Using Aesthetic Assessments of Azalea Lace Bug (Heteroptera: Tingidae) Feeding Injury to Provide Thresholds for Pest Management Decisions

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ABSTRACT Research on consumer, grower, and landscape manager perception of azalea lace bug, *Stephanitis pyrioides* (Scott), feeding and on plant productivity parameters, including gas exchange and growth, has increased our understanding of the nature of feeding injury. These studies made it possible to develop decision-making guidelines for cost-effective maintenance of aesthetically pleasing azaleas. Criteria were considered for three management situations: a 0.41-ha (1-acre) nursery production system that may use either insecticidal soap, acephate, or imidacloprid to control lace bugs; a landscape planting of a group of 10 azaleas; or maintenance of a single azalea in the landscape. Lace bug thresholds were calculated using a hybrid economic injury level (EIL) formula. Pesticide application decisions were determined using survey-based data from grower, landscape manager, and consumer perceptions of unacceptably injured azaleas at point-of-purchase for the nursery situation. Additional landscape scenarios incorporated the perceptions of growers, landscape managers, and consumers for those levels of lace bug feeding-injury that prompted the desire for treatment. Hybrid EIL determinations are appropriate for lace bug management in landscape systems where landscape professionals manage large plantings of azaleas and as a component of pest management among nursery production systems. Aesthetic considerations are more appropriate in determining control thresholds among a few or individual azaleas in the landscape.

KEY WORDS azalea lace bug, *Rhododendron* spp., *Stephanitis pyrioides*, hybrid economic injury level, aesthetic threshold

THE ECONOMIC INJURY level (EIL) of pest arthropods has been defined as the level at which pest density economically justifies the costs of initiating control tactics (Stern et al. 1959). Incorporating EIL considerations into many agricultural production systems has resulted in considerable reductions in chemical inputs (Pedigo et al. 1986). In urban habitats, where ornamental landscape plantings are the valued commodity, aesthetic considerations drive pest management decisions to a greater degree than strictly economic concerns (Raupp et al. 1988, 1989; Sadof and Alexander 1993; Sadof and Raupp 1996). Within an urban system, Olkowski (1974) defined the aesthetic injury level (AIL) as the lowest population density that causes visually displeasing, or aesthetic, injury. Consumer or homeowner perceptions of the loss in plant value, due to arthropod-induced injury, can be used to calculate the AIL (Olkowski 1974, Raupp et al. 1988). Contingency valuation techniques also provide a means for projecting plant value reductions as pest injury increases (Higley and Wintersteen 1992, Sadof and Alexander 1993, Sadof and Raupp 1996). A hybrid

EIL model has been developed using contingency valuation to calculate economic loss due to aesthetic injury (Sadof and Raupp 1996). The resulting formula for calculating AIL within an economic context may be derived from the EIL:

$$AIL = C/VIDK, \qquad [1]$$

where the cost of control (C) is divided by the value or price of an undamaged plant (V), the amount of chlorotic stippling injury caused by an individual arthropod pest (I), the damage which results from each unit of injury (D), and effectiveness of treatment measured as a proportion of control measures (K) (Pedigo et al. 1986, Sadof and Alexander 1993, Sadof and Raupp 1996). The principal difference between the generalized EIL and the hybrid EIL is that aesthetic considerations comprise the basis for assessing both damage (D) and value (V) variables for hybrid EIL calculations. This methodology has been used to generate predictive tools for managing spider mite (*Tetranychus urticae* Koch) on *Euonymus alatus* (Thunberg) 'Compacta' shrubs (Sadof and Alexander 1993, Sadof and Raupp 1996) and bagworms (*Thyriodopteryx ephemeraeformis* Haworth) on American arborvitae (*Thuja occidentalis* L.) (Raupp et al. 1988).

Azaleas, *Rhododendron* spp., are key plants that are common in landscapes throughout the eastern United States (Raupp et al. 1985, Braman et al. 1998). In a

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survey of landscape maintenance firms in the metropolitan Atlanta, GA, area, 87% of the respondents identified azaleas as a component of the landscapes they maintain. Further, 67% report that azaleas occasionally or often require insecticide applications (Braman et al. 1998). Most deciduous and evergreen azaleas readily support populations of azalea lace bug, *Stephanitis pyrioides* (Scott), (Raupp et al. 1985, Smith & Raupp 1986, Braman and Pendley 1992) which was imported from Japan circa 1915 (Weiss 1916). Voltinism in *S. pyrioides* ranges from two generations per year in central New England (Bailey 1951) to four annual generations in the central and southern Atlantic states (Braman et al. 1992, Neal and Douglass 1988). Females may live 121 d at 20.6°C and lay an average of 350 eggs (Neal and Douglass 1988). These factors are primary contributors to the successful establishment of this non-native pest, and indicate the injury-potential that azalea lace bugs present to urban landscapes.

