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HUNTING BILLBUG (COLEOPTERA: CURCULIONIDAE) RESISTANCE AMONG ZOYSIAGRASS (*ZOYSIA* SPP.) CULTIVARS

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ABSTRACT

Hunting billbugs (*Sphenophorus venatus vestitus* Chittenden) cause damage to zoysiagrass (*Zoysia* spp.) and bermudagrass (*Cynodon* spp), which is often misdiagnosed as the effects of drought, disease, or another soil insect. Populations have increased over the past several decades and are causing extensive damage on grasses in lawns, golf courses and other landscapes. Nine cultivars of *Zoysia* were evaluated for resistance to *S. venatus vestitus* in a field cage choice test in a paired cage split-plot experiment. Leaf-firing of plant canopy was considered an above ground expression of root feeding damage by billbug larvae. 'Diamond' and 'Zorro' exhibited significantly less leaf firing damage (a reduction of 6.1 and 9.8%, respectively). In contrast, 'Palisades', 'Meyer', and 'Crowne' showed >40% canopy damage. When root, shoot, and total plant dry weights were compared, 'Diamond', 'Zorro', 'Cavalier', and 'Royal' [all *Z. matrella* (L.) Merr.] sustained less dry weight reduction (<53%) than 'Palisades', 'Meyer', and 'El Toro' (all *Z. japonica* Steud.) with 76, 74, and 70% total dry weight reductions, respectively. Cultivars of *Z matrella* appear to be more resistant as a group than the *Z. japonica* cultivars.

Key Words: *Zoysia matrella*, *Zoysia japonica*, *Sphenophorus venatus vestitus,* host plant resistance, turfgrass, lawns, Curculionidae

RESUMEN

Los billbugs cazadores (*Sphenophorus venatus vestitus* Chittenden) afectan cultivares de zoysiagrass (*Zoysia* spp.) y bermudagrass (*Cynodon* spp). Con frecuencia, el dañó es confundido como sequía, enfermedad u otra plaga del suelo. Las poblaciones del insecto se han incrementado en las ultimas dos décadas causando un extensivo daño de pastos en céspedes y campos de golf. La resistencia a *S. venatus vestitus* en nueve cultivares de *Zoysia* fueron evaluados con jaulas en el campo, con una prueba de "opción múltiple" en un experimento de parcelas divididas. El "quemado" del follaje del pasto fue considerado como una expresión del dañó de la larva del insecto, al alimentarse en las raíces. 'Diamond' y 'Zorro' presentaron menor dañó del follaje significativamente (con una reducción del 6.1 y 9.8%, respectivamente). Por lo contrario, 'Palisades', 'Meyer', y 'Crowne' mostraron >40% daño foliar. En la comparación de pesos secos de la raíz, estolón, y peso total de la planta, 'Diamond', 'Zorro', 'Cavalier', y 'Royal' [todos *Z. matrella* (L.) Merr.] mostraron menos reducción del peso seco (<53%) en comparación con 'Palisades', 'Meyer', y 'El Toro' (Todos *Z. japonica* Steud.) con 76, 74, y 70% del peso total, respectivamente. Los cultivares de *Z matrella* como grupo parecer ser que son mas resistentes que el grupo de cultivares de *Z. japonica*.

Translation of the abstract was provided by Carlos Campos.

The genus *Sphenophorus* (Coleoptera: Curculionidae) (often referred to as *Calendra*) contains 71 species of which 64 occur in the North America (Niemczyk & Shetlar 2000; Vaurie 1951). At least 9 of these species are known to be pests of turfgrass, causing damage to both cool- and warm-season grasses (Morrill & Suber 1976; Johnson-Cicalese et al. 1990; Vaurie 1951; Vittum et al. 1999).

The hunting billbug (HBB) (*Sphenophorus venatus vestitus* Chittenden) has been listed as a damaging pest of turfgrass from New Jersey (Johnson-Cicalese & Funk 1990), south to Georgia (Morrill & Suber 1976) and Florida (Kelsheimer 1956); west to Kansas (Brissell & Clark 1968), Texas, California, and Hawaii (Davis & Krauss 1964; LaPlante 1966) and throughout the Caribbean Islands (Vaurie 1951; Vittum et al. 1999). It has been identified in Arizona and Idaho, but its total range of distribution across the Western United States is not fully established (K. Umeda, Univ. of Arizona; D. J. Shetlar, Ohio State Univ.; T. Salaiz, Univ. of Idaho, personal communication). Also it is listed as a serious turf pest in Japan (Hatsukade 1997).

