Azalea Growth in Response to Azalea Lace Bug (Heteroptera: Tingidae) Feeding

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ABSTRACT The effects of azalea lace bug, *Stephanitis pyrioides* (Scott), feeding injury on azalea growth and development were investigated using 'Girard's Rose' azaleas during a 2-yr field study in Georgia. Low, medium, and high injury treatments, which corresponded to 6, 8, and 14% maximum canopy area injury, were compared with control azaleas that received no lace bug infestation. Flower number, whole-shrub leaf and stem dry mass, and dry mass and size of new growth tissues were unaffected by treatments. In contrast, growth index measurements, a general measure of variability frequently used for horticultural differentiation, showed significant reductions for all treatments in comparison to control azaleas after 20 wk. Though not directly quantified, this apparent discrepancy may be explained as an artifact of lace bug feeding-induced leaf abscission. Growth index measurements had considerable variability and may not be the most reliable measurement of size. In July 1998, plant canopy densities among azaleas maintained in the high injury treatments were ≈15% less full than the canopies of control shrubs. Predaceous insects had a significant negative association with azalea lace bug number during the 2-yr study. Flower and new tissue production, measured destructively during two growing seasons, revealed azalea tolerance to 14% of maximum canopy area lace bug feeding-injury levels.

KEY WORDS *Rhododendron* spp., *Stephanitis pyrioides*, azalea lace bug

AZALEAS ARE IMPORTANT key plants in the management of urban landscapes (Holmes and Davidson 1984, Raupp et al. 1985, Braman et al. 1998). Feeding injury inflicted by azalea lace bug nymphs and adults, *Stephanitis pyrioides* (Scott), the principal arthropod pest of azaleas in the landscape, is both readily apparent and aesthetically displeasing (Johnson and Lyon 1991). Aspects of the biology and behavior of azalea lace bugs have been well studied (Bailey 1951, Neal and Douglass 1988, Braman et al. 1992, Nalepa and Baker 1994, Neal and Bentz 1997). The short-term effects of azalea lace bug feeding on plant gas exchange have also been determined (Buntin et al. 1996; Klingeman 1998). Within injured leaves, leaf respiration declines in response to stomatal closure. Net photosynthesis is also reduced because of both stomatal closure and direct removal of chloroplasts (Buntin et al. 1996). In whole-plant gas exchange studies, feeding injury exceeding 13% was required for short-term reductions in photosynthesis (Klingeman 1998). Long-term effects of azalea lace bug feeding, however, have not been adequately quantified. Reduced plant vigor, premature leaf abscission, or plant death have been attributed to azalea lace bug feeding injury (Bailey 1951, Mead 1967, Nalepa and Baker 1994).

In the landscape, the potential impact of natural enemies on azalea lace bugs has been demonstrated (Braman et al. 1992, Neal and Haldemann 1992, Trumbule and Denno 1995, Trumbule et al. 1995, Leddy 1996). Successful incorporation of beneficial arthropods into decision-making criteria for azalea lace bug management requires additional knowledge of predators and parasitoids associated with azalea lace bugs.

In this study, the effect that various levels of azalea lace bug feeding injury had on azalea growth parameters were compared with the growth of uninjured azaleas. Cumulative effects of azalea lace bug feeding were measured in successive years using nondestructive and destructive measures of azalea growth. In conjunction with field-plot growth assessments, azalea lace bug and associated arthropod populations were surveyed to identify potential or current natural enemies of the azalea lace bug.

Materials and Methods

Design and Installation. In November 1996, 120 'Girard's Rose' azaleas, commercially grown into 11.4-liter containers, were planted under shade in an untended pecan orchard at the Georgia Experiment Station in Griffin, GA. Pecan trees in the orchard had not received pesticide applications for 10 yr before the initiation of this project. Girard's Rose azaleas were selected for cold hardiness and for dark green foliage that would visually enhance lace bug feeding injury. Shrubs were arranged in a randomized complete block design with six replicated rows of 20 plants. Rows contained four treatments of five plants each and plants within treatments were sampled through time. Treatments were low (1–6%) feeding-injury levels, medium (7–9%) injury, and high (10–14%) canopy leaf area injury levels; these were compared with con-

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trol azaleas that were maintained without lace bugs. The low injury treatment approximated levels of injury unacceptable to consumers at point-of-purchase, and the medium level of injury approximated injury prompting treatment for azalea lace bugs in the landscape (Klingeman 1998). High injury levels were at levels previously found to reduce azalea photosynthesis and growth (Klingeman 1998).

Using a tractor-mounted auger, holes (45 by 45 cm) were bored in Cecil sandy clay loam (clay, kaolinitic, thermic Typic Hapludult) (USDA-SCS 1964). Shrubs were planted on 1.8-m centers with 1.8-m spacing between rows to limit lace bug migration. To avoid incorporating the boles of pecan trees into the treatment rows, 2.4-m spacing separated every other row. Rows received a 1-m band of pinebark mulch ≈5 cm deep for weed suppression and moisture retention. Azaleas were fertilized with StaGreen Azalea, Camellia and Rhododendron fertilizer 11-5-5 (Pursell Industries, Sylacauga, AL) in March and October 1997. Turf between rows was mowed every 2–3 wk. Azaleas were watered as needed using No. 2 (3.8 liters/min) Rainbug emitters (Rain Bird, San Diego, CA).

