Impact of Japanese Beetle (Coleoptera: Scarabaeidae) Feeding on Seashore Paspalum

S. K. BRAMAN[1] and P. L. RAYMER[2]

Department of Entomology, University of Georgia, College of Agricultural and Environmental Sciences, 1109 Experiment Street, Griffin, GA 30223–1797

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ABSTRACT Ten cultivars of seashore paspalum, *Paspalum vaginatum* Swartz, were compared for their response to Japanese beetle, *Popillia japonica* Newman, larval root feeding. Cultivars of Bermuda grass, *Cynodon* sp., and zoysiagrass, *Zoysia* sp., also were included for comparison. Turf grown in pots in the greenhouse was infested with second and third instars in this 2-yr study. Grub survival and weight gain, foliar growth, and root loss were compared among turfgrass species and cultivars. Few species-related differences were identified. Differences in grub tolerance were, however, observed to be a function of turfgrass cultivar. Some turf types demonstrating tolerance to grub feeding had rapid root growth and high root mass in control pots, but this was not consistent for all cultivars showing enhanced ability to maintain foliar growth despite grub feeding. The paspalum cultivars that seemed most tolerant of grub feeding were '561-79', 'Sea Isle 2000', 'Durban', 'HI-10', 'Kim-1', 'Sea Dwarf', and 'Sea Spray'.

KEY WORDS turfgrass, host plant resistance, grubs, Japanese beetle

The Japanese beetle, *Popillia japonica* Newman, is among the worst pests of turfgrasses and woody landscape plants in the eastern United States (Potter 1998). Adults feed on the foliage and flowers of nearly 300 host species (Vittum et al. 1999). Larvae feed on the roots of a variety of plants, including grasses. Grub-tolerant turfgrasses, if available, would provide a proactive management strategy for growers, homeowners, and commercial turf managers. Among cool-season turfgrasses, few differences in grub tolerance have been identified for the Japanese beetle (Potter et al. 1992, Crutchfield and Potter 1995), although tall fescue, *Festuca arundinacea* Schreb., seemed to be most tolerant of European chafer, *Rhizotrogus majalis* (Razoumowsky), grub feeding compared with perennial ryegrass, *Lolium perenne* L., and Kentucky bluegrass, *Poa pratensis* L., cultivars (Bughrara et al. 2003). Although Japanese beetles feed on all cool-season grasses (Vittum et al. 1999), the range in susceptibility among warm-season turfgrasses is not known.

Seashore paspalum, *Paspalum vaginatum* Swartz, is a highly salt-tolerant, warm-season perennial grass found in tropical to warm temperate regions (Duncan and Carrow 2000). Attributes of recently developed paspalum cultivars include low nitrogen and water requirements and superior salt tolerance, allowing them to tolerate most types of alternate water sources such as waste water, effluent, gray water, and brackish water. Paspalums have been evaluated for potential resistance/tolerance to mole crickets, *Scapteriscus* spp. (Braman et al. 2000b); twolined spittlebug, *Prosapia bicincta* (Say) (Shortman et al. 2002); and fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Wiseman and Duncan 1996, Braman et al. 2000a, 2002a). Extrinsic resistance characteristics, or the action of natural enemies as mediated by turfgrass with varying resistance levels, also has been documented for paspalum (Braman et al. 2002b, 2003, 2004). Our objective was to determine the tolerance of seashore paspalum to Japanese beetle grubs in comparison with other warm-season turfgrass species and cultivars.

Materials and Methods

Insects and Plants. Adult Japanese beetles were field collected from local residential landscapes by using standard attractant traps. Adults were caged on 19-liter plastic pots planted with Kentucky 31 tall fescue to allow oviposition and grub development. Grubs were harvested for use in experiments as needed. Grubs were placed in soil in individual 32-ml plastic cups and held for 24 h before infesting plants.

Experimental grasses included selections of seashore paspalum, Bermuda grass (*Cynodon* L.C. Rich), and zoysiagrass (*Zoysia* Willd). Grasses were grown in a greenhouse in 15.2-cm-diameter plastic pots in granular calcinated clay (Turface, Applied Industrial Materials, Corp., Deerfield, IL). Before the experiment,

[1] Department of Crop and Soil Sciences University of Georgia, Griffin, GA 30223.

