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Effects of Potato Leafhoppers on Soybean Plant Growth and Yield

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ABSTRACT: Various densities of adult potato leafhoppers were established on 'Essex' soybean at plant growth stage V2 in caged field plots. Cages were removed two weeks later, and plots remained uncaged for the rest of the growing season. Direct counts of nymphal leafhoppers on plants shortly after cage removal confirmed that a gradient of infestation levels was attained. In both years of the study, higher levels of infestation resulted in significant reductions in each of the following: plant height, number of nodes per plant, and average internodal length in the lower portion of the plant. Yield was significantly reduced at higher infestation levels in the first year of the study, but not in the second. Rainfall patterns were markedly different during the two growing seasons, and it is suggested that early season moisture stress may exacerbate the effect of potato leafhopper infestation on soybean yield.

The potato leafhopper, *Empoasca fabae* (Harris), is a migratory insect which typically is first collected each year in Kentucky alfalfa fields during May (Parr and Pass, 1989). In addition to alfalfa, the potato leafhopper is found on many other host plants, including nearly all leguminous crops. During early- and mid-summer, it is consistently one of the most abundant insects found on soybean in the midwestern United States (Helm et al., 1980, and references therein).

Population growth of the potato leafhopper on soybean and the damage it causes to this host plant are influenced by plant pubescence. Experimental soybean lines with glabrous or appressed pubescence characters are highly susceptible to damage from this insect (Johnson and Hollowell, 1935; Broersma et al., 1972). Commercial soybean varieties, however, typically are covered with normal, erect trichomes (Bernard and Singh, 1969) and usually appear to suffer little damage from natural infestations of potato leafhoppers.

In experiments using caged 'Amsoy' soybean (normal pubescence), Ogunlana and Pedigo (1974a) determined economic injury levels for potato leafhoppers at various soybean growth stages. In a companion study, in which they sampled potato leafhoppers in soybean fields throughout two growing seasons at four locations in central Iowa, leafhopper densities never reached the economic injury level (Ogunlana and Pedigo, 1974b). Poston and Pedigo (1975), however, found that removal of alfalfa at first harvest caused migration of potato leafhoppers from alfalfa plots into adjacent soybean plots, sometimes leading to damaging population levels on the young soybean plants. Others have suggested there is little evidence that typical natural populations of potato leafhopper on soybean cause significant damage or apparent effects on yield (e.g., Turnipseed and Kogan, 1976; Helm et al., 1980).

Several factors led us to investigate the effects of potato leafhopper on soybean plant growth and yield. First, and most importantly, soybean growers periodically

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inquire about this insect (and the possible need for control) when they notice potato leafhoppers associated with "hopperburn" and stunted plants during the early summer. In our studies of other soybean insects we, too, had observed severe early season symptoms of leafhopper damage in some years, but we did not know if such injury during vegetative growth stages of soybean resulted in yield reduction. Also, we were uncertain about the applicability of results determined previously for 'Amsoy' soybean, an indeterminate, early maturing variety (Ogunlana and Pedigo, 1974a), to varieties currently grown in Kentucky, especially later maturing, determinate varieties. Finally, studies in Kentucky alfalfa (Parr and Pass, 1989) and our observations in soybean indicated that numbers of colonizing leafhoppers varied tremendously from year to year. During years of highest populations, it seemed at least feasible that potato leafhoppers might reach infestation levels on soybean that could reduce yield. Even if hopperburn and plant stunting did not result in yield reductions, such information would be important in order to make appropriate recommendations to growers.

Our objectives were to determine the effects of the potato leafhopper on plant growth and whether symptomatic injury (e.g., plant stunting) led to yield reductions. The variety 'Essex' was used because it is a late-maturing, determinate variety widely grown in Kentucky. Effects of early season infestations were studied because the potato leafhopper typically is most abundant in Kentucky soybean fields during the early part of the growing season (Raney and Yeargan, 1977).

