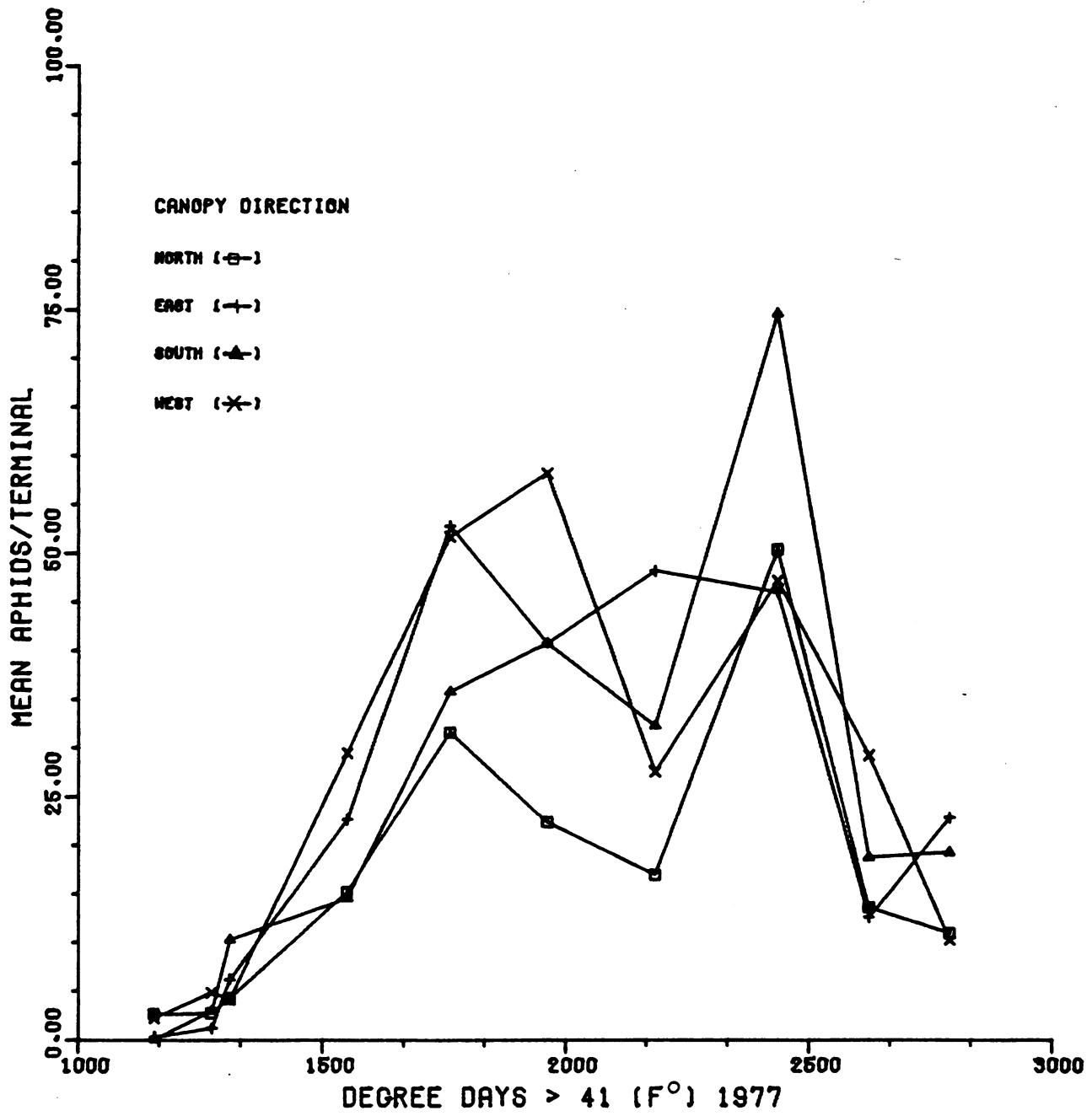


Figure 3c. APHID MEANS IN CANOPY DIRECTION

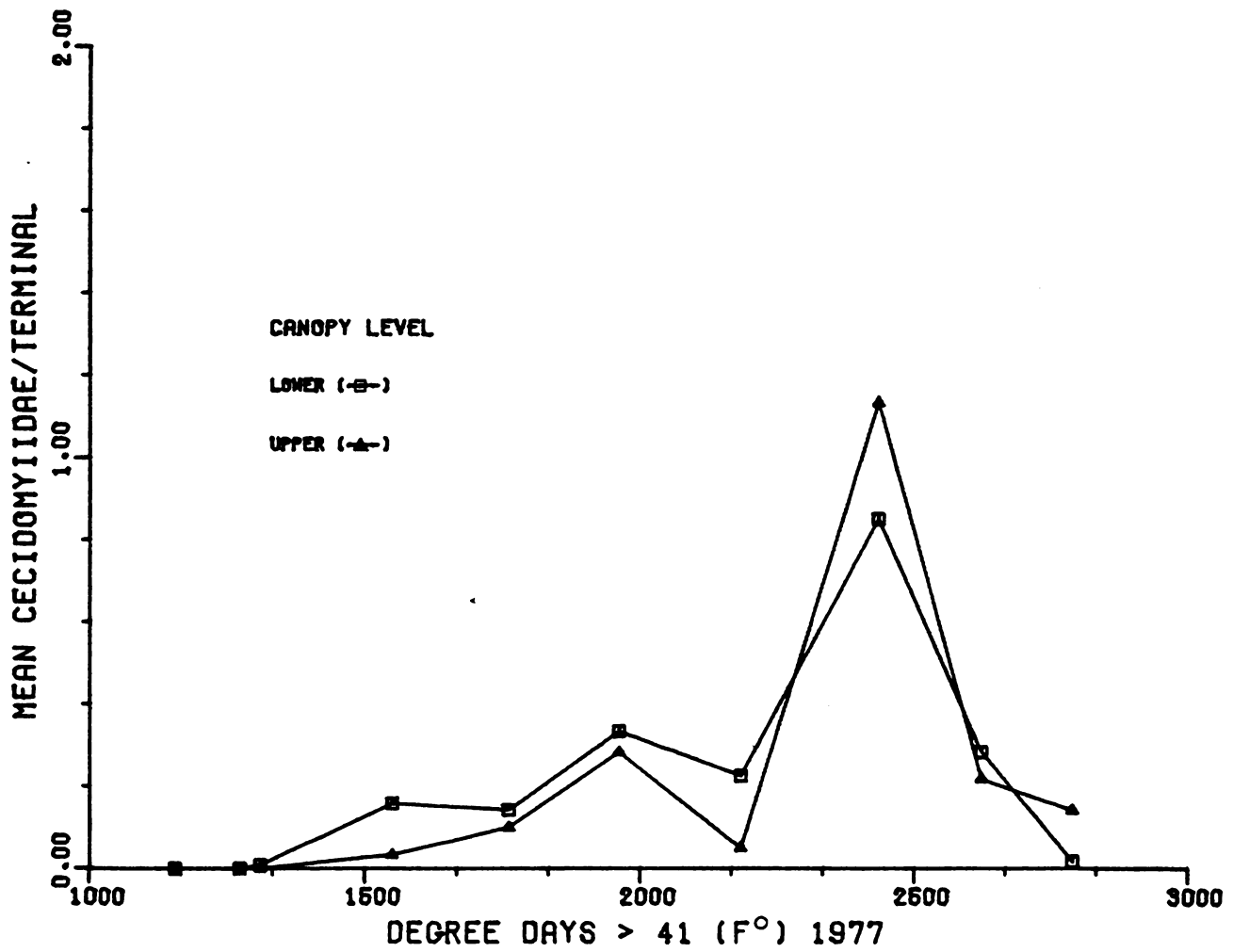


Figure 3d. CECIDOMYIIDAE MEANS IN CANOPY LEVELS

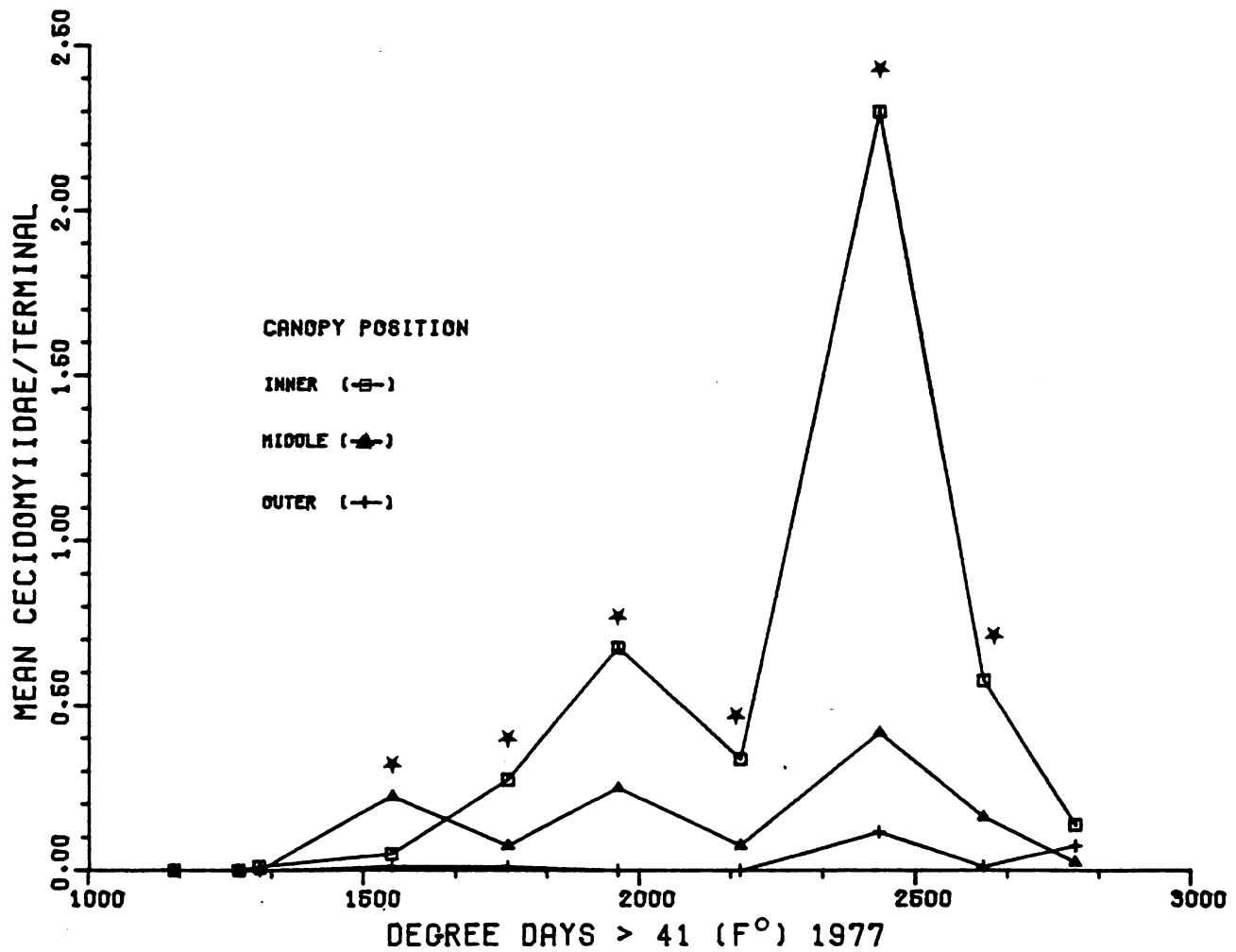


Figure 3e. CECIDOMYIIDAE MEANS IN CANOPY POSITION

the mean counts of cecidomyiids were not observed (Figure 3f). As in the aphid figures, where significant ($\alpha=0.01$) differences in any canopy quadrat occurred, the dates are starred (refer also to Table 2a).

The results of ANOVA comparisons between aphid densities per terminal for leaf primordia classes (0-4) on each sample date in 1977 are given in Table 3. For seven dates where significant differences occurred modified LSD tests showed terminals with the greatest number of leaf primordia to have the larger aphid populations (Table 4). Results from ANOVA comparison of aphid densities in six leaf classes of terminals showed almost identical results (Table 3). Table 5 presents the ranking of leaf class means for each sample date with significant differences. Again, higher aphid densities were associated with the larger leaf classes, which are indicative of more vigorously growing terminals.

Table 6, presents the equations derived to describe growth activity in canopy level and canopy position. Leaf primordia decline and leaf addition rates, indicated by their slopes in 1976 and 1977, show little difference between years. Comparison of these growth rates although influenced somewhat by sampling differences, showed 1977 leaf addition in the lower canopy to be roughly twice the rate of 1976 and nearly one and a half times the rate of the 1976 in the upper quadrat.