[2] Corresponding author, e-mail: kbraman@griffin.uga.edu.

pots were watered daily and fertilized once per week with a solution containing 250 ppm N–P–K (Peters 20–20-20). Grasses were transferred to native top soil in 2.8-liter "Tall One" pots, 10 cm in width by 36 cm in height (Stuewe & Sons, Inc., Corvallis, OR) 1 mo before infestation.

Year 1. Turfgrass cultivars used during year 1 were paspalum 'Durban', 'Sea Isle 1', 'Sea Isle 2000', 'Sea Dwarf', 'Salam', 'Sea Spray', 'Asul', Sea Isle Supreme, 'HI 10', and an Argentine selection '561-79'. Zoysiagrass cultivars were 'Cavalier' and 'Palisades', whereas bermudagrasses were 'TifSport' and 'TifEagle'. Japanese beetle second and third instars were harvested from the grub "nursery" and weighed before infestation of Tall One pots on 26 August 2003. Before infestation grasses were trimmed to a height of 6 cm. Three grubs per pot were introduced to the soil and observed to ensure that they had successfully burrowed in. Any grubs that had not entered the soil within 1 h were replaced. Foliar growth was clipped to a height of 6 cm on 4 November, placed in paper bags, oven-dried at 30°C for 7 d, and weighed. On 9 December, pots were destructively sampled, and third instars were counted and weighed. Roots were separated from shoots at the soil line, washed, oven-dried, and weighed. Foliage also was dried and weighed as described above. The design was a randomized complete block with eight replications. There also were eight uninfested pots of each grass type maintained and sampled identically to infested pots for comparison with determine root and foliage loss due to grub feeding.

Year 2. Turfgrass cultivars used during year 2 were paspalum Durban, Sea Isle 1, Sea Isle 2000, Sea Dwarf, Salam, Sea Spray, Asul, Sea Isle Supreme, 'Q 37956', and 'Kim-1'. Zoysiagrass and Bermuda grass cultivars were Cavalier and TifSport. During year 2, procedures were similar to those used for year 1 except that six grubs per pot were used to infest grasses on 24 September 2004. Design, replication, uninfested controls, and type of data collected were identical to year 1.

Data Analyses. Data were subjected to analysis of variance (ANOVA) using the GLM procedure of SAS (SAS Institute 1985). Data from each year were analyzed separately. Means for different grasses were separated using the least significant difference (LSD) method at the $\alpha = 0.05$ level.

Results

Year 1. Survival of grubs was influenced by cultivar ($F = 2.22$; df = 7, 13; $P < 0.006$) (Table 1). Average survival ranged from 90% on Cavalier zoysiagrass to 20% on Sea Dwarf paspalum. Weight of grubs at the termination of the trial varied with cultivar ($F = 3.2$; df = 7, 13; $P < 0.006$) and ranged from 184 to 249 mg on average. Weight of grubs initially assigned to pots did not differ ($F = 1.3$; df = 7, 13; $P = 0.6$). Average weight gain did vary with cultivar ($F = 16.2$; df = 7, 13; $P < 0.0001$). Weight gain of larvae feeding on the roots of the two bermudagrasses exceeded that which occurred on Palisades zoysiagrass and HI-10 and Sea Spray paspalums by ≈40% on average.

Table 1. Mean ± SE Japanese beetle grubs recovered, weight, and weight gain (milligrams) on greenhouse-grown turfgrass species and cultivars