Infestation and Damage Establishment. To establish injury levels for each of the treatments, azaleas were infested with azalea lace bugs from natural populations in Athens, GA, and from a colony. Lace bug colonies were maintained in an insect rearing facility at 27 ± 1°C under a photoperiod of 14:10 (L:D) h. Approximately every 2 wk, from April through July, in 1997, and from June through August, in 1998, treatments received an infestation of azalea lace bugs. Azaleas that required infestation were chosen based on visual inspections of apparent feeding injury made every 2 wk. Release numbers were based on the availability of lace bugs collected from field and colony. In 1997, treatments were infested with a total of 230, 180, and 115 azalea lace bugs per plant to achieve the high, medium, and low damage levels, respectively. Sex ratio of the released lace bugs ($n = 15{,}750$) averaged 3.2 females to each male during the 1997 season. In 1998, azalea lace bugs were released on five dates onto individual plants in groups of 20 lace bugs to maintain prescribed injury levels. A total of 320 lace bugs was released among azaleas in the low injury treatment. Azaleas maintained at the medium injury level received 1,080 lace bugs and plants at the high injury level received 1,420 lace bugs among the shrubs. The sex ratio of the azalea lace bugs released in 1998 ($n = 2{,}820$) averaged 3.3 females to each male.

Injury levels for azalea treatments were based on visual assessments of the overall physical appearance of individual azaleas under azalea lace bug feeding pressure. To quantify the overall injury level of sampled shrubs, Mocha software (Jandel Scientific 1994) was used to quantify injury on 24 images of azalea leaves that presented chlorosis caused by azalea lace bug feeding. Images that exhibited a range from 0% to 82% leaf area injury were arranged on a photographic array. Estimates of injury were made nondestructively by comparing leaves on six terminal stems per shrub to a photographic array of feeding-injured leaves. Injury estimated among the terminals was used to determine approximate treatment injury levels. When plants in the low-injury treatment approximated the target damage level, shrubs were treated with 29.7 g (AI)/100 liter Orthene T T & O formulation of acephate (Chevron Chemical, San Ramon, CA). Acephate applications were made to controls and low injury treatments on 24 June and five August 1997. Acephate was again applied to control plants on 6 July 1998. Previous research indicated that acephate had no significant effects on plant gas exchange when applied at this rate (Klingeman 1998).

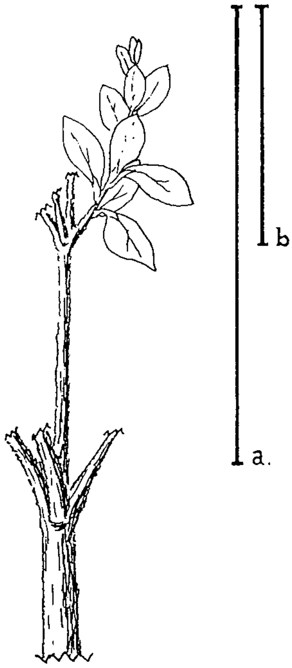

Fig. 1. A graphic representation of the "terminal" units (a) and the "new growth" units (b) measured on each destructive sampling date.

Destructive Sampling Measurements. Morphological effects of azalea lace bug feeding were assessed by destructive sampling in August 1997, February 1998, and August 1998 by using measurements taken among 24 azaleas, which represented six replicates of four treatments for each group. Azaleas, randomly assigned a sampling date at the onset of this study, were dug and sectioned. Measurements of plant growth and lace bug feeding injury were taken randomly among 15 of the most recently developed terminal stem units, defined as a stem section that terminated in a division of stem tissues and leaves, representing the current year's growth (Fig. 1). On each terminal, data on terminal length, terminal dry weight, leaf number and leaf dry weight, and percentage of leaf injury resulting solely from azalea lace bug feeding were collected. Variable means were used to provide a value for the entire shrub. For each shrub, dry mass measurements of stems and leaves, and total number of terminals were determined. Terminal diameter was measured 5 mm from the base of the stem using a Lyman Electronic Digital Caliper (Lyman Products, Middlefield, CT). Where leaf number permitted, six to eight leaves were taken from each of 15 sampled terminals for leaf area measurements using a LI-3100 leaf-area meter (LiCor, Lincoln, NE). Average leaf areas were calculated for each terminal and for the entire shrub. All of the leaves from the 15 sampled terminals were compared with Mocha software images and assigned an estimated percentage injury. Cumulative estimates of individual leaf damage provided a mean level of chlorotic stippling on each of 15 terminals. Feeding injury for the 15 terminals was used to provide an estimate of the actual mean damage level for the entire shrub.

Gross Morphology, Flower Productivity, and Photosynthetic Photon Flux (PPF) Measurements. An azalea growth index, the multiplied value of plant height and two measures of plant width, was recorded on 19 March and 5 August 1997, and on 2 February, and 29 July 1998. As an additional measure of plant quality for the second season, on 1 July 1998, density indices were taken among treatments by an independent observer by observing shrubs from ground level at parallel and perpendicular angles to the rows. An estimate, to the nearest 5%, was made of the proportion of the shrub canopy occupied by leaves, with the mean used to ascertain differences among treatments.

In 1998, bud development among treatments was ranked among shrubs using a 1–5 scale index: 1 = no open buds, 2 = few to ¼ of the buds opening, 3 = ¼–½ of the buds opening, 4 = ½–¾ of the buds opening, and 5 = ¾ to all of the buds opening or opened. Flower number counts were also obtained for each shrub to obtain a mean count within each replicated treatment group. To accomplish this, each shrub was visually halved and the total number of flowers per half was counted on 19 March 1997. To assess the effects of lace bug feeding injury on cold tolerance, on 20 March 1998, about 1 wk after a late-season frost, the average number of live or frost-killed flower buds per plant was counted on four randomly chosen stems per plant. Finally, flower numbers for each azalea were quantified on 2 April 1998, by counting the flowers on six terminal branches per shrub.

