A Re-Examination of Economic Injury Levels for Potato Leafhopper (Homoptera: Cicadellidae) on Soybean[1,2]

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Abstract The potato leafhopper, *Empoasca fabae* (Harris), is an occasional pest of seedling soybean throughout the eastern United States. Economic injury levels (EIL) for *E. fabae* on soybean are not available for all vulnerable soybean stages, nor do they reflect current understandings of soybean response to injury or EIL calculation methodology. Damage terms were estimated for seedling soybean stages using curve-fitting techniques that consider the vulnerability of the expanding leaf tissue of seedling soybean. Yield loss for stage V1 soybean was 43.58 kg/ha/*E. fabae*/plant, for V2 was 20.41 kg/ha/*E. fabae*/plant, for V3 was 13.10 kg/ha/*E. fabae*/plant, and for V4 was 9.55 kg/ha/*E. fabae*/plant. Economic injury level matrices were developed to reflect changing economic conditions and management costs for V1 through V4 soybean. The EILs are 1.4 to 3.6 *E. fabae*/plant for V1 soybean, 3.0 to 7.8 *E. fabae*/plant for V2 soybean, 4.7 to 12.2 *E. fabae*/plant for V3 soybean, and 6.5 to 16.7 *E. fabae*/plant for V4 soybean.

Key Words *Empoasca fabae, Glycine max,* insect injury

The potato leafhopper, *Empoasca fabae* (Harris), is a common migratory insect found on soybean throughout the eastern United States (Helm et al. 1980). Although normally not considered a serious soybean pest (Turnipseed and Kogan 1976, Helm et al. 1980, Yeargan et al. 1994), several scenarios can result in *E. fabae* populations reaching damaging levels on seedling soybean. Late-planted soybeans coupled with a large migration of *E. fabae* from the Gulf States can result in economically damaging *E. fabae* populations (Helm et al. 1980). Also, local movement of *E. fabae* from alfalfa into adjacent seedling soybean after first cutting can have the same result (Poston and Pedigo 1975).

Seedling soybean has great compensatory capacity, but when seedling injury results in delayed plant growth such that a critical leaf area index is not reached before reproductive stages, economic injury can occur (Hunt et al. 1994). Ordinarily, pubescence associated with current commercial soybean varieties protects soybean from *E. fabae* injury by interfering with the insect's movement, oviposition, and feeding (Lee et al. 1986, Elden and Lambert 1992). However, seedling soybean consists primarily of young and expanding leaf tissue (VC through V4) (Fehr and Caviness

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1977), and the pubescence is softer, less abundant on unifoliolates, and may be less of an impediment to *E. fabae* than the dense, stiff pubescence present on older, hardened-off leaves. The softer pubescence may allow for more efficient *E. fabae* movement, feeding and oviposition and results in seedling stunting, characteristic "hopperburn" (leaf chlorosis, deformation, and tissue death along margins), and possible economic loss.

Previously, economic injury levels (EIL) for *E. fabae* on soybean were developed by Olgunlana and Pedigo (1974), but these EILs are not appropriate for current use and illustrate several problems that exist in the use and past derivation of EILs. This is not a reflection on the quality of the research, but rather a consequence of the research being over 20 years old.

First, we now better understand stage-specific soybean response to insect injury and recognize that the seedling stage is most vulnerable to economic injury by *E. fabae*. Olgunlana and Pedigo (1974) provide a V1 EIL, but EILs are required for the other seedling stages through V4. Until approximately V4, 100% to 50% of the leaf tissue is expanding and lacks dense, stiff pubescence, making it vulnerable to injury by *E. fabae*. After V4, the percentage of vulnerable leaf tissue declines because the older expanded leaves have hardened-off and have the dense, stiff pubescence that is responsible for protecting the plant from *E. fabae* injury. Also, as previously stated, it is during the seedling stage that there exists a possibility of significant *E. fabae* infestation.