Hunting billbug damage is often misidentified as the effect of drought, dormancy, disease, or another root-feeding insect. Only 1 generation per year was reported in northern Florida (Kovitvadhi & Kerr 1968), Louisiana (Oliver 1984) and Arkansas (Young 2002), but Huang (2008) and Huang & Buss (2009) suggest that it may have at least 2 or 3 overlapping generations per year in Florida. The adult HBB feeds by notching the leaves of both *Zoysia* and *Cynodon* (Huang 2008), and it then lays its eggs in a small feeding scar usually in the crown of the plant. Larvae pass through 5 stadia (Hatsukade 1997; Huang 2008) with the early instars feeding within the crown, larger rhizomes, and stolons before the later instars emerge and continue feeding on the whole root system. Initial larval damage appears as small pockets of yellowing and dying grass, resembling dollar spot disease infections, which increase in size and later coalesce as the larvae continue feeding (Vittum et al. 1999). Infested sod fields often cannot be harvested since many of the roots and rhizomes have been severed and the cut sod will not hold together.

Populations of this billbug have increased over the past 10 to 15 years and it is responsible for extensive turf damage in lawns, golf courses and other landscapes, and a loss of sod production by its primary host grasses. Satterwhite (1932) and Woodruff (1966) provide an extensive host list that includes other commonly used turfgrasses: St. Augustinegrass (*Stenotaphrum secundatum* Walt. Kuntze), centipedegrass [*Eremochloa ophiuroides* (Munro) Hack], and bahiagrass (*Paspalum notatum* Flugge).

Several studies have identified resistance to a related species, the bluegrass billbug (*Sphenophorus parvulus* Gyllenhal) in cultivars of Kentucky bluegrass (*Poa pratensis* L.) (Lindgren et al. 1981; Ahmad & Funk 1982; Kindler et al. 1982; Shearman et al. 1983; Johnson-Cicalese et al. 1989, 1997; Bonos & Smith 1994; Westerholt 1994). Additionally, resistance to the bluegrass billbug was documented in 'Reveille' and other hybrids between Kentucky bluegrass (*P. pratensis*) × Texas bluegrass (*P. arachnifera* L.) (Reinert et al. 2005). The documented resistance to insect and mite pests in turfgrass has been summarized (Reinert et al. 2004).

Resistance to several other insect and mite pests has been identified in *Zoysia* spp. 'Emerald', 'Diamond', 'Zorro', 'Cavalier', and 'El Toro' exhibit moderate to high resistance to the fall armyworm (*Spodoptera frugiperda* J. E. Smith) (Reinert & Engelke 2010) and these cultivars (except 'Diamond') along with 'Royal', 'Crowne', and 'Palisades' also provide moderate to high resistance to the tropical sod webworm (*Herpetogramma phaeopteralis* Guenée). 'Emerald', 'Diamond', 'Cavalier', and 'Palisades' provided moderate resistance to the tawny mole cricket (*Scapteriscus vicinus* Scudder) (Braman et al. 1994). 'Emerald' was the most resistant to Rhodesgrass mealybug (*Antonina graminis* Maskel) among 5 cultivars of Zoysia (Reinert & Vinson 2010), while 'Emerald' and 'Royal' were the most resistant to the zoysiagrass mite (*Eriophyes zoysiae* Baker, Kona and O'Neill) (Reinert et al. 1993). 'Cavalier' was resistant to the differential grasshopper [*Melanoplus differentialis* (Thomas)] (Reinert et al. 2011). In all of these studies, 'Meyer' was highly susceptible to each of the respective pests.

Our experiment was designed to evaluate cultivars of *Zoysia* for resistance to HBB and to identify potential mechanisms of resistance. When the present experiment was initiated in 2000, no resistance had been identified to HBB in either bermudagrass or zoysiagrass; however, more recent studies in Florida have also shown differences in susceptibility among genotypes of these 2 grasses (Huang 2008).