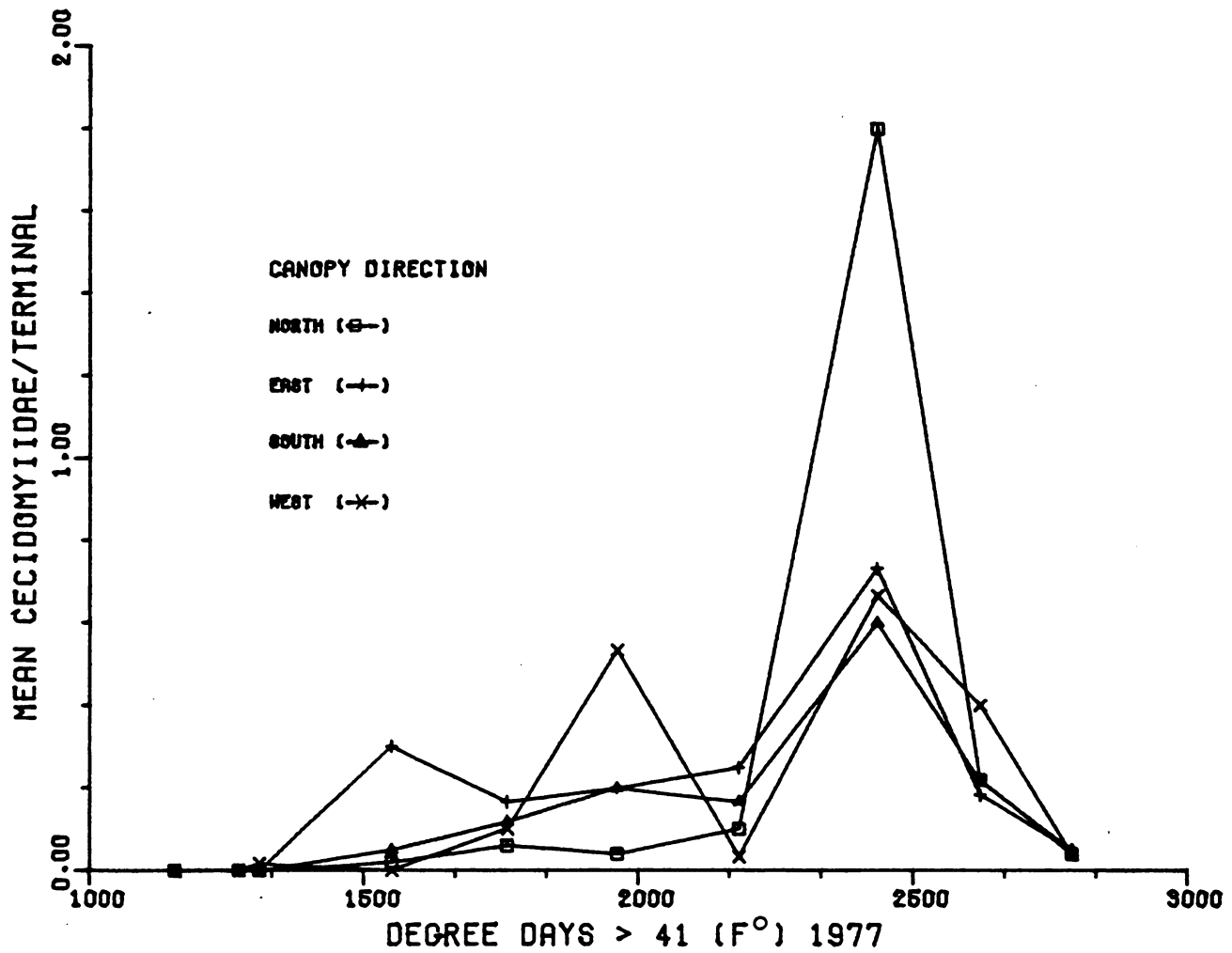


Figure 3f. CECIDOMYIIDAE MEANS IN CANOPY DIRECTIONS

Table 2a. Results From ANOVA For Determining Differences in Mean Predator Densities in Three Canopy Divisions, 1977.

Date	DD	Grand ¹ Mean	Canopy Level			Canopy Direction			Canopy Position		
			DF	F	Sign. F	DF	F	Sign. F	DF	F	Sign. F
6-15-77	1370	0.004	1	1.000	.318	3	1.000	.394	2	1.000	.369
6-22-77	1550	0.025	1	.415	.520	3	.755	.521	2	.538	.584
6-29-77	1761	0.096	1	.342	.560	3	.242	.857	2	.755	.001
7-06-77	1962	0.021	1	.033	.856	3	.398	.755	2	3.933	.002
7-13-77	2184	0.242	1	3.205	.075	3	1.252	.292	2	7.127	.001
7-20-77	2436	0.138	1	1.401	.238	3	1.222	.303	2	13.763	.000
7-27-77	2623	0.939	1	.352	.553	3	.073	.957	2	4.237	.016
8-03-77	2815	0.158	1	4.507	.035	3	.801	.495	2	1.331	.266

¹A. aphidimyza per terminal for all samples

Table 3. ANOVA Results From Testing For Mean Aphid Differences in The Classes of Leaf Primordia (0-4) and Leaf Classes (1-6), 1977.

Date	DD	Grand ¹ Mean	Leaf Primordia Classes			Leaf Classes		
			DF	F	Sign. F	DF	F	Sign. F
6-03-77	1155	1.22	4	.702	.591	2	.265	.768
6-10-77	1273	3.23	4	.562	.691	2	.309	.735
6-15-77	1370	6.04	4	1.952	.103	2	1.868	.157
6-22-77	1550	20.95	4	11.662	.001	2	12.769	.001
6-29-77	1761	45.34	4	24.308	.001	2	29.137	.001
7-06-77	1962	43.98	3	19.698	.001	2	30.410	.001
7-13-77	2184	33.80	3	36.384	.001	3	53.033	.001
7-20-77	2436	71.00	2	15.765	.001	3	30.178	.001
7-27-77	2623	18.78	3	73.508	.001	5	37.221	.001
8-03-77	2815	17.95	3	56.679	.001	4	26.496	.001

¹A. pomi per terminal

Table 4. Results of Modified LSD Tests for Sample Dates with Significant Differences Between Aphid Densities in Leaf Primordia Classes

Date	DD	Grand ¹ Mean	Leaf Primordia Classes			
			0	1	2	3
6-22-77	1550	20.95	.243a	.847b	.836b	.985b
6-29-77	1761	45.34	.648a	1.426b	1.504b	1.615b
7-06-77	1962	43.98	.677a	1.779b	1.692b	1.629b
7-13-77	2184	33.80	.371a	1.689b	2.436b	2.661b
7-20-77	2436	71.00	.442a	2.047b	2.930b	
7-27-77	2623	18.78	.085a	1.227b	1.584b	1.677b
8-03-77	2815	17.97	.169a	1.330b	1.824b	1.499b

¹A. pomi per terminal

Means presented for the classes are from transformed (1 log (x+1)) counts

Means followed by the same subscript do not differ



Table 5. Results of Modified LSD₁ Tests for Sample Dates With Significant Between Aphid Densities² in Leaf Classes.

Date	DD	Mean	Leaf Class Means ²					
			1	2	3	4	5	6
6-22-77	1550	20.95	0.19a	0.54a	0.99b			
6-29-77	1761	45.34		0.68a	1.73b	1.91b		
7-06-77	1962	43.98		0.41a	1.46b	0.88ab		
7-13-77	2184	33.80	0.00a	0.10a	0.89b	2.06c		
7-20-77	2436	71.00	0.00a	0.14a	0.66b	1.94c		
7-27-77	2623	18.78	0.00a	0.10a	0.21a	1.45b	2.30c	0.00a
8-03-77	2815	17.95	0.00a	0.14a	0.24a	1.20a	2.13b	

¹A. pomi per terminal

²Means presented are obtained from transformed ($\log (X+1)$) counts. Means followed by the same subscript do not differ

Table 6. Results of Curve Fitting For Leaf Primordia
Decline and Leaf Addition 1976 and 1977

Logarithmic Leaf Primordia Decline ($y = a(\log dd) + b$)

Year	Division	Slope a	Intercept b	r^2
1976	Lower	-1.98	15.66	0.90
	Upper	-3.08	24.75	0.92
1977	Lower	-2.46	19.38	0.90
	Upper	-3.09	24.38	0.91
	Inner	-3.13	24.96	0.89
	Middle	-3.02	23.70	0.90
	Outer	-2.14	16.77	0.91

Power Curve Fit of Leaf Addition ($\ln y = a \ln (dd) + \ln b$)

Year	Division	Slope a	Intercept b	r^2
1976	Lower	0.31	1.75	0.82
	Upper	0.38	1.04	0.73
1977	Lower	0.70	0.12	0.91
	Upper	0.53	0.40	0.93
	Inner	0.67	0.14	0.93
	Middle	0.41	0.86	0.82
	Outer	0.22	3.51	0.66

DISCUSSION

Total apple tree growth includes the subcomponents of leaf and terminal shoot production, woody tissue enlargement in both the tree canopy and root zone, bud and fruit formation and carbohydrate storage. In total, these processes are greatly influenced by the past and current cultural and environmental conditions to which an orchard tree has been and is exposed.

More specifically growth of terminal leaf primordia and subsequent new leaves is regulated by the rate of movement of soluble carbohydrates and amino acids from roots, bark and leaves to these sites (Zimmerman 1961). As observed in this study, these features of tree growth showed yearly variation over time (Table 6), but varied little in distribution between years at the same time period dd (Figure 1a, 1b, 2a, 2b). This indicated that similar management and environmental conditions were occurring annually and also that a relatively controlled process of tree growth was being maintained by the orchard manager from year to year. Probably due to the particular pruning practices used, the inner and upper quadrants of the tree consistently experienced the greatest amount of growth activity (Figures 1a, 1b, 2a, 2b).

Several workers have observed that aphids distribute themselves in close association with active plant growing

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at

sites (Kennedy et al. 1950, Kennedy 1958, Dixon 1979). These responses are related primarily to their ability to assimilate and utilize soluble carbohydrates and amino acids present at these locations of the plant host (Way and Cammell 1970). Takeda et al. (1968) and Specht (1970-72) have clearly shown that mature growth of apple, which includes primarily insoluble carbohydrates and amino acids and is made up of leaves with hardened cuticles, does not support reproducing populations of A. pomi.

In this study A. pomi showed little directional preference for terminal colonization, but as with the distribution of terminal growth and correspondingly nutrients, the most dense populations were found in the inner and upper level quadrants of the trees. Similar relationships (host-plant-aphid) have been reported for the sycamore inhabiting aphid Drepanosiphum platanoides (Dixon 1971) and the lime tree species Eucallipterus tiliae (Dixon 1971a). The methods utilized in Dixon's studies to obtain information of the aphid-host nutrient and energetic cycles could aid description of A. pomi impact on tree growth.

Effective natural enemies require a temporal or spatial distribution that is closely associated with their host. In this study the distribution of A. aphidimyza larvae relative to that of A. pomi reflected such an association (Fig. 3a-f). Predator larvae were most commonly found on inner and upper terminal growth of the apple tree and were always associated with aphid populations. The delayed colonization



and numerical response of the cecidomyiid to the increasing host density in the upper quadrat were indicative of its relatively immobile larval state (Wildbert 1972) and the host searching capacity of the female adult (El-Titi 1978). Thus, dispersion of this cecidomyiid in response to changing host distribution is controlled primarily by adult movement.

In summary, there are several factors which indicate that A. aphidimyza may be an effective natural enemy for control of A. pomi which can be incorporated with existing IPM systems on apple.

- 1) It is closely attuned to the spatial distribution of A. pomi and seems to occupy all components of the habitat used by the aphid.
- 2) It appears that pesticide resistant or tolerant strains of this natural enemy commonly occur in orchards (Adams 1977, Warner, unpublished data).
- 3) A. aphidimyza has a variety of alternate hosts (Harris 1973) which will support predator populations in the absence of the pest.
- 4) It has proven to be a very effective predator of other aphid species occurring in greenhouses (Markkula 1973).

Based on these data, there is further need to continue research on this species, to evaluate its potential for

controlling apple aphids in Michigan and to implement an effective management program compatible with existing apple IPM strategies.

APPENDICIES

APPENDIX A

This appendix contains environmental parameters for Graham Experiment Station for April - August 1976 and April - September 1977. Provided are the maximum and minimum temperatures ($^{\circ}\text{F}$), the precipitation, and the accumulated degree days (Base 41°F) estimated for A. pomi development (Jokinen unpublished analysis).

1000
1000
1000
1000
1000

Graham Station Weather Data

April 1976						May 1976					
Date	Max O F	Min O F	Precip In	DD's 41° F		Date	Max O F	Min O F	Precip In	DD's 41° F	
401	44	33	0.05	1		501	64	41		294	
402	40	31	0.04	1		502	61	35		302	
403	57	33		7		503	49	32	0.55	304	
404	64	33	0.02	16		504	42	29	0.01	304	
405	53	25		20		505	60	48		317	
406	55	35	0.02	25		506	76	37	1.48	333	
407	58	32		31		507	41	29	0.55	333	
408	55	24		35		508	50	28		336	
409	48	24		37		509	57	44		346	
410	54	31		41		510	68	46		362	
411	61	27	0.19	48		511	71	42	0.17	378	
412	41	20		48		512	51	31		381	
413	47	26		49		513	62	38		390	
414	61	44		61		514	73	51	0.03	411	
415	78	60		89		515	73	51		432	
416	80	58	0.80	117		516	66	57	0.38	452	
417	84	59		147		517	72	49	0.13	472	
418	83	55		175		518	57	36		479	
419	82	50	0.09	200		519	60	34		487	
420	62	47		214		520	62	47		501	
421	63	47	0.03	228		521	74	48	0.02	521	
422	72	45	0.66	246		522	70	38		534	
423	56	35	0.102	252		523	66	38		545	
424	61	45	0.14	264		524	53	39		550	
425	46	36	1.32	266		525	65	42	0.01	562	
426	36	27	0.52	266		526	60	43		572	
427	30	29		266		527	70	43		588	
428	47	30		268		528	76	53		612	
429	56	31		273		529	75	57	0.77	637	
430	60	34		281		530	64	59	0.37	657	
						531	75	58	0.16	683	

Graham Station Weather Date

June 1976

Date	Max Of	Min Of	Precip In	DD'S 41 Of
601	74	57		707
602	74	46		726
603	73	48		746
604	75	51		768
605	80	55		794
606	82	57		822
607	81	47		845
608	84	56		874
609	84	58		904
610	86	60		936
611	84	64		969
612	84	60		1000
613	89	66		1036
614	87	65		1071
615	86	70		1108
616	86	57	0.10	1138
617	65	48		1154
618	80	59		1182
619	86	53	0.67	1210
620	67	48		1226
621	79	53		1251
622	75	61		1278
623	81	55		1305
624	82	60	0.50	1335
625	68	59	0.10	1357
626	76	57		1383
627	83	61		1414
628	86	62	0.07	1447
629	80	55		1473
630	74	57		1497

July 1976

Date	Max Of	Min Of	Precip In	DD'S 41 Of
701	61	51	0.76	1512
702	77	49		1534
703	79	51		1558
704	78	52		1582
705	85	55		1611
706	86	54		1640
707	86	59		1672
708	83	59	0.01	1702
709	84	59		1732
710	85	67	0.02	1767
711	90	72		1807
712	90	53		1837
713	77	44		1857
714	82	56		1885
715	92	60		1920
716	90	59		1954
717	74	50		1975
718	77	53		1999
719	85	57		2029
720	84	70		2065
721	84	62	0.12	2097
722	82	61		2127
723	85	71	0.09	2164
724	88	62	0.01	2198
725	86	58		2229
726	87	61		2262
727	88	64	0.05	2297
728	89	60		2331
729	75	63	0.20	2359
730	76	56		2384
731	84	62	0.18	2416

