Potential Negative Effects of Earthworm Prey on Damage to Turfgrass by Omnivorous Mole Crickets (Orthoptera: Gryllotalpidae)

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ABSTRACT   The severity of damage to host plants by omnivorous pests can vary according to the availability of plant and animal prey. Two omnivorous mole crickets, *Scapteriscus vicinus* Scudder and *S. borellii* Giglio-Tos, were used to determine if the availability of prey influences damage to hybrid bermudagrass by adult mole crickets. Experiments were conducted in arenas with either grass alone (control), grass plus one mole cricket, grass plus earthworms (*Eisenia fetida* Savigny), or grass with earthworms and a mole cricket. Root growth variables (e.g., volume, dry weight) after 4 wk and weekly measurements of top growth were compared among the treatments. Surprisingly, bermudagrass infested with either mole cricket species caused no significant reduction in root growth and a minimal reduction on top growth with *S. vicinus* compared with controls. Survival of earthworms with *S. borellii* was significantly lower than survival in the earthworm-only treatment suggesting predation. Survival of earthworms with *S. vicinus*, however, was not different from the earthworm-only treatment. The addition of earthworm prey with mole crickets did not significantly impact bermudagrass root or shoot growth relative to grass with only mole crickets. Despite no negative impacts from earthworms or mole crickets separately, earthworms plus mole crickets negatively impact several root parameters (e.g., length) suggesting an interaction between these two soil-dwelling invertebrates. Increased use of more target-selective insecticides in turfgrass may increase available prey. This work suggests that alternative prey, when present, may result in a negative impact on turfgrass roots from foraging omnivorous mole crickets.

KEY WORDS   plant insect interactions, *Eisenia fetida*, *Scapteriscus*, bermudagrass, feeding ecology

The tawny mole cricket, *Scapteriscus vicinus* Scudder, and the southern mole cricket, *S. borellii* Giglio-Tos, are among the most significant turf pests in the southeastern United States (Walker and Nickle 1981). These inadvertently introduced species can cause severe damage to turfgrass by direct feeding and subsurface tunneling (Hayslip 1943, Potter 1998). Several studies (Taylor 1979, Matheny 1981, Fowler et al. 1985, Silcox and Brandenburg 2011) have used dissection to identify the gut contents and to interpret dietary patterns of field-collected mole crickets. Based on these studies, *S. vicinus* was considered herbivorous primarily because of plant material in their alimentary tracts, whereas *S. borellii* was deemed carnivorous because animal tissues were more prevalent. However, both species feed on plant material and animal tissues and should therefore be considered omnivorous.

Both species are considered destructive because their excessive subsurface activity uproots plants, dehydrates the roots, and may kill a turf stand (Hayslip 1943, Potter 1998). Their tunneling activity is related to soil moisture (Hayslip 1943, Ulagaraj 1975, Hertl and Brandenburg 2002); soil type (Reinert 1983, Villani et al. 2002); time of year (Hertl and Brandenburg 2002, Adjei et al. 2003); and also hypothetically related to their dietary needs (Villani et al. 2002). The more intensive tunneling at the root-soil interface is attributed to herbivory from *S. vicinus*, whereas the extensive branching of the tunnel below ground allegedly indicates a carnivorous habit of *S. borellii* (Villani et al. 2002).

The impact of omnivorous pests on the host plants can vary according to the availability of plant and animal prey (Coll and Guershon 2002, Rosenheim et al. 2004). During periods of limited prey, omnivores typically switch to herbivory (Gillespie and McGregor 2000). Likewise, when prey is abundant, omnivores may reduce consumption of plant material (Agrawal et al. 1999). Using omnivorous *Scapteriscus* mole crickets as a model system, we determined how the availability of prey would impact subsequent damage to turfgrass by omnivorous mole crickets.

