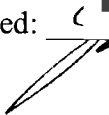AN ABSTRACT OF THE THESIS OF

Leslie M. Viguers for the degree of Master of Science in Entomology, presented on September 8, 2000. Title: Survey of Leafhoppers (Homoptera: Cicadellidae) in Integrated Production and Non-Integrated Production Vineyards of Western Oregon Using Yellow Sticky Traps and Sweep Net Methods.

Abstract approved: Redacted for Privacy

James R. Fisher/ Glenn C. Fisher

Leafhoppers (Homoptera: Cicadellidae) were surveyed in Western Oregon

vineyards in 1999. Four sites were sampled for leafhoppers using a sticky trap

method, and 29 vineyards were sampled for leafhoppers using a sweep net method in

the summer of 1999. The sticky trap and sweep net methods were chosen based on

cost, ease of use, and the fact that they are commonly used tools available for growers

and IPM programs. Populations varied according to sample method, date, location,

height, agricultural practices, and growing region. Each method resulted in the

capture of different leafhopper species. Sticky traps attracted, and caught mobile

insects such as the winged adults. The sweep net captured leafhoppers of all stadia

from the vegetation. There was seasonal variation seen for each leafhopper group.

Greatest numbers of leafhoppers were caught on the border and edges of the vineyard,

presumably because of the surrounding vegetation providing refuge and food. The

height of catch was dependent upon the preferred host plant of the leafhopper.

Species that feed on the grapevine were generally found in the canopy from 90 to 150

cm above the soil surface. Vineyard management influenced abundance and diversity

within the sites. Those vineyards using the least input had the highest diversity and

lowest overall abundance of leafhoppers. Chemical use, irrigation, and cover crop

choice influenced the species composition of the vineyard. The sites to the south of the Willamette Valley had a higher abundance of the species *Psamotettix* sp. The community structure of leafhoppers appeared to be more similar in the southern sites to California.

The vineyards that had a diverse mix of plants in the cover crop had a more diverse population of leafhoppers. Most species found in this study feed on herbaceous plants that are common as vineyard ground cover. The cover crop that most low input management sites use may increase the number of leafhoppers that feed on the vine, but the presence of a cover crop has many advantages in the vineyard system.

Survey of Leafhoppers (Homoptera: Cicadellidae) in Integrated Production and Non-Integrated Production Vineyards of Western Oregon Using Yellow Sticky Traps and Sweep Net Methods.

by

Leslie M. Viguers

A Thesis Submitted
to
Oregon State University

In Partial Fulfillment of
the requirements for the
degree of

Master of Science

Presented September 8, 2000
Commencement June 2001

Master of Science thesis of <u>Leslie M. Viguers</u> presented on September 8, 2000

Approved:

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Leslie M. Viguers, Author

Acknowledgment

I would like to acknowledge Dr. Jim Fisher for giving me the opportunity to pursue this degree. His support as a mentor and as a friend helped me through the past two years. His constructive criticisms and his door that was always open were invaluable. I thank Jon Umble, who spent countless hours helping me with whatever task I was working on. He was always understanding, encouraging, and willing to help. My mother Makenna Rielly, ceaselessly believed in my abilities, and was always there to listen and gently push me forward. Finally, I thank Simon Fentress, who was my Gabriel, providing an endless supply of support, love, and backrubs.

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Chapter 1

Literature Review

1.1 Survey methods

1.1.1 <u>Sweep net</u>

The sweep net is one method for monitoring insects in a vineyard. The sweep samples are taken from the cover crop vegetation between the vines. Because of its low cost, speed, and simplicity, the sweep net is still the most common tool that growers use for sampling (Schotzko and O'Keeffe 1989). Many states use sweep net sampling in their potato leafhopper management program and it is commonly used with IPM programs to sample adult populations of leafhoppers (Degooyer et al. 1998). This method is qualitative (Purcell and Frazier 1985) and cannot determine absolute density of an insect population, but it can be used to describe the relative abundance within and between species. Primarily, it is a good measure of the presence of adult leafhoppers because immatures of particular genera such as *Empoasca* stay too low on the vegetation (DeLong 1932; Fleischer and Allen 1982). The accuracy of sweep net samples can be influenced by a number of abiotic and biotic factors such as, weather, time of day, person sampling, height of vegetation, wind, and temperature (Schotzko and O'Keeffe 1989). For instance the adults of *Empoasca* spp. move up and down on the vegetation during the day. They stay lower on the vegetation when the temperature is high and may even move to the surface of

the ground and then, when the temperature is moderate ($< 25°$ C), they move up on the plants (DeLong 1932).

1.1.2 D-vacuum

The D-vacuum (D-vac) uses suction to collect insects. As opposed to other sampling methods it can be used to find absolute results, because of the unit area consistency (Wilson and Claridge 1991). The D-vac "vacuum insect net" suction sampler (D-vac Corp., Riverside, CA) is powered by a 12v battery; it weighs approximately 9 kilograms. It is attached to a frame and worn as a backpack. Attached to the motor is a flexible hose terminating in a plastic container with a fine mesh netted bottom. This method works best for collecting certain species of nymphs, mites, and very small insects that are relatively sessile and easily dislodgeable (Purcell and Frazier 1985). When sampling grapes, the D-vac probably gives a more accurate estimate of what is actually on the vines, versus incidentals found through sweep netting or other methods that sample from the cover crop. The D-vac usually causes less damage to vines than other methods such as the beating sheet or destructive leaf sampling (Schotzko and O'Keeffe 1989). The D-vac was not used in this study, but is an important and useful tool.

1.1.3 Sticky Traps

Sticky traps have been used for a number of years to monitor small flying insects (Pienkowski and Medler 1966). Commonly, a sticky trap card is 10 x 15 cm and coated with an inert sticky substance called "stickum" special. Though sweep net

samples have a lot of advantages, one consideration for using sticky traps is that insect thresholds are nominal with respect to sweeps and economic with respect to sticky traps (Degooyer et al. 1998). The sticky trap is an easy way for growers to monitor vineyard insects; they are inexpensive and do not damage the vines. Blue and yellow sticky traps attract different species of insects. Yellow sticky traps have been used to monitor leafhopper vectors of Pierce's Disease (Purcell 1981). Purcell (1975) evaluated the effect of color on attraction to Pierce's Disease vectors. Bright yellow had the best attraction for the blue-green sharpshooter *Graphocephala atropunctata* (Signoret), an efficient vector of Pierce's Disease. When sticky traps have been used for collecting sharpshooters, the optimum height of placement was 120 to 150 cm above the ground in the row (Purcell 1975). However, these traps will only attract adult leafhoppers. Purcell (1975) found that as few as 10 sticky traps could be used to monitor a vineyard. Sex ratio of leafhoppers in the field cannot be determined from sticky traps, as males of some species are attracted in greater number to the traps than females (Raine 1956). Additionally, the stickum renders most small insects identifiable only to genus, and can obscure diagnostic features of insects (Degooyer et al. 1998).

1.1.4 Other Survey Methods

Other methods of sampling for arthropods such as the beating sheet, leaf pulling, and pitfall traps are not commonly used in vineyard systems (Pienkowski and Medler 1966). Leaf pulling is ideal for the detection of mites, but has no real application in the detection of leafhoppers. Pitfall traps only would collect the ground

dwelling insect of the cover crop and would not give insight to the insects on the vines.

1.2 Pierce's Disease

Pierce's Disease has caused major vineyard losses in California. It is caused by a xylem-limited bacterium, *Xylella fastidiosa* Wells et al. that multiplies in the vascular tissue and plugs the vessels (Fry and Milholland 1990a). The host plant responds to the invasion by producing pectins, tyloses, and gums that also obstruct the xylem vessels intensifying water stress (Fry and Milholland 1990a). Certain species of Cicadellidae (Purcell 1981) and Cercopidae (Brcak 1979) vector Pierce's Disease. Pierce's Disease of grapes is transmitted only by species within the Cicadellinae. Symptoms of Pierce's Disease were first recognized in California as early as 1884. They were described by Newton B. Pierce in 1892 (Hewitt et al. 1945), who referred to the disease as "California vine disease." Later, it was renamed Pierce's Disease (Hewitt et al. 1945). Symptom expression of Pierce's Disease varies with the age of the vine, climate, cultivar, and season (Purcell 1975). Symptoms may include chlorosis, stunted growth and bud developement. The disease usually results in death of the vine in from 1 to 5 years after its diagnosis (Goheen and Hopkins 1988). Interestingly, *X. fastidiosa* has a wide host range including, alfalfa, grasses, herbs, shrubs, and trees (Hewitt et al. 1945).

Xyllela fastidiosa is maintained in the foregut of Cicadellinae vectors, (Brlansky et al. 1983), where it reproduces while attached to the food canal (cibirial pump) of the vector (Hill and Purcell 1995). Both nymphal and the adult leafhoppers

can transmit Pierce's Disease. However, nymphs lose the ability to transfer the bacteria with each molt because the foregut is shed as part of the exuviae (Brlansky et al. 1983). Therefore, there is no transtadial transmission of this disease. Once infected, adult leafhoppers retain and transmit Pierce's Disease for life (Purcell 1979a). Both male and female adult sharpshooters were found to have equal ability to transmit *X. fastidiosa* (Purcell 1975). *Xylella fastidiosa* is strictly a xylem limited bacteria (Brlansky et al 1983; Fry and Milholland 1990a,b; Hill and Purcell 1995). Inoculation of phloem or parenchyma cells does not result in infection. Even if a phloem-feeding leafhopper probes the xylem vessels, it will not spread the disease (Severin 1949a; Crane 1970). This suggests a link between disease transmission and feeding behavior (Golino 1993).

Vector efficiency will vary according to species. *Graphocephela atropunctata* (Signoret) has been the most efficient vector of Pierce's Disease (Purcell 1979b). This is primarily due to the relative feeding preference of *G. atropunctata*, which includes high host specificity to grapes, and the short latent period of the bacteria of 2 hrs. within the leafhopper (Purcell 1979a). *Graphocephala atropunctata* was first found in Oregon vineyards as a result of this study (Viguers and Fisher 1999). Other vectors that have been collected in Oregon include *Drauculacephala minerva* (Ball), and *Philaenus leucophalmus* L.

In California, from April, decreasing steadily into June, leafhoppers were found in greatest abundance near riparian borders of vineyards (Purcell 1975). As expected, the incidence of Pierce's Disease is highest in vines close to the shaded riparian zone. The host plants supply vectors that are already inoculated that migrate

into the vineyard. Raju et al. (1980) stated that the disease has usually been found in vineyards within 100 m of a water source. The occurrence of the disease spreads from the outside edges of the vineyard (Purcell 1979b). This happens because the leafhoppers have acquired the disease from the wild vegetation in the riparian area, and that these plants have acted as a reservoir (Raju et al. 1980).

1.3 Life History of Leafhoppers

Members of the order Homoptera are hemimetabolous. The life stages are egg, nymph, and adult. Within the family, Cicadellidae, there are over 15,000 described species (Wilson and Claridge 1991). Over 80% of the plant diseases that are vectored by insects are transmitted by Homopterans (Harris 1979). There are 128 species of known leafhoppers that vector plant diseases. Twenty-four transmit Pierce's Disease (Nielson 1979). Leafhoppers are particularly good vectors of plant disease because they are specialists at where they feed in the plant, and are confined to the host plant as nymphs. The fluid holding reservoirs, the clypeus and clypellus, of the leafhopper is swollen (Wilson and Claridge 1991). The enlarged clypeus supports powerful muscles that are needed to withdraw sap from the xylem (Nielson 1979).

Sharpshooter is the common name for leafhoppers belonging to the subfamily Cicidellinae of the Cicidellidae. The name sharpshooter was given to these insects because they forcefully eject large amounts of honeydew as they feed (Wilson and Claridge 1991). The xylem tissue is composed mostly of water, so most of the fluid that the insect extracts needs to be passed through the digestive system quickly to concentrate the nutrients; sharpshooters can feed up to 10 times their body weight in a

day (Degooyer et al. 1998). Both Cicadellidae and Cercopidae have evolved to have highly developed filter chambers to ingest the dilute xylem fluid and prepare it for absorption by the midgut (Purcell 1979b). The three most important vectors of Pierce's Disease are *Drauculacephala minerva* (Ball), the green sharpshooter, *Graphocephala atropunctata* (Signoret), the blue-green sharpshooter, and *Carneocephala fulgida* (Nott), the redheaded sharpshooter.