Second, EIL calculation methodology has advanced. The first formula for calculating EILs (Stone and Pedigo 1972) was published only 2 yrs before Olgunlana and Pedigo's (1974) EILs were published. At that time the total number of published articles addressing EIL formulation or derivation was fewer than ten (Peterson 1996). To be most useful, EIL matrices are required that reflect fluctuating crop value, management cost, plant growth stage, and can be adjusted when necessary for different expected yield. Olgunlana and Pedigo (1974) stress the dynamic nature of the EIL, but only present a single management cost-crop value EIL for each of three plant stages. This in itself presents another problem of EIL development. Rarely is there time, space, or labor available to empirically determine EILs for each plant stage. Appropriate methodology for "filling in the spaces" must be developed. Simple linear regression of EILs, while suitable in some cases, does not always reflect the true damage curve for the plant stages of interest. Knowledge of plant growth and response to insect injury can aid in estimating certain portions of this relationship. Also, the current EILs are based on experimental yields that are significantly larger than typical on-farm yields. This must be taken into consideration when calculating EILs.

Given the current understanding of soybean response to insect injury, the effects of pubescence on *E. fabae,* seedling vulnerability, and the need for stage-specific EILs for seedling soybean, we believe new EILs for *E. fabae* on seedling soybean are warranted. Our objectives, therefore, were to reexamine the results of Olgunlana and Pedigo (1974) and (1) more accurately estimate soybean yield loss per *E. fabae* for seedling soybean stages V1 through V4, and (2) develop EIL matrices reflecting current crop values and management costs for *E. fabae* on seedling soybean.

Materials and Methods

Caged studies were conducted by Olgunlana and Pedigo in 1971 and 1972 to determine EILs for *E. fabae* on soybean, cv. 'Amsoy' (Olgunlana and Pedigo 1974).

Amsoy is a pubescent, indeterminant, short-season soybean variety. The experimental design was a randomized complete block with three replications. Treatments were imposed at three soybean growth stages (V1, R1, and R5). Treatments consisted of an uninfested check and three *E. fabae* infestation levels. Infestation levels (insects/plant) were: V1 – 0, 5, 10, 15; R1 – 0, 40, 80, 120; and R5 – 0, 50, 100, 200. Specific research methods are published in Olgunlana and Pedigo (1974). Data from the 1972 studies (see Olgunlana 1973) were reevaluated. Data from 1971 were incomplete because of damage done by severe weather and unavailable.

Analysis of variance procedures were used to identify significant treatment effects ($P = 0.05$). When treatment effects were significant, regression analyses were used to identify significant relationships ($P = 0.05$).

Results and Discussion

Soybean yields were significantly affected by *E. fabae* injury when infested at stages V1, R1, and R5 (Table 1). For each growth stage, the trend was for yield to decrease as *E. fabae* infestation level increased (Fig. 1). The relative vulnerability of seedlings (stage V1) is illustrated by the steep slope of the V1 regression and the relatively small number of *E. fabae* required to cause the yield reductions. While scenarios for economic *E. fabae* infestation of seedling soybean exist, it is generally believed that economic *E. fabae* infestations of later vegetative and reproductive stages are very unlikely (Olgunlana and Pedigo 1973, Yeargan et al. 1994). Therefore, we developed EILs for selected seedling stages, V1 through V4.

Economic injury levels for *E. fabae* on soybean are expressed in number of *E. fabae* per plant. The general model for the EIL is

$$\mathrm{EIL} = \mathrm{C/VIDK}, \qquad [1]$$

where EIL = number of injury equivalents per production unit, C = cost of management per production unit, V = market value per production unit, I = injury units per insect per production unit, D = damage per injury unit, and K = proportionate reduction of the insect population (Pedigo et al. 1986). Because direct injury is difficult to quantify for sucking insects, D and I can be replaced with a single variable, D′ (yield loss per insect), to give

