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Potato Leafhopper Effects on Yield, Quality
And Persistence of Selected Alfalfa Cultivars

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POTATO LEAFHOPPER EFFECTS ON YIELD, QUALITY AND PERSISTENCE OF SELECTED ALFALFA CULTIVARS

By

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ABSTRACT

POTATO LEAFHOPPER EFFECTS ON YIELD, QUALITY AND PERSISTENCE OF SELECTED ALFALFA CULTIVARS

By

Timothy S. Dietz

Potato leafhopper-resistant alfalfa (*Medicago sativa* L.) is an important new tool for integrated pest management of potato leafhopper (*Empoasca fabae* [Harris]) (PLH) in alfalfa production; however, varying resistance levels among these cultivars may affect performance. The objectives of this study were to evaluate newly released and experimental (PLH-Resistant) alfalfa cultivars in the field with and without an insecticide to determine their impact upon PLH density, alfalfa yield, quality and stand persistence. A split-plot randomized complete block design was used to evaluate alfalfa cultivars, four at the Kellogg Biological Station (WL 324, Cleansweep 1000, 54H69, 3A14B, which have been characterized as having 0, 28, 45, and 60% PLH resistance, respectively) and fourteen commercial and experimental resistant and four susceptible cultivars at East Lansing. There was no significant difference in yield or quality between commercially released or experimental PLH-resistant cultivars in the East Lansing study. However, in the KBS study, as cultivar resistance increased, PLH density decreased within the non-insecticide treatment. Furthermore, during peak PLH density, yield, maturity and crude protein were greater in the 60% resistant alfalfa cultivar than the susceptible alfalfa cultivar. Resistant alfalfa cultivars were not immune to PLH feeding injury; however, the characteristics of resistance reduced the injurious effects of PLH on yield, quality, and maturation.

ACKNOWLEDGMENTS

Many people deserve thanks for their assistance in the field and lab. I would especially like to thank Nolan Gretzinger, Tim Boring and James DeYoung who worked diligently on many long days to collect and analyze data. Appreciation is also extended to Brian Graff and Tom Galecka as there input and guidance was imperative to the success of this research. Thank you to Dr. Peter Jeranyama for guidance in research methods and his willingness to participate in fieldwork. A special thank you to Dr. Richard Leep for his guidance and willingness to take the time required to teach me the many aspects field crop research.

Thanks to my wife, Stephanie, for her patience during the long hours of the field-seasons. Her support and understanding made this a reality. I would also like to thank my parents, Ron and Sharon, for 33 years of guidance and support.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Alfalfa is an essential crop for livestock and dairy producers in the north central region of the United States. In 1999, alfalfa production in Michigan exceeded 3.6 million tons with an estimated value of 255 million US dollars (Michigan Agriculture Statistics, 2000). The benefits of alfalfa include: a source of protein for livestock (Conrad and Klopfenstein, 1988), improved soil tilth (Hanson et al., 1998), enhancement of the environment with open green-space, and biological nitrogen fixation through a symbiotic relationship with *Rhizobium meliloti* (Dangead) (Burton, 1972; Hiechel, 1983). Dinitrogen fixation by alfalfa has been measured as high as 463 kg ha^{-1} yr^{-1} (Vance, 1978). With increasing inorganic nitrogen fertilizer costs, alfalfa becomes an increasingly important crop in a rotation. Forages are a necessary component of the ruminant diet (Thomas, 1967), and alfalfa is economically viable forage to produce (Dornfield et al. 1983); however, high yielding, long-term alfalfa stands require good management (Tesar and Marble, 1988) including integrated pest management (IPM).

Potato leafhoppers (PLH) (*Empoasca fabae* [Harris]) can significantly reduce alfalfa yield in the north central United States (Fenton and Hertzell, 1923; Hower and Muka, 1975; Nielson et al., 1990) with yield reductions from 13 to 27% reported (Poos and Johnson, 1936). Lamp et al. (1991) estimated PLH losses in Maryland at $66/ha. While some of the greatest damage from PLH is found in the north central and northeast regions, PLH do not over winter in these areas. Southern Louisiana and northern Florida are the primary over-wintering areas (Poos and Johnson, 1936; Decker and Cunningham, 1968). Annual movement of the PLH occurs when adults in the southern United States fly upward into the air currents that carry and disperse them throughout the alfalfa producing states in the northern US. (Pienkowski and Medler, 1964; Taylor and Shields, 1995). Maredia et al. (1998) collected data on the first occurrence of PLH in Michigan between the years of 1951 and 1997 and found that late-May was the average first date of PLH arrival. In this study PLH severity was also determined, they found that 15 of the 28 years in this study experienced heavy to severe PLH density. In Michigan, first cutting of alfalfa is usually taken by the first week of June; however, it is seldom affected by PLH due to cool, moist conditions that are not favorable for PLH growth and development. The polyphagous nature (Poos, 1932) of this insect (over 100 host species) enables it to thrive when alfalfa is not available following harvest and prior to regrowth. The female is capable of producing 60-100 eggs per month (Pedigo, 1999), and eggs hatch in 6-10 days (Delong, 1928) as a result rapid population increases of PLH occur and produce damage in second and third cuttings when environmental conditions are more favorable.

Potato leafhoppers have been shown to have a preference for alfalfa petioles over stems and for the underside of leaves (Gruenhagen and Backus, 1999). In this study they found that females more frequently caused expression of injury symptoms in alfalfa than males. The PLH utilizes a lacerate and flush method by inserting a stylet into the phloem tissue to pulverize and withdraw photoassimilates (Smith and Poos, 1931; Kabrick and Backus, 1990; Ecale and Backus, 1995). Physical damage and saliva left behind by PLH contribute to sieve element collapse (Kabrick and Backus, 1990; Ecale and Backus, 1995). The disrupted translocation of photoassimilates in the xylem and phloem reduces the rate of both transpiration and photosynthesis (Womack, 1984).

In 1936, Poos and Johnson reported that injury by PLH was directly proportional to PLH populations (density) feeding on the plants. The damage from PLH feeding results in stunting and leaf chlorosis, more commonly referred to as hopperburn (Manglitz and Ratcliffe, 1998). Other symptoms include: shoot retardation, wilting (Johnson, 1934; Granousky, 1930) and delayed plant maturity (Wilson et al., 1979; Oloumi-Sadeghi et al., 1988). Potato leafhoppers can cause damage to alfalfa by thinning new seedings, reducing yield (Poos and Johnson, 1936; Kouskolekas and Decker, 1968; Hutchins and Pedigo, 1989), decreasing forage quality (Hutchins et al. 1989), and reducing stand persistence (Wilson et al., 1979). Young plants are especially susceptible to PLH feeding because of thin cutin layers and lower lignin content (Faris et al., 1981), which seems to ease probing. Seedlings that exhibit PLH feeding damage have exhibited lower total nonstructural carbohydrates (TNC) in the roots than those plants not fed on by PLH (Shaw and Wilson, 1986; Oloumi-Sadeghi et al., 1988), which slows regrowth and decreases winter survival. Both Poos and Johnson (1936) and Vough et al. (1992) found carryover effects of PLH seeding year damage in subsequent years. Lamp et al. (2001) noted decreased carbon transport to lower stems, crown and root tissue in plants damaged by PLH feeding. In a study by Volenec et al. (1996), reduced translocation of N has been proposed as the limiting factor for regrowth rather than TNC.

Pedigo et al. (1986) determined an economic threshold for treatment of PLH using a 38.1 cm diameter sweep net passed 10 times over the canopy of an alfalfa stand. They determined the economic threshold justifying an insecticide treatment (based on spray costs and hay value) had been reached when PLH numbers exceeded 0.2, 0.5, 1.0

and 2.0 adults/sweep at plant heights of <7.6, 15.2, 25.4, and 35.6 cm, respectively. When economic thresholds are exceeded, either insecticide applications or harvesting of alfalfa to remove the plant matter on which the PLH depend are the most common forms of control. An insecticide application is usually associated with increased cost and time expenditures while early harvesting usually results in lower yields. Often the important step of field scouting, to determine when economic thresholds are reached, is neglected.

Several alfalfa seed companies released potato leafhopper resistant (PLHR) alfalfa cultivars in 1997 with the promise of increased yields and good resistance to PLH feeding. These new cultivars were developed by intercrossing resistant diploid and tetraploid *Medicago spp*. and reselecting those that possessed desirable characteristics. As a result of this selection process, a percentage of the plants in a population did not exhibit resistance mechanisms. Initially released in the 1980's, by Sorenson et al. (1985,1986) and Shade and Kitch (1986), these cultivars were selected as resistant after Brewer et al. (1986) noted reduced egg laying and nymph survival. Expression of resistance is associated with erect and procumbent glandular trichomes or non-glandular hairs on the stem and petiole (Elden and Elgin, 1992). Ranger and Hower (2001) captured electron images of exudates from the trichomes entrapping first-instar PLH. This study also determined that trichomes were most dense on the stem, petiole, and leaf midvein. The alfalfa seed industry used existing pest ratings for PLH resistance based on the percentage of plants that express the resistance trait (Table 1). The PLH-resistant varieties released in 1997 possess better growth characteristics than their predecessors (Flora and Sulc, 1997), which were derived from wild-type alfalfa cultivars that exhibited a prostrate growth habit. Recent studies of the newly released PLH-resistant varieties revealed reduced egg-laying and increased nymph mortality when PLH were caged with only PLH-resistant varieties (Elden and McCaslin, 1997).