The green sharpshooter, *Draeculacephala minerva* Ball, is a minor vector of Pierce's Disease (Purcell 1981) that has been collected throughout the Western and Southwestern US, including California, Oregon, Nevada, and Utah (Delong and Severin 1949). The females lay eggs singly in an incision made in the leaf petiole with the ovipositor (Severin 1949b). Reproduction takes place on grasses or other host plants, but not on the grapevine (*Vitis vinifera* L.). There are three generations of the green sharpshooter a year in California (Purcell 1981). The green sharpshooter has a wide host range, but it especially prefers irrigated, grass-farmed land (Hewitt et al. 1945). The green sharpshooter will frequent the vines more often in the spring before the growth of summer grasses. They will remain for several days on the vine during this time and feed at the tips of the canes that are bending to the ground (Hewitt et al. 1945). In the summer they will not feed on the grapes for more than a few hours, and will not be found on the vines as often as in the spring. The coloration will vary from bright green to dull brown though the winter, and in late spring all adults are bright green (Purcell 1981).

The blue-green sharpshooter, *Graphocephala atropunctata* Signoret, has one generation a year (Purcell 1981). The egg incubation is approximately five weeks

long. Hatching is most successful when early morning temperatures are between 54 and 68° F (Severin 1949b). Females will continue to lay eggs until their death (Hewitt et al. 1945). The pattern of hatch and egg laying is continuous throughout the summer in the blue-green sharpshooter. They overwinter in the adult stage and die in late June (Purcell 1981). Since, *G. atropunctata* overwinters as an adult, the most important time for possible spread of Pierce's Disease in vineyards is early in the growing season (Purcell 1981). These new adults have high concentration of the bacteria and feed for prolonged periods of time at the tips of the new shoots.

The redheaded sharpshooter, *Cameocephala fulgida* Nott, is a particularly effective vector (Hewitt et al. 1945). It is also quite abundant it is not uncommon to record up to 500 redheaded sharpshooters per vine. During late summer the redheaded sharpshooter moves to other hosts. Removing infected vines won't help an infested vineyard because the disease is not spread from vine to vine, rather from a wild host to grapes (Purcell 1979b) although it can move from grape to the other hosts. *C. fulgida* has four generations per year. Eggs hatch from March to August in central California (Purcell and Frazier 1985). Bermuda grass is an important host plant, and the redheaded sharpshooter prefers less dense vegetation than the blue-green or the green sharpshooter (Purcell and Frazier 1985).

There are some important leafhopper pests of vineyards that do not transmit Pierce's Disease: *Empoasca fabae* Harris, the potato leafhopper and *Erythroneura elegantula* Osborn, the grape leafhopper (Jubb 1988). These leafhoppers are important because the injuries they cause by feeding and oviposition are often mistaken for disease symptoms (Jubb 1988). By piercing the mesophyll tissue on the

underside of the leaves, white speckling (chlorosis) appears on the leaves (Purcell 1981). The vines can usually withstand large numbers of leafhoppers without apparent injury; however, necrosis of leaves occurs when extreme infestations occur (Jubb 1988). Since vectors of Pierce's Disease have a wide host range that includes many plants on riparian sites they become common when other host plants have matured and dried in late summer (Jensen 1982). Additional damage can be caused by the growth of sooty mold in shady areas promoted by the liquid excrement that settles on the leaves and berries.

Jubb (1988) described the life cycle of the potato leafhopper. They breed in the Southern states (TX and AZ) and migrate North in the spring. Their distribution covers most of the U.S. Adults do not migrate back to the South in the fall. In addition to the injury stated above, the potato leafhopper causes toxemia in some grape plants, where the leaves look mottled brown with yellow margins (Wilson et al. 1992).

Grape leafhopper, *Erythroneura elegantula,* is a pest in southern California. They are host specific and will not lay eggs on another plant, other than grape. They overwinter as sexually immature adults. Sexual maturation occurs the following spring (Wilson et al. 1992). If there is a delay in bud break, the females will mate, but only lay sterile eggs during that season. The grapevine is a necessary food source to produce mature eggs (Wilson et al. 1992). The grape leafhopper has three broods per season (Wilson et al. 1992).

The genus *Aceratagallia* spp. has many members. Identification to species is often complicated, requiring dissection and examination of genitalia (Hamilton 1998).

This can be difficult due to the many parts needed to be identified and the amount of membranous fold covering each structure (Hamilton 1998). Little is known about the host plant preferences and life cycle of this poorly understood group. They are pests of legumes, and may be potential vectors of disease (Hamilton 1998). *Aceratagallia* spp. is a wide spread group that covers much of the U.S. There are 46 species and 11 subspecies of *Aceratagallia,* 3 of which are found primarily in Oregon (Hamilton 1998). *Aceratagallia* spp. has been commonly misidentified as *Ceratagallia* spp. The two are now considered subgenera of a single genus. They have a wide range of host plants and have a multi-voltine life cycle.

1.4 Cover crop management

Cover crops benefit vineyards by increasing organic matter, slowing erosion, augmenting water retention, and improving soil quality (Bordelon and Weller 1997; Lanini et al. 1989). Cover crops also have an effect on the microclimate, which in turn affects occurrence of insects and soil pathogens (Bordelon and Weller 1997). Variegated leafhopper (*Erythroneura variabilis* Beamer) populations in central California are significantly lower in vineyard systems that have a cover crop (Altieri 1994). This may be partially due to the greater number of generalist predators in cover cropped systems such as lacewings and spiders Altieri (1994).

Integrated Production (IP) and Integrated Pest Management (IPM) are relatively new management concepts in Oregon viticulture. In Europe in 1974, many countries collaborated on the principles of reduced input management forming the IOBC (International Organization for Biological Control and Promotion of Integrated

Systems) (Boller 1992). Boller's publication in 1992 summarized the main interests

of the IOBC and reviewed some findings of major importance regarding cover crop

management in vineyards. The IOBC promotes and certifies vineyards based on its

ecological diversification of the agro-ecosytem (vineyard) and maintaining its long-

term sustainability. Floral diversity is often low for many reasons and the need for

weed management and increase yields leads to intensive management practices

(Schonenberger 1999). To help foster increased floral diversity and sustainability,

chemical use is limited and a permanent cover crop must be established (Zalom

1993). Cover crops can increase the number of beneficial insects and predatory mites

in a vineyard, and can promote an increased nitrogen cycle (Boller 1992). A study in

Switzerland showed a significant correlation between floral diversity and numbers of

predatory insects and mites (Boller 1992). The presence of cover crops usually result

in a decrease in the number of pest species (Altieri 1994), and at the same time an

increase in the number of beneficial arthropods (Boller 1992).

1.5 Oregon LIVE program

Low Input Viticulture and Enology of Oregon (LIVE program) participated in

the Pesticide Environmental Stewardship Program (PESP) of the Environmental

Protection Agency (EPA). The goals of this program are to develop guidelines for

wine grape production that maintains high quality grapes by using low input

management practices, and limiting polluting agents (PESP 2000). Points are

awarded to each grower every year for following the guidelines outlined in the LIVE

program strategy and progress is assessed through this point system.

Five strategies are used to obtain the project goal. The first strategy is to use herbicides with low persistence. Also, growers earn points for using other methods of weed control, and some long-persistent herbicides are not allowed. The second strategy is to reduce the use of fungicides and insecticides through natural control and cultural practices. Leaf removal and shoot thinning can reduce the need for sprays of fungi and molds by increasing air flow and circulation. Sampling methods such as sticky traps are used to monitor for insects and determine control. The third strategy is to conduct soil and tissue analysis prior to fertilization. Testing of the soil insures that only the necessary chemicals will be applied to the vine. The fourth strategy is to limit irrigation to young vines, shallow soils, or drought conditions. Over irrigation of the vines results in more disease and pest pressure because of excessive vine growth and shading of the fruit. The fifth strategy is to offer training programs in integrated production to growers. In these courses, the growers are instructed in the use of natural control methods, cultural techniques, and monitoring procedures that help reduce the use of pesticides. Many Oregon grape growers are now participating in this low input, sustainable management program.

Chapter 2

Survey of Leafhoppers (Homoptera: Cicadellidae) in Willamette Valley Vineyards Using Yellow Sticky Traps.

2.1 Introduction

The wine grape growing industry is rapidly increasing in Oregon. Over the last decade vineyard plantings have doubled in the state (OWAB 1998). Washington, with more extensive and contiguous acreage, has noted infestations of leafhoppers, mealy bugs, cutworms, and aphids (Wilson et al. 1992). As vineyard plantings expand in Oregon, there is a greater possibility that some indigenous insects that are presently minor pests may become major pests. In Western North America, species in the insect order Homoptera, i.e. phylloxera, leafhoppers, mealy bugs, and sharpshooters, are the greatest threats to vineyard production (Wilson et al. 1992). With the rapid growth of the wine grape industry there is also an increased likelihood that non-native pest species will become established. Additionally increased inter-state travel and use of uncertified rootstock adds to the pest problems. For example *Homolodisca coagulata* Baker, the glassy-winged sharpshooter (an efficient Pierce's Disease vector) has been noted moving north in California (Eddy 2000). It is thought to have moved into California from Southeastern U.S. on ornamental nursery stock (Eddy 2000). With few exceptions vineyards of western Oregon are relatively free of insect pests. The arthropod fauna of Oregon vineyards has never been thoroughly surveyed.

The objectives of this research were to: 1) using sticky traps, compare species composition and population levels of leafhoppers with different cover crop management practices as categorized by conventional or low input, 2) evaluate the effect that location within a vineyard has on the diversity of species and abundance of leafhoppers caught and, 3) what effect height has on the abundance and diversity of leafhopper species caught by yellow sticky traps.

2.2 Materials and Methods

Yellow 15 x 30 cm sticky traps (Gempler's Inc., Belleville, WI) were monitored from July to October 1999 in selected blocks at two Integrated Production vineyards (sites A and B) and two non-Integrated Production vineyards (sites C and D) in the Willamette Valley wine grape growing region of Oregon. Each vineyard block was approximately 0.5–2 ha. The traps were placed on poles (5 cm x 5 cm x 190 cm) that were strategically placed within each vineyard; 3 poles on the edge of the vineyard, 3 poles in the center and 3 poles on the border. A tenth pole was also placed at the border to maximize trap catch. In general, the border was defined as having forest or riparian vegetation adjacent to the vines, and the edge was defined as having surrounding agriculture or roadside vegetation nearby (Fig. 1). Six sticky traps were placed on each pole at 30-cm vertical intervals, from 30 to 180 cm. The range in heights was chosen so the area below the vegetation canopy, within the vegetation canopy, and above the canopy would be sampled. Approximately every 15 days the traps were removed, insects counted, and new traps attached to the poles. The traps at sites A and C were changed each time within a 3-day period and sites B

and D were changed within a different 3-day period. The leafhoppers present were identified to the lowest taxon possible and recorded in the field. The immatures of all leafhopper species were categorized in the nymph category (no species) to reduce identification errors. There were 12 frequently encountered groups of leafhoppers; uncommon specimens were collected and preserved in 70% alcohol.
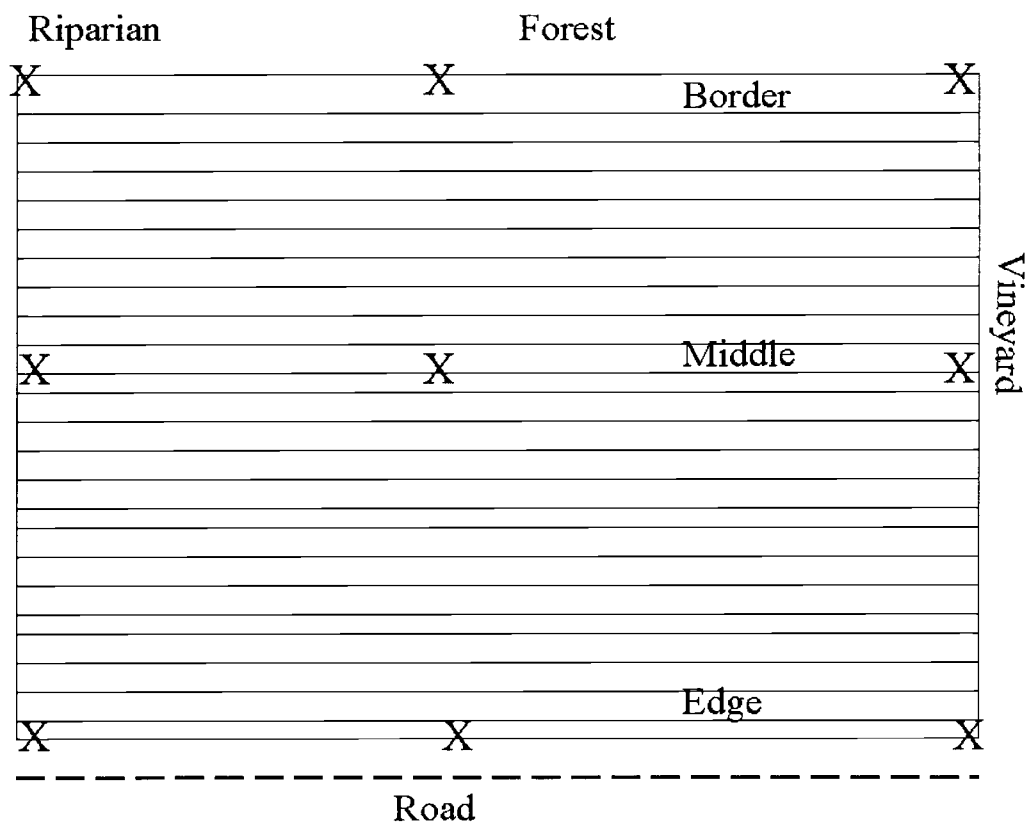
Figure 1. Layout of vineyard block.
Poles were located at each X.