Materials and Methods

An experiment was established to evaluate 9 *Zoysia* cultivars that were selected for their varying resistance to other turf pests and to compare the resistance potential between the 2 *Zoysia* spp. (listed in Tables 1 and 2) (including 4 *Z. matrella* (L.) Merr. and 5 *Z. japonica* Steud.) for resistance to the HBB. Metal livestock water tanks (0.76 m high and 2.44 m diam) were used as evaluation cages. Each cage was positioned above ground level on several concrete blocks, and set at a slight slant toward a 2.5 cm drain hole to eliminate any excessive water accumulating in the soil profile in the bottom of the cage. Each cage was filled to a depth of ca. 45 cm with 100% sand root zone media to facilitate uniform growth and to provide an easy medium to excavate and separate the root systems. The top of each cage was fitted with a screen (allowing 70% light transmission) to prevent movement into or out of the cages by either billbugs or other insects. A similar confined field cage has been used for the bluegrass billbug (Reinert et al. 2005) and mole cricket studies (Reinert and Busey 2001, 2005).

The *Zoysia* cultivars used in this experiment were produced in the greenhouse in 18-cell trays (each cell measuring 7.5 × 7.5 cm and 4 cm deep) and fertilized bi-weekly with Jack's Classic (formerly Peter's) 20-20-20 (NPK) + B (0.02%) Cu (0.05%), Fe (0.10%), Mn (0.05%), Mo (0.0009%), and Zn (0.05%) (J. R. Peters, Inc., Allentown, Pennsylvania) at ca. 170 ppm until transferred to the field cages. Plants were watered and fertilized as needed throughout the test period to maintain good plant growth.

For physical arrangement of the cages and plants within the cages, a modified randomized complete split-split plot design with 4 replicates was used. The main plot was billbug treatment

TABLE 1. RESISTANCE, MEASURED AS LEAF-FIRING OF PLANT CANOPY, AMONG ZOYSIAGRASS CULTIVARS TO LARVAL FEEDING BY HUNTING BILLBUG LARVAE (JUN-SEP 2000), DALLAS, TX (FOUR REPS OF PAIRED PLANTS).

Zoysiagrass		Leaf firing damage of plant canopy[b]		
Cultivar	Spp.[a]	Rating of plants with[c] billbug feeding	Difference[d] Ck - treat	Damage[e] %
Diamond	Zm	7.88 a*	0.50 a	6.08 a
Zorro	Zm	6.17 b	0.87 ab	9.76 ab
De Anza	Zj	4.83 cde	1.88 bc	21.91 abc
El Toro	Zj	5.63 bc	1.88 bc	24.93 abc
Cavalier	Zm	5.88 bc	2.25 cd	27.58 bc
Royal	Zm	5.13 bcd	3.38 cd	30.95 cd
Crowne	Zj	4.25 de	2.88 cd	40.55 cd
Meyer	Zj	3.57 e	3.38 d	44.38 d
Palisades	Zj	4.25 de	3.50 d	45.49 d

[a]*Zm = Zoysia matrella; Zj = Z. japonica*.
[b]Leaf firing was considered a measure of the above-ground symptom expression of the root feeding damage caused by billbug larvae.
[c]Plants were ranked on a scale of 1-9, 1 = severe leaf firing, 9 = no leaf firing.
[d]Difference was the adjusted leaf firing (check - treatment).
[e]Damage = [(check - treatment) / check] × (100).
*Means in a column followed by the same letter are not significantly different at $P < 0.01$ using Fisher's protected LSD test.

(e.g., cage), the subplot was location within the cage (north vs. south), and the sub-subplot was *Zoysia* cultivar. Within each replicate (consisting of 2 cages, one with and the other without billbugs), 2 plants from each cultivar were paired by total size and 1 plant was assigned to the north half of each cage. An analogous assignment of varieties was used for the south section of each cage, except that the location of variety was re-randomized. The matched arrangement based on plant size minimized the effect of the leaf area and root mass on the treated vs. untreated comparison. Likewise, the use of the same randomized placement of cultivars for the north side of each cage helped to minimize any effects due to plants being closer or further from the edge of the cage than its paired-partner in the other cage (e.g., such as shading). Because the north vs. south effect (subplot) was statistically inconsequential for all traits measured in our study, and grass plants responded the same regardless of their location in the cages, the average of the 2 plants of each cultivar per cage was used in the statistical analysis. Using the average of the 2 plants per cage, the data were subjected to analysis of variance (ANOVA) with the PROC GLM procedure of SAS (SAS Institute 2005).