Our objective was to use the principles of hybrid EIL determination to provide aesthetic thresholds for managing the azalea lace bug, *Stephanitis pyrioides* (Scott) (Heteroptera: Tingidae). Predictive tools were applied to nursery production systems and landscape settings for groupings of azaleas, as well as management of lace bugs on individual azaleas. Within the nursery setting, we provide analyses of three control options: an inexpensive chemical control, an organic control, and control using a new chemistry becoming widely adopted by landscape and nursery managers. This model synthesizes the results of field studies (Klingeman et al. 2001), greenhouse and laboratory trials (Klingeman et al. 2000b, 2000c), and end-user surveys (Klingeman et al. 2000a) into decision-making criteria for optimizing azalea lace bug control.

Materials and Methods

Assessment of Azalea Lace Bug Aesthetic Damage. Surveys were conducted to investigate grower and consumer perceptions of azalea lace bug feeding injury and to determine recognition thresholds for azalea lace bug injury. The surveys revealed that 2% or more leaf area injury, attributed to lace bug feeding, was required to ensure that 50% of survey participants would recognize damage (Klingeman et al. 2000a). A second, more comprehensive survey instrument, which incorporated injury-recognition thresholds, was designed to investigate the purchase and treatment decisions of both growers and consumers of azaleas having lace bug feeding injury (Klingeman et al. 2000a). One-half of the grower and consumer participants indicated that ≈11% of a shrub's leaves having feeding injury apparent on >2% of the leaf surface was sufficient to elicit an unwillingness-to-purchase response. This corresponded to lace bug chlorophyll removal, by feeding, from 1.03% of the azalea canopy (Klingeman et al. 2000a). In contrast to unwillingness-to-purchase trends, 50% of those surveyed indicated that an injured shrub required damage on >43% of its leaves, at >2% leaf injury, to prompt treatment. This corresponded to 3.3% actual injury to the azalea canopy and suggests that growers and consumers have a greater tolerance to azalea lace bug injury once plants are established in the landscape (Klingeman et al. 2000a).

Estimating Damage per Unit of Injury for the Hybrid EIL Equation. Our survey results revealed that azaleas having 60% or more proportional injury (the percentage of leaves in the canopy having 2% or more lace bug feeding injury), were deemed unacceptable for purchase by 85% of the participants (Klingeman et al. 2000a). Proportional injury levels >60% caused no appreciable increases in plant rejection among respondents. In comparison, shrubs continued to have increased treatment recommendations by survey participants as injury levels increased. To provide an estimate of the damage per unit of injury (D) in purchase considerations for the hybrid EIL, we excluded azaleas with >60% proportional injury from consideration and fit a linear regression model to the survey responses. The amount of injured leaf area (L.A.) on each shrub was determined by calculating:

$$(\text{Percent actual shrub injury}) \, (\text{Average canopy L.A.})$$
$$= \text{Feeding-injured shrub L.A.}, \qquad [2]$$

where average canopy leaf area was determined using destructive samples of uninjured, similarly sized 'Delaware Valley White' azaleas, which had not been used for our survey efforts. We calculated the specific leaf area (leaf area/dry weight) of 50 leaves per plant. Canopy leaf area was then estimated as the product of canopy leaf dry weight and specific leaf area:

$$(\text{L.A. 50 leaves}/\text{Dry mass 50 leaves})$$
$$(\text{Canopy leaf dry mass}) = \text{Average canopy L.A.}$$
$$[3]$$

Responses provided by survey participants also enabled damage per unit of injury estimations that were generated from the slope of the linear regression for treatment responses. The relationship of increasing leaf area injury to grower and consumer purchase and treatment decisions provides the damage (D) component of the hybrid EIL equation.

Estimating Injury for Hybrid EIL Calculations. The potential lifetime amount of injury inflicted by individual lace bugs has been experimentally determined under two temperature regimes (Klingeman et al. 2000b). For our hybrid EIL calculations, we combined the average injury potential of male and female lace bugs resulting from both experimental temperatures. This yielded an expected lifetime injury potential of 4.91 ± 3.01 cm^2 per lace bug and provided us with the injury component (I) of the hybrid EIL.