Materials and Methods

GENERAL: All studies were done near Lexington, Kentucky, using 'Essex' soybean planted in rows with 0.9 m spacing between rows. Soybean seedlings were thinned at growth stage VI (Fehr and Caviness, 1977) to a density of 26 plants per m of row. Soybeans were planted into tilled soil; the herbicides alachlor and linuron were applied at planting (2.2 and 1.1 kg active ingredient per ha, respectively).

Cages made of wooden frames covered with nylon screen (mesh size = 0.8 mm) were set in place one to three days prior to artificial infestation of selected plots with additional potato leafhopper adults. Each cage measured 0.9 × 1.8 × 0.9 m (l × w × h) and enclosed a total of 1.8 m of soybean row (i.e., 0.9 m in each of two adjacent rows). In both 1988 and 1989, cages remained in place for two weeks following artificial infestation of soybean plants. At the end of that period, cages were removed and the plots were not caged for the remainder of the season. Following cage removal, direct visual counts of leafhopper nymphs were made to determine if the treatments had produced the desired differences in infestation levels (sampling details for each year are provided below). Nymphal densities, rather than adult densities, were chosen as an index of success in establishing differential infestations because it is virtually impossible to accurately determine adult densities without disturbing the plants.

Potato leafhoppers used in these studies were collected by sweep net from nearby alfalfa fields several hours prior to their introduction into the field cages. No attempt was made to determine the sex of leafhoppers introduced into cages, but there is no reason to suspect sex ratios differed among the groups added to different cages.

In both years, the control treatment consisted of caged soybean plants which were sprayed after cage installation with permethrin (0.22 kg active ingredient per ha) to eliminate existing leafhoppers; no leafhoppers were added to these control plots. Also during both years, a treatment consisting of naturally occurring leafhoppers was used; it consisted of caged soybean plants to which no insecticide was applied nor were any adult leafhoppers added. This treatment was intended to reflect infestation levels existing in the plots at the beginning of the experiment. Remaining treatments consisted of adding specified numbers of adult leafhoppers to each cage; no insecticides were applied, so these treatments consisted of the existing population plus the number added. Care was taken during installation and removal of all cages to minimize disturbance of the plants and leafhoppers in the plots. In both 1988 and 1989, all treatments were imposed when the soybean plants reached growth stage V2.

1988: Soybeans were planted on 2 June, cages were set in place on 23 June, and treatments were imposed on 26 June. Five treatments, arranged in a randomized complete block design with six replicates, consisted of the control and naturally existing population treatments described above, plus the following: 5, 10, or 20 adult potato leafhoppers per plant added to the existing population. Cages were removed two weeks later and the number of nymphs per plant was determined four days after cage removal by examining in situ three randomly selected plants per plot. Soybean plant height was measured at plant growth stages V5, V8, and V14/R2 for three randomly selected plants per plot. After plants had dried to harvest maturity, the following data were recorded for two randomly selected plants per plot: total plant height, distance from the lowest (=cotyledonal) node to the seventh node, distance from the seventh node to the uppermost node, total number of nodes per plant, number of branches per plant, and numbers of pods on main stems and branches. All plants in each plot were harvested on 15 November; total yield per plot and weight per hundred seeds (as an index of seed size) were determined.

1989: Soybeans were planted on 31 May, cages were set in place on 19 June, and treatments were imposed on 20 June. Four treatments, arranged in a randomized complete block design with six replicates, consisted of the control and naturally existing population treatments described above, plus the following: 5 or 10 adult potato leafhoppers per plant added to the existing population. Cages were removed two weeks later and the number of nymphs per plant was determined the following day by examining in situ two randomly selected plants per plot. Soybean plant height was measured at plant growth stages V6, V8, and V14/R3 for two randomly selected plants per plot. Plant growth measurements made at harvest maturity were done in the same way as described above for the previous year. All plants in each plot were harvested on 21 November; total yield per plot and weight per 100 seeds were determined.