Grass genus and cultivar	Grubs recovered	Grub wt	Wt gain
	Year 1		
Paspalum			
561-79	1.1 ± 0.3abc	227.2 ± 12.6ab	60.4 ± 20.8ab
Durban	1.1 ± 0.5abc	212.2 ± 11.9ab	68.7 ± 56.5ab
Sea Isle 2000	1.5 ± 0.3ab	218.3 ± 4.8ab	65.0 ± 33.2ab
Sea Isle 1	1.7 ± 0.3a	215.3 ± 16.0ab	66.3 ± 43.0ab
Sea Dwarf	0.6 ± 0.3c	188.7 ± 15.4b	52.9 ± 5.6ab
Salam	1.2 ± 0.2abc	215.4 ± 14.4ab	53.8 ± 23.7ab
HI-10	0.9 ± 0.4bc	211.7 ± 3.4ab	32.4 ± 31.2b
Sea Spray	1.4 ± 0.4abc	194.2 ± 11.9b	36.0 ± 28.1b
Asul	1.0 ± 0.3abc	214.0 ± 26.4ab	66.1 ± 30.9ab
Sea Isle Supreme	1.0 ± 0.4abc	208.3 ± 12.8ab	66.1 ± 30.9ab
Zoysia			
Cavalier	1.5 ± 0.2ab	195.1 ± 12.9ab	63.4 ± 22.4ab
Palisades	0.9 ± 0.3bc	223.6 ± 18.4ab	30.6 ± 3.4b
Cynodon			
TifSport	1.4 ± 0.4abc	233.7 ± 15.6a	92.7 ± 20.2a
TifEagle	1.1 ± 0.3abc	196.2 ± 11.2ab	87.6 ± 25.9a
	Year 2		
Paspalum			
Kim-1	1.4 ± 0.7c	246.2 ± 22.5a	39.5 ± 31.4a
Durban	1.6 ± 0.6abc	183.5 ± 19.9a	−40.7 ± 11.9
Sea Isle 2000	1.9 ± 0.6abc	227.3 ± 13.2a	7.3 ± 2.0a
Sea Isle 1	1.5 ± 0.6bc	248.8 ± 29.1a	22.2 ± 17.2a
Sea Dwarf	1.9 ± 0.4abc	199.0 ± 23.2a	−23.9 ± 16.3a
Salam	2.6 ± 0.6ab	216.1 ± 7.2a	2.3 ± 8.7a
Q 37956	1.2 ± 0.6c	201.6 ± 55.1a	−48.4 ± 52.1a
Sea Spray	2.1 ± 0.9abc	200.6 ± 21.9a	−13.4 ± 24.6a
Asul	2.3 ± 0.6abc	214.0 ± 18.5a	−14.3 ± 21.4a
Sea Isle Supreme	1.1 ± 0.3c	245.5 ± 14.4a	26.1 ± 22.1a
Zoysia			
Cavalier	2.7 ± 0.5a	210.6 ± 17.3a	−8.5 ± 24.6a
Cynodon			
TifSport	2.0 ± 0.6abc	240.2 ± 11.5a	32.4 ± 11.9a

During the 105-d greenhouse study, turf in some of the pots wilted and died despite a consistent watering schedule. Foliar weights of infested grass during the first sampling period demonstrated cultivar-related differences ($F = 4.1$; df = 7, 13; $P < 0.0001$) (Table 2). There were, however, also significant cultivar-related differences in top growth of uninfested plants ($F = 5.4$; df = 7, 13; $P < 0.0001$). The difference between top growth of infested plants and their uninfested controls was significant by cultivar ($F = 2.9$; df = 7, 13; $P < 0.0003$) with Salam, Sea Dwarf, Sea Isle 2000, and Durban paspalums displaying the least grub-inflicted reductions in top growth during the first sampling period. Foliar dry weights during the second sampling period were influenced by cultivar for infested grasses ($F = 5.4$; df = 7, 13; $P < 0.0001$), for uninfested controls ($F = 6.2$; df = 7, 13; $P < 0.0001$), and for the difference between infested and uninfested ($F = 3.5$; df = 7, 13; $P < 0.0001$), with 561-79 and Durban paspalums demonstrating the least effect on top growth after 105 d in the greenhouse, although Durban was not significantly different from seven other selections evaluated (Table 2).

Root dry weights (Table 3) similarly showed cultivar-related effects for infested turf, uninfested con-

Table 2. Mean ± SE foliar growth dry weight (milligrams) of greenhouse-grown turfgrass species and cultivars infested by Japanese beetle grubs