Under cloud-free conditions, photosynthetic photon flux levels were recorded between 1200 and 1300 hours on 23 June 1997 and on 1 August 1998 using a LI-189 quantum meter (LiCor). PPF measurements were taken directly over the center of the shrub at a canopy height.

For all assigned variables, statistical tests for differences among treatments were made using (PROC GLM, SAS Institute 1985). Means among treatments were separated with Fisher protected least significant difference (LSD) test (SAS Institute 1985).

Field Scouting to Quantify Azalea Lace Bugs, Natural Enemies, and Egg Parasitism Levels. Juvenile and adult azalea lace bugs, spiders and insect predators were counted on 15 dates in 1997 from 22 May through 3 November. In 1998, azaleas were sampled on 30 January and nine dates from 6 May through 23 September. Presence of azalea lace bug nymphs was determined by visually inspecting the abaxial surfaces of all leaves on three terminal stems per shrub with the aid of a 16× magnifying lens. Shrubs were then visually quartered and live adult azalea lace bugs and predatory arthropods were quantified by giving three vigorous shakes to the azalea stems and foliage of each quarter. Stems were shaken over an opaque 13.2-liter Keepers storage container (Rubbermaid, Wooster, OH). PROC MEANS (SAS Institute 1985) was used to generate summed totals of spiders and potentially predatory insects present within treatments. The relationship of the number of spiders and beneficial insects to both the number of azalea lace bugs and the level of injury inflicted by lace bugs were determined using Pearson's correlation coefficient (PROC CORR, SAS Institute 1985). Correlation analyses were conducted for the sampling dates that preceded each of three destructive sampling periods and for all sampling dates combined for the 2-yr study.

The status of azalea lace bug eggs, either as viable, parasitized by the mymarid parasitoid, *Anagrus takeyanus* Gordh, or demonstrating lace bug emergence, was assessed in April and August 1998. Illuminated from beneath, eggs appeared as light oval regions in the leaf tissue and were usually located along the leaf midvein. Eggs with parasitoid emergence have a neat round hole cut through the chorion, operculum, and often any overlying fecal deposit with a portion of the operculum frequently left intact and in place (Balsdon et al. 1993). Eggs among three leaves per plant, collected in April 1998, contained a record of parasitism that had occurred in 1997. In August, mymarid parasitism was determined from inspections of five injured leaves per plant.

Egg status among the five plants in each treatment group were determined using PROC MEANS and were analyzed for statistical significance using PROG GLM (SAS Institute 1985). Treatment means separation were performed using Fisher protected LSD test (SAS Institute 1985).

Results

Shrub canopy injury levels were determined as the mean percentage injury encountered among the 15 terminal stems destructively sampled per treatment. By August 1997, azalea lace bug infestations achieved average canopy injury levels of 6.1% total leaf area for the low-injury treatment, 8.0% for the medium-injury treatment, and 13.9% mean canopy injury in the high-injury treatment (Fig. 2). A low level of injury, approximating 0.2% of the shrub canopy, was also seen among the control plants. In August 1998, lace bug feeding injury levels were lower. Injury means approximated 2.6% canopy injury levels for the low-injury treatments, 2.8% for the medium-injury treatments, and 4.8% mean canopy injury for the high-injury level (Fig. 2). The control plants again had low injury levels, approximating 1.1% of the shrub canopy (Fig. 2). Injury among control plants was attributed to early season lace bug pop-

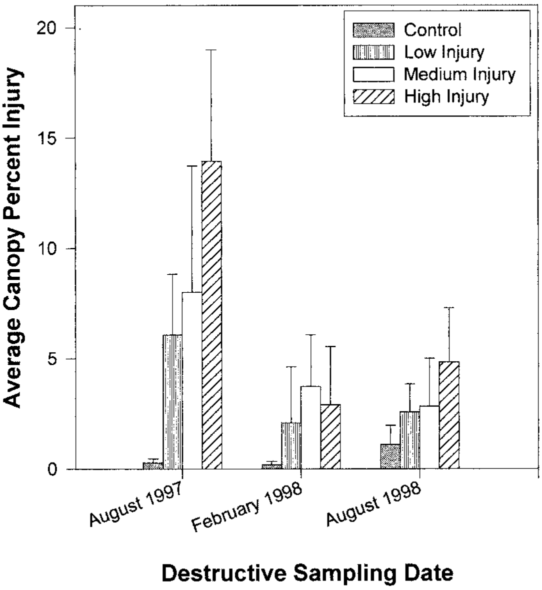

Fig. 2. Estimated mean ± SD canopy injury among treatments on each of the destructive sampling dates.