Table 1. Commercial standards for PLH-resistance ratings (NAAIC, 2001).

Percent of Plants Exhibiting Resistance	Resistance Class
0-5	Susceptible
6-15	Low Resistance
16-30	Moderate Resistance
31-50	Resistant
>50	Highly Resistant

Questions have been raised concerning the palatability of PLH-R alfalfa due to the presence of glandular trichomes (Burns, 1978). Lenssen et al. (1998) conducted a study to address these concerns and found that sheep preferred grazing glandular haired alfalfa compared to non-glandular alfalfa. Anti-qualities, namely lignin, may be a deterrent to PLH feeding; however, in studies of forage quality of PLH-R (glandular-haired) alfalfa, no loss of forage quality was observed (Lenssen et al. 1988a, b, c).

Resistance levels in cultivars used in this study ranged from 20 to 60% resistant. It is not clear whether PLH feed on the resistant portion of the population and the plant avoids injury (tolerance), the PLH feed on only the non-resistant plants in a population (non-preference), or if the PLH are adversely affected by the resistant plants (antibiosis) as suggested by Newton and Barnes (1965). Potato leafhopper resistant alfalfa may be an important tool for managing PLH if yield, quality, and persistence are similar to susceptible cultivars.

Objectives

This experiment was conducted to determine the level of resistance that provides adequate protection for alfalfa from PLH feeding. The specific objectives were to evaluate the effect of increasing cultivar resistance level upon PLH density, alfalfa herbage biomass, nutritive quality, and stand persistence.

MATERIALS AND METHODS

One experiment was established at the Michigan State University East Lansing Experiment Station (EL) in 1997 on a Capac loam (fine-loamy, mixed mesic, Aeric Ochraqualf) and two experiments were established in 1998 and 1999 at the Michigan State University Kellogg Biological Station (KBS) near Hickory Corners, Michigan on a Kalamazoo loam (fine-loamy, mixed mesic, Typic Hapludalfs). Seeding dates were May 14, 1997; May 5,1998 and April 28, 1999 for EL, KBS trial 1 (KBS1) and KBS trial 2 (KBS2), respectively. Seedbed preparation was by conventional tillage, cultipacking and an incorporated preplant herbicide EPTC (s-ethyl dipropylcarbamothioate) at 3.4 kg a.i. ha^{-1}. The experimental design was a randomized complete block with treatments arranged in a split-plot, replicated four times. Whole plots were insecticide treatments and subplots were alfalfa cultivars. Subplots were seeded with a Carter Forage Plot Seeder (Carter Manufacturing Co. Inc., Brookston, IN) at 17.92 kg ha^{-1} PLS inoculated with *Rhizobium meliloti* Dangead in plots consisting of 1.52 x 5.47 m. Borders of treatment blocks were seeded to the PLH susceptible cultivar Vernal in a strip 2.76 m wide. Plots were fertilized based upon the soil test recommendations from the Michigan

State University soil testing laboratory annually with P_2O_5, K_2O, and boron, using a Gandy 1.52 m drop spreader (Gandy Corporation, Inc., Owatonna, MN).

Four pest management treatments were used at KBS (year one/year two): (i) insecticide/insecticide (+,+), (ii) insecticide/non-insecticide (+,-), (iii) non-insecticide/insecticide (-,+), and (iv) non-insecticide/non-insecticide (-,-). The EL study had only insecticide (+) and non-insecticide (-) treatments. Insecticide treatments at both locations received Cyfluthrin (Cyano(4-fluoro-3-phenoxyphenl)-methyl-3-(2,2 dichloroethenyl)-2,2 dimethylcycopropane carboxylate) at a rate of 0.028 kg a.i. ha^{-1} applied biweekly from June to August with a backpack sprayer. Cultivars selected for the KBS trials were W-L Research cv. 'W L324', Agway/Allied Seed cv. 'Cleansweep 1000', Pioneer cv. '54H69', and Forage Genetics experimental cv. '3A14B' which represent one susceptible and three levels of resistance; 28, 45 or 60 %, respectively. W L 324 was selected as the susceptible check to represent current high yielding commercially available non-resistant cultivars. The EL study consisted of 8 commercial Potato leafhopper resistant (PLHR) cultivars, 6 experimental PLHR cultivars, and 4 non-resistant cultivars. In the seeding year of the KBS1, an application of imazethapyr (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid) at 0.0085 kg a.i.ha^{-1} was required to control redroot pigweed (*Amaranthus retroflexus* L.) and common lambsquarter (*Chenopodium album* L.).

POTATO LEAFHOPPER POPULATIONS

The EL study was sampled 26 times, using standard protocol for a 0.38 m diameter sweepnet, during the growing season from May 1998-Aug 2000. Potato leafhopper density at KBS was monitored using a 25 by 34 cm plastic water pan. Leafhoppers were sampled by two people that stood opposite each other in the 0.3 m alley between plots, at the center of the length of the plot. The sampling tray was held vertically and was swept in unison over the top of the plot, such that the long-edge of the tray touched the growing tips of the alfalfa. To avoid further bias, the same people collected data throughout the season. Nymphs on the tray were counted with six sampling events in 1998, nine sampling events in 1999, and nine sampling events in 2000. Non-insecticide treated border areas were monitored with the aforementioned sweepnet method and both nymph and adult PLH were counted and plant height was recorded.

FORAGE YIELD AND MATURITY

A Carter flail harvester (Carter Manufacturing Co. Inc., Brookston, IN) was used to harvest 1.22 by 4.56 m plots at a cutting height of 8.9 cm from the soil surface. Moisture content of harvested alfalfa was determined by collecting pre and post weights of a 500g sample of the harvested alfalfa dried at 60 degrees C for 72 hours. Maturity was determined by visual observation at KBS and reported as the percentage of buds or flowers present at harvest. To reduce bias the same person collected maturity data at each harvest.

FORAGE QUALITY

Samples of alfalfa used for nutritive evaluation were collected at the time of harvest by clipping ~250 g of alfalfa from each plot prior to harvest. Samples were dried at 60° C for 48 hours, ground to pass through 2mm screen in a Wiley Grinding Mill (Philadelphia, PA) and passed through a UDY Cyclone Mill (Fort Collins, CO.) with a 1 mm screen. A sub-sample of ~20 grams was retained for nutritive analysis. Each sample was scanned with a 6500 near-infrared spectrophotometer (FOSS NIRSystems, Inc., Silver Spring, MD) with wavelengths between 800 and 2500 nm. Reflected wavelengths were recorded.

A subset of samples was selected using the Select program from WinISI software (Infrasoft International, LLC., Port Matilda, PA.) to create equations for prediction of crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF). Total nitrogen was determined for the subset by the Hach modified Kjeldahl procedure (Watkins et al., 1987), and CP was estimated by multiplying total N by 6.25. The Goering and Van Soest (1970) method was used for NDF and ADF determination with the addition of one ml of alpha-amylase to the neutral detergent solution for the breakdown of starch. Dry matter (DM) content was determined by drying 0.5 g of sample in ceramic crucibles at 100°C for 12 hrs. The samples were then ignited in a muffle furnace at 500 degree C for 6 hrs to determine ash content.

STAND PERSISTENCE

Stand persistence was determined by plant counts that were made in the fall of the final year of each trial. A sod-cutter was used to remove crowns from a 0.45-m2 area of each plot and a 0.093 m^2 sampling square was randomly placed over two rows within the cut area. All taproots within the 0.093 m^2 sampling square were counted and recorded.

STATISTICAL ANALYSIS

Analysis of variance (ANOVA) was performed on yield, forage quality, and plant count data with Proc Mixed (SAS Institute, 2000) using the Kenward-Roger method for determining degrees of freedom. The cultivar and insecticide treatment were considered fixed effects, while replication and replication*spray treatment were considered random effects. Potato leafhopper count data was transformed when necessary via log (nymph + 1) and maturity ratings were transformed via arc sine to meet ANOVA assumptions for distribution. When significant effects of treatment occurred, means were compared using Fischer's Least Significant Difference. Proc Reg of SAS was used for regression analysis. Unless otherwise stated, differences were considered significant at an alpha level of 0.05.

RESULTS AND DISCUSSION

EXPERIMENTAL ENVIRONMENTAL CONDITIONS AND POTATO LEAFHOPPER POPULATION

The East Lansing study received slightly below normal precipitation in the 1997, 1998 and 1999 growing seasons, while 2000 precipitation exceeded the 30 yr. average (Figure 1).