Plants were transplanted on 23-24 Jun 2000 and allowed to establish for 5 d in the cages before HBB adults were introduced into the cages. Plants were planted in 2 concentric circles of 3 and 6 m circumference with 7 plants in the 3 m and 11 in the 6 m circle. Plants were spaced ca. 21 cm apart in each quadrant and a minimum of 20 cm from the side of the cage.

Treatment cages were infested at a similar rate of adults and manner of introduction to another experiment with *Poa* spp. vs. bluegrass billbug (Reinert et al. 2005). One cage of each pair was infested on 26 June 2000 at a rate of 30 female and 15 male HBB adults. The adult billbugs were released between the 2 concentric rows of plants (ca. 50 cm from the center of the cage), and allowed to migrate to the *Zoysia* plants they preferred as acceptable host. The open area between plants allowed the adult HBB to move freely from one plant to another to choose preferred hosts for oviposition. All HBB adults used in this study were field collected from a bermudagrass field at a sod farm. Collected HBB adults were held for < 1 wk in moist soil under refrigeration until released in the study tanks.

On 21 Sep 2000, "leaf firing" of the plant canopy (dead or dying leaf and shoot tissue in the surface growth of the plant) for each of the *Zoysia* cultivars both with and without HBB damage was estimated by rating each plant on a scale of 1 to 9, with 1 = 90% leaf firing or a dead plant, 9 = no leaf firing, with plants rated between the 2 extremes falling on a graduated scale between 1 and 9 (a modification of the procedure used by the National Turfgrass Evaluation Program, Morris 2011). Observations were recorded by 2 individuals. Whole plants were then excavated from the sand medium in the tanks and bagged from 22-29 Sep 2000 (after an evaluation period of about 13-14 weeks after adult infestation of the plants) by excavating the entire plant from the sand.

All plants from 1 replicate were dug and held under refrigeration until they were processed before the next replicate was harvested. In the laboratory, all tillers were cut at the soil line, washed, and counted. Roots and rhizomes were also washed before measurements were made.

TABLE 2. RESISTANCE AMONG ZOYSIAGRASS CULTIVARS TO LARVAL FEEDING BY HUNTING BILLBUG (JUN-SEP 2000), DALLAS, TX (FOUR REPS OF PAIRED PLANTS).

		Rhizome length[b]		No of rooted nodes[b]		Root mass[b]		Shoot mass[b]		Plant mass[b]	
Cultivar	Spp.[a]	diff (cm)[c]	% diff[d]	diff[c]	% diff[d]	diff (mg)[c]	% diff[d]	diff (mg)[c]	% diff[d]	diff (mg)[c]	% diff[d]
Diamond	Zm	203.3 a*	27.76 a	85.3 a	18.89 a	4.68 a	33.61 a	1.49 a	11.53 a	6.16 a	26.29 a
Zorro	Zm	437.5 ab	33.87 ab	188.9 bcd	34.63 ab	12.77 abc	44.89 a	1.39 a	12.70 a	14.16 ab	35.72 ab
Cavalier	Zm	448.8 ab	49.97 bc	162.1 abc	44.71 bcd	13.51 abc	60.76 b	2.73 ab	24.72 ab	16.24 ab	48.89 bc
Royal	Zm	625.1 bc	68.52 de	267.5 d	62.56 cde	11.66 ab	68.08 b	5.71 abcd	32.96 abc	17.37 ab	53.46 cd
Crowne	Zj	551.2 bc	54.02 cd	143.5 abc	43.38 bc	29.09 d	69.75 bcd	6.69 bcd	49.49 cd	35.78 d	65.42 de
De Anza	Zj	762.0 c	70.29 de	232.9 cd	65.3 e	17.51 bc	76.24 cd	4.58 abc	48.33 bcd	22.09 bc	68.64 de
El Toro	Zj	551.2 bc	62.94 cde	132.0 abc	48.9 bcde	32.55 d	78.42 cd	6.73 bcd	46.02 bcd	39.28 d	70.24 e
Meyer	Zj	421.2 ab	71.26 e	138.3 abc	60.46 de	22.51 cd	79.58 d	9.24 d	62.97 d	31.75 cd	73.90 e
Palisades	Zj	497.6 bc	59.60 cde	109.5 ab	37.68 ab	30.63 d	79.26 cd	8.40 cd	65.52 d	39.02 d	76.10 e

