Arthropod Predator Occurrence and Performance of *Geocoris uliginosus* (Say) on Pest-Resistant and Susceptible Turfgrasses

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ABSTRACT Interactions between host plant resistance and biological control may be advantageous or disadvantageous for pest management. Turfgrass cultivars have rarely been tested for extrinsic resistance characteristics such as occurrence and performance of beneficial arthropods on plants with resistance to known turf pests. Among six turfgrass cultivars tested, the bigeyed bug, *Geocoris uliginosus* (Say) nymphs varied in ability to reduce numbers of fall armyworm, *Spodoptera frugiperda* (J. E. Smith), larvae. The six grasses tested (Sea Isle 1 and 561-79 seashore paspalum, *Paspalum vaginatum* Swartz; TifSport and TifEagle bermudagrass, *Cynodon dactylon* [L.] *x C. transvaalensis* [Burtt-Davy]; and Cavalier and Palisades zoysiagrass *Zoysia japonica* von Steudel and *Z. matrella* [L.] Merrill) represented a range in resistance to *S. frugiperda*. In the laboratory, the greatest reduction in *S. frugiperda* larvae by a low density of *G. uliginosus* occurred on the resistant Cavalier zoysiagrass. A 7-fold difference in weight of 10-d-old larvae between those feeding on susceptible versus resistant grasses suggested that on the resistant grass larvae remained for a longer period in a size range susceptible to predation. Results of laboratory studies were not directly translated to the field, in which a diverse predatory arthropod community varied in composition depending on turfgras cultivar. In the field, the greatest reduction in *S. frugiperda* larvae by a low density of *G. uliginosus* occurred on Sea Isle 1 and 561-79 seashore paspalum grass. In the field, vacuum samples indicated that predaceous Heteroptera were most abundant in paspalum grasses and bermudagrasses, while Carabidae, Staphylinidae, and Araneae were more common in zoysiagrasses. In contrast, pitfall traps indicated that carabids were more common in bermudagrasses, Araneae and Staphylinids were similar among grass taxa, and Cicindellidae were most common in paspalum grasses and bermudagrasses. Predation was never significantly decreased on resistant turfgrass cultivars in any of the experiments described in this work, indicating no negative tritrophic interactions.

KEY WORDS turfgrass, host plant resistance, *Geocoris* spp., predators, biological control

A DIVERSE ENTOMOPHAGOUS arthropod fauna inhabits managed turfgrasses (e.g., Reinert 1978, Cockfield and Potter 1983, Braman and Pendley 1993, Heng-Moss et al. 1998). Predaceous insects in turfgrass have a demonstrated impact on common pest insects, including chinch bugs, *Blissus insularis* Barber (Reinert 1978); Japanese beetle, *Popillia japonica* Newman (Zenger and Gibb 2001); and the fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Terry et al. 1993).

Resistance among warm season turfgrasses to a wide variety of phytophagous pest species has been reported (e.g., Reinert 1982; Quisenberry 1990; Reinert et al. 1993, 1994, 1997, 1998; Reinert and Engelke 2000; Braman et al. 1994, 2000a, b, 2002; Shortman et al. 2002). The interactions between host plant resistance and biological control may be advantageous or disadvantageous for pest management (van Emden 1991). van Emden (1999) illustrated the frequent occurrence of a beneficial synergism between partial host plant resistance and pest suppression by natural enemies among various agronomic plant-pest-natural enemy systems. Price (1986) pointed out the need to understand the biology and ecology of each trophic level in detail before we can understand the complex interactions between host plant resistance and control by natural enemies.

Geocoris spp. (bigeyed bugs) have been shown to be opportunistic polyphagous predators (Crocker and Whitcomb 1980) that may play an important role in the prevention of pest outbreaks in a variety of agricultural and urban habitats. *Geocoris uliginosus* occurs commonly in turf (Dunbar 1971, Reinert 1978). Braman et al. (2003) reported greater abundance of *Geocoris* spp. in fall armyworm-susceptible Tifway ber-

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mudagrass (*Cynodon dactylon* [L.] *x C. transvaalensis* [Burtt-Davy]) compared with a more fall armyworm-resistant Emerald zoysiagrass (*Zoysia japonica* von Steudel *x Z. tenuifolia* Willdenow). Influence of resistant plant lines on bigeyed bugs, *Geocoris punctipes*, has been studied in soybean (Rogers and Sullivan 1987, Powell and Lambert 1993). Resistance factors (reduced pubescence, which is less preferred by corn earworm for oviposition and/or feeding) did not adversely affect egg predation by *G. punctipes* (Powell and Lambert 1993). Rogers and Sullivan (1987) demonstrated differences in fresh weight gain of nymphal *G. punctipes* in the field on attached leaves of susceptible versus resistant soybean lines. However, few studies have reported the potential interactions of pest-resistant warm season grasses with these predators and their subsequent influence on pest suppression.