Graham Station Weather Data

August 1976						April 1977					
Date	Max °F	Min °F	Precip In	DD'S 41°F		Date	Max °F	Min °F	Precip In	DD'S 41°F	
801	74	48		2436		401	42	25		0	
802	78	48	0.10	2458		402	55	38	1.47	6	
803	73	46		2476		403	65	31	0.14	15	
804	79	50		7500		404	50	35		18	
805	80	60	0.19	2529		405	47	30	0.49	20	
806	80	57	0.24	2557		406	34	18	0.05	20	
807	70	47		2575		407	34	22	0.06	20	
808	74	46		2594		408	50	18		22	
809	81	51		2619		409	39	21		22	
811	84	63		2679		410	58	42		31	
812	87	68	0.05	2715		411	78	55		57	
813	83	65	0.01	2748		412	80	49		81	
814	84	62	0.64	2780		413	79	55		107	
815	67	48	0.02	2796		414	71	43		123	
816	75	44		2814		415	64	45		137	
817	75	45		2833		416	68	46		153	
818	81	48		2857		417	78	50	0.01	176	
819	85	57		2887		418	78	56		202	
820	85	58		2917		419	84	56		231	
821	89	57		2949		420	76	58	0.41	257	
822	87	59		2981		421	78	60	0.64	285	
823	90	61		3015		422	71	52	0.22	305	
824	84	58		2045		423	55	48		315	
825	85	61		3077		424	64	39		326	
826	82	64		3109		425	53	37	0.67	331	
827	82	65	0.09	3143		426	53	32	0.07	335	
828	92	65		3181		427	61	34		343	
829	79	47	0.38	3203		428	74	37		358	
830	67	38		3215		429	53	28		362	
831	72	53		3237		430	61	33		370	

Graham Station Weather Data

May 1977						June 1977					
Date	Max O F	Min O F	Precip In	DD'S 41 O F		Date	Max O F	Min O F	Precip In	DD'S 41 O F	
501	69	41		384		601	78	53	0.74	1132	
502	73	50		404		602	59	45	0.11	1143	
503	72	43		420		603	68	36		1155	
504	70	50		439		604	72	46		1173	
505	63	56		457		605	85	62	0.35	1205	
506	76	49	0.40	479		606	72	53	0.26	1227	
507	75	40		496		607	64	40		1238	
508	65	31		505		608	64	47		1252	
509	63	29		513		609	61	38	0.12	1261	
510	58	33		519		610	67	39		1273	
511	66	32		529		611	74	52	0.19	1295	
512	72	40		544		612	64	57	0.14	1315	
513	75	52		566		613	62	48		1324	
514	82	56		594		614	68	51		1347	
515	82	51		620		615	77	51		1370	
516	85	57		650		616	81	56		1398	
517	88	60		683		617	85	60		1430	
518	85	57		713		618	87	63	0.32	1464	
519	84	60		744		619	77	52		1488	
520	90	59		778		620	77	54	0.03	1512	
521	92	62		814		621	71	46		1530	
522	90	61	1.14	848		622	77	45		1550	
523	85	60	0.41	880		623	80	54		1576	
524	87	63		914		624	82	63		1608	
525	86	61		946		625	85	61	0.02	1640	
526	88	56		977		626	84	50		1666	
527	79	54		1003		627	85	58		1696	
528	84	51		1024		628	90	60		1730	
529	88	52		1058		629	85	59	0.10	1761	
530	75	54		1082		630	75	55		1785	
531	78	57		1108							

Graham Station Weather Data

July 1977					August 1977				
Date	Max O F	Min O F	Precip In	DD'S 41° F	Date	Max O F	Min O F	Precip In	DD'S 41° F
701	74	52	0.95	1807	801	83	54	0.01	2765
702	75	49		1828	802	78	52		2789
703	80	56		1855	803	79	56	0.04	2815
704	79	62	2.05	1885	804	82	62	0.15	2846
705	89	69	0.01	1923	805	86	64	0.28	2880
706	90	70		1962	806	82	66	0.19	2913
707	91	68	0.01	2000	807	79	65		2944
708	82	61		2030	808	78	67	0.04	2976
709	85	60		2062	809	78	64	0.11	3006
710	82	57		2090	810	76	68	0.08	3037
711	81	60		2120	811	81	58		3065
712	82	67		2154	812	67	47	0.05	3081
713	86	56	0.03	2184	813	76	51		3103
714	83	54		2212	814	81	57	0.34	3131
715	92	74		2252	815	73	47		3150
716	92	67	0.04	2292	816	78	63		3180
717	88	65	0.18	2328	817	78	53	0.07	3204
718	88	66	0.15	2364	818	72	43		3220
719	80	67	1.04	2396	819	68	42		3234
720	91	70		2436	820	71	45		3251
721	90	68		2474	821	75	56		3275
722	82	55	0.81	2502	822	66	47	0.30	3291
723	81	54		2528	823	73	56		3315
724	82	58		2557	824	69	45	0.05	3331
725	74	65	0.25	2585	825	71	45		3348
726	75	48		2605	826	76	52		3371
727	74	45		2623	827	82	67		3405
728	78	52		2647	828	90	72		3445
729	81	62	0.10	2677	829	89	60	1.54	3479
730	77	60	0.22	2705	830	77	50		3501
731	84	61	0.05	2737	831	77	61		3529

Graham Station Weather Data

September 1977				
Date	Max °F	Min °F	Precip In	DD'S 41°F
901	86	67	0.30	3565
902	74	64	0.04	3594
903	72	54	0.05	3616
904	73	58	0.02	3640
905	80	59	0.02	3668
906	69	49		3686
907	76	57		3712
908	77	56		3738
909	75	58		3764
910	71	55		3786
911	66	43		3800
912	70	49		3818
913	68	52	0.17	3837
914	61	42	0.06	3847
915	70	50		
916	56	52	0.43	
917	72	58		
918	71	64	0.79	
919	77	62	1.05	
920	64	51		
921	55	50	0.10	
922	62	53	0.02	
923	64	56	0.03	
924	65	58	0.28	
925	69	51	0.80	
926	74	54		
927	68	47		
928	61	52		
929	64	42		
930	63	53		

APPENDIX B
Techniques Utilized for Establishing Laboratory
Colonies of Aphidoletes aphidimyza (Rondani)

This appendice provides a description of the techniques and equipment used in the establishment of the aphidophagous cecidomyiid Aphidoletes aphidimyza. The ease with which field samples were collected and laboratory colonies established facilitates use of A. aphidimyza to develop information on predator-prey interaction.

A review of literature on rearing methods reported for A. aphidimyza reveals that several studies describing mass rearing and effective release rates of A. aphidimyza have been conducted (Bandarenko 1975, Markkula 1973, and Ushchekov 1975). These and studies describing the life cycle (e.g. Uygun 1971) provide a fairly complete outline of its biology to initiate development of rearing programs.

Methods

Difficulty in the removal of small cecidomyiid larvae (0.4 - 3.4mm) from field colonies of the apple aphid, Aphis pomi (Degeer) necessitated development of techniques to obtain sufficient numbers of predators for experimentation and rearing. This is in part a modification of the techniques developed by Markkula and Tittanen (1976). It is not intended to provide a complete rearing methodology but rather methods

to combine and manipulate unique populations of A. aphidimyza.

Prior to field collection of the cecidomyiid, rearing units were prepared. These units were ca. 23cm x 30cm x 10cm deep plastic containers filled with approximately 7.0cm of slightly moistened white sand. Placed upright in the sand were three rows of five 15cm long test tubes. Each tube was two thirds full with equal parts of water and Hoaglands nutrient solution. Perma-seal [®], and celluloid film material, was used to cover the test tube top. These units were easily prepared, reusable, and of minimum cost.

Field colonies of A. pomi on apple terminals were observed for the presence of A. aphidimyza. The upper 30.0 - 50.0cm of reapidly growing terminals found with aphid and predator were removed and placed into plastic bags. These bags were immediately set into a chilled polyurethane cooler for transfer to the laboratory. Upon return to the laboratory, the terminals were sectioned to ca. 15.0 - 18.0cm and lower leaves without or with few aphids removed.

These sections, each with leaf primordia, immature leaves, an aphid colony, and predators were inserted singly into the test tubes. A 6.0cm diameter cage about 20.0cm in height was placed over each terminal and test tube. The test tube solution provided sufficient water and nutrients to maintain leaf turgor and the aphid colony for approximately four days at 25°C and 60-80% relative humidity. This was

sufficient time for the development of larval cecidomyiids and provided adequate host numbers.

At the completion of the larval development, roughly five days later, the larvae dropped to the sand below and formed the pupariums. Puparium were found at a depth of ca. 1.0cm below the sand surface and encased in sand, they were easily recognized by their size (1.0 x 1.5mm). The puparium were removed with forceps and placed in petri dishes. The confinement of the predator within the circumference of the cage further aided the recovery of puparium.

Once in the petri dishes the number of puparium were recorded and the dish placed at either room temperatures or at 8°C (in a refrigerator). A. aphidimyza in the petri dishes held at room temperature emerged in roughly twelve days. Survival of the cecidomyiids following cold storage was noted at periods up to six weeks later, when dishes placed at room temperature for twelve days were found to have adult cecidomyiids.

To determine if these rearing methods were adequate, the emergent adults were released in screened cages containing aphid colonies (Acrosiphum pisum) on broadbean plants. Following three days of development and oviposition the confined adults were removed with an aspirator. In the next four days aphid colonies were observed for egg and larval development. The experiment was concluded when second and third instar larvae were observed.

The methods presented here allowed the establishment of laboratory colonies of Aphidoletes aphidimyza from field colonies of the apple aphid Aphis pomi on apple terminals. The relative ease with which predators were manipulated using these methods could aid in mass rearing programs, determining pesticide tolerances of field populations by limited sprays to individual terminals, and in manipulating colonies in the laboratory to describe the predator-prey interaction. Finally, use of these methods to obtain accurate density and survival information of the predator is recommended.

and

laboratory

experiments

and

other

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other

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and

APPENDIX C
Frequency Class Distribution of Aphis pomi and
Aphidoletes Aphidimyza for 1976 and 1977

The following provides the frequency distribution of aphid and predator counts for 1976 and 1977 on each sample date. The sample dates are coded as:

A	6-10-76	A	6-03-77
B	6-18-76	B	6-10-77
C	6-25-76	C	6-15-77
D	7-02-76	D	6-22-77
E	7-09-76	E	6-29-77
F	7-16-76	F	7-06-77
G	7-23-76	G	7-13-77
H	7-30-76	H	7-20-77
I	8-06-76	I	7-27-77
J	8-13-76	J	8-03-77
K	8-20-76	K	8-10-77
L	8-27-76	L	8-17-77

[illegible]

14 11 21 22 23 24
 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100

12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100

1976 Predator Frequency Class Distribution

<u>Predator Count</u>	<u>Frequency Class</u>	<u>Sample Date</u>				<u>Total</u>
		<u>D</u>	<u>E</u>	<u>F</u>	<u>G</u>	
0	0	96	39	90	94	320
1	1	3	14	2		20
2	2	1	11	1		3
3	3		6	3		9
4	4		6	3	1	9
5	5		3		1	3
6	6		3			4
7	7		5			6
8	8		4			4
9	9		1		1	3
10	10		2			2
11	11		3			3
12	12		1			1
13	13		2			2
14	14					
15	15					
16	16					
17	17					
18	18					
19	19					
20	20					
21	21					
22	22					
23	23					
24	24					

1904
1905

1977 Aphid Counts Frequency Distributions For All Sample Dates

Aphid Counts	Freq. Class	Sample Dates		D	E	F	G	H	I	J	K	L	M	N
		A	B C											
0	0	226	193	203	105	67	40	156	126	203	192	234	236	234
1	1	11	35	23	81	75	27	36	18	15	14		3	3
21	2	1	6	5	23	23	13	7	4	2	6	1		
41	3		3	3	11	19	11	6	4	1	5	1		1
61	4		2	1	6	6	8	3	2	1	2	2		
81	5	2	1	3	1	11	2	5	2	2	6	1	1	1
101	6				3	10	3	2	1	4	5			1
121	7				2	4	9	4	3		3			1
141	8				3	5		2	2		1			1
161	9				1	1		4	1		2			
181	10				1	7	1	3	1	1	1			
201	11				1	1	1	4	1	1	1			
221	12			1	3	1	1		1		1			
241	13			1	2	1	1		2		1			
261	14				4	1	1	1	1		1			
281	15					1	1							
301	16					1	2	2		3				
321	17				1		1	2	1					
341	18						2	2						
361	19			1			2	2	2					
381	20						1							
401	21													
421	22			1				1						
441	23						2	1	1					
461	24							1						
481	25				1									
501	26						1							
521	27													
541	28													
561	29						1							
581	30			1				1						
601	31							5						

1977 Predator Frequency Distribution

Predator Count	Frequency Class	Sample Dates									
		C	D	E	F	G	H	I	J		
0	0	239	236	272	112	228	153	224	231		
1	1	1	3	9	2	2	4	6	3		
2	2			8	1	5	2	3	2		
3	3		1		1	1	3	3	4		
4	4			1	2	2	2	1			
5	5					2	4				
6	6				1						
7	7						4				
8	8				1		4				
9	9				1		4				
10	10						1				
11	11						1				
12	12						1				
13	13						1				
14	14						3				
15	15										
16	16										
17	17						1				
18	18										
19	19										
20	20										
21	21							1			
22	22									1	

APPENDIX D
Sample Site Means and Variances for
1976 and 1977

Appendix D contains the means and standard deviations for the variables observed for 1976 and 1977. The variables in 1976 were length of each shoot, number of leaf promordia, leaves, and A. pomi. counts, and in 1977 leaf primordia, leaves, A. pomi and A. aphidimyza counts. The results are sorted by sample site in a tree, thus, for each date 10 site means are shown for 1976 and 24 in 1977 (refer to the methods section of this thesis).