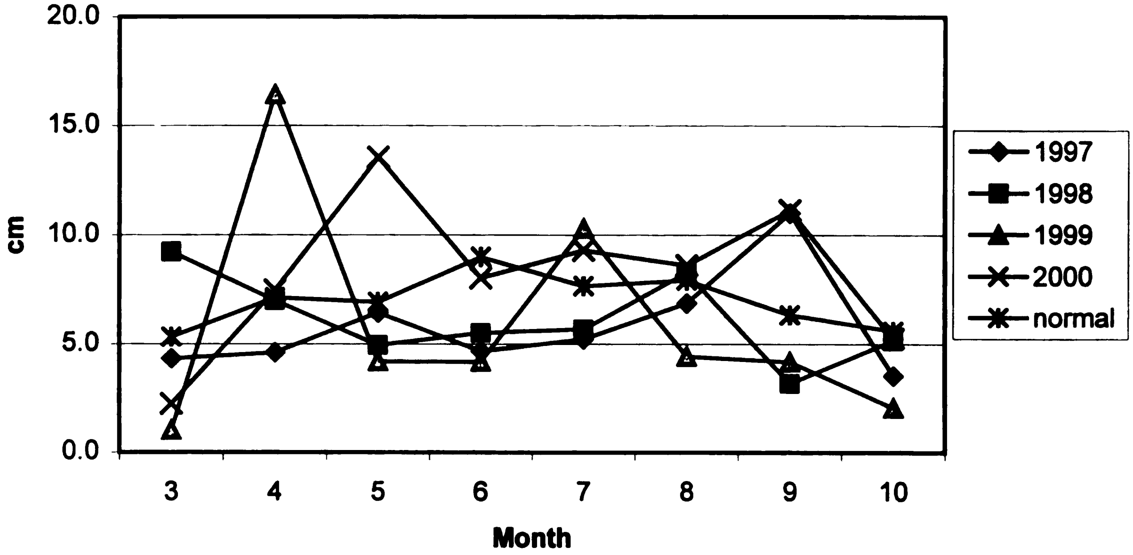

Figure 1. Precipitation East Lansing Experiment Station, MI, March to October 1997-2000.

Precipitation at KBS in the 1998 and 1999 growing seasons was below normal (Figure 2). The 1998 study was planted in an area of variable soil moisture conditions that contributed to higher than normal yield variation in seeding year due to below normal precipitation. Excessive precipitation in the 2000 growing season coincided with low PLH population. There were low alfalfa weevil (*Hypera postica* [Gyllenhal]) populations in all years of the trial and no evidence of non-uniform disease patterns.

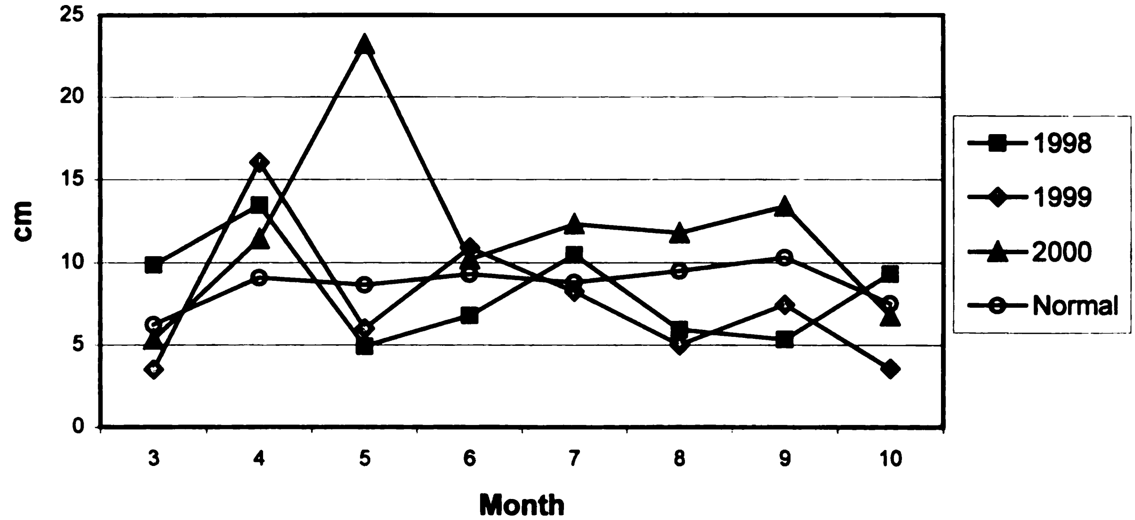

Figure 2. Precipitation Kellogg Biological Station, Hickory Corners, MI, March to October 1998-2000.

Potato leafhopper population at EL was highest in July 1999, with economic thresholds for treatment (the level at which control action was necessary to prevent PLH injury from reaching the economic injury level) exceeded in four of the 24 sampling events (Figure 3). PLH economic thresholds were considered exceeded when 0.2, 0.5, 1.0 and 2.0 adults/sweep were sampled at a plant height of <7.6, 15.2, 25.4, and 35.6 cm, respectively. This economic threshold is based upon the equation proposed by Pedigo et al. (1999) with the cost of insecticide spray at \$24.70 ha^{-1} and a hay value of \$91 Mg^{-1}. The average count in the three peak density periods was 1.6 PLH/sweep.

Potato leafhopper populations varied in all three years of the study at KBS (Figure 4). Pan sampling events commenced after the first PLH were found in the border areas in the following manner: six events in 1998, ten events in 1999 and eight events in 2000.

The first recorded PLH in the study occurred on June 4, May 18, June 1 for 1998, 1999 and 2000, respectively. Potato leafhopper counts were low in all but five of the 21 sampling events, which were the sampling events prior to: cut 1, 1998 and cut 2 and 3, 1999 of KBS1 and cut 1, 1999 of KBS2. The average PLH counts in the peak population periods were 6.8 PLH nymphs/pan sweep within the non-insecticide plots and 4.9 PLH/sweep in the border areas. Regression analysis of PLH nymphs per pan sweep (pan method) and PLH adults per net sweep (sweepnet method) was not possible because the same area was not sampled with both methods. However, unpublished data from a four-state study shows a significant relationship between the two sampling methods.

Potato leafhopper populations in 1998 and 1999 peaked prior to the first cutting seeding (Figure 5). Insecticide treatments had 82% fewer PLH than non-insecticide treatments and the non-insecticide treatment of the susceptible cultivar had higher PLH counts than either the 45 or 60% resistant cultivars. These results concur with the results of Lefko et al. (2000a), that in periods of high PLH density, PLHR cultivars will have fewer PLH when compared to susceptible cultivars. Significant ($P<0.0001$, $P=0.0004$) relationships between PLH nymph density and PLH resistance level occur in both of these peak periods (Figure 7 and 8). Heavy rainfall events (Figure 2) decreased PLH numbers in 2000 with counts (Figure 6) not exceeding economic threshold for insecticide treatment (Figure 4). These data from 2000 support the conclusions of Decker and Cunningham (1967) that excessive rainfall reduces PLH numbers by decreasing feeding occurrence and oviposition. Since potato leafhopper populations were greatest in 1999;

this is the year that will be the focus of the yield, quality, and stand persistence results from KBS.

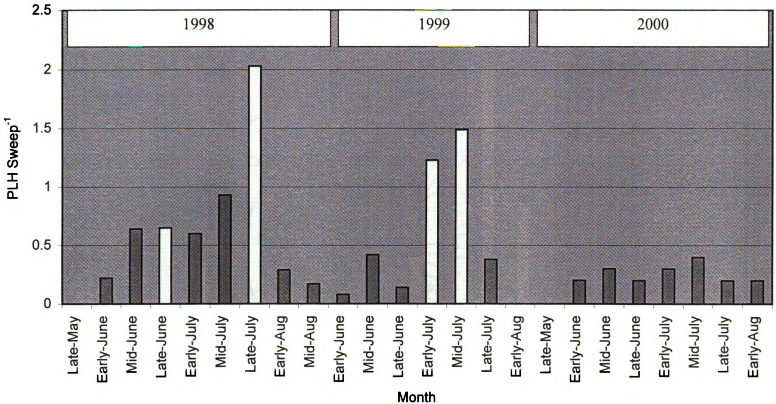

Figure 3. PLH densities (PLH per sweep) of non-insecticide susceptible in East Lansing 1998-2000 (Yellow bars signify sampling intervals exceeding economic threshold).

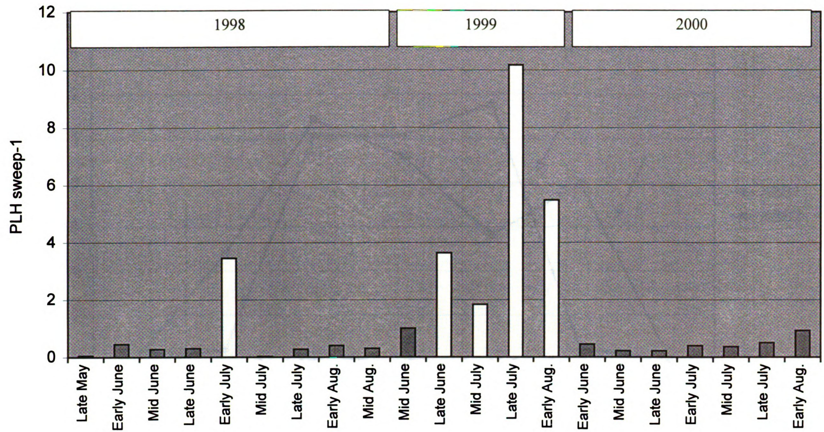

Figure 4. PLH densities (PLH per sweep) of non-insecticide susceptible border areas at KBS in 1998-2000 (Yellow bars signify sampling intervals exceeding economic threshold).