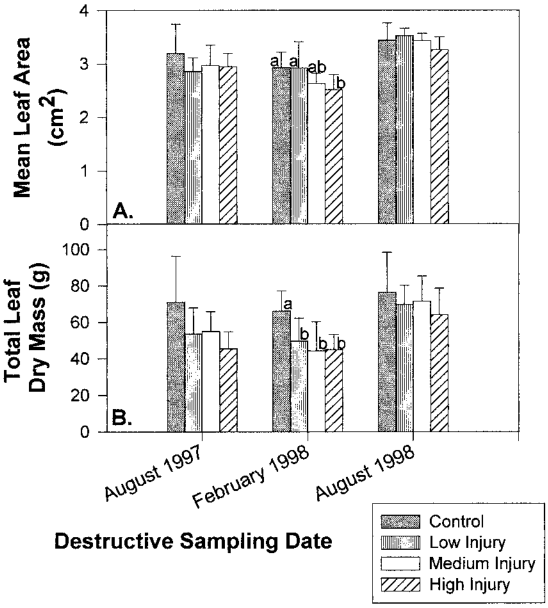

Fig. 3. (A) Mean ± SD leaf areas observed among treatments on each destructive sampling date. (B) Total leaf dry mass measurements observed among treatments on each destructive sampling date. Means with different letters represent statistically significant differences using Fisher protected LSD (α = 0.05).

ulations that escaped detection by developing within the interior of the shrubs.

Morphological Differences Determined through Destructive Sampling. No significant differences among treatment means were evident for either average stem height or new-tissue stem diameter, or for mean dry mass of new growth, the dry mass of stems, or the number of leaves per unit of new growth on any destructive sampling date. In August 1997 and August 1998, mean leaf areas and total leaf dry mass did not significantly differ among treatments. However, in February 1998, total leaf dry mass (F = 3.76; df = 3, 15; P = 0.03) and mean leaf area (F = 4.27; df = 3, 15; $P <$ 0.03) were significantly smaller in plants with high injury than control plants (Fig. 3).

No significant differences were detected for growth indices among azalea treatments in April 1997 (F = 0.66; df = 3, 115; P = 0.58) (Fig. 4). By August 1997, however, control azaleas had significantly higher growth index ratings than shrubs managed for medium or high injury levels (F = 2.94; df = 3, 115; P = 0.06) (Fig. 4). Measurements taken in February 1998 revealed that azaleas in all injury treatments had significantly smaller growth indices than control plants (F = 4.01; df = 3, 91; $P <$ 0.01) (Fig. 4), a trend that persisted in August 1998 (F = 8.88; df = 3, 68; $P <$ 0.0001). Growth index differences for low, medium, and high injury levels did not differ significantly from each other in February or August 1998 (Fig. 4). Analysis of the growth index value revealed that control and injured azalea shrub size differences were attributed to shrub circumference. None of the shrub treatments showed significant differences in plant height on any sampling date (F = 0.39–0.86, df = 3, P = 0.46–0.76).

Density indices measured on 1 July 1998 revealed significant differences in the average proportion of complete canopies among treatments (F = 6.29; df = 3, 68; P = 0.0005). In general, control shrubs had the highest percent of the canopy occupied by foliage (74.4 ± 8.0%) (Table 1). Shrubs that were maintained at the high azalea lace bug feeding-injury levels had the lowest percentage of leaves filling the canopy (60.0 ± 15.0%).

Freeze Injury, Floral Production, and Photosynthetic Photon Flux Analyses. At full bloom, flower numbers produced by shrubs were not significantly different among treatments in 1997 (F = 1.31; df = 3, 15; P = 0.31), or in 1998 (F = 0.61; df = 3, 15; P = 0.62). Flower numbers averaged 243.8 ± 66.1 per half-shrub in 1997, and 60.7 ± 34.9 among six terminal stems per shrub in 1998 (data not shown). No significant differences in frost injury were detected among treatments for either number of damaged flower buds (F = 2.57; df = 3, 15; P = 0.09), the number of undamaged flower buds (F = 1.26; df = 3, 15; P = 0.14), or the ranked status of flowering (F = 2.12; df = 3, 15; P = 0.14) in March 1998. Photosynthetic photon flux measurements taken between 1200 and 1300 hours did not differ significantly among treatments in either 1997 (F = 0.33; df = 3, 15; P = 0.81) or 1998 (F = 1.88; df = 3, 15; P = 0.35).

Natural Enemy, Injury, and Azalea Lace Bug Associations. Sixty-four taxa of potentially beneficial arthropods were observed on lace bug-infested azaleas (Table 2). Treatment differences among adult and nymphal lace bug numbers (Fig. 5) and potentially beneficial arthropods (Fig. 6) were pooled among sampling dates that preceded destructive sampling.

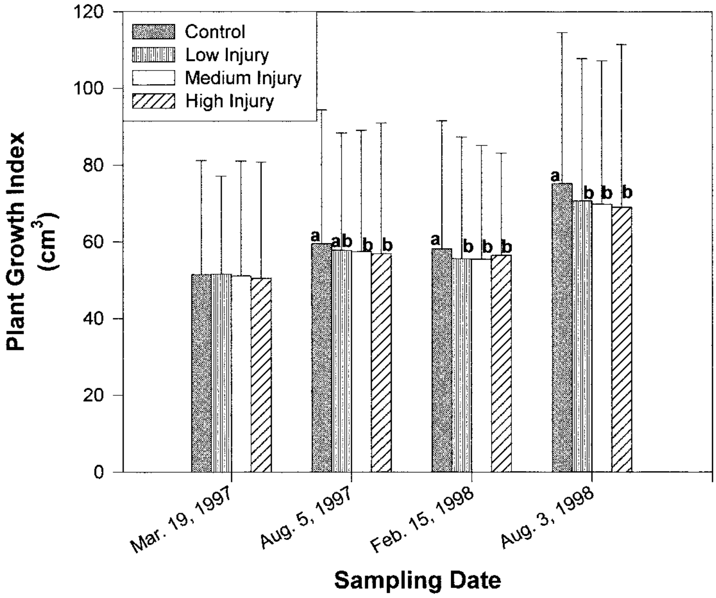

Fig. 4. Growth index measurements (mean ± SD) observed among treatments on each sampling date. Means with different letters represent statistically significant differences using Fisher protected LSD ($\alpha = 0.05$).