Materials and Methods

Sources of Insects. Adult female *S. borellii* were field collected using an acoustic trap with a modified pool

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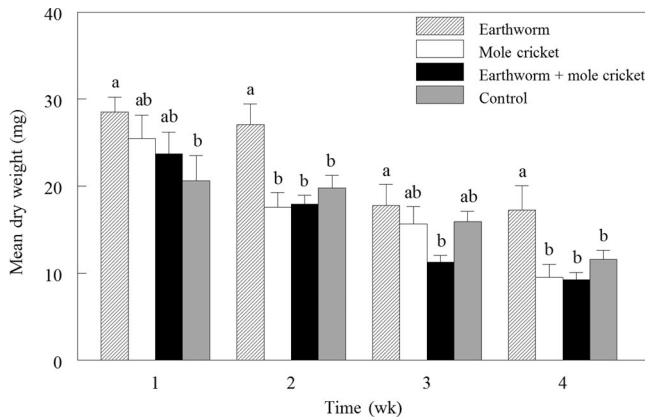
Fig. 1. Mean dry weight of hybrid bermudagrass clippings produced over a 4-wk period when infested with adult *S. borellii* in the presence and absence of earthworm prey. There were six replicates with four treatments (24 total). Means followed by the same letter are not significantly different from each other within each week ($P < 0.05$; MIXED; LSmeans [SAS Institute 2008]).

design (Thompson and Brandenburg 2004) from 1 to 5 June 2011 from the driving range at Grand National Golf Course in Opelika, AL. Adult *S. vicinus* were collected by soap flush (30 ml of Joy [Procter & Gamble, Cincinnati, OH] liquid detergent in 8 liters of water) on 25 October 2011 on tee boxes at Great Southern Golf Club in Gulfport, MS. Collected individuals were transferred immediately into 473-ml plastic cups (Dart, Mason, MI) with ventilated lids containing autoclaved, moistened sand. They were provided a mixed diet of organic carrot strips (Inter-American Products, Cincinnati, OH) and freeze-dried mealworms (Coleoptera: Tenebrionidae; Fluker Farms, Port Allen, LA), and held in a growth chamber (Percival Scientific Inc., Perry, IA) at 27°C with a photoperiod of 14:10 (L:D) h before the experiments.

Source of Turfgrass. Hybrid bermudagrass 'Tifway 419′, *Cynodon dactylon* (L.) Pers × *C. transvaalensis* Burtt-Davy, plugs were harvested from the Auburn University Turf Research Unit, Auburn, AL and transplanted to PVC arenas (15 cm in diameter by 38 cm tall) in April 2010 for the experiment with *S. borellii* and in July 2011 for the experiment with *S. vicinus.* Arenas were designed similarly to those by Braman et al. (2000). Each arena was covered at the bottom with a plastic petri dish lid (15 cm in diameter by 1 cm tall, VWR International, Radnor, PA); open on the top; and filled with the same volume of fine sand. Grasses were watered daily; fertilized weekly with a solution containing 250 ppm of Peters 20N-10P-20K (Scotts-Sierra Horticultural Products, Marysville, OH); and cut weekly to a height of 5 cm.

Experiment Setup. Greenhouse experiments were conducted with *S. borellii* and *S. vicinus* adults from 23 June to 14 July 2011 and from 14 December 2011 to 11 January 2012, respectively. For each assay, the following treatments were tested: grass only, grass with earthworms, grass with mole crickets, and grass with earthworms plus mole crickets. Arenas with mole crickets were infested with one adult mole cricket. For treatments with earthworms, 10 living *Eisenia fetida*

Savigny (≈4–6 cm long, 1.5 mm thick; Uncle Jim's Worm Farm, Spring Grove, PA) initially were added to each arena. Weekly, three more worms from the same source were added to each arena to supplement prey. Each treatment was replicated six times. All arenas were covered with aluminum insect screen (Phifer, Tuscaloosa, AL) to prevent the escape of mole crickets. The average day temperature was monitored with a temperature data logger (HOBO U23 Pro v2, Onset Computer, Bourne, MA). Watering and fertilization regimes were maintained as described previously.