Analysis of variance and polynomial contrasts were used to determine if dependent variables (e.g., plant height, yield) showed significant trends related to different levels of potato leafhopper infestation. Values of $P < 0.05$ were considered significant. Mean separation tests were not used because treatments represented different levels of a single quantitative factor (potato leafhopper density). Weather data were obtained from an official United States Weather Station (Spindletop) located about one kilometer from the site of the study.

Table 1. Potato leafhopper (PLH) nymphal densities on soybean plants after removal of cages from plots (means ± SE).

	Number of nymphs per plant	
	1988	1989
Control (insecticide-treated)	0.0	0.4 ± 0.2
Natural PLH[a]	0.4 ± 0.3	9.9 ± 0.9
Natural PLH + 5 PLH per plant	2.5 ± 0.6	16.8 ± 1.2
Natural PLH + 10 PLH per plant	4.1 ± 0.8	22.5 ± 2.3
Natural PLH + 20 PLH per plant	3.1 ± 0.5	–
ANOVA[b]	12.2 (4,50) $P < 0.001$	39.4 (3,20) $P < 0.001$
Linear	36.8 (1,50) $P < 0.001$	116.5 (1,20) $P < 0.001$
Quadratic	2.2 (1,50) $P > 0.14$	1.5 (1,20) $P > 0.22$

[a] Natural PLH (abbreviated as "N" in subsequent tables) refers to potato leafhoppers present in the plots when cages were installed.

[b] Values for ANOVA and polynomial contrasts represent F-value, degrees of freedom, and P-value, respectively.

Results and Discussion

Densities of potato leafhopper nymphs per plant following removal of cages showed that our experimental procedures generally succeeded in establishing the desired gradient in infestation levels (Table 1). The highest number of adults added in 1988 (20 per plant), however, did not result in a higher nymphal density than the second highest number added (10 per plant). Thus, this treatment was dropped from the experiment in 1989. Nymphal densities in the naturally infested plots indicated a much higher natural population of potato leafhoppers was present in the plots in 1989 than in 1988 (Table 1). Data from nearby alfalfa fields also showed that during late June of these two years, naturally occurring potato leafhopper population densities were much higher in 1989 (>60 per 20 sweeps) than in 1988 (<20 per 20 sweeps) (Parr and Pass, 1990; J. C. Parr, unpubl. data). Insect populations in our soybean plots were not sampled again during the remainder of the season in order to avoid disturbance of the established potato leafhopper populations. We observed no significant plant damage in our plots other than that caused by potato leafhoppers during either year of the study.

During both years of the study, added potato leafhoppers resulted in reduced soybean plant height (Table 2). Although cages were removed after only two weeks, thus allowing free movement of leafhoppers thereafter, effects on plant height persisted for the remainder of the season. For much of the 1988 growing season, plant heights in the naturally infested plots were similar to those in the insecticide-treated control plots, while in 1989 they were more similar to plant heights in plots to which adult leafhoppers were added (Table 2). This apparently reflects the much higher natural populations of potato leafhoppers that occurred in 1989 (Table 1).

The rainfall pattern during the two summers was markedly different, and this appeared to affect soybean plant growth. From the date of planting until cages were removed from the plots in early July of 1988, total rainfall was only 1.4 cm, which was 11.6 cm below normal for the period (average temperature was 23.3°C). During that same interval in 1989, total rainfall was 14.8 cm (average temperature was 22.2°C). In 1988 plants grew only from stage V2 to V5 during the two-week period when they were caged, while in 1989 they grew from stage V2 to V6 during

Table 2. Height of soybean plants at selected growth stages (based on control plots) following infestation with potato leafhoppers at growth stage V2 (means ± SE).