In this study, we report the results of four experiments designed to increase understanding of the interaction between host plant resistance in turfgrass cultivars and predation by bigeyed bugs on fall armyworm. Specific objectives were to determine in the laboratory the effects of: 1) turfgrass cultivars on predation of fall armyworm by bigeyed bugs, and 2) turfgrass cultivars and armyworm age on prey acceptability to bigeyed bugs, as well as to determine in the field the effects of turfgrass cultivars on: 3) predation of fall armyworms by bigeyed bugs, and 4) natural enemy community composition.

Materials and Methods

Insects Used in Experiments. Field-collected nymphs and the F_1 progeny of field-collected *G. uliginosus* adults were used in experiments in the laboratory and field. *G. uliginosus* were collected from stands of mixed grasses in Spalding County, Georgia, during June, July, and August 2001. Male and female pairs were held in petri dishes in the laboratory at 24°C and 14:10 (L:D) photoperiod and provided with *S. frugiperda* eggs, a moist paper towel, and a small section of cheesecloth as an oviposition site. *S. frugiperda* used in experiments described in this work were from a colony maintained on commercial diet (Bioserv, Frenchtown, NJ). The armyworm colony was initiated with eggs obtained from the United States Department of Agriculture (USDA)/Agricultural Research Service Crop Protection and Management Research Unit (Tifton, GA) in 1994 and supplemented annually with new material from the USDA colony.

Determination of Effects of Turfgrass Cultivars on Predation of Fall Armyworm by Big-Eyed Bugs in the Laboratory. Predation by fourth instar *G. uliginosus* on *S. frugiperda* larvae feeding on susceptible and resistant turfgrasses was evaluated at 21 and 27°C in Conviron environmental chambers with a 14:10 (L:D) photoperiod. The experiment was a randomized complete block design with four replications at each temperature of five turfgrass cultivars: Sea Isle 1 and 561-79 paspalum grasses, Cavalier and Palisades zoysiagrasses, and TifSport bermudagrass. Grasses were grown in a greenhouse in 15.2-cm-diameter plastic pots in granular calcinated clay (Turface, Applied Industrial Materials, Deerfield, IL). Before the experiment, pots were watered daily and fertilized once per week with a solution containing 250 ppm N-P-K (Peters 20-20-20). Turfgrass in each pot was cut to a height of 5 cm, infested with 15 neonate *S. frugiperda* larvae, and placed in a fiber plant sleeve (Kleentest Products, Milwaukee, WI). Four pots of each turf type also received two *G. uliginosus* fourth instar nymphs, and four pots had no predators added. The fiber sleeve was rolled down from the top and secured with staples to ensure that all insects remained on the designated pot. Pots were placed in the lean-in chambers for 10 d. At the conclusion of the experiment, larval survival and larval weights were recorded. Data were subjected to analysis of variance (ANOVA) using the General Linear Models (GLM) procedure in SAS (SAS Institute 1985). Mean separation for survival among cultivars was accomplished by least significant difference (LSD). Student's *t*-test was used to compare survival of larvae with and without predators on each grass.

Influence of Turfgrass Cultivar and Fall Armyworm Age on Prey Acceptability to *G. uliginosus*. *S. frugiperda* neonates were placed on turfgrass clippings in 15-cm-diameter petri dishes lined with moistened filter paper and placed in an environmental chamber at 27°C, 15:9 h (L:D). *G. uliginosus* hunger levels were standardized by withholding prey for 24 h. Individual predators were provided with five larvae that were 1, 3, 5, or 7 d old that had been feeding exclusively on one of six turfgrass genotypes: Sea Isle 1 and 561-79 paspalum grasses, Cavalier and Palisades zoysiagrasses, and TifSport and TifEagle bermudagrass. Number of larvae killed within 24 h on each grass type for each age of prey was recorded. Four replications of each prey age by grass type combination were completed. Data were subjected to ANOVA using the GLM procedure in SAS (SAS Institute 1985). Mean separation for mortality among cultivars within 1 day was by LSD. Data were transformed before analysis using the square root of the value +0.5 to meet assumptions of normality and equality of variances typically not met by count data, especially data sets containing zeros (Sokal and Rohlf 1981).