Grass genus and cultivar	Infested wt	Uninfested wt	Growth difference
Year 1, first sample			
Paspalum			
561-79	377.9 ± 110.4e	1,246.0 ± 377.0def	868.1 ± 359.6cd
Durban	275.7 ± 53.1e	760.7 ± 206.4f	485.0 ± 221.5d
Sea Isle 2000	521.6 ± 128.9de	934.5 ± 133.5def	412.8 ± 157.3d
Sea Isle 1	1,554.0 ± 791.9abc	3,349.5 ± 956.6ab	1,795.5 ± 827.1cde
Sea Dwarf	618.7 ± 147.7de	1,199.5 ± 229.8def	580.7 ± 144.3d
Salam	435.2 ± 92.5e	728.0 ± 70.7f	292.7 ± 80.1d
HI-10	223.1 ± 82.6e	895.8 ± 196.3ef	790.4 ± 172.9cd
Sea Spray	770.1 ± 122.6cde	2,045.5 ± 629.9cde	1,275.4 ± 649.1abcd
Asul	1,632.5 ± 579.6ab	4,040.8 ± 568.9a	2,408.2 ± 658.8a
Sea Isle Supreme	1,326.0 ± 415.6abcd	2,484.2 ± 436.9bc	1,158.2 ± 496.3bcd
Zoysia			
Cavalier	1,281.9 ± 169.9abcd	1,952.7 ± 225.3cde	670.8 ± 324.3cd
Palisades	1,340.5 ± 214.7abc	3,413.7 ± 502.9ab	2,073.2 ± 464.8ab
Cynodon			
TifSport	1,781.2 ± 517.6a	3,578.2 ± 195.5a	1,797.0 ± 511.9abc
TifEagle	878.0 ± 204.7bcde	2,113.5 ± 336.5cd	1,235.5 ± 351.4abcd
Year 1, second sample			
Paspalum			
561-79	112.5 ± 35.8d	175.0 ± 34.8g	62.5 ± 3.9d
Durban	85.7 ± 25.8d	170.0 ± 7.1g	84.3 ± 25.4cd
Sea Isle 2000	185.7 ± 85.9d	480.0 ± 103.9fg	258.6 ± 93.3bcd
Sea Isle 1	336.2 ± 117.8abcd	1,192.5 ± 282.2ab	856.2 ± 323.9a
Sea Dwarf	192.5 ± 65.2d	425.5 ± 114.1fg	232.5 ± 67.9bcd
Salam	222.8 ± 86.7d	547.5 ± 91.4ef	377.7 ± 102.1bcd
HI-10	110.0 ± 60.6e	447.5 ± 114.8fg	368.5 ± 114.3bcd
Sea Spray	246.2 ± 84.4bcd	842.5 ± 168.2cde	596.2 ± 214.6ab
Asul	560.0 ± 191.8a	1,382.7 ± 115.6a	822.7 ± 233.1a
Sea Isle Supreme	451.2 ± 165.3abc	942.5 ± 125.7bcd	491.2 ± 154.5ab
Zoysia			
Cavalier	458.7 ± 130.3abc	922.5 ± 122.5bcd	463.7 ± 147.9abc
Palisades	567.5 ± 127.9a	937.5 ± 20.2bcd	370.0 ± 130.8bcd
Cynodon			
TifSport	477.5 ± 143.9ab	1,007.5 ± 69.0bc	530.0 ± 149.1ab
TifEagle	266.2 ± 66.0bcd	645.0 ± 95.9def	378.7 ± 132.2bcd
Year 2, first sample			
Paspalum			
Kim-1	813.7 ± 223.4cde	436.2 ± 86.4d	−377.5 ± 221.7cd
Durban	1,407.5 ± 175.3bc	162.5 ± 280.4ab	205.0 ± 291.5abc
Sea Isle 2000	1,696.2 ± 369.6ab	1,488.7 ± 368.3abc	−207.5 ± 544.3bcd
Sea Isle 1	627.5 ± 143.7de	1,337.5 ± 345.9abc	710.0 ± 431.5ab
Sea Dwarf	1,061.2 ± 154.6bcd	1,267.5 ± 253.9abc	206.2 ± 209.2abc
Salam	581.2 ± 218.9de	1,031.2 ± 291.7bcd	450.0 ± 191.2abc
Q 37956	850.0 ± 235.4cde	1,960.0 ± 427.1a	1,110.0 ± 606.8a
Sea Spray	2,181.2 ± 554.8a	977.5 ± 151.2bcd	−1,203.7 ± 602.8d
Asul	251.2 ± 64.4e	736.2 ± 123.1bcd	485.0 ± 110.8abc
Sea Isle Supreme	651.2 ± 219.8de	117.5 ± 210.9bcd	523.7 ± 279.8abc
Zoysia			
Cavalier	1,382.5 ± 123.2bc	1,677.5 ± 400.3ab	295.0 ± 442.0abc
Cynodon			
TifSport	1,415.0 ± 230.1bc	1,091.2 ± 236.4bcd	−323.7 ± 384.0bcd
Year 2, second sample			
Paspalum			
Kim-1	53.7 ± 0.3bcd	92.5 ± 18.5bcd	38.7 ± 23.5ab
Durban	81.2 ± 19.8bc	136.2 ± 19.7bcd	55.0 ± 25.9ab
Sea Isle 2000	56.2 ± 18.5bcd	128.7 ± 25.9bcd	72.5 ± 33.6a
Sea Isle 1	50.0 ± 16.7bcd	106.2 ± 18.2bcd	56.2 ± 27.1ab
Sea Dwarf	86.2 ± 16.0bc	153.7 ± 33.6b	67.5 ± 34.5ab
Salam	25.0 ± 17.3d	105.0 ± 10.7bcd	80.0 ± 16.1a
Q 37956	60.0 ± 17.7bcd	148.7 ± 20.9bc	88.7 ± 30.7a
Sea Spray	57.5 ± 20.2bcd	141.2 ± 30.9bcd	83.7 ± 32.0a
Asul	18.7 ± 8.3d	88.7 ± 17.2cd	70.0 ± 17.7ab
Sea Isle Supreme	43.7 ± 15.2cd	113.7 ± 9.3bcd	70.0 ± 20.9ab
Zoysia			
Cavalier	150.0 ± 17.7a	247.5 ± 41.4a	97.5 ± 49.6a
Cynodon			
TifSport	91.2 ± 19.7b	85.0 ± 20.8d	−6.2 ± 31.2b