$$\mathrm{EIL} = \mathrm{C/VD'K} \qquad [2]$$

Because of geographic differences, production differences, cultivar differences, etc., mean soybean yields vary. In this case, the 1972 control mean yield cited by Olgunlana and Pedigo (1974) was significantly higher (4,876.4 kg/ha) than a 5-yr Nebraska yield mean (2,313.7 kg/ha). Therefore, yield reductions (g/row-m) were converted to percent yield loss, and then expressed as yield loss (kg/ha) based on a mean yield of 2,313.7 kg/ha (Fig. 2). The slopes of yield loss (kg/ha) versus *E. fabae* density (*E. fabae*/plant) regressions give a value for D′ for V1, R1, and R5 soybean. However, D′ values are required for V2, V3, and V4 soybean. To obtain these values, V1, R1, and R5 yield loss versus *E. fabae* density slopes where plotted against time (days after VC) (Fig. 3). Empirical data do not exist for the region of interest (V2, V3, and V4), so curves were fit (Advanced Graphics Software Inc. 1983) and evaluated using current understanding of insect injury to seedling soybean (Hunt et al. 1994) and seedling growth (Kumara 1969, Hunt et al. 1995). Seedling soybean leaf tissue

Table 1. Potato leafhopper (PLH) infestation levels and mean seed yields for V1, R1, and R5 soybeans in 1972. Data are from Olgunlana and Pedigo (1973).

Growth stage					
V1		R1		R5	
Infestation level	Yield (SE)	Infestation level	Yield (SE)	Infestation level	Yield (SE)
PLH/plant	g/row-m	PLH/plant	g/row-m	PLH/plant	g/row-m
0	596(2.9)a	0	599(3.3)a	0	598(9.9)a
5	537(7.3)b	40	543(3.9)b	50	558(12.6)b
10	474(1.6)c	80	498(13.0)c	100	542(3.6)b
15	430(7.3)d	120	438(11.0)d	200	473(5.8)c
$P > F$*	0.0001	$P > F$	0.0002	$P > F$	0.0004

Within column, means followed by the same letter are not significantly different at $P = 0.05$ based on LSD.
* $P > F$ from ANOVA.

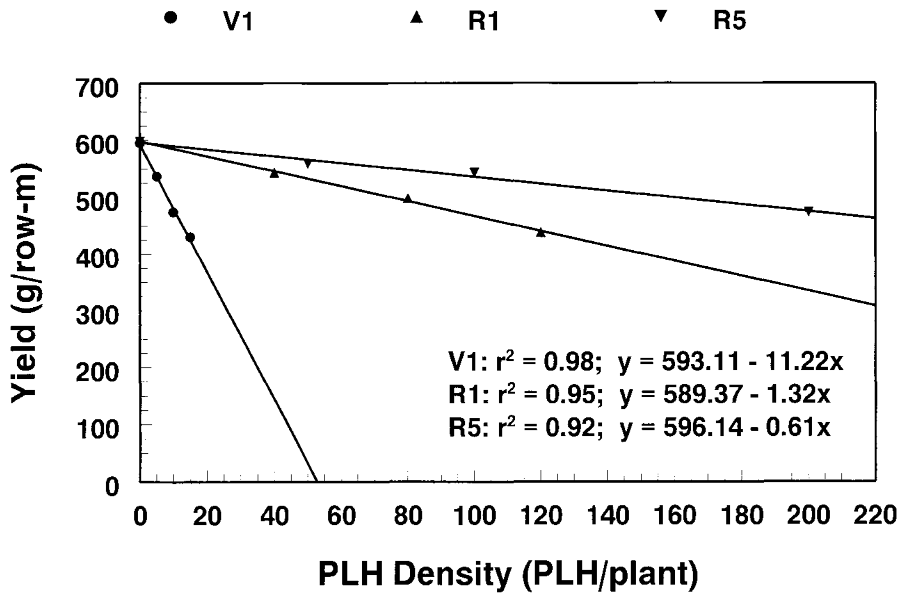

Fig. 1. Soybean yield by potato leafhopper density in 1972. Vertical capped lines equal standard error.

