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MOVEMENT AND RESPONSE OF POTATO LEAFHOPPER (Empoasca fabae Harris) (CICADELLIDAE: HOMOPTERA) TO HOST PLANT HABITATS IN A DIVERSE APPLE AGROECOSYSTEM

presented by

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has been accepted towards fulfillment of the requirements for

M.S. degree in Entomology

Major professor

Date 1 May 1998

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By

Melanie Joy Kaeb

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Entomology

1998

ABSTRACT

MOVEMENT AND RESPONSE OF POTATO LEAFHOPPER (*EMPOASCA FABAE* HARRIS) (CICADELLIDAE: HOMOPTERA) TO HOST PLANT HABITATS IN A DIVERSE APPLE AGROECOSYSTEM

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The movement of the highly mobile potato leafhopper (*Empoasca fabae* Harris) was studied in Michigan apple orchards and the surrounding agroecosystem. Potato leafhopper trap catch was linked to the habitat structure and seasonal potato leafhopper population fluctuations in and adjacent to the orchards. An extensive trapping network of geographically stable yellow sticky boards was used to monitor potato leafhopper. Potato leafhopper was seasonally present in Michigan orchards and was found in high numbers in the orchards compared to non-host habitats. The alfalfa, apple, soybean and other deciduous fruit habitats had the highest potato leafhopper trap catch means. The spatial distribution of potato leafhopper trap catch closely followed the spatial distribution of host habitat in the agroecosystem over two years.

ACKNOWLEDGEMENTS

The completion of this work was possible only with the help, support and guidance of many people. I would first like to thank Dr. Mark Whalon, my major professor, for his support over the past two years. Thank you for providing me with your guidance, prayers, technology, financial support and an uplifting, Godly work environment in which to complete this Master's project.

I would like to thank the Whalon lab for the time and patience that you have spent helping me with this project. Thank you to Dr. Utami DiCosty and Dr. Michael Bush for providing valuable on the spot scientific advice and encouragement and to Pat Bills for the statistical help and ideas. Thank you Andrea Coombs, David Mota-Sanchez and to all of the undergraduate students who have helped me.

I sincerely appreciate the suggestions, ideas and comments from the members of my guidance committee, Dr. Doug Landis and Dr. Stuart Gage. I also appreciate the time and patience that Dr. Manual Colunga-Garcia of the Computational Ecology and Bioinformatics Laboratory spent helping me with my spatial statistics and mapping.

Thank you to my immediate family and to my extended family for the prayers, love, support, encouragement and insect collecting over the past 24 years that have made it possible for me to follow my dreams. I would like to extend a special thank you to my mother, Luanne Kaeb, for her hard work in reading and editing this thesis multiple times.

This work was carried out and completed by the mercy and grace of God. I would like to thank God for His mercy and grace and for sending his son to die on the cross that all might be saved.

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CHAPTER 1

Introduction: Literature Review

Empoasca fabae, the potato leafhopper (PLH), is highly polyphagous. It feeds on over 200 plant hosts (Poos and Wheeler 1943, Lamp et. al. 1994) and is a pest in many Michigan cropping systems. Potato leafhopper has been documented to cause damage to alfalfa (Cuperus et. al. 1983), potato (Caneolado and Radcliffe 1979), bean (Roltsch and Gage 1990), soybean (Poston and Pedigo 1975), and deciduous fruit trees (Schoene 1932). It has also been documented in many non-crop habitats; including, forest, old field, and roadsides (Lamp et. al. 1989). The potato leafhopper can feed on hosts from most of the major dicotyledonous taxa. It utilizes native and introduced dicot crops, forages, weeds, shrubs and trees. Monocotyledonous plants, such as grasses and sedges, are non-hosts. Adult potato leafhoppers are frequently collected on them, and will feed in no choice tests, but females will not oviposit on non-host monocots (Lamp et. al. 1994).

The potato leafhopper is multivoltine, with three to five overlapping generations each year. A female can live up to six months and produce eggs for much of her life span (DeLong 1938). It is a mobile pest, exhibiting long and short range migration. The short range, interhabitat migration is active migration that occurs between host plants during the growing season (Medler 1957, Poston and Pedigo 1975, Lamp et. al. 1994). The long range migration is an annual passive interstate migration from south to north (Carlson et al. 1991).

Migration. The potato leafhopper is unable to survive the winter temperatures in the Midwest (Decker and Maddox 1987) and it disappears each winter when temperatures fall below survival thresholds. Decker and Cunningham (1968) report that potato leafhopper overwinter and begin spring reproduction on weedy annual legumes in the states near the Gulf of Mexico. Taylor and Shields (1995a,b) report the collection of potato leafhopper in Arkansas and Tennessee in January, and the collection of potato leafhopper from several *Pinus* spp. in the overwintering range. They found no evidence of oviposition on pine, but suggested that pine species serve as transient hosts during the winter (Taylor et. al. 1993). The number of potato leafhopper available for the northern spring migration depends on the availability and quality of host plants and the occurrence of lethal temperatures encountered at the overwintering sites (Berberet and Hutchison 1994).

Potato leafhoppers move north on early season air currents and arrive in Michigan in mid-May to late June on spring weather systems. Potato leafhopper arrival dates and corresponding weather patterns have been tracked in the midwestern and eastern states since 1951 (Maredia et. al. 1998). The exact weather transport conditions needed for potato leafhopper migration to occur have been determined (Carlson et. al. 1991, 1992). It is possible to predict potato leafhopper migration and arrival from weather patterns in the early spring. From 1986 until 1998, the Pesticide Alternatives Lab has conducted a spring migration detection trapping network. This extended and intense transect system confirms the potato leafhopper arrival date each year. From this transect data, we hypothesize that potato leafhoppers begin feeding and reproducing on deciduous trees. They are the only plants providing enough vegetative growth to support a phloem feeder when the potato leafhopper arrival occurs (DiCosty et. al. 1998, Kaeb and Whalon 1998).

The appearance of the first Michigan potato leafhopper generation depends on spring transport events and degree day (base 50°F) heat accumulation following arrival. The migratory generation is usually not large enough to cause economic damage to crops, but potato leafhoppers are prolific and the population may quickly rise to damaging levels if optimum conditions occur. Potato leafhopper development is based on ambient temperature because the potato leafhopper is poikilothermic (Higley and Peterson 1994). There are 5 temperature-based potato leafhopper development models found in the literature (Koukolekas and Decker 1966, Simonet and Pienkowski 1980, Onstad et al. 1984; Hogg 1985, Sher and Shields 1993). There is no correlation between the arrival date and the subsequent severity of potato leafhopper infestation (Maredia et. al. 1998)

Damage. Potato leafhoppers feed on the phloem tissue of host plants, puncturing, tearing and distorting the cells in the vascular bundle as they use their proboscis to empty the cell contents (Ecale and Backus 1995a). As the potato leafhopper probes into the plant tissue, it secretes a salivary fluid, which hardens into a sheath. This sheath remains in the plant for a long period of time (Ecale and Backus 1995b). Potato leafhopper feeding behavior and the resulting residue cause a V-shaped chlorotic area called 'hopper burn.' Hopper burn reduces plant photosynthesis, stunts plant growth and reduces crop yields (DeLong 1971, Welker 1992).

High numbers of potato leafhopper cause direct economic damage to forage crops such as alfalfa (Cuperus et. al. 1983). According to Berberet and Hutchison (1994), potato leafhopper populations as low as 0.3 to 2.0 potato leafhoppers per sweep in plants <30 cm tall will cause stunting and reduced yields. If 5 to 6 potato leafhoppers per sweep occur over an extended period (20- to 30-d), the crude protein content of the hay will be reduced and delayed maturity can limit the number of cuttings in a season. High numbers of potato leafhoppers cause indirect economic damage by foliar feeding to fruit crops such as apples (Schoene 1932) by reducing photosynthesis in the leaves and reducing fruit yield.

Orchards. Michigan orchards are very ecologically complex (Whalon and Croft 1985) due to the temporal and spatial architecture of the system. Upon reaching maturity, fruit bearing deciduous trees produce a crop each year for many years. Trees are expensive to establish and may take several years to reach fruit bearing age. They are planted in rows with ground cover between the rows and under the trees. The physical complexity and the diversity of vegetation found in orchard systems provide many opportunities for insects and diseases to attack the crop and damage the trees. The impact of the diverse insect pest complex found in Michigan orchards can be significantly influenced by disturbance (Wise 1990), nutrient flow (Strickler and Whalon 1985, Strickler et. al. 1987), and ground cover (Larson and Whalon 1987). This makes orchard pest management a difficult job. Producers manage tree health for short-term crop production and long term stability using fertilizers, insecticides, fungicides and integrated pest management techniques.

Many studies have been done on deciduous fruits and the damage caused by individual components of the pest complex. None of the studies in the past 50 years mention potato leafhopper as anything other than an occasional occupant of orchards. The 1998 Michigan Fruit Spraying Calendar (Jones et. al. 1998) states, as a side note, "most organophosphates (OPs) applied for other pests will control potato leafhoppers." The potato leafhopper has not been a pest in Michigan orchards since OPs came into wide spread usage in the 1950s. Prior to OPs, however, the potato leafhopper was a serious orchard pest.

Potato leafhopper + Apples. There are many extension reports from the early 1900's that describe the potato leafhopper as a pest in apple orchards (Garman 1908, Washburn 1903, Schoene 1932, DeLong 1931). According to Schoene (1932), potato leafhopper is a serious economic pest of young apple trees and cultivated orchards. Potato leafhopper damage to apples includes brown leaf margins in moderate infestations, stunting, reduced vigor, and delayed bearing or even tree death in medium and high infestations. Schoene and Underhill (1937) published an exhaustive study on the susceptibility of the (then) commonly grown apple varieties, classifying them as being low, moderate or highly susceptible. Low susceptibility is correlated to the presence of heavy pubescence on the apple leaves, similar to susceptibility results in glabrous vs. pubescent soybeans (Johnson and Hollowell 1935) and glandular hair alfalfa (Sulc et. al. 1997). There were no further studies of potato leafhopper damage in apples after OPs came into common orchard use.

FQPA. Rising environmental awareness and new pesticide laws, including the Food Quality Protection Act of 1996, are threatening Michigan fruit producers with the loss of OP insecticides (Gray et. al. 1996, Peterson 1998). The intent of FQPA is to provide a safe food supply, with special emphasis on pesticides in the diets of infants and children and on the safety of estrogen mimics (Colborn et. al. 1996) in the food supply. EPA is implementing FQPA by following a "worst-first" strategy, reviewing the registrations of the OPs, carbamates and B2 carcinogens in the first three years of the ten year implementation project. Loss of these pesticides because of reduced tolerances and canceled registrations will force producers out of business if there are no alternatives in place to control pest outbreaks.

The "soft," more pest specific chemicals and tactics being developed to replace the OPs for control of primary pests do not control secondary non-target pests. The loss of broad spectrum chemical control exposes other weaknesses in the current orchard production system. Commonly grown varieties of apple have little resistance to a phloem damaging pest such as the potato leafhopper. The trees are also grown on dwarf rootstocks, further lowering resistance. The stage is being set for the re-emergence of an "old-fashioned" pest, the potato leafhopper.

We face a number of challenges as we transition the Michigan fruit production system to softer, more environmentally friendly programs of pest control. Broad spectrum pesticides allowed producers to virtually ignore the effects of surrounding habitats on the pest complex within the orchard. With the loss of chemical control options, the impact of the agroecosystem on potato leafhopper/crop interactions becomes more important.

Agroecosystem. The agroecosystem is the physical landscape of the living and non living material in an agricultural production area and the interactions between the components of this landscape (Landis 1994). The size of an agroecosystem is plastic, depending on the scale of the landscape element being studied. It can be defined as a field, a group of fields and surrounding habitats, a farm, a township, a county, a region, a state, or a group of states. In this study, we define the agroecosystem as the crops, plants, pests, natural enemies, and interactions on the 380 acres of the Clarksville Horticultural Experiment Station and the target organism as the potato leafhopper.

Plants do not move once they begin growing, however, plants separated by large distances can have significant effects on each other due to the mobility of insects and diseases. Potato leafhopper populations can build up on one plant or group of plants, when the conditions change, they move to other plants suitable to growth and development and cause further damage. Host change may be due to long distance migration (Taylor and Shields 1995), disturbance (Pienkowski and Medler 1962), loss of nutrients in maturing or stressed hosts (Schoene 1932, Hoffman and Hogg 1992) or reproduction needs. More plants are suitable for adult survival than for oviposition and nymph survival due to morphological and chemical characteristics (Lamp et. al. 1984).

Aggregations of potato leafhopper populations occur for several reasons. Host habitat or close proximity to a host habitat is an indicator of potential potato leafhopper aggregations within an agroecosystem (Roltsch and Gage 1990,Wise 1990). Microclimates within a host habitat, such as the topographically elevated portions of the alfalfa field studied by Kieckhefer and Medler (1966), are also potential aggregation sites.

Plant repellency is another potential potato leafhopper-plant interaction in the agroecosystem. Mixtures of host and non host plants can reduce the number of potato leafhoppers feeding and reproducing on the host plant due to the repellent effect of the non host plant. Roltsch and Gage (1990) demonstrate this reduction in potato leafhopper numbers using tomato and bean intercropping. Roda et. al. (1997a,b) uses alfalfa – forage grass mixtures and Lamp (1991) uses alfalfa-oat intercrop systems.

The high mobility, highly phytophagous nature of the potato leafhopper and its ability to cause serious economic damage in many crops has caused it to be the subject of many studies. Studies have focused on potato leafhopper interactions within crops (Flinn et. al. 1986), between crops (Poston and Pedigo 1975), in habitats proximate to crops (Wise 1990) and between host and non-host crops (Roltsch and Gage 1990). This study attempts to link potato leafhopper trap catch to interactions with the habitats in the agroecosystem.

Trapping system. Sampling techniques, such as yellow sticky traps, provide a relative estimate of the target organism population of the that is not directly related to land surface area. The technique itself provides the reference for the estimates, expressing counts as the number of target organisms per trap (Buntin 1994). In pest management programs, relative trapping techniques provide a cost-efficient technique of arthropod monitoring. They give direct evidence of the presence and relative population size of the target organism, are low cost and require minimal labor.

Yellow sticky traps attract and capture potato leafhoppers (Higley and Peterson 1994). The yellow color provides a visual stimulus, mimicking the pigments in nitrogen rich foliage that are attractive to the potato leafhopper. When a potato leafhopper comes into contact with the board, the sticky substance retains it. Sampling is continuous and information is gathered about the potato leafhopper population 24 hours a day. The yellow sticky trap sampling method is dependent not only on the insect density, but on several other variables. Color attraction, flight behavior, wind speed, and temperature can affect the number of potato leafhoppers collected in a given sample (Wise 1990).

We used an extensive trapping system, limiting the number of traps in each habitat so many habitats can be sampled over a large geographic area (Buntin 1994). The sampling objectives were to detect potato leafhopper in a given habitat and to provide information on the status of potato leafhopper in the habitat.

Technology. The position of each trap was precisely recorded using a handheld GPS unit. The Global Positioning System (GPS) was developed by the U. S. Department of Defense to facilitate precise wartime troop movement over unknown terrain. This defense technology lends itself nicely to use in precision agriculture and research (Schueller and Stout 1995). The GPS system consists of 24 satellites orbiting the earth at an altitude of 11,000 miles. The satellites are used as precise reference points by the handheld GPS unit. From 3 reference points, GPS triangulates location and speed using distance measurements. Signals from 4 satellites allow the GPS to calculate elevation of the trap. There is an error factor induced by the Department of Defense into civilian GPS units which makes GPS only accurate to within 100m. This inaccuracy can be corrected by using a differential FM signal with the GPS unit to attain coordinates that have within 1 m accuracy (Trimble Navigation 1995).

The GPS data, potato leafhopper sample data and the vegetation data for each sample date are entered into a relational database. A relational database allows the user to manipulate large data sets without having to deal with the entire set all of the time. Each type of data is stored in a separate table. Tables contain similar reference fields that are used to join related data from separate tables. A query is used to join desired data from separate tables into a common table, allowing for the efficient manipulation of a small part of a large data set. The data in these small, specific tables can be moved out of the database program and used for statistical analyses, graphing or setting up other tables.

The final step in the manipulation process of spatial data is to transfer the data sets from the relational database into a Geographic Information System (GIS). GIS are computer-based systems that facilitate the input storage, manipulation and output of geo-referenced data, allowing users to relate disparate data on the basis of common geographic location (Morris 1996). In precision agriculture, GIS and GPS are combined for real-time data collection with accurate position information, and efficient manipulation and analysis of large amounts of spatial data. Applications of this data are field mapping, soil sampling, crop scouting, parallel swath guidance, variable rate applications of fertilizer and pesticide, and yield mapping. GIS and GPS have also been successfully used in entomological research. Michigan gypsy moth populations have been monitored and mapped for more than 10 years using an extensive geo-referenced pheromone trap system and GIS (Pijanowski and Gage 1996). Gage et. al. (1990) and Gage and Pijanowski (1993) used these maps to predict regional gypsy moth trends and to assess the ecological risk from the pest populations. The potato leafhopper data gathered in this study is analyzed in a similar manner, in a smaller agroecosystem.

Summary and Conclusions. This potato leafhopper study attempts to link potato leafhopper trap catch 'population dynamics' (Flinn *et. al.*, 1986) during the growing season to potato leafhopper seasonal population fluctuations and habitat structure (Pimentel 1961, Smith et. al. 1992) in and adjacent to the deciduous fruit orchards at the Clarksville Horticultural Experiment Station. Our data is used to gain basic insight into the short-range movement of potato leafhopper between orchards and the surrounding habitats by conventional statistics and GIS mapping. The goal of the project was to assess the difficulties associated with the control of a highly mobile pest that has the potential to re-emerge as a serious pest in many crop systems.

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CHAPTER 2

Potato leafhopper (*Empoasca fabae* Harris) (Cicadellidae: Homoptera) movement in a diverse deciduous fruit agroecosystem

Abstract

The movement of the highly mobile potato leafhopper (*Empoasca fabae* Harris) was studied in Michigan orchard systems and the surrounding agroecosystem. We linked potato leafhopper trap catch to potato leafhopper seasonal population fluctuations and the habitat structure in and adjacent to deciduous fruit orchards. We used an extensive trapping network of geographically stable yellow sticky boards to monitor the potato leafhopper in and around the habitats. The trap catch means followed a low – high – low pattern as the season progressed. Significant differences ($p<0.05$) were detected between habitats in the mid-season sample dates. Spring seeded alfalfa was the habitat with the largest means and greatest difference in 1996 ($p<0.05$). Alfalfa, soybeans, and apple were the habitats with the highest trap catch means in 1997. Alfalfa, apple, cherry, and soybeans had high populations of potato leafhopper when temperatures and conditions were favorable in the agroecosystem. Further research needs to be done to determine the effects of managed habitat manipulation on potato leafhopper damage in sensitive deciduous fruit crops.

Introduction

Empoasca fabae, the potato leafhopper, is highly polyphagous, feeding on over 200 plant hosts (Poos and Wheeler 1943, Lamp et. al., 1994). It is a pest in many Michigan cropping systems, including alfalfa, potatoes, beans, and deciduous fruit trees. It is also found in many non-crop habitats, including forest, old field, and roadsides (Lamp et. al. 1989). The potato leafhopper is very mobile, frequently migrating between hosts within an agroecosystem and as a long-range migrant between southern overwintering sites and northern summer habitat.

The potato leafhopper is unable to survive winter conditions in the Midwest (Decker and Maddox 1987) and it disappears when temperatures fall below survival thresholds. Decker and Cunningham (1968) report that potato leafhopper overwinter and begin spring reproduction on weedy annual legumes in the states on the Gulf of Mexico. Taylor and Shields (1995a,b) report the collection of potato leafhopper in Arkansas and Tennessee in January, and the collection of potato leafhopper from several Pinus spp. in the overwintering range. The number of potato leafhopper available for migration north in the spring depends on the availability and quality of host plants and the occurrence of lethal temperatures encountered at the overwintering sites (Berberet and Hutchison 1994).

Potato leafhoppers move north on early-season air currents and arrive in Michigan in mid-May to late June on spring weather systems. Potato leafhopper arrival dates and corresponding weather patterns have been tracked in the midwestern and eastern states since 1951 (Maredia et. al. 1998). The exact weather transport conditions needed for potato leafhopper migration to occur have been determined (Carlson et. al. 1991, 1992). It is possible to predict potato leafhopper migration and arrival from weather patterns in the early spring. From 1986 until 1998, our lab has conducted a spring migration detection trapping network. This extended and intense transect system confirms the potato leafhopper arrival date each year. From this transect data, we hypothesize that potato leafhoppers begin feeding and reproducing on deciduous trees. They are the only plants providing enough vegetative growth to support a phloem feeder when the potato leafhopper arrival occurs (DiCosty et. al. 1998, Kaeb and Whalon 1998).

The appearance of the first Michigan potato leafhopper generation depends on spring transport events and degree day (base 50°F) heat accumulation following arrival. The migratory generation is usually not large enough to cause economic damage to crops, but potato leafhopper are prolific and the population may quickly rise to damaging levels if optimum conditions occur. The potato leafhopper is multivoltine, with three to five overlapping generations each year. A female can live up to six months and produce eggs for much of her life span (DeLong 1938). There is no correlation between the arrival date and the subsequent severity of potato leafhopper infestation (Maredia et. al. 1998).