Field Plot Establishment. Turfgrass species and cultivars representing a range of resistance to fall armyworms (Braman et al. 2000b, 2002) were established in the field during May 2000. Plots (each 25 m^2) were located at the Research and Education Garden of the Georgia Station in Griffin. Cultivars evaluated were Palisades and Cavalier zoysiagrasses (*Zoysia japonica* von Steudel and *Z. matrella* [L.] Merrill); TifSport and TifEagle bermudagrasses (*Cynodon dactylon* [L.] *x C. transvaalensis* [Burtt-Davy]); and 561-79 and Sea Isle 1 paspalum grasses (*Paspalum vaginatum* Swartz). Previous work suggested that fall armyworm survival would be greatest on TifEagle bermudagrass, followed by the two paspalum grasses and TifSport bermudagrass, and least on the two zoysiagrasses (Braman et al. 2000b, 2002). Plots were irrigated as necessary to prevent wilt symptoms. Plots were fertilized using 13-13-13 (N-P-K) at 460.5 kg per hectare on 12 July 2000 and at 368.4 kg per hectare on 19 April and 22 August 2001. Herbicides to control broadleaf and grass weeds were: glyphosate at 4 kg (AI)/ha to maintain alleys between plots and for spot weed control and oxadiazon at 4.5 kg (AI)/ha on 22 February 2001.

A 3-m-wide wildflower border surrounded the turf area to assist in attracting beneficial arthropods to the location (Braman et al. 2003). Wildflowers from commercial sources (Border Patrol pest control wildflower mix from Clyde Robbins Seed Co., Castro Valley, CA; Southeastern wildflower mix from Wildseed Farms, Fredericksburg, TX; and Southeast mix from Applewood Seed Co., Arvada, CO) bloomed continuously from spring to fall.

Determination of Effects of Turfgrass Cultivars on Predation of Fall Armyworm by Bigeyed Bugs in the Field. Predation by fourth and fifth instar *G. uliginosus* on *S. frugiperda* larvae feeding on susceptible and resistant turfgrasses was also evaluated in field plots. The experiment was a randomized complete block design with six replications of six turfgrass cultivars: Sea Isle 1 and 561-79 paspalum grasses, Cavalier and Palisades zoysiagrasses, and TifSport and TifEagle bermudagrass. Three trials were conducted to account for seasonal variation. Fifteen first instar *S. frugiperda* were introduced into 72 cages, each constructed from a length of 15.2-cm-diameter polyvinyl chloride pipe inserted 5 cm into the soil in each turf plot on 11 June, 9 July, and 3 September 2001. Two cages per plot were infested with armyworms. One cage per plot also received two nymphal predators. No attempt was made to remove naturally occurring predators from plots. Therefore, the assessment of predation effects of introducing *G. uliginosus* to field plots was made in the presence of both potential alternative prey and predators in the plots. Cages were covered with 32-mesh nylon screen. Surviving larvae were collected by hand 9 d after placement on 20 June, 18 July, and 12 September. At the conclusion of the experiment, larval survival and larval weights were recorded. Data were subjected to ANOVA using the GLM procedure in SAS (SAS Institute 1985). Separation of significant survival means among cultivars was by LSD. Student's *t*-test was used to compare survival of larvae with and without predators on each grass.

Field Evaluation of Relationship Between Turfgrass Cultivar and On-Site Natural Enemies. Arthropod taxa in the turf plots were sampled using pitfall traps (Morrill 1975) and a Vortis vacuum sampler (Burkard Manufacturing Co., Herferdshire, United Kingdom). Weekly vacuum samples and pitfall trap collections were obtained from each turf plot to examine and compare the arthropod fauna among the different turfgrass species and cultivars. Vacuum samples were collected from 26 April to 29 August, 2001. Vacuum samples consisted of 10 suctions (0.2 m^2) of 10-s duration from each of the same 36 turfgrass plots. Pitfall samples were collected from 6 May to 29 August, 2001. One 120-ml (6 cm diameter × 7 cm h) pitfall trap, located in the center of each plot, was emptied weekly and returned to the laboratory. Samples were sorted and counted, and specimens were identified using appropriate keys and reference collections maintained in the museum at the Griffin campus and the Athens campus of the University of Georgia, or sent to specialists when necessary. Voucher specimens are retained in the collection at the Griffin campus.

Data concerning arthropod abundance as measured by pitfall trap collection and vacuum samples were subjected to ANOVA using the GLM procedure of SAS (SAS Institute 1985). Data were transformed before analysis using the square root of the value +0.5 to meet assumptions of normality and equality of variances typically not met by count data, especially data sets containing zeros. The experiment was treated as a split plot design with grass cultivar as the whole plot and dates as the split plot for repeated measures analysis. Whole plots were arranged in a randomized complete block design with six replications. Means were separated using Fisher protected LSD test. Orthogonal contrasts were used to identify the influence of turfgrass genera on arthropod community structure within the turf plot area. The procedure PROC CORR was used to examine possible relationships among predators and potential prey.