Table 3. Mean ± SE root growth dry weight (milligrams) of greenhouse-grown turfgrass species and cultivars infested by Japanese beetle grubs

Grass genus and cultivar	Infested wt	Uninfested wt	Growth difference
	Year 1		
Paspalum			
561-79	1,480.0 ± 495.6efg	2,950.0 ± 197.3de	1,470.0 ± 468.3bcd
Durban	974.3 ± 65.9fg	1,866.7 ± 76.6de	1,176.7 ± 292.4cd
Sea Isle 2000	1,537.5 ± 325.7efg	2,037.5 ± 322.4de	500.0 ± 213.4d
Sea Isle 1	2890.0 ± 655.6cdefg	4,135.0 ± 921.9cd	1,245.0 ± 664.4cd
Sea Dwarf	2,048.7 ± 674.9defg	6,207.5 ± 1,645.6bc	4,158.7 ± 1,248.5ab
Salam	1,180.0 ± 342.7efg	2,003.3 ± 165.7de	893.3 ± 352.9d
HI-10	281.2 ± 169.5g	917.5 ± 217.9e	636.2 ± 161.7d
Sea Spray	1,785.0 ± 369.1defg	970.0 ± 465.9de	1,185.0 ± 561.5cd
Asul	3,975.0 ± 772.9bcd	6,325.0 ± 606.1bc	2,350.0 ± 743.2abcd
Sea Isle Supreme	2,776.2 ± 421.3def	3,932.5 ± 258.7cd	1,156.2 ± 477.9cd
Zoysia			
Cavalier	5,021.2 ± 811.5bc	9,150.0 ± 2,139.1a	4,128.7 ± 2,247.0ab
Palisades	6,057.5 ± 715.0ab	9,952.5 ± 747.0a	3,895.0 ± 825.6abc
Cynodon			
TifSport	7,285.0 ± 2,117.0a	9,240.0 ± 2,152.5a	1,955.0 ± 1,670.8abcd
TifEagle	3,287.5 ± 735.9cde	7,815.0 ± 1,092.6ab	4,527.5 ± 1,190.2a
	Year 2		
Paspalum			
Kim-1	418.3 ± 172.8fg	563.3 ± 131.9f	145.0 ± 16.9bc
Durban	1,460.0 ± 246.6de	1,713.3 ± 390.9cdef	253.3 ± 382.4bc
Sea Isle 2000	1,240.0 ± 236.3def	2,461.7 ± 522.4bcd	1,221.7 ± 655.4ab
Sea Isle 1	1,098.3 ± 244.6de	1,955.0 ± 527.4bcde	856.7 ± 533.7abc
Sea Dwarf	1,700.0 ± 261.5cd	3,126.7 ± 336.8b	1,427.7 ± 502.9ab
Salam	255.0 ± 215.7g	835.0 ± 359.1ef	580.0 ± 169.5abc
Q 37956	701.7 ± 157.3efg	2,440.0 ± 695.7bcd	1,738.3 ± 619.0a
Sea Spray	2,958.7 ± 306.6c	2,123.3 ± 325.1bcde	68.3 ± 52.7bc
Asul	173.3 ± 106.0g	933.3 ± 342.1ef	760.0 ± 355.7abc
Sea Isle Supreme	646.7 ± 228.6efg	1,233.3 ± 203.5def	586.7 ± 84.1abc
Zoysia			
Cavalier	5,163.3 ± 519.1abcd	5,856.7 ± 1,002.4a	693.3 ± 92.3abc
Cynodon			
TifSport	2,906.7 ± 314.6b	2,703.3 ± 502.1bc	−203.3 ± 71.4c