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Appendix D

Date		Length		(IN)		Leaf Primordia		Leaves		Aphis pomi	
Site	N	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
1	20	10.15	2.97	2.70	0.73	12.55	2.11	9.10	13.114		
2	20	8.84	2.38	2.65	0.81	11.85	1.98	6.95	11.75		
3	20	11.36	3.25	2.60	0.75	13.25	2.45	7.15	10.99		
4	20	9.88	3.56	2.05	0.95	12.50	3.20	10.50	17.82		
5	20	9.15	1.92	2.05	0.83	12.25	1.94	23.10	32.28		
6	20	10.83	3.41	3.05	0.61	13.05	2.59	11.20	26.13		
7	20	10.54	3.62	3.10	0.64	15.45	10.87	27.35	50.07		
8	20	10.26	3.048	3.11	0.64	12.75	2.57	14.30	20.25		
9	20	9.65	2.69	2.80	0.70	13.30	2.90	9.30	17.86		
10	20	10.18	2.90	2.85	0.67	13.00	2.58	20.90	36.56		

Appendix D

Date												
6/18/76		Length		(IN)		Leaf Primordia		Leaves		Aphis pomi		
Site	N	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	
1	10	16.65	4.90	2.20	0.79	16.20	3.12	91.00	98.73			
2	10	12.98	3.52	2.30	1.06	14.90	2.27	82.40	157.38			
3	10	17.98	2.68	2.20	0.79	17.20	2.49	87.00	78.31			
4	10	15.33	4.38	1.60	1.08	16.40	4.09	23.10	18.51			
5	10	12.40	2.55	0.06	0.68	14.70	2.06	7.00	18.01			
6	10	16.05	4.42	3.30	0.68	16.70	3.16	118.80	87.46			
7	10	15.28	4.35	3.20	0.42	18.80	4.73	102.90	96.15			
8	10	15.65	3.28	2.90	1.10	17.20	2.04	400.10	955.07			
9	10	13.33	3.11	2.70	0.95	15.90	2.33	81.30	86.10			
10	10	14.60	2.89	2.80	1.32	17.10	2.38	99.50	77.15			

Appendix D

Date												
6/25/76	Length		(IN)		Leaf Primordia		Leaves		Aphis pomi			
Site	N	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	
1	10	18.75	4.46	2.10	1.10	17.90	3.14	554.50	1056.49			
2	10	18.33	5.85	2.10	16.10	18.50	3.24	302.40	202.20			
3	10	16.60	6.84	1.30	1.42	16.70	4.52	270.50	333.33			
4	10	9.93	4.73	0.10	0.32	14.30	2.67	48.70	98.31			
5	10	11.83	3.93	0.20	0.63	14.50	3.17	42.80	62.08			
6	10	22.98	3.49	3.10	0.74	20.70	2.75	387.70	286.67			
7	10	22.35	3.21	3.30	0.48	20.30	2.67	516.80	469.61			
8	10	19.13	2.47	0.80	0.78	20.00	1.87	352.90	157.10			
9	10	20.15	3.13	2.50	0.97	20.10	2.08	421.10	292.18			
10	10	17.53	5.32	1.90	1.37	18.90	3.57	486.80	576.97			

Appendix D

Date												
7/02/76	Length		(IN)		Leaf Primordia		Leaves		Aphis pomi			
Site	N	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	
1	10	22.48	6.23	1.60	1.43	19.60	3.13	253.90	271.66			
2	10	19.15	6.55	1.11	0.99	20.00	2.80	552.30	1273.75			
3	10	18.90	4.96	0.30	0.67	18.80	3.42	104.80	109.07			
4	10	14.90	6.70	0.00	0.00	17.00	4.52	34.90	33.61			
5	10	12.98	4.39	0.30	0.95	15.70	2.98	17.00	40.40			
6	10	24.45	5.38	2.80	0.63	24.10	3.10	608.10	259.01			
7	10	24.38	6.32	2.80	0.79	24.00	3.80	575.20	269.67			
8	10	21.05	4.13	2.30	1.06	22.80	2.39	391.10	233.38			
9	10	21.05	4.13	2.30	1.06	22.80	2.39	391.10	233.38			
10	10	18.73	4.58	1.30	1.25	21.70	3.85	219.60	160.87			

Appendix D

Date		Length		(IN)		Leaf Primordia		Leaves		Aphis pomi	
Site	N	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
7-09-76											
1	12	21.67	7.24	1.33	1.23	26.33	20.72	60.50	76.94		
2	12	21.98	8.62	1.25	1.22	21.83	5.06	79.92	108.72		
3	12	20.46	10.42	0.66	1.37	20.42	6.61	65.92	95.18		
4	12	11.00	5.44	0.00	0.00	14.50	3.03	1.25	4.03		
5	12	11.65	3.50	0.00	0.00	14.42	2.71	13.92	48.21		
6	12	29.60	4.69	2.58	1.17	27.25	3.11	111.52	93.57		
7	12	27.65	5.58	2.00	1.44	26.30	3.80	135.17	128.51		
8	12	24.50	4.95	1.75	1.49	25.33	3.88	110.09	113.38		
9	12	25.06	7.39	1.67	1.38	25.17	4.47	108.58	101.40		
10	12	20.88	8.09	1.33	1.23	22.25	5.88	86.99	97.05		

Appendix D

Date											
7-16-76		Length		(IN)		Leaf Primordia		Leaves		Aphis pomi	
Site	N	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
1	10	25.13	11.98	0.70	0.95	21.90	6.56	16.10	32.13		
2	10	20.55	9.43	0.70	1.16	20.10	5.69	1.90	3.64		
3	10	20.98	7.35	0.20	0.63	20.70	5.25	0.20	0.63		
4	10	18.22	3.20	0.00	0.00	19.33	2.39	0.00	0.00		
5	10	12.18	4.15	0.00	0.00	15.40	2.01	0.00	0.00		
6	10	32.78	7.57	2.30	0.68	31.20	2.53	12.20	25.88		
7	10	29.13	10.81	2.10	1.29	29.40	7.52	30.90	80.01		
8	10	27.60	6.60	1.50	1.35	29.20	5.03	161.10	505.58		
9	10	21.50	6.92	1.40	1.35	24.90	5.26	2.00	3.53		
10	10	21.68	7.96	1.20	1.32	24.90	6.56	0.60	1.35		



Appendix D

Date	7-23-76		Length		(IN)		Leaf Primordia		Leaves		Aphis pomi	
	Site	N	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
	1	10	24.23	8.52	0.50	0.80	24.30	7.27	2.40	7.50		
	2	10	24.88	11.48	0.70	0.94	35.10	7.98	0.00	0.00		
	3	10	19.25	11.79	0.10	0.31	21.10	8.17	0.30	0.95		
	4	10	9.15	4.40	0.20	0.63	14.10	2.77	0.00	0.00		
	5	10	11.63	4.00	0.00	0.00	15.00	3.33	0.00	0.00		
	6	10	35.33	7.41	1.40	1.43	33.10	5.15	22.20	55.38		
	7	10	32.68	8.80	0.50	0.97	31.60	6.28	13.98	43.61		
	8	10	27.20	8.12	0.40	0.69	28.90	7.10	1.00	2.00		
	9	10	29.23	6.64	0.06	0.69	29.00	6.24	0.80	1.62		
	10	10	23.90	9.81	0.40	0.96	24.80	7.12	0.50	1.52		



Appendix D

Date		Length		(IN)		Leaf Primordia		Leaves		Aphis pomi	
Site	N	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
1	10	25.78	14.26	0.20	0.63	20.80	8.51	0.20	0.64		
2	10	19.65	8.74	0.00	0.00	21.20	2.62	0.00	0.00		
3	10	21.30	8.66	0.00	0.00	23.30	6.31	11.60	36.68		
4	10	17.18	5.01	0.00	0.00	18.00	4.16	0.00	0.00		
5	10	12.23	4.19	0.00	0.00	15.10	3.07	0.00	0.00		
6	10	33.28	11.48	0.60	0.97	32.90	7.84	0.50	1.27		
7	10	32.45	12.39	1.00	0.94	34.60	8.37	11.30	22.23		
8	10	30.85	8.40	0.40	0.70	32.40	8.06	1.70	2.41		
9	10	22.65	7.49	0.20	0.63	29.30	12.89	3.20	6.27		
10	10	23.55	10.22	0.20	1.16	24.50	7.57	9.80	14.25		



Appendix D

Date													
8-06-76		Length		(IN)		Leaf Primordia		Leaves		Aphis pomi			
Site	N	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	
1	10	24.84	9.98	0.30	0.68	23.80	6.75	0.00	0.00	0.00	0.00	0.00	
2	10	24.78	12.00	0.30	0.48	25.20	8.15	0.00	0.00	0.00	0.00	0.00	
3	10	19.98	12.30	0.00	0.00	21.20	8.38	0.00	0.00	0.00	0.00	0.00	
4	10	9.15	4.40	0.00	0.00	14.10	2.77	0.00	0.00	0.00	0.00	0.00	
5	10	11.58	4.04	0.00	0.00	15.00	3.33	0.00	0.00	0.00	0.00	0.00	
6	10	37.45	9.28	0.80	1.03	34.40	7.49	2.80	5.73	2.80	5.73	5.73	
7	10	32.83	9.46	0.30	0.48	31.70	6.45	1.40	4.43	1.40	4.43	4.43	
8	10	27.35	8.22	0.22	0.42	29.10	7.45	0.30	0.95	0.30	0.95	0.95	
9	10	30.23	6.83	0.30	0.48	29.20	7.01	1.60	0.95	1.60	0.95	0.95	
10	10	20.68	8.24	0.10	0.32	23.50	6.54	0.00	0.00	0.00	0.00	0.00	

Appendix D

Date												
8-13-76		Length		(IN)		Leaf Primordia		Leaves		Aphis pomi		
Site	N	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean
1	10	27.18	16.01	0.30	0.95	21.10	9.63	0.00	0.00	0.00	0.00	0.00
2	10	20.65	9.69	0.00	0.00	21.20	7.02	0.00	0.00	0.00	0.00	0.00
3	10	24.05	10.59	0.40	0.84	21.90	7.56	0.00	0.00	0.00	0.00	0.00
4	10	17.18	5.01	0.00	0.00	18.20	4.21	0.00	0.00	0.00	0.00	0.00
5	10	12.28	4.19	0.00	0.00	15.10	3.07	0.00	0.00	0.00	0.00	0.00
6	10	35.48	9.14	0.00	0.00	35.30	6.26	0.11	0.11	0.33	0.33	0.33
7	10	34.13	14.11	0.40	0.70	35.70	9.63	17.80	17.80	38.27	38.27	38.27
8	10	32.38	7.42	0.10	0.32	34.40	7.91	1.70	1.70	5.38	5.38	5.38
9	10	22.70	7.41	0.00	0.00	26.40	7.07	0.00	0.00	0.00	0.00	0.00
10	10	24.20	11.08	0.00	0.00	28.00	10.29	22.30	22.30	45.08	45.08	45.08

Appendix D

Date		Length		(IN)		Leaf Primordia		Leaves		Aphis pomi	
Site	N	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
8-20-76											
1	10	25.10	10.73	0.10	0.32	24.00	7.07	0.00	0.00	0.00	0.00
2	10	25.18	13.09	0.10	0.32	25.00	8.46	0.00	0.00	0.00	0.00
3	10	19.98	12.30	0.00	0.00	21.20	8.38	0.00	0.00	0.00	0.00
4	10	9.15	4.40	0.00	0.00	14.10	2.76	0.00	0.00	0.00	0.00
5	10	13.33	5.55	0.00	0.00	17.20	5.87	0.00	0.00	0.00	0.00
6	10	38.23	10.10	0.70	0.82	36.40	7.98	0.10	0.10	0.32	0.32
7	10	32.83	9.46	0.30	0.48	31.70	6.45	0.00	0.00	0.00	0.00
8	10	25.85	8.45	0.20	0.42	28.80	7.24	0.00	0.00	0.00	0.00
9	10	29.23	6.36	0.20	0.42	28.00	7.30	0.00	0.00	0.00	0.00
10	10	23.03	9.25	0.10	0.32	25.10	7.23	0.00	0.00	0.00	0.00

Appendix D

Date		Length		(IN)		Leaf Primordia		Leaves		Aphis pomi	
8-27-76		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Site	N										
1	10	27.83	16.45	0.00	0.00	22.00	10.38	0.00	0.00	0.00	0.00
2	10	20.65	9.69	0.00	0.00	21.20	7.02	0.00	0.00	0.00	0.00
3	10	21.30	8.66	0.20	0.63	20.30	6.31	0.00	0.00	0.00	0.00
4	10	17.18	5.00	0.00	0.00	18.20	4.21	0.00	0.00	0.00	0.00
5	10	12.23	4.19	0.00	0.00	15.10	3.07	0.00	0.00	0.00	0.00
6	10	35.68	9.03	0.00	0.00	35.40	6.17	0.10	0.10	0.32	0.32
7	10	34.35	14.51	0.20	0.42	36.20	10.70	0.00	0.00	0.00	0.00
8	10	31.05	8.49	0.10	0.32	33.80	7.87	0.00	0.00	0.00	0.00
9	10	23.68	6.29	0.00	0.00	26.30	6.82	0.00	0.00	0.00	0.00
10	10	24.20	11.06	0.00	0.00	28.00	10.30	0.00	0.00	0.00	0.00



Appendix D

Date		Leaf Primordia			Leaves			Aphis pomi			Aphidoletes aphidymza		
Site	N	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
1	10	3.10	0.32	14.20	2.611	0	0	0	0	0	0	0	0
2	10	2.20	0.79	13.90	3.211	0	0	0	0	0	0	0	0
3	10	1.10	1.20	15.60	1.713	0.90	2.84	0	0	0	0	0	0
4	10	2.30	0.95	13.50	1.900	0	0	0	0	0	0	0	0
5	10	2.50	0.05	14.90	1.969	0	0	0	0	0	0	0	0
6	10	1.80	1.32	14.40	1.317	0	0	0	0	0	0	0	0
7	10	2.90	0.88	14.70	1.567	1.30	4.11	0	0	0	0	0	0
8	10	2.50	0.97	14.80	1.814	0	0	0	0	0	0	0	0
9	10	1.70	0.95	14.80	1.687	0	0	0	0	0	0	0	0
10	10	2.40	0.97	14.60	1.430	0	0	0	0	0	0	0	0
11	10	2.00	1.16	14.80	2.300	0.40	1.27	0	0	0	0	0	0
12	10	1.30	1.16	15.20	2.710	0.20	0.65	0	0	0	0	0	0
13	10	2.60	0.70	14.60	2.011	0	0	0	0	0	0	0	0
14	10	2.00	1.05	15.00	1.333	0	0	0	0	0	0	0	0
15	10	2.00	0.94	17.30	1.767	12.50	30.36	0	0	0	0	0	0
16	10	2.40	1.08	14.50	2.667	0	0	0	0	0	0	0	0
17	10	2.60	0.52	16.00	2.494	0	0	0	0	0	0	0	0
18	10	1.90	0.99	17.70	1.767	0	0	0	0	0	0	0	0
19	10	2.90	0.32	16.60	1.776	0	0	0	0	0	0	0	0
20	10	2.50	0.53	15.80	2.348	0	0	0	0	0	0	0	0
21	10	2.0	0.47	17.10	2.685	0.70	1.64	0	0	0	0	0	0
22	10	2.60	0.70	15.70	2.669	0	0	0	0	0	0	0	0
23	10	2.40	0.84	17.20	2.394	3.30	7.15	0	0	0	0	0	0
24	10	2.20	1.03	16.80	2.898	9.70	26.73	0	0	0	0	0	0