Results

Determination of Effects of Turfgrass Cultivars on Predation of Fall Armyworm by Bigeyed Bugs in the Laboratory. Fall armyworm larval survival per pot among all pots both with and without predators ranged from 0 to 73.3% in the laboratory under controlled temperature conditions. Larval survival was not influenced by temperature ($F = 0.5$; df = 1, 3; $P = 0.48$), so data from both temperature regimes were combined. Survival was influenced significantly by turfgrass cultivar ($F = 15.4$; df = 4, 12; $P = 0.0001$) and presence of *G. uliginosus* ($F = 16.4$; df = 1, 3; $P = 0.0001$) (Fig. 1). In the laboratory, a significant interaction was found between predation and turfgrass cultivar ($F = 12.6$; df = 3, 12; $P = 0.03$). Among all grasses tested, average larval survival in the absence of predators was 26%, but was only 13% when two *G. uliginosus* were added to the pots. Average larval survival was least on Palisades zoysiagrass and greatest on the two paspalum grasses in this trial (Fig. 1). Weights of surviving larvae were significantly higher on the paspalums in comparison with the two zoysiagrasses and intermediate on TifSport bermudagrass when predators were added (Table 1). Presumably, smaller larvae are more vulnerable to predation. In the absence of bigeyed bugs, weights of surviving larvae were significantly higher on the paspalums than on either of the zoysiagrasses or the bermudagrass (Table 1). Average larval weight on the paspalums was ≈5.9–7.4 times that on Cavalier zoysiagrass. Larval survival was significantly reduced by *G. uliginosus* only on Cavalier zoysiagrass in this laboratory trial (Fig. 1).

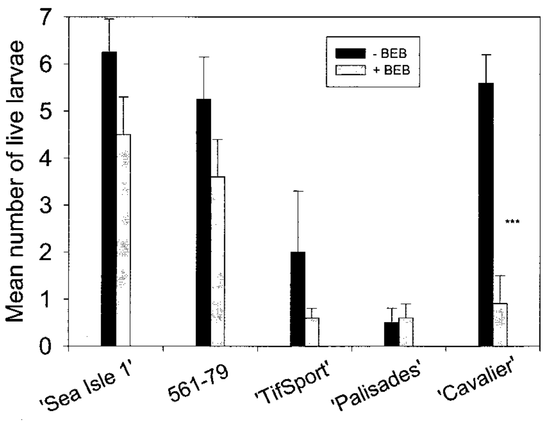

Fig. 1. Mean ± SEM survival of *S. frugiperda* larvae after exposure of first instars to fourth instar bigeyed bugs (BEB), *G. uliginosus*, on paspalum grass (Sea Isle 1, 561-79), bermudagrass (TifSport), and zoysiagrass (Cavalier, Palisades) in the laboratory. $^{***}P < 0.001$.

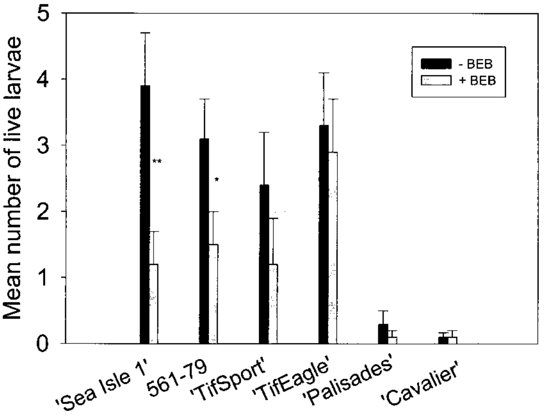

Fig. 2. Mean ± SEM survival of *S. frugiperda* larvae after exposure of first instars to fourth instar bigeyed bugs (BEB), *G. uliginosus*, on paspalum grass (Sea Isle 1, 561-79), bermudagrass (TifEagle, TifSport), and zoysiagrass (Cavalier, Palisades) in the field. $^{*}P < 0.05$; $^{**}P < 0.01$.

Determination of Effects of Turfgrass Cultivars on Predation of Fall Armyworm by Bigeyed Bugs in the Field. Larval survival per plot ranged from 0 to 80% in field cages. Fall armyworm survival was influenced significantly by turfgrass cultivar ($F = 9.9$; df = 5, 25; $P = 0.0001$) and presence of predaceous bigeyed bugs ($F = 9.8$; df = 1, 5; $P = 0.002$) (Fig. 2). In the field, there was no significant interaction between predation and turfgrass cultivar ($F = 1.6$; df = 5, 25; $P = 0.16$). Among all grasses tested, average larval survival in the absence of introduced predators was 14.7%, but only 7.8% when two *G. uliginosus* were added to the plots.

Average larval survival was least on Cavalier and Palisades zoysiagrasses and greatest on the two paspalum grasses and TifEagle bermudagrass in this field trial (Fig. 2). In the field, larval survival was significantly reduced by the addition of *G. uliginosus* to field cages for Sea Isle 1 and 561-79 paspalums (Fig. 2). Too few larvae were recovered from zoysiagrass field plots even across three trials with six replications to observe a significant reduction related to an increase in predator densities. These grasses demonstrated an even higher level of resistance in the field than has previously been observed in the laboratory, perhaps related to increased on-site predator effects, an intrinsic resistance characteristic of the grasses. Weights of surviving larvae were similar among paspalum and bermudagrasses and lowest on Cavalier zoysiagrass (Table 1).