	Height (cm) at growth stage:		
	1988		
	V5	V8	V14/R2
Control[a]	25.5 ± 2.5	40.8 ± 2.4	68.1 ± 1.6
N	23.3 ± 2.0	37.7 ± 1.4	65.7 ± 3.1
N + 5	17.2 ± 1.1	29.8 ± 0.9	56.2 ± 1.5
N + 10	14.3 ± 1.6	28.5 ± 1.6	52.1 ± 1.5
N + 20	12.6 ± 1.1	24.4 ± 1.2	48.8 ± 1.4
ANOVA[b]	20.7 (4,50) $P < 0.001$	24.0 (4,50) $P < 0.001$	19.8 (4,50) $P < 0.001$
Linear	79.6 (1,50) $P < 0.001$	91.9 (1,50) $P < 0.001$	76.0 (1,50) $P < 0.001$
Quadratic	0.9 (1,50) $P > 0.34$	0.8 (1,50) $P > 0.37$	0.4 (1,50) $P > 0.55$
	1989		
	V6	V8	V14/R3
Control	29.6 ± 0.5	40.5 ± 0.8	65.0 ± 1.0
N	22.8 ± 0.4	33.3 ± 0.6	57.6 ± 1.0
N + 5	19.0 ± 0.5	30.0 ± 0.8	56.3 ± 1.3
N + 10	19.4 ± 0.5	29.1 ± 0.7	54.4 ± 0.9
ANOVA	132.9 (3,20) $P < 0.001$	53.0 (3,20) $P < 0.001$	26.9 (3,20) $P < 0.001$
Linear	325.5 (1,20) $P < 0.001$	139.6 (1,20) $P < 0.001$	68.2 (1,20) $P < 0.001$
Quadratic	72.9 (1,20) $P < 0.001$	19.3 (1,20) $P < 0.001$	9.5 (1,20) $P < 0.01$

[a] Treatments were as follows: Control = insecticide sprayed plots with no leafhoppers added; N = naturally occurring leafhopper densities; N + 5, N + 10, and N + 20 = naturally occurring leafhopper densities plus 5, 10, and 20 adult PLH added per plant, respectively.

[b] Values for ANOVA and polynomial contrasts represent *F*-value, degrees of freedom, and *P*-value, respectively.

the same two-week interval. From the time when cages were removed until the end of August, rainfall amounts were similar in 1988 and 1989 (18.5 cm and 19.3 cm, respectively). By the end of August in both years, all plants were approaching reproductive growth stage R6 (full seed).

After plants had dried to harvest maturity, additional growth measurements revealed specifically how potato leafhopper infestation during early vegetative development led to reduced overall plant height. Plants with higher levels of leafhopper infestation had significantly fewer total nodes and shorter average internodal lengths in the lower portion of the plant (Table 3). Internodal lengths in the upper part of the plant (i.e., above the seventh node from the bottom) were not significantly affected (ANOVA: 1988—$F_{4,25} = 0.6$, $P > 0.66$; 1989—$F_{3,20} = 2.6$, $P > 0.08$).

The rationale for selecting the seventh node to divide the plant into lower and upper portions was as follows. Treatments were imposed when the plants were at growth stage V2 (two nodes) and cages were removed two weeks later when plants in control plots were at growth stages V5 (1988) or V6 (1989). Many of the nymphs present on plants when cages were removed probably continued to feed on those plants for several additional days. Thus, it is likely that the most serious impact of naturally existing (1989) and added leafhoppers (both years) on plant growth occurred during and shortly after the period when plots were caged. The majority of the plants in the infested plots matured with a total of about 14 nodes, so "lower" and "upper" as defined by the seventh node divided those

Table 3. Total plant height, number of nodes per plant, and internodal lengths in lower portion of soybean plants at harvest maturity (means ± SE).