[a]*Zm* = *Zoysia matrella*; *Zj* = *Z. japonica*.
[b]Length of rhizomes per plant, number of rooted nodes per plant, root, shoot and total mass for each treatment and each check plant.
[c]Difference = (amount in check) - (amount in treatment).
[d]% difference = [(amount in check) - (amount in treatment) / (amount in check)] × (100).
*Means in a column followed by the same letter are not significantly different at $P < 0.01$ using Fisher's protected LSD test.

Traits measured were: total rhizome length, longest rhizome, number of rooted nodes on rhizomes, and total plant biomass. Shoot and root biomass were collected separately, oven dried (72 hr at 70°C) and weighed. Stolons and rhizomes from each plant were also examined for larval feeding damage.

Zoysiagrass cultivars were all treated as equal entries and no nesting was considered. Two statistical analysis models were used. First, variations in plant traits among genotypes from untreated cages only were analyzed. Second, the percentage reduction of rhizome lengths, number of rooted nodes, shoots, root and whole plant dry weights was calculated as: [(check plant – infested plant) / (check plant)] × (100) (Abbott 1925). To analyze these differences, we used a traditional RCBD analysis with only replicate and cultivar as sources of variation. The actual difference data and percentage reduction data exhibited heterogeneity of variance but a square root transformation (for actual difference) and an arcsine transformation (for percentage reduction) resulted in homogeneity of variance. For both analyses (untreated plants only and difference between treatments), F-tests were made using cultivar mean square error as the numerator and residual (error mean square) as denominator. Treatment (billbug vs. no billbug) was excluded as a source of variation. Comparisons of means for weights and lengths and transformed percent difference in traits between uninfested and infested plants for each genotype were performed using Fisher's protected least significant differences (LSD). All values presented in the tables are untransformed means (percent difference between check and HBB damaged) with accompanying letters derived from the mean separation attained in the analysis of transformed values.

Results and Discussion

The percentage of leaf-firing or canopy damage for each of the *Zoysia* cultivars is presented in Table 1. Leaf-firing was considered as an above ground symptom expression of the root feeding damage by the billbug larvae. 'Diamond', 'Zorro', 'Cavalier', 'Royal', and 'El Toro' exhibited the least visual damage and were ranked highest when plants were exposed to billbugs. 'Meyer', a cultivar which has been the industry standard for years, exhibited the most leaf-firing and ranked lowest followed by 'Palisades' = 'Crowne' > 'De Anza'. Using a modification of Abbott's formula (1925), where the treatments are adjusted to the untreated check, 'Diamond' and 'Zorro' exhibited significantly less leaf firing damage (6.1 and 9.8% reduction, respectively) with all other cultivars showing >22% damage. 'Palisades', 'Meyer', and 'Crowne' showed the highest leaf firing (>40%) as a result of billbugs feeding on the roots. 'Diamond' and 'Zorro' sustained only 27.8 and 33.9%, respectively, reduction in total rhizome length, followed by 'Cavalier' with <50% reduction while 'Meyer' and 'De Anza' each exhibit >70% reduction. Another measure of feeding was the number of rooted nodes on the rhizomes. 'Diamond' and 'Zorro' showed the least reduction in total rooted nodes (18.9 and 34.6%, respectively). By contrast, 'Meyer' and 'De Anza' each sustained >70% reduction in total rhizome lengths (Table 2). Also, when the number of rooted nodes on the rhizomes was compared, 'Diamond' and 'Zorro' showed the least reduction with 18.9 and 34.6% difference, respectively, while 'Meyer' and 'De Anza' each produced >60% reduction in rooting.

