Population dynamics and management of potato leafhopper and other insect pests in forage systems

by

Todd Allen DeGooyer

A dissertation submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of
DOCTOR OF PHILOSOPHY

Major: Entomology
Major Professor: Larry P. Pedigo

Iowa State University
Ames, Iowa

1997

UMI Number: 9725406

UMI
300 North Zeeb Road
Ann Arbor, MI 48103

Graduate College
Iowa State University

This is to certify that the Doctoral dissertation of

Todd Allen DeGooyer

has met the dissertation requirements of Iowa State University

Signature was redacted for privacy.

Major Professor

Signature was redacted for privacy.

For the Major Program

Signature was redacted for privacy.

For the Graduate College

TABLE OF CONTENTS

CHAPTER 1. GENERAL INTRODUCTION

Dissertation Organization

The general introduction contains a brief discussion of the importance of alfalfa followed by the justification and objectives for this research. This is followed by the literature review that contains background information on potato leafhopper biology and ecology, potato leafhopper population dynamics, alternative alfalfa cropping systems research on alfalfa insect pests, and sampling methodology and management programs for potato leafhopper. Following the general introduction, there are four papers. The first paper assesses the population dynamics and diurnal activity of potato leafhopper in Iowa forages. The second paper discusses the effect of alfalfa and forage grass intercrops on alfalfa insect pests and associated natural enemy predator populations. A third paper describes the development of a sticky trap sampling technique for potato leafhopper adults in alfalfa using a series of comparative studies. The final paper describes the evaluation of grower-oriented sampling techniques and development of a management program for potato leafhopper in alfalfa. A general conclusion follows the fourth paper. References cited in the general introduction are listed after the general conclusions.

Introduction

Alfalfa, *Medicago sativa* L., is the world's most valuable cultivated forage crop (Grau et al. 1985) and the most important perennial forage crop in North America (Michaud et al. 1988, Fick and Mueller 1989). Over 11 million ha of land in the United States (Melton et al. 1988) and 4-5 million ha of land in Canada (Goplen et al. 1980) are committed to alfalfa production. Alfalfa is predominantly grown in the northeastern and northcentral regions of the U.S. (Bolten et al. 1972) and the southcentral prairie provinces of Canada (Goplen et al. 1980).

The perennial nature of alfalfa makes it a very important crop in terms of energy and soil conservation. It is fed to livestock as hay, silage, greenchop, pellets, or cubes and is grown for pasture and seed production. Alfalfa functions in crop rotation, fixing nitrogen for subsequent crops, improving soil structure and fertility, and reducing pest problems for other crops (Fick and Mueller 1989). Because of these characteristics, alfalfa is assuming an increasingly important role in sustainable agriculture.

However, alfalfa's perennial nature also permits insect pests to cause greater damage than they might cause in annual crops (Grau et al. 1985). The potato leafhopper, *Empoasca fabae* (Harris), and the alfalfa weevil, *Hypera postica* (Gyllenhal), are two pests that benefit from alfalfa production. The potato leafhopper is a major pest of alfalfa in the northeastern and northcentral U.S. and southern provinces of Canada (Lamp 1991), whereas the alfalfa weevil is an key pest from southern Canada south to California and Arizona (Armbrust 1981).

Current integrated pest management (IPM) programs utilize cultural, biological, and chemical tactics for management of these potato leafhopper and alfalfa weevil. However, in many instances, IPM is not practiced by alfalfa growers because of the cost and time involved in implementing these tactics (Rajotte et al. 1987). In addition, the growing concern over the increased reliance on chemicals as the sole management tactic for insect pests has demonstrated the need for alternative strategies.

One innovative strategy is the use of alternative cropping systems. Alternative cropping systems have been investigated to determine their potential for improving or replacing conventional management practices that are deemed less profitable, harmful to the environment, or perhaps less feasible in some geographical areas (Hammond and Jeffers 1990). Intercropping alfalfa and grass is one cropping system that has been shown to have beneficial agronomic properties that could possibly affect alfalfa pest populations. Some alfalfa producers currently are planting an alfalfa-grass intercrop for weed management purposes (Tesar and Marble 1988). However, little is known about the effect of these intercrops on insect pest populations and communities, the quality of the alfalfa, and the costs and benefits of this cropping system.

Sampling for making management decisions has received minimal research emphasis, even though it is a basic part of potato leafhopper management programs (Lamp and Smith 1989). Most sampling research conducted for making management decisions has shown that sweep-net sampling is the most reliable method for estimating adult and nymph potato leafhopper densities in alfalfa (Fleischer and Allen 1982, Smith and Ellis 1982, Luna et al. 1983).

However, very few alfalfa growers use sweep-net sampling, the first step in an IPM program. A 1990 survey of Iowa farmers showed that less than half of the farmers scouted any of their fields (alfalfa, corn, soybeans, etc.) with enough frequency necessary to obtain optimal benefits from IPM (Padgitt et al. 1990). The main reasons given for not scouting are that it takes too much time and that scouting services are too expensive (Rajotte et al. 1987). Other possible reasons are that sampling equipment (e.g., sweep nets) used for scouting is not readily available to alfalfa growers and that the public image of sweep netting (i.e., "butterfly net") is unacceptable. Thus, to encourage more farmers to use IPM in alfalfa for potato leafhoppers, there is a strong need to develop a more grower-oriented sampling technique that accurately assesses leafhopper populations. This technique then can be developed into a practical potato leafhopper sampling program.

Objectives

The specific objectives of this dissertation were:

1) To understand the population dynamics and diurnal activity of potato leafhopper in Iowa forage systems.

2) To determine the effect of alfalfa-grass intercrops on alfalfa insects .

   a. To determine the effect of alfalfa-grass intercrops on potato leafhopper as well as other alfalfa insect pests and predators.

   b. To assess the impact of intercropping on forage growth characteristics for determining the feasibility of intercropping as a management tactic.

3) To develop grower-oriented sampling techniques and a management program for potato leafhopper in alfalfa.

Literature Review

Biology of potato leafhopper

The potato leafhopper, *Empoasca fabae* (Harris) (Homoptera: Cicadellidae) is a major insect pest of alfalfa in the northcentral and northeastern United States (Lamp 1991). In many instances, potato leafhoppers are the only insect causing significant economic loss (Smith and Ellis 1983). In addition to alfalfa, potato leafhoppers also feed on over 200 other plant species (Poos and Wheeler 1949), some of which are important in maintaining populations before leafhoppers move into the alfalfa (Armbrust 1989).

Description of potato leafhopper

Potato leafhopper adults are approximately 3 mm long with a florescent-yellow-green, wedge-shaped body. Immature leafhoppers, called nymphs, look similar to adults in color and shape but are wingless. Nymphs are from 1 to 3 mm in length. Adult potato leafhoppers typically jump or fly when disturbed, whereas nymphs tend to walk sideways (Hutchins and Wintersteen 1988).

Potato leafhopper injury

Potato leafhoppers have piercing-sucking mouthparts that are used to extract plant juices. Injured alfalfa plants exhibit a distinct inverted V-shape yellowing of the leaf (chlorosis), commonly referred to as "hopperburn" (Pedigo 1989). Injury to the alfalfa plant results from phloem destruction and clogging from cell hypertrophy induced by saliva injected during repeated insertion of the stylet (Medler 1941). Potato leafhopper injury to alfalfa results in reduced photosynthesis and transpiration rates (Womack 1984), which decreases plant height and dry matter production (biomass) (Smith and Ellis 1983, Lamp et al. 1985, Hutchins and Pedigo 1989). However, Hutchins et al. (1989) found PLH-induced stunting slightly enhanced digestibility of alfalfa stems and leaves. In addition, alfalfa quality also may be altered by leafhopper feeding. Faris et al. (1981) noted reductions in crude protein from 15 to 24% and carotene content from 45 to 78% associated with excessive leafhopper feeding. Heavy leafhopper infestations also can cause a delay in phenological development of the alfalfa (Hutchins and Pedigo 1990) and reduced stand longevity (Simonet et al. 1979).

Potato leafhopper population dynamics

Each year potato leafhopper adults migrate northward from overwintering areas in the Gulf states (Pienkowski and Medler 1964). After arriving, females and males mate, and subsequently, females deposit 1 mm long eggs into stem pith (Simonet and Pienkowski 1977). The eggs hatch after the accumulation of 136 ± 39.7 degree days (base 7.6 °C) (Simonet and Pienkowski 1980) or approximately 10 days. This is followed by a two week period of development in which the nymphs molt five times. Adults may live and feed for more than 30 days (Hutchins and Wintersteen 1988). Throughout most of its summer range, potato leafhoppers have three to four generations (Hower 1987). Potato leafhoppers cannot survive winters in the northern states (Decker and Cunningham 1967, Hutchins and Wintersteen 1988), but evidence suggests that airflows may be sufficient to return at least some leafhoppers to overwintering sites in the Gulf states (Taylor 1989).

Many factors have been investigated with regard to their effects on population dynamics including weather (particularly temperature), natural enemies, host plants and crop harvesting (Hogg and Hoffman 1989). The effect of temperature on potato leafhoppers development has been studied more than any other weather variable. Temperature has been shown to influence developmental rates of immature stages (generation time) (Simonet and Pienkowski 1980, Hogg 1985) as well as oviposition rates (Kieckhefer and Medler 1964, Hogg 1985), adult longevity (Hogg 1985), and adult size (Simonet and Pienkowski 1980). Natural enemies of potato leafhoppers including egg parasitiods and insect predators have not been shown to play a significant role in terms of population dynamics (Hogg and Hoffman 1989). But, a fungal pathogen (*Zoophthora radicans* (Brefeld) Batko) of potato leafhopper has been found to have an impact on populations in Illinois (Hünter 1991). Host plants are important in determining leafhopper population dynamics. Leafhoppers have the ability to exploit a wide range of host plants during the growing season because of their mobility and polyphagous nature (van Emden and Way (1973). The removal of host plants through the human activity of harvesting also has been shown to dramatically effect population dynamics. For example, Simonet and Pienkowski (1979) found that cutting alfalfa to a 2-to 5-cm stubble height resulted in nymphal and egg mortality near 95 and 100%, respectively. However, adults can recolonize subsequent alfalfa crops and still reach economic populations.

Alternative alfalfa cropping systems for management of alfalfa insect pests

Diversified cropping systems (polycultures), such as intercropping and multicropping, have been shown to produce a more diverse insect community and result in significant changes in pest and beneficial insect populations relative to monocultures (Risch et al. 1983, Baliddawa 1985, Hammond and Jeffers 1990). Diversified cropping systems reduce the overabundance of any one species, particularly pest species, and result in less crop losses relative to monocultures (Risch et al. 1983, Baliddawa 1985). The hypotheses that have been suggested for the reduction in alfalfa pest densities in polycultures include: increased emigration of herbivores from polycultures (Risch 1981, Andow 1991), reduced oviposition in non-host plants (Smith 1987), decreased survival of young on non-host plants (Lamp et al. 1984), and increased activity of natural enemies in polycultures (Horn 1981).

Although the effects of polycultures on insect pest densities have been studied for some cropping systems, little research has been conducted to determine the effect of alfalfa-grass polycultures on alfalfa insect pests and associated natural enemies. One early study focused on the effect of intercropping alfalfa and oats (*Avena sativa* L.) on potato leafhopper density. Lamp (1991) found that interseeding oats into alfalfa reduced potato leafhopper adult and nymph density by as much as 82.6% and 89.5% per square meter, respectively, when compared to alfalfa monocultures. But intercropping reduced alfalfa biomass and maturity relative to the alfalfa monoculture. This loss of quantity and quality of alfalfa may be compensated for by the reduced need for responsive potato leafhopper management (Lamp 1991). Other studies found that intercropping alfalfa and three forage grasses reduced alfalfa weevil density and damage significantly in comparison to the monocultures (Coggins 1991, Roda et al. 1996). But potato leafhopper densities were not found to be as affected by these polycultures (Coggins 1991).

However, several researchers have studied the effects of weedy grasses in alfalfa on potato leafhopper density. The presence of weedy grasses in alfalfa stands has been shown to reduce potato leafhopper density (Gentsch 1982, Lamp et al. 1984, Barney and Pass 1987, and Oloumi-Sadeghi et al. 1987, 1989) and to reduce oviposition and increase flight of potato leafhoppers (Smith 1987). Nevertheless, an overabundance of weeds in an alfalfa field can limit and decrease the quality of yield (Kapusta 1983). This difference in leafhopper density was associated with reduced damage to the alfalfa (Oloumi-Sadeghi et al. 1989).

Potato leafhopper sampling techniques and management programs in alfalfa

The potato leafhopper is a particularly difficult insect to manage because control measures need to be implemented before the appearance of visual damage symptoms, e.g., leaf chlorosis or "hopperburn" (Gessel 1978). Therefore, having an effective and efficient sampling program is necessary for successful management of potato leafhoppers. However, sampling potato leafhopper for making management decisions has received minimal emphasis, even though it the most basic part of management programs (Lamp and Smith 1989).

Many sampling techniques have been investigated to determine their ability to accurately assess potato leafhopper adult and nymph densities. These techniques include: sweepnets (Fleischer and Allen 1982, Smith and Ellis 1982, Cuperus et al. 1983, Hutchins and Wintersteen 1988), ice cream cartons (Simonet and Pienkowski 1979), light traps (Decker et al. 1971), sticky traps (Pienkowski and Medler 1966, Smith and Ellis 1982), emergence traps (Cherry et al. 1977), removing stem bouquets (Simonet et al. 1978), drop traps (Simonet et al. 1978, 1979; Fleischer et al. 1982), water pan traps (Smith and Ellis 1982), and D-vac (suction samples) (Simonet et al. 1978, Fleischer et al. 1982). Of these sampling techniques, only the sweepnet and carton technique have been developed for use in potato leafhopper management programs.

However, all of the potato leafhopper management programs, designed for crop consultants and farmers today, utilize field-counted sweep-net samples of adults (Fleischer and Allen 1982) or adults and nymphs (Smith and Ellis 1982, Cuperus et al. 1983, Hutchins and Wintersteen 1988) to assess density. Cuperus et al. (1983) conducted experiments using sweep sampling to establish economic thresholds for potato leafhopper management. Their economic thresholds, based on the total number of adults and nymphs, were 0.32, 0.40, and 0.50 potato leafhoppers per pendulum sweep when alfalfa has reached 5, 12, and 17 cm of stem regrowth, respectively. Shields and Specker (1989) tested three sweep-net sampling methods (25 sweeps per site, 4 sites per field; 20 sweeps per site, 5 sites per field; and 10 sweeps per site, 10 sites per field) and found the 10 by 10 method most efficient because it saved time and performed the best. Additional research using sweep nets for management programs has led to the development of sequential sampling plans for leafhoppers in alfalfa (Luna et al. 1983, Shields and Specker 1989).

Nevertheless, there are many problems with using sweep net samples to estimate leafhopper density. One problem is that there is considerable variability in the number of leafhoppers collected, depending on the person collecting the sample (Wilson 1991). Weather, dew, time of day, plant height, and the sampling plan also contribute to variation of sweep-net samples (Saugstad et al. 1967), allowing for inaccurate estimates and improper IPM decisions.

Some sampling methods can accurately assess potato leafhopper density for ecological studies, but they are either too expensive, impractical, or labor intensive for potato leafhopper management programs (e.g., the vacuum-net sampling method). Other sampling methods, including trap catches of various types, were not reliable in estimating adult leafhopper density in alfalfa and were deemed unsuitable for making management decisions (Fleischer et al. 1983).

CHAPTER 2. POPULATION DYNAMICS AND DIURNAL ACTIVITY OF POTATO LEAFHOPPER IN IOWA FORAGE SYSTEMS

A paper to be submitted to the Journal of Agricultural Entomology

Todd A. DeGooyer, Larry P. Pedigo, and Marlin E. Rice

Abstract

Studies were conducted in Iowa forages from 1994 through 1996 to assess the population dynamics and diurnal activity of potato leafhopper, *Empoasca fabae* (Harris). The population dynamics study showed that potato leafhopper populations can reach economic levels in all three alfalfa crops during the growing season. However, economic thresholds were consistently exceeded only in the second alfalfa crop. In the second crop, current economic thresholds were exceeded approximately 3 weeks after first harvest. Potato leafhopper adults were collected in all three alfalfa crops, but nymphs were only collected in the second and third crops. The diurnal study showed that there are differences in potato leafhopper densities captured at different times of the day. For samples collected around 1000 h or at 1900 h or later, present economic thresholds may be too low. But there was not enough conclusive evidence from this study to justify development of different economic thresholds based on the time of day leafhoppers are sampled.

Introduction

The potato leafhopper, *Empoasca fabae* (Harris) (Homoptera: Cicadellidae) is a major insect pest of alfalfa in the northcentral and northeastern United States (Lamp 1991). In many instances, potato leafhoppers are the only insect causing economic loss (Smith and Ellis 1983). In addition to alfalfa, potato leafhoppers also feed on over 200 other plant species (Poos and Wheeler 1949), some of which are important in maintaining populations before leafhoppers move into the alfalfa (Armbrust 1989).

Because of its economic importance, the potato leafhopper is one of the most studied insect pests of alfalfa (Gyrisco et al. 1978, Armbrust and Lamp 1989). In fact, the population dynamics of potato leafhopper have been well documented in most regions of the United States. However, the population dynamics of potato leafhopper in Iowa are not well understood. In Iowa, three to four crops (cuttings) of alfalfa are harvested per season. Because of the leafhopper's biology (e.g., migration from southern U.S. in the spring and polyphagous nature), each alfalfa crop during the season may have different factors that affect potato leafhopper densities. To more effectively manage potato leafhopper in Iowa, a better understanding of population dynamics, as it relates to current economic thresholds, is needed.

Potato leafhopper populations have been found to exhibit different levels of flight activity within a 24-h period. Dysart (1962) determined that over 50% of daily flight occurred within 30 minutes after sunset. Smith and Ellis (1982) sampled alfalfa every hour for a 38-h period and collected the greatest number of leafhoppers 1 h before sunrise and 2 h after sunset. Daytime leafhopper estimates fluctuated but always were less than nighttime estimates; however, sampling for potato leafhopper management is usually conducted during the daytime hours. Therefore, an understanding of the influence of diurnal activity on leafhopper capture could potentially improve management.

Field studies were conducted to better understand potato leafhopper biology as it relates to Iowa forage systems. The objectives were to assess both the seasonal population dynamics and diurnal activity of the potato leafhopper as they relate to current economic thresholds.

Materials and Methods

Two fields, located at Iowa State University farms near Ames, IA, were selected for study from 1994 through 1996. A 3-ha field, located at the Ross farm 2-km north and 1-km west of Ames, was seeded with 'Apollo' alfalfa in the fall of 1993. A second 2-ha field, located at the Johnson farm 4-km south of Ames, was seeded with 'Defiant' alfalfa in the spring of 1994. Both alfalfa cultivars are commonly grown in the Midwest. Each field was divided into two sections. One section was used for the potato leafhopper population dynamics study, and the other section was used for the diurnal activity study. Alfalfa was cut and harvested when approximately 10 % of the alfalfa stems were flowering.