Four vineyards were used for this study. Site A used conventional viticulture management practices, i.e. inorganic herbicides and fungicides were used when necessary or as a preventative measure, and a drip irrigation system was used during

dry months. A cover crop between the rows of grapes was either absent, or the

between row space was covered with patchy grass. The surrounding vegetation was

composed of grass and brush. Site B also used conventional viticulture practices with

a mowed grass cover crop and frequent herbicide and fungicide treatments. This

location had a border of hops (*Humulus lupus* L.) on one side and a vineyard and a

residence on the other sides. Sites C and D used low input viticulture practices. Both

vineyards had a very diverse cover crop (naturally occurring or purposefully planted

forbs and grasses) and they restricted pesticide use to fungicides only when

necessary. Site C was bordered by a cherry (*Prunus avium* L.) orchard on one side

and had a natural forested and riparian area on the other. Site D had a riparian area

along its border and a paved road ran along the edge (Table 1).

Table 1. Site characteristics of the four vineyards studied.

Vineyard	Management (IP or Non-IP*)	Cover Crop	Surrounding Vegetation
1 (A)	Non-IP	Low grass	Grass and Brush
2 (B)	Non-IP	Low grass	Vineyard and Hops
3 (C)	IP	Diverse	Cherry Orchard and Riparian area
4 (D)	IP	Diverse	Riparian vegetation

*IP denotes Integrated Production, and Non-IP denotes Non-Integrated Production management practices.

2.3 Data Analysis

The data were analyzed through several methods, a combination of multi-

variant and uni-variant statistics to maximize the inferences in the study. I used the

ordination procedures Non-metric Multidimensional Scaling (NMS), Multi Response

Permutation Procedure (MRPP), and Indicator Species Analysis (ISA). The

parametric procedure Analysis of Variance (ANOVA) was used to specifically

analyze the four groups of leafhoppers in relation to the objectives. The NMS, MRPP, and ISA analyses were conducted using PC-ORD (Mather 1976, Kruskal 1964), and the ANOVA using NCSS (Hintze 1997). For the ordination procedures, the data were arranged into 3 species matrices and 3 corresponding environmental matrices. In the main matrices, species were the dependent variable and the plots were the independent variable. For the environmental matrices the environmental variables were the dependent variable with the plots as the independent variable. To assess the seasonal distribution of leafhoppers in the vineyards, (i.e. all sampling times together) I summed location and height data in to a single unit for each date at each vineyard (date matrix). In the secondary matrix, date was coded as 1 through 6 to represent each sample time interval of two weeks. To determine the effect of location within vineyards, a location matrix was formed in which height and date were summed for the season for each pole within each vineyard. In the corresponding environmental matrix, location was coded numerically 1 through 3: 1 represented the edge of the vineyard, and was defined as either an agriculture border or a man-made structure, 2 was the center of the block, and 3 was defined as a border that had riparian or roadside vegetation. For the third matrix I summed the vineyards, locations, and dates for each height (height matrix).

I used Non-metric Multidimensional Scaling (NMS) (procedures from the software PCORD, McCune and Medford 1999) to analyze the sticky trap data for significant groups based on the height of traps, location of traps, dates and vineyard. The sample units (poles or vineyards) were ordinated in species space. NMS is an iterative ordination method based on ranked distances between sample units. NMS

has no assumption of normality and is especially useful for data that are non-normal.

NMS tends to linearize the relationships in the data set. The procedure was

conducted using the Sorensen distance measure (McCune and Medford 1999). The

dimensionality of the ordinations was either 2 or 3 axes depending on which data set

was used and the speed at which each NMS was conducted using PCORD.

I used Multi-Response Permutation Procedures (MRPP) (McCune and

Medford 1999) to determine if there were significant differences within date and

location. MRPP is a non-parametric procedure, and tested the hypothesis that there

were no differences of within group variation. Indicator species analysis (ISA)

(McCune and Medford 1999) was used to describe species significance with respect

to date, height, and location and was used on all the data sets that had significant

values in the MRPP test. This procedure was used on the date matrix, height matrix,

and on vineyard differences because of the significantly low p values. Analysis of

Variance (ANOVA) (Hintz 1997) was used on selected groups of leafhoppers to

determine the impact of individual groups in the population on selected

environmental variables. The groups of leafhoppers used in the ANOVA analysis

were chosen by the results from the ISA analysis, and from selecting important

groups of vectors and pests based on past literature from California and Washington.

Four groups of selected leafhoppers were analyzed using ANOVA:

Graphocephela atropunctata (Signoret), the blue green sharpshooter, an efficient

vector of Pierce's disease; *Empoasca fabae* (Harris) the potato leafhopper, an

occasional economic pest of grapes; *Aceratagallia* spp., an extremely abundant group

in most vineyards that does not cause damage to grapes; and the family Cercopidae,

the spittle bugs, that can be potential vectors of Pierce's disease because they are all xylem feeders. I used GLMANOVA (Hintz 1997) and the Tukey-Kramer (Jones 1984) test to detect significant differences for each group between the heights of collection, date of collection, location and site.

2.4 Data Transformations

With each data matrix I deleted the singletons (species that only occurred 1 time in the data set). This is commonly done in community data sets because the distribution of rare species are often too scattered to accurately estimate habitat or site associations (Krebs, 1989). Then the transformation, log (x+1) was applied, to reduce species skewness and reduce the coefficient of variation for the species totals for the location and the date matrix (Tables 2-3). McCune (2000) recommends relativizing the data (re-scaling the rows by the row totals). Relativization equalizes the weights between abundant and less abundant species, by assigning a value of one to the site that has the highest abundance for a particular species. Values for that species in the other sites are then assigned in proportion to the maximum site; this is done for each species. However, I chose not to relativize the data, because I was interested in the effect of the most abundant species more than the least abundant species.

Table 2. Effect of data transformations on location main matrix.

Parameter	Before	Deleted rare species (singletons)	Log(x+1)
ROWS	40.0	40.0	40.0
Beta diversity	1.6	1.4	1.4
Average Skewness	2.6	2.3	0.9
CV of row sums	77.6	77.6	16.8
COLUMNS	12.0	10.0	10.0
Average skewness	2.9	2.2	0.6
CV of column sums	208.0	186.8	83.0

Table 3. Effect of data transformations on date main matrix.

Parameter	Before	Deleted rare species (singletons)	Log(x+1)
ROWS	24.0	24.0	24.0
Beta diversity	1.6	1.4	1.4
Average Skewness	2.5	2.2	0.8
CV of row sums	83.2	83.2	14.7
COLUMNS	12.0	10.0	10.0
Average skewness	2.9	2.5	0.7
CV of column sums	208.0	186.8	76.0

2.5 Results and Discussion

2.5.1 Abundance of leafhopper species found in vineyards with different management practices.
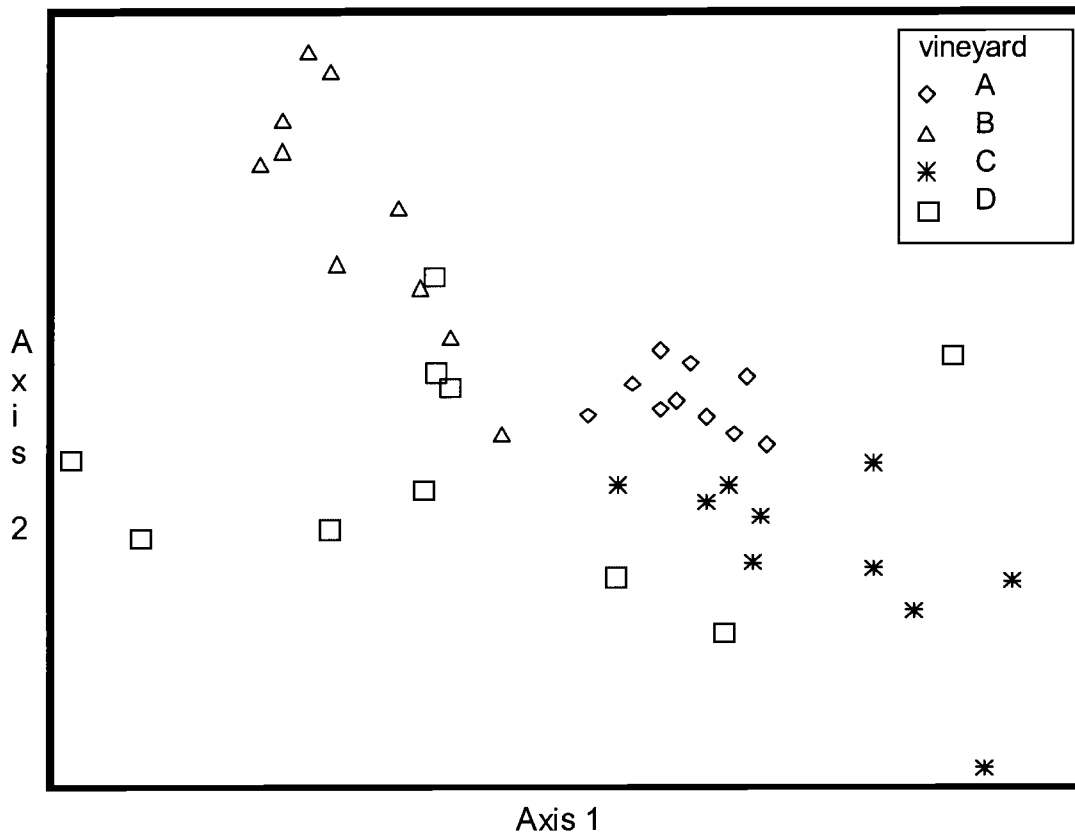
Figure 2. NMS ordination of poles in species space with an overlay of vineyard. All dates and heights were summed. A, non-Integrated Production vineyard; B, non-Integrated Production vineyard; C, Integrated Production vineyard; D, Integrated Production vineyard.

There were differences in the community structure of leafhoppers among the four vineyards (NMS, Fig 2). Site C was always distinct, in the ordination space for vineyard, from the other three sites. This site used low input management practices and had a riparian border. The types of leafhoppers found in this site were different then the other sites. Sample units (number of leafhoppers summed for all dates and heights) from vineyard A grouped together, and were not totally separate from the

other vineyards in the ordination. Vineyard A used conventional management practices and had a low grass cover crop. The abundance and diversity of leafhoppers in this vineyard was different than the others possibly because of the surrounding agricultural practices and vegetation. Sample units from vineyard B also tended to be clustered together. Vineyard B was located further east than the other three sites and in the ordination this site occupied a different space than the other three sites. There were definite groups seen in the ordinations, each vineyard formed a group. Based on the ordinations each vineyard had a community structure distinctly different from the others. There were significant differences among the four vineyards with respect to leafhopper diversity and abundance ($p < 0.05$, MRPP).

In the indicator species analysis (ISA) of significant leafhoppers with respect to vineyard, *G. atropunctata* and *Psamotettix* spp., a non-economic but sometimes abundant species, both had an r^2 value > 0.7 in the NMS (Table 4). The species were the indicator species for the four vineyards sampled with indicator values for each vineyard A-D. *Aceratagallia* spp. was an indicator species at all four vineyards. *G. atropunctata* was low at vineyard C, and *Psamotettix* spp. was low at vineyard B. *Colladonus motanus reductus* (Van Duzee), another non-pest species, was a good indicator taxa at site C with an indicator value of 46%. The indicator values in the Table show the percent of perfect indication, based on combining the relative frequency and the relative abundance of each species within each group.