Results

Estimating Damage per Unit of Injury for the Hybrid EIL Equation. Linear regressions based upon injured leaf area, which used the survey results for
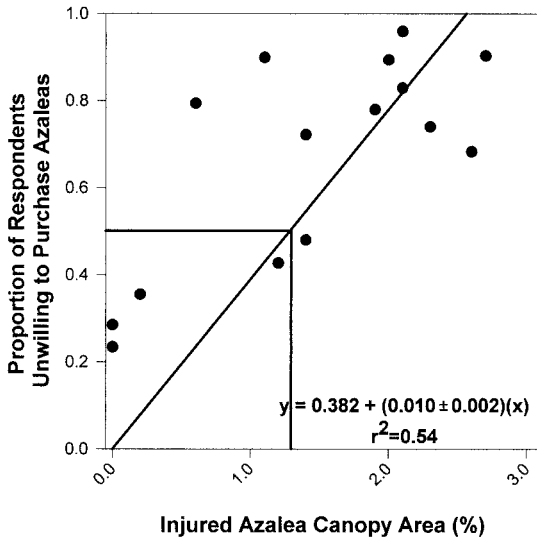
Fig. 1. Linear regression of the decisions to purchase azalea lace bug feeding-injured azaleas returned by survey participants. Slope of the line provides the damage per unit of injury (D) for purchase consideration.

purchase decisions (Klingeman et al. 2000a), revealed a positive correlation to increasing canopy leaf area injury ($y = 0.382 + [0.010 \pm 0.002] [x]; r^2 = 0.54; P < 0.002$) (Fig. 1). Treatment responses were also positively correlated to increasing canopy leaf area injury ($y = 0.302 + [0.004 \pm 0.001] [x]; r^2 = 0.62; P < 0.0001$) (Fig. 2). Slope values from these regressions provided the estimates of damage (D) resulting from each unit of injury for both purchase (Fig. 1) and treatment (Fig. 2) considerations.

Estimating Costs for the Hybrid EIL Equation. The value of an undamaged azalea grown in a 11.4-liter
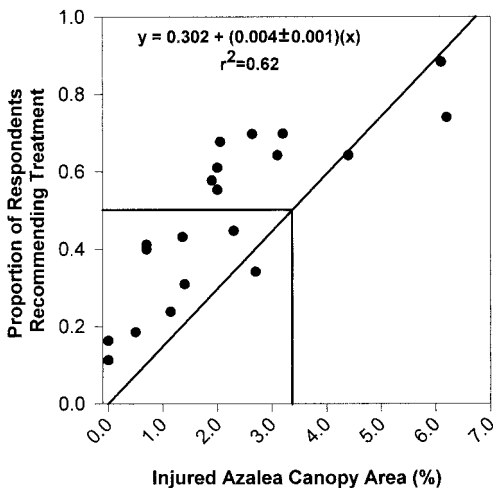

Fig. 2. Linear regression of the decisions to treat azalea lace bug feeding-injured azaleas returned by survey participants. Slope of the line provides the damage per unit of injury (D) for treatment considerations.

(3-gallon) nursery container was averaged from market values taken among eight retail garden centers in Athens, GA, during June 1998. Prices ranged from $5.84 to $12.99 with a retail average of $9.41 per 11.4-liter (3-gallon) container. Replacement costs were calculated for a damaged azalea in the landscape, using a valuation technique for amenity plants described by Neely (1988). For replacement purposes, we determined that azaleas qualified as a "Situation 2" amenity plants which Neely defines as "not vital to the landscape design" and which are "readily available in the market." We used the valuation formula for a 11.4-liter (3-gallon) azalea standard:

$$V = (P + R) CL, \qquad [4]$$

where P = retail value ($9.41 per plant), R = labor costs for removal and replacement (approximated as 3P, or $28.23 per plant), C = a correction factor for plant condition (assumed to be 100%), and L = the correction factor for plant location (estimated as 90%) (Neely 1988). Using these values, we calculated the replacement value for a 11.4-liter (3-gallon) azalea to be $33.88.