Influence of Turfgrass Cultivar and Fall Armyworm Age on Prey Acceptability to *G. uliginosus*. Number of larvae killed per day at 27°C was similar ($F = 0.4$; df = 5, 6; $P > 0.05$) among grasses for 1-d-old larvae (Fig. 3). By d 3, some separation in predation success related to cultivar was evident. By d 5, predators successfully captured more *S. frugiperda* larvae on Cavalier zoysiagrass than on any other turf species or cultivar ($F = 14.8$; df = 5, 18; $P = 0.0001$). One-week-old larvae were only successfully captured by *G. uliginosus* when larvae had been feeding on Cavalier zoysiagrass ($F = 7.5$; df = 5, 18; $P = 0.0006$). Mortality caused by predation is clearly evident from the carcasses that have been preyed upon (desiccated).

Table 1. Mean ± SEM weight (mg) of *Spodoptera frugiperda* larvae per pot or plot after feeding on turfgrass cultivars with or without the predator *Geocoris uliginosus* (BEB) in the laboratory or the field

	Laboratory with BEB	Laboratory without BEB	Field with BEB	Field without BEB
Paspalum				
561-79	174.3 ± 45.3a	164.5 ± 12.9a	314.0 ± 142.7a	132.4 ± 43.5a
Sea Isle 1	171.4 ± 44.1a	155.0 ± 9.6a	147.2 ± 86.5a	191.5 ± 48.2a
Cynodon				
TifEagle	NDA	NDA	106.0 ± 57.2a	184.7 ± 46.2a
TifSport	63.7 ± 12.3ab	57.5 ± 1.5b	98.0 ± 31.9a	126.8 ± 34.8a
Zoysia				
Cavalier	29.5 ± 10.7b	21.9 ± 3.7b	NDA	41.0 ± 0a
Palisades	18.8 ± 7.0b	51.0 ± 31.0b	NDA	NDA

Mean separation by LSD, means within a column with the same letter are not significantly different ($P > 0.05$); NDA, no data available. BEB, bigeyed bugs.

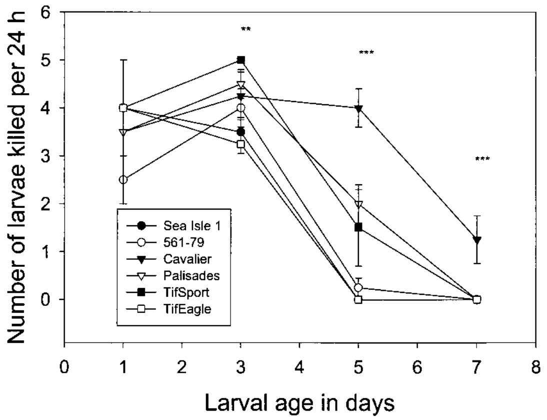

Fig. 3. Mean ± SEM *S. frugiperda* larvae killed in 24 h by *G. uliginosus* as affected by prey age on paspalum grass (Sea Isle 1, 561-79), bermudagrass (TifEagle, TifSport), and zoysiagrass (Cavalier, Palisades). $^{**}P < 0.01$; $^{***}P < 0.001$.

Field Evaluation of Relationship Between Resistant Plants and On-Site Natural Enemies. Vacuum and pitfall samples yielded 15,854 arthropods that were identified. Results from vacuum samples indicated that numerous predaceous taxa were significantly influenced by turfgrass species and cultivar during 2001 (Table 2). In vacuum samples, predaceous Heteroptera (Geocoridae, Nabidae, Miridae, Saldidae, and Anthocoridae) were most often collected in 561-79 and Sea Isle 1 paspalum grass ($F = 14.8$; df = 5, 25; $P = 0.0001$). Spiders were most abundant in Palisades zoysiagrass, followed by Cavalier zoysiagrass and TifSport bermudagrass ($F = 40.2$; df = 5, 25; $P = 0.0001$). Staphylinidae ($F = 33.3$; df = 5, 25; $P = 0.0001$) and Chilopoda ($F = 6.6$; df = 5, 25; $P = 0.0001$) were also more numerous in these three cultivars. Carabidae were most numerous in Palisades zoysiagrass ($F = 16.0$; df = 5, 25; $P = 0.0001$). Predaceous mirids (*Spanagonicus albofasciatus* [Reuter]) and Saldids (*Micracanthia* sp.) were more common in TifEagle bermudagrass and Sea Isle 1 paspalum grass ($F = 22.3$; df = 5, 25; $P = 0.0001$), while Anthocoridae were more abundant in both paspalum grasses and TifEagle bermudagrass than the other three cultivars in the experiment ($F = 10.6$; df = 5, 25; $P = 0.0001$). Formicidae ($F = 1.2$; df = 2, 25; $P = 0.3$) and parasitic Hymenoptera ($F = 0.8$; df = 5, 25; $P = 0.6$) were equally common among all turfgrass cultivars. Leafhopper nymphs ($F = 3.8$; df = 5, 25; $P = 0.001$) and adults ($F = 9.9$; df = 5, 25; $P = 0.0001$) were most abundant in 561-79 and Sea Isle 1 paspalum grasses, followed by TifEagle and TifSport bermudagrasses.