Potato leafhoppers feed on the phloem tissue of host plants, puncturing, tearing and distorting the cells in the vascular bundle as they use their proboscis to empty the cell contents (Ecale and Backus 1995a). As the potato leafhopper probes into the plant tissue, it secretes a salivary fluid, which hardens into a sheath. This sheath remains in the plant for a long period of time (Ecale and Backus 1995b). Potato leafhopper feeding behavior and the resulting residue cause a V-shaped chlorotic area called 'hopper burn.' Hopper burn reduces plant photosynthesis, stunts plant growth and reduces crop yields (DeLong 1971, Schoene 1932).

Michigan orchards are very ecologically complex (Whalon and Croft 1985). The insect pest complex found in Michigan orchards can be significantly influenced by disturbance (Wise 1990), nutrient flow (Stickler and Whalon 1985), ground cover (Larson and Whalon 1987) and the surrounding habitats. Many studies have been done on deciduous fruits and the damage caused by individual components of the pest complex. None of the studies in the past 50 years mention potato leafhopper as anything other than an occasional occupant of orchards. The 1998 Michigan Fruit Spraying Calendar (Jones et. al. 1998) states, as a side note, "most organophosphates (OPs) applied for other pests will control potato leafhoppers." The potato leafhopper has not been a pest in Michigan orchards since OPs came into wide spread usage in the 1950s. Prior to OPs, however, the potato leafhopper was a serious orchard pest.

Rising environmental awareness and new pesticide laws, including the Food Quality Protection Act of 1996, are threatening Michigan producers with the loss of OP insecticides (Gray et. al. 1996, Peterson 1998). The "soft," pest specific chemicals and tactics being developed to replace the OPs for control of primary pests do not control secondary non-target pests, especially one as mobile and polyphagous as the potato leafhopper. The loss of chemical control exposes other weaknesses in the current agricultural production systems. Commonly grown varieties of apple have little resistance to a phloem damaging pest such as the potato leafhopper. The trees are also grown on dwarf rootstocks, further lowering resistance. The stage is being set for the re-emergence of an "old-fashioned" pest, the potato leafhopper.

We face a number of challenges as we transition the Michigan fruit production system to softer, more environmentally friendly programs of pest control. Broad spectrum pesticides allowed producers to virtually ignore the effects of surrounding habitats on the pest complex within the orchard. With the loss of chemical control options, the impact of the agroecosystem on potato leafhopper/crop interactions becomes more important.

We studied the movement of the highly mobile potato leafhopper in Michigan orchard systems and the surrounding agricultural landscapes to give us an idea of the challenges that we will face as we begin the transition of Michigan fruit production systems to a softer, more environmentally friendly program. This study attempts to link potato leafhopper trap catch 'population dynamics' (Flinn *et. al.*, 1986) during the growing season to potato leafhopper seasonal population fluctuations and the habitat structure in and adjacent to the deciduous orchards at Clarksville Horticultural Experiment Station. The collected data was used to gain basic insight into the short-range movement of potato leafhopper in the agroecosystem in the orchards and the surrounding habitats.

Materials and Methods

Agroecosystem. We monitored the movement of potato leafhopper in the diverse agroecosystem at the Clarksville Horticultural Experiment Station during the 1996 and 1997 growing seasons. The station is managed for fruit crop research and field crop variety and spray trials. The composition of the crops in the agroecosystem changed with normal agronomic crop rotations between the years. Vegetative maps of the station show the habitats present during the respective years (Figures 2.1 and 2.2). In 1996, spring planted alfalfa (alfalfa1) was present. Soybeans, wheat, and several new apple plots were added and several alfalfa fields were taken out in 1997.

Traps. Ninety-five geographically stable sticky board stations were used to monitor the potato leafhopper in and around the habitats. The trap stations were freestanding and consisted of a yellow sticky board hung from a movable crosspiece set 0.95m above the ground on a step-in electric fence post. The sticky boards were 6"x 8" pieces of ¼" plywood painted safety yellow (Rust Stop, Ace Hardware Corp.) and encased in one quart ziplock bags coated with Tanglefoot (Tangletrap, Grand Rapids, MI).

Yellow sticky traps attract and capture potato leafhoppers. The yellow color provides a visual stimulus, and when a potato leafhopper comes into contact with the board, the sticky substance retains it. Sampling is continuous and information is accumulated about the potato leafhopper population 24 hours a day across the period between trap visits. The yellow sticky trap sampling method is dependent not only on the insect density, but also on several other variables. Color attraction, light quantity/quality, flight behavior, wind speed, and temperature also affect the number of potato leafhopper collected in a given sample (Wise 1990).

Sampling. We used an extensive trapping system, limiting the number of traps in each habitat so many habitats could be sampled over a large geographic area. The station was divided up into 19 - 20 acre blocks, and five trap stations were placed in each block. Traps were placed in locations based on several operational considerations, including;

roads, insecticide treated plots, surface water, slope and aspect. Latitude and longitude coordinates for each trap were recorded using a handheld Scoutmaster GPS unit (Trimble Navigation, Sunnyvale, CA) and location maps were generated using ArcView GIS (Environmental Systems Research Institute, Redlands, CA).

The composition of the vegetation surrounding each trap was recorded at the beginning of each year and when changes were made. Potato leafhopper sampling events were triggered by selected degree day (base 50°F) accumulation intervals during the growing season (7 samples in 1996 and 21 samples in 1997). Potato leafhopper specimens on the trap at the time of sampling were recorded and removed using a metal spatula on the sampling dates between sticky bag changes. The sampling objectives were to detect potato leafhopper in a given habitat and to provide information on the status of potato leafhopper in the habitat.

Analysis. Data was submitted to standard ANOVA, regression, mean separation, and analysis of deviate tests. Statistical tests were preformed using Minitab (Minitab, Inc., State College, PA). Log (x+1) transformed values were used in all statistical tests. Tukey's test, with the family error rate set at 0.05, was used for the ANOVA comparisons. Non-transformed values were presented in all figures and tables.

Results and Discussion

Data Transformation. Variances exceeded the means of the potato leafhopper trap catch numbers. From calculations based on Taylor's power law (Southwood 1978, Steel and Torrie 1980), the log (x+1) transformation, where x = potato leafhopper trap catch, was utilized to stabilize variances. The regression lines generated by the transformed (R^2=0.9125) and non-transformed (R^2=0.6691) means and variances are shown in Figure 2.3.

Within Habitat. Most habitats show trap catch differences ($p<0.05$) over time. The means ± SEM, F-tests and p-values of the habitats for each sample date in 1996 and 1997 were reported in Table 2.1. In the habitats with trap catch differences, the means followed a low – high – low pattern as the season progressed during each year. Alfalfa, alfalfa1, apple, cherry, grass, soybeans, and wheat followed the expected trends (Hogg 1985).

Trap catch in the corn was high early in the season, fell off abruptly at midseason and remained low. In oak and woods habitat, potato leafhopper trap catch remained low for most of the season. The trap catch means in six habitats were graphed at each sample date during the two years (Figure 2.4). The scale of the y-axis in several of the graphs varies, displaying the differentiation between years.

The trap efficiencies, in the habitats in which the potato leafhopper trap catches differed from the expected mean trends, were likely effected by factors other than the potato leafhopper densities. The traps placed in the corn measured the potato leafhopper numbers early in the season. When the height of the corn exceeded the height of the traps (1 m), the traps were obscured and few potato leafhoppers were collected on them. The sticky traps were placed below the tree canopy in the mature wood and oak stands, and did not measure potato leafhopper present in the tree canopy. We used the within habitat analyses to determine the effectiveness of the traps in each habitat. The traps were ineffective in woods, oak and corn after trap height was exceeded and the trap catch numbers were dropped from further analysis.

Between Habitat. The potato leafhopper trap catch was low at the beginning and ends of the growing seasons. No differences were detected between habitats in the early and late sample dates in either year. The habitat mean ± SEM, differences between the habitats, F-test, p-value, and sum of trap catch for each sample date is reported for 1996 (Table 2.2) and 1997 (Table 2.3). Significant differences ($p<0.05$) were detected between habitats in the mid-season sample dates.

Spring seeded alfalfa (alfalfa1) proved to be the habitat with the largest means and greatest difference throughout the sample dates in 1996 ($p<0.05$). This alfalfa was harvested late (after 1577 degree day [base 50° F]), and potato leafhopper populations were allowed to grow for most of the season. The trend continued after the alfalfa was cut, but the differences and means were less ($p>0.05$).

The high, early season trap catches in corn in 1997 may be explained by potato leafhopper early season emigration behavior. The low numbers collected from corn after the height obscured the traps were dropped from the analysis in both years (Table 2.2 and 2.3) as discussed above.

The soybean habitat consisted of five soybean varieties from four different companies (Asgrow, AG2701; Novartis [Northrup King], F20-B9; Pioneer, 9254 and 9294; Michigan Certified Seed, Conrad-94), and these varieties were used in herbicide trials. Large patches of ragweed, lamb's quarter and burdock were found near some of the traps during part of the season. The high and fluctuating potato leafhopper trap catch in the soybean habitat (Figure 2.4b) may have been due to the combination of multiple variety, weed presence, and herbicide spray schedule of this habitat.

Yearly habitat means ± SEM were displayed for 1996 (Figure 2.5) and 1997 (Figure 2.6). These figures included data from several habitats with only one trap where single sample period means could not be calculated. There were differences across the habitats in 1996 ($F=17.52$, $p<0.0001$) and 1997 ($F=10.47$, $p<0.0001$). Alfalfa1 (1996) and alfalfa, soybeans, and apple (1997) were the habitats with the highest trap catch means, as predicted by the within year analyses.

Conclusions

More potato leafhoppers are caught in host habitats than in non-host habitats. Alfalfa, apple, cherry, other deciduous fruit and soybean habitats have high populations of potato leafhopper during the season when temperatures and conditions are favorable in the agroecosystem. The trap efficiency impacts the number of potato leafhoppers caught in some habitats, and trap efficiency can change during the season. Habitat management, such as spraying or harvesting, can also impact the potato leafhopper trap catch in the broader agroecosytem.

Further research is necessary as we begin the transition of the Michigan fruit production system to softer, more environmentally friendly programs of pest control. Broader agroecosystem information about highly mobile, potentially destructive non-target pests, such as potato leafhopper will become invaluable as the broad spectrum pest control methods are lost. Future studies on potato leafhopper in the diverse fruit agroecosystem should include more intensive studies of the habitat and between habitat effects on crop damage. Further research is needed to determine the effects of managed habitat manipulation on potato leafhopper damage to sensitive deciduous fruit crops during the growing season and between seasons. Thresholds for economic damage in fruit crops based on potato leafhopper populations in neighboring habitats should also be determined.

Broad spectrum insecticides allowed fruit producers to virtually ignore the effects of surrounding habitats on mobile, polyphagous pests within the orchard. Habitat studies like this one and future ones are increasingly important, because producers will no longer be able to depend on them to control non-target pest, such as potato leafhopper.

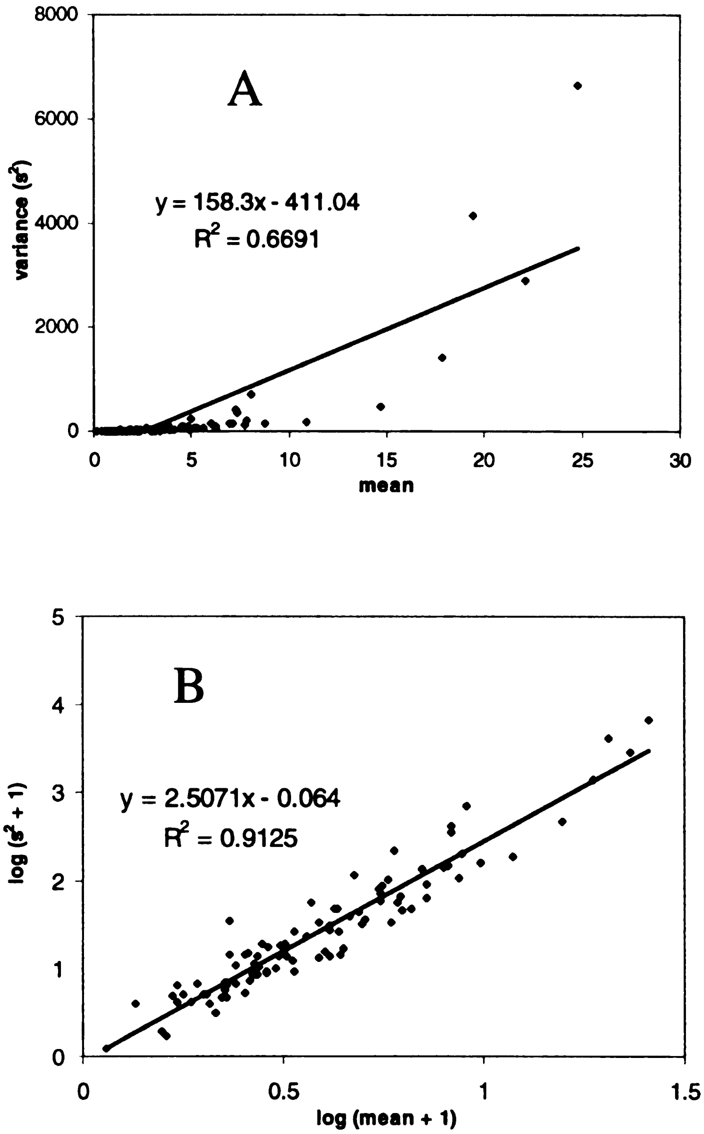

Figure 2.3. Taylor's Power Law regression lines (A) non-transformed means and variances showing that the data is not normally distributed (B) normally distributed log (x+1) transformed means and variances.

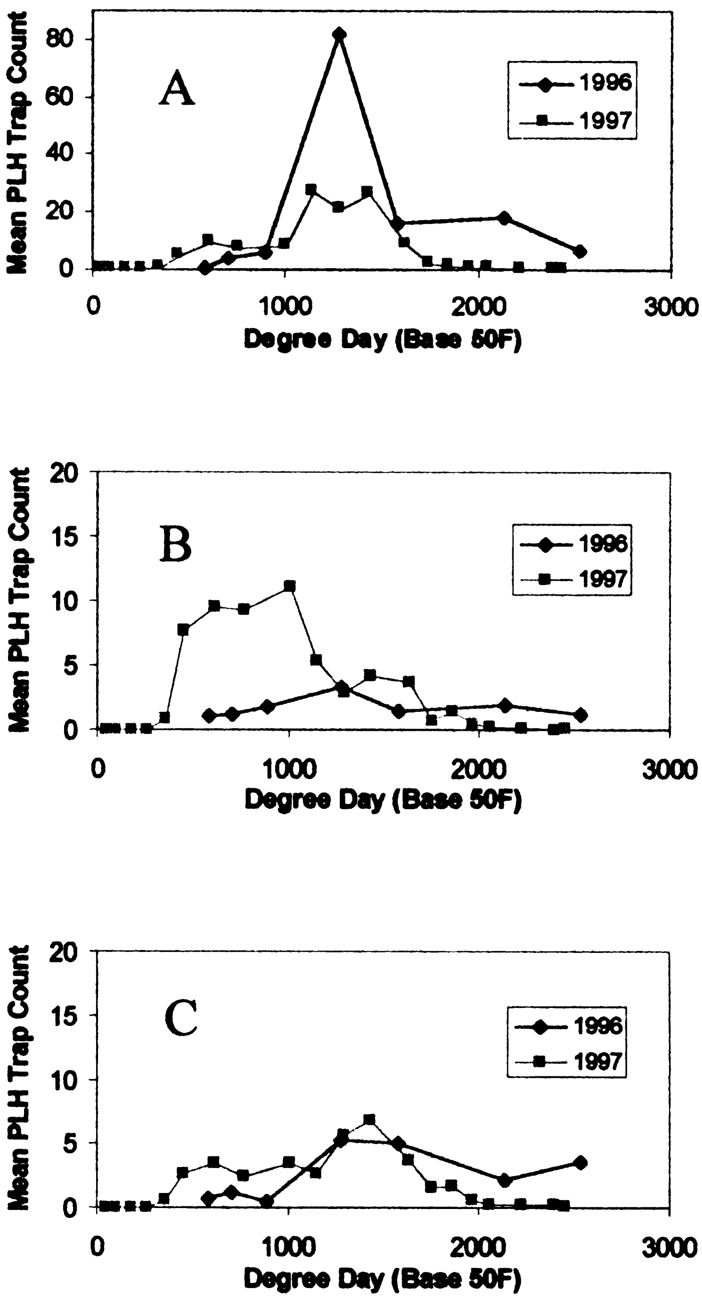

Figure 2.4. Mean potato leafhopper trap catches in habitat categories by degree day (base 50F) sample periods in 1996 and 1997, (A) alfalfa, (B) corn, (C) grass.

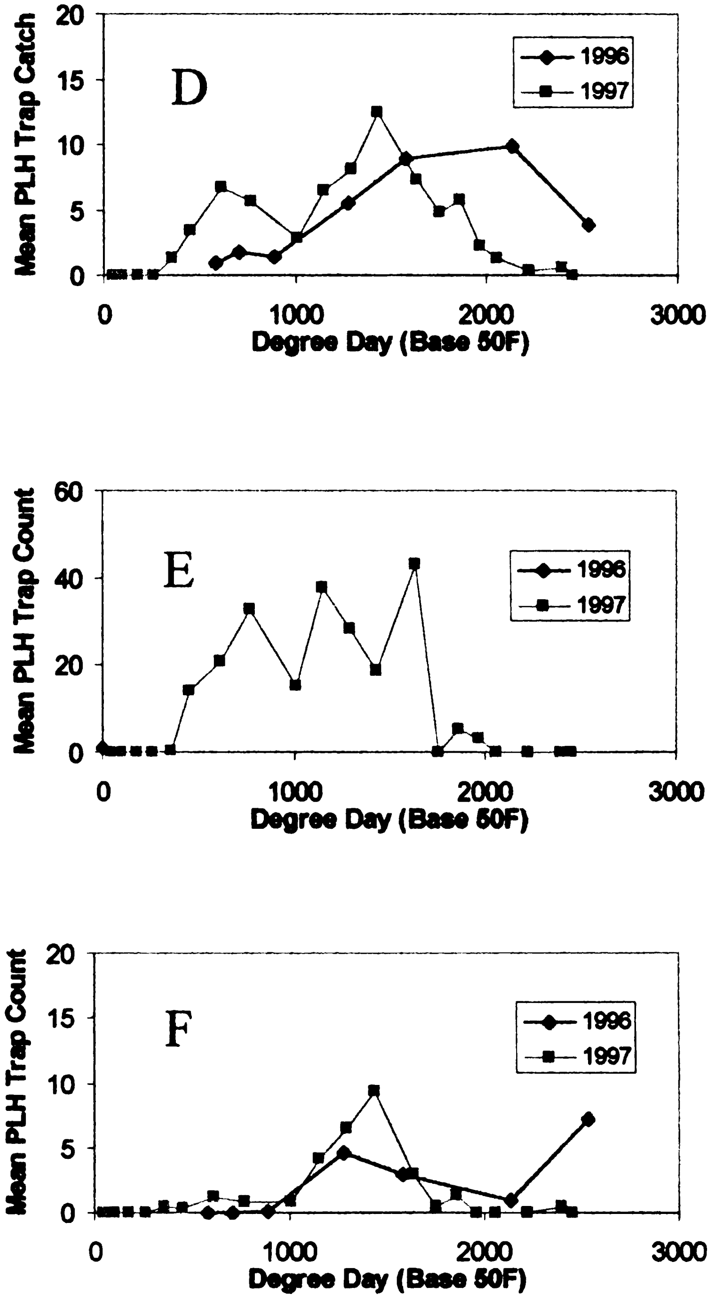

Figure 2.4 continued. Mean potato leafhopper trap catches in habitat categories by degree day (base 50F) sample periods in 1996 and 1997 (D) orchard, (E) soybeans, (F) woods.

Table 2.2. Potato leafhopper trap catch mean ± SEM for all sample dates and selected habitats, 1996.

Degree Day	Habitats							F-test	p-value
	alfalfa	alfalfa1	apple	cherry	corn	grass	weeds		
583	1.1 ± 0.3	0.6 ± 0.2	0.7 ± 0.4	1.3 ± 0.4	1.1 ± 0.3	0.6 ± 0.3	0.9 ± 0.5	0.7	0.649
706	3.7 ± 1.0	3.3 ± 1.6	2.3 ± 0.8	1.4 ± 0.3	1.3 ± 0.3	1.0 ± 0.4	1.7 ± 0.5	1.52	0.183
891	2.4 ± 0.7^{ab}	9.0 ± 2.3^{b}	1.9 ± 0.5^{b}	1.2 ± 0.4^{b}	1.9 ± 0.7^{b}	0.5 ± 0.2^{b}	0.7 ± 0.3^{b}	6.25	<0.0001
1280	8.9 ± 3.6^{ab}	154.2 ± 52.0^{a}	7.4 ± 2.3^{b}	4.5 ± 1.2^{b}	3.5 ± 2.1^{b}	4.7 ± 1.3^{b}	6.8 ± 4.0^{b}	6.88	<0.0001
1577	15.4 ± 3.7^{a}	15.11 ± 4.4^{ab}	13.1 ± 3.8^{ab}	6.0 ± 2.0^{ab}	*	5.7 ± 2.5^{b}	4.6 ± 1.8^{ab}	2.87	0.022
2138	15.7 ± 4.0^{a}	19.2 ± 3.4^{a}	13.6 ± 4.0^{a}	8.3 ± 1.6^{a}	*	2.4 ± 0.8^{b}	1.6 ± 0.8^{b}	11.43	<0.0001
2529	5.2 ± 1.8^{a}	11.8 ± 3.7^{a}	3.6 ± 2.0^{ab}	4.4 ± 1.5^{ab}	*	1.1 ± 0.4^{b}	4.6 ± 1.9^{ab}	4.1	0.003

Means followed by a different letter in the same row are statistically different ($P<0.05$; Tukey test done on log[x+1] transformed data).