Population dynamics study

This study was conducted at both locations in 1995 and 1996 throughout the growing season. Fields were divided into 3 quadrats (0.4 ha per quadrat). Insect sampling was conducted weekly between 1300 and 1400 h during the alfalfa growing season with a 38-cm-dia. sweep net to estimate potato leafhopper abundance. Thirty pendulum sweeps were taken at two sites (60 sweeps total) within each quadrat on each sampling date. Collecting two 30-sweep sampling units decreased the processing time for each treatment sample compared with processing one 60-sweep unit. Sampling units were collected, bagged, and frozen before counting. Adult and nymphal means were calculated to compare population trends at each site during both years. In addition, alfalfa stem height was estimated weekly by taking 25-alfalfa stem samples from each quadrat.

Diurnal activity study

This study was conducted at both locations from 1994 through 1995 in the second alfalfa crops. Each alfalfa field was divided into 10, 25 x 25 m quadrats. One, 10 sweep-net sampling unit was collected per quadrat for each time of day, using a 38-dia. sweep net. Samples were collected between 1000 and 1030 h, 1500 and 1630 h, 1900 and 1930 h, and 2200 and 2230 h. These times were chosen based on two factors: 1) possible times a scout or grower could sample the alfalfa field and 2) times of day following dew evaporation in the morning and dew formation in the evening. These sampling times avoided wet sweep samples that might bias population estimates. Sweep samples for each time of day were collected in each quadrat according to a stratified random design. Data were analyzed by analysis of variance (ANOVA), and means were separated by using Fisher's protected least significant difference (LSD) (SAS 1990).

Results and Discussion

Population dynamics study

First crops

Immigrating potato leafhopper adults were first collected on 19 May in 1995 and on 21 May in 1996 at both locations (Figs. 1- 4). Most adults were collected on the last two sampling dates of the first alfalfa crops. With the exception of the Johnson farm in 1996 (Fig. 3), population densities did not exceed current economic thresholds during the first alfalfa crop. Current economic thresholds are 0.1 leafhoppers per sweep for each 2.5 cm of plant height, if alfalfa is less than 25-cm tall and 2 or more leafhoppers per sweep, if the alfalfa is taller than 25 cm (Rice 1996). Furthermore, the leafhopper density at the Johnson farm was only greater than the economic threshold on the last sampling date before first crop harvest (alfalfa was greater than 25-cm tall and leafhoppers averaged 2.7 per sweep) (Fig. 3). No nymphs were collected in the first alfalfa crops in either year of the study.

Second crops

Both adult and nymphal densities tended to increase on each subsequent sampling date in the second alfalfa crops (Figs. 1-4). No nymphs were collected one week after the first harvest. The greatest number of all leafhopper stages collected during the alfalfa growing season always occurred on the last sampling date before the second harvest. Greater numbers of leafhoppers were collected in 1995 at both locations during the second crop than in 1996. The number of nymphs was greater than adults on the last sampling date of the second crops in all but one instance. Leafhopper populations (adults and nymphs combined) exceeded economic thresholds two to three weeks after the first alfalfa harvest at both locations in 1995 and 1996.

Third crops

Leafhopper populations did not reach economic levels in 1995 at either location (Figs. 1-2). In 1996, populations increased to economic levels two (Ross) to three (Johnson) weeks after the second alfalfa harvest; however, these populations declined to noneconomic levels by the next sampling date (Figs. 1-4). Potato leafhopper populations then remained noneconomic throughout the third alfalfa crops.

Both adult and nymphal numbers were reduced following each alfalfa cutting and harvest; however, because of their mobility, adults densities were affected less than nymphs in both years and locations. After cutting and harvest, many adult leafhoppers emigrate to adjacent fields or alternative hosts, whereas most nymphs are either removed with harvest or are dislodged from the alfalfa stems and starve to death (are unsuccessful at relocating a suitable host). Simonet and Pienkowski (1979) found that cutting alfalfa to a 2- to 5- cm stubble height resulted in nymphal and egg mortality near 95 and 100%, respectively.

The results of this study showed that the potato leafhopper populations can reach economic levels in any of the three alfalfa crops; however, economic thresholds were consistently exceeded only in the second alfalfa crops. The dramatic reduction in potato leafhopper densities after alfalfa harvest suggests that early harvest may be an effective management tactic for use in alfalfa. Early harvest is an especially useful tactic for the first crop, in which populations only build to economic levels late in the growth cycle. But, adults can recolonize subsequent alfalfa crops and still reach economic populations, as happened in the second and third alfalfa crops. Early harvest is not as practical in the second crop because thresholds are exceeded when alfalfa is early in the growth cycle. At this time, the most probable management option for growers is an insecticide application to rapidly reduce populations.

Diurnal activity study

The numbers of potato leafhoppers collected at three or four times during the day are shown in Figs. 5-8. With the exception of 28 June, significantly greater potato leafhopper numbers were collected at 1900 and 2200 h (samples only collected on 28 and 30 June) compared with 1500 h at the Ross farm in 1994 (Fig. 5). On the four sampling dates in 1994, 22 to 81% more leafhoppers were collected on the two later sampling times. Sampling, however, was discontinued at 2200 h after the first two sampling dates because of dew formation beginning on 5 July that interfered with sampling. In addition, consistently greater numbers of leafhoppers were collected at 1000 h compared with 1500 h on all four sampling dates in 1994. No consistent differences in the number of leafhoppers collected at different sampling times were found in 1995 (Figs. 6-7). But there were a few instances in 1995 when significantly greater numbers were collected at 1900 h compared with the other sampling times. In 1996, significantly greater densities of leafhoppers were collected on two of the three dates at 1000 h compared with 1500 h (Fig. 8).

The findings show that there are differences in the number of potato leafhoppers captured at different times of the day. Adult leafhoppers are highly mobile and have increased flight activity near sunrise (between 0400 and 0600 h) and especially near sunset (between 1900 and 2200 h) (Dysart 1962, Smith and Ellis 1982). Therefore, the greater numbers collected at 1900 and 2200 h in 1994 (and to some degree in 1995) were likely the result of increased local flight activity amongst the vegetation (Pienkowski and Medler 1966). The greater numbers of leafhoppers collected at 1000 h compared with 1500 h may have been the residual of the increased activity of adults observed around sunrise.

For samples collected around 1000 h or at 1900 h or later, present economic thresholds may be too low; however, there is not enough conclusive evidence from this study to justify development of different economic thresholds based on the time of day leafhoppers are sampled. Field studies to develop management programs for potato leafhoppers was likely conducted during normal working hours (~800 to 1800 h) (Saugstad et al. 1967, Simonet et al.1979) and growers (or scouts) are more likely to sample during this same time period, making current economic thresholds acceptable.

Acknowledgment

The authors thank Stephanie Peterson, Mike Anderson, Debbie Engels, Drew Felsted, Deni Scar, Mike Nagel, Anna Dierickx, and Brad Russell for their technical assistance. This research was funded in part by the Leopold Center for Sustainable Agriculture. This is Journal Paper J-17262 of the Iowa Agricultural and Home Economics Experimental Station, Ames, IA. Project No. 3207.

References Cited

Armbrust, E. J. 1989. Introduction. *In* E. J. Armbrust & W. O. Lamp [eds.], History and perspectives of potato leafhopper (Homoptera: Cicadellidae) research. Misc. Pub 72, Entomol. Soc. Am., Lanham, MD.

Armbrust, E. J. and W. O. Lamp. 1989. History and perspectives of potato leafhopper (Homoptera: Cicadellidae) research. Misc. Publ. 72, Entomol. Soc. Am., Lanham, MD.

Dysart, R. J. 1962. Local movement of potato leafhoppers in alfalfa. Proc. North Central Branch Entomol. Soc. Am. 17: 100-101.

Gyrisco, G. G., D. Landman, A. C. York, B. J. Irwin, and E. J. Armbrust. 1978. Literature of arthropods associated with alfalfa. IV. Bibliography of potato leafhopper (*Empoasca fabae* (Harris)) (Homoptera: Cicadellidae). Ill. Agr. Exp. Pub.

Lamp, W. O. 1991. Reduced *Empoasca fabae* (Homoptera: Cicadellidae) density in oat-alfalfa intercrop systems. Environ. Entomol. 20: 118-126.

Pienkowski, R. L. and J. T. Medler. 1966. Potato leafhopper trapping studies to determine local flight activity. J. Econ. Entomol. 59: 837-843.

Poos, F. W. and N. H. Wheeler. 1949. Some additional host plants of three species of leafhoppers of the genus *Empoasca*. Proc. Entomol. Soc. Wash. 51: 35.

Rice, M. E. 1996. Leafhoppers on the increase. Integrated Crop Management, Iowa State Univ. Ext., IC-476 (17): 116-117.

SAS Institute. 1990. SAS user's guide: statistics. SAS Institute, Cary, N.C.

Saugstad, E. S., R. A. Bram, and W. E. Nyqyust. 1967. Factors influencing sweep net sampling of alfalfa. J. Econ. Entomol. 60: 421-425.

Simonet, D. E., R. L. Pienkowski, D. G. Martinez, and R. D. Blakeslee. 1979. Evaluation of sampling techniques and development of a sampling program for potato leafhopper adults on alfalfa. Environ. Entomol. 8: 397-399.

Simonet, D. E. and R. L. Pienkowski. 1979. Impact of alfalfa harvest on potato leafhopper populations with emphasis on nymphal survival. J. Econ. Entomol. 72: 428-431.

Smith, S. M. and C. R. Ellis. 1982. Sampling for potato leafhopper (Homoptera: Cicadellidae) on alfalfa. Proc. Entomol. Soc. Ontario 113: 35-41.

Smith, S. M. and C. R. Ellis. 1983. Economic importance of insects on regrowths of established alfalfa fields in Ontario. Can. Entomol. 115: 859-864.

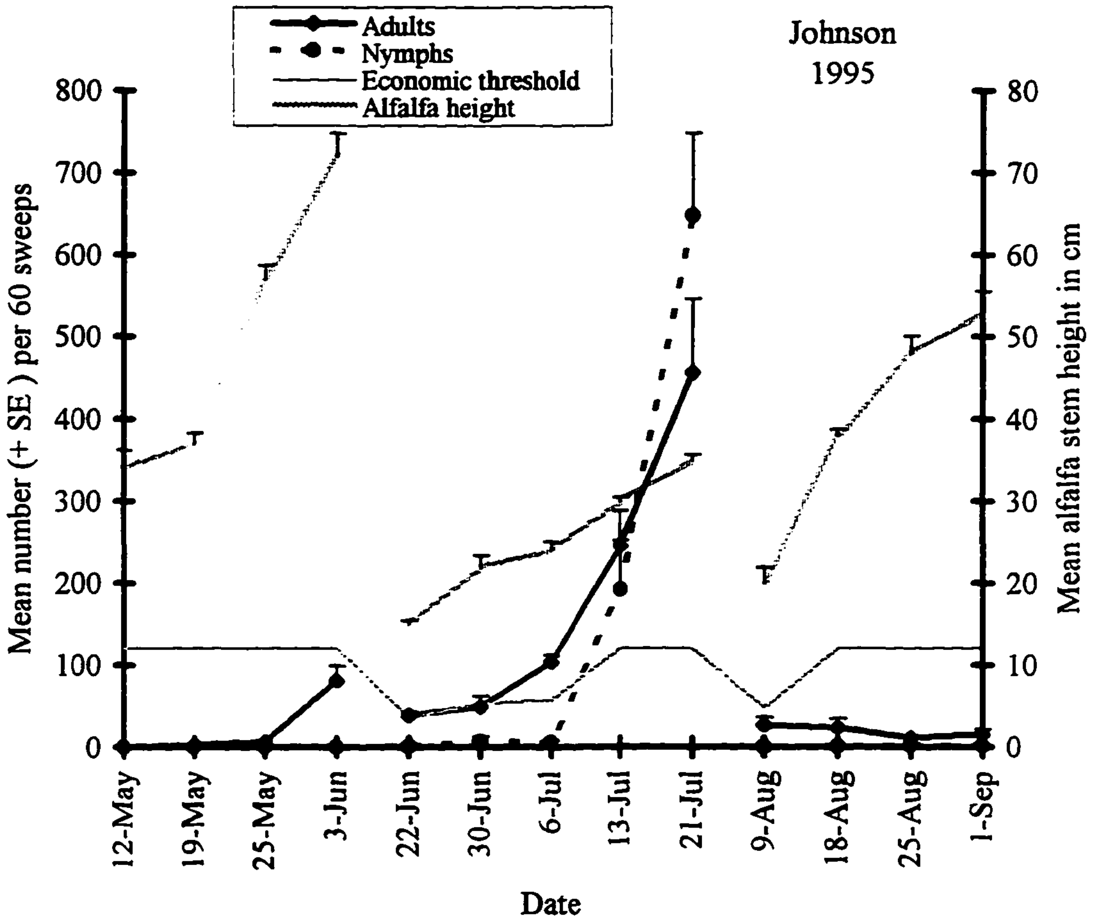


Figure 1. Mean number of potato leafhoppers collected during the alfalfa growing season at the Johnson farm, 1995. Breaks in lines indicate when alfalfa was harvested. Error bars represent one half of the standard error of the associated mean

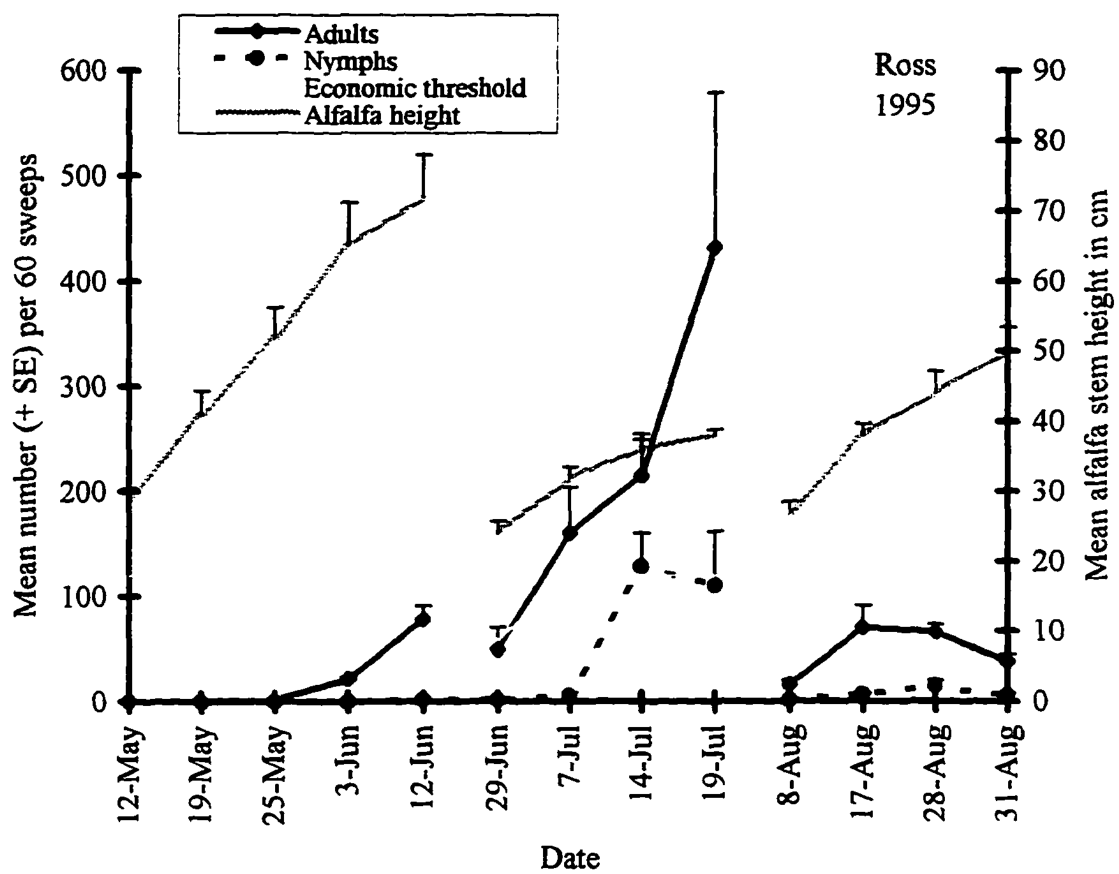


Figure 2. Mean number of potato leafhoppers collected during the alfalfa growing season at the Ross farm, 1995. Breaks in lines indicate when alfalfa was harvested. Error bars represent one half of the standard error of the associated mean

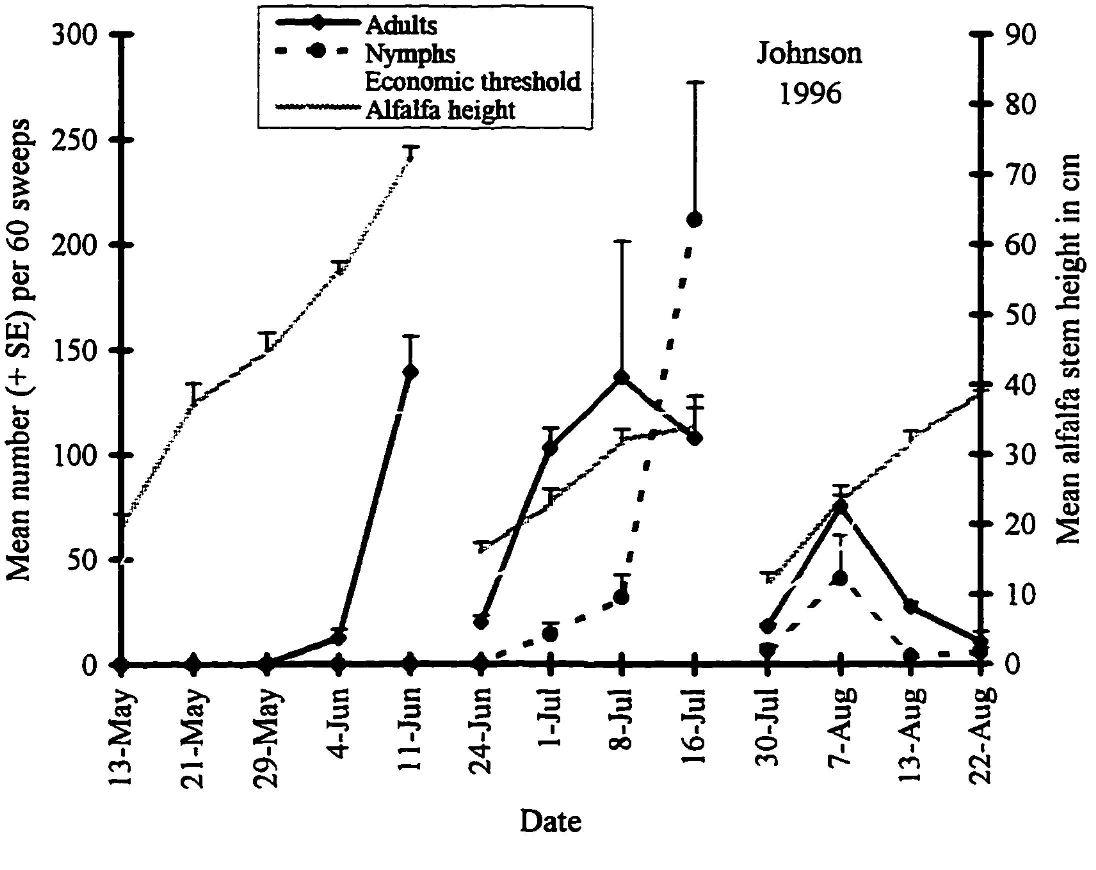


Figure 3. Mean number of potato leafhoppers collected during the alfalfa growing season at the Johnson farm, 1996. Breaks in lines indicate when alfalfa was harvested. Error bars represent one half of the standard error of the associated mean