Impact of treatments on damage to turfgrass was assessed using top growth and root growth measurements similar to Braman et al. (2000). Top growth of bermudagrass was clipped weekly to a height of 5 cm, beginning 1 wk after mole crickets were introduced into the arenas. Clippings were collected into labeled glass petri dishes and oven dried at 70°C for 4 h, then weighed, and weights recorded. After 4 wk, each arena was sampled to assess the survival of mole crickets, percentage survival of earthworms, and the growth and mass of roots. The intact root profile was harvested by removing the petri dish lid at the bottom, gently lifting the PVC cylinder, and washing away the sand. The above ground parts of bermudagrass were removed and the remaining roots were placed in plastic zipper bags (SC Johnson, Racine, WI). Freshly harvested roots immediately were transported to the Plant Pathology Laboratory, Auburn, AL for scanning and measuring using WinRHIZO system (Regent Instrument, Canada). This image analysis software determines total root length, surface area, volume, and other architectural characteristics. After this process, roots were oven dried at 70°C for 4 h, then weighed.

A repeated measures analysis of variance (ANOVA) was performed using the MIXED procedure to determine the effect of different treatments on dry weight of bermudagrass clippings produced within 4 wk, and treatment means within each week were separated using LSmeans. Root measurement analysis was con-

ducted using the GLM procedure with LSmeans for pairwise mean comparisons. Percentages of survival of earthworms were compared between treatments by two-sample *t*-tests. Data for each species were analyzed separately. All statistical analyses were conducted using SAS 9.2 (SAS Institute 2008).

Results

Experiment with *S. borellii*. All *S. borellii* adults remained alive after 4 wk. In the earthworm treatment, $23.68 \pm 5.73\%$ of the earthworms were recovered compared with $6.14 \pm 2.11\%$ in the earthworm and mole cricket treatment ($t = 2.87$; df $= 10$; $P = 0.0165$). The minimum and maximum air temperatures within 4 wk were 22 and 33°C, respectively.

Top growth of hybrid bermudagrass decreased weekly in all treatments (Fig. 1). There were significant main effects of time ($F = 45.2$; df $= 3$, 60; $P < 0.0001$); treatment ($F = 4.79$; df $= 3$, 20; $P = 0.0113$); and a significant treatment × time interaction ($F = 3.52$; df $= 9$, 60; $P = 0.0015$). No treatment resulted in significantly less top growth than the controls. At 2 and 4 wk, top growth was significantly greater in the earthworm treatment. At 1 and 3 wk, top growth in the earthworm treatment was significantly greater than the control and the earthworm plus mole cricket treatment, respectively (Fig. 1).

Overall, the root growth of bermudagrass infested with adult *S. borellii* was not influenced by the presence or absence of earthworm prey (Table 1). Root length, surface area, projecting area, and number of forks were reduced significantly relative to the controls only when prey was present (mole cricket and earthworm treatment; Table 1). Within each affected parameter, the earthworm treatment was significantly greater than either treatment with mole crickets, but not different from the control.

Experiment with *S. vicinus*. At 3 wk, one *S. vicinus* adult died on the surface of the arena in the earthworm plus mole cricket treatment. This observation was excluded before data analysis. At the end of the experiment, $46.49 \pm 5.16\%$ of the earthworms were recovered in the earthworm only treatment compared with $47.37 \pm 7.81\%$ in the earthworm plus mole cricket treatment ($t = -0.09$; df $= 7.2$; $P = 0.9278$). The minimum and maximum air temperatures within 4 wk were 20 and 30°C, respectively.

Weekly top growth of hybrid bermudagrass was reduced after 4 wk (Fig. 2; $F = 17.40$; df $= 3$, 59; $P < 0.0001$ ANOVA for repeated measures). There was a significant treatment effect ($F = 6.27$; df $= 3$, 20; $P = 0.0036$) but not significant time × treatment interaction ($F = 0.89$; df $= 9$, 59; $P = 0.5364$). There was no significant difference in top growth until after 2 wk when top growth in the controls was significantly greater than either treatment with mole crickets. At 3 and 4 wk, top growth in control was only significantly greater than the earthworm plus mole cricket treatment (Fig. 2).