Orthogonal contrasts revealed that, among grass genera, in vacuum samples, geocorids, primarily *G. uliginosus*, but also *G. punctipes* and *Isthmocoris piceus* (Say), were significantly more common in paspalum grass than zoysiagrass ($F = 6.2$; df = 1, 25; $P = 0.02$). The bermudagrass versus zoysiagrass and paspalum grass versus bermudagrass contrasts were not significantly different ($P > 0.05$). Spiders were signif-

Table 2. Mean ± SEM number of arthropods per 0.2 m^2 vacuum sample per week (n = 19) per replication (n = 6) during 2001, as influenced by turfgrass cultivar

Turf genotype	Geocoridae	Anthocoridae	Miridae & Saldidae	Predaceous Heteroptera (Total)	Araneae	Formicidae	Carabidae	Staphylinidae	Chilopoda	Lygaeidae	Cicadellid Nymphs	Cicadellid Adults
Paspalum												
Sea Isle 1	0.5 ± 0.1ab	0.2 ± 0.1a	0.2 ± 0.1b	1.0 ± 0.1a	2.3 ± 0.2c	0.9 ± 0.1a	0.5 ± 0.1c	0.5 ± 0.1b	0.04 ± 0.02b	0.1 ± 0.1b	5.7 ± 0.7ab	0.6 ± 0.1a
561-79	0.6 ± 0.1a	0.2 ± 0.1a	0.5 ± 0.1ab	1.2 ± 0.2a	2.0 ± 0.2c	1.4 ± 0.4a	0.6 ± 0.1bc	0.4 ± 0.1b	0.03 ± 0.01b	0.2 ± 0.1ab	7.1 ± 0.8a	1.0 ± 0.1a
Zoysia												
Cavalier	0.3 ± 0.1abc	0.01 ± 0.1b	0.04 ± 0.02c	0.3 ± 0.1b	3.3 ± 0.2b	0.7 ± 0.1a	0.6 ± 0.1bc	1.4 ± 0.2a	0.2 ± 0.1a	0.04 ± 0.02b	2.0 ± 0.2c	0.2 ± 0.1c
Palisades	0.3 ± 0.1abc	0.02 ± 0.1b	0.02 ± 0.01c	0.3 ± 0.1b	4.3 ± 0.3a	0.7 ± 0.1a	1.2 ± 0.2a	1.6 ± 0.2a	0.2 ± 0.1a	0.04 ± 0.04b	2.6 ± 0.3c	0.3 ± 0.1bc
Cynodon												
TifSport	0.6 ± 0.1a	0.01 ± 0.1b	0.04 ± 0.02c	0.7 ± 0.1a	3.1 ± 0.3b	0.8 ± 0.2a	0.8 ± 0.1b	1.3 ± 0.2a	0.2 ± 0.1a	0 ± 0b	3.0 ± 0.3bc	0.4 ± 0.1bc
TifEagle	0.2 ± 0.1c	0.2 ± 0.1a	0.6 ± 0.1a	1.0 ± 0.2a	0.9 ± 0.1d	0.8 ± 0.1a	0.1 ± 0.1d	0.1 ± 0.1b	0.03 ± 0.01b	0.3 ± 0.2a	3.2 ± 0.3bc	0.5 ± 0.1b

Mean separation by LSD, means within a column with the same letter are not significantly different ($P < 0.05$).

Table 3. Mean ± SEM number of arthropods pitfall sample per week (n = 16) per replication (n = 6) during 2001, as influenced by turfgrass genotype

Turf genotype	Araneae	Formicidae	Carabidae	Cicindellidae	Staphylinidae
Paspalum					
Sea Isle 1	9.4 ± 1.9a	0.7 ± 0.2a	2.1 ± 0.2bc	0.7 ± 0.2b	0.3 ± 0.1a
561-79	5.2 ± 0.4c	0.4 ± 0.1a	1.9 ± 0.2bc	1.8 ± 0.3a	0.3 ± 0.1a
Zoysia					
Cavalier	5.3 ± 0.3bc	0.6 ± 0.1a	1.9 ± 0.2bc	0.2 ± 0.1c	0.4 ± 0.1a
Palisades	6.5 ± 0.7bc	0.6 ± 0.1a	1.6 ± 0.2c	0.1 ± 0.1c	0.3 ± 0.1a
Cynodon					
TifSport	7.5 ± 0.8b	0.8 ± 0.1a	2.6 ± 0.3b	0.3 ± 0.1c	0.5 ± 0.1a
TifEagle	5.9 ± 0.9bc	0.8 ± 0.2a	3.4 ± 0.4a	1.8 ± 0.3a	0.3 ± 0.1a