Lace bug numbers were strongly correlated with shrub injury levels before sampling in August 1997 ($r^2 = 0.81$, $n = 24$; $P < 0.0001$), February 1998 samples ($r^2 = 0.40$, $n = 24$; $P = 0.05$), and August 1998 samples ($r^2 = 0.83$, $n = 24$; $P < 0.0001$). Azalea lace bug numbers showed no significant associations with either the total number of spiders ($r^2 = -0.18$–0.27, $n = 24$; $P = 0.21$–0.69) or the total number of predaceous insects ($r^2 = -0.40$ to -0.14, $n = 24$; $P = 0.06$–0.51) in any period preceding destructive sampling. The combined analysis for azaleas sampled during both seasons revealed a weak, yet significant negative association in the number of lace bugs observed to the total number of predaceous insects sampled per azalea ($r^2 = 0.28$, $n = 24$; $P = 0.02$). The association of spider number with total lace bug numbers was not significant ($r^2 = 0.28$, $n = 24$; $P = 0.76$).

Examination of lace bug-injured azalea leaves from 1997 revealed the presence of *A. takeyanus*, the mymarid parasitoid, among all treatments (Fig. 6A). Both the mean numbers of unhatched eggs per leaf ($F = 3.23$; df = 3, 90; $P < 0.03$) and the mean percentage of injured leaf area ($F = 4.13$; df = 3, 90; $P < 0.01$) were significantly different among treatments. Differences in the mean number of parasitized eggs per leaf, however, were not significant among treatments ($F = 1.57$; df = 3, 90; $P = 0.20$). Assessment of feeding-injured leaves collected in late-July 1998 revealed significant differences in injury levels that corresponded to experimental treatments ($F = 5.61$; df = 3, 92; $P < 0.002$) and the number of unhatched eggs at the time of inspection ($F = 12.00$; df = 3, 92; $P < 0.0001$) (Fig. 6B). A significantly greater number of unhatched eggs were found among population-managed azaleas than control plants ($F = 8.29$; df = 3, 92; $P < 0.0001$). However, means separations found no significant differences among unhatched egg numbers in leaves receiving low, medium, or high lace bug population levels. No significant differences were evident among treatments for the numbers of parasitized eggs ($F = 1.73$; df = 3, 92; $P = 0.17$) or numbers of eggs from which *S. pyrioides* successfully emerged ($F = 1.89$; df = 3, 92; $P = 0.14$). In 1998, higher parasitism levels of lace bug eggs, as well as migration and the possible predation of nymphs and adult lace bugs by beneficial arthropods, may have limited the successful establishment of lace bugs in the field. Although, azalea lace bug populations in Spalding County were also limited and may have been influenced by lack of rainfall (W.E.K., unpublished data).

Table 1. Effect of azalea lace bug feeding injury on proportion of azalea canopy filled by foliage on 1 July, 1998

Injury level	Proportion of foliage (± SD)
Uninjured	74.4 ± 8.0a
Low	65.0 ± 12.2bc
Medium	68.1 ± 11.5ab
High	60.0 ± 15.0c

Means followed by the same letter are not significantly different according to the protected LSD test ($P > 0.05$, SAS Institute 1985).

Discussion

The evidence presented by this study indicates that azaleas can tolerate lace bug feeding to injury levels as high as 14% of the available canopy area for at least 2 yr without significant impact on growth or flower production. Our destructive sampling efforts revealed

Table 2. Potential azalea lace bug predators collected from 'Girard's Rose' hybrid azaleas in an untended pecan orchard in Spalding County, GA