Control costs in a commercial nursery were based upon the mean size of azaleas grown in 11.4-liter (3-gallon) nursery containers, which were determined to have an average canopy diameter of 55 cm and $1,902 \pm 234$ cm^2 mean canopy leaf area. We calculated the number of azaleas that could be grown in a single acre (0.41 ha) of ornamental nursery based on a spacing of plants on 110-cm centers with rows of azaleas placed 122 cm apart. We also included three 6-foot-wide paths in our final calculations, which yielded 2,750 azaleas per 0.41 ha (per acre). Nursery costs of managing pests vary with the choice of pesticidal compounds. To address this, we based the cost of control on the Orthene T T & O formulation of acephate, an organophosphate insecticide (Chevron Chemical, San Ramon, CA), M-Pede Insecticidal Soap, a 2% solution of potassium salts of fatty acids (Ecogen, Langhorne, PA), and the Marathon II formulation of imidacloprid (Olympic Horticultural Products, Mainland, PA), a foliar-applied, chloronicotinyl insecticide that has been widely adopted for managing pests in commercial production. Pesticide rates were calculated with the assumption that formulated compounds would be applied through a hydraulic sprayer in 946.4 liters (250 gallons) of water, which was the estimated volume needed to achieve thorough coverage of azalea foliage within a production acre. The average retail cost of acephate was $14.67 per 0.41 ha. Insecticidal soap cost an average of $109.60 per 0.41 ha and imidacloprid cost an average of $143.00 per 0.41 ha. Pesticide costs per plant were $0.0053 for acephate, $0.0399 for insecticidal soap, and control with imidacloprid cost $0.0520 per plant. Each of the calculated per-plant control costs were adjusted to include a 2 h labor expense, at $7.50 per hour, estimated as the time needed to mix, apply, and clean up after pesticide applications (Table 1).

Table 1. Costs of managing *Stephanitis pyrioides* (Scott) on azaleas in landscape maintenance and nursery production scenarios

Management scenario	Control costs	Plant value[a]	Cost:Value
Nursery Production			
Acephate	$0.0108[b]	$9.41	0.0011
Insecticidal soap	$0.0417	$9.41	0.0044
Imidacloprid	$0.0575	$9.41	0.0061
Landscape (10 plants)	$4.50[c]	$33.88	0.1328
Landscape (1 plant)	$45.00	$33.88	1.328

[a] Calculated from Neely (1988) for azaleas identified as "Situation 2" plants, which are "Readily available [and] are not critical to the landscape design."

[b] Based on 2,750 azaleas per acre (0.41 hectare). Plant numbers were calculated based on shrubs spaced on 110-cm centers, which were 122 cm apart. Three 1.8-m roadways were included in the calculations. Costs include 2-h labor at $7.50 per hour to mix, apply, and clean up pesticide applications.

[c] Based on a minimum site-visit charge of $45. Costs of pesticides, mixing, and application are included within the site-visit charge.

The cost of controlling azalea lace bugs in landscape habitats was estimated to be $45, which is the minimum site-visit per client reported by commercial pest control firms in Athens, GA. For our purposes, we have assumed that the chemical, labor, and insurance costs associated with spot treatments to single azaleas, or for managing of a group of 10 azaleas were inconsequential and were included within the minimum site-visit charge.

Calculating the Hybrid EIL. The aesthetic injury levels for each of our management situations (Table 2) were derived from the hybrid EIL, such that:

$$\text{hybrid EIL} = (C{:}V)/IDK, \qquad [5]$$

where (C:V) = the ratio of cost of pest control to individual plant value; I = the individual lifetime potential for inflicted azalea lace bug feeding injury; D = the slope of the unacceptability curve for purchase considerations (in the nursery situations), or for treatment considerations (in the landscape); and K = 100% or 50% control effectiveness.

Discussion

The results of our hybrid EIL determinations under separate management situations show that the costs of

Table 2. Hybrid economic-injury levels (Hybrid EIL = C:V/IDK) for *S. pyrioides* feeding injury on 'Girard's Rose' azaleas

Management scenario	Azalea lace bugs per shrub	
	K = 1	K = 0.5
Nursery Production		
Acephate control	0.056	0.112
Insecticidal soap	0.224	0.448
Imidacloprid	0.311	0.621
Landscape maintenance		
10 azaleas	6.76	13.52
A single azalea	67.62	135.24

Three management situations are considered wherein control efforts are 100% effective (K = 1) and 50% effective (K = 0.5).

[a] Ratio of control costs to the plant value (after Neely 1988).

controlling ALB in a nursery or among groups of plants in the landscape were small compared with the value of plants in these settings. The hybrid EIL was not appropriate for managing pests on individual shrubs, where aesthetics were the principal contributors to treatment decisions. Under these conditions, the economics of control and shrub replacement alone would result in large ALB numbers and unacceptable levels of aesthetic damage. Therefore, management of single azaleas in the landscape should be based on aesthetic evaluations.

Similar conclusions were reached with twospotted spider mite feeding injury on *Euonymus alatus* (Thunberg) 'Compacta' in the landscape (Sadof and Alexander 1993). Control costs in a nursery or among landscape plant groupings were low in comparison to plant value (Sadof and Alexander 1993). Spider mite control decisions for individual shrubs, however, were more appropriately determined with a hybrid EIL model, using the aesthetic injury level, defined as the lowest pest population causing aesthetic damage (Olkowski 1974, Sadof and Raupp 1996).