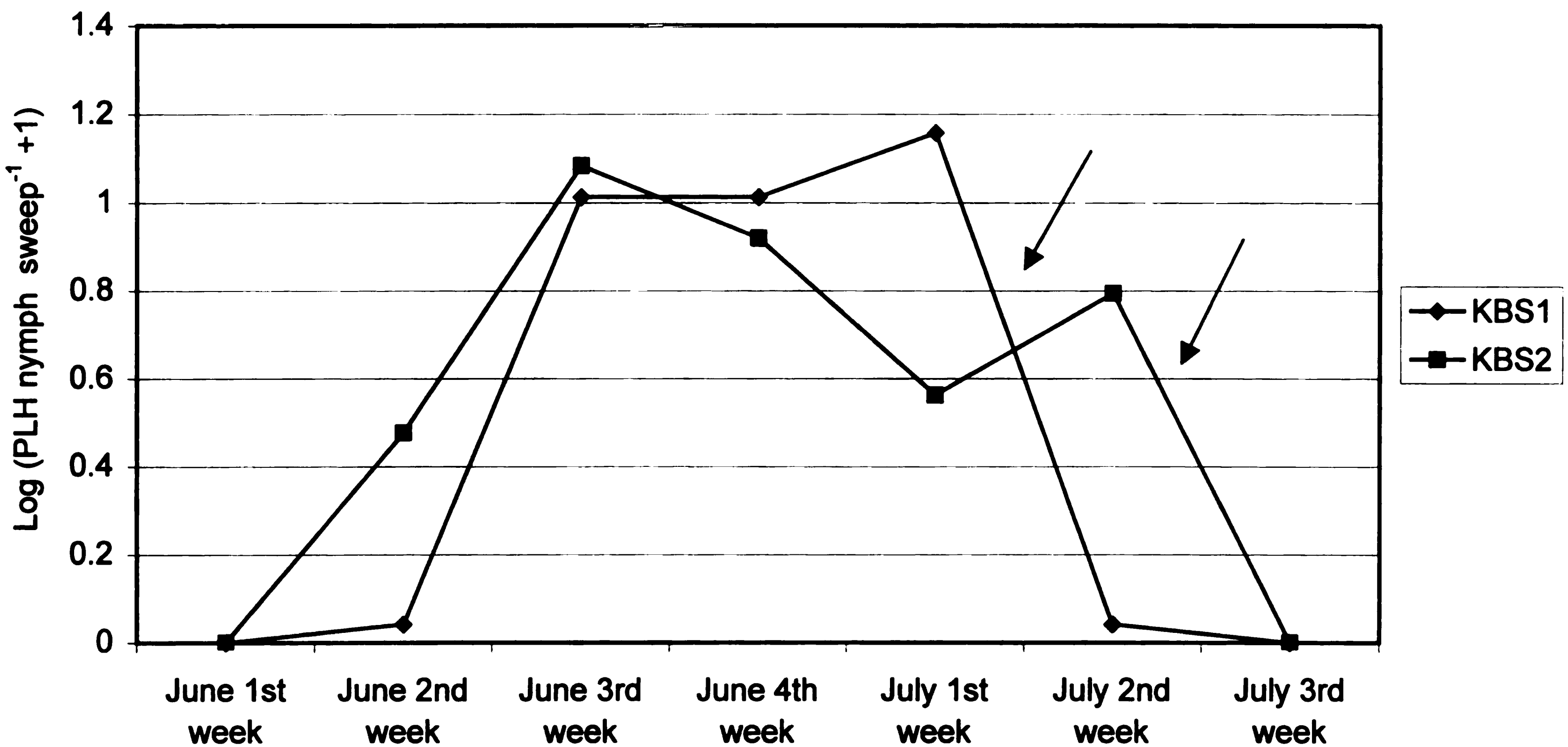

Figure 5. Potato leafhopper nymph density (log [PLH nymph per pan sweep+1]) at KBS in the seeding year within the non-insecticide treatment (arrows indicate harvest).

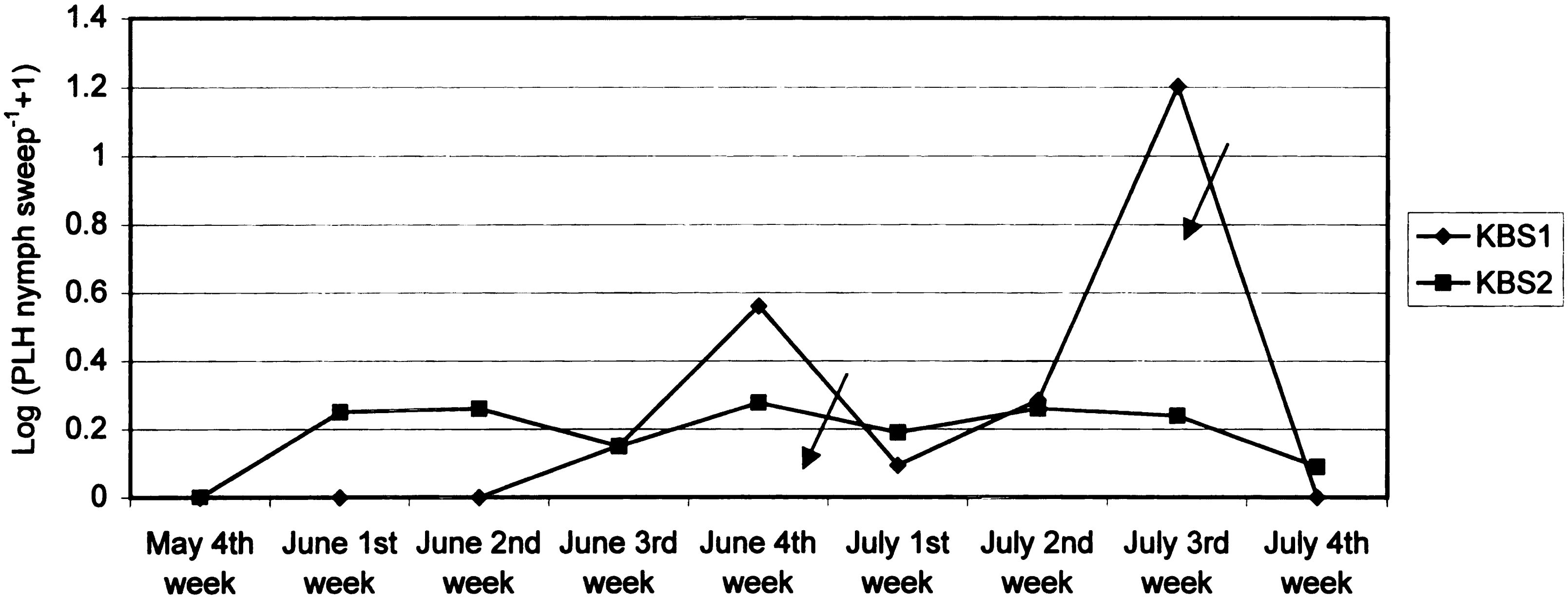

Figure 6. Potato leafhopper nymph density (log [PLH nymph per pan sweep+1]) at KBS in the second year within the non-insecticide plots (arrows indicate harvest).