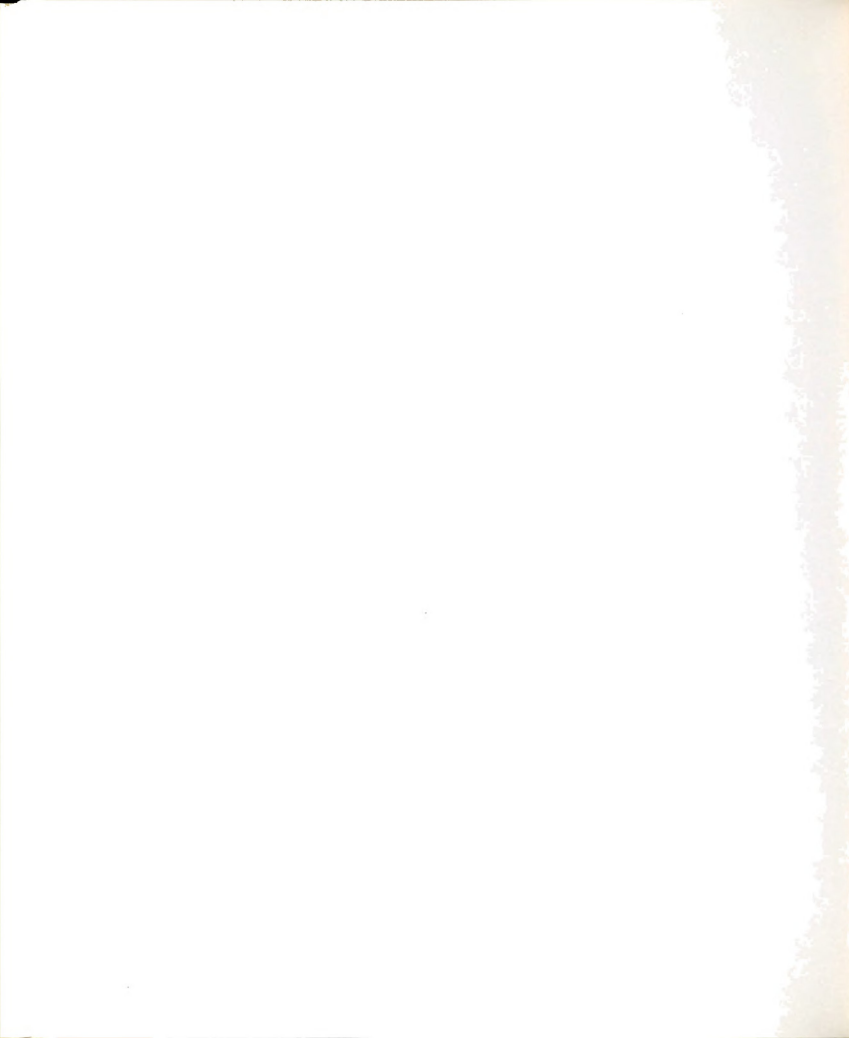


Appendix D

Date	6-10-77						Leaf Primordia			Leaves			Aphis pomi			Aphidoletes aphidmyza		
	Site	N	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
	1	10	2.40	0.70	16.30	3.34	6.20	19.61	0	0	0	0	0	0	0	0	0	0
	2	10	1.80	1.14	14.00	2.83	6.10	19.29	0	0	0	0	0	0	0	0	0	0
	3	10	0.70	1.06	14.90	2.23	1.00	3.16	0	0	0	0	0	0	0	0	0	0
	4	10	2.80	0.63	16.50	3.14	3.20	11.35	0	0	0	0	0	0	0	0	0	0
	5	10	2.10	1.52	14.60	2.01	6.50	11.21	0	0	0	0	0	0	0	0	0	0
	6	10	0.50	1.27	14.80	3.94	4.20	13.28	0	0	0	0	0	0	0	0	0	0
	7	10	2.60	0.57	15.60	2.17	4.40	5.70	0	0	0	0	0	0	0	0	0	0
	8	10	1.80	1.32	14.10	2.33	1.00	2.83	0	0	0	0	0	0	0	0	0	0
	9	10	1.20	1.23	15.90	1.91	0.50	1.58	0	0	0	0	0	0	0	0	0	0
	10	10	2.20	1.32	13.70	2.83	1.70	2.79	0	0	0	0	0	0	0	0	0	0
	11	10	2.30	0.95	15.00	3.62	12.50	15.21	0	0	0	0	0	0	0	0	0	0
	12	10	1.40	1.35	14.50	2.07	8.80	18.43	0	0	0	0	0	0	0	0	0	0
	13	10	2.10	1.20	16.10	2.23	9.00	28.46	0	0	0	0	0	0	0	0	0	0
	14	10	2.40	0.84	17.20	4.39	0.30	0.95	0	0	0	0	0	0	0	0	0	0
	15	10	2.10	1.20	17.70	1.70	0.30	0.95	0	0	0	0	0	0	0	0	0	0
	16	10	2.50	1.08	16.60	3.75	0.00	0.00	0	0	0	0	0	0	0	0	0	0
	17	10	2.50	0.85	17.90	2.18	1.80	4.47	0	0	0	0	0	0	0	0	0	0
	18	10	2.10	1.10	18.40	2.32	1.60	13.41	0	0	0	0	0	0	0	0	0	0
	19	10	2.40	1.27	18.30	3.65	0.70	1.48	0	0	0	0	0	0	0	0	0	0
	20	10	2.80	0.92	16.20	1.75	0.00	0.00	0	0	0	0	0	0	0	0	0	0
	21	10	1.40	1.17	16.50	2.64	0.80	2.53	0	0	0	0	0	0	0	0	0	0
	22	10	2.40	0.70	16.70	1.57	0.20	0.63	0	0	0	0	0	0	0	0	0	0
	23	10	2.70	0.68	15.00	2.26	1.20	3.57	0	0	0	0	0	0	0	0	0	0
	24	10	2.60	0.97	17.20	2.61	4.90	11.64	0	0	0	0	0	0	0	0	0	0

Appendix D

Date	6-15-77				Leaf Primordia				Leaves				Aphis pomi				Aphidoletes aphidmyza			
	Site	N	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
1	10	2.50	0.71	15.70	2.71	16.30	29.00	0	0	0	0	0	0	0	0	0	0	0	0	0
2	10	1.70	1.25	16.20	2.90	4.20	6.20	0	0	0	0	0	0	0	0	0	0	0	0	0
3	10	0.30	0.68	15.00	2.58	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0
4	10	2.20	1.32	16.60	3.81	4.60	134.16	0.10	0.32	0	0	0	0	0	0	0	0	0	0	0
5	10	1.30	1.25	15.40	3.30	1.90	5.38	0	0	0	0	0	0	0	0	0	0	0	0	0
6	10	0.80	1.32	14.00	3.46	0.10	0.36	0	0	0	0	0	0	0	0	0	0	0	0	0
7	10	3.20	0.92	15.60	3.06	10.40	25.84	0	0	0	0	0	0	0	0	0	0	0	0	0
8	10	1.90	1.52	15.10	2.77	1.10	3.48	0	0	0	0	0	0	0	0	0	0	0	0	0
9	10	1.30	1.57	15.00	2.59	2.80	7.21	0	0	0	0	0	0	0	0	0	0	0	0	0
10	10	2.90	0.57	17.40	2.72	4.90	14.80	0	0	0	0	0	0	0	0	0	0	0	0	0
11	10	2.20	1.40	16.10	2.38	5.70	11.24	0	0	0	0	0	0	0	0	0	0	0	0	0
12	10	1.50	1.18	14.40	3.20	3.90	7.89	0	0	0	0	0	0	0	0	0	0	0	0	0
13	10	2.50	1.08	17.60	3.10	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0
14	10	2.40	1.17	17.60	3.34	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0
15	10	2.30	1.25	15.70	2.54	0.60	1.35	0	0	0	0	0	0	0	0	0	0	0	0	0
16	10	2.40	1.17	18.60	3.27	9.60	24.16	0	0	0	0	0	0	0	0	0	0	0	0	0
17	10	2.80	1.14	18.20	3.29	5.60	17.71	0	0	0	0	0	0	0	0	0	0	0	0	0
18	10	1.60	1.43	18.00	2.45	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0
19	10	2.90	0.74	18.60	2.22	22.30	70.17	0	0	0	0	0	0	0	0	0	0	0	0	0
20	10	2.90	0.88	17.10	3.21	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0
21	10	1.80	1.23	17.60	3.24	0.60	1.90	0	0	0	0	0	0	0	0	0	0	0	0	0
22	10	2.70	0.48	17.10	3.26	0.00	0.00	0	0	0	0	0	0	0	0	0	0	0	0	0
23	10	2.60	0.97	17.50	3.44	2.34	4.99	0	0	0	0	0	0	0	0	0	0	0	0	0
24	10	2.00	1.27	16.60	2.76	8.20	25.93	0	0	0	0	0	0	0	0	0	0	0	0	0



Appendix D

Date	Leaf Primordia				Leaves				Aphis pomi				Aphidoletes aphidmyza			
	Site	N	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
6-22-78	1	10	1.50	1.27	18.90	4.61	41.70	72.60	0	0	0	0	0	0	0	0
	2	10	1.30	1.49	16.50	4.67	18.60	27.07	0	0	0	0	0	0	0	0
	3	10	0.30	0.95	16.20	3.19	3.60	8.85	0.10	0.32	0	0	0	0	0	0
	4	10	2.70	0.68	19.60	3.57	32.70	63.68	0	0	0	0	0	0	0	0
	5	10	1.50	.97	19.20	3.46	18.00	23.64	0	0	0	0	0	0	0	0
	6	10	0.50	0.85	15.10	4.12	1.70	4.42	0	0	0	0	0	0	0	0
	7	10	2.20	1.62	18.50	4.33	13.80	27.17	0	0	0	0	0	0	0	0
	8	10	1.20	1.23	16.30	3.43	2.60	6.40	0	0	0	0	0	0	0	0
	9	10	1.30	1.49	17.20	3.39	5.60	12.68	0	0	0	0	0	0	0	0
	10	10	2.50	1.08	20.60	2.76	22.80	44.23	0	0	0	0	0	0	0	0
	11	10	1.60	1.43	18.90	5.67	23.40	40.96	1.80	5.35	0	0	0	0	0	0
	12	10	0.60	1.08	17.20	4.34	7.00	11.83	0	0	0	0	0	0	0	0
	13	10	3.10	0.57	22.00	4.24	26.60	30.54	0.10	0.32	0	0	0	0	0	0
	14	10	2.20	1.13	19.30	3.65	4.80	6.46	0	0	0	0	0	0	0	0
	15	10	2.00	1.25	20.50	2.80	7.60	13.25	0	0	0	0	0	0	0	0
	16	10	2.00	0.92	18.80	3.88	18.20	19.00	0	0	0	0	0	0	0	0
	17	10	1.80	1.32	18.90	3.35	9.30	15.23	0	0	0	0	0	0	0	0
	18	10	1.70	1.49	17.90	1.79	7.10	10.72	0	0	0	0	0	0	0	0
	19	10	2.30	1.25	21.20	3.74	16.90	41.84	0.30	0.95	0	0	0	0	0	0
	20	10	2.10	0.99	20.60	4.08	69.10	183.30	0	0	0	0	0	0	0	0
	21	10	1.40	1.27	17.80	4.32	31.70	57.87	0	0	0	0	0	0	0	0
	22	10	2.40	1.75	20.10	3.34	37.60	53.62	0	0	0	0	0	0	0	0
	23	10	1.90	1.87	18.46	4.00	41.50	63.15	0	0	0	0	0	0	0	0
	24	10	2.10	1.20	19.20	3.26	44.50	116.63	0	0	0	0	0	0	0	0



Appendix D

Date		Leaf Primordia			Leaves			Aphis pomi			Aphidoletes aphidmyza		
Site	N	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
1	10	1.00	1.41	21.70	3.47	78.80	100.09	0.20	0.63				
2	10	0.70	1.25	21.00	3.59	28.70	33.64	0	0				
3	10	0.00	0.00	20.20	3.82	1.00	2.21	0	0				
4	10	1.30	1.16	24.20	3.65	89.50	89.86	.40	.84				
5	10	0.70	0.83	20.20	3.01	47.60	73.96	0	0				
6	10	0.10	0.32	20.30	3.71	2.50	5.21	0	0				
7	10	2.20	0.79	23.40	2.76	140.30	149.13	0.5	0.71				
8	10	0.30	0.48	19.90	5.30	24.40	41.14	0	0				
9	10	0.40	0.70	21.10	2.42	1.70	2.50	0	0				
10	10	1.50	1.35	22.30	4.32	74.60	55.76	0.60	1.77				
11	10	0.50	0.71	20.60	4.22	46.80	60.53	0	0				
12	10	0.00	0.00	16.60	3.81	3.00	9.49	0	0				
13	10	2.10	1.37	25.00	4.14	99.70	88.41	0.30	0.68				
14	10	1.80	1.62	24.70	5.70	35.10	73.92	0	0				
15	10	0.80	1.03	21.20	4.47	14.30	32.30	0.10	0.32				
16	10	1.90	1.37	23.20	4.13	32.20	31.75	0	0				
17	10	0.80	1.03	20.80	3.12	36.20	53.60	0.20	0.63				
18	10	1.00	1.15	19.80	4.52	10.70	8.83	0	0				
19	10	1.60	1.35	27.00	5.59	59.90	70.09	0	0				
20	10	1.30	1.25	23.10	4.82	66.20	103.41	0.20	0.63				
21	10	0.80	1.23	18.20	3.33	24.00	34.65	0	0				
22	10	1.90	1.45	23.00	4.47	100.00	74.48	0.20	0.63				
23	10	0.80	1.03	17.90	3.21	43.20	44.17	0.20	0.42				
24	10	0.40	0.97	19.60	4.93	42.30	84.91	0	0				