Even when control tactics are 100% effective, our determination of a hybrid EIL in nursery systems indicates that almost no lace bug presence is tolerated for decisions regarding azalea lace bug control. The efficiency and low cost of readily available pesticides creates conditions where economic motives outweigh possible considerations of acceptable aesthetic losses. Growers relying on strictly economic thresholds would have zero-tolerance for lace bugs. Control recommendations of nursery integrated pest management (IPM) scouts would be based upon the detection of azalea lace bugs. Still, withholding pesticide applications until the first lace bug is seen will save the grower cost associated with a routine calendar spray schedule. Regardless, to be practical and cost-effective, a successful nursery IPM scouting program will not be established around individual pest species, but should include routine monitoring of typical and emergent arthropod and plant disease problems.

Within the landscape, our hybrid EIL determinations were based on treatment thresholds of survey respondents (Klingeman et al. 2000a) suggesting that the hybrid EIL may be a useful tool for managing lace bugs among groups of azaleas. Within a grouping of azalea shrubs that have ≈55 cm³ individual canopies, beat samples can be taken by visually quartering individual shrubs and delivering three vigorous beats per quarter. Samples that averaged >7 lace bugs per shrub would justify pesticide treatment. Management of pests at this level would be expected to maintain shrubs at injury levels satisfactory to 50% of the landscape manager's clientele. A portion of the clientele is likely to be dissatisfied, however, suggesting that this approach may not be readily accepted by all segments of the market. Still, our hybrid EIL may find use among consumers who are increasingly concerned with the potential interactions of pesticides and the environment. The hybrid EIL would be inappropriate for maintenance of individual azaleas. A beat sample would have to yield >67 lace bugs to provide an

economic justification for the application of a pesticide control. Management of individual azaleas may be best conducted using the lowest population levels of azalea lace bug that cause aesthetic injury. From our survey determination, treatment of a single shrub would be indicated when 3.3% of the shrub canopy was injured. This corresponds to ≈44% of the canopy presenting 2% or greater leaf injury due to azalea lace bug feeding. Landscape managers or homeowners can scout for this readily observable lace bug feeding injury level and make pesticide applications once the physical presence of feeding lace bugs is confirmed.

In this model, management is considered using single applications of pesticides for control. Strategies that reduce lace bug populations by only 50% (K = 0.5) double the number of lace bugs that are required to meet the hybrid EIL. At these levels, particularly among azaleas in the landscape, feeding injury rapidly exceeds aesthetic considerations, will be visually unacceptable to clients, and will begin to inhibit plant physiological performance (Klingeman et al. 2000c).

In each case, thresholds that formed the basis for grower, landscape manager, and homeowner decisions about azalea purchase and treatment were well below physiologically relevant levels of azalea lace bug feeding injury. Whole-plant gas exchange measurements revealed that azalea lace bug feeding injury in the plant canopy must exceed 13% actual injury, equivalent to 61% proportional injury, to affect significant reductions in net photosynthesis and plant growth (Klingeman et al. 2000c). Productivity parameters among field-grown azaleas, which supported sustained levels of azalea lace bug feeding injury, were recorded over 2 yr. Neither whole-shrub flower number, leaf and stem dry masses, nor shoot length, number, and leaf and stem dry masses of new shoots differed significantly with up to 14% maximum canopy area lace bug feeding-injury levels (Klingeman et al. 2001).

These thresholds do not incorporate the effect of predators and parasitoids on population suppression and might be refined with the inclusion of beneficial arthropod activity. Additional research is also needed to develop an appropriate sampling protocol for azalea lace bugs in the nursery. Arthropod pest populations are seldom evenly distributed. Knowledge of azalea lace bug or other pest distribution and dispersal patterns are crucial in developing a practical and effective sampling pattern for nursery IPM. Variability of horticultural characteristics and pest or disease resistance among plant species, including azaleas, may affect treatment decision criteria. The cultivars that were used to develop this synthesis included 'Girard's Rose', 'Delaware Valley White', and 'Pleasant White' azaleas, which present dark green foliage with light leaf trichomes, on which the chlorotic stippling induced by azalea lace bug feeding injury is readily apparent. Light colored foliage or dense leaf trichomes are expected to limit recognition of feeding injury, which may result in increased consumer acceptance of azaleas having higher levels of injured leaf tissue.

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