* Data removed from analysis due to reduced trap catch efficiences in the corn habitat.

Table 2.3. Potato leafhopper trap catch mean ± SEM for all sample dates and selected habitats, 1997.

Degree Day	Habitats								F-test	p-value
	alfalfa	apple	cherry	corn	grass	weeds	soybeans	wheat		
261	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.36	0.909
357	0.4 ± 0.3	1.5 ± 0.7	0.9 ± 0.3	0.7 ± 0.3	0.7 ± 0.4	1.1 ± 0.3	0.3 ± 0.3	1.0 ± 0.6	0.56	0.784
454	4.3 ± 1.4	4.0 ± 1.7	2.8 ± 1.4	7.7 ± 1.5	2.9 ± 1.2	3.2 ± 0.9	14.0 ± 2.5	1.5 ± 1.2	2.86	0.01
611	6.6 ± 1.7^{abc}	9.9 ± 2.2^{a}	2.7 ± 1.1^{bc}	12.1 ± 2.2^{ab}	2.2 ± 0.8^{c}	4.9 ± 1.5^{abc}	20.8 ± 7.8^{abc}	1.8 ± 1.0^{abc}	7.72	<0.0001
767	5.0 ± 0.8^{abc}	8.1 ± 2.2^{ab}	2.7 ± 0.7^{abc}	10.6 ± 1.9^{a}	3.4 ± 1.7^{bc}	2.9 ± 0.7^{bc}	32.7 ± 12.8^{ab}	0.3 ± 0.3^{c}	6.31	<0.0001
1009	11.1 ± 5.4	2.3 ± 1.2	3.9 ± 0.9	10.7 ± 3.1	2.8 ± 1.3	5.1 ± 2.4	15.3 ± 3.0	2.3 ± 0.9	2.59	0.019
1147	45.0 ± 10.0^{a}	10.0 ± 3.1^{b}	2.0 ± 0.7^{b}	*	4.1 ± 1.0^{b}	4.3 ± 1.4^{b}	37.7 ± 17.3^{ab}	20.5 ± 19.5^{b}	8.37	<0.0001
1293	44.4 ± 13.5^{a}	12.3 ± 3.8^{ab}	2.8 ± 0.6^{b}	*	5.1 ± 1.1^{b}	5.0 ± 1.3^{b}	28.3 ± 12.7^{ab}	14.5 ± 10.9^{ab}	7.62	<0.0001
1435	51.6 ± 19.7^{a}	17.1 ± 4.0^{a}	8.3 ± 1.5^{ab}	*	3.4 ± 0.9^{b}	6.8 ± 2.7^{b}	18.7 ± 10.7^{ab}	35.0 ± 20.9^{a}	7.06	<0.0001
1632	11.3 ± 5.1	10.9 ± 3.6	3.7 ± 1.1	*	4.3 ± 1.1	4.3 ± 1.4	43.0 ± 15.9	7.5 ± 2.9	4.41	0.001
1756	1.6 ± 0.7	5.7 ± 1.8	3.8 ± 1.1	*	1.5 ± 0.4	2.1 ± 0.7	0.0 ± 0.0	1.3 ± 0.8	2.9	0.015
1856	1.6 ± 0.8^{ab}	7.9 ± 2.8^{a}	3.6 ± 0.7^{ab}	*	1.6 ± 0.4^{b}	1.9 ± 0.6^{ab}	5.3 ± 2.9^{ab}	1.0 ± 0.7^{ab}	3.08	0.011
1961	1.1 ± 0.5^{abc}	2.5 ± 0.6^{a}	2.3 ± 0.8^{ab}	*	0.6 ± 0.4^{bc}	0.3 ± 0.1^{c}	3.3 ± 1.3^{abc}	0.8 ± 0.3^{abc}	4.97	<0.0001
2056	1.3 ± 0.7^{ab}	2.1 ± 0.9^{a}	0.4 ± 0.2^{ab}	*	0.2 ± 0.1^{b}	0.1 ± 0.1^{b}	0.0 ± 0.0^{ab}	0.8 ± 0.3^{ab}	4.5	0.001
2220	0.0 ± 0.0	0.4 ± 0.2	0.4 ± 0.2	*	0.4 ± 0.2	0.1 ± 0.1	0.0 ± 0.0	0.3 ± 0.3	1.27	0.286
2395	0.1 ± 0.1^{ab}	1.2 ± 0.5^{a}	0.0 ± 0.0^{b}	*	0.5 ± 0.5^{ab}	0.1 ± 0.1^{b}	0.0 ± 0.0^{ab}	0.0 ± 0.0^{ab}	2.79	0.019
2451	0.1 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	*	0.1 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.57	0.755

Means followed by a different letter in the same row are statistically different ($P<0.05$; Tukey test done on log[x+1] transformed data).

* Data removed from analysis due to reduced trap catch efficiences in the corn habitat.

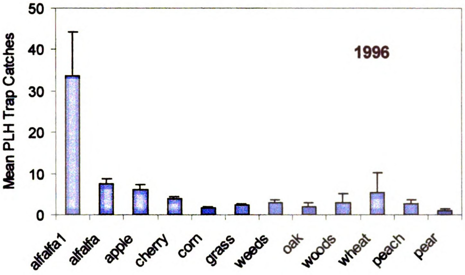

Figure 2.5. Means ± SEM for all habitats, 1996. First year alfalfa (alfalfa1) is significantly different ($p<0.05$; Tukey's test) from all other habitats.

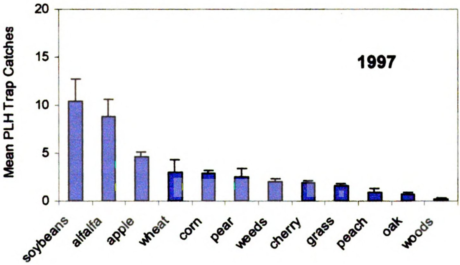

Figure 2.6. Means ± SEM for all habitats, 1997. Soybeans, alfalfa and apple are significantly different ($p<0.05$; Tukey's test) from all other habitats.

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CHAPTER 3

Impact of two alternative management systems on potato leafhopper (*Empoasca fabae* Harris) (Cicadellidae: Homoptera) in Michigan Apple Orchards

Abstract

The effect of two alternative orchard treatment systems on the numbers of potato leafhopper (*Empoasca fabae* Harris) present in Michigan apple orchards was studied. Yellow sticky traps were used to monitor the movement of potato leafhopper in and around the apple plots and treatments. There were significantly higher trap counts in the unsprayed checks than in any of the spray treatments ($P<0.003$). There were no significant trap catch differences between three apple varieties in either year. The alfalfa, apple and orchard habitats had trap catch means higher than other habitats over both years. High trap catches were recorded in surrounding habitats in the sample period following alfalfa cutting. Potato leafhopper is seasonally present in Michigan orchards and is found in high numbers compared to non-host habitats. More work is needed to determine the actual effects of treatment, variety, and surrounding habitat on the economic impact of potato leafhopper in Michigan orchards.

Introduction

Empoasca fabae, the potato leafhopper (potato leafhopper), is highly polyphagous. It feeds on over 200 plant hosts (Poos and Wheeler 1943, Lamp et. al., 1994) and is a pest in many Michigan cropping systems, including alfalfa, potatoes, beans, and deciduous fruit trees. The potato leafhopper is mobile as an interhabitat migrant between hosts in an agroecosystem and as a long-range migrant between southern overwintering sites and northern summer habitats.

Potato leafhoppers feed on the phloem tissue of host plants, puncturing, tearing and distorting the cells in the vascular bundle as they use their proboscis to empty the cell contents (Ecale and Backus 1995a). As the potato leafhopper probes into the plant tissue, it secretes a salivary fluid that hardens into a sheath. This sheath remains in the plant for a long period of time (Ecale and Backus 1995b). Potato leafhopper feeding behavior and the resulting residue causes a V-shaped chlorotic area called 'hopper burn.' Hopper burn reduces plant photosynthesis, stunts plant growth and reduces crop yields (DeLong 1971). High numbers of potato leafhopper cause direct economic damage to forage crops and indirect damage to deciduous crops such as apples.

Many studies have been done on the damage caused by individual components of the pest complex in deciduous fruits. None of the studies in the past 50 years mention potato leafhopper as anything other than an occasional occupant of orchards. The 1998 Michigan Fruit Spraying Calendar (Jones et. al. 1998) states, as a side note, "most organophosphates (OPs) applied for other pests will control potato leafhoppers." The potato leafhopper has not been a pest in Michigan orchards since OPs came into widespread usage in the 1950's. Prior to OPs, however, the potato leafhopper was a serious orchard pest.

There are many cooperative extension reports from the early 1900's that describe the potato leafhopper as a pest in apple orchards (Garman 1908, Washburn 1903, Schoene 1932). According to Schoene (1932), potato leafhopper is a serious economic pest of young apple trees and cultivated orchards. Potato leafhopper damage to apples includes brown leaf margins in moderate infestations, and stunting, reduced vigor, delayed bearing or even tree death in high infestations. Schoene and Underhill (1937) published an exhaustive study on the susceptibility of the (then) commonly grown apple varieties, classifying them as being low, moderate or highly susceptible to potato leafhopper. There were no further studies of potato leafhopper damage after OPs came into common orchard use.

Rising environmental awareness and new pesticide laws, including the Food Quality Protection Act of 1996, are threatening Michigan fruit producers with the loss of OP insecticides (Gray et. al. 1996, Peterson 1998). The "soft," pest specific chemicals being developed to replace the OPs do not control secondary non-target pests. The loss of broad spectrum chemical control exposes other weaknesses in the current production system. Commonly grown varieties of apple have little resistance to a phloem damaging pest such as the potato leafhopper. The trees are also grown on dwarf rootstocks, further lowering resistance. The stage is being set for the re-emergence of "old-fashioned" pests such as potato leafhopper.

This study seeks to determine the effect of several alternative orchard treatment systems on the numbers of potato leafhopper present in the orchards. The treatment systems we studied included multiple pest control strategies; a hedgerow barrier, environmentally friendly chemicals with novel modes of action, pheromone disruption for control of lepidoptera pests, "bait and kill" techniques, and conventional OP treatments. The objectives of the study were to 1) determine if any control of potato leafhopper occurred in our varied treatment regimes, 2) if there were any differences between potato leafhopper incidence in 3 apple varieties, and 3) the effects of the vegetation surrounding our test plots on potato leafhopper trap catches.

Materials and Methods

Plots. We studied the movement of potato leafhopper in and around eight - ½ acre dwarf apple plots at the Clarksville Horticultural Experiment Station during the 1996 and 1997 growing seasons. The physical design and layout of the plots was developed for a multidisciplinary project entitled "Alternative Pest Management Systems in Apple" by a multidisciplinary committee. This committee included entomologists, plant pathologists, horticulturists and agricultural economists. There were four replicates of the IPM (no-barrier) plots and four replicates of the low input (barrier) plots. Each plot was separated from the others by at least 150 m. Four rows of three apple varieties, 'Empire,' 'Ida Red,' and 'Liberty,' on Mark V dwarf rootstocks were randomly placed within the plots (Figure 3.1). Barrier plots were surrounded by a 7 m high hedgerow barrier of hybrid poplar, gray alder, and white pine trees (Figure 3.2).

Treatments. Each plot was divided up into three treatment subplots. The no-barrier plots included a negative control, a "soft" treatment (imidacloprid, tebufenozide) and a positive control using conventional OP and carbamate treatments (methomyl, guthion) (Figure 3.1A). The treatments within the barrier plots included a pheromone disruption treatment, a non-OP soft treatment to control lepidopterous pests (spinosad, imidacloprid, tebufenozide) and a negative control (Figure 3.1B). In 1996, we sprayed the barriers themselves with garlic formulation as to make them repellant-protectant. In 1997, the barriers were sprayed with esfenvalerate to make them toxic to insect pests.

Traps. Two separate sets of yellow sticky traps were used to monitor the movement of potato leafhopper in and around the plots and treatments. These traps were used in separate analyses and were not compared. The "interior traps" were Pherocon AM (Trece Inc, Sandoz Ltd) yellow panels. These traps were placed in the tree 1.5 m above the ground. We placed one trap in each treatment of each variety for a total of 48 traps in the plots and 6 check traps in unsprayed orchards at other sites on the station.

The second set of traps, the "exterior traps," measured the movement of potato leafhopper around the edges of the plots. The traps were constructed of ¼" plywood painted safety yellow (Rust Stop, Ace Hardware Corp.) and encased in one quart ziplock bags coated with Tanglefoot (TangleTrap Corp., Grand Rapids, MI). The trap stations were freestanding and consisted of a yellow sticky board hung from a movable crosspiece set 0.95 m above the ground on a step-in electric fence post. Four traps were placed at -X, X, X^2, and X^3 intervals (X=1.27m) on 4 sides of the ½ acre apple plots (Fig. 3.3). We monitored 16 exterior traps per plot, for a total of 128 traps.

Sampling. Sampling events were triggered by selected degree day (base 50°F) intervals during the growing seasons. Traps were checked on 13 sample dates during 1996 and 21 sample dates during 1997. Traps were changed once per month, and insects

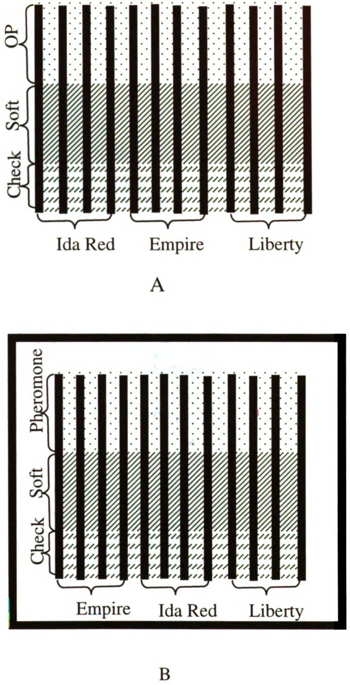


Figure 3.1. (A) Diagram of an IPM (no barrier) plot, showing the randomly assigned treatments and variety layouts used in the project. (B) Diagram of a low input (barrier) plot.

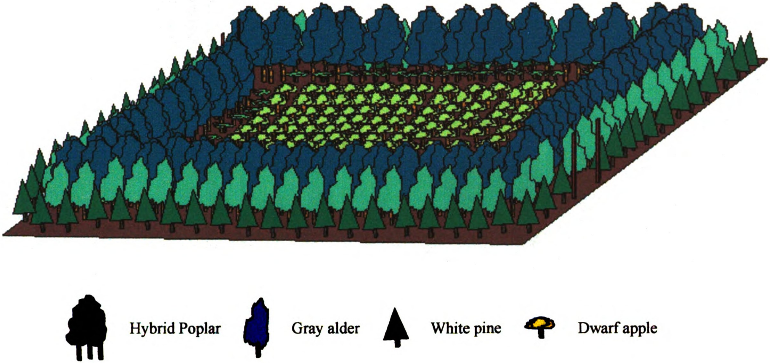


Figure 3.2. Placement of the barrier tress surrounding the apple trees in a low input plot.

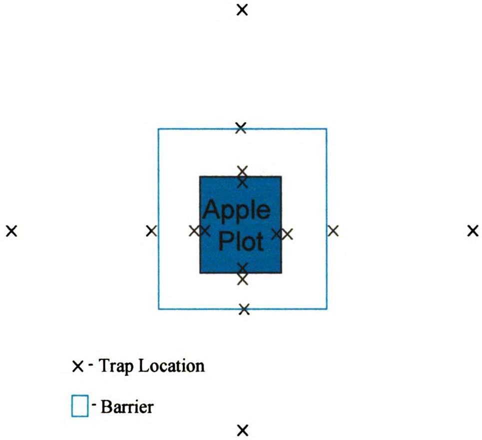


Figure 3.3. Layout diagram of the yellow sticky trap stations surrounding the "Alternative Pest Management Systems in Apple" plots (not to scale).

were scraped off using a metal spatula on the sample dates between trap changes. The composition of the vegetation surrounding the apple plots was surveyed and was used in analyzing the potato leafhopper trap count data. The latitude/longitude location of each trap was also recorded using a Global Positioning System (GPS) (Scoutmaster, Trimble Navigation, Ltd., Sunnyvale, CA).

Analysis. Data was submitted to standard ANOVA, regression, mean separation, and analysis of deviate tests. Statistical tests were preformed using the JMP (SAS Institute 1995) statistical package. The student's t test (Steel and Torrie 1980) with error rate set at 0.05 was used for analysis of variance (ANOVA) (SAS Institute 1995) test on the effects of the barrier, habitat, variety and treatment on potato leafhopper trap catch. The trap catch mean ± SEM was presented in the tables and figures.

Results and Discussion

Barrier Treatments. There were significantly higher potato leafhopper trap count means in and around the barrier plots than in the no barrier plots ($P<0.0001$) in 1996. There were more potato leafhopper captured on the exterior traps physically in the barrier than on traps outside the barrier. In 1997, the barrier plots had trap count means lower than the no barrier plots over the entire season ($P<0.0569$). The trends in mean trap catch at first arrival, first generation, season population peak and season end were shown (Figure 3.4). Differences were seen at the season peak sample date (~1300 degree day [base 50^{o}F]) when the population was the highest. There was little change in the no barrier mean trap catch in the two years, even though the overall number of potato leafhopper captured in 1997 was half the number captured in 1996. The difference between the two years occurred in the barrier plots. Adults and nymphs were collected in net sweep samples of the barrier in both years.

Hybrid popular (*Populus* sp.) is a deciduous tree that can serve as a host for the potato leafhopper (Lamp et. al. 1994). The gray alder (*Alnus incana*) and white pine (*Pinus strobus*) trees in the barrier, potential feeding sites, did not have as much of an effect as the poplar on potato leafhopper in the barrier plots. These trees did not grow well and remained short in comparison to the poplar trees (poplar = 7 m, gray alder and white pine < 1 m).

In 1996, we treated the barrier with garlic to make it repellant to potato leafhopper. This was not effective for potato leafhopper control in the barrier plots. In 1997, the barriers were treated with esfenvalerate to make them toxic. The barrier treatment difference was reflected by the potato leafhopper trap catch and may account for the mean trap catch differences between the two seasons in the barrier plots, when the no barrier mean trap catches remained the same.

Spray Treatments. There were significantly higher mean interior trap counts on the unsprayed checks than on any of the spray treatments ($P<0.003$) within the plots in 1997. We showed this by graphing the mean interior trap counts for treatments in the barrier and no barrier plots on seven sample dates in 1997 (Figure 3.5). Check trap catches mirrored the trap catches in the no barrier treatments for most of the season. The barrier traps had lower catches than the checks until after 1500 degree day (base 50F) heat units. There were no treatment differences ($p<0.05$) observed on the exterior traps in either year.

We expected to see a trap catch difference only in the OP treatments, as there was no anticipated potato leafhopper control in any of the other treatments. Esfenvalerate and imidacloprid show activity against potato leafhopper in high doses, but the application rate and the timing of the sprays was not conducive to potato leafhopper control in the treatments. Imidacloprid, a nicotine analog, also had activity against potato leafhopper natural enemies. The small size of the treatment areas, immigrations from outside habitats, and the visual attractiveness of the yellow traps may have masked any treatment effects.

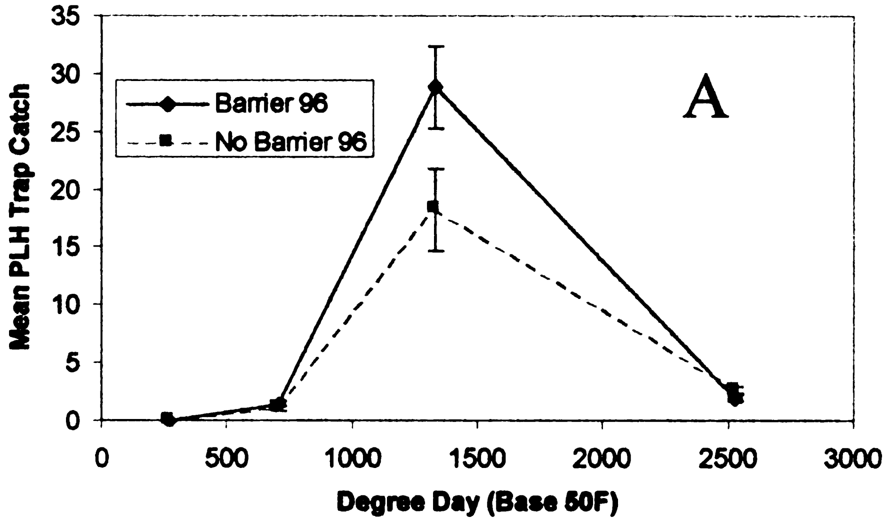
Variety Differences. There were no significant overall differences between the three apple varieties in either year, however, differences were shown on individual sample dates. Mean ± SEM interior trap catches from the first arrival, first generation, peak activity, population crash and season end sample dates were used to illustrate this (Figure 3.6). At peak potato leafhopper activity in 1996, 'Liberty' showed higher potato leafhopper counts than 'Ida Red' and 'Empire' ($P<0.0676$). In 1997, 'Liberty' showed slightly lower counts than the other two varieties in the same sample period ($p<0.3204$).