Appendix D

Date		Leaf Primordia		Leaves		Aphis pomi		Aphidoletes aphidmyza	
Site	N	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
1	5	0.60	0.81	24.40	6.19	83.60	70.62	.20	0.45
2	5	0.00	0.00	19.80	5.07	7.20	15.54	0	0
3	5	0.00	0.00	14.80	1.92	0.00	0.00	0	0
4	5	1.00	1.00	24.20	2.86	109.00	55.00	0.80	1.79
5	5	0.40	0.89	22.60	3.21	55.40	103.54	1.60	3.59
6	5	0.00	0.00	15.60	1.67	0.00	0.00	0	0
7	5	1.00	0.71	23.00	4.74	111.00	85.40	1.20	2.68
8	5	0.40	0.55	18.60	4.98	18.00	18.91	0	0
9	5	0.60	1.34	20.20	2.59	14.00	26.08	0	0
10	5	1.20	1.10	25.40	3.21	123.00	82.51	0.20	0.45
11	5	0.00	0.00	19.80	5.22	10.20	22.25	0	0
12	5	0.00	0.00	16.40	4.88	15.00	20.62	0	0
13	5	1.00	1.00	22.80	4.03	105.00	70.36	1.60	3.58
14	5	0.40	0.89	25.20	6.06	17.00	21.39	0	0
15	5	0.40	0.89	22.20	1.92	4.00	6.52	0	0
16	5	1.60	0.59	25.60	6.80	68.00	50.82	0.80	1.78
17	5	0.40	0.90	22.60	3.21	12.00	16.43	0	0
18	5	0.80	0.84	20.40	4.62	4.00	6.52	0	0
19	5	1.40	1.52	27.80	3.33	76.20	47.35	0	0
20	5	0.40	0.89	22.20	3.03	18.40	13.80	0	0
21	5	0.20	0.45	20.80	4.66	7.20	9.58	0	0
22	5	1.00	1.00	26.60	1.82	141.00	145.75	0.60	1.34
23	5	0.40	0.90	23.60	2.41	48.00	52.03	0.40	0.81
24	5	0.20	0.45	23.20	6.76	12.20	16.63	0	0



Appendix D

Date		Leaf Primordia			Leaves			Aphid pomi			Aphidoletes aphidimyza		
Site	N	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
1	10	.10	0.32	21.50	5.60	17.90	53.41	0.50	1.58				
2	10	0.00	0.00	17.80	5.03	11.80	4.47	0	0				
3	10	0.00	0.00	15.30	2.43	0.00	0.00	0	0				
4	10	0.30	0.68	22.30	6.08	63.20	126.10	0	0				
5	10	0.00	0.00	15.60	3.28	0.40	0.70	0	0				
6	10	0.20	0.63	16.20	4.26	33.00	104.36	0	0				
7	10	0.50	0.71	24.20	5.12	86.90	93.33	0.90	1.52				
8	10	0.00	0.00	14.00	4.72	0.10	0.32	0	0				
9	10	0.00	0.00	14.50	2.46	0.00	0.00	0	0				
10	10	0.10	0.32	22.30	4.35	30.10	41.07	0.80	1.40				
11	10	0.00	0.00	20.20	7.15	8.00	21.78	0.50	1.59				
12	10	0.00	0.00	15.60	3.10	0.00	0.00	0	0				
13	10	0.70	1.16	26.70	7.92	87.40	147.19	0	0.32				
14	10	0.10	0.32	21.30	5.91	42.90	112.31	0	0				
15	10	0.00	0.00	23.10	4.48	22.20	43.81	0	0				
16	10	0.20	0.63	24.50	4.28	76.00	140.16	0.20	0.63				
17	10	0.10	0.32	22.50	3.89	17.50	29.56	0	0				
18	10	0.00	0.00	18.30	4.72	3.50	11.07	0	0				
19	10	0.40	0.97	25.00	4.47	133.60	211.25	0	0				
20	10	0.00	0.00	22.80	4.19	56.00	103.36	0.10	0.32				
21	10	0.00	0.00	18.50	5.58	12.50	39.53	0	0				
22	10	0.30	0.68	24.90	6.49	117.00	161.58	0.20	0.63				
23	10	0.00	0.00	19.70	5.66	9.60	23.46	0	0				
24	10	0.00	0.00	18.30	3.23	0.00	0.00	0	0				

Appendix D

Date		7-20-77 Leaf Primordia			Leaves			Aphis pomi			Aphidoletes aphidimyza		
Site	N	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
1	10	0.10	0.32	25.60	7.55	188.20	267.57	5.80	6.23				
2	10	0.00	0.00	17.70	5.76	0.00	0.00	0	0				
3	10	0.00	0.00	16.70	4.76	0.00	0.00	0	0				
4	10	0.10	0.22	22.20	6.56	39.20	104.01	0.90	2.85				
5	10	0.00	0.00	17.90	4.43	0.00	0.00	0	0				
6	10	0.00	0.00	15.50	4.55	62.00	196.06	0.10	0.32				
7	10	0.10	0.32	22.40	8.10	91.00	97.43	1.80	2.63				
8	10	0.10	0.32	16.32	4.17	13.50	42.69	0.30	0.95				
9	10	0.10	0.32	16.20	4.64	0.00	0.00	0	0				
10	10	0.00	0.00	22.60	6.65	64.60	149.95	1.30	4.11				
11	10	0.00	0.00	18.60	5.95	16.00	50.60	0	0				
12	10	0.10	0.32	16.50	5.52	32.00	101.19	0	0				
13	5	0.00	0.00	31.20	4.82	199.00	268.42	1.60	3.05				
14	5	0.00	0.00	26.80	2.78	25.00	34.28	2.60	5.81				
15	5	0.00	0.00	23.60	4.51	1.40	2.19	0.20	0.45				
16	5	0.40	0.89	32.20	7.69	365.20	480.15	3.40	3.44				
17	5	0.20	0.45	26.60	6.54	103.00	219.22	0.60	1.34				
18	5	0.00	0.00	19.00	0.21	0.00	0.00	0	0				
19	5	0.00	0.00	27.00	5.92	88.60	190.89	0	0				
20	5	0.00	0.00	25.60	3.72	51.00	108.48	0.20	0.45				
21	5	0.00	0.00	26.00	4.95	65.00	145.34	1.00	2.24				
22	5	0.00	0.00	28.20	1.79	155.00	332.76	3.00	5.20				
23	5	0.00	0.00	24.60	5.98	44.00	69.86	1.00	2.24				
24	5	0.00	0.00	23.80	3.11	0.20	0.45	0.00	0.00				



Appendix D

Date		Leaf Primordia		Leaves		Aphis pomi		Aphidoletes aphidimyza	
Site	N	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
1	10	0.40	0.84	24.80	9.60	45.00	97.21	0.70	1.49
2	10	0.00	0.00	18.60	4.53	0.00	0.00	0	0
3	10	0.00	0.00	18.50	2.92	0.00	0.00	0	0
4	10	0.70	0.95	23.60	7.52	73.10	125.62	2.40	6.92
5	10	0.00	0.00	19.60	2.91	0.00	0.00	0	0
6	10	0.00	0.00	17.90	5.41	0.00	0.00	0	0
7	10	0.40	0.97	23.90	4.04	15.80	40.40	0	0
8	10	0.20	0.63	20.00	5.35	0.00	0.00	0	0
9	10	0.20	0.63	19.40	3.95	0.20	0.63	0	0
10	10	0.60	1.08	24.10	6.45	75.50	144.46	0.20	0.63
11	10	0.10	0.32	20.00	7.12	22.00	69.57	0	0
12	10	0.00	0.00	16.60	3.86	0.00	0.00	0.10	0.32
13	10	0.50	0.85	27.90	8.22	19.50	59.93	0.10	0.32
14	10	0.20	0.63	26.20	3.94	21.30	59.71	0.40	0.97
15	10	0.20	0.63	20.10	4.36	1.50	4.93	0	0
16	10	0.10	0.32	26.40	6.29	37.50	113.41	0	0
17	10	0.00	0.00	22.50	3.24	0.20	0.63	0	0
18	10	0.00	0.00	19.80	3.98	1.60	5.06	0	0
19	10	0.40	0.84	36.60	21.38	20.50	49.80	0.50	1.58
20	10	0.40	0.84	25.70	5.97	39.00	79.96	0.80	1.38
21	10	0.00	0.00	18.20	3.55	0.00	0.00	0	0
22	10	0.50	0.85	28.70	6.40	45.40	114.06	0.70	1.49
23	10	0.20	0.63	23.00	6.40	32.50	102.77	0.10	0.32
24	10	0.00	0.00	20.80	4.98	0.00	0.00	0	0



Appendix D

Date		Leaf Primordia		Leaves		Aphis pomi		Aphidoletes aphidimyza	
Site	N	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
1	10	0.50	1.08	24.50	6.21	1.70	4.72	0	
2	10	0.00	0.00	17.70	3.80	0.00	0.00	0	0
3	10	0.00	0.00	19.80	8.19	0.40	1.27	0	0
4	10	0.40	0.97	22.90	3.14	7.70	23.66	0.10	0.32
5	10	0.00	0.00	19.30	4.45	0.20	0.42	0	0
6	10	0.10	0.32	18.80	4.89	12.50	28.41	0.10	0.32
7	10	0.80	1.32	23.60	7.33	51.50	103.23	0	0
8	10	0.90	2.03	20.20	4.73	0.00	0.00	0	0
9	10	0.20	0.63	19.00	4.17	27.50	44.92	0	0
10	10	0.50	1.08	24.20	7.52	20.50	44.25	0	0
11	10	0.00	0.00	21.40	4.14	0.00	0.00	0	0
12	10	0.00	0.00	20.50	5.04	1.30	3.20	0	0
13	10	0.60	1.08	33.00	9.38	62.00	100.53	0.70	1.25
14	10	0.30	0.68	25.70	6.29	52.50	113.95	0.20	0.63
15	10	0.00	0.00	20.90	4.23	0.00	0.00	0	0
16	10	0.20	0.63	26.90	5.30	11.00	34.79	0	0
17	10	0.30	0.68	25.60	7.68	15.00	44.03	0	0
18	10	0.00	0.00	21.60	7.68	69.00	151.03	0.20	0.63
19	10	0.90	1.79	30.80	4.78	33.60	47.84	0.30	0.95
20	10	0.20	0.63	23.60	3.24	16.50	34.96	0	0
21	10	0.20	0.63	20.50	5.76	8.00	19.32	0	0
22	10	0.30	0.68	28.30	6.73	19.80	37.70	0	0
23	10	0.00	0.00	23.30	4.57	0.00	0.00	0	0
24	10	0.00	0.00	18.60	2.80	20.00	63.25	0.30	0.95

APPENDIX E
APHID AND PREDATOR BIOLOGICAL OBSERVATIONS

In the following appendice four tables are presented. The first is the raw counts of terminals in several quadrats of the tree (see also Results). The second are the results from the examination of the 200 terminals, from 1976 sampling, for A. pomi eggs. The data also shows the seasonal growth total for each terminal. The third table provides the aphid mean/terminal for each tree sampled in 1976 and 1977. The final table presents results of emergence cage trapping of adult Aphidoletes aphidimyza.



Table E1.

Estimated for Lower and Upper Quadrat Terminal Numbers,
Taken at Graham Station 1977.

<u>Tree #</u>	<u>Lower</u>	<u>Upper</u>
2	107	116
3	68	71
4	68	108
6	37	32
10	73	100
12	78	86
15	66	82
17	47	63
29	93	129
33	54	165
34	47	90
$\bar{X}$	67.09	94.73
S	20.75	35.40
N	11	11

<u>Tree</u>	<u>Quadrat</u>	<u>Canopy Level</u>	
		<u>Lower</u>	<u>Upper</u>
1	NE	57	64
5	NE	25	36
5	SW	28	36
7	NE	41	38
7	SW	50	41
9	NE	53	57
9	SW	52	56
35	SW	52	46



The following table presents the results from examining the terminals used in 1976 sampling for A. pomi eggs. In all a total of 5 eggs were found, suggesting limited oviposition occurred within the Red Delicious block.

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Table E2.

Egg Deposition and shoot length on red delicious trees.
 Samples taken in February 1977 prior to pruning and egg
 hatch. Most terminals were those observed in 1976.

<u>Terminal Code</u>	<u>Length In</u>	<u>Status</u>	<u>Eggs</u>
0111	22		0
0121	26.5		0
0131	9.5		0
0141	16.5		0
0141	14		0
0112	35.5		0
0122	50		0
0132	31.5		0
0142	30.5		0
0152	37		0
0311	28		0
0321	35		0
0331	26		0
0341	13		0
0351	8		0
0312	33.0	New	0
0322	33		0
0332	35.5		0
0342	38.5		0
0352	25		0
1111	69		0
1121	5.5		0
1131	17		0
1141	17		0
1151	12		0
1112	16	New	0
1122	30		0
1132	18		0
1142	11		0
1152	19.5		0

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Table E2. (Cont'd)

<u>Terminal Code</u>	<u>Length In</u>	<u>Status</u>	<u>Eggs</u>
1311	26.5		0
1321	24.5		0
1331	20.5		0
1341	6	Broken	0
1351	31	New	0
1312	39		0
1322	58		0
1332	30.5		0
1342	35		0
1352	39		0
2111	22		0
2121	24		0
2131	11.5		0
2141	10		0
2151	9		0
2112	33		0
2122	31		0
2132	15.5		0
2142	22		0
2152	15		0
2311	23.5		0
2321	17		0
2331	20.5		0
2341	9		0
2351	19		0
2312	39.5		0
2322	32		0
2332	35	New	0
2342	4	Broken	0
2352	31		0
3111	38		0
3121	11.5		0
3131	5		0
3141	9.5		0
3151	7.5	New	0
3112	20		0

Table

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Table E2. (Cont'd)

<u>Terminal Code</u>	<u>Length In</u>	<u>Status</u>	<u>Eggs</u>
3122	17		0
3132	16		0
3142	23.5		0
3152	14		0
3311	29.5		0
3321	11		0
3331	14		0
3341	6		0
3351	7.5		0
3312	26		0
3322	28		0
3332	25		0
3342	24		0
3352	21		0
4111	94	New	0
4121	42	New	0
4131	9.5		0
4141	9		0
4151	15		0
4112	39		0
4122	38	New	0
4132	23.5		0
4142	27		0
4152	28	New	0
4311	18		0
4321	38.5	New	0
4331	31	New	0
4341	18		0
4351	15		0
4312	48.5		0
4322	37		0
4332	38		0
4342	23		0
4352	33		0
5211	28.0	New	0
5221	28.5		0
5231	20		0

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Table E2. (Cont'd)

<u>Terminal Code</u>	<u>Length In</u>	<u>Status</u>	<u>Eggs</u>
5241	23.5		0
5251	15		0
5212	33.5		0
5222	44		0
5232	34		0
5242	29		0
5252	19		0
5411	29		0
5421	21.5		0
5431	6.5		0
5441	9		0
5451	11		0
5412	50		0
5422	35.5		0
5432	18.25		0
5442	18.5	New	0
5452	8.5		0
6211	21.5		0
6221	44		0
6231	45		0
6241	7		0
6251	9		0
6212	46		0
6222	34.5		0
6232	36.5		0
6242	29		0
6252	25		0
6411	24		0
6421	20.5		0
6431	12	New	0
6441	13		0
6451	11		0
6412	24		0
6422	17		0
6432	21.5		0
6442	25		0

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Table E2. (Cont'd)

<u>Terminal Code</u>	<u>Length In</u>	<u>Status</u>	<u>Eggs</u>
6452	23.5		0
7211	33		0
7221	11		0
7231	43		0
7241	18	New	0
7251	9.5		0
7212	19		0
7222	18		0
7232	28		0
7242	28.5		0
7252	30.5	New	0
7411	6.5		0
7421	8		0
7431	10.5		0
7441	11		0
7451	27.5		0
7412	18		0
7422	27		0
7432	27.5		0
7442	17		0
7452	11.5		0
8211	20		0
8221	32.5		0
8231	27.5		0
8241	12.5		0
8251	13.5		0
8212	47.5		0
8222	43.5		1
8232	23		0
8242	37		0
8252	35.25		0
8411	15.25		0
8421	17.75		0
8431	21.5		0
8441	21		0
8451	11.5		0

Table

Level

Table E2. (Cont'd)

<u>Terminal Code</u>	<u>Length In</u>	<u>Status</u>	<u>Eggs</u>
8412	35		2
8422	4.8		1
8432	44		0
8442	30		1
8452	27		0
9211	37.5		0
9221	10		0
9231	3.5	Broken	0
9241	7.5		0
9251	4.5	Broken	0
9212	32		0
9222	14.5		0
9232	27		0
9242	19.5		0
9252	8.75		0
9411	52		0
9421	25		0
9431	19		0
9441	12.5		0
9451	12		0
9412	20		0
9422	17		0
9432	33.5		0
9442	23.5		0
9452	34		0

200 Terminals

Mean Length = 23.93 S = 11.98

Total Length 4786.5 Inches
(398.88 Feet)

01007

Excluded

800

Table E3.