trols and the difference between the two ($F = 4.7$; df = 7, 13; $P < 0.0001$; $F = 8.1$; df = 7, 13; $P < 0.0001$; and $F = 2.8$; df = 7, 13; $P < 0.005$, respectively). Cultivars demonstrating the least root loss were Sea Isle 2000, HI-10, and Salam paspalum.

Although grub survival and final weights varied among cultivars, they were similar among the three grass genera ($F = 0.1$; df = 7, 2; $P = 0.9$; and $F = 0.2$; df = 7, 2; $P = 0.7$, respectively) ((Table 4). However, weight gain was greatest on *Zoysia* ($F = 38.1$; df = 7, 2; $P < 0.0001$). Foliar growth dry weights from infested grasses were least for *Paspalum* during the first and second samples ($F = 4.3$; df = 7, 2; $P < 0.0001$; and $F = 6.2$; df = 7, 2; $P < 0.001$, respectively) (Table 5). Uninfested weights were least for *Paspalum* ($F = 4.8$; df = 7, 2; $P < 0.01$) during the first sample, but they were similar for the second sample ($F = 2.5$; df = 7, 2; $P = 0.08$). The growth differences during the first and second samples were also similar among species ($F = 1.3$; df = 7, 2; $P > 0.05$; and $F = 0.04$; df = 7, 2; $P > 0.05$, respectively). Root dry weights among species during

Table 4. Mean ± SE Japanese beetle grubs recovered, weight, and weight gain (milligrams) on greenhouse-grown turfgrass species

Grass genus	Grubs recovered	Grub wt	Wt gain
Year 1			
Paspalum	1.2 ± 0.1a	211.6 ± 4.6a	54.7 ± 10.3b
Zoysia	1.2 ± 0.2a	214.9 ± 10.7a	90.1 ± 15.6a
Cynodon	1.2 ± 0.2 a	206.1 ± 10.9a	50.8 ± 18.7b
Year 2			
Paspalum	1.8 ± 0.2a	219.1 ± 7.5a	−3.4 ± 0.7a
Zoysia	2.8 ± 0.5a	210.6 ± 17.3a	−8.5 ± 2.5a
Cynodon	2.0 ± 0.6a	240.1 ± 11.4a	32.4 ± 11.9a

Table 5. Mean ± SE foliar growth dry weight (milligrams) of greenhouse-grown turfgrass species infested by Japanese beetle grubs

Grass genus	Infested wt	Uninfested wt	Growth difference
	Year 1, first sample		
Paspalum	780.5 ± 119.8b	1,768.4 ± 185.8b	1,009.5 ± 154.2a
Zoysia	1,329.6 ± 293.1a	2,845.9 ± 266.6a	1,516.2 ± 308.6a
Cynodon	1,311.2 ± 132.5a	2,683.2 ± 326.2ab	1,372.1 ± 328.2a
	Year 1, second sample		
Paspalum	255.5 ± 36.4b	660.5 ± 39.8a	422.5 ± 59.1a
Zoysia	371.9 ± 81.2ab	826.2 ± 73.8a	454.4 ± 98.2a
Cynodon	513.1 ± 89.3a	930.0 ± 60.0a	416.9 ± 96.1a
	Year 2, first sample		
Paspalum	1,012.1 ± 101.7a	1,202.2 ± 94.3a	190.1 ± 135.2a
Zoysia	1,382.5 ± 123.2a	1,677.5 ± 40.3a	295.0 ± 412.0a
Cynodon	1,415.0 ± 230.1a	1,091.2 ± 236.4a	−323.7 ± 384.0a
	Year 2, second sample		
Paspalum	53.2 ± 5.4b	1,215 ± 7.1b	68.2 ± 8.2a
Zoysia	150.0 ± 17.6a	247.5 ± 41.4a	97.5 ± 19.6a
Cynodon	91.2 ± 19.7b	85.0 ± 20.8b	−6.2 ± 3.2b