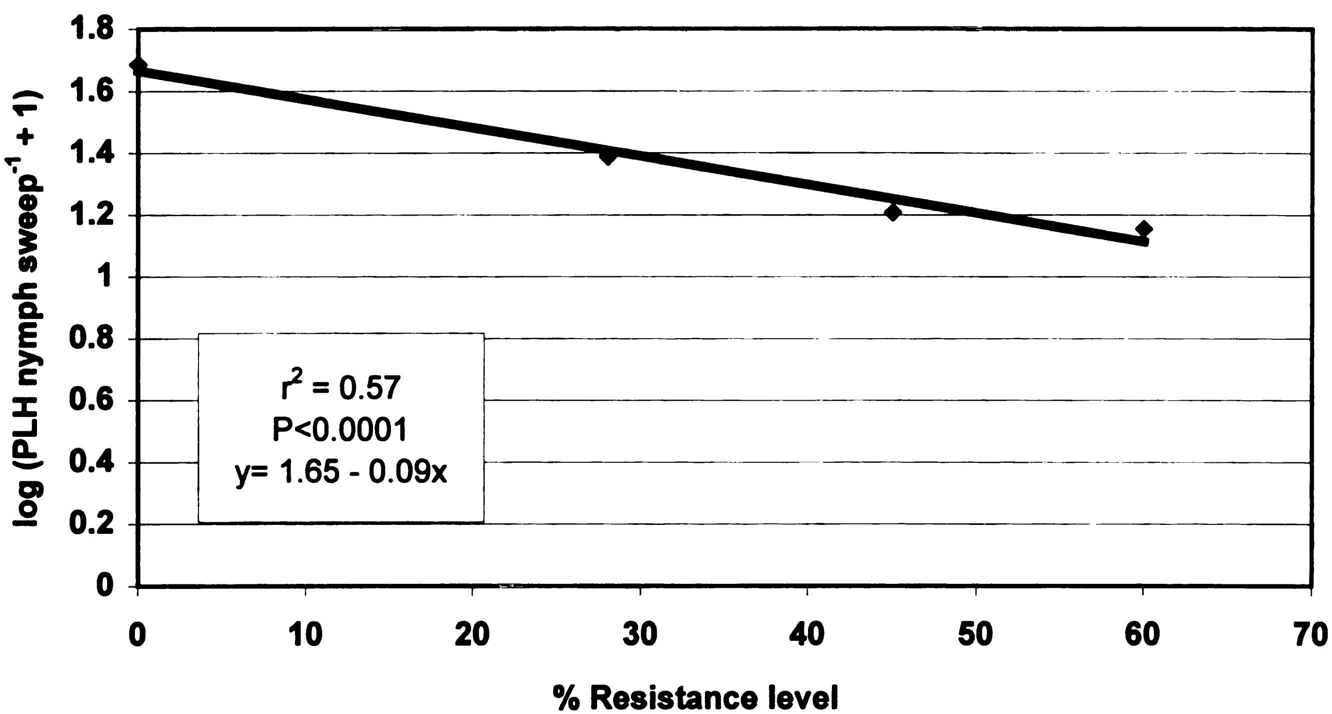

Figure 7. Alfalfa cultivar resistance level effects on PLH density (log [PLH nymphs per sweep +1]), KBS2 in July of the seeding year within the non-insecticide treatment.

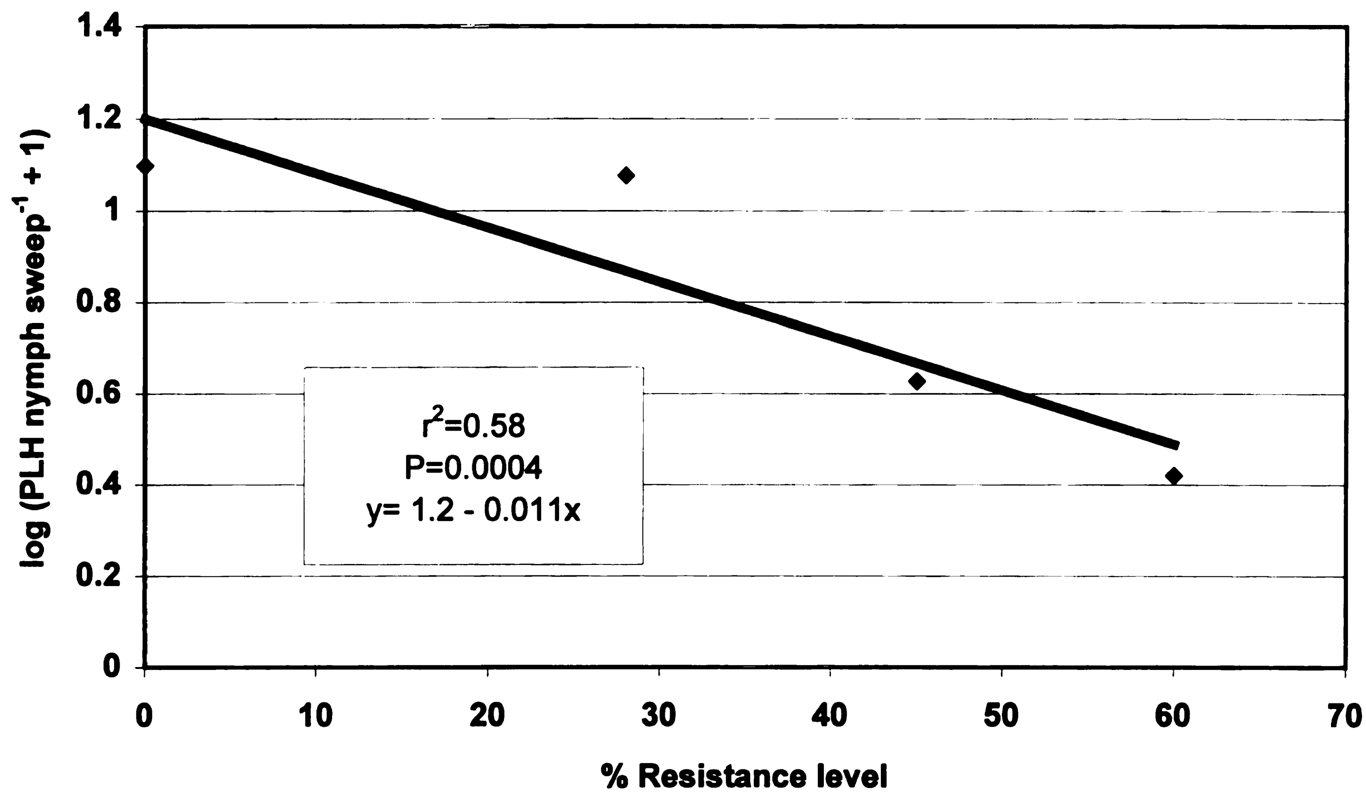

Figure 8. Alfalfa cultivar resistance level effects on PLH density (log (PLH nymph per sweep +1), KBS1 in June of the second year within the non-insecticide treatment.

YIELD

Although yield was collected from twenty-five harvests in the three studies, economic thresholds for insecticide treatment were only exceeded in seven harvests including: EL, cut 2 and 3, 1998 and cut 3, 1999; KBS1 cut 1, 1998 and cuts 2 and 3, 1999; and KBS2 cut 1, 1999. Insecticide treated cultivars in EL resulted in greater yields (3.25 Mg ha^{-1}) than non-insecticide cultivars; however yields of PLHR cultivars were not significantly different than susceptible within the non-insecticide treatment (Table 2). The two-year total yields means were 13.35 and 13.95 Mg ha^{-1} for KBS1 and KBS2, respectively. While an additional cutting was taken in KBS1, KBS2 produced greater yields due to above average rainfall in 2000. Yield from KBS is presented within a cutting due to varied PLH population pressures between cuttings.

Seeding Year

Means of alfalfa yield in the seeding year were 2.64 Mg ha^{-1} (2 cuts) and 1.63 Mg ha^{-1} (1 cut) for KBS1 and 2, respectively. The first cutting in the both seeding years at KBS were taken in the mid bloom growth stage to allow accumulation of non-structural carbohydrates in the alfalfa roots.

KBS1

In the seeding year, PLH population was high; however, variable soil moisture conditions within the trial had a greater effect than PLH damage on yield. Seeding year yields averaged 2.98 and 2.55 Mg ha^{-1}, for the insecticide treated and non-insecticide treated cultivars, respectively.

KBS2

A single harvest was taken in the seeding year following above-average PLH populations. Alfalfa dry matter yield was 79% higher in the insecticide treated treatments (2.29 Mg ha^{-1}) than in the non-insecticide treatments (1.35 Mg ha^{-1}) (Table. 4). These data are supported by several studies on the deleterious effects of PLH on forage yield (Smith and Poos, 1931; Lamp et al., 1991; Undersander et al. 1994; Hutchins et al., 1990; Lefko et al., 2000). Yields did not differ significantly between cultivars sprayed with insecticide; however, within the non-insecticide treated cultivars, the yield of the susceptible and 28% resistant cultivars were less than that of 45 and 60% resistant cultivars. The corresponding plant height of the non-insecticide treated cultivars from 1999 correlate with the dry matter yields (r=0.78) with an average height of resistant cultivars at 33.3 cm compared to the height of the susceptible cultivar at 24.7 cm (Table 5).

Second Year

The carryover effect of PLH damage in the seeding year was apparent in the second year with greater dry matter yield in the +/+ treatment compared to the -/+ treatment in the first cutting (Table 6). However, there were no significant difference between yield of the resistant cultivars and the susceptible cultivar in the first cutting within the -/+ treatment (Table 7). This may suggest that even the highest level of resistance tested (60%) sustained injury in the seeding resulting in dry matter yield loss in the subsequent year.

KBS1

With lower PLH population at the time of cut 2, both the 45 and 60% PLH resistant cultivars resulted in significantly higher yield than the susceptible cultivar with non-insecticide treatment. PLH population increased from May through July, with peak population occurring during the regrowth of cut 3 (Figure 5). Within the non-insecticide treatment, the yield of the 60% PLH resistant cultivar was 0.8 Mg ha^{-1} greater yield than the susceptible cultivar. These data suggest that under high PLH populations, a PLH-resistance level of at least 60% is necessary to prevent yield reduction when no insecticide is used. (Table 8).

KBS2

Potato leafhopper density was low throughout the 2000-growing season; however, significantly lower yields resulted from the -/- treatment. The interaction of treatment * cutting permits slicing by cutting; however, PLH populations were not high enough in any cutting to invoke decreased yields in the susceptible cultivar (Table 10).

Table 2. Cultivar effects on forage yield (Mg ha^{-1}) of PLHR and four susceptible check alfalfa cultivars, seeded 1997 at East Lansing.