Table 4. Indicator species analysis for vineyard.

Species group	Indicator Value	p-value	Indicator Value/Vineyard			
			A	B	C	D
Aceratagallia sp.	32.4	0.015	21	32	21	26
G. atropunctata	47.0	0.001	14	33	3	47
Psamotettix sp.	47.5	0.004	21	9	47	17
C. motanus	46.1	0.037	10	6	46	11

When analyzing the data using ANOVA, *Empoasca* spp. was the most abundant at the conventional management sites (A and B). Perhaps with the reduced competition from other species it was able to feed directly on the grapes. The most *Aceratagallia* spp. was at the conventional site (B) that had a border of hops. The hops may have been a reservoir for this group because population increase was seen after the hops were harvested in August. *Graphocephela* spp. was most abundant in the low input vineyard with the riparian borders (Fig. 3). This was expected because the plants that surround the riparian habitat are alternative hosts of the blue-green sharpshooter (Raju et al. 1980). These plants include Himalayan blackberry (*Rubus discolor* Weihe and Nees), Bermuda grass (*Cynodon dactylon* (L.)), and Beach grass (*Panicum amarum* (L.)). The abundance and distribution of Cercopidae was variable among the four sites. The high variation may be attributed to the consideration of this group on the family level instead of the generic or species level. However, species identification was difficult and all species of this group are non-economic.
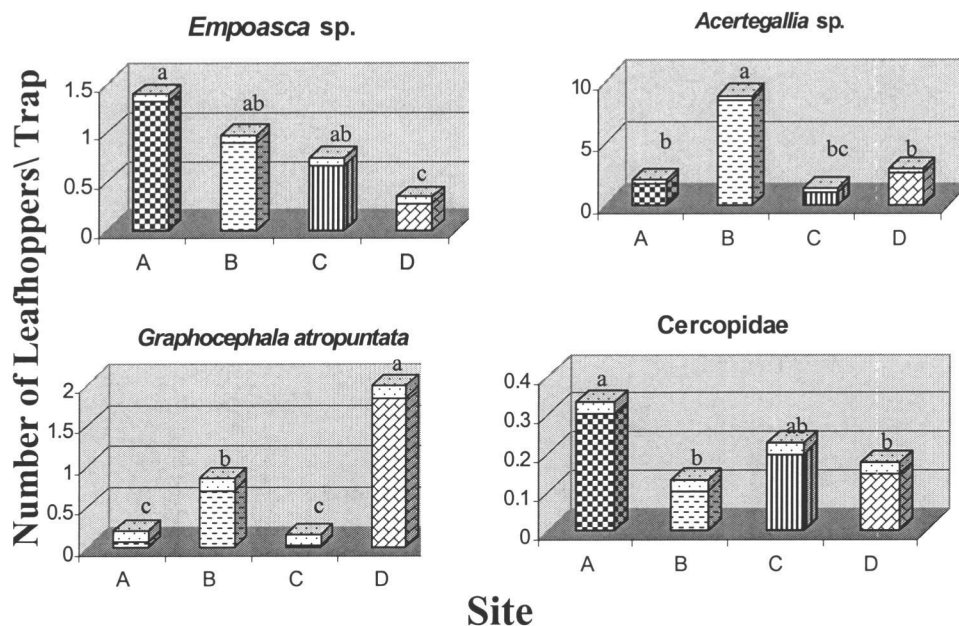
Figure 3. The average distribution of leafhoppers among sites for all dates combined.

* Columns followed by the same letter above are not significantly different from each other; Tukey Kramer test, p ≤ 0.05

2.5.2   Effects of trap location within the vineyard on leafhopper species diversity and abundance.

The ordination points for different locations (border, middle, and edge) did not appear to occupy distinct areas in the ordination space (Fig 4). The placement of poles within the vineyard did not show a significantly different number or type of leafhoppers caught.
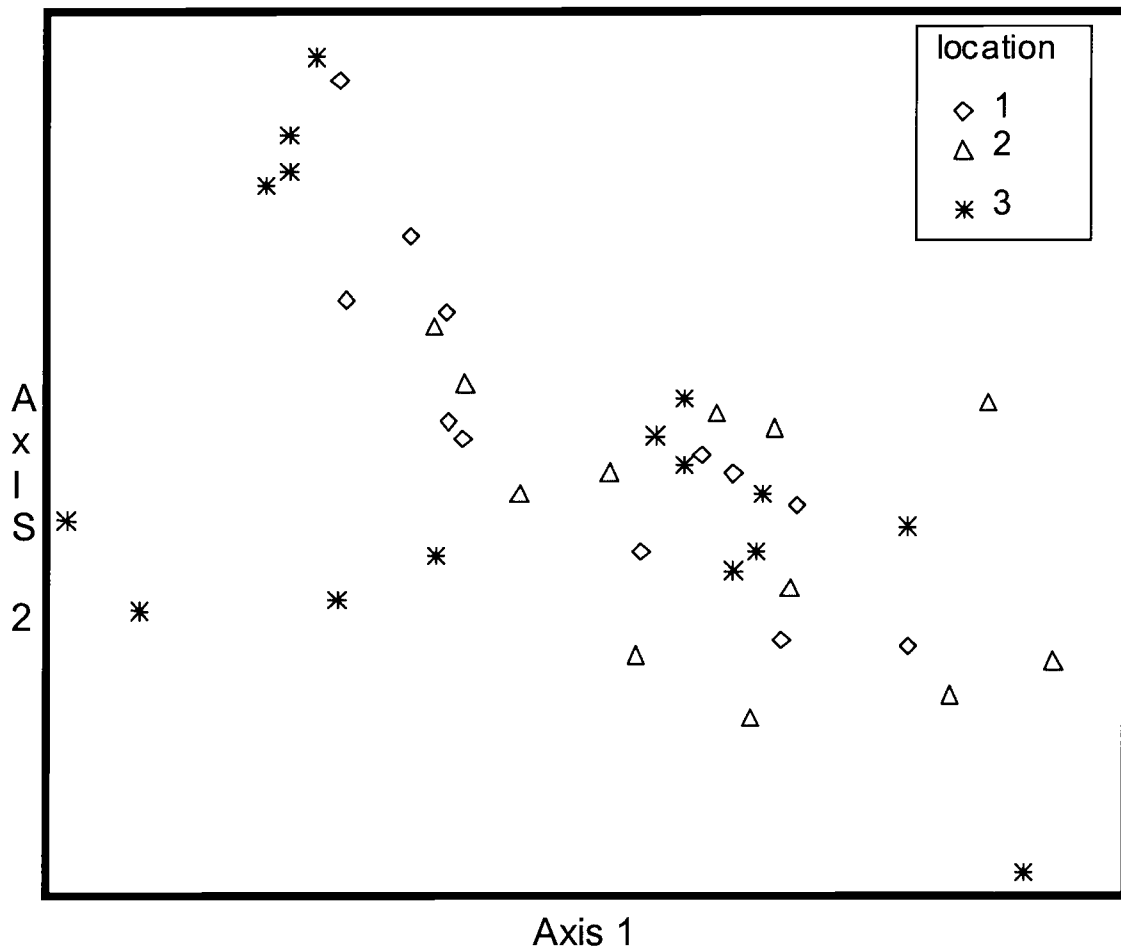
Figure 4. NMS ordination of poles, with an overlay of within vineyard location, in species space averaged across time for each vineyard.
1, edge; 2, middle; and 3, border.

Apparently, the effect of different management practices, border characteristics,

surrounding vegetation, and surrounding agriculture were more important in

determining leafhopper species diversity and abundance than the location of the traps

within the vineyard. Because all sample dates were combined in this matrix and the

ordination detects the strongest patterns within the data, it is possible that the effect of

location is not strong enough to be detected. The ordination evaluates the effect of all

the species. Additionally, Purcell (1975) found that the border is the best location to maximize catch of certain leafhoppers. There were no significant differences, according to the MRPP, for the number and diversity of leafhoppers by pole location (p = 0.58).

When I used the uni-variant method ANOVA, I found location differences for two groups. In general more leafhoppers were caught on the borders than in the middle or edge of the vineyard (ANOVA, Fig. 5). These differences were significant for the catch of *Graphocephela atropuntata* and *Aceratagallia* spp. (ANOVA, p ≤ 0.05). Both of these groups of leafhoppers do not complete their lifecycle on grapes (Hamilton 1998; Severin 1949b). They enter the vineyard occasionally to feed, then leave to feed and reproduce on their preferred host plant.

Location
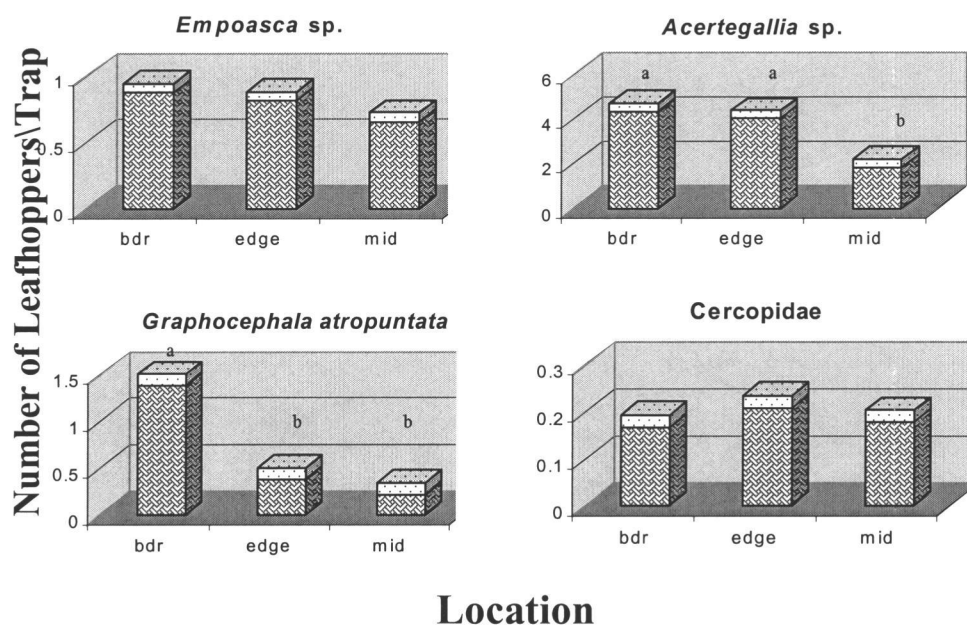
Figure 5. The distribution of leafhoppers within the vineyard with combined samples for all sites and all dates.   * Columns followed by the same letter above are not significantly different from each other; Tukey Kramer test, p < 0.05

Blue-green sharpshooters use blackberry as one host as well as grasses associated with the riparian habitat. Purcell (1975) found that the optimum sampling location for these two groups is the outside border of the vineyard. The present study supports this earlier research. Cercopidae and *Empoasca* sp. did not have significant differences with respect to within vineyard location. Cercopidae was found throughout the vineyard at about the same level on the border, middle, and edge. Cercopidae feed on a wide range of host plants, and were likely feeding on the cover crop vegetation. *Empoasca* sp. had no significant differences for location. *Empoasca* sp. feed on grape as one of their preferred host plants (Jubb 1988). Because of this host plant preference, the potato leafhopper will immigrate into the vineyard versus aggregating at the edges as seen with *G. atropunctata* and *Acerategallia* spp.

2.5.3   Effects of height of monitoring devices on the abundance and diversity of leafhopper species caught

There were loose groups formed based on the height of the sticky trap (Fig. 6, NMS). The tightness of the groups seen for height 1 may have been, because the types and abundance of leafhoppers caught at this low height was greater than the other heights. Most likely the cover crop in the vineyard provided an alternate food source and habitat for the leafhoppers. The diversity of food sources within the cover crop probably offered a corresponding diversity of leafhopper species. The other heights shared the same space but definite groups could be seen, especially for height 5 (at the top of the vegetation canopy) and height 6 (above the vegetation canopy). The height of the trap also had a significantly different within group variation ($p \leq 0.05$, MRPP).