Differences in root mass were very small in absolute terms (≤13.5 mg) for 'Diamond', 'Zorro', 'Cavalier', and 'Royal' although the percentage differences were more apparent with 33.6, 44.9, 60.8, and 68.1% differences, respectively. Root weight differences exceeded 22.5 mg for 'Crowne', 'El Toro', 'Meyer', and 'Palisade' with percent differences of 70-80% being very prominent for these grasses. A similar trend was recorded for shoot weights with ≤3 mg difference for 'Diamond', 'Zorro', and 'Cavalier' followed with 5.7 mg difference for 'Royal'. The percentage loss in shoot mass was <33.0% for these same cultivars. By comparison, the loss in root mass was >63% for 'Meyer' and 'Palisades'. When the combined shoot and root dry weight or total dry plant mass was compared, differences ranged from 6.2 mg for 'Diamond' to >39 mg for 'Palisades' and 'El Toro'. Percentage differences between treatment and check plants ranged from 26.3 for 'Diamond' to >65% difference for 'Palisades', 'Meyer', 'El Toro', 'De Anza', and 'Crowne'.

These cultivars exhibited marked differences in impact of HBB feeding on the total growth potential of the test plants. 'Diamond' (a *Z. matrella)*, was the most resistant (26.3% loss in total plant dry weight) while 'Meyer' (a *Z. japonica*) was highly susceptible and exhibited substantial larval feeding damage (73.9% loss in total plant dry weight) (Fig. 1). The assays for shoot dry weight and total plant dry weight show that all 4 cultivars of *Z. matrella* sustained the least impact from HBB feeding while all 5 cultivars of *Z. japonica* sustained greater than 46 and 65% difference in weights for shoot and total plant mass, respectively. Experiments by Huang (2008) confirm the highest resistance in 'Diamond', 'Zorro', 'Cavalier', and 'Royal' based upon density and quality ratings and that 'El Toro' and 'Palisades' provided the lesser quality and density.

Additionally, Huang (2008) found no oviposition of eggs on 'Diamond' and 'Zorro', and only an average of 0.2 and 0.4 eggs per plant on 'Royal' and 'Cavalier', respectively, within 1 month of adult confinement on these cultivars. In contrast, the adult HBB had oviposited 1.0, 1.8, 2.6, and 3.0