Mean separation by LSD, means within a column with the same letter are not significantly different ($P > 0.05$).

icantly more common in zoysiagrass than bermudagrass (F = 47.9; df = 1, 25; P = 0.0001) or paspalum grass (F = 36.8; df = 1, 25; P = 0.0001). Differences between paspalum grass and bermudagrass were not significant ($P > 0.05$). Total predaceous Heteroptera were more abundant in bermudagrass than in zoysiagrass (F = 15.7; df = 1, 25; P = 0.0005) and in paspalum grass than in zoysiagrass (F = 32.0; df = 1, 25; P = 0.0001).

Staphylinid beetles, Chilopodoa, and Carabidae were more common in zoysiagrass than bermudagrass (F = 34.1; df = 1, 25; P = 0.0001; F = 12.6; df = 1, 25; P = 0.007; F = 18.1; df = 1, 25; P = 0.0003) or paspalum grass (F = 61.1; df = 1, 25; P = 0.0001; F = 31.3; df = 1, 25; P = 0.001; F = 8.5; df = 1, 25; P = 0.003). Formicidae were more common in paspalum grass than in zoysiagrass (F = 4.4; df = 1, 25; P = 0.05). Anthocoridae were more common in paspalum grass than bermudagrass (F = 12.0; df = 1, 25; P = 0.002) or zoysiagrass (F = 46.9; df = 1, 25; P = 0.0001), and were more common in bermudagrass than zoysiagrass (F = 11.5; df = 1, 25; P = 0.002). No differences among grass genera were found for parasitic Hymenoptera.

Leafhopper nymphs were more common in paspalum than bermudagrass (F = 9.1; df = 1, 25; P = 0.006) or zoysiagrass (F = 16.7; df = 1, 25; P = 0.0004). Differences between bermudagrass and zoysiagrass were not significant ($P > 0.05$). Chinch bugs, *Blissus* sp., were most commonly collected in TifEagle bermudagrass (F = 4.0; df = 1, 25; P = 0.001). They were least common in zoysiagrass (bermudagrass versus zoysiagrass, F = 4.5; df = 1, 25; P = 0.04; paspalum grass versus zoysiagrass, F = 4.2; df = 1, 25; P = 0.05).

Correlation analysis indicated a significant positive relationship between predaceous Heteroptera and leafhopper nymphs (r = 0.4, P = 0.0001) and adults (r = 0.4, P = 0.0001). Leafhopper nymphal and adult abundance were also significantly associated with geocorids (r = 0.3 and 0.3, P = 0.0001 and 0.0001), predaceous plant bugs (r = 0.3 and 0.2, P = 0.0001 and 0.0001), and anthocorids (r = 0.2 and 0.2, P = 0.0001 and 0.0001), respectively.

Pitfall traps indicated that Carabidae, Araneae, and Cicindellidae were affected by turfgrass species and cultivar (Table 3). Formicidae and Staphylinidae in pitfall traps were not affected by turfgrass cultivar ($P > 0.05$). Cicindellidae, primarily *Megacephala carolina carolina* L., were most often found in 561-79 paspalum grass and TifEagle bermudagrass plots (F = 27.0; df = 5, 25; P = 0.0001). Carabidae were also most commonly collected in TifEagle pitfalls (F = 7.5; df = 5, 25; P = 0.0001). Because pitfall traps measure activity rather than abundance, the increased activity of tiger beetles or carabids may be explained by the less dense characteristics of the TifEagle and/or 561-79 paspalum turfgrasses.

Among turfgrass genera, orthogonal contrasts indicated that carabid ground beetles were more common in bermudagrass than zoysiagrass (F = 26.3; df = 1, 25; P = 0.0001) or paspalum grass (F = 14.9; df = 1, 25; P = 0.0007). Carabids were equally numerous in paspalum grass and zoysiagrass (F = 1.6; df = 1, 25; P = 0.2). No contrasts were significant for ground-dwelling spiders among turfgrass species ($P > 0.05$). Cicindellidae were more common in bermudagrass than zoysiagrass (F = 15.2; df = 1, 25; P = 0.0006) and in paspalum grass than zoysiagrass (F = 24.6; df = 1, 25; P = 0.0001). Cicindellidae were not significantly more numerous in bermudagrass versus paspalum (F = 1.1; df = 1, 25; P = 0.3). Formicidae and Staphylinidae were equally common among turfgrass species in pitfall traps ($P > 0.05$).