Figure 6. NMS ordination of heights in species space summed for all sites and dates.
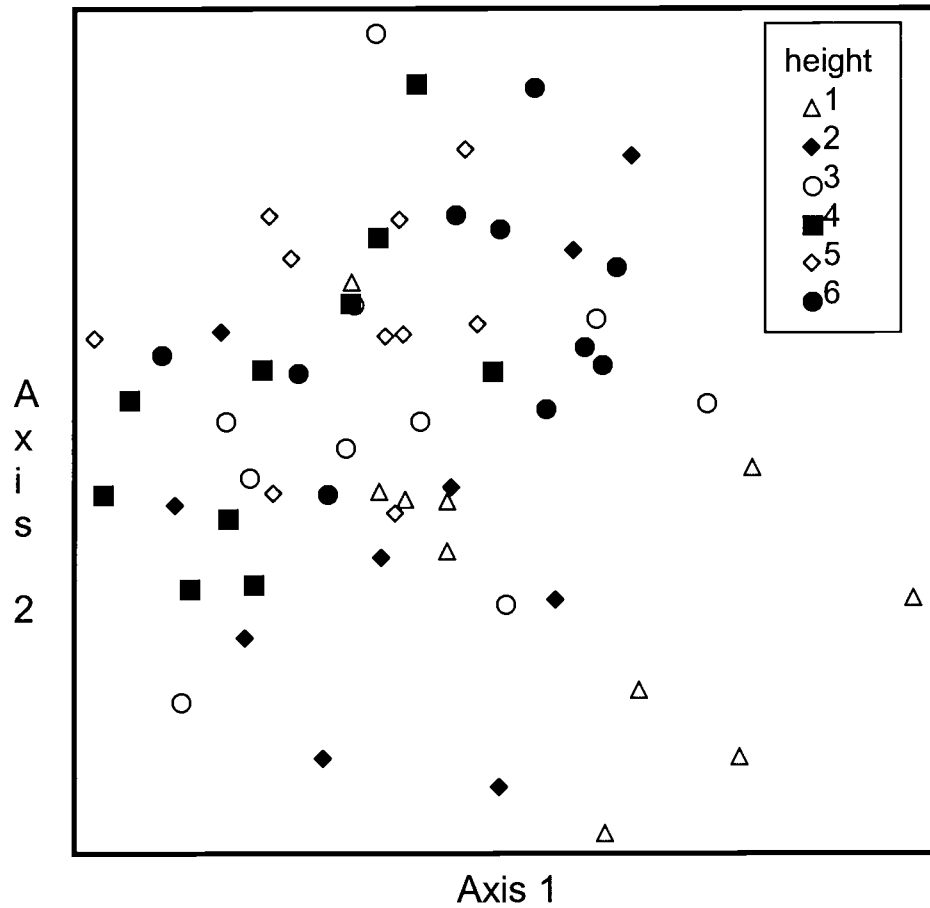Each number in the legend corresponds with the height of the trap, 1, 30 cm; 2, 60 cm; 3, 90 cm; 4, 120 cm; 5, 150 cm; and 6, 180 cm.

There were four groups of leafhoppers that had p values less than 0.05 in the ISA of height. Those groups were *Psamotettix* sp., nymphs, *Aceratagallia* spp. and *Colladonus montanus* (Table 5).

Table 5. Indicator species analysis for height of traps.

Species group	Indicator Value	p-value	Indicator Values/Height (in centimeters)					
			30	60	90	120	150	180
Psamotettix	24.0	0.02	10	10	11	16	24	19
Nymphs	26.0	0.04	26	7	16	8	6	6
Aceratagallia	18.6	0.001	19	17	17	17	16	15
C. montanus	24.0	0.04	7	11	24	24	10	3

The preferred host plants, of *Psamotettix* sp., are the graminaceous vegetation in the ground cover (Bosco et al. 1997). However, *Psamotettix* sp. had the highest indicator values at 120 to 180 cm, implying that some feeding is occurring within the vegetation canopy. The nymphs likely spend most of their time in the cover crop vegetation, and have the highest indicator value of 26% at the lowest height 30 cm from the ground. *Aceratagallia* spp. showed high indicator value at all heights. *Aceratagallia* spp. can feed on a wide range of host plants including those found in the cover crop (Hamilton 1998). *Colladonus montanus* had the highest values in the middle heights of 90 to 120 cm. These four groups are responsible for the pattern seen in the NMS ordinations of height.

The traps were placed from 30 to 180 cm to monitor below the canopy, within the canopy, and above the canopy. Significantly more *Aceratagallia* sp. ($p \leq 0.05$) was found at the lower heights of 30 to 90 cm (ANOVA, Fig. 7). This group feeds on grasses and forbs and is more likely to be found foraging in this lower area (Hamilton 1998). Cercopidae also followed this trend and was found in greater abundance below the canopy. Most of this family is omnivorous and tend to feed on grasses and

other plants in the cover crop. *Empoasca* spp. was generally found in greatest abundance from 90 to 150 cm. Presumably they feed on the new growth at the tips of the canopy. Significantly more *G. atropunctata* were found from 120 to 150 cm than at any other heights. Purcell (1975) found that using yellow sticky traps at 120 to 150 cm on the border of the vineyard was the best way to trap *G. atropunctata*. The sharpshooters have a range of hosts including Bermuda grass and blackberry. They can easily travel back and forth between the vine and the host plant. They are agile fliers and were intercepted by the yellow sticky traps at the canopy level. The differences in height interception among groups of leafhoppers were largely due to host plant preferences and flight patterns (Fig. 7).
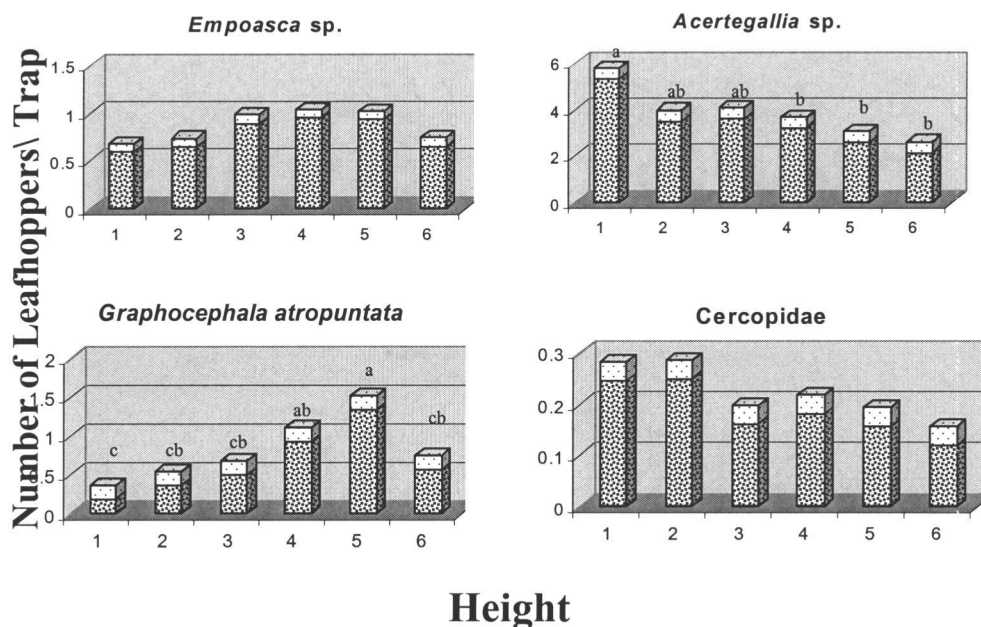
Figure 7. Height at which leafhoppers were caught for combined dates, sites and location.
1, 30 cm; 2, 60 cm; 3, 90 cm; 4, 120 cm; 5, 150 cm; and 6, 180 cm.

2.5.4 <u>Seasonal distribution and abundance of leafhoppers as measured by sticky traps.</u>

When I analyzed the effect of date on seasonal distribution of leafhopper

species, I found there were distinct groups in the date matrix (Fig 8).
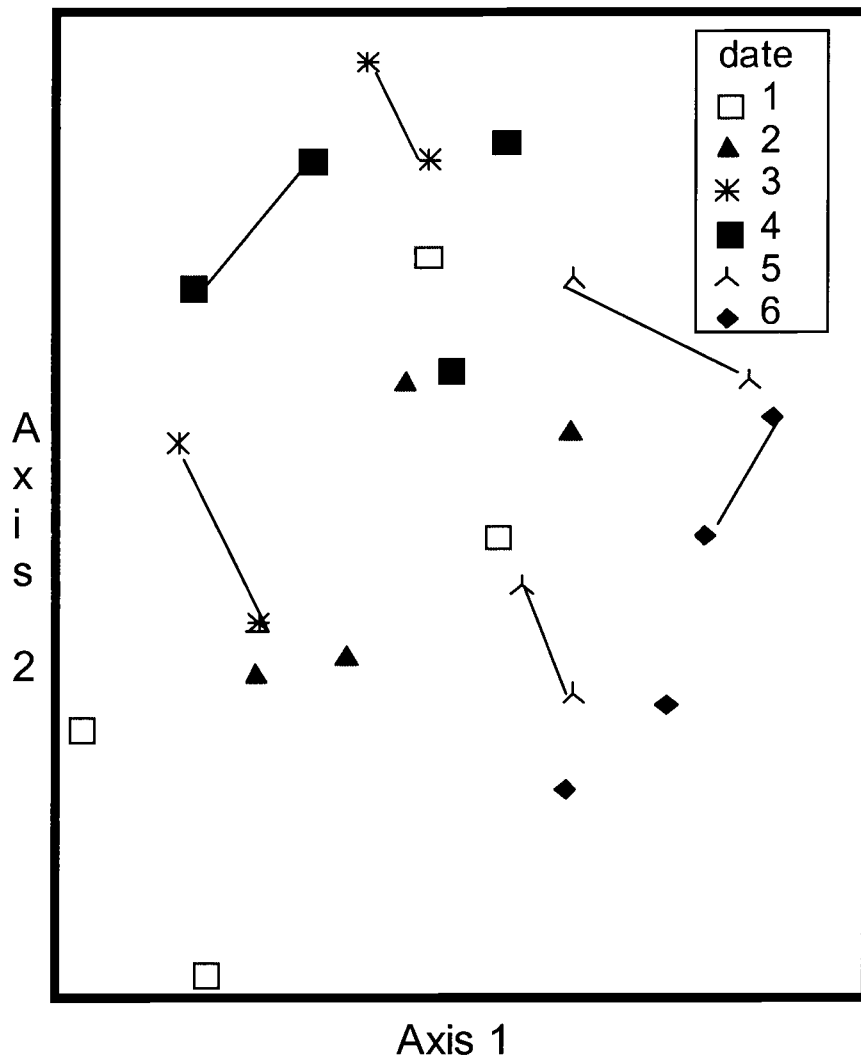
Figure 8. NMS ordination of vineyards in species space with an overlay of date.
Dates indicated by symbols above 1, July 6 to July 14; 2, July 21 to July 29; 3, Aug. 11 to Aug 18; 4,
Aug 26 to Sep. 2; 5, Sep. 10 to Sep. 17; and 6, Oct.5 to Oct. 12. The lines connect sites that were
sampled on similar dates and demonstrate that comparable leafhopper abundance was found on these
dates, based on their proximity in the graph. Date is correlated with axis 1, as the season progressed,
the ordination points move further to the right.

In the ordination the sample units (vineyard) were labeled by vineyard and sample date. Interestingly, sites A and C were near each other in ordination space and sites B and D were usually close to one another in the ordinations as well. The vineyards that paired together in this space had very different management practices and surrounding vegetation at contrast from one another. Sites A and C were sampled closer in date to one another and sites B and D were sampled on similar dates. Possibly, the spread of one week may be enough to cluster these dates together in ordination space. MRPP gave a p-value of .04 for the same parameter by date matrix. My interpretation of this p value was that there are seasonal effects on the total amount of leafhoppers found at each date.

The pattern of leafhopper life cycles and peak abundance can be detected by ISA. With respect to date the significant indicator groups (all $p \leq 0.05$) of leafhoppers were *Empoasca fabae*, Cercopidae, and nymphs (Table 6). The indicator value can be interpreted to identify the seasonal changes of these groups of leafhoppers. Cercopidae was a good indicator throughout the entire season (Table 6).

Table 6. Indicator species analysis results for date.