1977

Aphid Means for Each Tree (N = 24) and Percent of Infested Terminals

Sample Dates

Tree #	A		B		C		D		E		F	
	Mean	%	Mean	%	Mean	%	Mean	%	Mean	%	Mean	%
1	0.000	0	2.197	16.7	11.375	12.5	41.583	70.8	38.958	75.0	32.542	58.3
2	0.125	4.2	3.167	33.0	0.000	0.0	27.917	66.7	26.458	54.2	54.125	58.3
3	0.167	4.2	0.625	8.3	22.958	29.2	16.708	62.5	55.792	79.2	32.125	75.0
4	0.458	12.5	0.750	12.5	2.792	29.2	19.292	83.3	36.083	66.7	38.167	62.5
5	1.583	8.3	4.375	12.5	0.292	8.3	10.875	62.5	91.917	83.3	62.917	75.0
6	1.042	8.3	4.708	37.5	7.792	16.7	0.333	8.3	26.625	62.5		
7	7.542	8.3	5.625	20.8	6.917	20.8	9.042	50.0	31.917	66.7		
8	1.208	8.3	2.792	20.8	6.125	16.7	27.917	62.5	37.208	70.8		
9	0.000	0	6.667	25.0	0.292	12.5	53.042	66.7	72.167	75.0		
10	0.083	4.2	0.625	8.3	1.875	12.5	2.417	29.2	40.667	79.2		
Date Means	1.25	6.24	3.15	19.45	6.04	15.84	20.91	56.25	45.78	71.26	43.98	65.82



Table E3. (Cont'd)

Aphid Means and Percent of Infested Terminals

Tree #	Sample Date					
	G		H		I	
	Mean	%	Mean	%	Mean	%
1	24.875	33.0	122.167	50.0	9.125	12.5
2	39.625	37.5	17.708	20.8	13.875	16.7
3	4.708	12.5	22.208	33.0	66.250	41.7
4	67.625	41.7	187.792	54.2	15.417	25.0
5	69.500	54.2	5.125	12.5	9.292	12.5
6	20.333	50.0	50.917	25.0	0	0
7	30.750	25.0	0	0	4.167	8.3
8	0.042	4.2	39.917	41.7	15.042	8.3
9	3.042	25.0	33.083	25.0	54.167	16.7
10	81.250	62.5	44.167	16.7	0.417	12.5
					40.000	54.2
Date						
Means	34.18	34.56	52.31	46.61	18.78	15.42
					17.95	20.42

In 1977 emergence cages were distributed singly at the base of ten trees. Cages were examined weekly and the number of Syrphidae, Cecidomyiidae, and Chrysopidae adults counted. These are the total catches each week.

On every third sample date the traps were moved in close proximity to the prior site under the tree. This was to capture Cecidomyiidae which had dropped to pupate in the soil area around the trap, in the previous two weeks.

base
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area

Table E4.

Emergence Trap Catches of Adult Predators in 1977 at Graham Station

<u>Date</u>	<u>Syrphidae</u>	<u>Cecidomyiidae</u>	<u>Chrysopidae</u>
507	19	9	0
511	0	10	0
518	25	39	1
525	30	110	0
602	0	5	0
610	8	28	1
615	10	31	0
622	10	40	0
629	3	53	0
706	6	47	1
713	2	19	6
720	9	23	3
727	14	32	3
803	20	33	4
810	9	25	4

Syrphidae (Diptera)

Cecidomyiidae (Diptera)

Chrysopidae (Neuroptera)

APPENDIX F Sample Size Estimation

Introduction

The organization of the following appendices is to show the steps involved in taking raw sample data through several distributional analyses. The distribution coefficients estimated were α and β of the mean crowding-mean relationship (Iwao and Kuno 1968), k and k_c of the negative binomial (Bliss and Fisher 1953, Elliott 1971) and a and b for the mean-variance relationship (Taylor 1961). Using the appropriate formulas sample size estimates of several sample designs are computed.

In the analysis which follow the results are shown primarily for the 1977 data. Samples were not taken randomly in 1976 and these initial attempts at defining the habitat sample unit and the sample universe are occasionally included in an analysis as a general index only. Loss of randomness makes interpretation of the 1976 data difficult and further analysis unwarranted.

The sample universe chosen was the tree, within which the habitat sample unit, the apple terminal, was located. Stratified sampling conducted in 1977 (see Methods, main text) allowed several sample designs to be tested. Four sample designs were selected and distribution analysis using



both A. pomi and A. aphidimyza performed for designs where sufficient data existed.

Throughout all analysis, the total tree sampling scheme (N = 24) is presented for both A. pomi and A. aphidimyza. Analysis is also presented for the lower and upper canopy sampling quadrats. These were chosen for accessibility and host growth-high aphid density characteristics, respectively. Finally, data from the four lower-inner canopy positions (at the center of the lower canopy) in analyzed and presented where sufficient information existed.

The analysis were performed using the estimates per tree from each sample date. These were also used as estimates when combining all dates. Thus, results presented include each sample date and the combination of all dates for a sample design.

Mean Crowding and the Mean

Calculation of Iwao and Kuno's (1968) α and β required obtaining estimates of mean and m^* , a mean crowding index proposed by Lloyd (1967). Using the estimates, linear least squares regression was performed to obtain α and β for each sample date and for the total season. Tables F1 and F2 present the 1976 and 1977 values of α , β and r^2 for A. pomi on each sample date and for the total season.

1000

1000

1000

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1000

Using the total season values (1977) sample size estimates in the three sample design for A. pomi are presented in Table F3. The formula used in their computation was

$$q = t^2 / D^2 \frac{(\alpha + 1 + \beta - 1)}{\bar{x}}$$

where q = sample size, corrected for error relative to the mean

t = students modified t statistics

D = error relative to the mean

α and β = Iwao and Kuno's regression coefficients

$\bar{x}$ = desired mean value

Table F4 shows the regression coefficients for A. aphidimyza on each sample date and for the combined sample date. Table F5 provides the total tree sample size estimates for the predator using the combined seasonal estimates of α and β .

100
100
100
100

Table Fl. 1976 Iwao and Kund Regression Results For Aphid Population Counts

Date	Lower Quadrat			Upper Quadrat			Total Tree		
	α	β	r^2	α	β	r^2	α	β	r^2
A	10.70	2.09	.471	8.53	2.83	.727	6.12	2.93	.879
B	24.09	2.72	.991	29.62	1.34	.772	14.04	2.00	.916
C	51.45	1.64	.996	-33.12	1.48	.971	61.22	1.58	.884
D	-201.53	4.62	.726	172.71	0.94	.927	-32.29	2.12	.815
E	82.72	1.49	.619	20.87	1.36	.932	-43.39	2.96	.603
F	6.31	10.47	.991	-3.54	7.11	1.000	-15.49	14.07	.993
G	0.00	7.65	1.00	-4.48	8.49	.998	-8.21	17.25	.989
H	-2.60	10.09	.993	-9.76	6.93	.481	-9.93	13.23	.765
I	0.00	8.00	1.00	-0.02	6.70	.782	1.37	10.50	.534

All Dates	12.58	2.36	.750	36.42	1.25	.950	42.82	1.65	.880
Means For A-I	5.086			4.126			7.404		
Variance A-I	14.201			9.576			39.471		

Note Lower Quadrat Dates G & I Contain Only 1 or 2 Points - May be Insufficient For Analysis

very positive tone

Table F2. 1977 Iwao and Kuno Regression Results For Aphid Population Counts

Date	Lower Quadrat			Upper Quadrat			Total Tree		
	α	β	r^2	α	β	r^2	α	β	r^2
A	-0.258	10.429	.946	1.922	5.884	.988	0.025	11.930	.998
B	-1.782	5.864	.907	-3.842	9.917	.853	2.784	7.937	.722
C	-4.869	7.823	.975	-4.668	10.074	.897	-14.668	14.872	.965
D	2.503	3.159	.920	-11.536	4.156	.929	-19.255	5.657	.733
E	25.408	2.490	.858	39.321	1.430	.811	57.061	1.904	.704
F	-3.888	2.970	.866	-14.848	3.431	.731	-14.204	3.276	.868
G	27.233	4.207	.859	10.741	3.316	.967	58.876	3.837	.845
I	23.773	5.822	.860	31.995	3.544	.619	97.739	4.321	.468
J	8.436	5.750	.790	25.242	3.686	.695	54.013	4.140	.496

All Dates

12.758 4.051 .744 16.430 3.140 .814 38.900 3.708 .720

$\bar{X}$

5.338

4.830

6.114

S^2

5.860

8.621

17.05

Table F3. Sample Sizes (Tree Number) For Estimating A. pomii populations Bases
On Three Canopy Divisions Iwad and Kuno Method.

Mean	Lower Quadrat			Upper Quadrat			Total Tree		
	.1	.2	.3	.1	.2	.3	.1	.2	.3
1	67012	3981	926	78019	4635	1078	169863	10092	2348
5	2356	316	93	2284	306	90	4340	582	170
10	1453	208	62	1275	183	54	2194	315	94
15	1219	178	54	1015	148	45	1650	241	73
20	1113	164	50	896	132	40	1399	206	62
25	1051	156	47	828	123	37	1256	186	56
30	1011	151	45	784	117	35	1168	173	53
40	963	144	44	730	109	33	1051	157	48
50	936	140	43	700	105	32	987	148	45
60	916	138	42	679	102	31	942	142	43
75	900	135	41	680	99	30	901	137	41
100	881	133	40	639	96	29	859	130	39
120	870	131	40	628	95	29	836	126	38
	α	β		α	β		α	β	
	12.76	4.05		16.43	3.14		38.90	3.71	



Table F4. 1977 Predator Linear Regression Values From Iwao and Kuno Analysis

Date	α	β	r^2
6-22-77	-.259	19.955	.982
6-29-77	.311	2.832	.144
7-06-77	-0.088	6.552	.972
7-13-77	.344	6.895	.446
*7-20-77	2.549	3.361	.626
7-27-77	-0.869	13.923	.929
8-03-77	-0.022	7.184	.966
Combined	.222	7.014	.637

* Does not include lower canopy level of last five trees sampled.



Table F5. 1977 Predator Sample Sizes (Trees) Estimated
Using Iwao and Kuno's Method

<u>Mean</u>	<u>Error Relative to Mean</u>		
	<u>.1</u>	<u>.2</u>	<u>.3</u>
1.0	28847	1714	397
1.5	14556	1052	260
2.0	5649	589	160
2.5	4522	499	140
3.0	3555	431	122
3.5	3198	400	115
4.0	2872	371	107
4.5	2704	356	104
5.0	2541	241	100
6.0	2347	322	95
7.0	2222	310	92
8.0	2133	301	90
9.0	2066	294	88
10.0	2015	289	86
11.0	1976	284	85
12.0	1942	281	84
13.0	1916	278	84
14.0	1892	276	83
15.0	1873	274	82
20.0	1807	267	81

$$\alpha = 0.222$$

$$\beta = 7.014$$

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Negative Binomial

The estimates of the negative binomial k obtain was derived with formulas presented by Elliott (1971). Difficulties in estimation of the negative binomial coefficient by other methods (e.g. Bliss and Fisher 1953) limits the study to perhaps a bit less regorous methodology.

Tables F6-F8 present the estimates used to obtain k values on each sample date for lower, upper and total tree sample designs. To determine if computation of c common K (K_c) was applicable, linear regression of $1/k$ and $\bar{X}$ was performed (see lower portion of each table). If the computed slopes were not significantly different from a horizontal line, the common K was computed.

Using the formula

$$n = t^2/D^2 (1/\bar{X} + 1/K_c)$$

tree sample number estimates were computed (Elliott 1971). These are presented in Table F9 for A. pomi.

Similarly the approaches used in calculation of K values for A. aphidimyza are presented in Table F 10. The sample size estimates (trees) for the total tree sample design are presented in Table F10.

Table F6. 1977 Calculation of Common K for A. pomi.

$$x' = \bar{x}^2 - s^2/n$$

$$y' = s^2 - \bar{x}$$

$$1/k = y^1/x^1$$

$$1/k_c = \Sigma y' / \Sigma x'$$

Sample Date	Lower Canopy						
	$\bar{X}$	S^2	n	X'	Y'	1/K	K
6-03	0.26	2.28	120	0.049	2.021	41.564	.024
6-10	4.72	148.98	120	21.037	144.260	6.857	.146
6-15	7.98	1658.97	120	49.856	1650.99	33.115	.030
6-22	15.98	1312.94	120	244.419	1296.960	5.306	.188
6-29	43.83	5923.99	120	1871.702	5880.160	3.142	0.318
7-06	45.20	3469.79	60	1985.210	3424.590	1.725	0.580
7-13	14.88	4014.47	120	187.960	3999.590	21.279	0.047
7-20	42.25	15398.42	120	1656.742	15356.170	9.269	0.108
7-27	19.30	5899.97	120	323.324	5880.670	18.188	0.055
8-03	10.28	1446.35	120	93.625	1436.070	15.338	0.065

$$1/k_c = 6.073 =$$

$$K_c = .165$$

Check for independence: plot of

1/K vs $\bar{x}$

Regression Equation

$$y = 26.311 + -0.524 (\bar{x}) \quad r^2 = .45$$

As slope is not greatly different from a horizontal line the points may assume to be independent.