	Height (cm)	Total number of nodes	Lower internodal length (cm)[a]
		1988	
Control[b]	80.5 ± 2.4	17.0 ± 0.5	4.9 ± 0.2
N	75.2 ± 1.7	16.3 ± 0.5	4.2 ± 0.1
N + 5	68.5 ± 2.0	15.8 ± 0.4	3.9 ± 0.1
N + 10	62.6 ± 2.2	14.2 ± 0.6	4.1 ± 0.4
N + 20	57.9 ± 2.2	14.2 ± 0.3	3.5 ± 0.1
ANOVA[c]	21.6 (4,25) $P < 0.001$	7.2 (4,25) $P < 0.001$	6.2 (4,25) $P < 0.001$
Linear	85.9 (1,25) $P < 0.001$	27.0 (1,25) $P < 0.001$	20.3 (1,25) $P < 0.001$
Quadratic	0.002 (1,25) $P > 0.96$	0.04 (1,25) $P > 0.84$	0.7 (1,25) $P > 0.40$
		1989	
Control	74.9 ± 0.3	15.2 ± 0.2	5.2 ± 0.1
N	67.8 ± 1.5	14.2 ± 0.2	4.3 ± 0.1
N + 5	61.1 ± 1.7	14.2 ± 0.2	3.3 ± 0.1
N + 10	61.3 ± 1.4	14.2 ± 0.2	3.5 ± 0.1
ANOVA	22.3 (3,20) $P < 0.001$	8.4 (3,20) $P < 0.001$	375.7 (3,20) $P < 0.001$
Linear	58.7 (1,20) $P < 0.001$	15.1 (1,20) $P < 00.001$	965.3 (1,20) $P < 0.001$
Quadratic	7.0 (1,20) $P < 0.02$	8.4 (1,20) $P < 0.01$	121.8 (1,20) $P < 0.001$

[a] Lower internodal lengths are the averages of those between the lowest (=cotyledonal) node and the seventh node.

[b] Treatments were same as described in Table 2.

[c] Values for ANOVA and polynomial contrasts represent F-value, degrees of freedom, and P-value, respectively.

plants approximately into halves, reflecting early- and late-season vegetative growth, respectively.

Analysis of the 1988 yield data indicated a significant linear trend for reduced yield with increased potato leafhopper infestation (Table 4). Similar significant linear trends existed for an index of seed size (weight per 100 seeds) and for number of pods on the main stem; i.e., heavy infestation led to smaller average seed size and fewer pods on the main stem (Table 4). Numbers of pods on branches did not differ among treatments (ANOVA: $F_{4,25} = 1.9$, $P > 0.12$), nor did numbers of branches per plant at maturity (ANOVA: $F_{4,25} = 0.9$, $P > 0.49$). Similarly, Broersma et al. (1972) found that glabrous 'Harosoy' soybean had fewer nodes per plant, fewer pods per main stem, and less weight per 100 seeds when infested with potato leafhoppers than when protected from this insect with insecticidal treatment, but the number of branches per plant did not differ.

Recall that naturally occurring leafhopper populations were low in 1988, and the density of nymphs subsequently observed in plots receiving the highest level of added leafhoppers (20 per plant) differed little from that found in plots receiving the second highest level (10 per plot) (Table 1). Thus, it may be biologically more meaningful to compare the average yield from the control plots and the "naturally infested" plots with the average yield obtained from all plots that received added potato leafhoppers. The average yield from the former was 465.3 g per plot, and that from the latter was 343.2 g per plot; this represents an average yield reduction of about 26% due to added leafhoppers.

Average yields in 1989 also suggested a trend of decreasing yield with increasing

Table 4. Yield, index of seed size, and number of pods on main stems of soybean plants from plots infested with different densities of potato leafhoppers (means ± SE).