Potential predator	Frequency collected[a]	Life stages of predator[b]
Class Arachnida		
Order Pseudoscorpiones	R	A
Order Opiliones	C	A
Order Araneae		
Family Uloboridae		
Uloborus sp.	R	A
Family Gnaphosidae		
Cesonia bilineata (Hentz)	R	A
Other	R	A,N
Family Linyphiidae		
Tribe Linyphiinae	O	A,N
Tribe Erganini	O	N
Frontinella communis (Hentz)	O	A,N
Other	O	A,N
Family Thomisidae		
Coriarchne sp.	C	A,N
Synema sp.	C	A,N
Philodromus sp.	O	A,N
Misumenops oblongus (Keyserling)	O	A,N
Other	O	A,N
Family Clubionidae		
Cheiracanthium sp.	O	A,N
Clubiona sp.	O	A,N
Agroecia sp.	O	A,N
Family Anyphaenidae		
Anyphaena sp.	C	A,N
Aysha sp.	O	A,N
Aysha gracilis (Hentz)	O	A
Family Tetragnathidae		
Tetragnatha sp.	R	A
Family Agalenidae		
Agalenopsis sp.	O	A,N
Family Oxyopidae		
Oxyopes sp.	R	N
Peucetia viridans (Hentz)	R	N
Family Lyssomanidae		
Lyssomanes viridis (Walckenaer)	C	N
Family Salticidae		
Peckhami sp.	R	A,N
Phiddippus sp.	R	A,N
Other	C	A,N
Family Araneadae		
Mecynogea sp.	O	A,N
Araneus sp.	C	A,N
Other	C	A,N
Family Theridiidae		
Argaroides sp.	O	A,N
Episinus sp.	R	A,N
Achaeaeranea sp.	C	A,N
Argyrodes sp.	R	A,N
Other	C	A,N
Class Insecta		
Order Orthoptera		
Family Gryllidae		
Oecanthus nigricornis quadripunctatus Beutenmiller	C	A,N
Order Blattodea		
Family Blatellidae		
Choriosneurus texensis Saussere & Zehntner	C	A,N
Order Mantidea		
Family Mantidae		
Stegmomantis carolina (Johannson)	O	N
Order Heteroptera		
Family Lygaeidae		
Subfamily Geocorinae		
Geocorus punctipes (Say)	R	A
Other	R	A,N
Family Reduviidae		
Subfamily Ploiariinae		
Ploiaria carolina (Herrich-Schaeffer)	O	A,N
Subfamily Harpactorinae		
Zelus luridus Stal	O	A,N
Sinea sp.	R	A
Family Berytidae		
Jalysus spinosus (Say)	R	A
Family Miridae		
Rhinocapsus vanduzeei	R	A,N
Lopidea sp.	R	A,N
Lygus sp.	R	A,N
Family Pentatomidae		
Podisus maculiventris (Say)	R	A
Family Nabidae		
Nabis roseipennis Reuter	R	A,N
Order Coleoptera		
Family Elateridae		
Melanotus sp.	C	A
Anchastas sp.	C	A
Family Coccinellidae		
Chilocorus stigma (Say)	R	A
Cycloneda munda (Say)	R	A
Coleomegilla maculata lengi Timb.	R	A
Harmonia axyridis Pallas	C	A,L
Coccinella septempunctata L.	C	A,L
Order Neuroptera		
Family Chrysopidae		
Chrysopa sp.	C	A,L
Family Hemerobiidae		
Hemerobius sp.	C	A,L
Micromus sp.	C	A,L
Family Berothidae	R	A
Family Coniopterygidae	R	A
Order Hymenoptera		
Family Formicidae		
Solenopsis invicta (Buren)	C	A
Family Mymaridae		
Anagrus takayanus Gordh	C	E

[a] Frequency of collection during azalea beat sampling. C, common (found on almost every date in each season); O, occasional (found on several dates within the season); R, rare (found infrequently in each season or only on a few shrubs).

[b] Life stage encountered in beat sampling. E, egg; N, nymph; L, larvae; A, adult.

significant reductions in total azalea leaf dry mass and mean leaf areas that corresponded to increasing injury levels. This observation may be explained by leaf abscission occurring in response to lace bug feeding-injury. Although neither rate of abscission nor levels of feeding injury required to cause abscission were directly quantified in this study, several researchers have reported premature senescence and leaf drop in response to azalea lace bug feeding injury (Bailey 1951, Mead 1967, Johnson and Lyon 1991). Fully mature and expanded leaves have the greatest probability of having been exposed to lace bug feeding pressure throughout the growing season. Reduced stomatal conductance or the loss of photosynthetic assimilates may create a resource-sink that triggers the abscission of injured leaves (Andrews and La Pre 1979, Ellsworth et al. 1995, Pollock and Farrar 1996). Leaf abscission

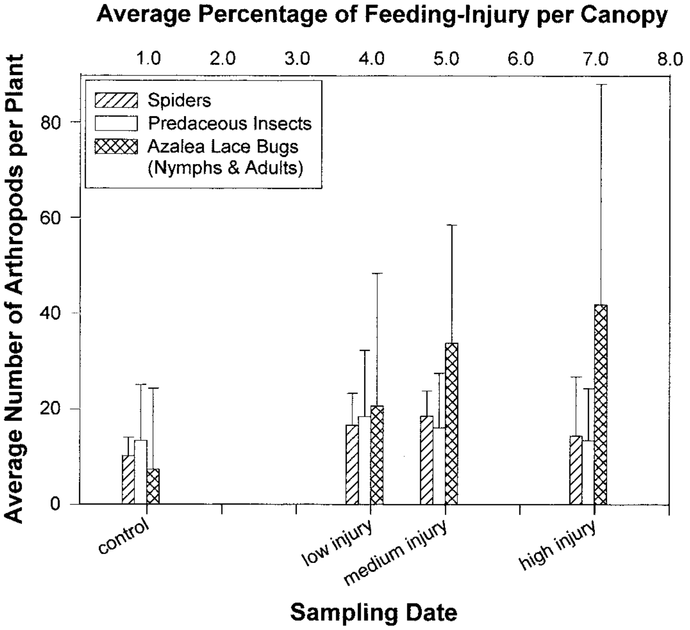

Fig. 5. Mean ± SD number of beneficial arthropods within treatments summed among samples made before each destructive sampling period.

also provides an explanation for the reduced growth index values apparent among injury treatments, in comparison to control shrubs. Although these differences, which were attributed to a greater circumference of control azaleas, were consistent after August 1997, it is improbable that they were the result of any significant reductions in plant productivity. We hypothesize that the terminal stems of undamaged azaleas, bearing a full compliment of leaves, were heavier throughout the growing season than stems of other treatments that aborted injured leaf tissues. Undamaged azalea stems increased the diameter of shrubs because of the presence of a greater wet mass of leaf tissues in both seasons. However, it is important to note that, regardless of injury level, azaleas were able to produce abundant flowers and leaves the following season and no significant differences in leaf dry mass or leaf area were evident among treatments in August 1998.