Discussion

Previous laboratory work had suggested that fall armyworm survival would be greatest on TifEagle bermudagrass, followed by the two paspalum grasses and TifSport bermudagrass, and lowest on the two zoysiagrasses (Braman et al. 2000b, 2002). While mechanisms conferring this resistance have not been determined, this trend was again observed in laboratory and especially in new field confirmation in the current study. The use of resistant plants may enhance or reduce the ability of generalist predators to control target pests. If the resistant plants improve foraging efficiency of predators, a synergistic level of pest control may result. Isenhour et al. (1989) demonstrated enhanced predation on *S. frugiperda* by *Orius insidiosus* (Say) on resistant corn (*Zea mays* L.) cultivars because the age range of prey that were susceptible to attack by predators increased when armyworms fed on resistant plant material. A similar response to resistant plant material was observed in the current study in which larvae feeding on more resistant zoysiagrasses, and to a lesser extent TifSport bermudagrass, were substantially smaller than those that fed on TifEagle or the paspalum grasses. Previous work (Reinert et al. 1994, 1997; Braman et al. 2000b, 2002) also demonstrated that many zoysiagrass selections not only increased mortality, but for those individuals that did survive, developmental times were extended as much as 3-fold over those typical for susceptible grasses. Larvae remained for extended periods in the second and third instar, and thus, were potentially vulnerable to attack by natural enemies. Differences between laboratory and field results in relative larval survival on various turfgrass species and cultivars when predators were added to the system, we believe, reflect the variation that we found in turfgrass cultivar-related effects on beneficial arthropod fauna.

In the laboratory, *G. uliginosus* effectiveness was higher on the resistant cultivar Cavalier zoysiagrass. However, outcomes of cage experiments in greenhouse and laboratory may not directly apply to more complex situations in the field. In field plots, in our experiments, in the presence of alternative prey and other predators, addition of even the low numbers of *G. uliginosus* nymphs used in this study reduced *S. frugiperda* larval density significantly on both paspalum grasses, whereas these differences were not significant in the laboratory when there was no additional background predation. Larval survival on the resistant zoysiagrasses in the field in which predators are abundant, however, was so low even without addition of predaceous bigeyed bugs to the system, that predation was not substantially improved by the addition of more predators to the system. Larval survival was high on susceptible TifEagle in the field and not significantly reduced by addition of bigeyed bugs probably because, we believe, larvae so quickly exceeded acceptable prey range in size.

The mechanism for the observed increased predation rate on Cavalier in the laboratory was most likely an increased foraging efficiency on prey that remain an acceptable size for a greater length of time than *S. frugiperda* that fed on other turf cultivars in the study. When *S. frugiperda* fed on more susceptible grasses, escape from predation was observed because larvae developed rapidly past the acceptable prey size range for *G. uliginosus* nymphs. These short-term studies did not measure any direct effects of grass cultivar on *G. uliginosus* biology or behavior. Plant feeding by *Geocoris* spp. provides a means of obtaining moisture and/or nourishment, although particular plant species or cultivars have variable effects on development and longevity of *Geocoris* spp. predators (Naranjo and Stimac 1985, Rogers and Sullivan 1987).

The beneficial arthropod taxa sampled during this study varied among turfgrass genera and individual turfgrass cultivars. Predaceous Heteroptera, for example, were better represented in bermudagrass or seashore paspalum than in the zoysiagrasses included in this project. A significant correlation of predaceous Heteroptera with leafhopper abundance may indicate that predators were more numerous where potential alternative prey were more abundant in paspalum grass and bermudagrass. Spiders and centipedes from vacuum samples, however, were more abundant in the zoysiagrasses.

Sampling method was important in determining relative abundances of predator taxa. Carabids collected in pitfalls were most plentiful in TifEagle bermudagrass, while carabids in vacuum samples were most numerous in Palisades zoysiagrass. Staphylinids were equally common among turf types in pitfall traps, but were more numerous in zoysiagrasses and TifSport bermudagrass in vacuum samples.

Not all species collected were typical of the reported turfgrass fauna. The mirid, *S. albofasciatus,* collected in vacuum samples in this study has been reported as an insect and mite predator in cotton (*Gossypium hirsutum* L.), where its wide host range includes lepidopteran larvae (Butler 1965, Butler and Stoner 1965). The shore bugs, *Micracanthia* sp., may have been attracted to irrigated turf plots from a nearby (≈180-m) pond. Both taxa were relatively common in the turf plots and have not, to our knowledge, been typically associated with managed turfgrass.

Turfgrass cultivars have rarely been tested for extrinsic resistance characteristics such as influence on the biology and behavior of predators. These results indicated that substantial differences in predator fauna and impact on known pest species may be anticipated among turfgrass species and cultivars. A better understanding of insect plant interactions at all trophic levels will permit development of more sustainable landscapes.

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