The small plot sizes and immigration from surrounding habitats may have masked variety differences if they occurred in our plots. None of the varieties present in our plots were discussed in "Resistance of certain varieties of apple trees to injury by the leafhopper (*Empoasca fabae*)" (Schoene 1937). This study can be summarized by saying potato leafhopper is not equally injurious to all varieties of apples, but the differences in the degree of injury are less when potato leafhopper is very numerous. Susceptibility of apple varieties to potato leafhopper varies inversely with foliage pubescence (Schoene 1937). Similar results have been found in soybeans (Johnson and Hollowell 1935) and glandular hair alfalfa (Sulc et. al. 1997). The three varieties we studied had approximately the same amount of leaf pubescence, which may also explain the lack of differences between the varieties.

Habitat Differences. The mean ± SEM exterior trap catches for the potato leafhopper first arrival, first generation, population peak, season end and pooled data from all sample dates was presented for 1996 (Table 3.1) and 1997 (Table 3.2). In 1996, the overall potato leafhopper population was higher and the differences in habitats were not as pronounced as in 1997. More differences were apparent in 1997, with the non-host habitats and the plot barriers having significantly lower trap catches on several sample dates and in the pooled data.

First arrival potato leafhopper detection occurred in the apple habitat in 1996. In 1997, the first potato leafhopper catches occurred on barrier and corn traps. Alfalfa, apple and orchard habitats usually had trap catch means higher than other habitats over both years. High trap catches were recorded in the woods, grass and apple habitats surrounding alfalfa in the sample period following alfalfa cutting.

The difference in the barrier trap catch means between 1996 and 1997 was due to the repellent vs. toxic treatments of the barrier between the two years. The high numbers in corn compared to the other habitats in first generation 1997 may have been due to the attractiveness and visibility of the yellow traps compared to the corn foliage. The lack of suitable plants in other habitats at this time of year for the adults to feed on may have also had an impact. Disturbance (alfalfa cutting) pushed adult potato leafhoppers from the disturbed areas into surrounding habitats, boosting trap counts.



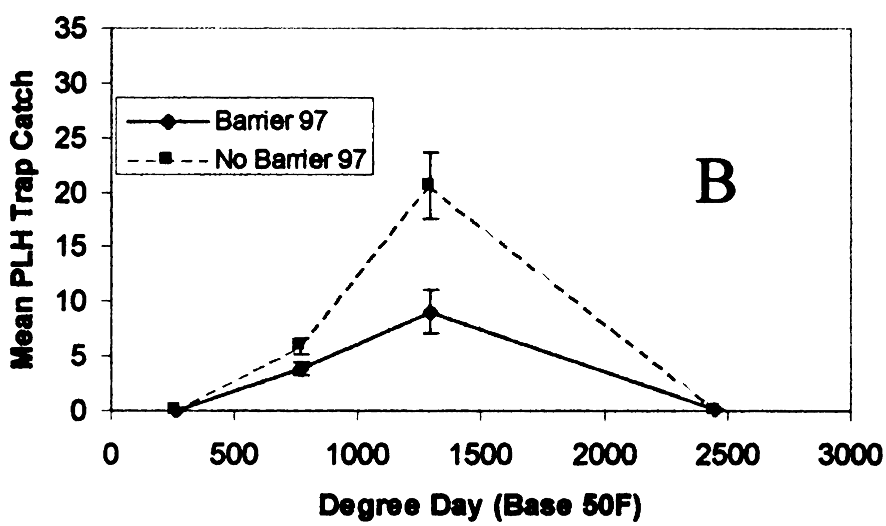
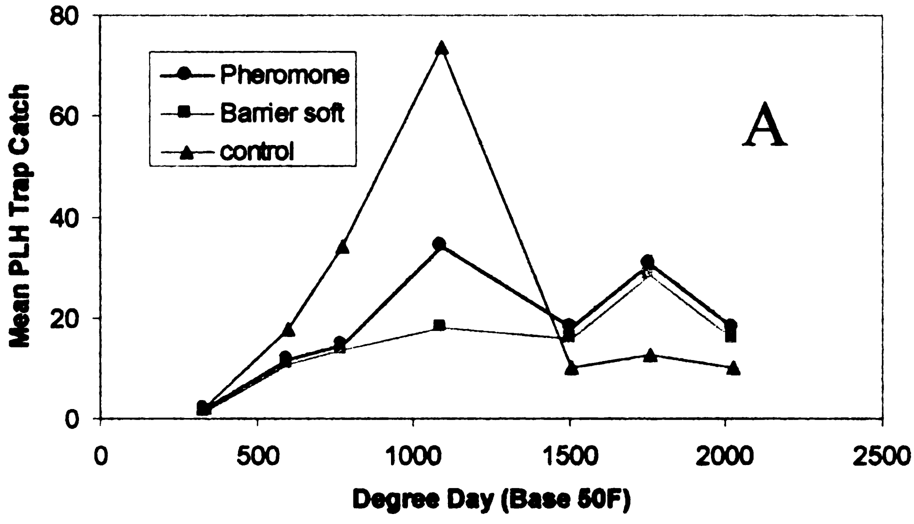


Figure 3.4. Effect of the barrier on the potato leafhopper mean ± SEM trap catch over time in 1996 and 1997. (A) There were significantly more captured in the barrier than the no barrier plots in 1996 ($P<0.0001$). (B) There were fewer potato leafhopper captured in the barrier than the no barrier plots in 1997 ($P<0.0569$).



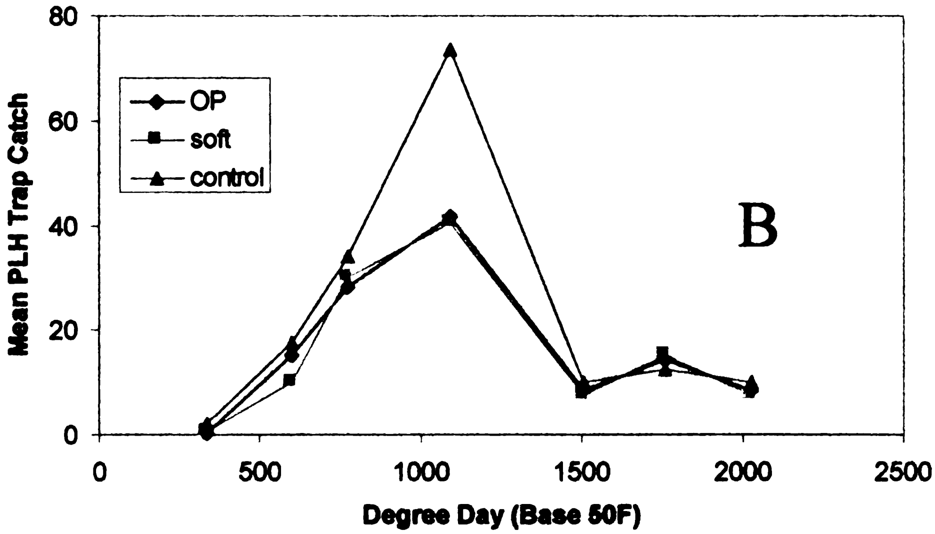


Figure 3.5. Effect of treatment on mean PLH trap catch over time in 1997. The mean potato leafhopper trap catch in the check was significantly different (P<0.001) than any of the treatments in the (A) barrier and the (B) no barrier plots.

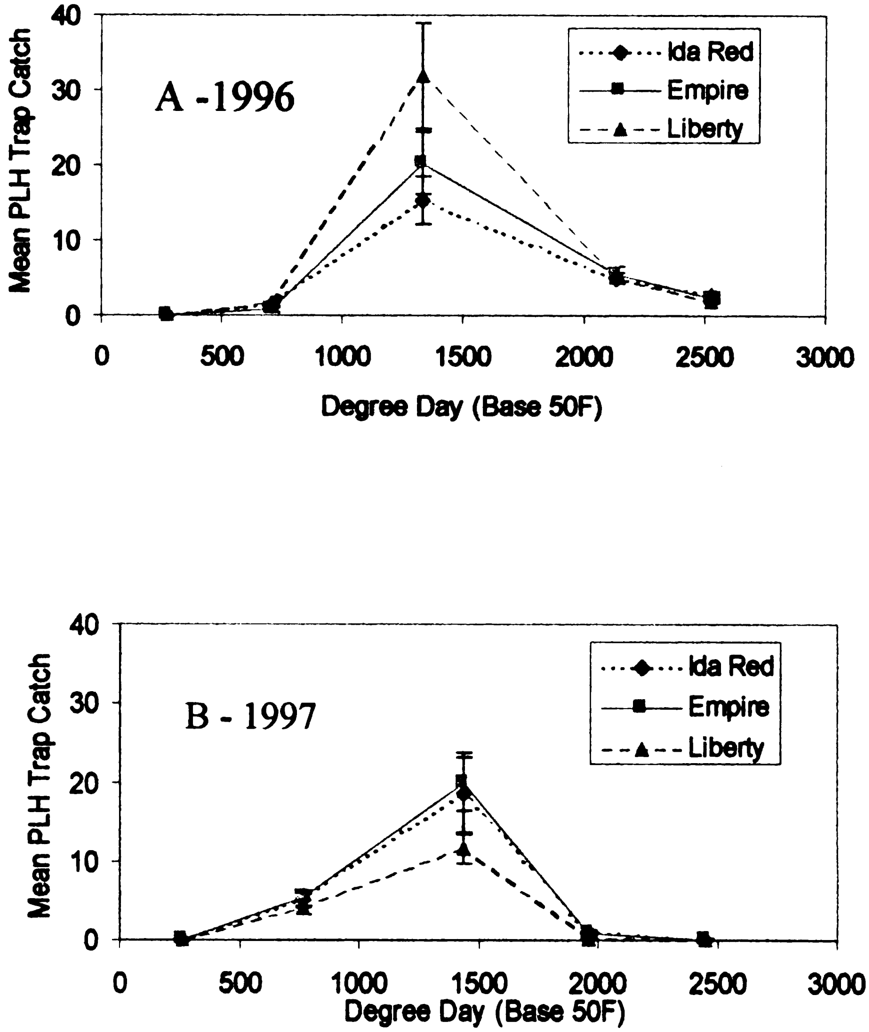


Figure 3.6. Effect of variety on the mean PLH trap catch over time in (A) 1996 and (B) 1997. Overall, there were no significant differences between the different varieties (P<0.05). Liberty showed higher numbers at one sample date in 1996, but showed lower numbers at the same degree day (base 50F) in 1997.

Table 3.1. Potato Leafhopper (PLH), *Empoasca fabae* (Harris), trap count means in a replicated IPM apple orchard system related to surrounding habitat, 1996.

Habitat[1]	**Arrival** **DD_{50}273** X±SE[2]	**First Generation** **DD_{50}706** X±SE[2]	**Alfalfa Cutting** **DD_{50}1333** X±SE[2]	**Season End** **DD_{50}2529** X±SE[2]	**All dates combined** X±SE[2]
Apple	0.05±0.3 [a]	1.8±0.2 [a]	28.9±4.2 [a]	2.7±0.3 [a]	9.8±0.6 [a]
Alfalfa	0.0±0.0 [a]	1.8±0.8 [a]	17.8±4.8 [a]	3.4±0.5 [a]	8.7±2.0 [a]
In Barrier	0.0±0.0 [a]	0.5±0.3 [b]	20.1±8.2 [a]	2.1±0.7 [a]	7.3±1.6 [a]
Woods	0.0±0.0 [a]	0.0±0.0 [a]	28.0±14.0 [a]	1.5±0.5 [a]	6.8±2.7 [a]
Orchard	0.0±0.0 [a]	1.4±0.9 [a]	23.3±12.1 [a]	2.6±1.0 [a]	6.2±1.3 [a]
Out Barrier	0.0±0.0 [a]	0.7±0.4 [a]	19.5±7.7 [a]	0.7±0.4 [a]	5.4±0.9 [b]
Grass	0.0±0.0 [a]	0.5±0.2 [b]	17.6±4.2 [a]	2.0±0.4 [a]	4.6±0.5 [b]
Corn	0.0±0.0 [a]	1.2±0.5 [a]	4.0±0.6 [a]	0.6±0.6 [a]	1.5±0.2 [b]

[1]Orchard habitat includes peach, pear, apple, and cherry.
[2]Means followed by the same letter are not different at the $P<0.05$ level using Student's t (SAS Institute, 1996).

Table 3.2. Potato Leafhopper (PLH), *Empoasca fabae* (Harris), trap count means in a replicated IPM apple orchard system related to surrounding habitat, 1997.

Habitat[1]	**Arrival** **$DD_{50}261$** X±SE[2]	**First Generation** **$DD_{50}767$** X±SE[2]	**Alfalfa Cutting** **$DD_{50}1293$** X±SE[2]	**Season End** **$DD_{50}2451$** X±SE[2]	**All dates combined** X±SE[2]
Apple	0.0±0.0 [a]	5.8±0.7 [a]	19.4±3.0 [a]	0.1±0.04 [a]	4.9±0.3 [a]
Alfalfa	0.0±0.0 [a]	5.2±2.1 [a]	26.4±17.3 [a]	0.0±0.0 [a]	6.1±1.8 [a]
In Barrier	0.3±0.3 [b]	1.2±0.6 [b]	2.0±0.9 [b]	0.0±0.0 [a]	1.1±0.2 [b]
Woods	0.0±0.0 [a]	2.0±1.0 [ab]	14.0±3.0 [a]	0.0±0.0 [a]	3.3±1.1 [a]
Orchard	0.0±0.0 [a]	7.7±4.9 [a]	25.7±11.4 [a]	0.0±0.0 [a]	6.0±1.3 [a]
Out Barrier	0.1±0.1 [b]	2.0±1.2 [b]	3.4±0.8 [b]	0.1±0.1 [a]	1.4±0.2 [b]
Grass	0.0±0.0 [a]	2.0±0.3 [b]	9.2±1.3 [a]	0.1±0.07 [a]	4.9±0.2 [b]
Corn	0.2±0.2 [b]	14.2±2.1 [c]	5.2±1.5 [b]	0.4±0.4 [a]	3.3±0.7 [b]

[1]Orchard habitat includes peach, pear, apple, and cherry.
[2]Means followed by the same letter are not different at the P<0.05 level using Student's t (SAS Institute, 1996).

Conclusions

Potato leafhopper is seasonally present in Michigan orchards and is found there in reasonably high numbers when compared to non-host habitats. More studies need to be undertaken to determine the actual effects of spray treatment, variety, and surrounding habitat on the economic impact of potato leafhopper in Michigan orchards. We have barely scratched the surface and were unable to find other research in the past 50 years that combined both potato leafhopper and apple.

This study has revealed several interesting questions regarding the use of a hedgerow barrier strategy for management of potato leafhopper in orchards. The poplar trees were shorter in the first season, and the gray alder and white pine remained small for the entire project. This study ended up testing a poplar barrier, not the mix, for pest control. Poplar is a deciduous tree, and is a potential potato leafhopper host. In the first year, we found that the barrier was attractive to potato leafhopper. In the second year, we exploited this by making the barrier toxic. Did the poplar trees attract potato leafhopper more strongly than the apple trees? Were the potato leafhopper drawn from the apple by the poplar and killed, or were they simply unable to reach the apple because of the poison barrier blocking them? Further work needs to be done to determine whether this was an "attract and kill" strategy or a poison barrier strategy.

Future studies are needed to determine the impact of secondary, non-target pests, including the potato leafhopper and other mobile pests, on Michigan apple and deciduous fruit orchards as we begin the transition of the Michigan fruit production system to softer, more environmentally friendly programs of pest control. Larger plots, additional modern varieties of apple, and more absolute sample methods should be included in future studies. However, in an experiment of the suggested scale, the experimental design constraints of time, money, equipment and amount of information gained must be carefully balanced. The effect of managing the habitat surrounding orchards for potato leafhopper control on economic damage to the crop needs to be studied, and thresholds for economic damage in apple, based on potato leafhopper populations in neighboring habitats should be determined.

Broad spectrum insecticides have ceased to be the answer to controlling secondary pests because of FQPA, rising environmental awareness, and insect resistance. Alternative pest control strategies, such as growing apple varieties resistant to potato leafhopper damage (Schoene 1937) and using ground cover mixes of plants undesirable to potato leafhopper (Larson and Whalon 1987, Roda et. al. 1997), must be developed to fill the pest control vacuum. Perhaps broad scale (i. e. barriers and trap crops) and within orchard habitat manipulation can answer some of the perplexing pest control challenges we face in this changing production system.

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CHAPTER 4

Mapping potato leafhopper (*Empoasca fabae* Harris) (Cicidellidae: Homoptera) movement in a diverse deciduous fruit agroecosystem using GIS

Abstract

The spatial distribution of potato leafhopper populations in the habitats of a diverse deciduous fruit agroecosystem was characterized using Global Information Systems (GIS). An extensive trapping system of geographically stable yellow sticky boards was used to monitor the potato leafhopper movement in and around the habitats. The spatial distribution of the trap catch was computed and mapped using ArcView GIS (Environmental Systems Research Institute, Redlands, CA). The highest average trap catch intensities in the two years were found in habitats comprised of first year alfalfa followed by alfalfa and alfalfa followed by soybeans. Alfalfa had the strongest map surface intensities overall, indicating that it had the highest potato leafhopper trap catch. The orchard habitats had potato leafhopper populations visible on all map surfaces when potato leafhopper was present in the agroecosystem. Potato leafhopper population intensities did appear to move over time based on the trap catch surface maps. The spatial distribution of the potato leafhopper closely followed the spatial distribution of host habitat. The high trap catch map surface area expanded and contracted in host habitats as the potato leafhopper populations followed seasonal cycles.

Introduction

Geographic Information Systems (GIS) are powerful tools for mapping insect populations over a geographic area (Gage et. al. 1990). The use of GIS to link data sets related only by a geographic location makes it possible to map the spatial dynamics of a pest population in a diverse agroecosystem. GIS map layers allow the effects of other landscape elements, including temperature, vegetation, slope, and time, to be included in pest population spatial models. State-wide gypsy moth studies have been conducted in Michigan over the past ten years using GIS (Gage and Pijanowski 1993, Pijanowski and Gage 1996).

Empoasca fabae, the potato leafhopper, is highly polyphagous. It feeds on over 200 plant hosts (Poos and Wheeler 1943, Lamp et. al., 1994) and is a pest in many Michigan cropping systems, including alfalfa, potatoes, soybeans, and deciduous fruit trees. It is also found in many non-crop habitats, including forest, old field, and roadsides (Lamp et. al. 1989). The potato leafhopper is mobile as an interhabitat migrant between hosts in an agroecosystem and as a long-range migrant between southern overwintering sites and northern summer habitat.

The potato leafhopper is unable to survive the winter temperatures in the Midwest (Decker and Maddox 1987) and it disappears each winter when the temperatures fall below survival thresholds. Each spring, potato leafhoppers move north on early season air currents and arrive in Michigan in mid-May to late June on spring weather systems. Potato leafhopper arrival dates and corresponding weather patterns have been tracked in the midwestern and eastern states since 1951 (Maredia et. al. 1998). The exact weather transport conditions needed for potato leafhopper migration to occur have been determined (Carlson et. al. 1991, 1992). It is possible to predict potato leafhopper migration and arrival from weather patterns in the early spring.

From 1986 until 1998, our lab has conducted a potato leafhopper spring migration detection trapping network. This extended, intense, GIS linked transect system confirms the potato leafhopper arrival date each year. From this transect data, we hypothesize that potato leafhopper begins feeding and reproducing on deciduous trees because these are the only plants with sufficient vegetative growth to support a phloem feeder at the time of potato leafhopper arrival (DiCosty et. al. 1998, Kaeb and Whalon 1998).

The migratory generation is usually not large enough to cause economic damage to crops. However, under optimum conditions, potato leafhopper are prolific and the population may rapidly rise to damaging levels. The potato leafhopper is multivoltine, with three to five overlapping generations each year. A female can live up to six months and produce eggs for much of her life span (DeLong 1938). There is no correlation between the arrival date of the migratory generation and the subsequent severity of potato leafhopper infestation (Maredia et. al. 1998).