Table F7. 1977 Calculation of Common K for A. pomi

Sample Date	Upper Canopy					
	$\bar{X}$	S^2	n	$\bar{X}'$	$\bar{Y}'$	$1/K$ K
6-03	2.18	144.97	120	3.544	142.790	40.287 0.025
6-10	1.73	81.73	120	2.312	80.00	34.605 0.029
6-15	4.10	534.76	120	12.354	530.660	42.956 0.023
6-22	25.91	4941.18	120	630.152	4915.270	7.800 0.128
6-29	46.86	4580.70	120	2157.687	4533.840	2.101 0.476
7-06	42.75	5321.24	60	1738.875	5278.490	3.036 0.329
7-13	47.43	12563.63	120	2144.908	12516.200	5.835 0.171
7-20	91.12	20242.14	120	7965.485	20151.020	2.530 0.395
7-27	18.25	4244.64	120	262.319	4226.390	16.112 0.062
8-03	25.62	4925.25	120	574.297	4899.630	8.532 0.117

$$1/K_C + 3.697$$

$$K_C = 0.270$$

Check for independence: Plot of $1/K$ vs $\bar{X}$

$$\text{Regression Equation} \quad Y = 30.732 + 0.469 (\bar{X}) \quad r^2 = .625$$

No dependence (slope ~ 1.0) common K applicable

Table F8. 1977 Calculation of common K for A. pomi

Sample Date	Total Tree					
	$\bar{X}$	S^2	N	X'	Y'	L/K K
603	1.22	74.08	240	1.180	72.860	61.760 0.016
610	3.23	117.10	240	9.945	113.870	11.450 0.087
615	6.04	1096.07	240	31.915	1090.030	34.155 0.029
622	20.95	3138.70	240	425.825	3117.825	7.322 0.137
629	45.98	5233.05	240	2033.911	5187.710	2.551 0.392
706	43.98	4360.09	120	1897.900	4316.420	2.275 0.440
713	33.80	8347.91	240	1107.657	8314.110	7.506 0.133
720	71.00	22235.80	240	4855.702	22164.798	4.565 0.219
727	17.95	3231.56	240	308.738	3213.610	10.409 0.096

$$1/K_C = 4.782$$

$$K_C = 0.209$$

Check for independence: Plot of

$$1/K \text{ vs } \bar{X}$$

Regression Equation

$$Y = 29.76 - 0.54(\bar{X}) \quad r^2 = .409$$

: Common K Applicable

Table F9. 1977 Sample Size Estimates For A. pomi Populations based on K_C
(number of trees) at Varying Errors Relative to the Mean

Mean	Lower Canopy			Upper Canopy			Total Tree		
	.1	.2	.3	.1	.2	.3	.1	.2	.3
1	28148	1672	389	18752	1114	259	23062	1370	319
5	2542	341	100	1585	213	62	2024	271	79
10	2023	290	87	1249	179	54	1604	228	69
15	1883	275	83	1159	170	51	1491	218	66
20	1818	268	81	1117	165	50	1439	212	64
25	1780	264	80	1092	162	49	1407	209	63
30	1755	261	79	1076	160	49	1387	207	63
40	1726	258	78	1057	158	48	1364	204	62
50	1711	257	78	1048	157	48	1348	203	62
60	1697	255	78	1039	156	48	1341	202	61
75	1690	254	77	1034	156	47	1335	201	61
100	1677	253	77	1026	155	47	1324	200	61

$$K_C = .165$$

$$K_C = .270$$

$$K_C = .209$$

$$\text{Formula } n = t^2/D^2 \quad (1/\bar{x} + 1/K_C)$$



Table F10. Computation of Common K, For 1977 Aphidoletes Aphidimyza Counts
(Refer to Elliott1971) for Total Tree Sampling.

Sample Date	$\bar{X}$	S^2	N	X'	Y'	1/K (EST)
6-29	.09583	1.25019	240	.00397	1.15436	290.77
7-06	.12083	0.22383	240	.01367	0.10300	7.53
7-13	.24167	1.17640	120	.04860	0.93473	19.23
7-20	.13750	0.45382	240	.01702	0.31632	18.58
7-27	.93889	7.90127	180	.083762	6.96223	8.31
8-03	.15833	0.46855	240	.02312	0.31022	13.42

$$\Sigma Y' / \Sigma X' = 10.36109 = 1/K_C$$

$$K_C = 0.09651$$

$$X' = \bar{X}^2 - S^2/N$$

$$Y = S^2 - \bar{X}$$

$$1/K = Y' / X' \text{ (Est)}$$

Table F11. 1977 Sample Size Estimates for A.
Aphidimyza Using K_c (number of Trees)

Mean	Total Tree		
	.1	.2	.3
1.0	45294	2691	626
1.5	23509	1698	420
2.0	9261	966	262
2.5	7483	826	231
3.0	5921	757	203
3.5	5352	670	192
4.0	4823	623	180
4.5	4553	599	174
5.0	4288	575	168
6.0	3975	545	161
7.0	3772	525	156
8.0	3628	512	152
9.0	3519	501	149
10.0	3435	492	147
15.0	3205	469	141
20.0	3098	457	138

$$K_c = .09651$$

$$n = \frac{t^2}{D^2} \left(\frac{1}{\bar{X}} + \frac{1}{K_c} \right)$$

Mean Variance Relationship

The computation of Taylor's (1961) coefficients from the mean-variance relationship involved obtaining individual tree estimates for A. pomi and A. aphidimyza in three sample designs. The results, from log-log regression, for total tree, lower canopy and lower inner canopy sampling designs of A. pomi and A. aphidimyza populations are presented in Table F11.

The formula for sample size estimation using Taylor's coefficients was presented by Croft, Welch and Dover (1975).

It is:

$$n = \frac{t^2}{D^2} \left(\frac{1}{.9\bar{X}} + \left(m + \frac{1}{k}\right) \frac{V(\bar{X})}{\bar{X}^2} + 1/k \right)$$

where

n = number of samples

t = students modified t statistic ($\alpha + .05$)

D = error relative to the mean

a = sampling efficiency (a = 0.9)

$\bar{X}$ = desired mean

M = number of secondary sample units (terminals)

K = negative binomial coefficient

V(x) = Variance estimate using Taylor's coefficients

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1000

Tables F12 and F13 show the estimated variances for several means of A. pomi and A. aphidimyza, respectively. Also shown are the K_c values used for each sample design for both species. Table F14 presents the student t values used in the formula. Table F15. and Table F16 present the terminal sample number and the tree sample number at varying densities and at three levels of error relative to the mean for the A. pomi and A. aphidimyza sampling designs.

1917
1918
1919

Table F12. Results For 1977 Taylor's Mean Variance Relationship (per tree bases)

A. pomi

	Sample Design		
	Total Tree	Lower Canopy	Lower Inside
Intercept	19.82	7.71	3.28
Slope	1.4956	1.771	1.754
r^2	.760	.965	.957
K_c	.209	.165	.209

A. aphidimyza

	Sample Design		
	Total Tree	Lower Canopy	Lower Inside
Intercept	7.32	7.348	3.45
Slope	1.658	1.692	1.495
r^2	.943	.841	.715
K_c	.097		

Table F13. Computed Variances ($V\bar{X}$) From Taylor's Mean Variance Relationship A. pomi 1977.

$\bar{X}$	Vx Tree	Vx Lower	Vx Inner
1	7.320	7.348	3.450
5	105.320	111.899	38.263
10	333.051	361.551	107.850
15	652.335	717.985	197.731
20	1051.039	1168.186	303.990
25	2058.629	2319.841	557.334
40	3316.855	3774.458	856.838
50	4801.792	5505.876	1196.132
60	6496.596	7495.508	1570.924
75	9405.084	10933.842	2197.985
100	15153.435	17789.721	3371.468
$K_c =$	.209	.165	.209

Table F14. Computed Variances ($V\bar{X}$) From Taylor's Mean
Variance Relationships A. aphidimyza 1977.

$\bar{X}$	$\frac{V\bar{X}}{\text{Tree}}$	$\frac{V\bar{X}}{\text{Lower}}$	$\frac{V\bar{X}}{\text{Inner}}$
1	19.820	7.710	3.008
1.5	35.965	15.809	6.037
2.0	54.889	26.313	9.896
2.5	76.190	39.067	14.519
3.0	99.601	53.956	19.860
3.5	124.924	70.892	25.881
4.0	152.008	89.805	32.555
4.5	180.733	110.635	39.856
5.0	211.000	133.331	47.765
6.0	275.831	184.145	65.334
7.0	345.960	241.949	85.144
8.0	420.968	306.497	107.099
9.0	500.519	377.508	131.119
10.0	584.337	445.045	157.137
15.0	1060.328	933.065	315.357
20.0	1618.249	1553.025	516.949

$$K_c = 0.09651$$



Table F15. t - Values Used In Computation of Sample Size Estimates

<u>A. pomi.</u>		<u>A. aphidimyza</u>	
Mean	$t = 0.05$	Mean	$t = 0.05$
1	6.314	1.0	6.314
5	2.015	1.5	4.617
10	1.812	2.0	2.920
15	1.753	2.5	2.637
20	1.725	3.0	2.353
25	1.708	3.5	2.242
30	1.697	4.0	2.132
40	1.684	4.5	2.074
50	1.678	5.0	2.015
60	1.671	6.0	1.943
75	1.668	7.0	1.895
100	1.662	8.0	1.860
		9.0	1.833
		10.0	1.812
		15.0	1.753
		20.0	1.725

Error Relative to the mean

D = 0.1

0.3

0.5

1000

1000

1

2

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Table F16. Terminal and Tree Sample Size Estimates for *A. aphidimyza* Populations
Using Formulae of Croft, Welch, and Dover (1976).

Sample Design and Terminal Sample Size Estimates ¹									
Mean	Total Tree (N = 24)			Lower Canopy (N = 12)			Lower Inside (N = 4)		
	.1	.3	.5	.1	.3	.5	.1	.3	.5
	2.7+E06	298447	110400	73229	81359	55474	217119	24124	8685
1.0	1.2+E06	132688	47768	358289	39810	14332	105508	11723	4220
1.5	411254	37267	16450	134642	14960	5386	39513	4390	1581
2.0	298736	33193	11949	104653	11628	4186	30655	3406	1266
2.5	216445	24019	8658	80127	8903	3205	23449	2605	938
3.0	181476	20164	7259	70386	7821	2815	20589	2288	824
3.5	153199	17022	6128	61862	6874	2474	18094	2010	724
4.0	136461	15162	5458	57095	6344	2284	16702	1856	668
4.5	122032	13559	4881	52702	5856	2108	15421	1713	617
5.0	103362	11485	4134	47151	5239	1886	13808	1534	522
6.0	90888	10099	3636	43418	4824	1737	12729	1414	509
7.0	81817	9091	3273	40673	4519	1627	11938	1326	478
8.0	75199	8317	2994	38539	4282	1542	11326	1258	453
9.0	69357	7706	2774	36841	4093	1474	10841	1205	434
10.0	52964	5885	2119	31883	3533	1268	9388	1043	376
15.0	44592	4954	1778	28931	3229	1157	8620	958	345

Sample Design and Tree Sample Size Estimates									
Mean	Total Tree (N = 24)			Lower Canopy (N = 12)			Lower Inside (N = 4)		
	.1	.3	.5	.1	.3	.5	.1	.3	.5
	115000	12435	4600	61019	6780	4623	54280	6031	2171
1.0	48758	5529	1990	29857	3317	1194	26377	2931	1055
1.5	17136	1553	685	11220	1247	449	9878	1098	395
2.0	12447	1383	498	8721	969	349	7664	852	307
2.5	9019	1002	361	6677	742	267	5862	572	206
3.0	7562	840	302	5865	652	235	5147	572	206
3.5	6383	709	255	5155	573	206	4524	503	181
4.0	5686	632	227	4578	529	190	4175	464	167
4.5	5085	565	203	4392	488	176	3855	428	154
5.0	4307	479	172	3929	437	197	3452	384	138
6.0	3787	421	151	3618	402	145	3183	354	127
7.0	3409	379	136	3389	377	136	2985	332	119
8.0	3133	347	125	3212	357	128	2836	315	113
9.0	2890	321	116	3070	341	123	2710	301	108
10.0	2207	245	88	2657	294	106	2347	261	94
15.0	1858	206	74	2411	269	96	2155	239	86

¹95% certainty of meeting the specified error level

Table F17. Terminal and Tree Sample Size Estimates For A. pomi. Populations Using Formulas of Croft, Welch, and Dover (1976).

Sample Design: Estimates of Terminal Sample Numbers ¹									
Mean	Total Tree (N = 24)			Lower Canopy (N = 12)			Inside Lower (N = 4)		
	.1	.3	.5	.1	.3	.5	.1	.3	.5
1	862668	95852	35174	480703	53411	19228	143487	15943	5739
5	51353	5706	2054	30721	3363	1211	7474	831	299
10	33077	3675	1323	19993	2221	800	4711	552	188
15	27134	3015	1085	16646	1850	666	3864	429	154
20	23943	2660	958	14844	1649	594	3424	380	137
25	21850	2428	874	13657	1517	546	3146	350	126
30	20348	2261	814	12804	1423	512	2953	328	118
40	18285	2032	731	11874	1292	465	2697	300	108
50	16909	1879	676	10843	1205	434	2543	282	101
60	15845	1761	634	10228	1136	409	2443	268	96
75	14725	1636	590	9584	1065	383	2290	254	92
100	13373	1486	535	8333	977	352	2142	238	86

Mean	Total Tree (N = 24)			Lower Canopy (N = 12)			Lower Inside (N = 4)		
	.1	.3	.5	.1	.3	.5	.1	.3	.5
1	35944	3994	1466	40059	4451	1602	35872	3986	1435
5	2140	238	86	2523	280	101	1869	208	75
10	1378	153	55	1666	185	67	1178	138	47
15	1131	126	45	1387	154	55	966	107	39
20	998	111	40	1237	137	49	856	95	34
25	910	101	36	1138	126	46	787	87	31
30	848	94	34	1067	119	43	738	82	30
40	762	85	30	990	108	39	674	75	27
50	705	78	28	904	100	36	634	70	25
60	660	73	26	852	95	34	611	67	24
75	614	68	25	799	89	32	573	64	23
100	557	62	22	736	81	29	536	60	21

¹95% Certainty of meeting the specified error level

APPENDIX F
Pertinent Literature

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