Entry	2000 Non-insecticide	2000 Insecticide	1999 Non-insecticide	1999 Insecticide	1998 Non-insecticide	1998 Insecticide	1997 Non-insecticide	1997 Insecticide	3-yr Total Non-insecticide	3-yr Total Insecticide
					DM Mg ha^{-1}					
Commercial PLHR										
Rhino	11.38	12.43	12.84	13.62	15.16	15.21	5.31	6.16	42.56	45.36
5347 LH	10.89	11.51	11.87	13.22	14.45	14.34	6.00	6.12	41.44	43.30
Clean Sweep 1000	10.44	11.45	12.07	12.16	14.58	14.20	5.44	5.80	40.03	41.17
Arrest	10.89	11.74	11.16	12.59	14.65	14.58	5.40	6.00	39.74	42.87
Interceptor	10.64	11.22	11.24	12.59	14.04	13.96	5.44	5.76	39.33	42.36
Safegaurd	10.19	11.60	11.04	12.79	14.09	14.54	5.35	5.62	38.75	44.04
Ameriguard 301	10.44	11.29	11.04	13.64	13.48	15.16	5.15	6.14	38.15	44.04
DK 121 HG	9.99	11.51	11.29	12.30	12.88	14.02	5.35	6.05	37.56	41.57
8-variety average	10.62	11.60	11.58	12.86	14.16	14.49	5.44	5.96	**39.69**	43.08
Experimental PLHR										
DS 9710	10.86	11.87	11.54	13.26	14.45	14.83	5.24	5.89	39.69	43.86
4R30 A	10.55	11.42	11.16	12.12	14.22	13.78	5.47	5.67	39.27	41.04
4R25 A	10.98	11.67	11.38	12.54	13.82	14.74	5.33	6.12	39.33	43.10
CW 6035	10.66	11.40	10.95	12.19	13.75	13.96	5.44	6.27	38.60	41.69
CW 6043	10.93	12.01	11.36	13.06	13.42	14.56	5.26	6.05	38.64	43.46
CW 6034	10.57	11.96	10.95	12.99	13.37	14.65	5.11	5.91	37.65	43.48
6-variety average	10.75	11.72	11.22	12.70	13.84	14.43	5.31	5.98	**38.86**	42.76
Non-Resistant Check Varieties										
Magnum III WET	12.21	12.66	12.66	13.78	14.31	14.36	5.49	6.05	42.54	45.00
Innovator + Z	11.83	12.41	12.36	13.66	14.07	15.21	5.56	6.25	42.67	45.65
Pioneer 5454	11.76	12.72	12.19	13.35	14.09	14.63	5.33	6.29	41.37	44.98
Vernal	11.33	11.98	11.16	11.78	14.20	13.31	5.15	5.38	39.58	40.39
4-variety average	11.78	12.45	12.10	13.15	14.18	14.38	5.38	6.00	**41.55**	44.02
18-variety mean	10.91	11.83	11.56	12.86	14.09	14.45	5.38	5.98	39.80	43.05
5% LSD										
treatments	0.18		0.36		0.96		0.09		0.60	
cultivar within trtmnt	0.83	0.60	1.21	1.16	1.34	1.25	0.40	0.54	2.64	1.11
CV (%)	4.92		8.96		6.79		6.2		4.4	

Table 3. Cultivar effect on forage yield (Mg ha^{-1}) in the seeding year of KBS1.

		Yield	
Harvest	Cultivar	Insecticide	Non-insecticide
1	Susceptible	1.61	1.43
	28%	1.55	1.55
	45%	1.48	1.50
	60%	1.75	1.48
	LSD (0.05)		
	Within spray trtmnt	NS	NS
	Between spray trmnts	NS	
2	Susceptible	1.23	1.05
	28%	1.37	1.12
	45%	1.48	0.96
	60%	1.43	1.05
	LSD (0.05)		
	Trtmnt	NS	
	Cv. (trtmnt)	NS	NS

Table 4. Cultivar effects on forage yield ($Mgha^{-1}$) in the seeding year of KBS2 (Different letters indicate significant differences at P=0.05)

		Yield	
Harvest	Cultivar	Insecticide	Non-insecticide
1	Susceptible	2.29	0.92 b
	28%	2.07	1.16 ab
	45%	2.05	1.29 a
	60%	2.05	1.35 a
	Mean	2.12	1.18
LSD (0.05)			
treatment		0.8	
Cv.(trtmnt)		NS	0.28

Table 5. Cultivar effects on plant height (cm) in the seeding year of KBS2 (Different letters indicate significant differences at P=0.05).

		Height	
Harvest	Cultivar	Insecticide	Non-insecticide
1	Susceptible	44.2	24.9c
	28%	40.6	29.5b
	45%	43.9	35.1a
	60%	44.2	35.6a
	Mean	43.2	31.2
LSD (0.05)			
treatment		1.09	
Cv.(trtmnt)		NS	1.4

Table 6. Treatment effects on yield (Mg ha^{-1}) in the second year of both trials at KBS.

Treatment	Cut 1	Cut 2	Cut 3	Cut4
+/+	3.90	2.97	2.59	2.20
+/-	3.95	2.84	2.56	2.51
-/+	3.42	2.81	2.42	2.30
-/-	3.28	2.79	2.45	2.41
LSD (0.05)	0.42	NS	NS	NS

Table 7. Cultivar effects on yield (Mg ha^{-1}) within the -/+ treatment for cut 1 in the second year of KBS2.

Treatment	Cut 1
Susceptible	3.51
25%	3.20
45%	3.09
60%	3.34
LSD (0.05)	NS

Table 8. Cultivar effects on forage yield (Mg ha^{-1}) in -/- treatment in the second year of KBS1 (Different letters indicate significant differences at P=0.05).

Cultivar	Cut 2	Cut 3
Susceptible	1.59 b	2.42 b
28%	2.22 ab	2.55 b
45%	2.34 a	2.59 b
60%	2.46 a	3.24 a
LSD (0.05)	0.73	0.54

Table 9. ANOVA for all cuttings in 2000, showing the effect of spray treatment and cultivar resistance on forage yield in the second year of KBS2.

Source	Ndf	Ddf	F value	P>F
Cultivar	3	180	12.24	0.0001
Treatment	3	9	0.92	0.4681
Trtmnt*Cut	3	180	2.55	0.0088
Cv*Cut	9	180	0.94	0.4906
Cv*Trtmnt	9	180	0.58	0.8086
Cv*Trtmnt*Cut	27	180	0.27	0.9999

Table 10. Cultivar effects on forage yield (Mg ha^{-1}) in the second year of KBS2.

	Cut1		Cut2		Cut3		Cut4	
	Insecticide	Non-insecticide	Insecticide	Non-insecticide	Insecticide	Non-insecticide	Insecticide	Non-insecticide
Cultivar								
Susceptible	3.68	3.22	3.66	3.42	2.69	2.17	3.10	2.92
28%	3.24	3.23	3.52	3.33	2.69	2.24	2.92	2.78
45%	3.37	3.20	3.63	3.31	2.46	2.10	2.96	2.65
60%	3.53	2.95	3.84	3.36	2.82	2.29	3.20	2.81
Mean	3.46	3.15	3.66	3.36	2.67	2.20	3.05	2.79
LSD (0.05)								
treatment	NS		NS		NS		NS	
Cv(trtmnt)	NS	NS	NS	NS	NS	NS	NS	NS

GROWTH STAGE

Observations of alfalfa growth stage were taken just prior to harvest on all cuttings of KBS1 and 2 to further explore the effects of PLH on PLHR alfalfa. Growth stage or maturity is expressed as the percentage of plants that exhibited either buds or blooms.

Seeding year

KBS1 and 2

The first harvest in the seeding years was delayed until the alfalfa reached mid-bloom to allow non-structural carbohydrates to increase in the roots. Alfalfa maturity (% bloom) ranged from 28 to 45% flower in the first cutting. The insecticide treated cultivars exhibited more bloom than the non-insecticide treated cultivars in all cuttings in the seeding year. These data support the conclusions of Oloumi-Sadeghi et al., (1998) and Hutchins and Pedigo (1990), that PLH feeding causes delayed maturity. There were no significant differences in maturity among the insecticide treated cultivars (P=0.3886). However, a significant effect (P=0.0204) of cultivar did occur among the non-insecticide treated cultivars. Within the non-insecticide treatment, 45 and 60% resistant cultivars were more mature than susceptible (Table 11). The non-insecticide treatment of the 60% resistant cultivar was not more mature than the insecticide treated susceptible. These data indicate that the impact upon alfalfa maturity from the non-insecticide treated 60% resistant cultivar is equivalent to the insecticide treated susceptible cultivar at this PLH population. These results are as expected, in that, growth stage ratings were assessed by viewing the entire stand, a stand with more resistant plants (less desirable to PLH) should show less signs of delayed maturity.

Second Year

KBS1 and 2

There was no study*cultivar or study*treatment interaction (Table 12), therefore, second year data from KBS1 and 2 studies was combined. The insecticide treated cultivars were 15 % more mature than the than the non-insecticide treated cultivars and the 45 and 60% resistant alfalfa cultivars were more mature than the resistant within the non-insecticide treatment (Table 13).

Table 11. Effect of PLH on cultivar and treatment on growth stage (percent bloom) at harvest for both trials at KBS in the seeding year (Different letters indicate significant differences at *P*=0.05).