Species group	Indicator Value	p-value	Indicator Value/Sampling Time					
			1	2	3	4	5	6
Cercopidae	26.2	0.011	16	21	11	4	17	26
Empoasca fabae	41.9	0.016	1	3	5	4	24	42
Nymph	29.0	0.018	8	20	29	13	15	4

This family was a ubiquitous group throughout the summer and only dropped in abundance in late July, 4% at sample date 4. Cercopidae had the highest abundance

at the end of the season with an indicator value of 26% at sample date 6, when the availability of preferred host plants was reduced due to dry weather. *E. fabae* had a low indicator value at the beginning of the season and at the end it went to 24% at sample date 5 and to 42% at the final sample date 6. This pattern of increased indicator value at the end of the summer was expected for *E. fabae* based on the seasonal patterns of this species, i.e. adults overwinter in the Gulf-States only and disperse northward in the spring (Cherry et al. 1977). Nymphs showed high indicator values in the middle of the summer, dropping at the beginning and end of the season. Most likely this happened because most species were adults in the spring and fall, and immature leafhoppers were abundant in the middle of the summer, after hatch and before full development.
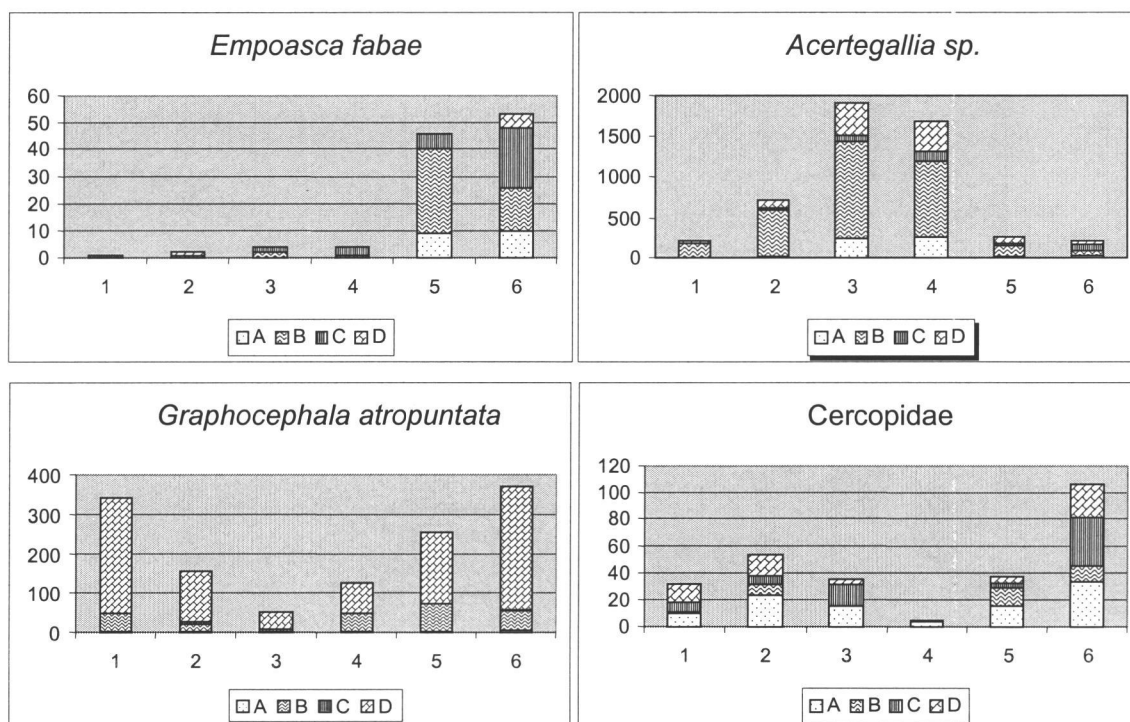
Figure 9. Seasonal distribution of leafhoppers.
Each site contributes to the total abundance. The numbers on the bottom represent the time of collection on a two-week scale. A, site 1; B, site 2; C, site 3; and D, site 4.

Empoasca fabae migrates from the south (Jubb 1988), so it reaches it peak abundance at the end of the summer (Fig. 9). The adults do not overwinter in the north. They die after the first heavy frost and another generation will migrate next year (Jubb 1988). The blue-green sharpshooter does overwinter as an adult, then begins laying eggs in late June (Severin 1949b). It was found to have peak abundance of adults in the beginning and end of the summer. Purcell (1975) has recommended that monitoring of the blue-green sharpshooter be done at these times, especially at the beginning of the season because the adults that overwinter with the Pierce's disease bacteria will be highly infective. *Aceratagallia* spp. have a bell shaped curve distribution with low populations at the beginning of the season peaking in the middle of summer, and dying off again at the end of the summer. Nymphs and adults of *Acertegallia* spp. were present together because of multiple broods. The Cercopidae had variable seasonal abundance, no patterns could be detected probably because the group was identified to family instead of species.

2.6 Conclusions

Leafhoppers showed patterns of abundance throughout the season, depending on their life cycle. The leafhopper groups that could be used as indicator taxa to identify seasonal patterns in 1999 were Cercopidae, *E. fabae*, and the nymphs of all species. *E. fabae* usually migrate north and their numbers increase as the season progresses. Cercopidae were only identified to the family level and their indicator values do not change much through the summer, probably because the level of taxonomic precision was not acute enough to detect species differences. The nymphs

were the highest in number in the middle of the summer after the eggs from the previous year have hatched. This pattern was shown in the NMS ordination as well as in the indicator species analysis. The four vineyards were distinct from one another with respect to leafhopper community abundance and distribution. These differences were most likely based on the viticultural management practices, surrounding agriculture, and vegetation near each site.

Patterns in abundance according to trap site, location, and height were different among the four groups of leafhoppers monitored. Significantly higher numbers of particular leafhoppers were caught on the borders than at the other vineyard locations; for example, border areas had the highest catch for *Graphocephela atropunctata*. The differences in height of catch may have been influenced by flight patterns, and host plant preferences. There were 6 cards on each post, the lower traps collected more and the higher traps collected less. Significant differences were found between the sites studied; still, the specific reasons for these differences were not clear. I speculate that the occurrence and abundance of *G. atropunctata* is associated with the presence and density of blackberry and/or riparian habitat close to the vine. However, there was no clear trend in leafhoppers found when compared to agricultural practices. *E. fabae* showed a trend in abundance according to most conventional to more organic. Possibly, the potato leafhopper prefers the conventional sites because of less competitive pressure and predation associated with reduced cover crop habitat.

Chapter 3

Sweep Net Survey of Leafhoppers (Homoptera: Cicadellidae) in Oregon Vineyards.

3.1 Introduction

An increasingly popular trend in Oregon viticulture is the use of Integrated Production (IP) management practices. The practices are laid out in the Oregon Low Input Viticulture and Enology (LIVE) program guide (PESP 2000). The goals of the program are to reduce the use of chemical treatments by using alternative growing practices. IP vineyards use a permanent cover crop, limit irrigation to young vines and drought conditions, and limit pesticide spraying to necessary applications. There are still many vineyard growers that use conventional management practices (non-IP). These growers spray regularly, irrigate, and usually have a low or barren cover crop between the vines. For growers that are electing low input grape management it is of interest to have a measure of the quality of the health of the vineyard.

When obtaining a measure of vineyard health, growers should look at more than just fruit quality and yield. The abundance and diversity of arthropods within the system is also important in determining health of the vine. Wine grapes can handle an enormous amount of any single leafhopper species before economic damage occurs (Wilson et al. 1992). Therefore, a diverse system may have more insects, per se, but there will be an increase in competition and decrease in the abundance of any single species. Botanical as well as arthropod diversity has been exemplified as a key component to a healthy agro-ecosystem and is used as a main component in IPM (insect pest management) programs (Altieri 1994; Boller 1992;

Bordelon and Weller 1997). Altieri (1994), and Altieri and Nicholls (1999) explained

how the cover crop functions to increase diversity of insects and the health of a

system. Cover crop vegetation provides an increase in refugia for beneficial insects,

decreases the frequency with which a specialized herbivore encounters its host plant,

and provides alternate food sources for the generalized herbivores.

As with any agricultural crop, it is important for wine grape growers to have

an inexpensive and reliable method to monitor insect populations in the vineyard.

Early detection of pests is a valuable tool in efforts to control many economically

damaging insects. The sweep net method is widely used to monitor arthropod

populations. It is easy to use and inexpensive, compared with most other methods of

monitoring insects. (Degooyer et al. 1998; Fleischer and Allen 1982; Schotzko and

O'Keeffe 1989). Despite its popularity, the sweep net has some disadvantages. For

instance, many factors influence the efficiency of the sweep method: time of day,

weather, and wind speed (Saugstad et al. 1967; Schotzko and O'Keeffe 1989). Thus,

many researchers criticize the sweep method and advocate methods that provide

absolute densities (DeLong 1932; Fleischer and Allen 1982). Certainly, the sweep

net can only give an indication of what species are present and an indication of insect

quantity in relation to samples over time. However, most growers are satisfied with

this kind of measure because of cost and time invested. Also, growers tend to

compare observations made over time.

The objectives of this study were to 1) compare the abundance and diversity

of leafhopper species in vineyards that use conventional (Non-IP) management

practices to vineyards that use reduced input (IP) management practices, 2) evaluate

the effect of wine grape growing region on the leafhopper community, and 3)
determine the seasonal distribution and abundance of leafhoppers as measured by
sweep net.

3.2 Materials and Methods

A canvas sweep net with a fine mesh cloth end over a metal wire was used to
sample the vineyards. The net was 38 cm in diameter, and was 1 m in length. The
handle was a 1 m long wooden stick. Twenty-nine vineyards were sampled from
June 1999 to September 1999. Each vineyard was sampled seven times, at
approximately 2-week intervals. The sweeps were taken at ten locations within a
selected block (0.5-2 ha.) at each vineyard. At each location within a block, ten 180
degree sweeps were taken as the sampler walked forward, keeping the net low to the
ground. The 29 vineyards had a broad spectrum of agricultural practices ranging
from low input crop management methods to high input crop management methods.

After collection the insects were frozen, and later sorted and identified to the
lowest taxonomic level possible. Specimens were compared with previously
identified leafhoppers in the Oregon State Arthropod Collection (OSAC).
Representative leafhopper specimens were sent to the Natural History Museum in
Washington D.C. and to Dr. Alexander Purcell at the University of California,
Berkeley, CA for confirmation of identifications.

3.3 Data Analysis

Because of the complex nature of this study the data were analyzed using
ordination with the computer software PCORD (McCune 1999). I chose NMS

ordination (Non-metric multidimensional scaling), because this procedure requires no assumptions of normality. I used multi-response permutation procedure (MRPP) to test for the significance in the data. If there was a significant pattern detected by the MRPP then the analysis was taken one step further using indicator species analysis (ISA) to determine which leafhopper groups were responsible for the patterns being detected in the ordination space.

Each vineyard was assigned an Integrated Production (IP) score of 1 to 5 based on cover crop and spraying practices. A score of 1 represented the most conventional sites. These sites sprayed frequently, had a low or patchy grass cover crop, and many used irrigation. A score of 5 represented the sites that used the lowest amount of input. These sites had a diverse cover crop, sprayed only when necessary, attempted to use lower impact products, and used no irrigation. Although this scoring system was difficult and some of the sites may not have been properly scored I feel it was the best and perhaps the only way to separate out the 29 vineyards in this study to be able to isolate the effect of agricultural practices on leafhopper populations. I used the criteria stated above, as well as the LIVE program scores, and consulted with the wine grape growers on how they viewed there own agricultural practices. Many of the vineyards sprayed similar products, for example all sites used sulfur on a regular basis, but the ones that were rated 1 additionally used insecticides on occasion for thrips, ants, or black vine weevils. It was distinctions such as this, or the installment of a permanent irrigation system that was used to separate out the low input from the high input sites. I feel that a gradient of 1 to 5 was adequate to separate out the varying management practices in the vineyards that I sampled in this study.

In the NMS ordination of IP values each point represented a vineyard. I summed all the leafhoppers found at all the dates for each site in the IP matrix. In the date matrix I summed the ten sweeps together for each date at each site. The data were transformed by relativizing (re-scaling based on matrix row totals) and using the log (x+1) transformation (Table 7).

Table 7. The effect of data transformations on the sweep net data set IP matrix.

Parameter	Before	Relativized	Log(x+1)
ROWS	202	202	202
Beta diversity	3.5	3.5	3.3
Average Skewness	2.76	2.6	1.9
CV of row sums	111.83	107.3	49.5
COLUMNS	16	16	16
Average skewness	7.0	7.2	3.2
CV of column sums	170.86	134.3	73.2

McCune (2000) recommends relativizing the data (re-scaling the rows by the row totals). Relativization equalizes the weights between abundant and less abundant species, by assigning a value of one to the site that has the highest abundance for a particular species. Values for that species in the other sites are then assigned in proportion to the maximum site; this is done for each species.