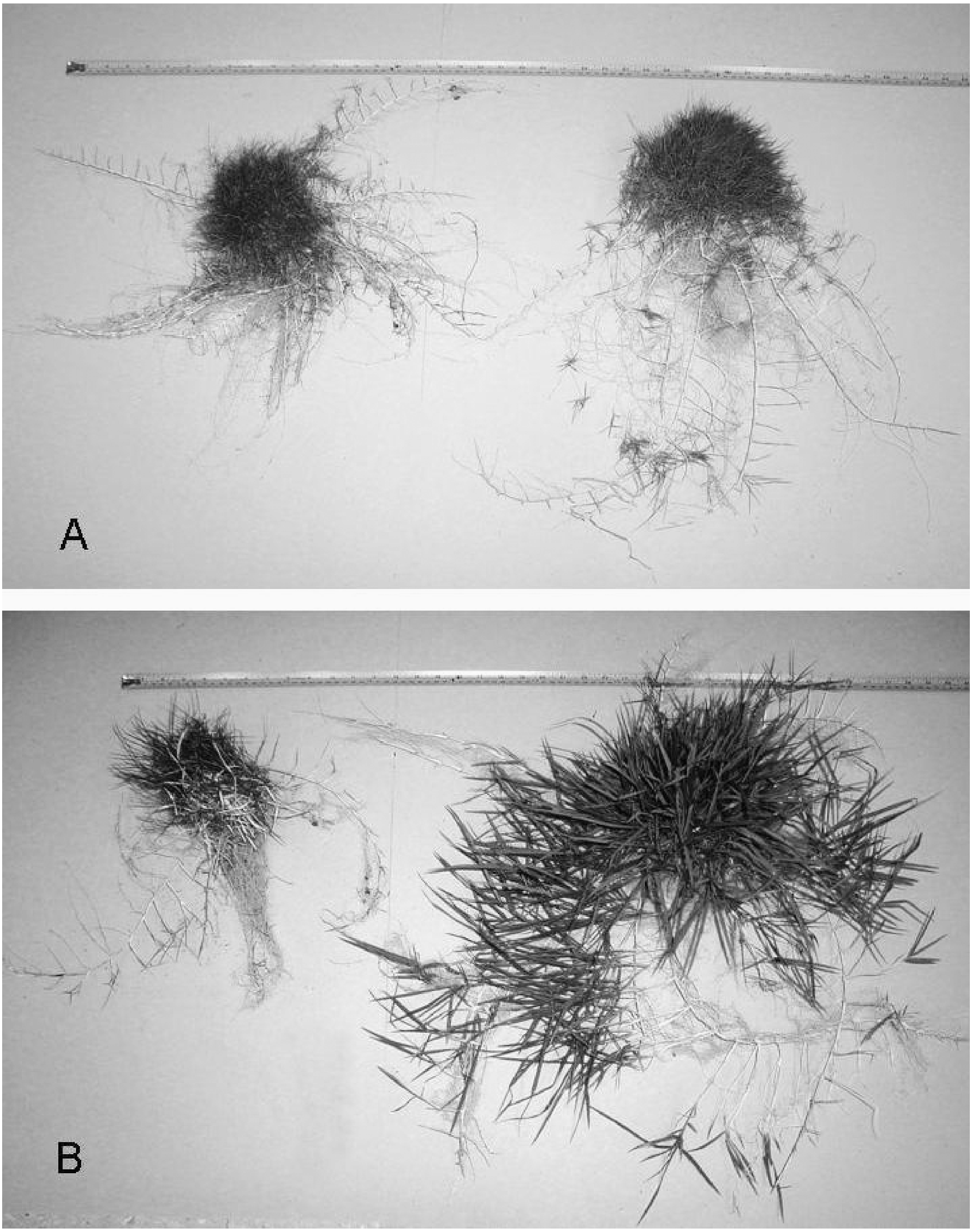

Fig. 1. (A) Example of *Z. matrella* cultivar with hunting billbug resistance: 'Diamond' zoysiagrass plant only sustained ca. 26% reduction in growth potential due to billbug larval damage. (B) Example of reduction in growth potential due to hunting billbug larval feeding on susceptible cultivar of *Z. japonica*. 'Meyer' zoysiagrass plants sustained a 76% average loss in total plant weight. (Billbug damaged plant on left, plant without exposure to billbugs on right).

eggs per plant on 'Palisades', 'El Toro', 'Crowne', and 'Meyer', respectively, in their greenhouse study. Although different parameters were evaluated in our study than in the Huang's (2008) study, the 2 studies provided very similar results for the cultivars that were common to both studies.

Two growth factors associated with *Z. matrella* may be responsible for its resistance to feeding damage by HBB. First, rhizomes developing on *Z. matrella* appear to have much shorter internodes and almost every internode will develop a shoot and it is rooted (Fig. 2A). Therefore, when the rhizome is severed by larval feeding, the isolated section of the rhizome with existing shoots and roots will continues to grow, independently of the parent plant, with only minimal loss of growth potential. This also results in a much denser root system with many more intertwined rhizomes (Fig. 1A).

A second mechanism of resistance is the ability of the cultivars of *Z. matrella* to exhibit apical dominance; when the rhizome is severed, it responds by developing new growth points—new stolons and rhizomes with roots and shoots. In this study, when a rhizome was severed, new lateral branch rhizomes were initiated just before the point of larval feeding damage. Fig. 2B shows a rhizome of 'Diamond' that was severed by billbug feeding and the plant's response by generating 6 lateral branches just before the damaged area. It was common to observe 3 or 4, and up to 6 lateral branches on the billbug infested plants of any of the *Z. matrella* cultivars.

Among plants of the *Z. japonica* cultivars, it was common to see no lateral branching, occasionally only 1branch, and rarely 2 lateral branches just before the point of injury. A damaged rhizome of 'Meyer', with the production of only 1 lateral branch produced just before the point where the rhizome was severed is shown in Fig. 2C. Both the higher number of shoots and roots developed and the ability of the *Z. matrella* cultivars to compensate for feeding damage to the rhizome by developing lateral branching are forms of tolerance.

Granted, there is a range of resistance among the 4 cultivars of *Z. matrella*, and also a range of susceptibility among the 5 *Z. japonica* cultivars, but there appears to be a difference in response to this pest and its damage between the 2 species of *Zoysia*. There will always be exceptions, but one may speculate that other cultivars of *Z. matrella* may also carry levels of resistance to this primary pest. The study in Florida by Huang (2008) supports this conclusion since several other cultivars of both *Zoysia* species were evaluated, and based upon density, quality, and egg deposition results, these cultivars tend to also follow species separations for resistance vs. susceptibility as well.