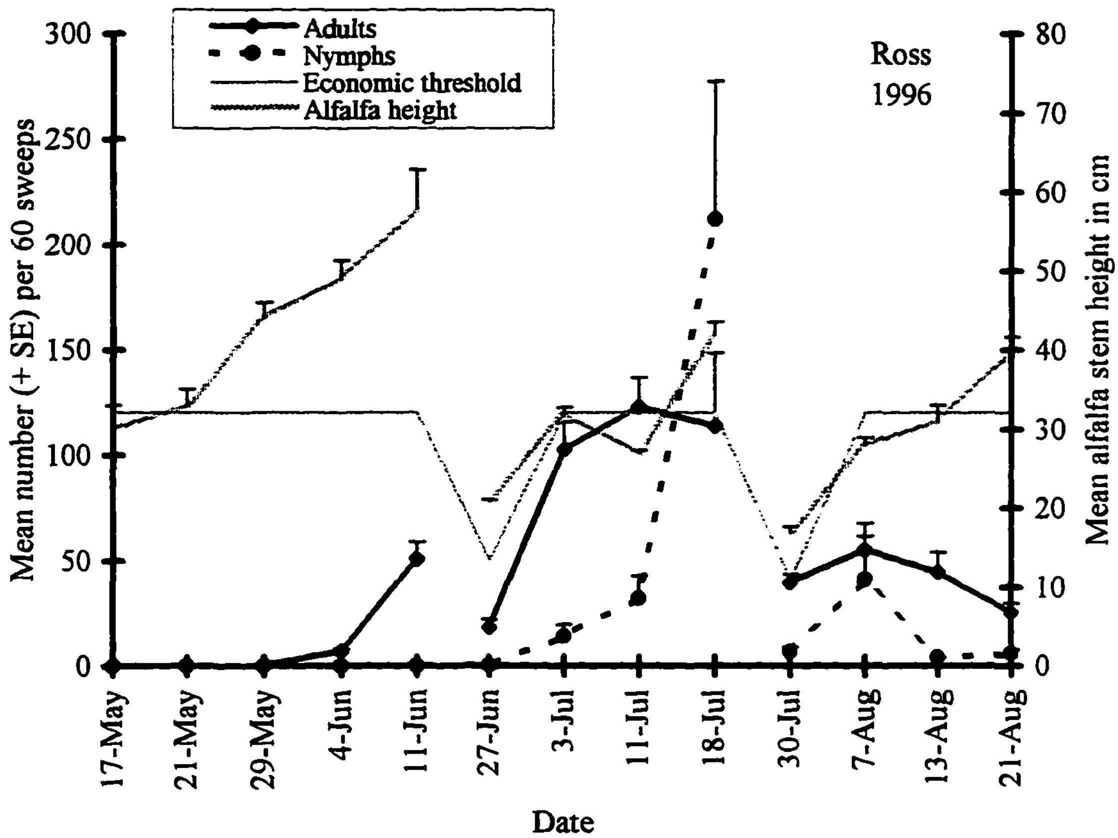


Figure 4. Mean number of potato leafhoppers collected during the alfalfa growing season at the Ross farm, 1996. Breaks in lines indicate when alfalfa was harvested. Error bars represent one half of the standard error of the associated mean

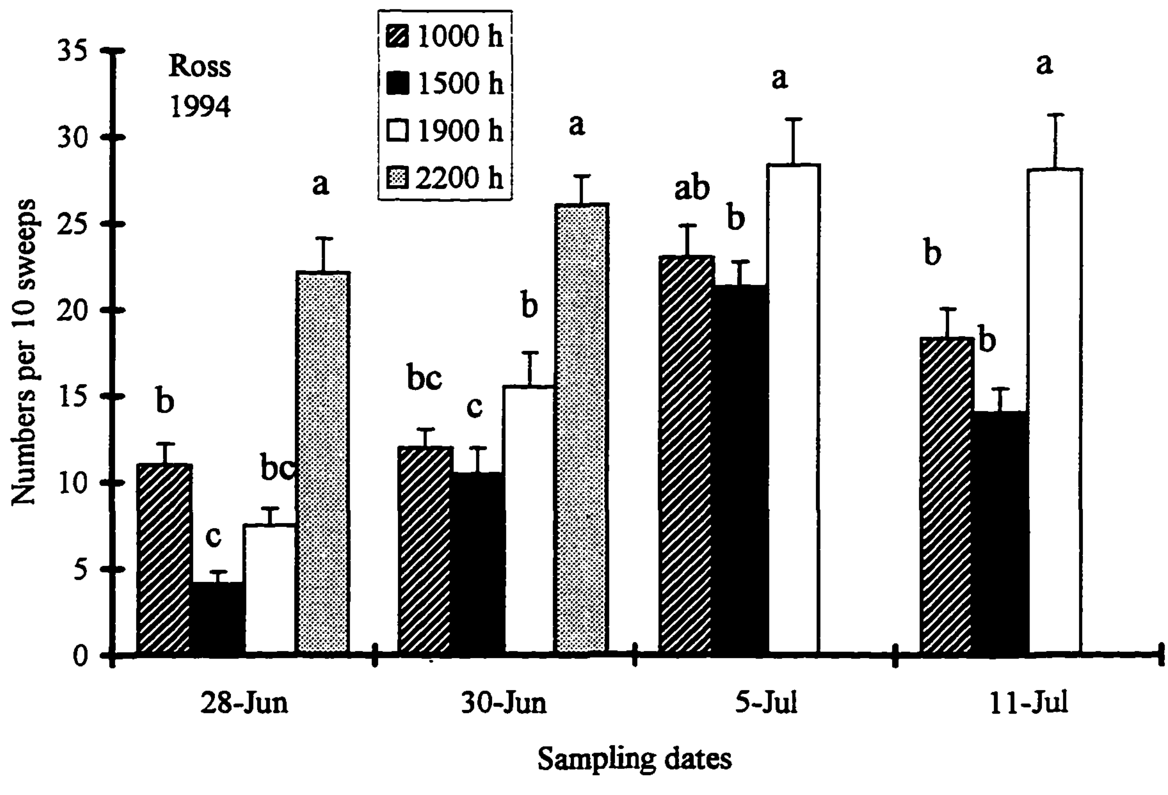


Figure 5. Mean number of potato leafhoppers collected at 4 times of the day, Ross farm, 1994. Means (bars) on each sampling date with the same letter are not signficantly different (ANOVA, LSD, $P < 0.05$)

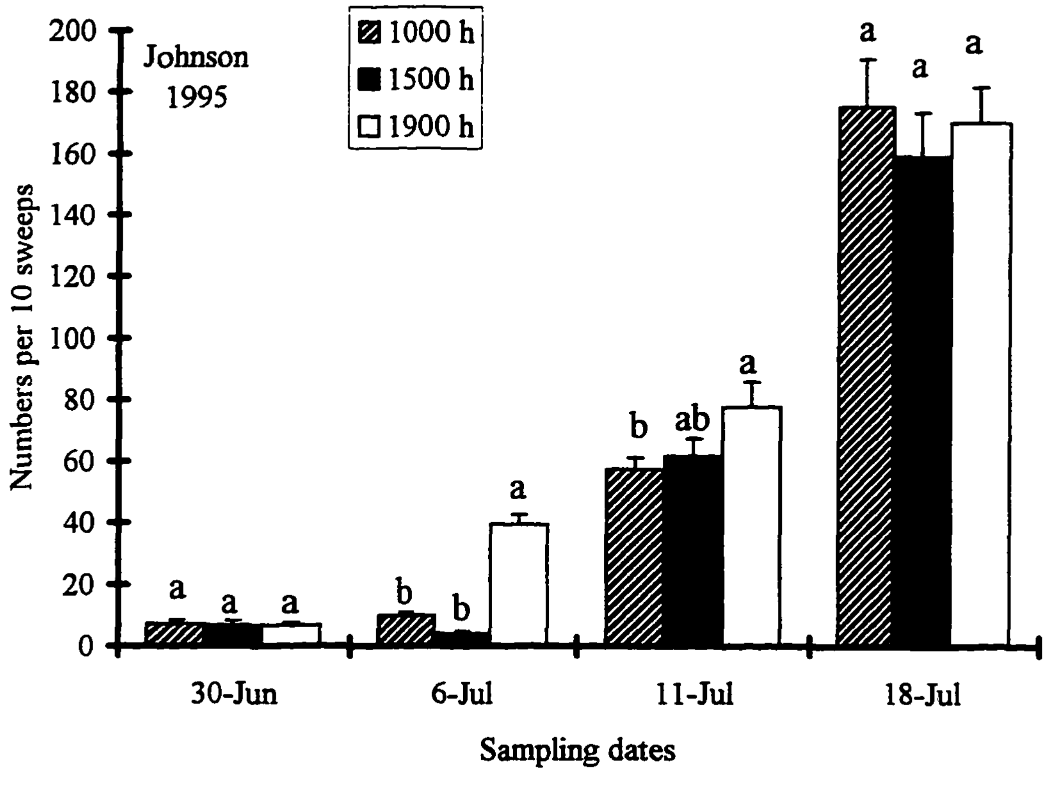


Figure 6. Mean number of potato leafhoppers collected at 3 times of the day, Johnson farm, 1995. Means (bars) on each sampling date with the same letter are not signficantly different (ANOVA, LSD, $P < 0.05$)

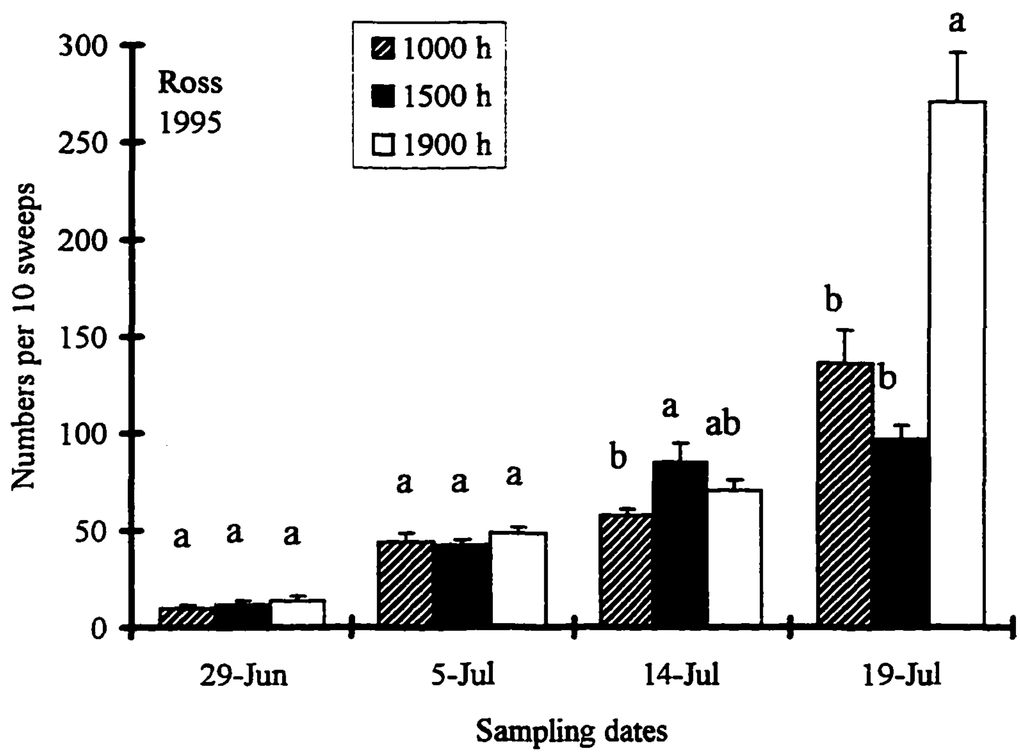


Figure 7. Mean number of potato leafhoppers collected at 3 times of the day, Ross farm, 1995. Means (bars) on each sampling date with the same letter are not signficantly different (ANOVA, LSD, $P < 0.05$)

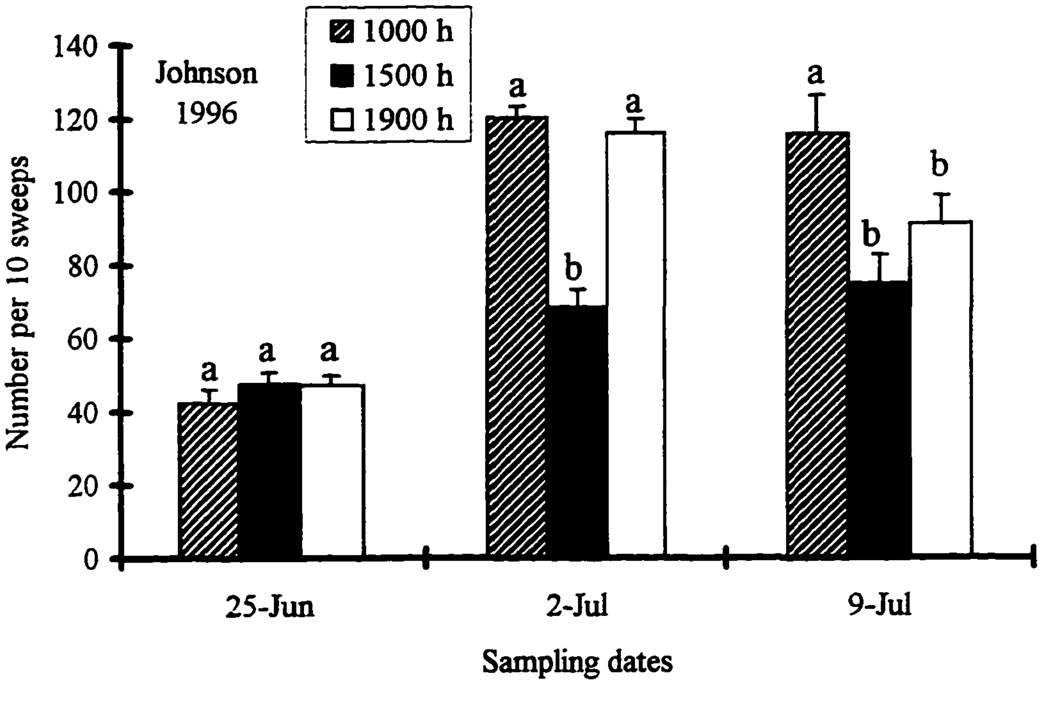


Figure 8. Mean number of potato leafhoppers collected at 3 times of the day, Johnson farm, 1996. Means (bars) on each sampling date with the same letter are not signficantly different (ANOVA, LSD, $P < 0.05$)

CHAPTER 3. EFFECT OF ALFALFA-GRASS INTERCROPS ON INSECT POPULATIONS

A paper to be submitted to the Journal of Economic Entomology

Todd A. DeGooyer, Larry P. Pedigo, and Marlin E. Rice

Abstract

Alfalfa, *Medicago sativa* L., and two alfalfa-grass intercrops were sampled in 1995 and 1996 to determine the effects of intercrops on alfalfa insect pests and associated insect predator populations. The two grasses intercropped with alfalfa were smooth bromegrass, *Bromus inermis* Leyss., and orchardgrass ,*Dactyli glomerata* L. In the first forage crops, potato leafhopper, *Empoasca fabae* (Harris)), numbers were significantly greater in the alfalfa monocultures than the two alfalfa-forage grass intercrops. Significantly greater numbers of alfalfa weevil, *Hypera postica* (Gyllenhal), larvae were collected from alfalfa monocultures than alfalfa-orchardgrass intercrops, but monocultures were not significantly different than alfalfa-bromegrass intercrops. In the second alfalfa crops, significantly greater numbers of potato leafhoppers were collected in the alfalfa monocultures compared to the alfalfa-ochrardgrass intercrops. Significantly greater numbers of common damsel bugs, *Nabis americoferus* Carayon, were collected on alfalfa monocultures compared to the intercrops, but no consistent significant differences were observed between alfalfa-grass intercrops and the monoculture. Alfalfa stand densities and biomass estimates were significantly greater in alfalfa monocultures than alfalfa-forage grass intercrops. In the first and second crops, orchardgrass densities and biomass were consistently larger than bromegrass. Few differences in total biomass were found among the treatments in either

year. No significant differences in potato leafhopper and alfalfa weevil intensities on alfalfa plants were found among the treatments. The results of this study suggest that alfalfa-forage grass intercrops reduce insect pest populations compared to monocultures, but additional management tactics may be needed to reduce insect pest levels below economic thresholds.

Introduction

The effect of insect pest feeding on alfalfa, *Medicago sativa* L., has been well studied (Hutchins et al. 1990). Much of the research has focused on the potato leafhopper, *Empoasca fabae* (Harris), and the alfalfa weevil, *Hypera postica* (Gyllenhal), two of the most serious economic pests of alfalfa in North America. The potato leafhopper is a key pest of alfalfa in the northeastern and northcentral United States and southern provinces of Canada (Lamp 1991), whereas the alfalfa weevil is a important pest in southern provinces of Canada and throughout the 48 contiguous states (Steffey et al. 1994). Feeding by these pests contributes to reduced biomass, quality, and stand longevity of alfalfa.

Current integrated pest management (IPM) programs utilize cultural, biological, and chemical tactics for managing these insect pests. However, in many instances, IPM is not practiced by alfalfa growers because of the cost and time involved in implementing these tactics (Rajotte et al. 1987). In addition, the growing concern over increased reliance on chemicals as the sole management tactic for insect pests has demonstrated the need for alternative strategies.