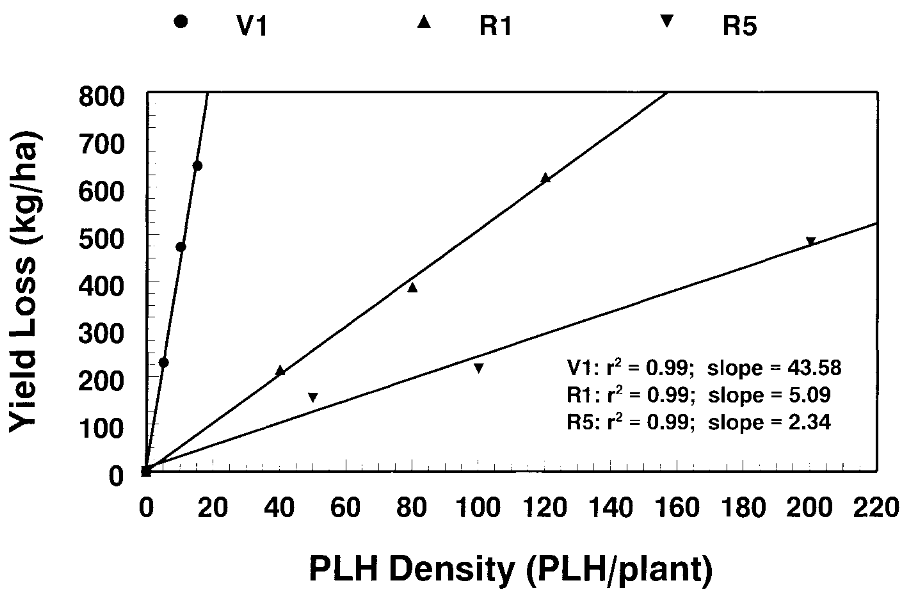

Fig. 2. Soybean yield loss by potato leafhopper density in 1972.

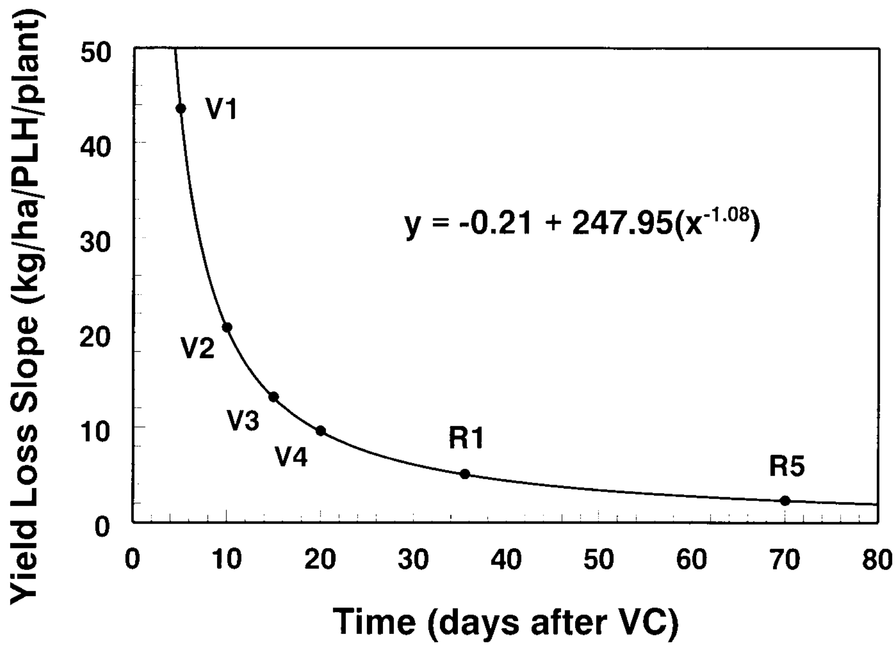

Fig. 3. Slopes of potato leafhopper-soybean yield loss relationships by time after plant stage VC. Points V1, R1, and R5 are from data. Points V2, V3, and V4 are derived from the equation.