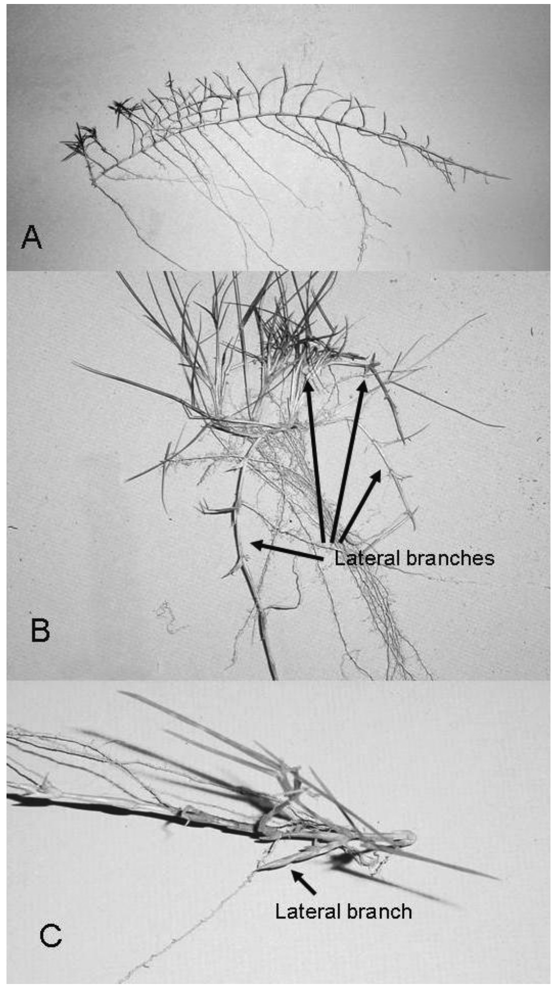

Fig. 2. (A) Rhizome of *Z. matrella* showing the short internodes and presence of shoot and root growth at almost every node. (B) Mechanism of resistance in the *Z. matrella* cultivars: Note just before the point where this rhizome of 'Diamond' was severed by billbug feeding, the plant has generated six lateral branches to compensate for the lost terminal of the rhizome. (C) Cultivars of *Z. japonica* produced only one and sometimes two lateral branches on the rhizome at the point just before where the rhizome was severed by billbug feeding. This rhizome of 'Meyer' has generated only one lateral branch.

It is interesting to note that several of these cultivars of *Z. matrella* have also exhibited good resistance to other insect and mite pests. 'Cavalier', for example has good levels of resistance to fall armyworm, tropical sod webworm, tawny mole cricket, Rhodesgrass mealybug, and differential grasshopper. 'Royal' has resistance to the zoysiagrass mite, tropical sod webworm, and Rhodesgrass mealybug; 'Diamond' is resistant to fall armyworm, tawny mole cricket, and Rhodesgrass mealybug; while 'Zorro' is resistant to fall armyworm, tropical sod webworm, and Rhodesgrass mealybug (Reinert & Vinson 2010). The host resistance responses of these various *Z. matrella* cultivars have been summarized by Reinert et al. (2004).

This experiment provides a controlled study to assay a group of *Zoysia* cultivars for resistance to the HBB, one of the primary limiting pests of *Zoysia*. *Zoysia* cultivars are used worldwide for lawns, other landscapes, and on golf courses. The experiment included 4 cultivars of *Z. matrella* ('Cavalier', 'Diamond', 'Royal', and 'Zorro') and 5 cultivars of *Z. japonica* (Crowne, 'De Anza', 'El Toro', 'Meyer', and 'Palisades'). Based on these results, when the surface damage was assayed as leaf-firing of the plant canopy, 'Diamond' and 'Zorro' (both *Z. matrella*), were resistant and sustained minimal loss in plant canopy appearance. The visual appearance of the plant canopy appears to strongly reflect the associated health or damage to the root system. When rhizome length and number of rooted nodes on the rhizome were compared, the plants sustaining the least damage were, again, all *Z. matrella* cultivars, including 'Diamond', 'Zorro', and 'Cavalier'. Assays of the dry plant mass also showed that the *Z. matrella* cultivars were resistant while the *Z. japonica* cultivars were highly susceptible to damage.

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