Table 6. Mean ± SE root growth dry weight (milligrams) of greenhouse-grown turfgrass species infested by Japanese beetle grubs

Grass genus	Infested wt	Uninfested wt	Growth difference
Year 1			
Paspalum	1,913.7 ± 188.8b	3,408.2 ± 288.b	1,500.4 ± 220.6b
Zoysia	5,286.2 ± 1,199.4a	8,527.5 ± 1,180.4a	3,241.2 ± 1,045.1a
Cynodon	5,539.4 ± 539.3a	9,551.2 ± 1,099.4a	4,011.9 ± 456.7a
Year 2			
Paspalum	974.8 ± 104.9c	1,738.5 ± 158.4b	763.7 ± 146.3a
Zoysia	5,163.3 ± 519.1a	5,856.7 ± 1,002.4a	693.3 ± 92.3a
Cynodon	2,906.7 ± 314.6b	2,703.3 ± 502.1b	−20.3 ± 7.a

year 1 (Table 6) were always least for *Paspalum* compared with *Cynodon* and *Zoysia* for infested, uninfested, and the growth difference ($F = 5.9$; df = 7, 2; $P < 0.0001$; $F = 11.7$; df = 7, 2 $P < 0.0001$; and $F = 3.2$; df = 7, 2; $P < 0.002$, respectively).

Year 2. Survival of grubs was influenced by cultivar ($F = 6.2$; df = 7, 11; $P < 0.0001$) (Table 1). Average survival ranged from 45% on Cavalier zoysiagrass to 18% on Sea Isle Supreme paspalum. Weight of grubs at the termination of this trial was similar among cultivars ($F = 0.7$; df = 7, 11; $P > 0.05$). Average weight difference did not vary with cultivar ($F = 0.9$; df = 7, 11 $P > 0.05$).

Foliar weights of infested grass during the first sampling period demonstrated cultivar-related differences ($F = 4.3$ df = 7, 11; $P < 0.0001$) (Table 2). There were also significant cultivar-related differences in top growth of uninfested plants ($F = 2.3$; df = 7, 11; $P <$ 0.01). The difference between top growth of infested plants and their uninfested controls was significant by cultivar ($F = 2.4$; df = 7, 11; $P < 0.004$ with Kim-1, Sea Isle 2000, Sea Spray, and TifSport, actually demonstrating an increase in topgrowth compared with uninfested control plants during the first sampling period. Foliar dry weights during the second sampling period were again influenced by cultivar for infested grasses ($F = 3.9$; df = 7, 11; $P < 0.0001$), uninfested controls ($F = 3.6$; df = 7, 11; $P < 0.0001$), and for the difference between infested and uninfested ($F = 1.7$; df = 7, 11; $P < 0.05$), with TifSport Bermuda grass demonstrating the best top growth at the end of the infestation period.

Root dry weights (Table 3) similarly showed cultivar-related effects for infested turf, uninfested controls, and the difference between the two ($F = 16.3$; df = 7, 11; $P < 0.0001$; $F = 7.2$; df = 7, 11; $P < 0.0001$; and $F = 1.6$; df = 7, 11; $P < 0.09$, respectively). Cultivars demonstrating the least root loss were TifSport Bermuda grass and Sea Spray and Kim-1 paspalums.

During year 2, grub survival, final weights, and weight differences were similar among the three grass genera ($F = 2.5$; df = 7, 2; $P > 0.05$; $F = 0.4$; df = 7, 2; $P = 0.7$; and $F = 0.7$; df = 7, 2; $P > 0.05$, respectively) (Table 4). Foliar growth dry weights from infested grasses were least for *Paspalum* and *Cynodon* during the second sample ($F = 5.7$; df = 7, 2; $P < 0.0001$) (Table 5). Uninfested weights were least for *Cynodon* and *Paspalum* during the second sample only ($F =$ 16.0; df = 7, 2; $P < 0.0001$). The growth differences during the second sample was least for the Bermuda grass ($F = 3.4$; df = 7, 2; $P < 0.001$). Root dry weights among species during year 2 (Table 6) were least for *Paspalum* compared with *Cynodon* and *Zoysia* for infested and uninfested root dry weights, but they were similar for the growth difference ($F = 17.6$; df = 7, 2; $P < 0.0001$; $F = 9.4$; df = 7, 2; $P < 0.0001$; and $F = 1.6$; df = 7, 2; $P > 0.05$, respectively).