One innovative management strategy is the use of alternative cropping systems. Alternative cropping systems have been investigated to determine their potential for improving or replacing conventional management practices that are deemed less profitable, harmful to the environment, or perhaps, unfeasible in some geographical areas (Hammond and Jeffers 1990). Intercropping alfalfa and grass is an alfalfa cropping system has been shown to have beneficial agronomic properties, which could possibly affect alfalfa pest populations. In the 1940's, most alfalfa was sown with smooth bromegrass, *Bromus inermis* Leyss., in the north central U.S., but with improved soil drainage and deductions in grade and price for mixtures, the present trend is to grow pure alfalfa stands (Smith 1981). Nevertheless, some alfalfa producers currently are planting an alfalfa-grass intercrop for reducing soil erosion and managing weeds (Tesar and Marble 1988). However, little is known about the effect of these intercrops on insect pest and natural enemy populations, the quality of the forage intercrop, and the costs and benefits of this cropping system.

A few studies have investigated the effect of alfalfa-grass intercropping on insect densities and alfalfa damage. Lamp (1991) found that an alfalfa-oat intercrop reduced the densities of potato leafhopper adults and nymphs by as much as 82.6 and 89.5% per square meter, respectively, when compared to alfalfa monocultures. But intercropping reduced alfalfa biomass and maturity relative to the alfalfa monoculture. Other studies have found that intercropping alfalfa and three forage grasses reduced alfalfa weevil density and alfalfa tip damage significantly compared to the monocultures (Coggins 1991, Roda et al. 1996). But, potato leafhopper densities were not as affected by forage-grass intercropping (Coggins 1991).

Related research, however, has shown that the presence of weedy grasses in alfalfa stands reduces potato leafhopper density (Gentsch 1982, Lamp et al. 1984, Barney and Pass 1987, and Oloumi-Sadeghi et al. 1987, 1989). Differences in potato leafhopper density were associated with reduced damage to the alfalfa (Oloumi-Sadeghi et al. 1989). Reduced oviposition and increased flight of potato leafhoppers also has been observed when weedy grasses are present in alfalfa stands (Smith 1987).

The main objective of this study was to determine the effect of alfalfa and forage grass intercrops on alfalfa insect pests and associated insect predator populations. A concurrent objective was to assess the impact of intercropping on forage growth characteristics for determining the feasibility of intercropping as a management tactic.

Materials and Methods

Selection of grasses for alfalfa-grass intercrops

Grasses for the intercrop treatments were selected based on their perennial nature and ability to grow in association with alfalfa. Orchardgrass, *Dactyli glomerata* L., and smooth bromegrass are two commonly grown, cool-season grasses that grow well, in mixture, with alfalfa in the midwestern U.S. Smooth bromegrass produces its highest yields in the first forage crop but is less prominent in the second and third crops (Smith et al. 1986). Orchardgrass has a life cycle that matches well with alfalfa's and exhibits consistent growth throughout the growing season (Miller 1984).

Study location and design

Studies were conducted at two field locations in 1995 and 1996. The first field was located at the Iowa State University (I.S.U.) Ross Farm, 3 km north and 1 km west of Ames, IA. The second field was located 4 km south of Ames, IA at the I.S.U. Johnson Farm.

A 4-ha field at the Ross Farm was seeded with 'Apollo' alfalfa and alfalfa-forage grass mixes on 20 August 1992. Because of poor grass establishment in 1992, treatments were reseeded with the forage grasses on 1 April 1994. The intercrop treatments consisted of 'Lincoln' smooth bromegrass or 'Potomac' orchardgrass seeded into the existing alfalfa plots. A randomized complete block design (RCBD) was used in the experiment, with alfalfa and alfalfa-forage grass intercrops as the treatments. Each treatment was planted once in each of the three blocks. Plot size within each treatment was 50 x 50 m. The treatments were seeded as follows: alfalfa only (14 kg/ha) (control); alfalfa (6 kg/ha) interseeded with bromegrass (9 kg/ha); and alfalfa (10 kg/ha) interseeded with orchardgrass (7 kg/ha).

An additional 3-ha field was seeded to 'Defiant' alfalfa and alfalfa-forage grass mixes at the Johnson Farm on 18 April 1994. The field was a RCBD with four blocks and three treatments. The seeding rates were slightly modified in the alfalfa-forage grass treatments to encourage grass establishment in those plots. The treatments were seeded as follows: alfalfa only (12 kg/ha) (control); alfalfa (9 kg/ha) interseeded with 'Lincoln' smooth bromegrass (9 kg/ha); and alfalfa (9 kg/ha) interseeded with 'Potomac' orchardgrass (7 kg/ha). One block was not used for the study because of poor alfalfa and grass emergence in two adjacent plots.

Insect sampling

Insect sampling was conducted weekly during the alfalfa growing season with a 38-cm-dia. sweep net to estimate species composition and abundance within and among the alfalfa and alfalfa-grass treatments. Thirty pendulum sweeps were taken at two sites (60 sweeps total) within each of the treatments on each sampling date. Collecting two smaller sweep-net sampling units decreased the processing time compared to one larger sampling unit.

Plant samples

Stem density and biomass (yield) were measured to determine the feasibility of intercropping as a management tactic for alfalfa insect pests. A comparison of these forage characteristics provided a more thorough understanding of alfalfa-forage grass intercrop effects on the insect community. Stand density and biomass estimates were measured by collecting five quadrats (0.1 m^2) per plot one week before each alfalfa harvest. Alfalfa and grass plants were separated in each biomass sample. The number of alfalfa stems were counted in each treatment as well as the number of grass stems in each intercrop treatment. The number of yellow foxtail, *Setaria lutescens* (Weigel) Hubb., stems also were counted in the second forage crops because of their substantial contribution to the grass biomass in the alfalfa monoculture and alfalfa-bromegrass treatments. The samples then were dried at 60°C for 3 days before weighing.

Data analysis

Insect data were analyzed by analysis of variance (ANOVA) or general linear models (GLM) and means were separated using Fisher's protected least significant difference (LSD) (SAS 1990). Plant growth characteristics, density, and biomass of the alfalfa monocultures and alfalfa-grass intercrops were compared using ANOVA, and means were separated using Fisher's protected LSD.

Results and Discussion

Insect diversity and abundance

Table 1 shows a list of insect pests (Undersander et al. 1994) and natural enemy predators commonly associated with alfalfa production, which were considered in this study.

All of the insect pests and predators considered were collected in all 3 treatments. Therefore, precluding any formal analysis of species composition among the treatments. Nine alfalfa insect pests and two associated natural enemy predators were found in the greatest abundance and were used for initial data analysis (PROC ANOVA and PROC GLM) to test for treatment effects (Table 1). The insect species collected during each forage crop (3 crops total per growing season) that had significant treatment differences ($P < 0.05$) in at least 3 out of 4 fields (2 locations x 2 years = 4 fields) were further analyzed to separate the means of the treatments (LSD). In the first crops, alfalfa weevil and potato leafhopper had significant treatment effects in 3 out of the 4 fields. Potato leafhopper and common damsel bug, *Nabis americoferus* Carayon, had significant treatment effects in 3 out of 4 fields in the second forage crops. This criterion was not met by any species during the third forage crops. Data were not combined by year or by location because of the significant difference in alfalfa and grass stand density at the 2 locations and in the 2 years

The mean number of potato leafhoppers and alfalfa weevils for the first forage crop is shown in Table 2. Potato leafhopper numbers (adults only) were significantly greater in the alfalfa monocultures than the two alfalfa-grass intercrops ($P < 0.05$). No significant differences in leafhopper numbers were found between the two alfalfa-grass intercrops.

Significantly greater numbers of alfalfa weevil larvae were collected from alfalfa monocultures than alfalfa-orchardgrass intercrops (Table 2), but monocultures were not significantly different than alfalfa-bromegrass intercrops. The number of weevil larvae in the alfalfa-bromegrass intercrops was larger than the alfalfa-orchardgrass treatment on two occasions. These findings agree with those of Roda et al. (1996), who found that weevil density and number of damaged tips were significantly less in alfalfa-forage grass intercrops (including alfalfa-bromegrass and alfalfa-orchardgrass intercrops) compared to the monocultures near first cutting.

In the second forage crops (Table 3), significantly greater numbers of potato leafhoppers (adults plus nymphs) were collected in the alfalfa monocultures compared to the alfalfa-orchardgrass intercrops. No significant differences were found between alfalfa-bromegrass intercrops than on alfalfa-orchardgrass intercrops.

Significantly greater numbers of common damsel bugs were collected on alfalfa monocultures compared with the intercrops on two of the four instances for each intercrop (Table 3). No significant difference in numbers of common damsel bugs were found in monocultures compared to the alfalfa-bromegrass treatments at both locations in both years.

The differences in leafhopper densities among the treatments may be at least partially explained by research of Coggins (1991), who found that adult leafhoppers were feeding and could survive on forage grass monocultures but could not reproduce. Leafhopper nymphs were found on alfalfa-orchardgrass mixtures but not alfalfa-bromegrass mixtures or any forage grass monoculture. The presence of grass weed or grass-weed volatiles also have been associated with reduced oocyte production and the number of eggs oviposited per female, as well as increased flight activity (Smith 1987). Coggins (1991) also observed that leafhopper adults left alfalfa-forage grass mixtures more than alfalfa monocultures. One or a combination of these factors likely contributed to reducing potato leafhoppers numbers on alfalfa-forage grass intercrops compared to the monocultures.

Plant stand density and biomass comparisons

Alfalfa and grass stand densities and biomass estimates (dry weights) at the Johnson and Ross farms are shown in Tables 4-5. Alfalfa stand densities and biomass estimates were significantly greater in alfalfa monocultures than alfalfa-grass intercrops for both first and second crops in 1995 and 1996 ($P < 0.05$). Stand densities and biomass estimates of the two intercrops did not significantly differ at either location during the first forage crops. However, alfalfa densities and biomass were greater in alfalfa-bromegrass intercrops compared to alfalfa-orchardgrass intercrops. Likewise, in the second crops, stand densities and biomass of alfalfa monocultures were significantly greater than that of alfalfa in the intercrops. Alfalfa densities were significantly different between the two intercrops at the Ross farm, but the difference was likely because of the difference in seeding rates. In addition, alfalfa stand densities in all treatments tended to be greater in the second crops than the first, but alfalfa biomass estimates almost always were less in the second crops.

In first and second crops, orchardgrass densities were consistently larger than bromegrass densities in the intercrops (Tables 4-5). A larger grass biomass estimate also was found for orchardgrass, which was largely caused by the greater density of the orchardgrass. This difference in densities was related to larger biomass estimates in the orchardgrass intercrops. In both years at both sites, there were greater grass densities in the first forage crop than the second. But, grass biomass estimates were less in the second crop. Yellow foxtail plants were present in the alfalfa monocultures and alfalfa-bromegrass intercrops in the second crop during both years at the Johnson farm but did not contribute greatly to the overall biomass (Table 4).

No significant differences in total biomass were found among the treatments at the Johnson farm in either year (Table 6). These findings were similar to those of Mooso and Wedin (1990), who concluded that there is little, if any, yield advantage or loss to growing alfalfa-grass mixtures compared to alfalfa monocultures. Less biomass was produced in all the treatments in the second crops compared to the first crops in both years and both farms.

The effect of alfalfa weevil and potato leafhopper feeding on forage quality were not investigated in this study. However, Coggins (1991) studied forage quality effects in the field and found no significant differences in percent crude protein in alfalfa from alfalfa monocultures and alfalfa-forage grass intercrops in either the first or second crops. Furthermore, intercropping did not significantly alter neutral detergent fiber or acid detergent fiber of alfalfa in any treatments throughout the growing season. Surprisingly, alfalfa-orchardgrass intercrops had the highest overall quality in the first forage crops, based on lowest acid detergent fiber and neutral detergent fiber (lower fiber is more desirable) combined with the highest crude protein (higher crude protein is desirable). Coggins (1991) findings show that alfalfa can be grown in association with forage grasses without jeopardizing forage quality, and the findings of this study suggest there are no reductions in total biomass using alfalfa-grass intercrops.

Relative intensity of alfalfa weevil and potato leafhopper on alfalfa

Even though there were significant differences in the number of alfalfa weevils and potato leafhoppers in the monocultures, compared to the intercrops, there still was the question of whether insects have a stronger impact on the alfalfa in the intercrops than that in the monoculture. To investigate this question, relative intensity values were estimated for alfalfa weevils and potato leafhoppers in the treatments. The relative intensity value (RIV) is defined as the mean number of insects per relative sampling estimate divided by the mean stem density per treatment. In this analysis, potato leafhopper and alfalfa weevil were assumed to mainly feed and oviposit on alfalfa stems in the intercrops.

No significant differences ($P < 0.05$) in RIVs were found among the treatments for alfalfa weevils or potato leafhoppers (Tables 7-8). Moreover, there were no obvious trends in RIVs for the weevils. Fewer alfalfa weevil larvae were present in the intercrops compared to the monocultures, but there were significantly fewer alfalfa stems in the intercrop treatments. This may explain, in part, why differences in RIVs were not evident. No significant differences in RIV was found between the intercrops for leafhoppers. This study did not demonstrate that alfalfa weevil and potato leafhopper injury were more intense on the alfalfa in monocultures than that in the intercrops.

Management Implications

The findings of this study show that alfalfa-forage grass intercrops reduce insect pest populations compared to monocultures. Potato leafhopper numbers were reduced but were not suppressed below current economic thresholds (2 leafhoppers per sweep when alfalfa is < 25 cm tall (Rice 1996)). Thus, additional management tactics may be needed to adequately suppress this pest. When deciding whether or not to use alfalfa intercrops as a management tactic to reduce insect populations, a grower must consider the additional benefits from intercropping including weed and soil erosion control, as well as production of a high-quality forage throughout the growing season.

Acknowledgment

The authors thank Stephanie Peterson, Mike Anderson, Debbie Engels, Drew Felsted, Deni Scar, Mike Nagel, Anna Dierickx, and Brad Russell for their technical assistance. This research was funded in part by the Leopold Center for Sustainable Agriculture. This is Journal Paper J-______ of the Iowa Agricultural and Home Economics Experimental Station, Ames, IA. Project No. 3207.

References Cited

Barney R. J. and B. C. Pass. 1987. Influence of no-tillage planting on foliage-inhabiting arthropods of alfalfa in Kentucky. J. Econ. Entomol. 80: 1288-1290.

Coggins, M. L. 1991. Potato leafhopper (*Empoasca fabae*) and alfalfa weevil (*Hypera postica*) density and damage in alfalfa-forage grass binary mixtures. M. S. thesis, Michigan State University, East Lansing, MI.

Gentsch, B. J. 1982. The influence of weeds on the incidence of potato leafhopper in alfalfa. M.S. thesis. Southern Illinois Univ., Carbondale, IL.

Hammond, R. B. and D. L. Jeffers. 1990. Potato leafhopper (Homoptera: Cicadellidae) populations on soybean relay intercropped into winter wheat. Environ. Entomol. 19: 1810-1819.

Hutchins, S. H., G. D. Buntin, and L. P. Pedigo. 1990. Impact of insect feeding on alfalfa regrowth: a review of physiological responses and economic consequences. Agron. J. 82: 1035-1044.

Lamp, W. O. 1991. Reduced *Empoasca fabae* (Homoptera: Cicadellidae) density in oat-alfalfa intercrop systems. Environ. Entomol. 20: 118-126.

Lamp, W. O., R. J. Barney, E. J. Armbrust, and G. Kapusta. 1984. Selective weed control in spring-planted alfalfa: effect of leafhoppers and planthoppers (Homoptera: Auchenorrhyncha), with emphasis on potato leafhopper. Environ. Entomol. 13: 207-213.

Miller, D. A. 1984. Forage crops. McGraw-Hill, New York.

Mooso, G. D. and W. F. Wedlin. 1990. Yield dynamics of canopy components in alfalfa-grass mixtures. Agron. J. 82: 696-701.

Oloumi-Sadeghi, H., L. R. Zavaleta, W. O. Lamp, E. J. Armbrust, and G. Kapusta. 1987. Interactions of the potato leafhopper (Homoptera: Cicadellidae) with weeds in an alfalfa ecosystem. Environ. Entomol. 16: 1175-1180.

Oloumi-Sadeghi, H., L. R. Zavaleta, G. Kapusta, W. O. Lamp, and E. J. Armbrust. 1989. Effects of potato leafhopper (Homoptera: Cicadellidae) and weed control on alfalfa yield and quality. J. Econ. Entomol. 82: 923-931.

Rajotte, E. G., R. F. Kazmierczak Jr., G. W. Norton, M. T. Lambur, and W. A. Allen. 1987. The National Evaluation of Extension's Integrated Pest Management Programs. Publ. 491-010. Virginia Cooperative Ext. Ser. Blacksburg, Virginia. pp. 123-29.

Rice, M. E. 1996. Leafhoppers on the increase. Integrated Crop Management, Iowa State Univ. Ext., IC-476 (17): 116-117.

Roda, A. L., D. A. Landis, M. L. Coggins, E. Spandl, and O. B. Hesterman. 1996. Forage grasses decrease alfalfa weevil (Coleoptera: Curculionidae) damage and larval numbers in alfalfa-grass intercrops. J. Econ. Entomol. 89: 743-750.

SAS Institute. 1990. SAS user's guide: statistics. SAS Institute, Cary, N.C.

Smith, D. 1981. Seeding establishment of legumes and grasses, pp. 15-29. *In* Forage management in the North. 3rd ed. Kendall/Hunt, Dubuque, IA.

Smith, L. M. 1987. Mechanism by which grass reduces potato leafhopper, *Empoasca fabae* (Harris) (Homoptera: Cicadellidae), abundance in alfalfa. Ph.D. dissertation, University of Illinois, Urbana-Champaign.

Smith, D., R. J. Bula, and R. P. Walgenbach. 1986. Forage management. 5th ed. Kendall/Hunt, Dubuque, IA.

Steffey, K. L., E. J. Armbrust, and D. W. Onstad. 1994. Management of insects in alfalfa, pp. 469-506. *In* Introduction to insect pests. 3rd ed. Wiley-Interscience, New York.

Tesar, M. B. and V. L. Marble. 1988. Alfalfa establishment, pp. 303-332. *In* A. A. Hanson, O.K. Barnes & R.R. Hill, Jr. [eds.], Alfalfa and alfalfa improvement. Agronomy Monograph 29, American Society of Agronomy, Inc., Madison Wis.