Michigan orchard agroecosystems are very ecologically complex (Whalon and Croft 1985). Disturbance (Wise 1990), nutrient flow (Stickler and Whalon 1985), ground cover (Larson and Whalon 1987) and the surrounding habitats can significantly influence the insect pest complex. Many studies have been done on deciduous fruit and the damage caused by individual components of the pest complex. In the past 50 years, none of the studies mention potato leafhopper as anything other than an occasional occupant of orchards. The 1998 Michigan Fruit Spraying Calendar (Jones et. al. 1998) states, as a side note, "most organophosphates (OPs) applied for other pests will control potato leafhoppers." The potato leafhopper has not been a pest in Michigan orchards since OPs came into wide spread usage in the 1950's. Prior to OPs, however, the potato leafhopper was a serious orchard pest.

Rising environmental awareness and new pesticide laws, including the Food Quality Protection Act of 1996, are threatening Michigan producers with the loss of OP insecticides (Gray et. al. 1996). The "soft," pest specific chemicals and tactics being developed to replace the OPs for control of primary pests do not control secondary non-target pests, especially one as mobile and polyphagous as the potato leafhopper. The stage is being set for the re-emergence of an "old-fashioned" pest (Schoene 1932), the potato leafhopper.

We face a number of challenges as we transition the Michigan fruit production system to softer, more environmentally friendly programs of pest control. Broad spectrum pesticides allowed producers to virtually ignore the effects of the surrounding habitats on the pest complex within the orchard. With the loss of chemical control options, the impact of the agroecosystem on potato leafhopper/crop interactions becomes vitally important.

The objectives of this study were to use GIS: to 1) characterize the spatial distribution of potato leafhopper populations in a diverse agroecosystem. 2) Determine which habitats had the highest potato leafhopper trap catch over time, 3) discover if the population high density regions were moving over time, and 4) to find out which habitat or portions of habitats were driving the population changes over time.

Materials and Methods

Agroecosystem. We monitored the movement of potato leafhopper in the diverse agroecosystem at the Clarksville Horticultural Experiment Station during the 1996 and 1997 growing seasons. The station is managed for fruit crop research and field crop variety and spray trials. The composition of the crops in the agroecosystem changed with normal agronomic crop rotations between the years. Vegetative maps of the station show the habitats present during the respective years (Figures 2.1 and 2.2). In 1996, spring planted alfalfa (alfalfa1) was present. Soybeans, wheat, and new apple plots were added and several alfalfa fields were plowed under in 1997.

Traps. Ninety-five geo-static sticky board stations were used to monitor the potato leafhopper in and around the habitats. The trap stations were freestanding and consisted of a yellow sticky board hung from a movable crosspiece set 0.95 m above the ground on a step-in electric fence post. The sticky boards were 6"x 8" pieces of ¼" plywood painted safety yellow (Rust Stop, Ace Hardware Corp.) and encased in one quart ziplock bags coated with Tanglefoot (Tangletrap, Grand Rapids, MI).

Yellow sticky traps attract and capture potato leafhoppers. The yellow color provides a visual stimulus, and when a potato leafhopper comes into contact with the board, the sticky substance retains it. Sampling is continuous and information is accumulated about the potato leafhopper population 24 hours a day across the period between trap visits. The yellow sticky trap sampling method is dependent not only on the insect density, but also on several other variables. Color attraction, light quantity/quality, flight behavior, wind speed, and temperature also affect the number of potato leafhopper collected in a given sample (Wise 1990, Buntin 1994).

Sampling. We used an extensive trapping system, limiting the number of traps in each habitat so many habitats could be sampled over a large geographic area. The station was divided up into 19 - 20 acre blocks, and five trap stations were placed in each block. Traps were placed in locations based on several operational considerations, including; roads, insecticide treated plots, surface water, slope and aspect. Latitude and longitude coordinates for each trap were recorded using a handheld Scoutmaster GPS unit (Trimble Navigation, Sunnyvale, CA) and location maps were generated using ArcView GIS (Environmental Systems Research Institute, Redlands, CA). The 100 m error in the GPS unit induced by the U. S. Department of Defense greatly affected the map location of the trap stations. The actual, physical positions of the traps varied considerably from the computer generated locations (Figure 4.1).

The composition of the vegetation surrounding each trap was recorded at the beginning of each year and during the seasons when changes were made. Potato leafhopper sampling events were triggered by selected degree day (base 50°F) accumulation intervals during the growing season (7 samples in 1996 and 21 samples in 1997). Potato leafhopper specimens on the trap at the time of sampling were recorded and removed using a metal spatula on the sampling dates between sticky bag changes. The sampling objectives were to detect potato leafhopper in a given habitat and to provide information on the status of potato leafhopper in the habitat.

Analysis. All data was submitted to standard ANOVA, regression, mean separation, and analysis of deviates tests. Statistical tests were preformed using Minitab

(Minitab, Inc., State College, PA). Log (x+1) transformed values were used in all statistical tests. Tukey's test, with the family error rate set at 0.05, was used for the ANOVA comparisons.

Spatial analysis. The spatial distribution of the potato leafhopper trap catch was computed using ArcView and ArcView Spatial Analyst. Data from the field was stored and manipulated in the Microsoft Access (Microsoft Corp., Redmond, WA) environment. For clarity, the data management stream is diagramed in Figure 4.2. Latitude and longitude coordinates from the GPS were uploaded into Access and linked to the potato leafhopper trap catch, surrounding vegetation and habitat data. After the data was formatted in Access, it was linked into ArcView tables.

Point maps of the X, Y coordinates and related data fields were mapped for each sample date. From these points, the data was transferred into raster format. Surfaces of the log (x+1), where x = trap catch, were calculated for each point map using the nearest neighbor Inverse Distance Weighting Format (IDW) (ESRI 1996) to produce the raster image.

Boolean maps of the high trap catch areas were generated for each degree day (base 50F) sample surface. We considered low trap catch surface areas to have values less <5.3 (<0.8 log(x+1) transformed) and high trap catch areas to have values >5.3, based on the habitat means of alfalfa and apple in 1996 and 1997 and soybeans in 1997. These habitats were significantly different from all other habitats in 1997 ($P<0.05$). Difference maps and intensity maps were generated from the boolean maps using the map calculator. The difference maps were generated by subtracting the boolean surfaces. The intensity maps were generated by adding the boolean images together, and the

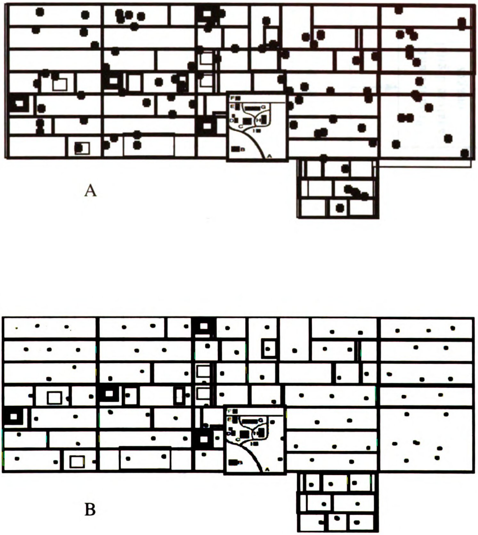

Figure 4.1. Map of yellow sticky trap locations on the Clarksville Horticulture Experiment Station. Each large rectangle on the maps represents 10 acres. (A) Computer generated locations from GPS coordinates, (B) Hand drawn locations from field notes.

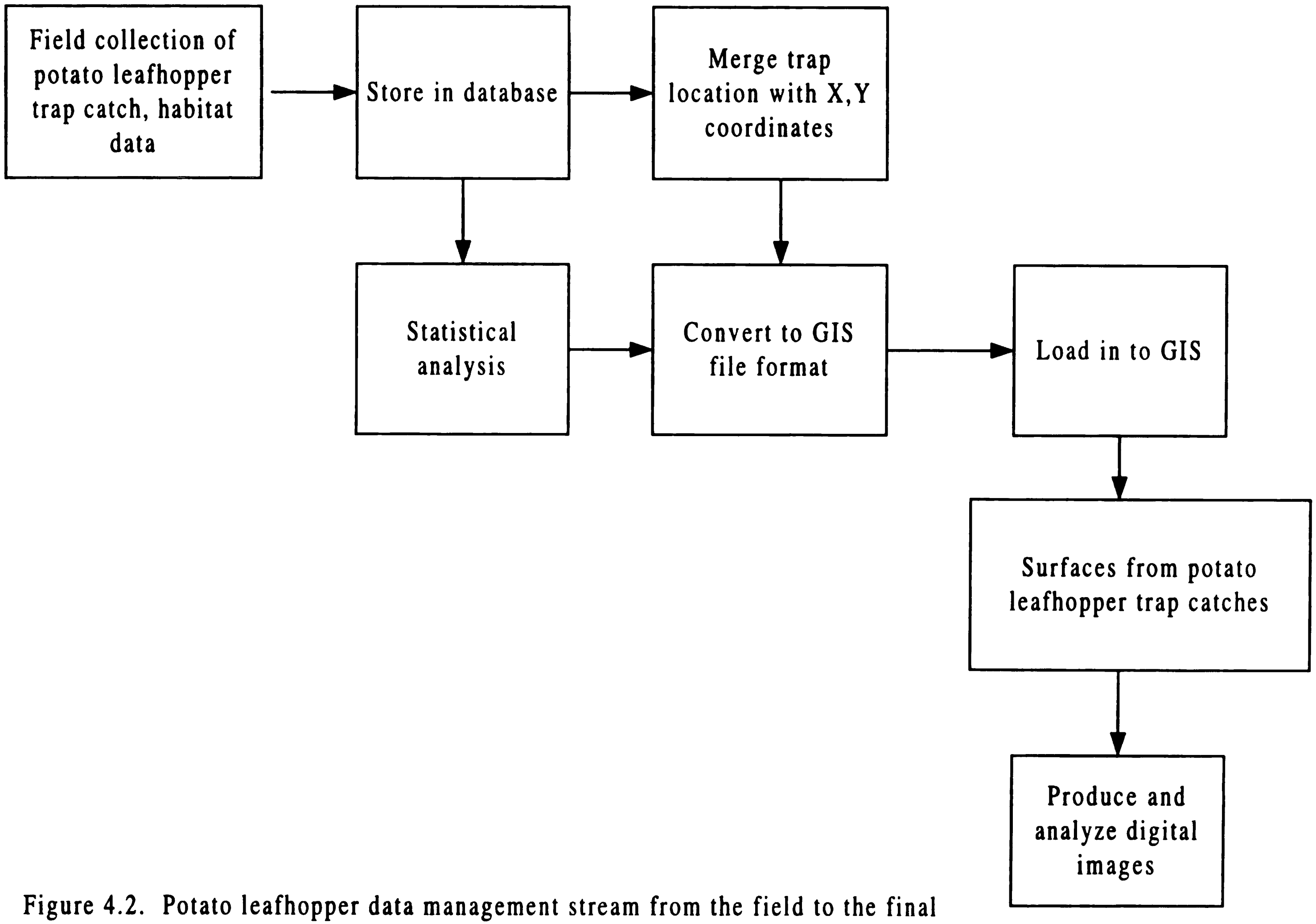

Figure 4.2. Potato leafhopper data management stream from the field to the final GIS analysis (Gage et. al. 1990).

average intensity map was generated by adding the maps together and dividing by the number of maps.

The resolution of the maps generated in ArcView was good, but due to the GPS error, the precision of them was not. To compensate for this variance, a point vegetation map for each year was generated. This vegetation map was overlaid on all surface maps to be sure the habitat linked inferences were the result of potato leafhopper trap catch in a particular habitat, not due to the GPS variance.

Results and Discussion

Spatial Distribution. The highest trap catch intensities were visible on the east side of the northwest quadrant and in the southeast extension of the station (Figure 4.3). The eastern side of the station had very little trap catch activity. In 1996 (Figure 4.4A), the highest intensities were found in the first year alfalfa (alfalfa1) on the right sides of the northwest and southwest quadrants with a gradient between them. The northwest and northeast corners of the station had little potato leafhopper activity. In 1997, the hot spots were in the southeast extension and in the southwest corner of the station (Figure 4.4B), with several other spots in the middle of the station. The entire west side of the station and the northeast quadrant had potato leafhopper activity of varying intensities.

The highest intensities on the two year average map were found in habitats comprised of alfalfa1 followed by alfalfa and alfalfa followed by soybeans. The habitat on the eastern side of the station was comprised of corn, woods and grass during both years. The maps showed very little activity, because corn and grass are not potato leafhopper hosts (Lamp et. al. 1994). Although the woods may have served as a host, the traps were placed below the canopy of the mature trees (Table 2.1) and therefore, could not measure the presence and intensity of potato leafhopper accurately.

The gradient that connected the alfalfa1 hot spots in 1996 contained several apple orchards, and the other spots of medium intensity were in apple and cherry orchards. In 1997, many of the apple habitats showed high intensity. The activity in the northeastern quadrant was driven by a trap that was in a weedy erosion strip in the corn, The high intensity spot in the middle of the station was in weedy habitat, and the soybean habitat in the southeastern extension also contained weeds.

Habitats. In 1996, potato leafhopper was first detected in the apple habitat and was mapped in the apple and cherry habitats early in the season (Figure 4.5A). These habitats remained visible in most of the surfaces throughout 1996. Potato leafhopper populations were mapped next in alfalfa and alfalfa1 habitats. These habitats had the highest trap catch map surfaces for the entire season until the population dropped off at the season end.

In 1997, potato leafhopper was detected first in corn. Trap catch map surface activity in the corn habitat remained higher than the expected level until the 1009 degree day (base 50F) sample date (Figure 4.5B). No trap catch activity was mapped in corn later in the season. Activity was mapped in the apple, cherry and other fruit habitats as long as potato leafhopper was present in the agroecosystem. Alfalfa showed high trap catch activity on the degree day 1147, 1295 and 1435 maps. Some activity was mapped in alfalfa earlier, but it was not as strong as in 1996. Soybeans had high activity mapped at many sample dates throughout the season.

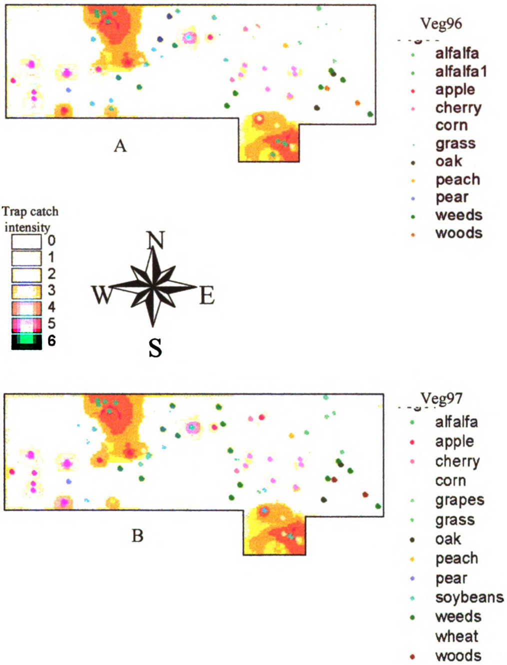

Figure 4.3. Surface of two year average trap catch intensity with (A) 1996 vegetation overlay and (B) 1997 vegetation overlay.

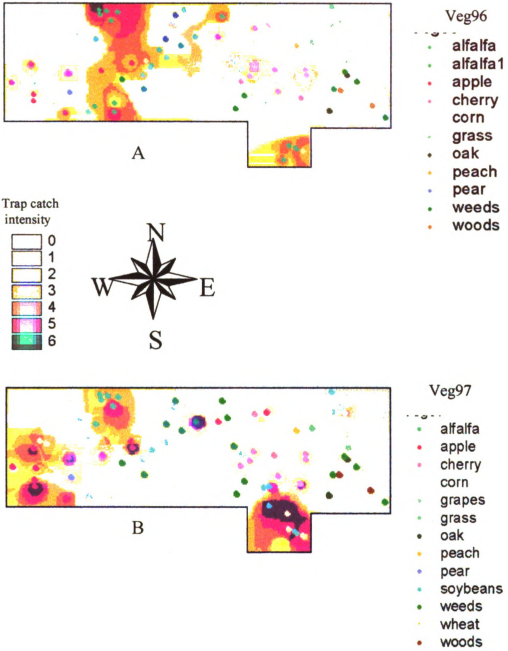

Figure 4.4. Trap catch intensity surface maps of the Clarksville Horticultural Experiment Station with vegetation overlays for (A) 1996 and (B) 1997.

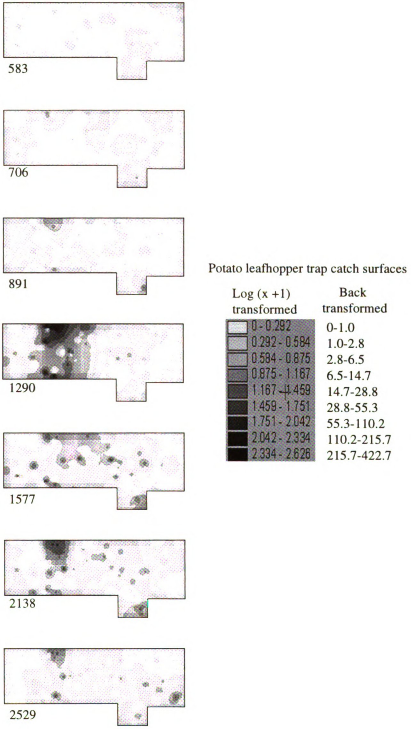

Figure 4.5. (A) Nearest neighbor surface maps of transformed potato leafhopper trap catches on individual degree day (base 50F) sample dates in 1996.

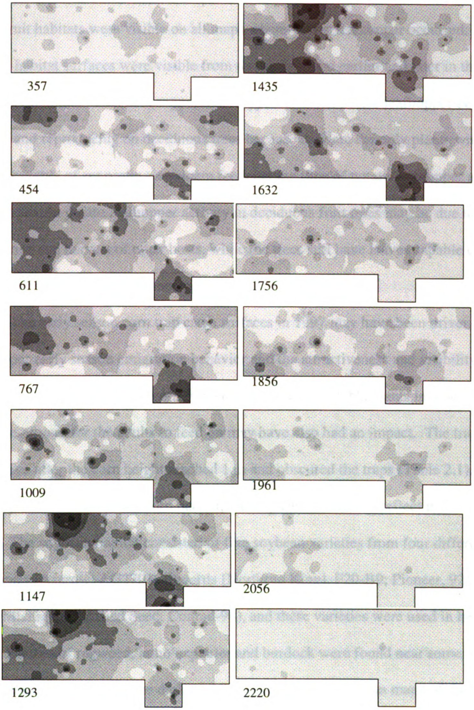

Figure 4.5. (cont'd). (B) 1997

Apple, cherry, peach, pear and alfalfa all serve as hosts for the potato leafhopper (Lamp et. al. 1994). Alfalfa had the strongest surface intensities overall, but at least some of the fruit habitats were visible on all maps where potato leafhopper occurred. The orchard habitat surfaces were visible from the background earlier and later in the seasons than other habitats. This data supports our hypothesis that potato leafhopper begins feeding and reproducing on deciduous trees because they are the only plants with enough growth capable of supporting a phloem feeder at the time of potato leafhopper arrival. The late season potato leafhopper activity in deciduous fruit trees may be due to the senescence and harvest of other hosts, while the trees still have leaves capable of supporting potato leafhopper feeding.

The early season corn trap catch surfaces in 1997 may have been driven by potato leafhopper early season emigration behavior and the attractiveness and visibility of the yellow traps compared to the corn foliage. The lack of suitable plants in other habitats at this time of year for the adults to feed on may have also had an impact. The traps became ineffective after the corn height reached 1 m and obscured the traps (Table 2.1). If potato leafhoppers remained in the corn habitat, the trap catches did not reflect it.

The soybean habitat consisted of five soybean varieties from four different companies (Asgrow, AG2701; Novartis [Northrup King], F20-B9; Pioneer, 9254 and 9294; Michigan Certified Seed, Conrad-94), and these varieties were used in herbicide trials. Patches of ragweed, lamb's quarter and burdock were found near some of the traps during part of the season. The dark surface area of the soybeans in many of the sample date maps may have been due to the combination of multiple soybean variety and weed presence in this habitat.

Population Movement. Potato leafhopper populations did appear to migrate over time, based on the surface maps of trap catch. The areas of high trap catch surface were isolated from seven matched degree day (base 50F) sample periods in 1996 and 1997 (Figure 4.6). Six difference maps (Figure 4.7) were generated from these maps to illustrate the trap catch change between consecutive sample periods.

In early 1996, only small pockets of high potato leafhopper trap catch surface were found. The first high population surfaces were found in the alfalfa habitats. In midseason, some of the apple and cherry traps were showing high potato leafhopper surface. High potato leafhopper surface area remained in alfalfa until the season end sample. In 1997, the season was colder and the date was more advanced than the equivalent degree day in 1996. The first two maps showed potato leafhopper high trap catch surface in the corn, soybeans, alfalfa and some apple and cherry habitats. The traps in the weeds (see above) were visible as high areas in five of the maps. In the low potato leafhopper population at the end of the season, the only habitats which still had small pockets of high trap catch surface were apple and soybeans. The final 1997 map showed only apple.

The difference maps showed how the population changed over time. In the early season sample periods, most of the changes were increases. The exception to this was the corn in the northwestern corner of the station in 1997. At the end of the season, the changes were decreases in most habitats as the populations fell. The difference maps were difficult to decipher, as there were residuals of the interpolation variances visible on the maps. There were thin shells of "difference" which may not have been actual differences visible on some maps.