Discussion

Among the paspalums evaluated, those demonstrating improved ability to tolerate grub feeding measured as reduced impact on foliar growth were 561-79, Sea Isle 2000, Durban, HI-10, Kim-1, Sea Dwarf, and Sea Spray. We expected turf types with the largest root mass to be the most tolerant of grub injury. Among paspalums, the cultivar with the largest root mass was Sea Dwarf. However, this turf type also had the largest root loss among the paspalums. Among all turf types tested, Cavalier and Palisades zoysiagrasses and TifSport Bermuda grass had the greatest uninfested root weights. Cultivars within the paspalums that lost the least root mass, Sea Isle 2000, HI-10, and Salam during year 1 and Sea Spray during year 2, were among those demonstrating the best top growth despite grub feeding. A comparison of cool-season grasses infested with European chafer grubs showed that when all cultivars of the four species examined were grouped together, plants with a large root mass lost just as large a proportion of roots as did plants with a small root mass, although in two cases, the cultivar within a species with the largest root mass had the smallest percentage of root loss (Bughrara et al. 2003).

Grubs gained the most weight and consumed the most roots on TifEagle Bermuda grass. Grub survival varied considerably between years. Year-to-year variation in Bughrara et al. (2003) was attributed to differences in soil moisture and drought stress. We did not impose drought stress during our study, but we did increase grub densities. Grubs survived better at the lower densities used during the year 1 evaluations. We expected that grub survival and weight gain would be a function of root mass size, as shown in Bughrara et al. (2003). Whereas this was sometimes the case, e.g., high survival on the densely rooted Cavalier zoysiagrass, the relationship was not consistent. For example, survival on Sea Dwarf was least during year one in spite of its large root mass.

Potter et al. (1992) determined that susceptibility of six cool-season turfgrasses to grub feeding by Japanese beetles or southern masked chafers, *Cyclocephala immaculata* (Olivier), is a function of their ability to tolerate root feeding rather than any apparent antibiosis. Bughrara et al. (2003) suggested that the apparent connection between drought tolerance and grub tolerance in grasses may be a function of the proportion of fine and coarse roots, with fine roots perhaps being more preferred.

Paspalums vary in their response to other important pests impacting turfgrass in the southeastern United

States. Paspalums have been shown to be relatively susceptible to fall armyworms (Braman et al. 2000a, 2002a) among other warm-season grasses and in comparison with the cool-season grass, tall fescue. Parasitism of the fall armyworm by *Aleiodes laphygmae* Viereck was highest in the field on paspalum versus that which occurred on Bermuda or zoysiagrass cultivars (Braman et al. 2004). Predation by bigeyed bugs *Geocoris uliginosus* Say in laboratory evaluations was greatest on zoysiagrass, but in the field, mortality of fall armyworms due to bigeyed bugs was greatest on paspalums (Braman et al. 2003). Survival of twolined spittlebugs in greenhouse studies was greatest on centipedegrass followed by Bermuda grass, seashore paspalum, and zoysiagrass (Shortman et al. 2002). Developmental times were extended when spittlebugs were feeding on paspalums. In field trials, SeaIsle 2000 was among four paspalums that demonstrated the best regrowth potential following spittlebug infestation. In greenhouse, laboratory and field evaluations for mole cricket tolerance, none of the tested genotypes was highly resistant to mole cricket injury, but TifSport Bermuda grass and 561-79 paspalum were the most tolerant (Braman et al. 2000b).

The gradients in response among paspalums to grub induced injury mirror the previously observed variation in response to other turf pests. Those turf selections that demonstrated greater ability in the greenhouse to tolerate Japanese beetle larval feeding require further evaluation under low maintenance conditions in the field. It is possible that predation or parasitism by natural enemies of grubs could be similarly influenced by turf type. Tiger beetles *Megacephala carolina carolina* L. were most abundant in 561-79 paspalum and TifEagle Bermuda grass plots in the field (Braman et al. 2003). The activity of predaceous adults overlaps with larval Japanese beetles upon which the adult beetles have been observed to feed. Extrinsic resistance or the action of natural enemies as influenced by turf types offers opportunities for pest management and conservation biological control that merit further research.

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