Our difficulty in establishing azalea lace bug populations and achieving extreme levels of injury highlights the importance of appropriate site selection for azalea plantings. The result of our efforts at infestation and injury-infliction in 1998 succeeded in causing maximal injury to only 4% of the available canopy in our high injury treatment. Although azaleas are often grown in high sunlight exposures, their cultural preferences are for medium to light shade (Galle 1987, Ball and Ball 1989). Azaleas in sunny exposures often have higher lace bug populations than azaleas in shade (Raupp 1984, Coyier and Roane 1986, Trumbule and Denno 1995; Trumbule et al. 1995). High population levels have been attributed to fewer natural enemies in sunny exposures (Trumbule et al. 1995), which has, in turn, been correlated with a reduction in habitat complexity (Leddy 1996). Large lace bug populations in exposed sites can be expected to reduce flowering and growth with levels of canopy feeding-injury >14%.

We had limited success at maintaining injurious lace bug population levels in the second season. Control shrubs that did not receive artificial lace bug infestations had light injury levels, which indicated that lace bug dispersal from infested azaleas might have occurred. Lace bug populations were often found initially within the sheltered interior of the shrub. Limited growth of lace bug populations might also indicate the potential for natural enemies to colonize and control populations of pest organisms. For instance, during the second season, parasitism by *A. takeyanus*, the mymarid egg parasitoid was much higher. Still, statistical analyses did not reveal any clear associations between lace bug numbers and the numbers of beneficial arthropods in any period that preceded our destructive samplings. The observed range of lace bug and predator population sizes may have been too small in each season to detect significant associations. Lack of clear associations may also be attributed to our small sample sizes ($n = 24$), resulting in unreliable comparisons. This hypothesis is supported by the analysis of associations made for the entire 2-yr period, which increased the sample size to 72 and provided a significant negative correlation for lace bug numbers and associated populations of predaceous insects. Although foraging efficacy of predaceous insects was beyond the scope of this study, red imported fire ants, *Solenopsis invicta* (Buren), were generally prevalent within samples that also included lady bird beetles

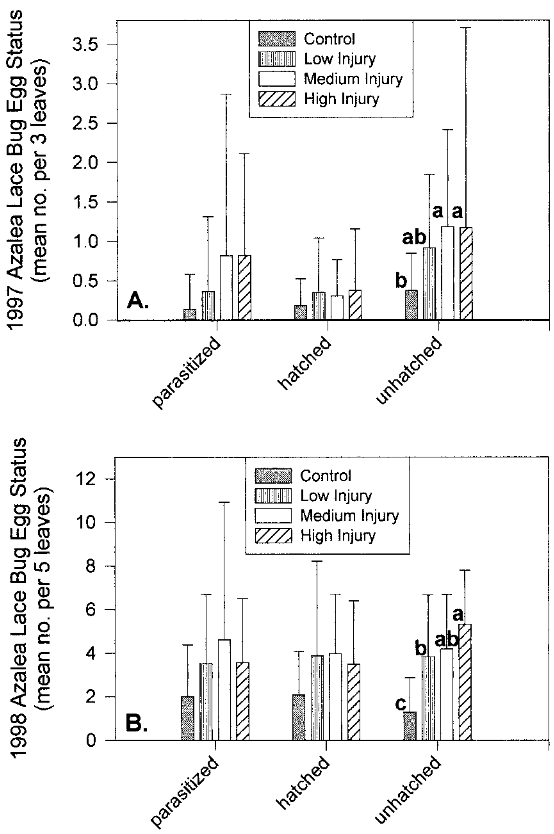

Fig. 6. Status of azalea lace bug eggs, as parasitized, successfully hatched, or unhatched, observed on feeding-injured leaves among treatments. (A) In April 1998. (B) In August 1998. Statistically significant mean ± SD differences are represented by different letters, where they occurred, using Fisher protected LSD ($\alpha = 0.05$).

(Coccinellidae), lacewings (Chrysopidae and Hemerobiidae), tree crickets (Gryllidae), and cockroaches (Blattellidae). These have been described as potential lace bug predators within the landscape (Leddy 1996). Leddy (1996) reported that the leaf-foraging spider *Anyphaena celer* was abundant in complex landscapes in Maryland. Samples taken throughout the season at our site also frequently included anyphaenid spiders (*Anyphaena* sp.) and the thomisid spiders, *Coriarchne* sp. and *Synema* sp. (Klingeman 1998). The mymarid egg parasitioid *A. takeyanus* was also present in our artificial landscape. Parasitism levels seen in our study were consistent with previous research that found up to 33% parasitism on azaleas in Spalding County, GA (Balsdon et al. 1993).

The highest injury levels achieved through our lace bug infestations in the field represented ≈14% canopy injury. We have determined, on the basis of whole-plant gas-exchange studies, that azalea lace bug feeding injury to 13% of the available canopy of plants did not significantly reduce gas exchange or the rate of photosynthesis below that of uninjured plants (Klingeman 1998). The lack of significant reductions in new growth of any treatment level on azaleas maintained in the 2-yr field study is consistent with the results of our whole-plant gas-exchange research. Increased tolerance for moderate pest pressure may be integrated into a landscape management plan for *S. pyrioides.* Currently, grower and consumer thresholds for pest control have been established at injury levels approximating 3% of the available plant canopy (Klingeman 1998). Educational efforts may be undertaken with the assurance that azaleas have the potential to tolerate lace bug injury to 13% of the plant canopy without resulting in significant reductions in azalea growth or floral production. All landscape maintenance clients may not readily accept incorporating higher threshold levels in treatment determinations. However, this research presents alternative control thresholds with evidentiary support that might be adopted by segments of the market that are acutely concerned with the hazards of pesticide use.