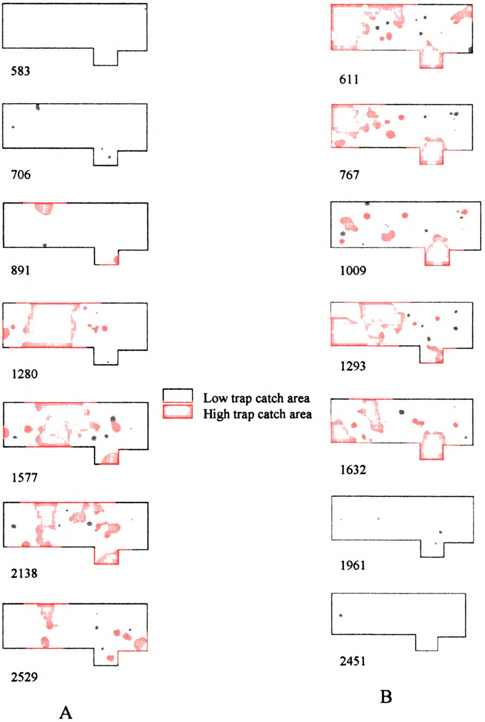

Figure 4.6. Surface maps of high vs. low potato leafhopper trap catch surface for 7 selected sample periods in (A) 1996 and (B) 1997.

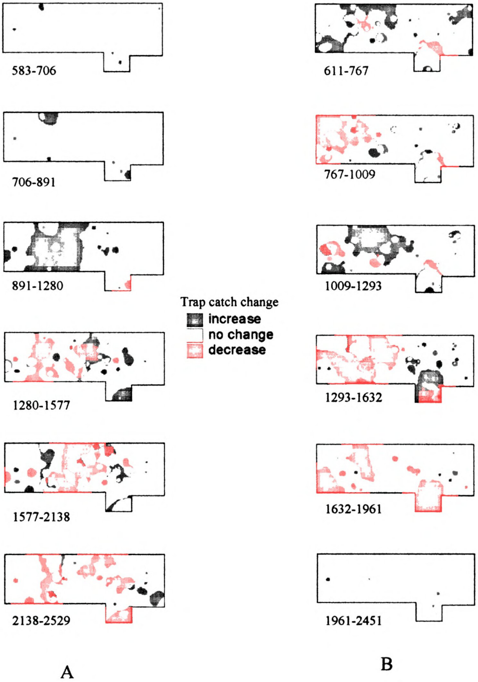

Figure 4.7. Potato leafhopper high trap catch surface differences for 6 selected sample periods in (A) 1996 and (B) 1997.

Conclusions

The spatial distribution of the potato leafhopper closely followed the habitat vegetation present in the agroecosystem. When there were potato leafhopper present in the agroecosystem, presence of host plants = presence of potato leafhopper. Potato leafhopper appeared in some non-host habitats during the study, but other factors, including the presence of host plants and emigration behavior may have had an impact on these populations. The alfalfa habitat had the highest populations over the two years. Alfalfa and the deciduous fruit orchards had the most consistent populations, and the soybean and weed habitats had high population intensities in 1997. Potato leafhopper population hot spots moved over time as the populations followed their seasonal cycles. The populations peaked in some habitats but remained steady in fruit.

There were some weaknesses in this study that need to be corrected in future studies. The lack of accuracy in habitat intensity analysis due to the error in the GPS unit can be corrected by using differential GPS (DGPS) technology. The relative yellow trap sampling technique needs to be augmented with other, more absolute sampling techniques. However, in an experiment of the suggested scale, the experimental design constraints of time, money, equipment and amount of information gained must be carefully balanced.

This project barely scratched the surface of GIS capabilities in agroecosystem and pest studies. There are many other GIS tools that can be incorporated into future studies. Overlay maps of vegetation, greening index and productivity can be produced by screen digitization of time sequence satellite images. Soil maps, topographic maps and land use

maps can also be obtained or digitized for the study area. These overlays, combined with powerful spatial statistics, can add new dimensions to the pest model. Predictions based on the spatially improved agroecosystem/pest model can be tested in the field using DGPS linked GIS. When the model is deemed accurate in small trials, pest thresholds in adjacent habitats can be determined and the model scaled up to commercial agroecosystem size for use in conjunction with precision agriculture and integrated pest management.

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APPENDIX A

APPENDIX 1

Record of Deposition of Voucher Specimens*

The specimens listed on the following sheet(s) have been deposited in the named museum(s) as samples of those species or other taxa which were used in this research. Voucher recognition labels bearing the Voucher No. have been attached or included in fluid-preserved specimens.

Voucher No.: 1998-1

Title of thesis or dissertation (or other research projects):

MOVEMENT AND RESPONSE OF POTATO LEAFHOPPER (EMPOASCA FABAE HARRIS) (CICADELLIDAE: HOMOPTERA)TO HOST PLANT HABITATS IN A DIVERSE APPLE AGROECOSYSTEM

Museum(s) where deposited and abbreviations for table on following sheets:

Entomology Museum, Michigan State University (MSU)

Other Museums:

Investigator's Name (s) (typed)
Melanie Joy Kaeb

Date 20 April 1998

*Reference: Yoshimoto, C. M. 1978. Voucher Specimens for Entomology in North America. Bull. Entomol. Soc. Amer. 24:141-42.

Deposit as follows:

Original: Include as Appendix 1 in ribbon copy of thesis or dissertation.
Copies: Included as Appendix 1 in copies of thesis or dissertation.
Museum(s) files.
Research project files.

This form is available from and the Voucher No. is assigned by the Curator, Michigan State University Entomology Museum.

APPENDIX 1.1

Voucher Specimen Data

Page 1 of 1 Pages

Species or other taxon	Label data for specimens collected or used and deposited	Number of: Eggs	Larvae	Nymphs	Pupae	Adults ♀	Adults ♂	Other	Museum where deposited
Empoasca fabae (Harris)	Leelanau Co., MI 3 Sept. 1997					15	7		M.S.U

(Use additional sheets if necessary)

Investigator's Name(s) (typed)

Melanie Joy Kaeb

Date 20 April 1998

Voucher No. 1998-1

Received the above listed specimens for deposit in the Michigan State University Entomology Museum.

[signature] 20 Apr 1998

Curator Date

APPENDIX B

APPENDIX B

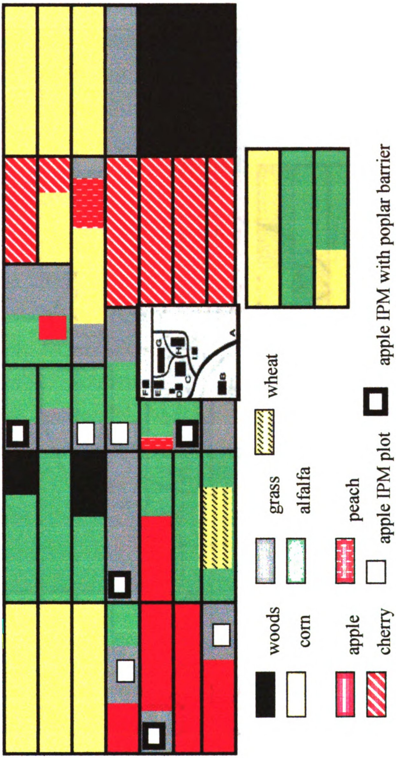

Figure 2.1. 1996 map of the Clarksville Horticultural Experiment Station vegetation, showing the location and physical surroundings of the apple IPM plots.

APPENDIX B

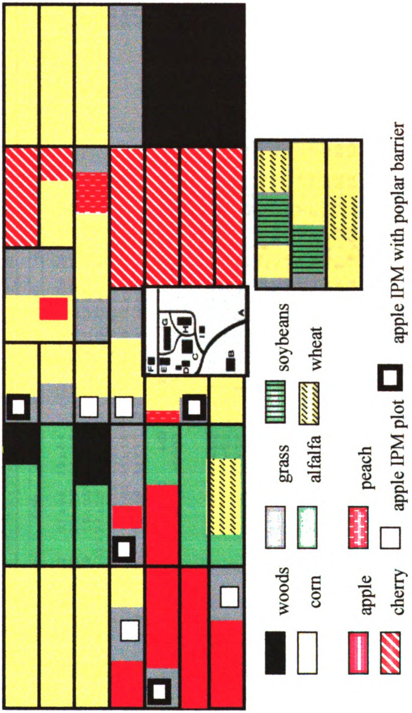

Figure 2.2. 1997 map of the Clarksville Horticultural Experiment Station vegetation, showing the location and physical surroundings of the apple IPM plots.

APPENDIX B

Table 2.1. Potato leafhopper trap catch mean ± SEM and F-test p-values for all habitats in 1996 and 1997.

Degree Day	Habitats											F-test	p-value
	alfalfa	alfalfa1	apple	cherry	corn	grass	oak	weeds	woods	soybeans	wheat		
1996													
583	1.1 ± 0.3	0.6 ± 0.2	0.7 ± 0.4	1.3 ± 0.4	1.1 ± 0.3	0.6 ± 0.3	0.0 ± 0.0	0.9 ± 0.5	0.0 ± 0.0	*	*	0.9	0.537
706	3.7 ± 1.0	3.3 ± 1.6	2.3 ± 0.8	1.4 ± 0.3	1.3 ± 0.3	1.0 ± 0.4	0.0 ± 0.0	1.7 ± 0.5	0.0 ± 0.0	*	*	1.75	0.083
891	2.4 ± 0.7	9.0 ± 2.3	1.9 ± 0.5	1.2 ± 0.4	1.9 ± 0.7	0.5 ± 0.2	0.3 ± 0.3	0.7 ± 0.3	0.0 ± 0.0	*	*	4.61	<0.0001
1280	8.9 ± 3.6	154.2 ± 52.0	7.4 ± 2.3	4.5 ± 1.2	3.5 ± 2.1	4.7 ± 1.3	7.0 ± 5.7	6.8 ± 4.0	0.0 ± 0.0	*	*	4.44	<0.0001
1577	15.4 ± 3.7	15.11 ± 4.4	13.1 ± 3.8	6.0 ± 2.0	1.5 ± 0.7	5.7 ± 2.5	4.5 ± 2.5	4.6 ± 1.8	0.0 ± 0.0	*	*	5.23	<0.0001
2138	15.7 ± 4.0	19.2 ± 3.4	13.6 ± 4.0	8.3 ± 1.6	2.0 ± 0.5	2.4 ± 0.8	1.5 ± 0.9	1.6 ± 0.8	0.0 ± 0.0	*	*	9.46	<0.0001
2529	5.2 ± 1.8	11.8 ± 3.7	3.6 ± 2.0	4.4 ± 1.5	1.2 ± 0.5	1.1 ± 0.4	1.0 ± 0.4	4.6 ± 1.9	19.5 ± 10.5	*	*	4.71	<0.0001
F-test	7.34	6.91	5.96	4.93	0.92	4.9	1.75	1.55	25.71	*	*		
p-value	<0.0001	<0.0001	<0.0001	<0.0001	0.484	<0.0001	0.159	0.18	<0.0001	*	*		
1997													
261	0.0 ± 0.0	*	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.28	0.983
357	0.4 ± 0.3	*	1.5 ± 0.7	0.9 ± 0.3	0.7 ± 0.3	0.7 ± 0.4	0.5 ± 0.5	1.1 ± 0.3	0.0 ± 0.0	0.3 ± 0.3	1.0 ± 0.6	0.53	0.877
454	4.3 1.4	*	4.0 ± 1.7	2.8 ± 1.4	7.7 ± 1.5	2.9 ± 1.2	0.5 ± 0.5	3.2 ± 0.9	0.5 ± 0.5	14.0 ± 2.5	1.5 ± 1.2	2.23	0.02
611	6.6 ± 1.7	*	9.9 ± 2.2	2.7 ± 1.1	12.1 ± 2.2	2.2 ± 0.8	0.5 ± 0.5	4.9 ± 1.5	0.0 ± 0.0	20.8 ± 7.8	1.8 ± 1.0	6.76	<0.0001
767	5.0 ± 0.8	*	8.1 ± 2.2	2.7 ± 0.7	10.6 ± 1.9	3.4 ± 1.7	0.5 ± 0.5	2.9 ± 0.7	0.0 ± 0.0	32.7 ± 12.8	0.3 ± 0.3	5.34	<0.0001
1009	11.1 ± 5.4	*	2.3 ± 1.2	3.9 ± 0.9	10.7 ± 3.1	2.8 ± 1.3	1.0 ± 0.0	5.1 ± 2.4	0.0 ± 0.0	15.3 ± 3.0	2.3 ± 0.9	2.33	0.015
1147	45.0 ± 10.0	*	10.0 ± 3.1	2.0 ± 0.7	5.8 ± 1.5	4.1 ± 1.0	0.0 ± 0.0	4.3 ± 1.4	0.0 ± 0.0	37.7 ± 17.3	20.5 ± 19.5	5.81	<0.0001
1293	44.4 ± 13.5	*	12.3 ± 3.8	2.8 ± 0.6	2.7 ± 0.8	5.1 ± 1.1	5.0 ± 2.0	5.0 ± 1.3	0.5 ± 0.5	28.3 ± 12.7	14.5 ± 10.9	6.51	<0.0001
1435	51.6 ± 19.7	*	17.1 ± 4.0	8.3 ± 1.5	4.1 ± 1.2	3.4 ± 0.9	0.0 ± 0.0	6.8 ± 2.7	0.0 ± 0.0	18.7 ± 10.7	35.0 ± 20.9	6.38	<0.0001
1632	11.3 ± 5.1	*	10.9 ± 3.6	3.7 ± 1.1	3.7 ± 1.4	4.3 ± 1.1	3.0 ± 3.0	4.3 ± 1.4	3.0 ± 3.0	43.0 ± 15.9	7.5 ± 2.9	3.13	0.001
1756	1.6 ± 0.7	*	5.7 ± 1.8	3.8 ± 1.1	0.7 ± 0.4	1.5 ± 0.4	0.0 ± 0.0	2.1 ± 0.7	0.0 ± 0.0	0.0 ± 0.0	1.3 ± 0.8	3.46	0.001
1856	1.6 ± 0.8	*	7.9 ± 2.8	3.6 ± 0.7	1.6 ± 0.7	1.6 ± 0.4	1.5 ± 0.5	1.9 ± 0.6	0.0 ± 0.0	5.3 ± 2.9	1.0 ± 0.7	2.68	0.005
1961	1.1 ± 0.5	*	2.5 ± 0.6	2.3 ± 0.8	0.4 ± 0.3	0.6 ± 0.4	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	3.3 ± 1.3	0.8 ± 0.3	4.45	<0.0001
2056	1.3 ± 0.7	*	2.1 ± 0.9	0.4 ± 0.2	0.2 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.8 ± 0.3	3.45	0.001
2220	0.0 ± 0.0	*	0.4 ± 0.2	0.4 ± 0.2	0.1 ± 0.1	0.4 ± 0.2	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.3	1.13	0.348
2395	0.1 ± 0.1	*	1.2 ± 0.5	0.0 ± 0.0	0.1 ± 0.1	0.5 ± 0.5	1.5 ± 1.5	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.17	0.024
2451	0.1 ± 0.1	*	0.2 ± 0.1	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.1	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.31	0.981
F-test	30.68	*	16.95	11.2	29.97	10.16	2.16	9.93	0.93	14.47	4.51		
p-value	<0.0001	*	<0.0001	<0.0001	<0.0001	<0.0001	0.043	<0.0001	0.56	<0.0001	<0.0001		

* Missing data, habitat not present in agroecosystem during season.

APPENDIX C

APPENDIX C

Table C.1. Total potato leafhopper (*Empoasca fabae* (Harris)) trap catch for each sample period measured by degree day (base 50F) heat accumulation at the end of the sample period in the diverse agroecosystem at the Clarksville Horticultural Experiment Station, 1996.

Trap identification				Number of potato leafhopper captured for each degree day sample period							
Trap #	**Longitude**	**Latitude**	**Habitat**	**583**	**706**	**891**	**1280**	**1577**	**2138**	**2529**	**Total 1996**
26	-85.267317	42.87187	grass	0	0	0	9	0	0	4	13
27	-85.2688	42.87178	apple	0	1	0	8	5	15	1	30
28	-85.270783	42.87255	apple	0	1	2	1	0	4	1	9
29	-85.270783	42.87295	apple	3	4	3	2	25	4	0	41
30	-85.2685	42.8731	pear	0	0	1	1	0	0	4	6
31	-85.272217	42.8737	apple	0	1	0	13	12	1	0	27
32	-85.270717	42.8736	grass	0	0	1	4	0	5	0	10
33	-85.270933	42.87483	apple	0	7	2	11	5	13	0	38
34	-85.2705	42.8754	corn	3	1	2	0	1	0	0	7
35	-85.270033	42.87525	corn	0	3	1	1	1	0	3	9
36	-85.2686	42.87427	apple	0	2	5	19	28	4	5	63
37	-85.266483	42.87445	apple	0	0	2	13	6	21	2	44
39	-85.266833	42.87645	alfalfal	1	2	0	87	1	9	4	104
41	-85.270817	42.87843	corn	0	0	2	0	0	0	1	3
42	-85.271033	42.87757	corn	0	0	2	1	1	3	0	7
43	-85.267867	42.87675	grass	0	0	0	9	1	0	0	10
44	-85.268433	42.87828	corn	0	2	0	2	0	0	0	4
45	-85.26845	42.8774	corn	0	1	5	1	0	0	0	7
46	-85.257367	42.87288	weeds	0	1	0	0	16	3	0	20
47	-85.257933	42.87205	weeds	0	0	0	0	2	0	1	3
48	-85.257617	42.87377	cherry	0	1	2	0	0	0	2	5
49	-85.2561	42.87247	grass	0	0	1	0	0	0	2	3
50	-85.25525	42.8732	cherry	4	1	0	4	9	11	2	31

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Table C.1. Continued.

Trap #	Longitude	Latitude	Habitat	583	706	891	1280	1577	2138	2529	Total 1996
51	-85.253767	42.87273	cherry	3	0	0	0	1	4	3	11
52	-85.2532	42.87202	corn	3	3	1	3	0	3	4	17
53	-85.253417	42.87417	cherry	0	0	3	5	6	5	16	35
54	-85.253467	42.87453	cherry	2	2	1	1	21	17	2	46
55	-85.257067	42.87408	cherry	1	2	2	11	7	9	2	34
56	-85.256783	42.87472	cherry	1	3	2	6	9	13	9	43
57	-85.25545	42.87448	cherry	2	3	0	9	1	5	2	22
58	-85.257567	42.87452	grass	0	1	2	6	6	0	0	15
59	-85.258033	42.87508	alfalfa	0	0	1	7	42	11	4	65
60	-85.25785	42.87632	corn	2	0	0	1	0	2	2	7
61	-85.25405	42.87605	peach	1	1	0	2	9	3	2	18
62	-85.253067	42.87623	grass	0	0	1	2	2	1	0	6
63	-85.255917	42.8773	cherry	0	1	0	3	3	6	0	13
64	-85.255967	42.87723	corn	1	0	1	0	0	5	0	7
65	-85.256717	42.87717	cherry	0	1	2	6	3	13	6	31
66	-85.256317	42.8768	corn	0	0	2	0	0	2	0	4
67	-85.2585	42.87685	grass	3	5	1	1	19	0	0	29
68	-85.2588	42.87795	alfalfa	0	5	1	7	5	9	2	29
69	-85.259067	42.87663	apple	2	5	1	0	7	23	4	42
70	-85.26045	42.87663	alfalfa	0	4	0	3	10	10	1	28
71	-85.24845	42.87797	corn	7	1	0	0	0	0	0	8
72	-85.24845	42.87775	corn	2	0	0	0	0	2	0	4
73	-85.250967	42.87725	corn	1	0	0	4	0	0	0	5
74	-85.2512	42.87752	grass	4	4	0	0	1	3	0	12
75	-85.251783	42.8786	grass	2	3	0	0	0	0	0	5
76	-85.251717	42.87732	grass	0	2	1	5	3	2	3	16
77	-85.2512	42.87635	corn	0	2	0	3	1	4	0	10
78	-85.25125	42.8766	corn	1	3	4	0	1	1	0	10
79	-85.250883	42.87593	corn	0	1	0	0	0	6	0	7

Table C.1. Continued.