Table 1. Common alfalfa insect pests and predators

Scientific name	Common name	Collected in sufficient numbers for comparison
	Pests	
Adelphocoris lineolaris (Goeze)	alfalfa plant bug	Y
Acyrthosiphon pisum (Harris)	pea aphid	Y
Colias eurytheme Boisduval	alfalfa caterpillar	Y
Empoasca fabae (Harris)	potato leafhopper	Y
Epicauta spp.	blister beetles	N
Hypera punctata (F.)	clover leaf weevil	N
Hypera postica (Gyllenhal)	alfalfa weevil	Y
Lygus lineolaris (Palisot de Beauvois)	tarnished plant bug	Y
Melanoplus differentialis (Thomas)	differential grasshopper	Y
Melanoplus femurrubrum (DeGeer)	redlegged grasshopper	Y
Peridroma saucia (Hübner)	variegated cutworm	N
Philaenus spumarius (L.)	meadow spittlebug	Y
Sitona hispidulus (F.)	clover root curculio	N
	Insect predators	
Chyrsoperla carnea Stephens	common green lacewing	N
Hippodamia convergens Guérin	convergent lady beetle	N
Coleomegilla maculata DeGeer	---	Y
Nabis americoferus Carayon	common damsel bug	Y
Orius insidiosus (Say)	minute pirate bug	N

Table 2. Mean number ± SEM of potato leafhopper and alfalfa weevil collected during the first forage crop in alfalfa monocultures and alfalfa-grass intercrops

	Johnson		Ross	
Treatment	1995	1996	1995	1996
	Empoasca fabae (Harris)			
Alfalfa	40.7 ± 19.9a	76.0 ± 29.4a	51.3 ± 14.2a	28.8 ± 10.4a
Alfalfa/bromegrass	12.7 ± 6.9 b	45.7 ± 18.3 b	16.7 ± 3.3 b	23.2 ± 8.1a
Alfalfa/orchardgrass	8.0 ± 3.6 b	52.3 ± 19.5 b	15.3 ± 3.5 b	20.8 ± 7.2a
	LSD = 20.0	LSD = 19.5	LSD = 13.5	LSD = 10.9
	Hypera postica (Gyllenhal)			
Alfalfa	45.3 ± 10.5a	93.5 ± 21.9a	22.1 ± 6.5a	55.7 ± 13.8a
Alfalfa/bromegrass	47.8 ± 11.4a	60.4 ± 15.5 b	17.7 ± 4.2ab	60.8 ± 15.0a
Alfalfa/orchardgrass	20.2 ± 5.7 b	68.2 ± 16.5 b	9.73 ± 2.0 b	35.7 ± 8.7 b
	LSD = 17.0	LSD = 11.0	LSD = 8.6	LSD = 15.3

Means within each column for each species followed by the same letter are not significantly different ($P < 0.05$) using the Fisher's protected LSD test.

Table 3. Mean number ± SEM of potato leafhopper and common damsel bug collected during the second forage crop in alfalfa monocultures and alfalfa-grass intercrops

Treatment	Johnson 1995	Johnson 1996	Ross 1995	Ross 1996
	Empoasca fabae (Harris)			
Alfalfa	258.2 ± 82.7a	156.6 ± 40.4a	275.3 ± 72.2a	189.7 ± 41.3a
Alfalfa/bromegrass	124.5 ± 35.6 b	153.3 ± 45.9a	216.9 ± 48.1ab	137.8 ± 31.4 b
Alfalfa/orchardgrass	66.9 ± 17.7 b	105.8 ± 28.1a	160.2 ± 29.6 b	128.6 ± 24.8 b
	LSD = 99.7	LSD = 63.1	LSD = 78.4	LSD = 49.8
	Nabis americoferus Carayon			
Alfalfa	5.1 ± 1.1a	6.1 ± 2.1a	9.3 ± 2.0a	10.3 ± 2.4a
Alfalfa/bromegrass	4.5 ± 1.3ab	5.5 ± 1.7a	5.8 ± 1.2 b	4.9 ± 1.5 b
Alfalfa/orchardgrass	3.3 ± 1.2 b	6.4 ± 2.1a	4.8 ± 1.8 b	6.5 ± 1.6ab
	LSD = 1.4	LSD = 2.1	LSD = 2.7	LSD = 4.3

Means within each column for each species followed by the same letter are not significantly different ($P < 0.05$) using the Fisher's protected LSD test.

Table 4. Mean stand density ± SEM and dry weight ± SEM of alfalfa and grass samples (in grams) collected during the first and second forage crops , Johnson farm, 1995 and 1996

Treatment[ab]	Alfalfa		Grass	
dry weight	dry weight	density	dry weight	density[c]
	First crop: 7 June 1995			
Alfalfa	41.4 ± 4.0a	44.7 ± 3.3a	-	-
Alfalfa/bromegrass	25.6 ± 2.9 b	23.1 ± 2.3 b	39.9 ± 2.6 b	30.6 ± 2.5a
Alfalfa/orchardgrass	18.2 ± 2.0 b	17.1 ± 2.2 b	74.6 ± 6.7a	26.7 ± 3.0a
	LSD = 8.2	LSD = 6.7	LSD = 16.7	LSD = 2.3
	Second crop: 20 July 1995			
Alfalfa	63.5 ± 3.3a	31.4 ± 1.6a	41.2 ± 6.9a	5.5 ± 0.9 c
Alfalfa/bromegrass	52.3 ± 2.7 b	24.1 ± 1.5 b	49.6 ± 5.5a	11.3 ± 0.8 b
Alfalfa/orchardgrass	43.9 ± 3.4 b	21.2 ± 1.6 b	53.4 ± 6.5a	15.3 ± 1.0a
	LSD = 8.4	LSD = 4.2	LSD = 16.7	LSD = 2.3
	First crop: 5 June 1996			
Alfalfa	42.7 ± 3.8a	50.2 ± 2.9a	3.5 ± 2.7 c	0.8 ± 0.4 b
Alfalfa/bromegrass	33.7 ± 3.0 b	34.1 ± 3.0 b	41.4 ± 5.1 b	17.9 ± 1.5a
Alfalfa/orchardgrass	28.0 ± 2.0 b	27.7 ± 2.8 b	95.7 ± 30.0a	20.9 ± 1.7a
	LSD = 8.4	LSD = 8.0	LSD = 16.0	LSD = 3.9
	Second crop: 16 July 1996			
Alfalfa	62.5 ± 4.0a	34.4 ± 2.0a	76.4 ± 14.2 b	2.9 ± 0.6 c
Alfalfa/bromegrass	45.9 ± 4.0 b	31.6 ± 3.2ab	143.1± 24.5a	7.8 ± 0.9 b
Alfalfa/orchardgrass	38.6 ± 2.2 b	26.8 ± 1.6 b	103.9± 9.0ab	15.5± 1.1a
	LSD = 9.9	LSD = 6.7	LSD = 45.8	LSD =2.6

a Per 0.1 m^2.

b Means within each column for each species followed by the same letter are not significantly different ($P < 0.05$) using the Fisher's protected LSD test.

c Yellow foxtail plants were present in the alfalfa monocultures and alfalfa-bromegrass intercrops in the second crops during both years.

Table 5. Mean stand density ± SEM and dry weight ± SEM of alfalfa and grass samples (in grams) collected during the first and second forage crops, Ross farm, 1995 and 1996

Treatment[ab]	Alfalfa density	Alfalfa dry weight	Grass density[c]	Grass dry weight
	First crop: 8 June 1995			
Alfalfa	60.1 ± 3.7a	44.8 ± 3.2a	-	-
Alfalfa/bromegrass	37.5 ± 2.4 b	27.6 ± 2.1 b	53.9 ± 4.8a	31.2 ± 2.5 b
Alfalfa/orchardgrass	30.9 ± 3.8 b	27.2 ± 3.3 b	69.9 ± 6.7a	42.1 ± 3.6a
	LSD = 9.8	LSD = 8.3	LSD = 16.9	LSD = 9.0
	Second crop: 19 July 1995			
Alfalfa	78.8 ± 3.6a	36.9 ± 2.6a	-	-
Alfalfa/bromegrass	61.5 ± 3.8 b	23.7 ± 1.8 b	44.2 ± 22.8a	8.5 ± 1.6a
Alfalfa/orchardgrass	53.7 ± 2.7 c	25.1 ± 1.8 b	54.7 ± 28.6a	10.5 ± 1.5a
	LSD = 6.8	LSD = 4.1	LSD = 12.9	LSD = 3.0
	First crop: 5 June 1996			
Alfalfa	49.3 ± 3.6a	43.5 ± 2.9a	1.7 ± 1.7 c	0.4 ± 0.4 c
Alfalfa/bromegrass	32.4 ± 2.0 b	26.2 ± 2.5 b	39.3 ± 5.6 b	11.7 ± 1.9 b
Alfalfa/orchardgrass	30.4 ± 2.7 b	24.5 ± 2.9 b	63.2 ± 9.2a	17.2 ± 2.3a
	LSD = 8.2	LSD = 8.1	LSD = 17.9	LSD = 5.0
	Second crop: 11 July 1996			
Alfalfa	58.3 ± 3.4a	32.7 ± 2.1a	3.7 ± 2.6 b	0.2 ± 0.1 b
Alfalfa/bromegrass	52.8 ± 3.8a	24.3 ± 2.3 b	14.1 ± 4.5 b	2.5 ± 0.7 b
Alfalfa/orchardgrass	39.0 ± 4.0 b	18.7 ± 2.0 b	54.3 ± 7.0a	9.8 ± 1.9a
	LSD = 10.7	LSD = 6.3	LSD = 14.2	LSD = 3.2

a Per 0.1 m^2.

b Means within each column for each species followed by the same letter are not significantly different ($P < 0.05$) using the Fisher's protected LSD test.

c Various grasses were present in small quantities in the alfalfa monocultures.

Table 6. Mean dry-weight biomass ± SEM of alfalfa and alfalfa-grass intercrops (in grams) collected during the first and second forage crops, 1995 and 1996

	Johnson		Ross	
Treatment[ab]	1995	1996	1995	1996
	First crop			
Alfalfa	44.7 ± 3.3a	51.0 ± 2.7a	44.8 ± 3.2 c	44.0 ± 2.9a
Alfalfa/bromegrass	53.8 ± 3.4a	51.9 ± 2.6a	69.2 ± 4.1a	37.9 ± 1.9a
Alfalfa/orchardgrass	43.9 ± 3.8a	48.6 ± 3.7a	58.8 ± 2.6 b	41.8 ± 3.2a
	LSD = 10.1	LSD = 8.6	LSD = 9.6	LSD = 7.7
	Second crop			
Alfalfa	36.9 ± 1.4a	37.4 ± 2.2a	36.8 ± 1.8a	32.8 ± 2.1a
Alfalfa/bromegrass	35.4 ± 1.5a	39.4 ± 3.4a	35.5 ± 1.4ab	26.8 ± 2.2 b
Alfalfa/orchardgrass	36.5 ± 1.5a	42.2 ± 1.4a	32.2 ± 1.6 b	28.5 ± 1.6ab
	LSD = 4.1	LSD = 7.0	LSD = 4.6	LSD = 5.8

a Per 0.1 m^2.

b Means within each column for each species followed by the same letter are not significantly different ($P < 0.05$) using the Fisher's protected LSD test.

Table 7. Relative intensity values ± SEM for alfalfa weevil on alfalfa in alfalfa and alfalfa-grass intercrops during the first forage crop, 1995 and 1996

	Johnson		Ross	
Treatment [ab]	1995	1996	1995	1996
	First crop			
Alfalfa	2.0 ± 0.7a	4.0 ± 0.3a	0.2 ± 0.1a	2.0 ± 0.4a
Alfalfa/bromegrass	2.4 ± 0.7a	3.8 ± 0.3a	1.0 ± 0.5a	2.9 ± 0.6a
Alfalfa/orchardgrass	1.8 ± 0.5a	6.5 ± 0.9 b	1.4 ± 0.6a	2.4 ± 0.3a
	LSD = 2.5	LSD = 1.6	LSD = 1.4	LSD = 1.5

a Relative intensity value = mean number of alfalfa weevils per 60 sweeps / mean alfalfa stem density per treatment.

b Means within each column for each species followed by the same letter are not significantly different ($P < 0.05$) using the Fisher's protected LSD test.

Table 8. Relative intensity values ± SEM for potato leafhopper on alfalfa in alfalfa and alfalfa-grass intercrops during the first and second forage crops, 1995 and 1996

		Johnson		Ross	
Treatment [ab]		1995	1996	1995	1996
		First crop			
Alfalfa		1.9 ± 0.3a	3.4 ± 0.6a	1.4 ± 0.3a	1.1 ± 0.2a
Alfalfa/bromegrass		1.1 ± 0.5a	2.6 ± 0.4a	0.5 ± 0.2 b	1.3 ± 0.1a
Alfalfa/orchardgrass		1.0 ± 0.2a	3.5 ± 0.5a	0.7 ± 0.2 b	1.2 ± 0.3a
		LSD = 1.3	LSD = 2.0	LSD = 0.6	LSD = 0.7
		Second crop			
Alfalfa	10.4 ± 4.8a	5.3 ± 1.6a	6.9 ± 2.7a	4.7 ± 0.6a	
Alfalfa/bromegrass		5.9 ± 0.8a	7.7 ± 1.4a	6.1 ± 1.0a	3.3 ± 1.3a
Alfalfa/orchardgrass		2.9 ± 0.6a	5.5 ± 2.1a	4.5 ± 0.6a	4.4 ± 0.5a
		LSD = 9.4	LSD = 6.3	LSD = 5.9	LSD = 2.3

a Relative intensity value = mean number of potato leafhoppers per 60 sweeps / mean alfalfa stem density per treatment.

b Means within each column for each species followed by the same letter are not significantly different ($P < 0.05$) using the Fisher's protected LSD test.

CHAPTER 4. DEVELOPMENT OF STICKY TRAP SAMPLING TECHNIQUE FOR POTATO LEAFHOPPER ADULTS

A paper to be submitted to the *Note* section of the Journal of Agricultural Entomology

Todd A. DeGooyer, Larry P. Pedigo, and Marlin E. Rice

Abstract

A series of studies were conducted to develop an effective sticky trap technique for sampling adult potato leafhopper, *Empoasca fabae* (Harris), densities in alfalfa. The results of these studies showed that a yellow sticky trap, placed horizontally at the top of the canopy, is the most effective arrangement for collecting the greatest number of potato leafhoppers.

Introduction

The potato leafhopper, *Empoasca fabae* (Harris) (Homoptera: Cicadellidae), is a major pest of alfalfa in the north-central and northeastern United States. In many instances, potato leafhoppers are the only insects that cause significant economic loss (Smith and Ellis 1983). Potato leafhopper injury to alfalfa may result in reduced yield, quality, and stand longevity or in delayed phenological development (Smith and Ellis 1983, Hutchins and Pedigo 1989).

The potato leafhopper is a particularly difficult insect to manage because management tactics need to be implemented before the appearance of visual damage, specifically leaf chlorosis or "hopperburn" (Gessel 1978). Various techniques have been used for sampling leafhoppers including sweep net, pans, in situ counts, D-vac, and traps, but few techniques have been found adequate for management decision making (Lamp and Smith 1989). Sweep-net sampling is currently the main technique used for management programs (Gessel 1978, Smith and Ellis 1982, Undersander et al. 1994).

Limited research has been conducted to develop other sampling techniques for use in potato leafhopper management. The use of sticky traps as a sampling technique may be acceptable to farmers. Sticky traps were first utilized for monitoring leafhopper flight activity (Pienkowski and Medler 1966) and later were used, with limited success, to estimate leafhopper densities (Smith and Ellis 1982, Fleischer et al. 1983). But, the color, orientation, and height of the sticky traps (relative to the canopy) necessary for consistent potato leafhopper catches is not well understood. This paper describes the development of a sticky trap sampling technique for potato leafhopper adults in alfalfa by using a series of comparative studies.

Materials and Methods

Studies were conducted in 1993 at the Iowa State University Ross farm near Ames, IA. A 3-ha field was seeded with 'Apollo' alfalfa in the spring of 1993, and the studies were conducted in the second crop of alfalfa. When possible, trials within each study were initiated on consecutive days to minimize the influence of alfalfa plant height on trap catch. Three studies were implemented to compare numbers trapped according to trap color, orientation (horizontal vs. vertical), and height. Trap color studies were repeated two times on consecutive days, whereas trap orientation and height studies were repeated three times. For each study, the number of adult leafhoppers adhering to the sticky traps were counted after 24-h in the field. Insect counts for each study were analyzed by using analysis of variance (ANOVA) (SAS 1990).

Color preference study

Yellow non-baited Pherocon® AM sticky traps (23 x 28 cm (644 cm^2)) were compared with white sticky traps (20 x 32 cm (640 cm^2)). Yellow- and white-colored traps were used because these are the main colors available for monitoring insect pests. Traps were folded and tied vertically on lath stakes. The bottom of the traps were positioned even with the top of the canopy in the alfalfa. A yellow and a white sticky trap were placed in each of 10 quadrats (5 x 5 m quadrat) according to a stratified random design.

Trap orientation study

Yellow sticky traps (described above) were placed either in a vertical or horizontal orientation in the alfalfa. Traps were either folded, tied, and placed on lath stakes in a vertical orientation or placed flat and tied in a horizontal position on plywood platforms. A horizontally and a vertically oriented sticky trap was placed in each of 10 quadrats (5 x 5 m quadrat) in a stratified random design.

Trapping height study

Yellow sticky traps were placed either 25 cm above the canopy or even with the top of the alfalfa canopy. Traps were placed flat and tied in a horizontal position on plywood platforms. The height of the trap was adjusted by using different sized stakes. One sticky trap at each height (25 cm above canopy and even with top of canopy) was placed in each of 10 quadrats (5 x 5 m quadrat) in a stratified random design.

Results and Discussion

Color preference study

In both trials (Table 1), significantly greater numbers ($P < 0.05$) of adult potato leafhoppers were collected on yellow sticky traps than on white traps. These data agree with Pienkowski and Medler (1966) who found the adult leafhoppers prefer yellow surfaces to white surfaces. Based on these findings, yellow sticky traps were used for the orientation study.

Trap orientation study

Significantly greater numbers ($P < 0.05$) of adult leafhoppers were captured on the horizontal sticky traps compared with the vertical traps in all 3 trials (Table 2). These findings conflict with Fleischer et al. (1983) who did not find any difference in numbers of leafhoppers captured per day when using horizontal and vertical trap orientations. But, in their study, 3-dimensional yellow cylinders, painted with Tac Trap®, were used instead of the 2-dimensional (flat) sticky traps used in these studies. The difference between vertical and horizontal spatial orientations, when using a 3-dimensional trap,was not as contrasting as when a 2-dimensional trap (90° difference in spatial plane) was used. Therefore, traps were placed horizontally in the alfalfa for the trapping height study.

Trapping height study

Significantly greater numbers ($P < 0.05$) of potato leafhoppers were collected on the traps placed even with the top of the alfalfa canopy compared with the traps placed 25 cm above the canopy in 2 out of 3 trials (Table 3). Alfalfa height ranged from 25 to 35 cm during the study. These findings are supported by Pienkowski and Medler (1966) who found that local flight patterns were those of low level flight within the alfalfa. Fleischer et al. (1983) also captured more leafhoppers at lower sticky trap heights in alfalfa.

The results of our series of studies showed that yellow sticky traps, placed horizontally, even with the top of the alfalfa canopy, will capture the most potato leafhoppers. This sticky trap technique was developed for use in sampling programs to make absolute estimates of potato leafhopper density (DeGooyer 1997).