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References Cited

Andrews, K. L., and L. F. La Pre. 1979. Effects of Pacific spider mite on physiological processes of almond foliage. J. Econ. Entomol. 72: 651–654.

Bailey, N. S. 1951. The Tingoidea of New England and their biology. Entomol. Am. 31: 1–140.

Ball, J., and L. Ball. 1989. Rodale's landscape problem solver. Rodale, Emmaus, PA.

Balsdon, J. A., S. K. Braman, A. F. Pendley, and K. E. Espelie. 1993. Potential for integration of chemical and natural enemy suppression of azalea lace bug (Heteroptera: Tingidae). J. Environ. Hortic. 11: 153–156.

Braman, S. K., A. F. Pendley, B. Sparks, and W. G. Hudson. 1992. Thermal requirements for development, population trends, and parasitism of azalea lace bug (Heteroptera: Tingidae). J. Econ. Entomol. 85: 870–877.

Braman, S. K., J. G. Latimer, and C. D. Robacker. 1998. Factors influencing pesticide use and integrated pest management in urban landscapes: a case study. HortTechnology 8: 145–149.

Buntin, G. D., S. K. Braman, D. A. Gilbertz, and D. V. Phillips. 1996. Chlorosis, photosynthesis, and transpiration of azalea leaves after azalea lace bug (Heteroptera: Tingidae) feeding injury. J. Econ. Entomol. 89: 990–995.

Coyier, D. L., and M. K. Roane. 1986. Compendium of diseases of rhododendrons and azaleas. American Phytopathological Society, St. Paul, MN.

Ellsworth, D. S., M. T. Tyree, B. L. Parker, and M. Skinner. 1995. Impact of pear thrips damage on sugar maple physiology: a whole-tree experiment, pp. 53–58. *In* B. L. Parker, M. Skinner, and T. Lewis [eds.], Thrips biology and management. Plenum, New York.

Galle, F. C. 1987. Azaleas. Timber Press, Portland, OR.

Holmes, J. J., and J. A. Davidson. 1984. Integrated pest management for arborists: implementation of a pilot program. J. Arboric. 10: 65–70.

Jandel Scientific. 1994. User's manual, version 1.2.10. Jandel Scientific, San Rafael, CA.

Johnson, W. T., and H. H. Lyon. 1991. Insects that feed on trees and shrubs, 2nd ed. Cornell University Press, Ithaca, NY.

Klingeman, W. E. 1998. Developing decision-making guidelines for controlling the azalea lace bug, *Stephanitis pyrioides* (Scott) (Heteroptera: Tingidae). Ph.D. dissertation, University of Georgia, Athens, GA.

Leddy, P. M. 1996. Factors influencing the distribution and abundance of azalea lace bug, *Stephanitis pyrioides*, in simple and complex landscape habitats. Ph.D. dissertation, University of Maryland, College Park, MD.

Mead. F. W. 1967. Stephanitis lace bugs of the United States (Hemiptera: Tingidae). Fla. Dep. Agric. Div. Plant Ind. Entomol. Circ. 62.

Nalepa, C. A., and J. R. Baker. 1994. Winter oviposition of the azalea lace bug (Hemiptera: Tingidae) in North Carolina. J. Entomol. Sci. 29: 482–489.

Neal, J. W., and Bentz, J. 1997. Physical dynamics of the noncleidoic egg of *Stephanitis pyrioides* (Heteroptera: Tingidae) during development. Environ. Entomol. 26: 1066–1072.

Neal, J. W., Jr., and L. W. Douglass. 1988. Development, oviposition rate, longevity, and voltinism of *Stephanitis pyrioides* (Heteroptera: Tingidae), an adventive pest of azalea, at three temperatures. Environ. Entomol. 17: 827–831.

Neal, J. W., Jr., and R. L. Haldemann. 1992. Regulation of seasonal egg hatch by plant phenology in *Stethoconus japonicus* (Heteoptera: Miridae), a specialist predator of *Stephanitis pyrioides* (Heteroptera: Tingidae). Environ. Entomol. 21:793–798.

Pollock, C. J., and J. F. Farrar. 1996. Source-sink relations: the role of sucrose, pp. 261–279. *In* N. R. Baker [eds.], Photosynthesis and the environment. Kluwer, The Netherlands.

Raupp, M. J. 1984. Effects of exposure to sun on the frequency of attack by the azalea lace bug. J. Am. Rhododendron Soc. 38: 189–190.

Raupp, M. J., J. A. Davidson, J. J. Holmes, and J. L. Hellman. 1985. The concept of key plants in integrated pest management for landscapes. J. Arboric. 21: 317–322.

SAS Institute. 1985. SAS user's guide: statistics, 5th ed. SAS Institute, Cary, NC.

Trumbule, R. B., and R. F. Denno. 1995. Light intensity, host-plant irrigation, and habitat-related mortality as determinants of the abundance of azalea lace bug (Heteroptera: Tingidae). Environ. Entomol. 24: 898–908.

Trumbule, R. B., R. F. Denno, and M. J. Raupp. 1995. Management considerations for the azalea lace bug in landscape habitats. J. Arboric. 21: 63–68.

USDA Soil Conservation Service. 1964. Soil survey: Spalding County, Georgia. Series 1961. USDA Soil Conserv. Serv. 10.

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