consists of 100% expanding tissue during VC. The first fully-expanded leaves (unifoliolates) occur at the end of V1. By mid-V2 the unifoliolates are hardened-off, and at the end of V2, the first fully-expanded trifoliolate appears. During V2 the fully-expanded, and subsequently hardened-off, leaves are less susceptible to *E. fabae* injury, so seedlings are expected to become gradually less vulnerable to *E. fabae* injury. A power curve fits the model of vulnerable V1 and partial V2 stages, followed by increasingly less vulnerable stages as defined by the presence of fully expanded, hardened-off leaves (Fig. 3). The D′ values where derived using the Fig. 3 equation for V2, V3, and V4 soybean. Yield loss (D′) for V1 is 43.58 kg/ha/*E. fabae*/plant, for V2 is 20.41 kg/ha/*E. fabae*/plant, for V3 is 13.10 kg/ha/*E. fabae*/plant, and for V4 is 9.55 kg/ha/*E. fabae*/plant. If expected yield is significantly different from 2,313.7 kg/ha (34.4 bu/acre), the equation of a power curve fitted to percent yield loss/*E. fabae*/plant versus time (days after VC, Fig. 3) can be used to obtain damage terms for V2 through V4 based on percent loss (Advanced Graphics Software Inc. 1983). This equation is $y = -0.01 + 10.57(x^{-1.07})$, where y = percent yield loss/*E. fabae*/plant and x = time (days after VC).

Stage-specific EILs for seedling soybean expressed in number of *E. fabae* per plant were calculated from equation [2]. Assuming a C of \$14.83/ha (\$6.00/acre), a V of \$0.17/kg (\$4.50/bu), a K of 1 (100% control), and given D′ calculated above, the EIL is 2.0 *E. fabae*/plant for V1 soybean. If infestation occurs at V3, variables C, V, and K remain the same, but D′ changes to reflect the decreasing vulnerability of the seedling soybean. For a V3 soybean, D′ = 13.1 kg/ha/*E. fabae*/plant, and the EIL is 6.7 *E. fabae*/plant.

The economic variables (V and C) will fluctuate with changing economic conditions, insecticide choice, application method, etc., so EIL matrices were developed to reflect these changes for V1 through V4 soybean (Table 2). The effect of changing C and V is clear from Table 2, where the highest EIL for each stage is approximately 3X that of the lowest. The original EIL calculated by Olgunlana and Pedigo (1974) for V1 soybean is 0.94 *E. fabae*/plant, which is lower than the EILs calculated in Table 2 for

Table 2. Economic injury levels (EILs) for potato leafhopper (insects/plant) on V1, V2, V3, and V4 soybean.*

	Commodity value (V)		Control cost (C) (top = \$/acre, bottom = \$/hectare)		
	\$/bu	\$/kg	7.00 17.30	9.00 22.24	11.00 27.18
Stage V1					
	4.50	0.17	2.3	3.0	3.6
	5.50	0.20	2.0	2.6	3.1
	6.50	0.24	1.7	2.1	2.6
	7.50	0.28	1.4	1.8	2.2
Stage V2					
	4.50	0.17	5.0	6.4	7.8
	5.50	0.20	4.2	5.5	6.7
	6.50	0.24	3.5	4.5	5.6
	7.50	0.28	3.0	3.9	4.8
Stage V3					
	4.50	0.17	7.8	10.0	12.2
	5.50	0.20	6.6	8.5	10.4
	6.50	0.24	5.5	7.1	8.7
	7.50	0.28	4.7	6.1	7.4
Stage V4					
	4.50	0.17	10.7	13.7	16.7
	5.50	0.20	9.1	11.6	14.2
	6.50	0.24	7.6	9.7	11.9
	7.50	0.28	6.5	8.3	10.2

* EIL = C/(V*DI*K) where K = 1 and for: V1, DI = 43.58; V2, DI = 20.41; V3, DI = 13.10; V4, DI = 9.55 (DI for V1 from Fig. 1 and DI for V2, V3, and V4 from Fig. 2 Equation). For insects/row-foot multiply the EIL by 7.62; for insects/row-m multiply the EIL by 25.

V1 soybean (1.4 to 3.6 *E. fabae*/plant). This reflects the difference in both the current economic conditions and expected soybean yield under field conditions. Although only the V1 EILs are directly derived from empirical data, we believe the curve-fitting rationale and resultant EIL matrices for V2 through V4 soybean are sound and provide better decision-making tools than are currently available.

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