	Yield per plot (g)	Weight per 100 seeds (g)	Number of pods per main stem
		1988	
Control[a]	484.5 ± 27.9	14.0 ± 0.9	34.9 ± 3.8
N	446.1 ± 21.0	15.0 ± 0.6	30.0 ± 4.6
N + 5	320.3 ± 23.0	11.4 ± 0.7	20.9 ± 3.0
N + 10	387.2 ± 39.0	12.8 ± 0.4	22.1 ± 2.8
N + 20	322.2 ± 46.4	11.3 ± 1.0	23.3 ± 1.4
ANOVA[b]	5.4 (4,20) $P < 0.01$	5.8 (4,20) $P < 0.01$	3.4 (4,25) $P < 0.02$
Linear	14.4 (1,20) $P < 0.01$	11.6 (1,20) $P < 0.01$	9.2 (1,25) $P < 0.01$
Quadratic	1.0 (1,20) $P > 0.31$	0.1 (1,20) $P > 0.78$	3.3 (1,25) $P > 0.07$
		1989	
Control	420.0 ± 23.8	12.4 ± 0.1	33.2 ± 2.0
N	379.7 ± 19.8	11.8 ± 0.1	34.8 ± 1.7
N + 5	376.2 ± 17.6	11.8 ± 0.2	29.8 ± 2.0
N + 10	368.4 ± 19.6	12.2 ± 0.1	32.3 ± 1.4
ANOVA	1.8 (3,15) $P > 0.18$	6.3 (3,15) $P < 0.01$	2.9 (3,20) $P > 0.06$
Linear	4.3 (1,15) $P > 0.05$	1.4 (1,15) $P > 0.24$	1.9 (1,20) $P > 0.18$
Quadratic	0.9 (1,15) $P > 0.35$	17.4 (1,15) $P < 0.001$	0.1 (1,20) $P > 0.70$

[a] Treatments were same as described in Table 2.

[b] Values for ANOVA and polynomial contrasts represent F-value, degrees of freedom, and P-value, respectively.

potato leafhopper infestation, but analysis of variance indicated this apparent relationship was not statistically significant (Table 4). The lowest average yield in 1989 (368.4 g per plot when 10 leafhoppers per plant were added) was only about 12% lower than that obtained from the control plots; this is less than half the percentage reduction observed in 1988. Thus, if any reduction in yield occurred in 1989, it was too small to be statistically significant. A statistically significant quadratic relationship between treatment and seed size was detected in 1989, but the small differences among treatment means suggest this was a spurious result (Table 4). Unlike 1988, when yield was significantly affected by leafhopper infestation, numbers of pods on the main stem did not differ among treatments in 1989 (Table 4). As had occurred in 1988, numbers of pods on branches also did not differ among treatments in 1989 (ANOVA: $F_{3,20} = 0.6$, $P > 0.63$), nor did numbers of branches per plant at maturity (ANOVA: $F_{3,20} = 2.3$, $P > 0.10$).

Our results suggest that moisture stress influences the impact of potato leafhopper infestation on soybean yield. While significant reductions in plant height occurred in both years, significant yield reductions occurred only in 1988, a year in which soybean plants were under moisture stress during the heaviest leafhopper infestation (i.e., during early vegetative growth). These yield reductions occurred despite the fact that nymphal potato leafhopper densities were much lower in 1988 than 1989, even in plots to which adult leafhoppers were added (Table 1). This indicates the greater reductions in yield during the dry conditions of 1988 were not related to enhanced reproduction by the potato leafhopper. Instead, droughty conditions might have increased the amount of feeding (frequency and/ or duration) by individual leafhoppers or those conditions might have intensified the plant's response to a given amount of feeding.

In order to confirm or refute this hypothesized interaction between moisture stress and potato leafhopper damage to soybean, further studies are needed, specifically experiments in which both factors are controlled and replicated. Previous authors (Ogunlana and Pedigo, 1974b; Poston and Pedigo, 1975; Helm et al., 1980) have suggested that soybean plants may be most vulnerable to economic damage from potato leafhoppers during early vegetative growth. Our results indicate that under conditions of adequate early season soil moisture, significant plant stunting can occur with little or no yield reduction. It appears, however, that the greatest potential for significant yield reduction may occur when high potato leafhopper infestations coincide with early season moisture stress.

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