		Growth Stage	
	Cultivar	Insecticide	Non-insecticide
KBS1	Susceptible	40	28 b
	28%	41	31 b
	45%	44	36 a
	60%	45	36 a
	Mean	43	33
	LSD (0.05)		
	Treatment	9	
	Cv.(trtmnt)	NS	4.8
KBS2	Susceptible	41	18 b
	28%	40	25 ab
	45%	41	31 ab
	60%	45	36 a
	Mean	42	28
	LSD (0.05)		
	Treatment	7	
	Cv.(trtmnt)	NS	16

Table 12. ANOVA for Growth stage in the second year of KBS1and 2.

Effect	Num DF	Den DF	F value	Pr>F
Treatment	3	160	6.92	0.0002
Cultivar	3	160	5.28	0.0017
Treatment * Cultivar	9	160	0.40	0.9353
Study*Cultivar	3	160	0.68	0.5637
Study*Treatment	3	160	1.03	0.3818
Study*Cultivar*Treatment	9	160	0.45	0.9069

Table 13. Average growth stage (% bud) in the second year of KBS1 and 2 (Different letters indicate significant differences at P=0.05).

	Growth Stage	
Cultivar	Insecticide	Non-insecticide
Susceptible	34	16c
28%	41	22bc
45%	51	33ab
60%	36	45a
Mean	41	29
LSD (0.05)		
Treatment	6	
Cv.(trtmnt)	NS	15

FORAGE QUALITY

Forage quality for all studies ranged from 150 to 290, 180 to 400 and 252 to 515 g kg^{-1}, for CP, ADF and NDF, respectively. Delayed harvests in the seeding year, low moisture conditions and high PLH populations were all factors that contributed to the range of CP, ADF and NDF observed. There was an increase of 8 g kg^{-1} CP in the experimental PLH- resistant cultivars compared to the PLH-susceptible cultivars within the non-insecticide treatment in the EL study (Table 14). However, there were no significant differences observed in fiber levels between the insecticide and non-insecticide treatments (Table 14).

Seeding Year

KBS1 and 2

The results of forage quality in the seeding year were from the two cuttings that were taken in July and August from KBS1, and one cutting that was taken in July from KBS2. Varied PLH populations required comparisons to be made within a study. In KBS1, a significant ($P<0.0001$) treatment * cut interaction occurred (Table 15), hence, crude protein was compared within a cutting and insecticide treatment. Cultivars treated with an insecticide maintained higher CP levels than non-insecticide treated cultivars with differences of 3.3 and 1.3 g kg^{-1} for cut one and two, respectively. These data support the conclusions of Hutchins et al (1989) that high PLH populations adversely affect CP content of alfalfa. The 45 and 60%PLH-resistant cultivars maintained higher CP content than the susceptible cultivar in the non-insecticide treatment in both the first and second cuttings (Table 16). In cut 1, CP content in the non-insecticide treatment of 45 and 60%PLH-resistant cultivars was not different than the insecticide treated susceptible cultivar. However, the insecticide treated 60% PLH-resistant cultivar crude protein was higher than non-insecticide treatment 60% PLH-resistant cultivar. These data may indicate that PLH damage did occur in the resistant cultivars, but to a lesser extent than the susceptible cultivar. In cut 2, CP content was 30 g kg^{-1} higher in the insecticide treated treatments and all PLH-resistant cultivars resulted in higher crude protein than the susceptible cultivar. In the seeding year of KBS1, neutral detergent fiber (NDF) and acid detergent fiber (ADF) were not significantly different between the insecticide treatments. In 1999, crude protein levels were significantly ($P \leq 0.1$) higher in insecticide treatments and, within the non-insecticide treatment, the 60% resistant cultivar crude protein was significantly ($P \leq 0.05$) higher than the susceptible cultivar. There were no differences in ADF or NDF between insecticide treatments.

Second Year

KBS 1 and 2

The only significant effect of the insecticide treatment or cultivar was in the second and third cuttings of KBS1. Cultivars within the insecticide treatment resulted in greater CP content than those cultivars within the non-insecticide treatment. Within the non-insecticide treatment, the 60%PLH-resistant cultivar resulted in greater CP content than the other cultivars in cut two. In cut three, both the 45 and 60% PLH-resistant cultivars had greater CP content than the susceptible cultivar (Table 18). There were no differences in ADF or NDF between insecticide and non-insecticide treatments.

Table 14. Crude protein, acid detergent fiber, neutral detergent fiber (g kg^{-1}) 3-yr. averages for PLH-resistant and check cultivars seeded in East Lansing.

Entry	Forage Quality 3 yr. averages Untrt CP	Untrt ADF	Untrt NDF	Trt CP	Trt ADF	Trt NDF
Commercial Resistant Varieties						
Rhino	209	288	385	216	288	380
Arrest	214	278	370	220	277	368
Cleansweep 1000	214	281	373	220	276	366
5347 LH	210	284	380	215	282	378
Safegaurd	214	275	372	218	281	372
Interceptor	210	279	375	212	291	386
Ameriguard 301	212	278	370	217	286	378
DK 121 HG	216	275	367	219	278	369
8-variety average	212	280	374	217	282	375
Experimental Resistant Varieties						
DS 9710	209	280	376	218	283	375
4R30 A	221	273	366	222	277	367
4R25 A	219	273	365	219	279	369
CW 6035	215	277	373	220	278	370
CW 6043	215	278	371	219	283	377
CW 6034	214	274	369	218	279	364
6-variety average	216	276	370	219	280	370
Non-Resistant Check Varieties						
Magnum III WET	206	286	382	210	294	393
Vernal	211	284	384	212	288	386
5454	204	290	390	209	298	394
Innovator + Z	212	281	380	217	286	380
4-variety average	208	285	384	212	292	388
18-variety mean	212	280	375	217	283	376
5% LSD variety	4	7	8	3	6	8
between spray treatments						
CP			1.9			
ADF			NS			
NDF			NS			
CV (%)	1.4	2	2	1.2	1.7	1.6

Table 15. ANOVA for cuts 1 and 2 in 1998 and cuts 2 and 3 in 1999 of KBS1.

Source	Ndf	Ddf	F value	P>F
Cultivar	3	180	34.68	0.0001
Treatment	3	9	2.68	0.1101
Cv*Cut	9	180	1.85	0.0620
Trtmnt*Cut	9	180	7.62	0.0001
Cv*Trtmnt	9	180	2.16	0.0272
Cv*Trtmnt*Cut	27	180	0.81	0.7410

Table 16. Cultivar effects on crude protein content (g kg^{-1}), KBS1 in the seeding year (Different letters indicate significant differences at *P*=0.05).

		CP g kg^{-1}	
	Cultivar	Insecticide	Non-insecticide
Harvest 1	Susceptible	249	218 b
	28%	255	223 ab
	45%	255	238 a
	60%	257	236 a
LSD (0.05)		NS	17
Harvest 2	Susceptible	228 b	214 b
	28%	239 a	227 a
	45%	237 a	234 a
	60%	240 a	234 a
LSD (0.05)		8	11

Table 17. The effect of PLH on crude protein content (g kg^{-1}) in the seeding year, KBS2 (Different letters indicate significant differences at *P*=0.05).

		CP g kg^{-1}	
Harvest	Cultivar	Insecticide	Non-insecticide
1	Susceptible	197	170 b
	28%	191	175 b
	45%	196	182 ab
	60%	201	188 a
LSD (0.05)			
	Between treatments	5	
	Cultivar(treatment)	NS	12

Table 18. The effect of cultivar on crude protein content (g kg-1) within the Non-insecticide treatment, KBS1 at KBS in the second year (Different letters indicate significant differences at *P*=0.05).

	Cut1	Cut2	Cut3	Cut4
Cultivar	CP g kg^{-1}			
Susceptible	190	220 b	181 c	191
28%	191	220 b	196 b	200
45%	188	229 ab	209 a	198
60%	190	238 a	208 ab	201
LSD (0.05)	NS	11.7	12	NS

STAND PERSISTENCE

There was no significant difference in stand persistence between insecticide treatments or cultivars in any trial in the East Lansing study (Table 19 and 20). Insecticide treated cultivars resulted in an average of 14 plants per 0.09 m^2 while non-insecticide treatments resulted in an average of 12.5 plants per 0.09 m^2. In the KBS studies, insecticide treated cultivars resulted in an average of 15 plants per 0.09 m^2 while non-insecticide treatments resulted in 15.5 plants per 0.09 m^2. Although there was no apparent decrease in stand persistence in the three years of these studies, multiple years of high PLH density may have a greater effect on susceptible alfalfa cultivars as compared to PLHR alfalfa cultivars when PLH are not controlled with an insecticide.

Table 19. ANOVA for stand persistence at EL.

Source	Ndf	Ddf	F value	P>F
Cultivar	7	102	0.88	0.5956
Treatment	1	6	1.98	0.2090
cultivar*trt	17	102	0.98	0.4869

Table 20. ANOVA for stand persistence at KBS.