3.4 Results and Discussion

3.4.1   Comparison of the abundance and diversity of leafhopper species in vineyards that use conventional (Non-IP) management practices to vineyards that use reduced input (IP) management practices

When vineyards were ordinated using NMS and overlayed with IP scores there were distinct patterns (Fig. 10). The vineyards with the low IP score of 1 for most conventional were occupying a distinct space in the figure. The rest of the vineyards occupied the same space; no groups could be identified based on IP score for the vineyards with a score from 2 to 5. Diversity (Simpson's diversity measure) and abundance (Richness) were correlated with axis 1 and axis 2 respectively on the graph. Diversity was highly correlated (r = 0.7) with axis 1, and abundance was correlated with axis 2 (r = 0.5). The high r-values indicate a strong correlation between these environmental variables and the axes, so the ordinations were rotated along these axes to maximize the interpretability of the figure. Altieri and Nicholls (1999) found an increase in beneficial insects and a decrease in pest species when comparing low input management crops to high input management crops.
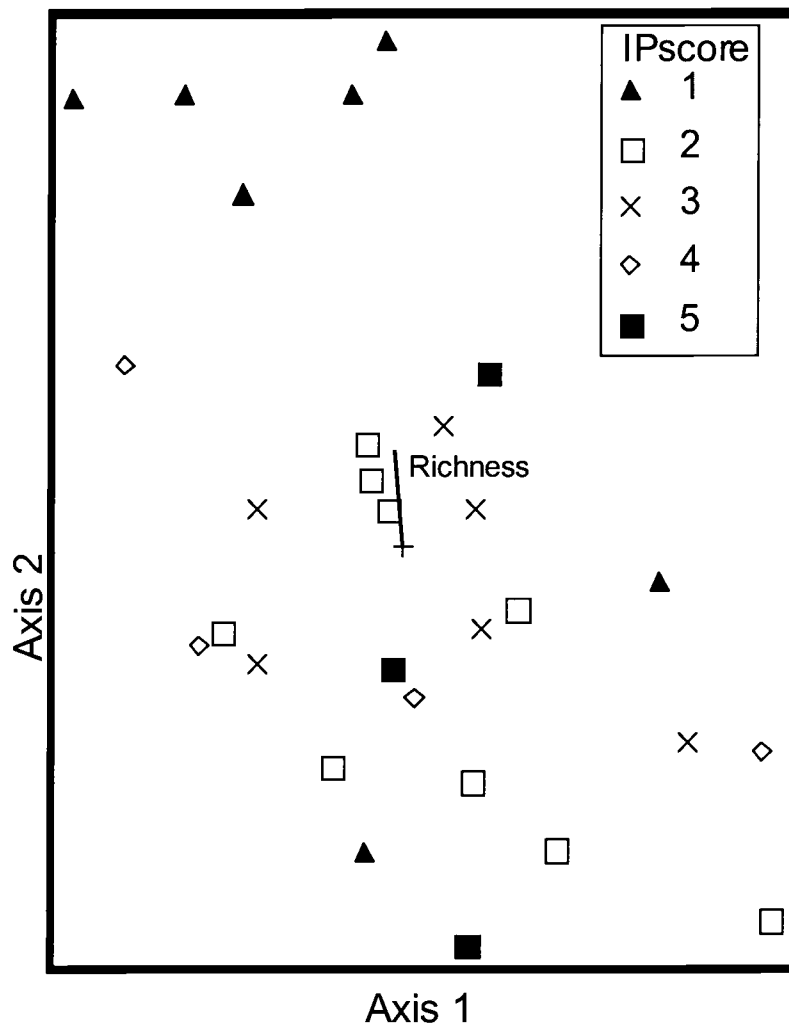
Figure 10. NMS ordination of vineyards based on IP scores.

Each symbol represents a vineyard with all species of leafhoppers at each date summed. The vineyards were scored from 1 (Conventional) to 5 (Organic). Diversity increased on axis 1 (r = 0.7) and abundance increased on axis 2 (r = 0.5). The vector labeled richness represents the correlation of leafhopper abundance with axis 2.

In Figure 10, the conventional vineyards showed higher numbers of leafhoppers and lower diversity in the vineyard. This could be interpreted to mean that if a grower would take any step toward a lower input system, there may be a reduction in the abundance in any particular species of leafhoppers and an increase in the diversity of leafhoppers. This would include planting a more diverse cover crop,

spraying less frequently, and limiting irrigation to young vines and drought conditions. There were two conventional vineyards that did not group together with the other conventional sites in the ordination. The site at the bottom of the ordination had very little surrounding vegetation to provide an alternate food source for the leafhoppers, and this is likely why the abundance was so low. In addition, this site had a barren cover crop, so very few insects could be collected, and most likely were using the vines as refuge and food. The site at the right of the ordination had a man-made lake on its border which, no doubt, increased the diversity seen at this site by the abundance of riparian vegetation in the area. The pattern detected, for IP scores, in the NMS ordination was significant ($p = 0.003$, MRPP) (Fig. 10). The conventional sites were significantly different from the other vineyards with reduced input management practices. Even the vineyards that had an IP score of 2, (fairly conventional management sites), were separate from the more conventional sites with a score of 1.

Using the indicator species analysis, I was able to determine which species were responsible for the differences seen in the conventional sites. The groups of leafhoppers that had significant p values ($\alpha < 0.05$) were the nymphs of all species combined, *Psamotettix* spp. and *Aceratagallia* spp. Each group had the highest indicator value at the most conventional sites (Table 8) and much lower values for the other sites.

Table 8. Indicator values for significant leafhopper groups with respect to IP scores.

Species group	Indicator Value	p-value	Indicator Value/IP Score				
			1	**2**	**3**	**4**	**5**
Nymph	39.8	0.015	40	13	16	18	13
Psamotettix spp.	63.5	0.025	63	7	13	5	8
Aceratagallia spp.	40.3	0.015	40	15	13	18	13

The numbers in bold represent the IP scores of 1 to 5. 1 is the most conventional and 5 is the most organic.

The less conventional sites had a reduction in the abundance of these groups. It was expected that fewer nymphs would be present in low input systems possibly due to an increase in abundance of generalist predators. Additionally the abundance of leafhoppers overall was lower in the low input sites. Therefore, there were fewer nymphs present at these sites.

3.4.2 The effect of growing region on the leafhopper community.

Each region sampled was coded 1 through 6. One represented the most northern sites and 5 the most southern, 6 represented the sites to the East of the Willamette River. All the sites appeared to be randomly distributed throughout the ordination space except for region 5, which was distinctly a group in the figure (Fig. 11). Region 5 was the Rogue Valley area and is located approximately four miles north of the California border. The warm, drier climate in the south of Oregon is different than the wet, cooler climate found in the northern regions of the Umpqua and Willamette Valley. Many factors are likely responsible for differences in region such as climate, host plant differences, and the migratory patterns of leafhoppers. When the MRPP was run on the regions, significant differences were found (p = .02 x

10^{-3}). In the NMS ordination of region, the points appeared random except for a

groups of points in the Rogue Valley.
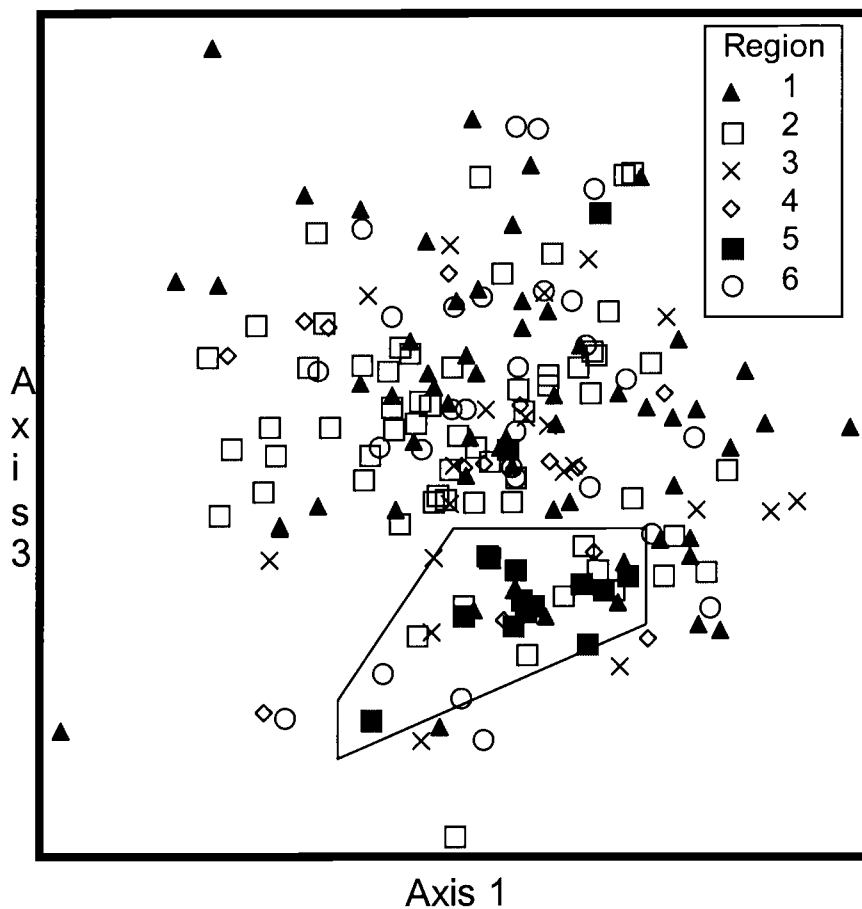
Figure 11. NMS ordination of region.
All vineyards are summed for each date. 1, North Willamette; 2, Central Willamette; 3, South
Willamette; 4, Umpqua; 5, Rogue; and 6, Eastern Willamette. The symbols representing region 5 are
enclosed by the box.

The indicator species analysis of region had only one species that was

significant (Table 9). *Psamotettix* sp. had a p value of 0.03 and an indicator value of

17.8. The highest indicator value was at region 5, the sites in the Rogue region.

Psamotettix sp. was more abundant at these sites and its distribution was responsible

for the grouping of these sites in the NMS ordination. Other species like

Aceratagallia spp. and *Empoasca fabae* had high indicator values in the ISA analysis,

but were not statistically significant.

Table 9. Indicator values for significant leafhopper groups with respect to Region.

Species group	Indicator Value	p-value	Indicator Value/Region					
			1	**2**	**3**	**4**	**5**	**6**
Psamotettix spp.	17.8	0.036	4	4	6	5	18	7

The numbers in bold represent the regions. 1 is the most northern site 5 is the most southern and 6 is the eastern Willamette Valley.

3.4.3 Seasonal distribution and abundance of leafhoppers as measured by sweep net.

I used NMS ordination to detect patterns in seasonal distribution of

leafhoppers. This ordination used 202 sample units representing a vineyard at one of

seven dates. Therefore, there was a large amount of variability in the ordination.

Despite the apparently random nature of the ordination of date, some pattern could

still be detected (Fig. 12). Dates 1, 5, and 7 each typically grouped together in the

figure. Dates were significantly different from one another (p < 0.001). The MRPP

detected the difference in date and found there were significant differences when the

data was analyzed in a k dimensional space
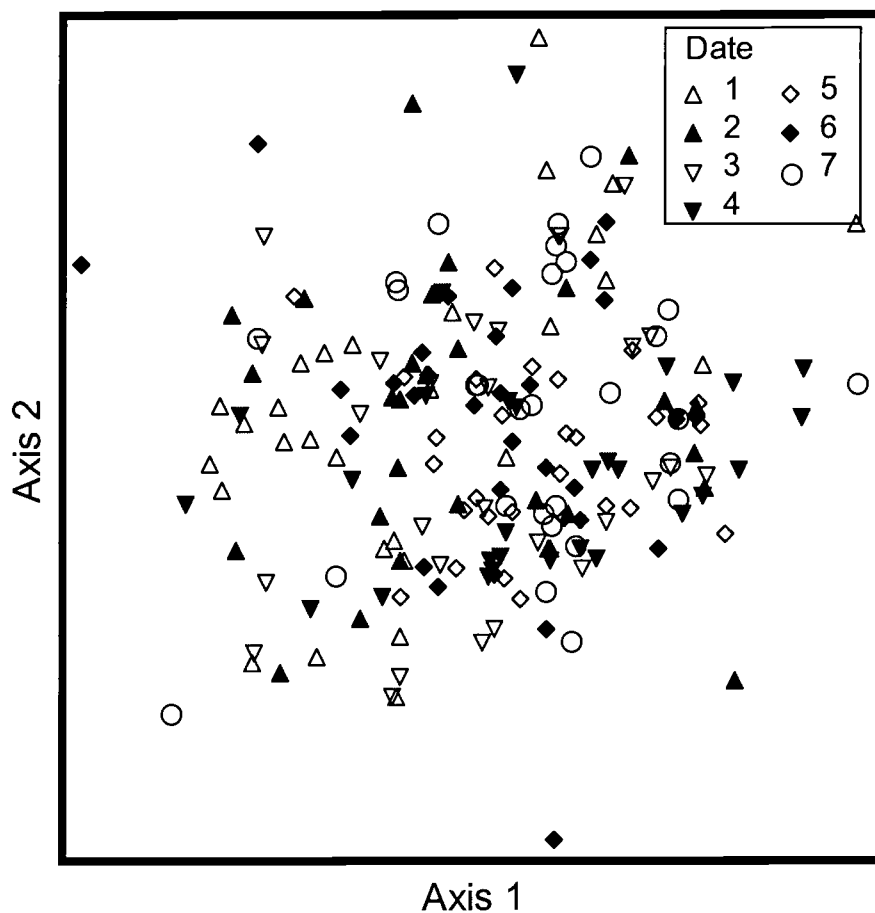
Figure 12. NMS ordination of leafhoppers caught at each sample date at each vineyard. Each symbol represents a sampling date from May to September.