Trap #	Longitude	Latitude	Habitat	583	706	891	1280	1577	2138	2529	Total 1996
80	-85.250717	42.875	grass	0	0	0	0	3	2	0	5
81	-85.250217	42.87373	weeds	0	1	0	0	3	0	2	6
82	-85.2508	42.8742	oak	0	0	0	0	0	3	0	3
83	-85.2669	42.87223	alfalfa1	0	0	4	94	37	19	0	154
84	-85.265667	42.87187	alfalfa1	1	0	11	140	26	16	5	199
85	-85.265633	42.87242	alfalfa1	0	0	0	0	0	4	34	38
86	-85.2645	42.87497	apple	1	0	2	0	30	37	19	89
87	-85.26325	42.87482	alfalfa	2	2	4	36	4	16	3	67
88	-85.265167	42.87392	weeds	0	1	0	10	5	2	4	22
89	-85.263783	42.87332	weeds	3	1	3	35	6	0	1	49
90	-85.262667	42.87382	corn	1	1	2	6	3	4	0	17
91	-85.263833	42.8742	grass	0	0	0	17	7	6	0	30
92	-85.2636	42.87508	corn	0	0	0	50	14	4	8	76
93	-85.26275	42.87577	alfalfa	1	0	1	7	11	5	2	27
94	-85.2623	42.87532	grass	1	1	1	13	38	3	4	61
95	-85.26135	42.87607	weeds	3	4	1	16	0	7	4	35
96	-85.26185	42.8776	grass	0	0	0	4	7	9	0	20
97	-85.26115	42.87835	alfalfa	1	4	3	21	16	0	3	48
98	-85.261717	42.87802	oak	0	0	0	24	11	0	2	37
99	-85.262333	42.8765	oak	0	0	1	4	6	0	1	12
100	-85.263333	42.87463	grass	0	0	0	1	2	0	2	5
101	-85.2549	42.8688	alfalfa	1	5	1	6	6	10	2	31
102	-85.2541	42.86955	alfalfa	2	0	3	0	22	41	19	87
103	-85.2545	42.86972	alfalfa	1	10	3	2	26	27	12	81
104	-85.253617	42.86935	corn	0	2	15	2	10	8	2	39
105	-85.254033	42.86948	alfalfa	3	7	7	0	12	28	4	61
106	-85.255783	42.87253	corn	2	3	1	1	0	3	2	12
107	-85.2546	42.87077	corn	0	1	4	1	0	0	0	6
108	-85.2558	42.87125	corn	2	6	1	1	0	0	6	16

Table C.1. Continued.

Trap #	Longitude	Latitude	Habitat	583	706	891	1280	1577	2138	2529	Total 1996
109	-85.266617	42.87838	alfalfal	0	11	11	430	21	19	10	502
110	-85.2661	42.87828	alfalfal	0	0	12	342	10	36	20	420
111	-85.265817	42.87767	alfalfal	2	5	21	31	0	16	17	92
112	-85.266533	42.87807	alfalfal	0	11	13	0	23	21	0	68
113	-85.265417	42.8782	alfalfal	1	1	9	264	18	33	16	342
114	-85.24835	42.87153	weeds	0	0	0	0	0	0	2	2
115	-85.249217	42.87225	woods	0	0	0	0	0	0	30	30
116	-85.251933	42.87193	oak	0	0	0	0	1	3	1	5
117	-85.251667	42.8733	weeds	2	4	1	0	0	1	9	17
118	-85.25095	42.87435	weeds	0	3	1	0	9	1	18	32
119	-85.251233	42.87328	woods	0	0	0	0	0	0	9	9

APPENDIX C

Table C.2. Total potato leafhopper (*Empoasca fabae* (Harris)) trap catch for each sample period measured by degree day (base 50F) heat accumulation at the end of the sample period in the diverse agroecosystem at the Clarksville Horticultural Experiment Station, 1997.

Trap identification				Number of potato leafhopper captured for each degree day sample period																
Trap #	Longitude	Latitude	Habitat	357	454	611	767	1009	1147	1293	1435	1632	1756	1856	1961	2056	2220	2395	2451	Total
26	-85.267317	42.87187	grass	0	1	0	0	6	2	8	8	3	6	2	0	1	2	0	0	39
27	-85.2688	42.87178	apple	0	1	27	0	0	11	22	26	8	8	6	3	2	0	1	0	115
28	-85.270783	42.87255	apple	3	6	12	18	9	8	12	25	12	7	18	2	1	2	3	0	138
29	-85.270783	42.87295	apple	0	7	5	1	3	7	10	5	6	4	4	1	0	0	0	0	53
30	-85.2685	42.8731	pear	0	4	15	6	0	6	8	8	2	2	1	0	0	0	0	0	52
31	-85.272217	42.8737	apple	1	0	3	4	0	2	5	5	9	0	1	2	2	0	1	0	35
32	-85.270717	42.8736	apple	0	0	8	4	8	2	4	13	7	1	3	3	1	0	0	1	55
33	-85.270933	42.87483	apple	0	0	18	17	0	33	47	39	19	11	5	6	10	1	2	0	208
34	-85.2705	42.8754	corn	0	2	5	19	20	5	8	14	1	0	0	0	0	0	0	0	74
35	-85.270033	42.87525	corn	1	1	6	18	54	7	9	0	0	0	0	0	0	0	0	0	96
36	-85.2686	42.87427	apple	3	2	10	15	9	0	11	13	9	6	10	3	1	0	1	0	93
37	-85.266483	42.87445	apple	0	0	11	9	0	9	8	14	3	2	7	1	3	0	0	0	67
39	-85.266833	42.87645	alfalfa	0	2	2	5	40	43	93	160	42	4	0	3	1	0	0	0	395
41	-85.270817	42.87843	corn	1	17	8	7	0	0	0	0	0	0	0	0	0	0	0	1	34
42	-85.271033	42.87757	corn	1	17	8	12	0	1	2	5	0	0	0	0	0	0	0	0	46
43	-85.267867	42.87675	grass	0	6	4	4	0	8	2	5	6	1	0	0	0	1	0	0	37
44	-85.268433	42.87828	corn	6	12	14	5	3	1	0	2	0	0	1	0	0	0	0	0	44
45	-85.26845	42.8774	corn	0	18	12	8	0	0	0	1	1	0	2	0	1	0	0	0	43
46	-85.257367	42.87288	weeds	3	2	3	3	3	1	1	6	1	1	3	0	0	0	0	0	27
47	-85.257933	42.87205	weeds	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
48	-85.257617	42.87377	cherry	0	0	3	1	1	2	2	16	0	2	5	2	0	0	0	0	34
49	-85.2561	42.87247	grass	0	1	2	3	3	1	0	1	10	2	1	0	0	1	0	0	25
50	-85.25525	42.8732	cherry	2	2	0	4	8	4	1	12	4	3	5	5	0	0	0	0	50

Table C.2. Continued.

Trap #	Longitude	Latitude	Habitat	357	454	611	767	1009	1147	1293	1435	1632	1756	1856	1961	2056	2220	2395	2451	Total
51	-85.253767	42.87273	cherry	1	13	3	7	6	7	4	11	10	9	6	7	2	0	0	0	86
52	-85.2532	42.87202	corn	0	0	0	8	4	2	0	5	11	0	1	0	0	0	0	0	31
53	-85.253417	42.87417	cherry	0	1	6	3	4	0	4	7	3	9	7	4	1	0	0	0	49
54	-85.253467	42.87453	cherry	0	0	2	1	2	0	2	8	1	2	2	0	0	0	0	0	20
55	-85.257067	42.87408	cherry	1	9	11	5	8	4	5	3	6	6	1	1	0	1	0	0	61
56	-85.256783	42.87472	cherry	1	0	0	2	5	2	6	8	8	5	3	3	0	2	0	0	45
57	-85.25545	42.87448	cherry	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	-85.257567	42.87452	grass	3	1	1	3	1	3	2	2	7	0	4	1	0	0	0	0	28
59	-85.258033	42.87508	weeds	2	2	5	0	5	13	8	11	9	6	1	0	0	0	0	0	62
60	-85.25785	42.87632	corn	0	0	6	2	3	8	2	1	2	2	0	1	0	0	0	0	27
61	-85.25405	42.87605	peach	1	1	0	0	0	4	8	0	2	1	0	0	1	0	0	0	18
62	-85.253067	42.87623	grass	0	2	0	2	0	0	2	0	2	1	0	0	1	0	0	1	11
63	-85.255917	42.8773	cherry	2	1	2	2	1	1	3	12	2	2	2	1	1	0	0	0	32
64	-85.255967	42.87723	apple	0	5	3	0	2	3	4	4	0	2	0	0	0	0	0	0	23
65	-85.256717	42.87717	cherry	2	2	0	2	4	0	1	6	3	0	5	0	0	1	0	0	26
66	-85.256317	42.8768	corn	2	10	10	9	5	1	1	0	2	0	4	0	0	1	0	0	45
67	-85.2585	42.87685	weeds	0	4	1	1	0	0	2	1	2	0	2	1	0	0	0	0	14
68	-85.2588	42.87795	weeds	0	2	0	2	0	0	0	0	2	1	2	1	0	0	0	0	10
69	-85.259067	42.87663	apple	3	4	4	4	0	25	7	5	3	2	2	0	0	1	0	0	60
70	-85.26045	42.87663	weeds	4	9	9	11	16	9	8	20	12	6	2	0	0	0	1	1	108
71	-85.24845	42.87797	corn	0	8	4	4	2	2	0	1	2	0	3	1	0	0	0	0	27
72	-85.24845	42.87775	corn	0	9	9	2	1	0	0	0	0	0	1	0	0	0	0	0	22
73	-85.250967	42.87725	corn	0	29	34	17	43	18	14	6	3	0	0	0	0	0	0	0	164
74	-85.2512	42.87752	grass	1	4	0	2	0	6	1	3	6	0	0	1	0	0	0	0	24
75	-85.251783	42.8786	grapes	1	5	4	3	2	2	3	1	2	2	2	0	0	0	0	0	27
76	-85.251717	42.87732	grass	0	11	3	7	7	7	4	2	1	3	4	1	0	0	0	0	50
77	-85.2512	42.87635	corn	2	6	3	8	11	5	0	2	4	1	0	0	0	0	0	0	42
78	-85.25125	42.8766	corn	1	1	18	0	1	2	0	9	2	0	0	0	0	0	0	0	34
79	-85.250883	42.87593	corn	3	10	9	2	5	4	1	0	5	0	0	0	1	0	0	0	40

Table C.2. Continued.

Trap #	Longitude	Latitude	Habitat	357	454	611	767	1009	1147	1293	1435	1632	1756	1856	1961	2056	2220	2395	2451	Total
80	-85.250717	42.875	grass	0	1	1	0	0	0	2	10	2	0	3	5	0	0	7	0	31
81	-85.250217	42.87373	weeds	0	12	0	1	0	0	0	1	0	0	0	0	0	0	0	0	14
82	-85.2508	42.8742	oak	0	0	1	0	1	0	7	0	6	0	2	0	0	0	0	0	17
83	-85.2669	42.87223	wheat	2	0	0	1	4	3	6	21	9	3	0	1	1	0	0	0	51
84	-85.265667	42.87187	wheat	0	0	0	0	0	0	1	16	7	0	1	1	1	0	0	0	27
85	-85.265633	42.87242	wheat	2	5	4	0	3	0	47	97	0	2	3	1	1	1	0	0	166
86	-85.2645	42.87497	apple	7	19	8	17	0	10	5	39	44	20	31	6	3	0	5	1	215
87	-85.26325	42.87482	alfalfa	1	1	5	4	8	13	9	10	6	0	0	1	1	0	0	1	60
88	-85.265167	42.87392	weeds	1	0	2	1	0	2	0	0	7	0	0	0	0	0	0	0	13
89	-85.263783	42.87332	weeds	0	0	8	5	37	1	8	1	6	6	4	0	2	1	0	0	79
90	-85.262667	42.87382	corn	0	1	10	15	11	16	2	0	0	0	0	1	0	0	0	0	56
91	-85.263833	42.8742	grass	0	0	1	0	2	3	4	3	13	1	2	0	0	0	0	0	29
92	-85.2636	42.87508	corn	0	0	1	6	6	5	5	19	4	9	0	0	3	0	0	0	58
93	-85.26275	42.87577	corn	0	5	10	13	3	21	6	0	0	3	0	0	0	0	0	0	61
94	-85.2623	42.87532	grass	1	0	1	2	0	0	7	1	1	2	0	0	0	0	0	0	15
95	-85.26135	42.87607	weeds	3	6	24	4	3	5	7	0	0	0	1	0	0	0	0	0	53
96	-85.26185	42.8776	grass	0	0	5	0	2	6	8	5	0	1	0	0	0	0	0	0	27
97	-85.26115	42.87835	corn	0	8	27	0	4	1	0	0	0	0	2	0	0	0	3	0	45
98	-85.261717	42.87802	weeds	2	0	6	3	0	16	17	38	3	2	2	0	0	0	0	0	89
99	-85.262333	42.8765	weeds	0	0	0	1	3	9	11	18	3	1	3	0	0	0	0	0	49
100	-85.263333	42.87463	grass	0	0	2	2	0	8	7	0	1	1	2	0	0	1	0	0	24
101	-85.2549	42.8688	wheat	0	1	3	0	2	79	4	6	14	0	0	0	0	0	0	0	109
102	-85.2541	42.86955	soybeans	0	16	15	36	21	71	50	37	72	0	0	6	0	0	0	0	324
103	-85.2545	42.86972	corn	0	5	45	37	9	2	0	11	6	0	4	0	0	0	0	0	119
104	-85.253617	42.86935	corn	0	5	16	28	3	3	3	1	8	0	2	0	0	1	0	0	70
105	-85.254033	42.86948	grass	5	14	11	25	18	11	14	0	8	0	4	1	1	1	0	0	113
106	-85.255783	42.87253	soybeans	0	17	36	53	11	13	29	0	40	0	6	2	0	0	0	0	207
107	-85.2546	42.87077	corn	0	10	15	13	25	26	8	17	32	0	16	6	0	0	0	0	168
108	-85.2558	42.87125	soybeans	1	9	11	9	14	29	6	19	17	0	10	2	0	0	0	0	127

Table C.2. Continued.

Trap #	Longitude	Latitude	Habitat	357	454	611	767	1009	1147	1293	1435	1632	1756	1856	1961	2056	2220	2395	2451	Total
109	-85.266617	42.87838	alfalfa	0	2	3	2	19	71	66	15	8	0	0	0	5	0	0	0	191
110	-85.2661	42.87828	alfalfa	0	4	10	6	6	31	15	39	7	2	4	0	0	0	0	0	124
111	-85.265817	42.87767	alfalfa	0	12	15	9	5	27	27	23	6	0	0	0	0	0	0	0	124
112	-85.266533	42.87807	alfalfa	0	5	5	5	0	41	16	42	4	1	3	3	2	0	0	0	127
113	-85.265417	42.8782	alfalfa	2	4	6	4	0	89	85	72	6	4	4	1	0	0	1	0	278
114	-85.24835	42.87153	weeds	0	2	9	0	5	0	0	0	1	0	0	0	0	0	0	0	17
115	-85.249217	42.87225	woods	0	0	0	0	0	0	1	0	6	0	0	0	0	0	0	0	7
116	-85.251933	42.87193	oak	1	1	0	1	1	0	3	0	0	0	1	0	0	0	3	0	11
117	-85.251667	42.8733	weeds	1	7	2	5	2	0	3	0	0	0	9	0	0	0	0	0	29
118	-85.25095	42.87435	weeds	0	0	5	6	6	11	12	12	20	8	0	2	0	0	0	0	82
119	-85.251233	42.87328	woods	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

APPENDIX C

Table C.3. Total potato leafhopper (*Empoasca fabae* (Harris)) trap catch for each sample period measured by degree day (base 50F) heat accumulation at the end of the sample period in the eight "Alternative Pest Management Systems in Apple" plots, 1996.

Trap identification			Number of potato leafhopper captured for each degree day sample period													
Plot	Trap	Habitat	273	390	583	706	891	1036	1176	1280	1333	1577	1722	2138	2529	Total
1	E I	apple	0	0	0	0	4	5	0	3	11	0	14	2	1	40
1	E X	apple	0	0	0	0	1	6	5	5	5	2	8	0	0	32
1	E X2	grass	0	1	0	0	0	2	4	7	2	0	1	0	2	19
1	E X3	grass	0	0	0	0	0	3	1	9	28	0	0	0	4	45
1	N I	apple	0	2	0	0	0	8	4	6	6	4	24	6	3	63
1	N X	apple	0	0	0	0	0	0	0	4	4	0	7	2	1	18
1	N X2	grass	0	1	0	0	0	5	5	4	4	0	4	0	2	25
1	N X3	pear	0	0	0	0	1	3	4	1	4	0	0	0	4	17
1	S I	apple	0	1	4	0	5	2	4	13	8	3	5	2	3	50
1	S X	apple	0	1	2	0	1	1	2	9	2	3	7	1	1	30
1	S X2	grass	0	0	0	0	1	1	0	4	2	4	9	5	0	26
1	S X3	grass	0	0	0	0	0	0	1	8	3	2	12	4	5	35
1	W I	apple	0	0	5	1	2	0	5	13	11	12	6	6	1	62
1	W X	apple	0	0	11	1	10	0	1	9	10	13	10	4	3	72
1	W X2	grass	0	1	1	0	1	0	1	3	3	2	0	0	2	14
1	W X3	apple	0	0	0	1	0	2	2	8	5	5	20	15	1	59
2	E I	apple	0	4	4	3	1	11	3	15	12	8	10	8	2	81
2	E X	apple	0	0	6	4	1	6	6	10	3	2	19	12	0	69
2	E X2	out barrier	0	0	1	0	0	5	12	6	1	2	2	8	0	37
2	E X3	grass	0	0	0	0	1	4	1	4	6	0	2	5	0	23
2	N I	apple	0	0	4	1	3	15	1	2	16	8	19	8	1	78
2	N X	apple	0	0	2	1	1	5	3	18	15	7	16	6	4	78
2	N X2	in barrier	0	0	3	0	0	0	3	5	3	6	2	3	1	26
2	N X3	grass	0	0	0	0	2	0	8	13	4	2	7	8	1	45
2	S I	apple	0	0	3	0	1	7	14	11	23	9	10	4	5	87

Table C.3. Continued.

Plot	Trap	Habitat	273	390	583	706	891	1036	1176	1280	1333	1577	1722	2138	2529	Total
2	S X	apple	0	0	2	0	0	4	3	7	9	2	1	4	0	32
2	S X2	in barrier	0	0	2	1	2	4	6	9	4	7	5	0	2	42
2	S X3	apple	0	2	0	1	0	6	4	13	17	12	18	1	0	74
2	W I	apple	0	0	3	7	6	18	10	7	21	0	25	1	0	98
2	W X	apple	0	0	8	0	3	8	4	21	13	4	14	3	2	80
2	W X2	out barrier	0	0	1	0	1	1	0	1	12	3	14	3	0	36
2	W X3	grass	0	3	1	0	3	1	0	8	5	0	5	2	0	28
3	E I	apple	0	0	6	1	1	6	0	2	3	11	6	0	1	37
3	E X	apple	0	0	1	0	1	6	2	5	0	3	9	0	0	27
3	E X2	corn	0	0	5	1	0	0	3	1	6	0	0	0	0	16
3	E X3	corn	0	0	0	3	1	3	6	1	3	1	0	0	3	21
3	N I	apple	0	0	6	2	3	7	4	12	3	6	8	14	8	73
3	N X	apple	0	0	4	1	1	6	5	0	11	1	2	1	2	34
3	N X2	grass	0	0	1	1	0	10	2	6	6	3	8	4	2	43
3	N X3	corn	0	0	3	1	2	1	2	0	3	1	0	0	0	13
3	S I	apple	0	4	5	5	3	3	3	9	9	5	22	4	2	74
3	S X	apple	0	0	3	0	1	4	0	11	15	4	13	0	0	51
3	S X2	grass	0	0	1	0	0	4	3	8	11	8	18	9	0	62
3	S X3	apple	0	3	0	1	1	12	4	11	11	12	8	6	3	72
3	W I	apple	0	0	7	3	0	4	0	0	3	20	12	0	1	50
3	W X	apple	0	0	5	2	0	4	10	19	7	7	6	1	0	61
3	W X2	grass	0	0	5	0	3	4	6	8	1	5	9	0	0	41
3	W X3	apple	0	0	0	7	2	20	0	11	16	5	13	13	0	87
4	E I	apple	0	6	16	5	2	10	9	36	57	6	7	13	0	167
4	E X	apple	0	1	2	4	0	6	14	26	8	7	17	8	2	95
4	E X2	out barrier	0	1	1	0	2	10	3	23	8	9	20	0	1	78
4	E X3	grass	0	0	0	0	0	6	0	4	4	2	9	8	2	35
4	N I	apple	0	0	5	2	0	14	4	41	0	3	4	7	2	82
4	N X	apple	0	0	5	1	1	10	8	15	4	5	2	4	4	59
4	N X2	in barrier	0	1	0	0	0	3	5	9	0	4	1	4	6	33
4	N X3	alfalfa1	0	0	1	2	0	85	6	87	2	1	12	9	4	209

Table C.3. Continued.