Acknowledgment

The authors thank Stephanie Peterson, Mike Anderson, Debbie Engels, Drew Felsted, Deni Scar, Mike Nagel, Anna Dierickx, and Brad Russell for their technical assistance. This research was funded in part by the Leopold Center for Sustainable Agriculture. This is Journal Paper J-17242 of the Iowa Agricultural and Home Economics Experimental Station, Ames, IA. Project No. 3207.

References Cited

DeGooyer, T. A. 1997. Population dynamics and management of potato leafhoppers and other insect pests in forage systems. Ph.D. dissertation, Iowa State Univ., Ames, IA.

Fleischer, S. J., W. A. Allen & R. L. Pienkowski. 1983. Relationship between absolute density and sticky trap catches of adult potato leafhoppers in alfalfa. J. Georgia Entomol. Soc. 18: 213-218.

Gessel, S. G. 1978. An insect management program for alfalfa. Pa. State Univ. Coop. Ext. Serv. Publ. 9-262.

Hutchins, S. H. & L. P. Pedigo. 1989. Potato leafhopper-induced injury on growth and development of alfalfa. Crop. Sci. 29: 1005-1011.

Lamp, W.O. & L. M. Smith. 1989. Sampling Objectives and Problems., pp. 3-9. *In* E.J. Armbrust and W.O. Lamp [eds.], History and perspectives of potato leafhopper (Homoptera: Cicadellidae) research. Misc. Pub 72, Entomol. Soc. Am. Lanham, MD.

Pienkowski, R. L. & J. T. Medler. 1966. Potato leafhopper trapping studies to determine local flight activity. J. Econ. Entomol. 59: 837-843.

SAS Institute. 1990. SAS user's guide: statistics. SAS Institute, Cary, N.C.

Smith, S. M. & C. R. Ellis. 1982. Sampling the potato leafhopper (Homoptera: Cicadellidae) on alfalfa. Proc. Entomol. Soc. Ont. 113: 35-41.

Smith, S. M. & C. R. Ellis. 1983. Economic importance of insects on regrowth of established alfalfa fields in Ontario. Can. Entomol. 115: 859-864.

Undersander, D., N. Martin, D. Cosgrove, K. Kelling, M. Schmitt, J. Wedberg, R. Becker, C. Grau, J. Doll & M. E. Rice. 1994. Alfalfa Management Guide. Am. Soc. Agron., Inc. Madison, WI. 51 pp.

Table 1. Mean number ± SE of adult potato leafhoppers captured on white and yellow sticky traps placed vertically in alfalfa

Trial	Yellow	White	*F* test
1	8.1 ± 1.2	3.0 ± 0.4	$F = 14.55$; df = 1, 9; $P = 0.004$
2	7.3 ± 1.0	1.6 ± 0.3	$F = 29.81$; df = 1, 9; $P = 0.029$

SE, standard error of mean

∝ level = 0.05.

Table 2. Mean number ± SE of adult potato leafhoppers captured on vertical and horizontal yellow sticky traps in alfalfa

Trial	Horizontal	Vertical	*F* test
1	16.2 ± 2.1	3.0 ± 0.5	$F = 41.53$; df = 1, 9; $P = 0.0001$
2	28.9 ± 2.4	3.9 ± 0.5	$F = 126.12$; df = 1, 9; $P = 0.0001$
3	48.9 ± 4.8	0.6 ± 0.3	$F = 97.09$; df = 1, 9; $P = 0.0001$

SE, standard error of mean

∝ level = 0.05.

Table 3. Mean number ± SE of adult potato leafhoppers captured on horizontal yellow sticky traps at two heights in alfalfa

Trial	Even with top of canopy	10" above canopy level	*F* test
1	10.2 ± 2.4	7.2 ± 1.5	$F = 0.94$; df = 1, 4; $P = 0.3878$
2	31.0 ± 1.6	16.2 ± 9.0	$F = 15.27$; df = 1, 4; $P = 0.0174$
3	49.8 ± 4.2	24.0 ± 2.9	$F = 49.53$; df = 1, 4; $P = 0.0021$

SE, standard error of mean

∝ level = 0.05.

CHAPTER 5. EVALUATION OF GROWER-ORIENTED SAMPLING TECHNIQUES AND PROPOSAL OF A MANAGEMENT PROGRAM FOR POTATO LEAFHOPPER IN ALFALFA

A paper to be submitted to the Journal of Economic Entomology

Todd A. DeGooyer, Larry P. Pedigo, and Marlin E. Rice

Abstract

A sampling study was conducted from 1994-1996 comparing four grower-oriented sampling techniques (sticky trap, suction, sweep, and water pan) with an absolute (drop trap) technique for estimating potato leafhopper, *Empoasca fabae* (Harris), density in alfalfa. For each relative sampling technique, the number of adults or adults and nymphs combined (total) were regressed on the number of adults or adults nymphs combined from the absolute technique. The relative variation (RV) and relative net precision (RNP) of each sampling technique also were calculated as well as the optimum number of sampling units required for each technique for a desired precision. Based on the regression analysis and comparison of RV and RNP, suction (adult), sweep (adult), and sticky trap (48 hr) are all adequate sampling techniques for estimating adult potato leafhopper population levels. Economic thresholds were calculated from economic injury levels for each of these techniques by using different alfalfa prices and management costs. Because of the low RV and high RNP, the sticky trap sampling technique seems the most promising technique for use in a management program in alfalfa. A program utilizing sticky traps for estimating potato leafhopper density is proposed.

Introduction

The potato leafhopper, *Empoasca fabae* (Harris) (Homoptera: Cicadellidae) is a major pest of alfalfa in the north central and northeastern United States (Lamp 1991). In many instances, potato leafhoppers are the only insects that cause significant economic loss (Smith and Ellis 1983). The pest injures alfalfa by inserting its piercing-sucking mouthparts into the alfalfa and removing plant juices (Hutchins and Wintersteen 1988). The injury results in reduced photosynthesis, which translates into a reduction in plant height and dry matter production (Smith and Ellis 1983, Hutchins and Pedigo 1989).

The potato leafhopper is a particularly difficult insect to manage because management tactics need to be implemented before the appearance of visual damage symptoms, specifically leaf chlorosis or "hopperburn" (Gessel 1978). Therefore, having an effective and efficient sampling program is necessary for successful potato leafhopper management. Most of the potato leafhopper integrated pest management (IPM) programs, designed for crop consultants and farmers, utilize field-counted sweep-net samples of adults (Fleischer and Allen 1982, Shields and Specker 1989) or adults and nymphs (Smith and Ellis 1982, Cuperus et al. 1983, Luna et al. 1983, Hutchins and Wintersteen 1988) to assess density. But, very few alfalfa growers use sweep-net sampling and, consequently, do not follow an IPM strategy. A 1990 survey of Iowa farmers showed that less than half of the farmers scouted any of their fields (alfalfa, corn, soybeans, etc.) with enough frequency to obtain optimal benefits from IPM (Padgitt et al. 1990). The main reasons given for not scouting are the time required and the expenses involved in contracting IPM consultants (Rajotte et al. 1987). Other possible reasons are that sampling equipment (e.g., sweep nets) used for scouting is not readily available to alfalfa growers and that the public perception of sweep netting is unacceptable. Thus, to encourage more farmers to use IPM in alfalfa for potato leafhoppers, there is a strong need to develop a more grower-oriented sampling technique that accurately assesses leafhopper populations. This technique then can be developed into a practical potato leafhopper management plan. This paper describes the evaluation of grower-oriented sampling techniques and development of a management program for potato leafhopper in alfalfa.

Materials and Methods

Two fields located at Iowa State University farms near Ames, IA were used from 1994 through 1996 for this study. One 3-ha field was seeded with 'Apollo' alfalfa in the fall of 1993. A second 2-ha field was seeded with 'Defiant'alfalfa in the spring of 1994. Both alfalfa cultivars are commonly grown in the Midwest. At each location, the alfalfa fields were not used until the second year after planting. Each alfalfa field was divided into 10, 25 x 25 m quadrats. Samples for each technique were taken in each quadrat according to a stratified random design.

Sampling techniques

Drop-trap sampling (Simonet and Pienkowski 1979a) was used for estimating absolute densities of potato leafhoppers. Four relative sampling techniques (suction, sticky trap, sweep net, and water pan) were compared with the absolute technique to determine their effectiveness in estimating potato leafhopper densities. The sweep net was included in the study because it is the recommended sampling technique for many state potato leafhopper management programs (Hutchins and Wintersteen 1988, Undersander et al. 1994) and has been shown to be the most reliable relative method for estimating adult and nymphal densities (Simonet et al. 1979b). The other three relative sampling techniques were chosen because the materials used for each technique are readily available to growers. The time required to collect and count potato leafhoppers also was recorded for each sampling technique. Drop-trap, suction, and sweep samples, collected in the field, were counted in the laboratory. Estimates of time to process sampling units in the field also were determined for comparing techniques. To minimize variability within each technique, the same person collected samples for each sampling technique throughout the study.

Absolute sampling technique

The absolute technique used a combination of a drop trap (Fig. 1, upper left) and a leaf blower, with suction attachment (Model GBI 22, Weed Eater®, Shreveport, LA) (Fig. 1, upper right) and mesh collection net. The drop trap consisted of a Plexiglas box (0.5 x 0.5 x 0.5 m = 0.25 m^2) with one open end and two holes cut into two sides. One 20-cm diameter hole was cut in the top of the trap, and the other 13-cm diameter hole was cut on one of the sides. A cloth sleeve then was sown around each hole, preventing leafhopper escape and allowing insertion of the suction device into the trap. To obtain one sampling unit, the cage was dropped on the alfalfa (1.5 m in front of the individual sampling), the suction device was then put though the sleeve of the top hole, and all the leafhoppers were vacuumed from within the trap. Leafhoppers on the inside top of the box were counted directly. Two sampling units were collected per plot (20 sampling units per date).

Relative sampling techniques

The suction sampling technique used a gas-powered blower with a suction attachment (Model GBI 22, Weed Eater®, Shreveport, LA) and mesh collection net (Fig. 1, upper right). The technique consisted of placing the 12-cm diameter suction tube completely over the foliage and vacuuming it for 2 s. This was repeated 20 times per site. Two sampling units were collected per quadrat (20 sampling units per date per location).

For the sticky-trap technique, one yellow, non-baited Pherocon® AM sticky trap (25- x 25 cm) was attached horizontally on a wooden platform in each quadrat (10 sampling units per date per location) (Fig. 1, lower right). The height of the platform was adjusted so that the trap was even with the top of the alfalfa canopy. The number of adult leafhoppers trapped was recorded after the traps had been in the field for 24 and 48 h. The trapping period was limited to no more than 48 h because adult potato leafhoppers were difficult to identify or distinguish from other leafhopper species in the alfalfa after that time.

The sweep-sampling technique consisted of 10 pendular sweeps with a 38-cm diameter sweep net. One, 10-sweep-sampling unit was collected from each quadrat (10 sampling units per date per location).

For the water pan technique, one automotive crankcase drain pan (0.49 m diameter), painted Sun Yellow (Wal-Mart Color Place®), was placed in each quadrat (10 sampling units per date per location) (Fig. 1, lower left). The height of the water pan was adjusted so that the top of the lip was even with the top of the alfalfa canopy. Wooden supports mounted on electric-fence posts, were used as a platform for the water pans, allowing adjustments in the height of the pan. Four liters of soapy water were placed in each pan. Adults in the water pan were collected by sieving with a no. 30 U.S.A. standard testing sieve and the number was recorded after the pan had been in the field for 24 and 48 h. Adults collected in pans were not distinguishable from other leafhopper species if left in the pan for more than 48 h.

Data analysis

Insect samples were collected for all sampling techniques during the second alfalfa cropping period from the 1994 through the 1996 growing seasons. The mean number of leafhoppers collected with each relative technique was compared to the drop-trap (absolute) estimate for each date, and regression models were calculated for each technique. The coefficients from each relationship can be used to transform mean catches from each technique into estimates of absolute density (PROC REG, SAS 1990). A significance level of 0.05 was chosen to test for linear relationships.

Additionally, the sampling data were used to compare the relative variation and relative net precision of each technique. Relative variation (RV) is a measure of precision or degree of error (variability) in making the estimates. The RV of each sampling technique was calculated from the equation RV = (SE / mean) x 100, where SE = the standard error of the mean (Buntin 1994). A lower RV indicates greater precision. Relative net precision (RNP) takes into account the RV of the sampling technique and cost (in time) of the workers to collect and count each sampling unit in the field. The equation used for calculating RNP is RNP = 100 / (RV x C), where C = the cost (in h) for a worker to collect and count each sampling unit (Buntin 1994). A higher RNP value indicates greater precision relative to the cost of each technique.

Results and Discussion

Comparisons of techniques

For each relative sampling technique, linear regressions of adults and adults and nymphs combined (total) were made with absolute estimates of adults or adults and nymphs combined. Because of the inability of sticky traps or water pans to capture potato leafhopper nymphs, only adult density estimates for these techniques were used in the analysis.

Results of linear regressions between the absolute and relative sampling techniques are shown in Table 1. Regression coefficients from the linear equations can be used to estimate absolute densities from relative sampling techniques. Linear regressions are reported here because polynomial models did not improve fit of the data. Linear models accounting for more variation (higher r^2 value) produce density estimates with the greatest accuracy. Linear relationships were significant for all but one of the comparisons (P (b=0) < 0.05).

For all comparisons, relative adult density estimates had greater fidelity (accuracy) for adult and total absolute estimates than total relative estimates. Suction-sample adult estimates had greatest fidelity to total absolute estimates and produced the best fit among any of the comparisons of relative and absolute density estimates ($r^2 = 0.83$). Adult suction estimates showed greater fidelity to either adult or total absolute estimates than total suction estimates. The sweep-net sampling technique produced the best-fitting models overall, regardless of how density data were grouped. Fidelity was greater when adult sweep-net means were regressed on adult or total absolute means. For the sticky trap technique, fidelity was greater when either 24- or 48-h interval means were regressed on adult absolute estimates than on total absolute estimates. Fidelity of sticky traps left in the field for 24- and 48-h intervals were nearly identical when compared with adult absolute estimates. Water pan adult estimates for either 24- or 48-h intervals had lower fidelity for all comparisons with absolute estimates.

To estimate RV, overall means and standard deviations were calculated for each sampling technique from sampling date means (Table 2). The technique with the lowest variability gives the greatest precision in estimating potato leafhopper populations. Relative variations of adult estimates were smaller than total estimates for drop trap, suction, and sweep-sampling techniques. Less variation was observed after sticky traps and water pans had been in the field for 48 h. Suction (total) and water pan (24 h) samples had the greatest RVs of all techniques. The most precise sampling techniques, ranked in decreasing order, were suction (adult), sticky trap (48 h), sweep (adult), and sticky trap (24 h). Relative variation and cost (in worker-h per technique) were used to calculate the RNP (sampling efficiency) of each sampling technique (Table 2). Cost was determined for a technique by calculating the time it would take a worker to collect and count each sampling unit in the field. The highest RNPs in decreasing order were sticky trap (48 h), suction (adult), sweep (adult), and sticky trap (24 h). The extra time required to count leafhoppers, because of the exorbitant amount of soil and debris in the suction sampling units, had a negative effect on the RNP of the suction technique. Otherwise, the suction (total) technique might have had the highest RNP.

To determine the number of sampling units required to estimate potato leafhopper density at a desired precision, an understanding of its spatial distribution is necessary. Adult leafhoppers, because of their mobility, tend to exhibit a Poisson (random) distribution (Fleischer et al. 1982, Luna et al. 1983, Shields and Specker 1989) in alfalfa. Nymphs tend to have a negative binomial distribution (aggregated) because of their limited mobility (walking and jumping only) (Simonet and Pienkowski 1979). However, there are exceptions to these trends. Simonet et al. (1979) determined that adult leafhopper populations fit the negative binomial distribution more often than the Poisson, and Luna et al. (1983) found that 58% of the replicates did not reject a Poisson distribution, when nymphs were added to adult counts.

For this study, adults or adults and nymphs (total) were collected, depending on the sampling technique used. Analysis of the data by the χ^2 (chi-square) goodness-of-fit test showed that 70% of the replicates (42 out of 60) did not reject the null hypothesis of a negative binomial distribution ($P < 0.05$). Of the sampling techniques that only collected adults, 15 out of 22 replicates also fit the negative binomial distribution pattern.

Once the distribution pattern of the potato leafhopper population has been determined, an optimal sample size formula can be used to calculate the number of samples required for a given level of precision (Karandinos 1976). Precision can be defined as a measure of error in making estimates of a population's size (Pedigo 1996). The equation for a negative binomial distribution is $n = ((1 / \text{mean}) + (1 / k)) / D^2$; where, k = the dispersion parameter, and D is the desired level of precision as a decimal equivalent of the coefficient of variation (CV). The dispersion parameter $k = \text{mean}^2 / (s^2 - \text{mean})$; where s^2 is the sample variance.

The optimum number of sampling units required for 10 and 25% precision (CV) for a 2 ha field is shown in Table 3. These sample size estimates were determined by using an overall mean and standard deviation calculated from sample date means. Calculating sample means and standard deviation by this method gives a conservative estimate of optimum sample size. Suction and sweep sampling of total leafhoppers requires more sampling units than sampling for adults only. At a 10% precision level, all of the sampling techniques required an unrealistically high number of sampling units for use in a sampling program. At a 25% precision level, using adult counts, the number of sampling units required for suction, sweep, and sticky trap techniques is feasible for a grower-oriented IPM program.

Based on the regression analysis and comparison of RV and RNP, suction (adult), sweep (adult), and sticky trap (48 hr) are all adequate sampling techniques for estimating adult potato leafhopper population levels. Adult sampling is most appropriate for making management decisions because few nymphs are present during the time when decisions are required.

Development of potato leafhopper management program

Many states currently use sweep-net sampling to estimate potato leafhopper population levels in their management programs (Hutchins and Wintersteen 1988, Undersander et al. 1994). Based on the estimated population levels, there are two management tactics available to the growers. One tactic is to harvest the alfalfa early when high densities of potato leafhopper are present and alfalfa is too near harvest to use insecticides. Another management tactic is using insecticides to reduce leafhopper populations to a noneconomic level. Decisions to treat a field are usually made when alfalfa is relatively short (<25-cm tall), before leafhopper feeding causes extensive blockage of the plant's vascular system (Gesell 1978). At decision time, mainly adults are present in the field because of the high mortality of nymphs and eggs, associated with the previous alfalfa harvest (Simonet and Pienkowski 1979).