In the indicator species analysis of date there were three species that were significant. *Aceratagallia* spp., nymphs of all species combined, and *Forcipita* spp. all had low p-values < 0.05 (Table 10).

Table 10. Indicator species analysis results for date 1999 using sweep net method.

Species group	Indicator Value	p-value	Indicator Value/Sampling time						
			1	2	3	4	5	6	7
Acertegallia	22.1	0.001	4	9	8	14	21	14	22
Nymphs	20.6	0.005	11	13	21	14	12	10	8
Forcipita	20.1	0.001	20	0	0	0	0	0	0

Aceratagallia spp. increased in abundance at the end of the season, when the alternative host plants were drying up. This group had an indicator value of 22% at the end of the season. Nymphs were most abundant in the middle of the season, when the eggs had hatched but the leafhoppers were not yet fully developed. At sample date 3 the nymphs had an indicator value of 21%. *Forcipita* spp. had a high indicator value at the beginning of the season with a value of 20% at date 1. It was not frequently encountered in the vineyard after the first sampling date. This group feeds on early blooming plants and then emigrates from the cover crop plants to other surrounding foliage.

3.5 Conclusions

Vineyards in most of Oregon are unique as a group in plant and arthropod community structure from the vineyards south of Oregon (California). In general conventional sites have higher abundance and lower diversity of leafhoppers than low input sites. In the classical view of the agro-ecosystem this equates with lower overall health of the system. Even small changes toward reduced input management, in the vineyard or surrounding area, leads to an increase in diversity most likely by increasing refugia and the occurrence of generalist predators in the system. The vineyards that participate in the LIVE program follow guidelines and choose practices to reduce potential negative impact. They are urged to reduce pesticide use, increase cover crop planting, mow every other row, and decrease the use of irrigation. Many vineyards in Oregon are participating in this program. There are some key

leafhopper species that are present at particular dates, and regions and can be used as indicator species in vineyard sampling programs. These groups include *Psamotettix* sp. *Aceratagallia* sp. and *Empoasca fabae*. Previously, it has been assumed that the community structure of arthropods is similar in Oregon to California, but these findings contradict that notion for certain leafhoppers. Perhaps the Rogue area is more similar to California vineyards because of close proximity, but clearly there is a difference among vineyards in Oregon from vineyards in California in leafhopper community. Oregon vineyards, apparently, need to be studied and treated separately from other grape growing appellations.

Chapter 4

Conclusion

Four sites were sampled using a sticky trap method, and 29 vineyards were sampled using a sweep net method in the summer of 1999. There were differences seen in the leafhopper populations based on sample method, date, location, height, agricultural practices, and appellation. The sticky trap and sweep net methods were chosen based on cost, ease of use, and the fact that they are commonly used tools available for growers and IPM programs. Each method resulted in the capture of different leafhoppers. Sticky traps attracted mobile insects, primarily flying adults attracted to yellow. The sweep net captured leafhoppers from the cover crop canopy vegetation. There was seasonal variation seen for each leafhopper group. The highest numbers of leafhoppers were caught on the border and then the edges of the vineyard because of the surrounding vegetation providing refuge and food. The height of catch was dependent upon the preferred host plant of the leafhopper. Species that feed on the grapevine were found at the canopy level of 90 to 150 cm. The influence of agricultural practice on abundance and diversity was seen in this study. The most low input sites had the highest diversity and lowest overall abundance of leafhoppers, with the exception of *G. atropunctata* found in high abundance at site D due to the riparian habitat on its border. Any reduction of pesticide use, irrigation or increasing the diversity of cover crop leads to a more diverse vineyard system. The sites in the south had a higher abundance of the

indicator species *Psamotettix* sp. The community structure of the most southern site near California was distinct from the other sites to the north.

The vineyards that had a diverse cover crop had a more diverse population of leafhoppers. Most species live on herbaceous plants that are common as vineyard ground cover. The cover crop that most low input management sites use may increase the number of leafhoppers that feed on the vine, but the presence of a cover crop has many advantages in the vineyard system.

With little exception, vineyards with high input management practices had higher abundance of leafhoppers and a lower diversity when compared to vineyards with low input management practices. Although not always significant, the largest numbers of leafhoppers were caught on the borders of the vineyard. The optimum height of catch varied by species and was dependent on flight patterns and host plant preferences. The sites studied in the South had a different leafhopper community structure than the vineyards to the North. Vineyards in Oregon should be studied separately from California vineyards.

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Appendices

Appendix 1

Taxonomic list of insects found in vineyards during the sampling period in1999 using the sweep net method.

Collembolla
Sminthuridae
Entomobryidae
    Orchesella ainsliei Folsom
Ephemeroptera
Odonata
Coenagrionidae
    Enallagma anna Williamson
    Enallagma civile (Hagen)
Lestidae
    Lestes congener Hagen
Orthoptera
Acrididae
    Melanoplus differentialis
    (Thomas)
    Melanoplus sangumipes (F.)
Tettigoniidae
Gryllidae
    Oecanthus fultoni Walker
Dermatptera
Forficulidae
    Forficula auricularia L.
Dictyoptera
Mantidae
    Stagmomantis californica
    Rehn and Hebard
Psocoptera
Thysanoptera
Thripidae
Heteroptera
Anthocoridae
    Orius minutus (L.)
    Orius tristicolor (White)
    Geocoris spp.
    Nabis spp.
    Zelus renardii (Kolenati)
Lygaeidae
Miridae
Scutelleridae

Pentatomidae
    Podisus maculatus Say
Tingidae
    Corythuca ciliata Say

Homoptera
Cicadellidae
    Draeculacephala minerva Ball
    Empoasca fabae Harris
    Empoasca viridescens Walsh
    Graphocephela atropunctata
    (Signoret)
    Graphocephela coccinea
    (Forster)
    Erythroneura elegantula Osborn
    Erythroneura comes (Say)
    Idiocerus couleanus Ball
    Idiocerus dolosus Ball
    Colladonus montanus reductus
    (Van Duzee)
    Aceratagallia spp.
    Psamotettix spp.
    Forcipita spp.

Cercopidae
    Philaenus spumarius (L.)
Membracidae
    Stictocephela brevicornis Fitch
Neuroptera
Chrysopidae
    Chrysoperla carnea (Stephans)
Hermerobiidae
    Hermerobius sp.
Myrmerleontidae
    Brachynemurus ferox (Walker)
Coleoptera
Coccinellidae
    Adalia bipunctata (L.)

Taxonomic list (continued)

Coccinellidae (continued)

Coccinella novanotata oregona Casey
Coccinella transversosus richardsoni Brown
Cycloneda polita Casey
Hippodamia convergens Guerin-Meneville
Chrysomelidae
Altieinae
Chrysochus colbaltinus LeConte
Diabrotica undecimpunctata howardi Barber
Curculionidae
Physonota sp.
Odontocorynus denticornis Casey
Mordellidae
Mordella atrata Melsheimer
Mecoptera

Lepidoptera
Maanduca sexta (L.)
Pieris rapae (L.)
Hymenoptera
Braconidae
Apanteles spp.
Chalcididae
Chrysididae
Trichrysis sp.
Colletidae
Cynipidae
Ichneumonidae
Rhyssa lineolata (Kby.)
Vespidae
Dolichovespula arenaria (F.)
Andrenidae
Andrena sp.
Agopostemon sp.
Halictidae
Diptera
Asilidae
Muscidae
Sarcopahgidae
Syrphidae
Tachinidae

Appendix 2

Statistical Methods

Non-metric Multidimensional Scaling (NMS) is an ordination method. It allows the analysis to be visually perceived in the data space. It is a mathematical way to plot the data point of K dimensions on a 2 or 3 dimensional space. It is often disconcerting that the axes of the figures are labeled as axis 1 and axis 2. Having arbitrary axes is counter-intuitive to our traditional way of viewing data. The number of axes sets the dimensionality of the solution. The meaning of the axes is left up to interpretation. Ordinations provide a visual way of describing the distances between points in species space. Sample units close to one another in species space have a more similar composition and relative abundance than do points farther away. The value Tau represents the weight given to a species when determining the ordination axes.

Multi-response Permutation Procedure (MRPP) is similar to the *t* test and one-way analysis of variance *F* test. MRPP uses Euclidean space to measure the within-group average of each pair of points. MRPP can be easily used on multivariate problems and requires few assumptions of the data. The purpose of the MRPP test (similar to the *t* and *F* tests) is to detect differences among *a priori* groups. The data need not be normally distributed, or have homogenous variance (as is needed in the *t* and *F* tests). Only the internal variability of the data is important for the MRPP. The equation explaining the MRPP statistic, with the distance measure involving K and L objects, is as follows

$$\Delta_{K,L} = \left[\sum_{j=1}^{r} (X_{k,j} - X_{L,j})^2 \right]^{v/2},$$

where r is the number of repeated measurements taken on the Kth object and $v > 0$. In

this thesis the distance measure was $v = 1$ because I used Euclidean distance.

Appendix 3

Table A. Results of MRPP for location, date, vineyard and height for poles in 1999.

Test	T-statistic	A-value	p-value
Location	0.39	-0.005	0.58
Date	-1.85	0.07	0.04
Vineyard	-7.94	0.21	<.05
Height	-6.29	0.08	<.05

The p-value is the probability of Type I error for the hypothesis of no difference between treatments.
The A-value is the chance-corrected within group agreement.

Table B. MRPP scores for IP values, Region and Date from 1999 sweep net samples.

Test	T-Statistic	A-value	p-value
IP-value	-3.74	0.149	0.003
Region	-5.40	0.015	0.02×10^{-3}
Date	-9.25	0.136	0.05×10^{-5}

The p-value is the probability of Type I error for the hypothesis of no difference between treatments.
The A-value is the chance-corrected within group agreement.

Table C. Location of *Graphocephala atropunctata* within the vineyard, Analysis of

Variance Table

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level
A (Location)	2	339.68	169.84	26.13	0.0000001
S	1293	8405.15	6.50		
Total (Adjusted)	1295	8744.83			
Total	1296				

Table D. Date, Height, and Location of *Empoasca fabae* GLM Analysis of Variance

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level
A (Dates)	15	318.72	21.25	12.5	0.0000001*
B (Height)	5	21.97	4.39	2.59	0.024*
AB	75	129.38	1.73	1.01	0.446
C (Location)	2	12.01	6.00	3.53	0.029*
AC	30	80.45	2.68	1.58	0.025*
BC	10	23.04	2.30	1.36	0.196
ABC	150	195.63	1.30	0.77	0.979
S	1008	1713.33	1.70		
Total (Adjusted)	1295	2500.56			
Total	1296				

* Term significant at alpha = 0.05

Table E. ANOVA table of *Aceratagallia* spp. for date and height.

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level
A (Dates)	15	854.78	56.99	9.42	0.0000001*
B (Heights)	5	206.07	41.21	6.82	0.000003*
AB	75	446.94	5.96	0.99	0.514
S	1200	7255.67	6.05		
Total (Adjusted)	1295	8744.83			
Total	1296				

* Term significant at alpha = 0.05