Source	Ndf	Ddf	F value	*P*>F
Cultivar	3	93	0.18	0.9105
Treatment	3	93	0.73	0.5390
cultivar*trial	3	93	1.22	0.3065
trt*trial	3	93	0.63	0.5943
cultivar*trt	9	93	0.84	0.5844
cv*trt*trial	9	93	0.51	0.8648

AN ECONOMIC ASSESSMENT OF PLHR ALFALFA CULTIVARS

A comparison of cultivars within low (<30% of economic threshold) and high (exceeding economic threshold) PLH population years was made to determine the net benefit/loss of using PLHR alfalfa cultivars. This comparison combines the effects of PLH on forage yield and quality. Yield and quality data from the seeding year of KBS1 and KBS2 were used for the low and high PLH population scenarios, respectively. In the subsequent year, KBS2 data was used for the low population and KBS1 data was used for the high population. Due to seasonal differences, comparisons should not be made between PLH population levels. Assumptions were made that growers would apply insecticide in periods of high PLH populations and the cost of spray (\$24.00 ha^{-1}) and cost of field scouting (\$12.00 ha^{-1}) were expensed for this scenario, while only field scouting was expensed in the low PLH population scenario. The value of the hay (72.60 Mg^{-1}) was based upon an eight-year average (1992-2000) (Michigan Agriculture Statistics Service, 2001) and was adjusted (+/-\$2.90 Mg^{-1} for each point (CP) derivation from the insecticide treated susceptible check) for crude protein content. The economic analysis is split by year (seeding v. subsequent) because the resistant cultivars appeared to perform better in the subsequent year. *Expected net returns* were determined by multiplying yield by the hay value as adjusted for CP content. Field scouting and insecticide treatment was expensed in the high PLH population scenario.

Comparison of Economic Returns at KBS

The seed cost of the PLHR alfalfa cultivars is currently equal to top-susceptible cultivars, in addition, there is no evidence of decreased yield or quality in the PLHR cultivars based upon this research. Therefore, there is no economic reason for growers to continuing using susceptible cultivars. There are still questions about the continued use of insecticide in PLHR cultivars. Is there a benefit to spraying PLHR cultivars when PLH populations are high? Data from these studies on the effect of high PLH density in the seeding year upon yields and CP content clearly indicate the need for spray for both PLHR and susceptible cultivars. The income advantage of the insecticide treated susceptible over the untreated 60% resistant cultivar was \$35.90 ha^{-1}. The advantage of the insecticide in the subsequent year is diminished, possible due to increased expression of resistance. Yields of the non-insecticide treated 60% resistant cultivar in cut two and three of the second year are not significantly lower than the insecticide treated susceptible; however, there was a slight advantage in CP content for the insecticide treated susceptible. This CP content advantage was not enough to offset the additional cost of field scouting (\$12.00 ha^{-1}) and spray (\$24.00 ha^{-1}) resulting in a greater (\$5.40 ha^{-1}) net benefit for the non-insecticide treated 60 % resistant cultivar.

In the seeding year, there was no significant difference in net return. Seeding year spray action (Table 21) was based on the economic threshold that was exceeded for all cultivars in the high population scenario. The yield (Table 22) and CP content (Table 23) were not significantly different within a PLH population; therefore, the expected alfalfa price (Table 24) would not be different between cultivars.

In the second year, net return under high PLH population was greatest for the 60% resistant cultivar. Fewer PLH were found in the 60% resistant cultivar under high PLH population, so insecticide was not applied in this scenario (Table 27). Yield (Table 28) and CP content (Table 29) of the non-insecticide treated 60% resistant cultivar was not significantly different from the insecticide treated susceptible which resulted in expected alfalfa values (Table 30) that were also not different. Since insecticide was not applied to the 60% resistant cultivar the cost of insecticide was not expensed (Table 31), resulting in a greater net return (Table 32) for the resistant cultivar.

Table 21. Seeding year insecticide spray action (Y=spray, N=no spray) based upon economic threshold (ET) in susceptible border.

	PLH Populations	
Resistance level	Low	High
0	N	Y
28	N	Y
45	N	Y
60	N	Y

Table 22. Seeding year expected yield (Mg ha^{-1}) based upon insecticide spray decision.

	PLH Populations	
Resistance level	Low	High
0	1.43	2.29
28	1.53	2.07
45	1.49	2.05
60	1.47	2.05

Table 23. Seeding year expected alfalfa CP content (g kg^{-1}) based upon spray decision.

	PLH Populations	
Resistance level	Low	High
0	218	197
28	223	191
45	238	196
60	236	201

Table 24. Seeding year expected alfalfa price ($\$$ Mg^{-1}) based upon CP content.

	PLH Populations	
Resistance level	Low	High
0	64.20	72.60
28	65.60	70.86
45	70.00	72.31
60	69.40	73.76

Table 25. Seeding year expected cost ($\$$ ha^{-1}) based upon insecticide spray decision

	PLH Populations	
Resistance level	Low	High
0	12	36
28	12	36
45	12	36
60	12	36

Table 26. Seeding year expected net return ($\$$ ha^{-1}) given insecticide spray decision

	PLH Populations	
Resistance level	Low	High
0	80	130
28	88	110
45	92	112
60	90	115

Table 27. Post-Seeding year insecticide spray action (Y=spray, N=no spray) based upon economic threshold (ET).

	PLH Populations	
Resistance level	Low	High
0	N	Y
28	N	Y
45	N	Y
60	N	N

Table 28. Post-Seeding year expected yield (Mg ha^{-1}) based upon insecticide spray decision.

	PLH Populations	
Resistance level	Low	High
0	2.77	3.23
28	2.63	2.81
45	2.46	3.00
60	2.77	3.24

Table 29. Post-Seeding year expected alfalfa CP content (g kg^{-1}) based on insecticide spray decision.

	PLH Populations	
Resistance level	Low	High
0	227	202
28	229	179
45	234	192
60	240	208

Table 30. Post-Seeding year expected alfalfa price ($ Mg^{-1}) based upon CP content.

	PLH Populations	
Resistance level	Low	High
0	71.73	72.60
28	72.31	69.70
45	73.76	72.02
60	75.50	74.34

Table 31. Post-Seeding year expected cost ($ ha^{-1}) based upon insecticide spray decision.

	PLH Populations	
Resistance level	Low	High
0	12	36
28	12	36
45	12	36
60	12	12

Table 32. Post-Seeding year expected net return ($ ha^{-1}) given insecticide spray decision.

	PLH Populations	
Resistance level	Low	High
0	187	199
28	178	179
45	169	200
60	197	228

CONCLUSIONS

Potato leafhopper injury of alfalfa was inversely related to PLH–resistance level in cultivars in sampling periods when PLH population was high. Significantly more PLH were found in the susceptible and 28% PLH-resistant cultivars than the 45% and 60%PLH-resistant cultivars, explaining the higher yields of the later. Assessment of the four cultivars under the -/- insecticide treatment reveals a yield, phenological development, and CP content advantage for the 60% PLH-resistance level in time periods with high PLH density. Observations of phenological development are important because slowed development, as a result of PLH-induced changes, alter harvest schedules and reduce root carbohydrate level regeneration (Huthchins et al. 1990). There was no advantage in yield with the PLH-resistant cultivars under the insecticide treated treatments. A minimal PLH resistance level of approximately 45% may be required to protect alfalfa against PLH feeding to obtain higher yields and maintain crude protein content. Stand persistence, in the three years of the 1998 seeding and two years of the 1999 seeding was not affected by cultivar PLH-resistance levels or by insecticide treatment. However, multiple years of high PLH populations may decrease stand persistence. As previously mentioned, historical data from Michigan (1951-1997) show that PLH population is considered to be heavy to severe in approximately 50% of seasons (Maredia et al., 1998); therefore, remaining seasons have PLH populations that could be characterized as having low and moderate pressures. It is in these seasons of low to moderate PLH populations that questions still exist as to whether an insecticide application may be necessary for resistant cultivars. However in periods of high PLH population, cultivars exhibiting greater than 60% PLH-resistant plants may serve as an important tool for integrated pest management, especially for growers who do not normally apply insecticides. While reduced PLH numbers were observed in the higher PLH- resistance levels of cultivars, scouting these cultivars is still required as severe PLH populations would likely result in injury symptoms of alfalfa if no insecticide was applied.

APPENDICES

Appedix 1. Potato leafhopper sampling intervals with corresponding dates for sweepnet data taken in EL and KBS.

	EL			KBS		
Interval	1998	1999	2000	1998	1999	2000
Late-May	21-May	-	28-May	28-May	-	-
Early-June	2-Jun	5-Jun	5-Jun	4-Jun	-	5-Jun
Mid-June	16-Jun	15-Jun	15-Jun	17-Jun	16-Jun	15-Jun
Late-June	23-Jun	25-Jun	26-Jun	24-Jun	23-Jun	26-Jun
Early-July	8-Jul	8-Jul	3-Jul	1-Jul	7-Jul	3-Jul
Mid-July	14-Jul	15-Jul	11-Jul	15-Jul	14-Jul	11-Jul
Late-July	29-Jul	30-Jul	25-Jul	28-Jul	21-Jul	25-Jul
Early-Aug	10-Aug	7-Aug	3-Aug	4-Aug	1-Aug	3-Aug
Mid-Aug	17-Aug	-	-	-	-	-

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