The economic thresholds (ETs), or pest densities at which management actions are recommended, currently used in Iowa are based on the height of the alfalfa stems relative to the average number of adults and nymphs (combined) per sweep. The ETs are 0.1 leafhoppers per sweep for each 2.5 cm of plant height, if the alfalfa is less than 25-cm tall, and 2 or more leafhoppers per sweep, if the alfalfa is taller than 25 cm (Rice 1996). But these ETs were not developed by using economic injury levels (EILs), usually expressed as the number of insects per unit area, e.g., potato leafhoppers per m^2. The EIL is defined as the lowest number of insects that will cause economic damage (when amount of pest injury justifies cost of management action), and the EIL can be calculated by using the equation: $EIL = C / V * I * D*K$; where C =management cost, V = market value of crop, I = injury units per insect per production unit, D = damage per unit injury , and K = proportionate reduction in potential injury or damage (Pedigo 1996). Hutchins (1987) calculated EILs for potato leafhoppers on alfalfa, managed on a dry matter basis (assuming K =1), but a sampling technique was not calibrated to utilize these EILs.

Therefore, to incorporate the grower-oriented sampling techniques into a management plan, our sampling regression models (Table 1) were integrated with Hutchins (1987) EIL data to estimate ETs for potato leafhoppers by using suction (adult), sweep (adult), and sticky trap (48 h) sampling techniques (Table 4). Fixed ETs were calculated as 75% of the EILs to account for delays in initiating the program and insect death after treatment. Fixed ETs change constantly with changing EILs, but ignore differences in population growth and injury rates (Pedigo 1991). Although all of these sampling programs are adequate for estimating leafhopper adult numbers, the sticky trap technique seems most promising for use in a management program. As discussed previously, a sweep-net sampling program (for whatever reason) is not often acceptable to growers. The drawbacks of the suction sampling technique are the cost of a leaf blower (with suction attachment) and the longer time necessary to count leafhoppers in these sampling units.

The recommended management program using sticky traps would consist of placing four traps every 2 ha (~5 acre) of the field. Care would be taken not to place traps near field margins because of edge effects. Each field would be divided into equal-size areas. Based on data from this study, a 2-ha area would be divided into four parts, with one sticky trap placed in each part. Traps would be placed horizontally, at canopy height, 7 days after the first harvest. Inverted buckets or wooden stakes (2.5 x 2.5 cm stakes with plywood platform) could be used to hold the traps in a horizontal orientation. Traps would be placed in the field, and the number of adult leafhoppers per trap would be counted after the sticky traps had been in the field for 48 h. The average number of adult leafhoppers per trap would be compared with the ETs in Table 4. If the average number of leafhoppers per trap is less than the ET, another set of traps would be placed in the field 10-14 days after the first harvest. Sampling should be conducted more frequently in hot, dry weather because of the increased developmental rate of leafhoppers under these conditions. Other circumstances, such as the presence of alternative hosts for leafhoppers in adjacent fields and spring weather systems important in leafhopper migration, may also influence trap estimates as adults move into the alfalfa field from outlying areas. With this proposed program, a 10-ha (~25 acre) field would require about 20 sticky traps to make an estimate of the leafhopper population.

This management program is an alternative to current programs using a sweep-net sampling technique to collect potato leafhopper adults or adults and nymphs. The program is unique because it employs ETs calculated from EILs (Hutchins 1987) for management decisions instead of nominal thresholds, based on an entomologist's or farm manager's experience.

Acknowledgment

The authors thank Stephanie Peterson, Mike Anderson, Debbie Engels, Drew Felsted, Deni Scar, Mike Nagel, Anna Dierickx, and Brad Russell for their technical assistance. This research was funded in part by the Leopold Center for Sustainable Agriculture. This is Journal Paper J-17262 of the Iowa Agricultural and Home Economics Experimental Station, Ames, IA. Project No. 3207.

References Cited

Buntin, G. D. 1994. Developing a primary sampling program, pp. 99-115. *In* L. P. Pedigo & G. D. Buntin [eds.], Handbook of sampling methods for arthropods in agriculture. CRC Press, Boca Raton, Florida

Cuperus, G. W., E. B. Radcliffe, D. K. Barnes and J. C. Marten. 1983. Economic injury levels and economic thresholds for potato leafhopper (Homoptera: Cicadellidae) on alfalfa in Minnesota. J. Econ. Entomol. 76: 1341-1349.

Fleischer, S. J. and W. A. Allen. 1982. Field counting efficiency of sweep-net samples of adult potato leafhoppers (Homoptera: Cicadellidae) in alfalfa. J. Econ. Entomol. 75: 837-840.

Gessel, S. G. 1978. An insect management program for alfalfa. Pa. State Univ. Coop. Ext. Serv. Publ. 9-262.

Hutchins, S. H. 1987. The influence of potato leafhopper-induced injury on crop development physiology and economic utility of alfalfa. Ph.D dissertation, Iowa State Univ. 246 pp.

Hutchins, S. H. and Pedigo, L .P. 1989. Potato leafhopper-induced injury on growth and development of alfalfa. Crop. Sci. 29: 1005-1011.

Hutchins, S. H. and W. Wintersteen. 1988. Potato leafhopper management in alfalfa. Iowa State Ext. Publ. IC-433. 3 pp.

Karandinos, M. G. 1976. Optimum sample size and comments on some unpublished formulae. Bull. Entomol. Soc. Am. 22: 417-421.

Lamp, W. O. 1991. Reduced *Empoasca fabae* (Homoptera: Cicadellidae) density in oat-alfalfa intercrop systems. Environ. Entomol. 20: 118-126.

Luna, J. M., S. J. Fleischer and W.A. Allen. 1983. Development and validation of sequential sampling plans for potato leafhopper (Homoptera: Cicadellidae) (*Empoasca fabae*)in alfalfa. Environ. Entomol. 12: 1690-1694.

Padgitt, S., S. Watkins and D. Grundman. 1990. Assessing extension opportunities for integrated pest management. Iowa State Univ. Ext. Pub. IFM-13. 12 pp.

Pedigo, L. P. 1991. Concepts and advances in economic thresholds for IPM. pp. 79-86. *In* 1989 ADAP Crop Protection Conf. Johnson, Ullman and Vargo [eds.], Research Extension Series 134.

Pedigo, L. P. 1996. Entomology and pest management. Prentice-Hall, Upper Saddle River, New Jersey. 679 pp.

Rajotte, E. G., R. F. Kazmierczak Jr., G. W. Norton, M. T. Lambur and W. A. Allen. 1987. The National Evaluation of Extension's Integrated Pest Management Programs. Publ. 491-010. Virginia Cooperative Ext. Ser. Blacksburg, VA.

Rice, M. E. 1996. Leafhoppers on the increase. Integrated Crop Management, Iowa State Univ. Ext., IC-476 (17): 116-117.

SAS Institute. 1990. SAS user's guide: statistics. SAS Institute, Cary, N.C.

Shields, E. J. and D. R. Specker. 1989. Sampling for potato leafhopper (Homoptera: Cicadellidae) on alfalfa in New York: relative efficiency of three sampling methods and development of a sequential sampling plan. J. Econ. Entomol. 82: 1091-1095.

Simonet, D. E. and R. L. Pienkowski. 1979a. Impact of alfalfa harvest on potato leafhopper populations with emphasis on nymphal survival. J. Econ. Entomol. 72: 428-431.

Simonet, D. E. and R. L. Pienkowski. 1979b. A sampling program developed for potato leafhopper nymphs, *Empoasca fabae* (Homoptera: Cicadellidae), on alfalfa. Can. Entomol. 111: 481-486.

Simonet, D. E., R. L. Pienkowski, D. G. Martinez, and R. D. Blakeslee. 1979. Evaluation of sampling techniques and development of a sampling program for potato leafhopper on alfalfa. Environ. Entomol. 8: 397-399.

Smith, S. M. and C. R. Ellis. 1982. Sampling for potato leafhopper (Homoptera: Cicadellidae) on alfalfa. Proc. Entomol. Soc. Ontario 113: 35-41.

Smith, S. M. and C. R. Ellis. 1983. Economic importance of insects on regrowth of established alfalfa fields in Ontario. Can. Entomol. 115: 859-864.

Undersander, D., N. Martin, D. Cosgrove, K. Kelling, M. Schmitt, J. Wedberg, R. Becker, C. Grau, J. Doll, and M. E. Rice. 1994. Alfalfa Management Guide. Am. Soc. Agron., Inc. Madison, WI. 51 pp.

Table 1. Linear regression equations for comparing relative sampling techniques with an absolute technique using mean catch of potato leafhoppers on each date

Regression	Number of sampling dates	a ± SE[a]	b ± SE[b]	P[c]	r^2
Suction					
adults on adults[d]	13	12.90 ± 4.21	0.86 ± 0.16	**	0.71
adults on total	13	15.53 ± 2.87	0.38 ± 0.05	**	0.83
total on adults	13	-	-	NS	0.17
total on total	13	5.83 ± 19.58	1.54 ± 0.33	*	0.66
Sweep					
adults on adults	14	5.07 ± 4.22	1.27 ± 0.16	**	0.82
adults on total	14	0.55 ± 9.42	2.34 ± 0.37	**	0.76
total on adults	14	13.25 ± 6.12	0.44 ± 0.11	*	0.59
total on total	14	10.67 ± 8.95	0.94 ± 0.16	**	0.72

a a, intercept; SE, standard error of mean.

b b, slope.

c P (b=0) < 0.05. P < 0.05, *; P < 0.01, **; NS, nonsignificant.

d Regression of relative sampling technique on absolute technique (drop trap); sample counts were grouped as adults or adults and nymph combined (total).

e Sticky traps and water pans were placed in the field for 24 and 48 h intervals.

Table 1. (continued)

Sticky trap[e]					
24 h interval on adults	13	7.98 ± 6.09	1.13 ± 0.23	**	0.66
48 h interval on adults	13	27.42 ± 9.56	1.79 ± 0.37	**	0.66
24 h interval on total	13	16.08 ± 7.33	0.36 ± 0.13	*	0.39
48 h interval on total	13	41.32 ± 11.90	0.54 ± 0.21	*	0.36
Water pan					
24 h interval on adults	11	-0.16 ± 3.19	0.47 ± 0.13	*	0.57
48 h interval on adults	11	3.02 ± 6.82	0.86 ± 0.24	*	0.55
24 h interval on total	11	2.30 ± 3.86	0.17 ± 0.06	*	0.42
48 h interval on total	11	6.59 ± 6.92	0.34 ± 0.11	*	0.47

Table 2. Comparison of relative variation, worker-hours per sample and relative net precision of sampling techniques for potato leafhopper

Sampling technique	Sample category[a]	Mean (SE)[b]	RV[c]	Cost[d]	RNP[e]
Drop trap	adults	21.47 (4.34)	20.21	.33	14.99
	total	41.92 (10.77)	25.69	.33	11.80
Suction	adults	34.80 (4.16)	11.96	.25	33.44
	total	75.10 (21.18)	28.20	.25	14.18
Sweep	adults	32.33 (6.07)	18.77	.17	31.35
	total	50.34 (11.91)	23.66	.17	24.86
Sticky trap	24 h	32.52 (6.15)	18.90	.17	31.09
	48 h	66.68 (9.22)	13.83	.17	42.53
Water pan	24 h	11.00 (1.00)	30.68	.17	19.17
	48 h	25.38 (5.94)	23.39	.17	25.15

a Sample counts were grouped as adults or adults and nymphs combined (total); adult samples were collected after 24 and 48 h in the field.

b Mean number of potato leafhopper collected per sampling unit for duration of study; (SE) standard error of mean calculated from sampling date means.

c RV, relative variation = (SE / mean) x 100.

d Cost = worker-hours to collect and count a sampling unit in the field.

e RNP, relative net precision = 100 / (RV x cost per sample).

Table 3. Optimum number of sampling units required per 2 ha field for 10 and 25% precision for potato leafhopper sampling techniques

Sampling technique[a]	Sampling interval	Number of sampling units required[b]			
		Adults		Total	
		10%	25 %	10%	25%
Drop trap	-	57	9	93	15
Suction	-	19	3	103	17
Sweep	-	49	8	78	13
Sticky trap	24 hr	50	8	-	-
	48 hr	27	4	-	-
Water pan	24 hr	103	17	-	-
	48 hr	60	10	-	-

a Optimum sample size (number of sampling units) based on overall mean and standard error calculated from sampling date means.

b Number of sampling units = ((1 / mean) + (1 / k) / D^2; k, dispersion parameter, and D, desired sampling precision. k = $mean^2 / (s^2 - mean)$; s^2, variance.

Table 4. Economic injury levels (EILs) and economic thresholds (ETs) for potato leafhopper adults (per sampling unit) on alfalfa for 3 relative sampling techniques

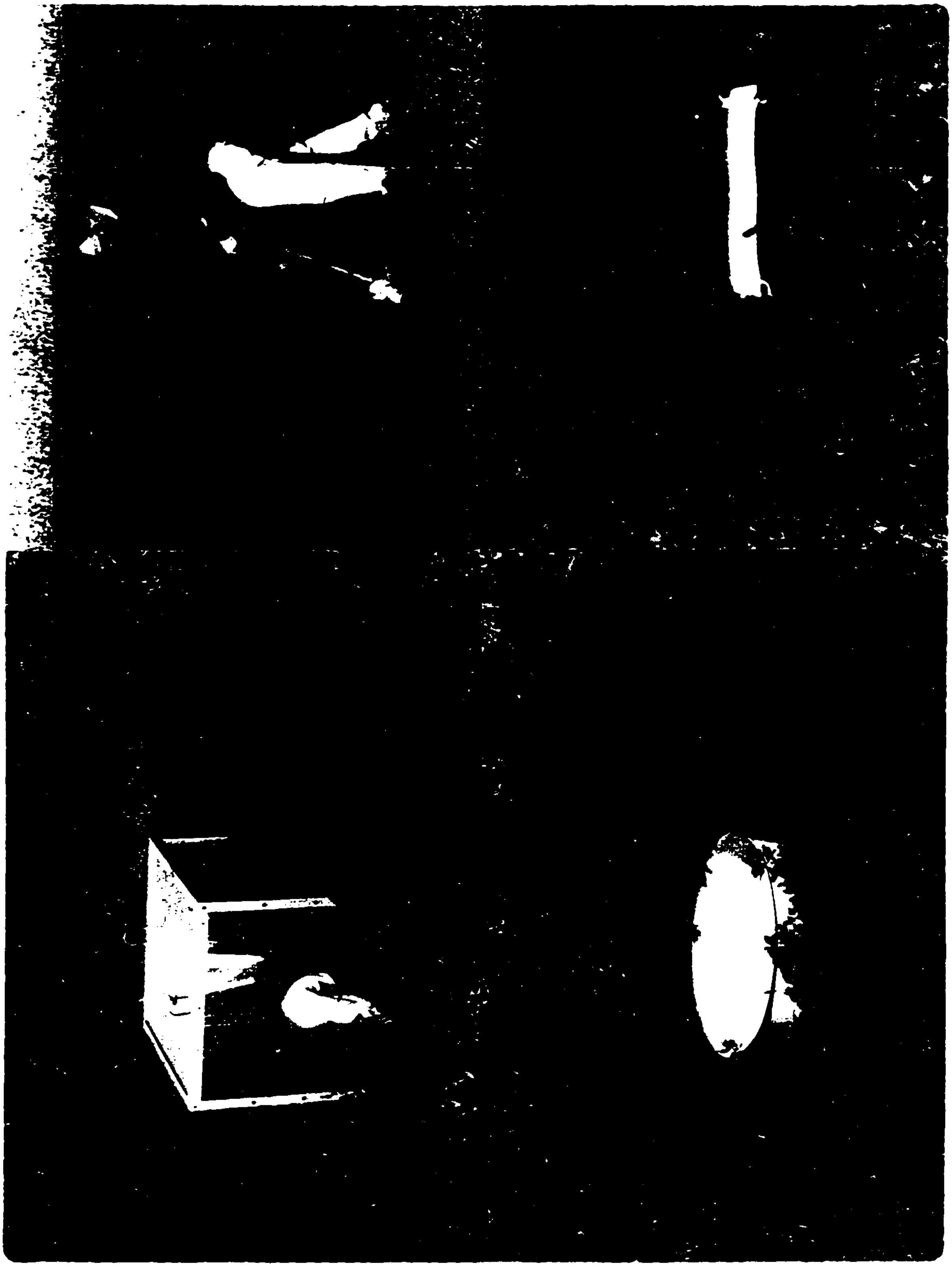
Sampling technique[ab]	Crop value $/kg ($/ton)	Management costs -$/ha ($/acre)					
		$14.82 ($6.00)		$19.76 ($8.00)		$24.70 $10.00)	
		EIL	ET[c]	EIL	ET	EIL	ET
Suction	$0.055 ($50)	20	15	23	17	26	19
	$0.082 ($75)	18	13	20	15	21	16
	$0.110 ($100)	17	13	18	13	19	14
	$0.138 ($125)	16	12	17	13	18	13
Sweep	$0.055 ($50)	19	13	20	15	24	18
	$0.082 ($75)	16	12	15	11	18	13
	$0.110 ($100)	11	8	13	9	14	11
	$0.138 ($125)	10	7	11	8	12	9
Sticky trap	$0.055 ($50)	43	32	48	36	54	40
	$0.082 ($75)	38	28	42	31	45	34
	$0.110 ($100)	35	26	38	28	41	30
	$0.138 ($125)	34	25	36	27	38	28

a EILs calculated for alfalfa harvested on a 28-day calender schedule and dry matter basis and using an the overall equation for calculating time delay caused by leafhopper injury (from Hutchins 1987).

b Suction: number per 20 touches; sweep: number per 10 pendular sweeps; sticky trap: number per trap.

c Fixed ET at 75% of EIL.

Figure 1. Potato leafhopper sampling techniques. Beginning upper left and moving clockwise: drop trap, suction, sticky trap, and water pan



CHAPTER 6. GENERAL CONCLUSIONS

The potato leafhopper, *Empoasca fabae* (Harris) (Homoptera: Cicadellidae) is a major insect pest of alfalfa in the north central and northeastern United States. Studies were conducted from 1994 through 1996 to better understand the population dynamics of potato leafhopper in Iowa, as well as improve sampling and management of this and other alfalfa pests. The specific objectives of this dissertation were to (1) understand the population dynamics and diurnal activity of potato leafhopper in Iowa forage systems; (2) determine the effect of alfalfa-forage grass intercrops on potato leafhopper, as well as other alfalfa insect pests and predators; (3) assess the impact of intercropping on forage growth characteristics for determining the feasibility of intercropping as a management tactics, and (4) develop grower-oriented sampling techniques and a management program for potato leafhopper in alfalfa.

Two studies were conducted in Iowa forages from 1994 through 1996 to assess the population dynamics and diurnal activity of potato leafhopper, *Empoasca fabae* (Harris). The results of population dynamics study showed that the potato leafhopper populations can reach economic levels in any of the three alfalfa crops. However, economic thresholds were consistently exceeded only in the second alfalfa crops. In the second crop, current economic thresholds were exceeded approximately 3 weeks after first harvest. The results of the diurnal study showed that there are differences in the number of potato leafhoppers captured at different times of the day. The influence of the sampling time on leafhopper capture is likely related to the adult-to-nymph ratio of the leafhopper population. For samples collected at 1900 h or later, present economic thresholds may be too low. However, there was not enough conclusive evidence from this study to justify development of different economic thresholds based on the time of day leafhoppers are sampled.