Plot	Trap	Habitat	273	390	583	706	891	1036	1176	1280	1333	1577	1722	2138	2529	Total
4	S I	apple	1	0	9	1	2	7	4	18	14	6	8	4	0	74
4	S X	apple	0	6	9	2	5	8	3	14	15	11	8	7	2	90
4	S X2	in barrier	0	0	6	1	0	1	3	31	14	7	5	2	0	70
4	S X3	apple	0	0	0	0	2	6	0	13	15	6	7	21	2	72
4	W I	apple	0	2	4	2	14	25	18	61	26	36	9	11	3	211
4	W X	apple	0	0	10	0	7	26	15	25	15	12	9	6	5	130
4	W X2	out barrier	0	0	2	0	1	3	8	13	13	0	4	3	0	47
4	W X3	corn	0	0	0	0	0	2	5	3	5	2	0	0	0	17
5	E I	apple	0	1	4	5	15	21	10	67	56	18	26	3	4	230
5	E X	apple	0	1	15	2	3	10	14	30	25	18	22	0	6	146
5	E X2	out barrier	0	0	4	3	0	4	6	21	14	7	7	2	2	70
5	E X3	corn	0	0	1	1	2	2	9	6	3	3	0	4	0	31
5	N I	apple	0	0	1	0	13	11	27	46	120	22	14	1	5	260
5	N X	apple	0	0	0	0	3	4	9	21	37	4	14	3	2	97
5	N X2	in barrier	0	0	2	0	0	8	10	44	22	20	8	1	3	118
5	N X3	grass	0	0	0	0	0	5	3	17	14	7	14	6	0	66
5	S I	apple	0	0	11	4	4	10	11	75	117	49	21	6	0	308
5	S X	apple	0	0	3	4	3	12	11	43	37	9	15	0	1	138
5	S X2	in barrier	0	0	2	2	2	3	6	130	72	15	17	2	3	254
5	S X3	weeds	0	0	3	1	3	0	5	35	46	6	18	0	1	118
5	W I	apple	0	1	7	0	6	9	22	122	159	65	32	3	0	426
5	W X	apple	0	0	7	0	3	6	4	204	137	65	40	4	1	471
5	W X2	out barrier	0	0	7	2	2	3	8	30	70	8	19	2	0	151
5	W X3	weeds	0	0	0	1	0	3	6	10	46	5	5	2	4	82
6	E I	apple	0	1	0	0	0	1	1	6	6	7	18	13	1	54
6	E X	apple	0	2	0	1	3	1	7	3	22	14	21	5	4	83
6	E X2	alfalfa	0	0	1	0	0	3	1	6	16	2	26	5	5	65
6	E X3	alfalfa	0	0	1	0	1	3	5	7	31	11	16	5	2	82
6	N I	apple	0	0	5	4	1	2	2	8	36	29	26	9	7	129
6	N X	apple	0	1	2	0	1	2	3	5	15	4	0	9	7	49
6	N X2	grass	0	0	2	2	3	0	0	0	0	5	8	1	2	23

Table C.3. Continued.

Plot	Trap	Habitat	273	390	583	706	891	1036	1176	1280	1333	1577	1722	2138	2529	Total
6	N X3	grass	0	0	1	1	1	4	11	13	47	38	14	3	4	137
6	S I	apple	0	1	4	3	1	2	9	9	30	26	28	19	0	132
6	S X	apple	0	1	0	0	0	8	2	10	17	6	20	10	2	76
6	S X2	grass	0	0	0	0	0	0	2	7	8	2	7	2	2	30
6	S X3	corn	0	0	0	0	0	3	4	50	95	14	9	4	8	187
6	W I	apple	0	1	2	1	4	22	17	18	22	20	17	29	5	158
6	W X	apple	0	0	9	0	3	9	1	6	7	12	4	24	1	76
6	W X2	grass	0	0	0	1	0	1	4	10	12	3	16	3	2	52
6	W X3	grass	0	0	0	0	0	4	3	1	5	2	1	0	2	18
7	E I	apple	0	0	7	1	4	10	16	6	50	24	62	3	0	183
7	E X	apple	0	1	1	3	6	5	24	6	51	38	80	3	1	219
7	E X2	alfalfa	0	0	2	3	0	12	16	4	24	14	8	8	3	94
7	E X3	weeds	0	0	3	4	1	1	7	16	95	0	10	7	4	148
7	N I	apple	0	0	6	0	4	14	36	18	47	25	92	8	1	251
7	N X	apple	0	0	2	3	1	6	13	16	40	5	8	7	4	105
7	N X2	grass	0	1	1	0	1	4	14	8	17	7	10	0	0	63
7	N X3	grass	0	0	0	0	0	11	27	24	26	5	7	5	0	105
7	S I	apple	0	1	0	2	1	7	8	12	31	4	18	6	11	101
7	S X	apple	0	0	3	3	5	9	14	11	34	10	5	10	2	106
7	S X2	grass	0	0	1	0	0	10	16	14	20	14	3	4	6	88
7	S X3	grass	0	0	1	2	4	2	15	30	65	38	9	4	0	170
7	W I	apple	0	1	1	4	0	15	20	18	31	64	17	11	8	190
7	W X	apple	0	0	4	0	0	8	23	25	19	18	16	12	12	137
7	W X2	grass	0	0	2	0	1	2	8	27	13	7	0	6	8	74
7	W X3	oak	0	0	0	0	1	0	4	4	14	6	0	0	1	30
8	E I	apple	0	0	0	2	7	8	39	23	82	10	57	11	2	241
8	E X	apple	0	0	1	7	12	10	33	14	16	31	31	9	2	166
8	E X2	out barrier	0	0	0	0	0	5	19	6	27	24	15	10	0	106
8	E X3	alfalfa	0	0	1	4	3	2	11	21	16	16	40	0	3	117
8	N I	apple	0	0	9	6	8	5	40	24	89	29	12	11	4	237
8	N X	apple	0	0	3	1	1	0	32	12	20	12	16	4	2	103

Table C.3. Continued.

Plot	Trap	Habitat	273	390	583	706	891	1036	1176	1280	1333	1577	1722	2138	2529	Total
8	N X2	in barrier	0	0	0	0	0	3	11	19	28	16	1	3	0	81
8	N X3	grass	0	0	0	1	0	1	10	6	2	3	5	2	2	32
8	S I	apple	0	3	4	3	10	6	66	85	43	34	49	9	3	315
8	S X	apple	2	0	1	0	3	4	44	23	16	17	42	8	3	163
8	S X2	in barrier	0	0	0	0	0	4	36	27	18	30	8	8	2	133
8	S X3	grass	0	0	0	0	0	7	14	4	14	7	17	9	0	72
8	W I	apple	0	4	3	3	6	7	97	75	61	30	10	16	9	321
8	W X	apple	0	0	7	1	3	8	61	76	16	18	13	12	3	218
8	W X2	out barrier	0	0	0	1	1	2	2	7	11	2	5	4	3	38
8	W X3	oak	0	0	0	0	0	1	56	24	42	11	11	0	2	147

APPENDIX C

Table C.4. Total potato leafhopper (*Empoasca fabae* (Harris)) trap catch for each sample period measured by degree day (base 50F) heat accumulation at the end of the sample period in the eight "Alternative Pest Management Systems in Apple" plots, 1997.

Trap identification			**Number of potato leafhopper captured for each degree day sample period**																	
Plot	Trap	Habitat	**261**	**357**	**454**	**611**	**767**	**1009**	**1147**	**1293**	**1435**	**1632**	**1756**	**1856**	**1961**	**2056**	**2220**	**2395**	**2451**	**Total**
1	E I	apple	0	0	3	24	2	8	7	10	15	16	0	2	2	0	0	0	0	89
1	E X	apple	0	1	4	10	6	3	6	8	10	14	0	2	0	0	0	0	0	64
1	E X2	grass	0	1	3	7	4	5	3	11	7	9	0	0	1	0	0	0	0	51
1	E X3	grass	0	0	1	0	0	6	2	8	8	3	6	2	0	1	2	0	0	39
1	N I	apple	0	0	6	71	9	24	9	10	21	22	10	2	3	1	0	0	0	188
1	N X	apple	0	0	2	31	12	16	4	4	12	4	0	0	1	0	0	0	0	86
1	N X2	grass	0	0	6	6	2	0	8	15	22	18	7	1	0	0	0	0	0	85
1	N X3	pear	0	0	4	15	6	0	6	8	8	2	2	1	0	0	0	0	0	52
1	S I	apple	0	0	23	45	25	25	14	12	20	16	8	2	2	0	1	0	0	193
1	S X	apple	0	0	8	23	8	15	7	16	12	8	7	0	0	0	0	0	1	105
1	S X2	grass	0	0	2	7	3	16	8	9	5	22	5	0	0	0	0	0	0	77
1	S X3	grass	0	0	0	8	4	8	6	13	23	26	29	1	1	0	1	1	0	121
1	W I	apple	0	3	2	21	9	5	8	18	25	23	6	3	0	2	1	0	1	127
1	W X	apple	0	3	2	26	2	13	23	41	26	28	0	0	1	0	0	1	0	166
1	W X2	grass	0	2	2	3	0	3	4	17	5	3	0	2	0	1	0	0	0	42
1	W X3	apple	0	0	1	27	0	0	11	22	26	8	8	6	3	2	0	1	0	115
2	E I	apple	0	0	5	23	0	4	4	8	12	7	3	1	1	0	2	0	0	70
2	E X	apple	0	0	1	18	5	0	4	8	8	6	4	1	6	0	1	0	1	63
2	E X2	out barrier	0	1	2	4	1	1	7	6	7	6	1	0	1	0	0	0	0	37
2	E X3	grass	0	0	0	8	4	8	2	4	13	7	1	3	3	1	0	0	1	55
2	N I	apple	0	0	7	4	9	12	12	7	26	14	7	2	1	4	2	2	0	109
2	N X	apple	0	0	5	23	10	5	6	8	10	10	5	4	0	5	0	0	0	91
2	N X2	in barrier	0	0	1	3	1	2	4	0	0	8	0	5	0	0	0	0	0	24
2	N X3	grass	0	0	0	3	1	2	0	4	0	4	3	1	0	4	0	0	0	22
2	S I	apple	0	0	3	13	2	12	5	16	21	17	1	3	2	5	3	0	0	103

Table C.4. Continued.

Plot	Trap	Habitat	261	357	454	611	767	1009	1147	1293	1435	1632	1756	1856	1961	2056	2220	2395	2451	Total
2	S X	apple	0	0	6	22	3	11	5	12	16	7	4	3	1	0	3	0	0	93
2	S X2	in barrier	0	0	0	0	2	3	8	0	5	8	1	2	0	5	0	0	0	34
2	S X3	apple	0	1	0	3	4	0	2	5	5	9	0	1	2	2	0	1	0	35
2	W I	apple	0	0	4	41	16	25	20	18	52	21	9	13	5	3	0	1	0	228
2	W X	apple	0	0	8	26	5	37	15	21	45	23	8	3	4	1	2	2	0	200
2	W X2	out barrier	0	0	1	0	10	1	2	2	0	5	0	1	1	0	0	0	0	23
2	W X3	grass	0	0	3	4	3	2	7	4	5	6	3	0	1	0	0	0	1	39
3	E I	apple	0	0	0	13	4	2	7	24	10	11	3	1	1	0	0	0	0	76
3	E X	apple	0	0	1	15	14	5	3	7	2	5	2	0	0	0	0	0	0	54
3	E X2	corn	0	1	1	14	8	11	6	5	0	1	2	1	0	0	0	0	0	50
3	E X3	corn	0	1	1	6	18	54	7	9	0	0	0	0	0	0	0	0	0	96
3	N I	apple	0	2	0	44	13	2	2	11	16	8	0	1	3	0	0	0	0	102
3	N X	apple	0	0	2	18	6	1	2	7	3	2	0	0	0	0	0	0	0	41
3	N X2	grass	0	1	0	6	3	2	3	15	21	8	0	1	1	0	0	0	0	61
3	N X3	corn	0	0	2	5	19	20	5	8	14	1	0	0	0	0	0	0	0	74
3	S I	apple	0	0	2	6	15	4	4	10	14	6	2	2	1	0	0	0	0	66
3	S X	apple	0	1	0	5	7	5	2	14	4	2	0	0	0	1	1	0	0	42
3	S X2	grass	0	0	0	6	0	3	1	5	10	6	1	2	2	0	0	0	0	36
3	S X3	apple	0	0	0	6	19	0	11	0	16	1	8	4	1	0	3	1	0	70
3	W I	apple	0	0	0	12	3	0	2	8	4	1	0	2	0	0	0	0	0	32
3	W X	apple	0	0	0	4	2	0	0	4	2	1	0	0	1	0	0	0	0	14
3	W X2	grass	0	0	0	5	2	0	3	13	7	4	1	2	0	0	1	0	0	38
3	W X3	apple	0	0	0	18	17	0	33	47	39	19	11	5	6	10	1	2	0	208
4	E I	apple	0	0	5	4	0	4	0	12	13	8	5	2	1	0	0	0	0	54
4	E X	apple	0	0	3	10	1	0	0	7	6	4	2	3	0	0	0	0	0	36
4	E X2	out barrier	0	0	1	2	1	3	6	2	5	1	0	2	0	0	0	0	0	23
4	E X3	grass	0	0	0	0	4	0	2	11	7	0	3	0	0	0	0	0	0	27
4	N I	apple	0	3	1	14	8	0	6	14	42	7	5	4	3	1	0	0	0	108
4	N X	apple	0	0	4	9	0	3	4	7	12	5	2	4	0	1	0	1	0	52
4	N X2	in barrier	0	0	0	1	3	0	7	4	11	3	2	11	1	1	0	0	0	44
4	N X3	alfalfa1	0	0	2	2	5	40	43	93	160	42	4	0	3	1	0	0	0	395

Table C.4. Continued.

Plot	Trap	Habitat	261	357	454	611	767	1009	1147	1293	1435	1632	1756	1856	1961	2056	2220	2395	2451	Total
4	S I	apple	0	0	0	17	8	8	1	6	6	8	2	2	2	0	0	0	0	60
4	S X	apple	0	0	1	11	4	16	5	13	13	9	0	2	2	0	1	0	0	77
4	S X2	in barrier	0	0	1	0	0	2	2	1	9	0	0	2	0	0	0	0	0	17
4	S X3	apple	0	0	0	11	9	0	9	8	14	3	2	7	1	3	0	0	0	67
4	W I	apple	0	0	11	14	2	11	2	5	24	5	6	7	0	1	0	0	0	88
4	W X	apple	0	2	4	10	9	15	10	17	35	25	7	6	2	4	0	0	0	146
4	W X2	out barrier	0	0	0	1	0	0	1	6	4	5	4	4	0	0	0	0	1	26
4	W X3	corn	1	0	2	8	11	34	3	2	0	1	2	1	0	0	0	0	2	67
5	E I	apple	0	0	0	27	11	13	4	19	6	10	5	0	0	1	0	0	0	96
5	E X	apple	0	0	6	26	13	19	4	6	5	2	2	2	0	1	0	0	0	86
5	E X2	out barrier	0	0	1	1	2	1	0	0	1	8	2	0	1	4	1	0	0	22
5	E X3	corn	0	0	1	10	15	11	16	2	0	0	0	0	1	0	0	0	0	56
5	N I	apple	0	0	1	10	2	5	5	15	11	16	0	2	1	0	0	0	0	68
5	N X	apple	0	0	2	5	1	6	3	4	1	3	1	0	2	2	0	0	0	30
5	N X2	in barrier	1	0	0	0	1	2	2	3	4	0	1	0	1	1	0	0	0	16
5	N X3	grass	0	0	0	1	0	2	3	4	3	13	1	2	0	0	0	0	0	29
5	S I	apple	0	0	2	11	3	3	1	3	1	12	5	1	0	3	0	0	0	45
5	S X	apple	0	3	2	3	1	1	4	13	3	8	2	0	0	0	0	0	0	40
5	S X2	in barrier	0	0	1	2	0	5	4	1	0	3	1	2	1	0	1	0	0	21
5	S X3	weeds	0	0	0	8	5	37	1	8	1	6	6	4	0	2	1	0	0	79
5	W I	apple	0	0	0	20	4	7	8	6	3	11	1	2	0	1	1	0	0	64
5	W X	apple	0	0	1	18	2	6	2	4	1	7	2	2	0	2	0	0	0	47
5	W X2	out barrier	1	0	0	0	0	0	0	3	0	6	1	6	0	1	1	0	0	19
5	W X3	weeds	0	1	0	2	1	0	2	0	0	7	0	0	0	0	0	0	0	13
6	E I	apple	0	0	1	12	7	2	14	46	13	6	3	0	0	1	0	0	0	105
6	E X	apple	0	0	10	38	21	9	12	35	10	6	3	0	1	1	0	0	0	146
6	E X2	alfalfa	0	1	1	15	5	3	6	6	6	9	8	2	0	1	1	0	0	64
6	E X3	alfalfa	0	0	5	10	13	3	21	6	0	0	3	0	0	0	0	0	0	61
6	N I	apple	0	1	2	3	1	2	19	36	28	9	2	0	1	0	0	0	0	104
6	N X	apple	0	0	4	12	1	4	8	15	22	0	1	0	1	0	0	1	0	69
6	N X2	grass	0	0	0	6	2	6	11	23	9	7	1	1	0	0	0	0	0	66

Table C.4. Continued.

Plot	Trap	Habitat	261	357	454	611	767	1009	1147	1293	1435	1632	1756	1856	1961	2056	2220	2395	2451	Total
6	N X3	grass	0	1	0	1	2	0	0	7	1	1	2	0	0	0	0	0	0	15
6	S I	apple	0	0	0	5	2	5	7	16	31	12	6	2	1	2	0	1	0	90
6	S X	apple	0	0	0	4	2	4	8	6	1	3	0	0	0	0	0	0	0	28
6	S X2	grass	0	0	0	1	1	3	4	9	4	8	4	0	0	1	0	0	0	35
6	S X3	corn	0	0	0	1	6	6	5	5	19	4	9	0	0	3	0	0	0	58
6	W I	apple	0	0	6	17	8	3	9	33	35	15	2	0	1	0	0	1	0	130
6	W X	apple	0	0	3	15	8	4	15	21	26	9	5	4	0	0	0	0	0	110
6	W X2	grass	0	0	0	5	5	1	8	12	0	2	1	0	0	1	0	0	0	35
6	W X3	grass	0	0	0	2	2	0	8	7	0	1	1	2	0	0	1	0	0	24
7	E I	apple	0	0	4	22	8	4	11	61	40	8	2	1	0	0	0	1	0	162
7	E X	apple	0	0	6	34	16	6	3	17	25	3	3	0	0	0	0	0	0	113
7	E X2	alfalfa	0	0	3	14	3	1	8	27	19	0	1	0	0	0	0	0	0	76
7	E X3	weeds	0	3	6	24	4	3	5	7	0	0	0	1	0	0	0	0	0	53
7	N I	apple	0	3	2	18	2	3	10	56	45	4	3	2	0	4	0	1	1	154
7	N X	apple	0	0	6	18	3	9	7	16	15	4	4	1	0	1	0	1	0	85
7	N X2	grass	0	0	4	4	1	2	7	17	22	3	1	3	0	1	0	0	0	65
7	N X3	grass	0	0	0	1	1	4	12	7	7	0	1	1	2	0	0	0	0	36
7	S I	apple	0	1	5	31	5	5	25	71	44	4	11	2	3	4	1	0	0	212
7	S X	apple	0	1	6	6	5	3	22	23	19	5	3	0	0	3	1	0	0	97
7	S X2	grass	0	0	1	1	1	1	0	13	9	0	0	0	0	0	0	0	0	26
7	S X3	grass	0	1	0	1	2	3	5	7	14	0	2	0	0	0	0	0	0	35
7	W I	apple	0	1	6	41	8	10	22	100	57	2	5	4	0	2	2	0	0	260
7	W X	apple	0	0	2	16	0	6	17	87	53	7	7	3	2	1	2	1	0	204
7	W X2	grass	0	0	0	0	0	5	20	7	16	6	3	0	2	2	0	0	0	61
7	W X3	oak	0	0	0	0	1	3	9	11	18	3	1	3	0	0	0	0	0	49
8	E I	apple	0	0	0	23	1	7	18	7	24	3	6	2	0	1	0	0	0	92
8	E X	apple	0	2	5	10	3	8	10	8	23	4	10	5	0	1	0	0	0	89
8	E X2	out barrier	0	0	1	4	2	7	8	2	17	1	0	3	0	0	0	0	0	45
8	E X3	alfalfa	0	0	8	27	0	4	1	0	0	0	0	2	0	0	0	3	0	45
8	N I	apple	0	0	3	10	1	2	12	15	37	3	1	2	0	2	1	0	0	89
8	N X	apple	0	0	4	8	2	4	14	7	10	0	3	1	0	1	0	1	0	55

APPENDIX C

Table C.4. Continued.

Plot	Trap	Habitat	261	357	454	611	767	1009	1147	1293	1435	1632	1756	1856	1961	2056	2220	2395	2451	Total
8	N X2	in barrier	0	0	0	0	0	3	1	1	1	0	0	2	0	1	0	0	0	9
8	N X3	grass	0	0	0	2	1	1	4	2	6	1	0	1	0	0	1	0	0	19
8	S I	apple	0	2	2	6	0	5	7	20	55	1	1	5	3	5	0	0	0	112
8	S X	apple	0	0	2	7	4	5	15	5	23	0	5	2	1	1	0	0	0	70
8	S X2	in barrier	0	0	0	0	0	6	1	1	24	0	3	3	0	0	2	1	0	41
8	S X3	grass	0	0	0	5	0	2	6	8	5	0	1	0	0	0	0	0	0	27
8	W I	apple	0	3	7	19	6	12	12	17	51	11	3	4	0	2	0	0	0	147
8	W X	apple	0	1	8	4	2	11	2	15	75	8	4	7	0	1	0	0	1	139
8	W X2	out barrier	0	0	1	0	0	3	1	6	20	2	0	0	0	0	0	0	0	33
8	W X3	oak	0	2	0	6	3	0	16	17	38	3	2	2	0	0	0	0	0	89