Alfalfa and alfalfa-grass intercrops were sampled from 1995 through 1996 to determine the effects of intercrops on alfalfa insect pests and associated insect predator populations. In the first forage crops, potato leafhopper numbers were significantly greater in the alfalfa monocultures than the two alfalfa-forage grass intercrops. Significantly greater numbers of alfalfa weevil larvae were collected from alfalfa monocultures than alfalfa-orchardgrass intercrops, but monocultures were not significantly different than alfalfa-bromegrass intercrops. In the second alfalfa crops, significantly greater numbers of potato leafhoppers were collected in the alfalfa monocultures compared to the alfalfa-ochrardgrass intercrops. Significantly greater numbers of common damsel bugs were collected on alfalfa monocultures compared to the intercrops, but no consistent significant differences were observed between alfalfa-grass intercrops and the monoculture. Alfalfa stand densities and biomass estimates were significantly greater in alfalfa monocultures than alfalfa-forage grass intercrops for both first and second crops in 1995 and 1996. In the first and second crops, orchardgrass densities and biomass were consistently larger than bromegrass estimates. Few differences in total biomass were found among the treatments in either year. No significant differences in potato leafhopper and alfalfa weevil intensities on alfalfa plants were found among the treatments. The results of this study suggest that alfalfa-forage grass intercrops reduce insect pest populations compared to monocultures, but additional management tactics may be needed to reduce insect pest levels below economic thresholds.

A sampling study was conducted from 1994-1996 comparing four grower-oriented sampling techniques (sticky trap, suction, sweep, and water pan) with an absolute (drop trap) technique for estimating potato leafhopper, *Empoasca fabae* (Harris), density. For each relative sampling technique, the number of adults or adults and nymphs combined (total) were regressed on the number of adults or adults nymphs combined from the absolute technique. The relative variation (RV) and relative net precision (RNP) of each sampling techniques also were calculated as well as the optimum number of sampling units required for each technique for a desired precision. Based on the regression analysis and comparison of RV and RNP, suction (adult), sweep (adult), and sticky trap (48 hr) are all adequate sampling techniques for estimating adult potato leafhopper population levels. Economic thresholds (ETs) were calculated from economic injury levels (EILs) for each of these techniques using different alfalfa prices and management costs. Because of the low RV and high RNP, the sticky trap sampling technique seems the most promising technique for use in a management program. A management program utilizing sticky traps for estimating potato leafhopper density is proposed for alfalfa.

These studies improved the sampling and management of potato leafhopper and other insect pests in alfalfa. We found that (1) potato leafhopper populations can reach economic levels in any of the three alfalfa crops; (2) there are differences in the number of potato leafhoppers captured at different times of the day; (3) alfalfa-forage grass intercrops reduce insect pest populations compared to monocultures, and (4) the sticky trap sampling technique seems the most promising technique for use in a management program.

REFERENCES CITED

Andow, D. A. 1991. Vegetational diversity and arthropod population response. Ann. Rev. Entomol. 36: 561-586.

Armbrust, E. J. 1981. Pest management systems for alfalfa insects. *In* D. Pimentel (ed.) CRC Handbook of pest management in agriculture. Vol. III. CRC Press, Boca Raton.

Armburst, E. J. 1989. Introduction. *In* E. J. Armbrust & W. O. Lamp [eds.], History and perspectives of potato leafhopper (Homoptera: Cicadellidae) research. Misc.Publ. 72, Entomol. Soc. Am., Lanham, MD.

Baliddawa, C. W. 1985. Plant species diversity and crop pest control. An analytical review. Insect Sci. Appl. 6: 479-486.

Barney R. J. and B. C. Pass. 1987. Influence of no-tillage planting on foliage-inhabiting arthropods of alfalfa in Kentucky. J. Econ. Entomol. 80: 1288-1290.

Bolten, J. L., B. P. Goplen, and H. Baenziger. 1972. World distribution and historical developments, pp. 1-34. *In* Alfalfa science and technology. Am. Soc. Agronomy. Madison, WI.

Cherry, R. H., K. A. Wood, and W. G. Ruesink. 1977. Emergence traps and sweep-net sampling for adults of potato leafhopper from alfalfa. J. Econ. Entomol. 70: 279-282.

Coggins, M. L. 1991. Potato leafhopper (*Empoasca fabae*) and alfalfa weevil (*Hypera postica*) density and damage in alfalfa-forage grass binary mixtures. M. S. thesis, Michigan State University, East Lansing, MI.

Cuperus, G. W., E. B. Radcliffe, D. K. Barnes, and J. C. Marten. 1983. Economic injury levels and economic thresholds for potato leafhopper (Homoptera: Cicadellidae) on alfalfa in Minnesota. J. Econ. Entomol. 76: 1341-1349.

Decker, G. C. and H. B. Cunningham. 1967. The mortality rate of the potato leafhopper and some related species when subjected to prolonged exposure at various temperatures. J. Econ. Entomol. 60: 373:379.

Faris, M. A., H. Baenziger, and R. P. Terhune. 1981. Studies on potato leafhopper (*Empoasca fabae*) damage in alfalfa. Can. J. Plant Sci. 61: 625-632.

Fick, G. W. and S. C. Mueller. 1989. Alfalfa: quality, maturity, and mean stage development. Cornell Univ. Inform. Bull. 217: 1-13

Fleischer, S. J. and W. A. Allen. 1982. Field counting efficiency of sweep-net samples of adult potato leafhoppers (Homoptera: Cicadellidae) in alfalfa. J. Econ. Entomol. 75: 837-840.

Fleischer, S. J., W. A. Allen, J. M. Luna, and R. L. Pienkowski. 1982. Absolute-density estimation from sweep sampling, with a comparison of absolute-density sampling techniques for adult potato leafhoppers in alfalfa. J. Econ. Entomol. 75: 425-430.

Fleischer, S. J., W. A. Allen, and R. L. Pienkowski. 1983. Relationship between absolute density and sticky trap catches of adult potato leafhoppers in alfalfa. J. Georgia Entomol. Soc. 18: 213-218.

Gentsch, B .J. 1982. The influence of weeds on the incidence of potato leafhopper in alfalfa. M.S. thesis, Southern Illinois Univ., Carbondale.

Gessel, S. G. 1978. An insect management program for alfalfa. Pa. State Univ. Coop. Ext. Serv. Publ. 9-262.

Goplen, B. P., H. Baenziger, L. D. Bailey, A. T. H. Gross, M. R. Hanna, R. Michaud, K. W. Richards and J. Waddington. 1980. Growing and managing alfalfa in Canada. Agric. Can. Publ. 1705.

Grau, C. R., G. C. Brown, and B. C. Pass. 1985. Implementing IPM in alfalfa. pp. 604-618. *In* R.E. Frisbie and P.L. Adkisson [eds.]. Integrated Pest Management on Major Agriculture Systems. CIPM. Texas Agr. Exp. Stn.

Hammond, R. B. and D. L. Jeffers. 1990. Potato leafhopper (Homoptera: Cicadellidae) populations on soybean relay intercropped into winter wheat. Environ. Entomol. 19: 1810-1819.

Hogg, D. B. 1985. Potato leafhopper (Homoptera: Cicadellidae) immature devlopment, life tables, and population dynamics under flucuating temperature regimes. Environ. Entomol. 14: 349-355.

Hogg, D. B. and G. D. Hoffman. 1989. Potato leafhhopper population dynamics. *In* E. J. Armbrust & W. O. Lamp [eds.], History and perspectives of potato leafhopper (Homoptera: Cicadellidae) research. Misc. Publ. 72, Entomol. Soc. Am., Lanham, MD.

Horn, D. J. 1981. Effect of weedy backgrounds on colonization of collards by green peach aphid, *Myzus persicae*, and it major pedators. Environ. Entomol. 10: 285-289.

Hower, A. A. 1987. Ecology of the potato leafhopper on alfalfa and other crops, pp. 257-266. *In* M. R. Wilson and L. R. Nault [eds.], Proc. 2nd Int. Workshop on leafhoppers and planthoppers of economic importance. CAB Int. Inst. Entomol. London, England.

Hunter, C. E. 1991. Factors influencing *Zoophthora radicans* (Zygomycetes: Entophthorales) infection in potato leafhoppers (*Empoasca fabae*) (Homoptera: Cicadellidae) on alfalfa. Ph. D. dissertation, Univ. of Kentucky, Lexington, KY.

Hutchins, S. H. and Pedigo, L. P. 1989. Potato leafhopper-induced injury on growth and development of alfalfa. Crop. Sci. 29: 1005-1011.

Hutchins, S. H. and L. P. Pedigo. 1990. Phenological disruption and economic consequence of injury to alfalfa induced by potato leafhopper (Homoptera: Cicadellidae). J. Econ. Entomol. 83: 1587-1594.

Hutchins, S. H. and W. Wintersteen. 1988. Potato leafhopper management in alfalfa. Iowa State Ext. Publ. IC-433. 3 pp.

Hutchins, S. H. , D. R. Buxton, and L. P. Pedigo. 1989. Forage quality of alfalfa as affected by potato leafhopper feeding. Crop Sci. 1541-1545.

Kapasta, G. 1983. Weed management in alfalfa. Consortium Integrated Pest Management Success Stories. pp. 34-35.

Kieckhefer, R. W. and J. T. Medler. 1964. Some environmental factors influencing oviposition by the potato leafhopper, *Empoasca fabae*. J. Econ. Entomol. 57: 482-484.

Lamp, W. O. 1991. Reduced *Empoasca fabae* (Homoptera: Cicadellidae) density in oat-alfalfa intercrop systems. Environ. Entomol. 20: 118-126.

Lamp, W. O. and L. M. Smith. 1989. Sampling Objectives and Problems, pp. 3-9. *In* E. J. Armbrust and W. O. Lamp [eds.], History and perspectives of potato leafhopper (Homoptera: Cicadellidae) research. Misc. Publ. 72, Entomol. Soc. Am., Lanham, MD.

Lamp, W. O., R. J. Barney, E. J. Armbrust, and G. Kapusta. 1984. Selective weed control in spring-planted alfalfa: effect of leafhoppers and planthoppers (Homoptera: Auchenorrhyncha), with emphasis on potato leafhopper. Environ. Entomol. 13: 207-213.

Lamp, W. O., S. J. Roberts, K. L. Steffey, and E. J. Armbrust. 1985. Impact of insecticide applications at various growth stages on potato leafhopper (Homoptera: Cicadellidae) abundance and crop damage. J. Econ. Entomol. 78: 1393-1398.

Luna, J. M., S. J. Fleischer, and W. A. Allen. 1983. Development and validation of sequential sampling plans for potato leafhopper (Homoptera: Cicadellidae) (*Empoasca fabae*). in alfalfa. Environ. Entomol. 12: 1690-1694.

Medler, J. T. 1941. The nature of injury to alfalfa caused by *Empoasca fabae* (Harris). Ann. Entomol. Soc. Am. 439-450.

Melton, W., J. B. Moutray and J. H. Bouton. 1988. Geographical adaptation and cultivar selection, pp. 595-620. *In* Alfalfa and alfalfa improvement. A. A. Hanson, K. D. Barnes, and R. R. Hill, Jr. [eds.], Am. Soc. of Agronomy, Inc. Madison, WI.

Michaud, R., W. F. Lehman, and M. D. Rumbaugh. 1988. World distribution and historical development, pp. 25-92. *In* Alfalfa and alfalfa improvement. A. A Hanson, D. K. Barnes, and R. R. Hill, Jr. [eds.], Am. Soc. of Agronomy, Inc. Madison, WI.

Oloumi-Sadeghi, H., L. R. Zavaleta, W. O. Lamp, E. J. Armbrust, and G. Kapusta. 1987. Interactions of the potato leafhopper (Homoptera: Cicadellidae) with weeds in an alfalfa ecosystem. Environ. Entomol. 16: 1175-1180.

Oloumi-Sadeghi, H., L. R. Zavaleta, G. Kapusta, W. O. Lamp, and E. J. Armbrust. 1989. Effects of potato leafhopper (Homoptera: Cicadellidae) and weed control on alfalfa yield and quality. J. Econ. Entomol. 82: 923-931.

Padgitt, S., S. Watkins, and D. Grundman. 1990. Assessing extension opportunities for integrated pest management. Iowa State Univ. Ext. Publ. IFM-13. 12 pp.

Pedigo, L. P. 1989. Entomology and pest management. Macmillan, New York.

Pienkowski, R. L. and J. T. Medler. 1964. Synoptic weather conditions associated with long-range movement of the potato leaf hopper, *Empoasca fabae*. J. Econ. Entomol. 55: 973-978.

Pienkowski, R. L. and J. T. Medler. 1966. Potato leafhopper trapping studies to determine local flight activity. J. Econ. Entomol. 59: 837-843.

Poos, F. W. and N. H. Wheeler. 1949. Some additional host plants of three species of leafhoppers of the genus *Empoasca*. Proc. of the Entomol. Soc. of Washington. 51: 35.

Rajotte, E. G., R. F. Kazmierczak Jr., G. W. Norton, M. T. Lambur, and W. A. Allen. 1987. The National Evaluation of Extension's Intergrated Pest Management Programs. Publ. 491-010. Virginia Cooperative Ext. Ser. Blacksburg, Virginia. pp. 123-30.

Risch, S. J. 1981. Insect herbivore abundance in tropical monocultures and polycultures: an experimental test of two hypotheses. Ecol. 62: 1325-1340.

Risch, S. J., D. Andow, and M. A. Altieri. 1983. Agroecosystem diversity and pest control: data, tentative conclusions, and new research directions. Enviorn. Entomol. 12: 625-629.

Roda, A. L., D. A. Landis, M. L. Coggins, E. Spandl, and O. B. Hesterman. 1996. Forage grassses decrease alfalfa weevil (Coleoptera: Curculionidae) damage and larval numbers in alfalfa-grass intercrops. J. Econ. Entomol. 89: 743-750.

Saugstad, E. S., R. A. Bram, and W. E. Nyquist. 1967. Factors influencing sweep-net sampling in alfalfa. J. Econ. Entomol. 60: 421-426.

Shields, E. J. and D. R. Specker. 1989. Sampling for potato leafhopper (Homoptera: Cicadellidae) on alfalfa in New York: relative efficiency of three sampling methods and development of a sequential sampling plan. J. Econ. Entomol. 82: 1091-1095.

Simonet, D. E. and R. L. Pienkowski. 1977. Sampling and distribution of potato leafhopper eggs in alfalfa stems. Ann. Entomol. Soc. Am. 70: 933-936.

Simonet, D. E. and R. L. Pienkowski. 1979. A sampling program developed for potato leafhopper nymphs, *Empoasca fabae* (Homoptera: Cicadellidae), on alfalfa. Can. Entomol. 481-486.

Simonet, D. E. and R. L. Pienkowski. 1980. Temperature effect on development and morphometrics of the potato leafhopper. Environ. Entomol. 9: 798-800.

Simonet, D. E., R. L. Pienkowski, D. G. Martinez, and R. D. Blakeslee. 1978. Laboratory and field evaluation of sampling techniques for the nymphal stages of the potato leafhopper on alfalfa. J. Econ. Entomol. 71: 840-842.

Simonet, D. E., R. L. Pienkowski, D. G. Martinez, and R. D. Blakeslee. 1979. Evaluation of sampling techniques and development of a sampling program for potato leafhopper on alfalfa. Environ. Entomol. 8: 397-399.

Smith, L. M. 1987. Mechanism by which grass reduces potato leafhopper, *Empoasca fabae* (Harris) (Homoptera: Cicadellidae), abundance in alfalfa. Ph.D. dissertation, University of Illinois, Urbana-Champaign, IL.

Smith, S. M. and C. R. Ellis. 1982. Sampling for potato leafhopper (Homoptera: Cicadellidae) on alfalfa. Proc. Entomol. Soc. Ont. 113: 35-41.

Smith, S. M. and C. R. Ellis. 1983. Economic importance of insects on regrowths of established alfalfa fields in Ontario. Can. Entomol. 115: 859-864.

Taylor, R. A. 1989. Mystery of the return migration., pp. 18-25. *In* E. J. Armbrust and W.O. Lamp [eds.], History and perspectives of potato leafhopper (Homoptera:Cicadellidae) research. Misc. Publ. 72, Entomol. Soc. Am., Lanham, MD.

Tesar, M. B. and V. L. Marble. 1988. Alfalfa establishment, pp. 303-332. *In* A. A. Hanson, O. K. Barnes, and R. R. Hill, Jr. [eds.], Alfalfa and alfalfa improvement. Agronomy Monograph 29, Am. Soc. of Agronomy., Inc., Madison WI.

van Emden, H. F. and M. J. Way. 1973. Host plants in the population dynamics of insects, pp. 181-199. *In* H. F. van Emden [ed.], Insect plant relationships. Blackwell, Oxford.

Wilson, H. R. 1991. Variability among field personnel in sampling potato leafhopper (Homoptera: Cicadellidae) populations in alfalfa. J. Agric. Entomol. 8: 71-76.

Womack, C. L. 1984. Reduction in photosynthetic and transpiration rates of alfalfa caused by potato leafhopper (Homoptera: Cicadellidae) infestations. J. Econ. Entomol. 77: 508-513.

ACKNOWLEDGMENTS

First of all, I would like to thank my wife Angie, who has given me the love, support, and encouragement to continue my education and remain focused so that we could achieve our common goals. I also thank my parents, Jim and Charlene, who have supported me in all my academic endeavors.

I am very grateful to my mentor Dr. Larry Pedigo for giving me the opportunity to continue my education. His guidance and expertise have been invaluable to the development of my entomological career. Additionally, I thank Dr. Pedigo and Dr. Marlin Rice for their ideas and suggestions that contributed to the development of my dissertation objectives and research. I also would like to thank Drs. Rice, John Obrycki, Dwayne Buxton, and Paul Hinz for providing their expertise and suggestions while serving on my Ph.D. committee.

I also would like to thank all of my fellow co-workers (past) Joe Browde, Tom Klubertanz, Mike Zeiss, (and present) Lamar Buckelew, Frankie Lam, Steve Lefko, and Carol (Simmons) Pilcher for their suggestions, advice, and friendship. In addition, I would like to thank Mike Anderson, Stephanie Peterson, Debbie Engels, Drew Felsted, Deni Scar, Mike Nagel, Anna Dierickx, and Brad Russell, who helped me gather and process my numerous insect samples. And a special thanks to Kris Giles, who has helped keep me focused on the important things in life: applied entomology, basketball, and buffets (not necessarily in that order).