Overall, root growth of bermudagrass infested with adult *S. vicinus* was not influenced by the absence of

Table 1. Bermudagrass root measurements after 4-wk exposure to adult *S. borellii* and earthworm prey treatments

Treatment	Length (cm)	Avg diam (mm)	Surface area (cm²)	Projecting area (cm²)	Vol (cm³)	No. tips	No. forks	No. cross	Dry weight (g)
						Mean (±SEM) values of root measurements ($N = 6$)			
Earthworm	3,011.61 ± 275.56a	0.7 ± 0.03a	671.78 ± 78.2a	213.84 ± 24.89a	12.07 ± 1.92a	15,212.17 ± 2,274.93a	50,227.67 ± 6,177.63a	7,330 ± 1,166.44a	1.78 ± 0.38a
Mole cricket	2,213.2 ± 232.79bc	0.75 ± 0.05a	505.51 ± 21.66bc	160.91 ± 6.9bc	9.4 ± 0.41a	15,367 ± 1,919.11a	36,932.33 ± 2,966.54bc	5,549 ± 767.97ab	1.27 ± 0.11ab
Earthworm + mole cricket	1,864.94 ± 126.59c	0.79 ± 0.1a	452.81 ± 45.98c	144.13 ± 14.63c	9.47 ± 2.27a	12,842.83 ± 1,456.31a	31,886.67 ± 2,027.94c	4,681.5 ± 447.93b	1.07 ± 0.17b
Control	2,699.65 ± 142.4ab	0.77 ± 0.05a	641.88 ± 29.03ab	204.32 ± 9.24ab	12.37 ± 1.12a	14,762 ± 1,733.8a	48,431.83 ± 2,908.06ab	7,542.67 ± 665.45ab	1.41 ± 0.06ab
F value	4.97	0.29	3.92	3.92	0.87	0.35	4.38	2.42	1.93
P value	0.0137	0.833	0.03	0.03	0.4783	0.7908	0.0211	0.1069	0.1687

Means presented are actual means. Within a column, means ± SEM followed by the same letter are not significantly different from each other ($P < 0.05$; GLM; LSmeans [SAS Institute 2008]).
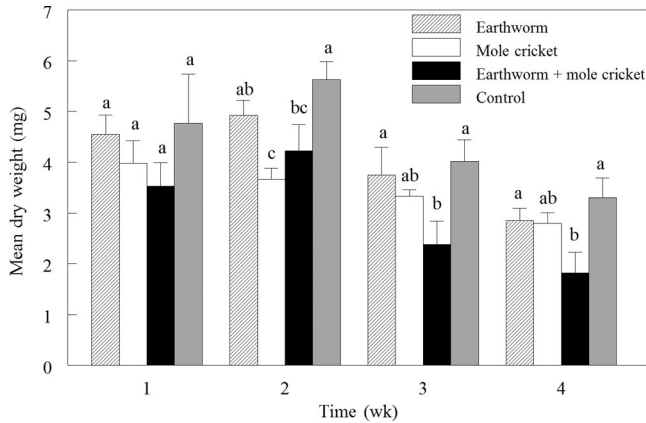
Fig. 2. Mean dry weight of hybrid bermudagrass clippings produced over a 4-wk period when infested with adult *S. vicinus* in the presence and absence of earthworm prey. There were six replicates with four treatments (24 total). One mole cricket in the earthworm plus mole cricket treatment died after 3 wk, and this observation was not used at 4 wk. Means followed by the same letter are not significantly different from each other within each week ($P < 0.05$; MIXED; LSmeans [SAS Institute 2008]).

earthworm prey (Table 2). All root measurements, except average diameter, were reduced approximately in half (relative to controls) when earthworms and mole crickets were present but not when mole crickets alone were present. The number of forks and cross were significantly affected by treatment. However, there were marginally significant differences ($P \geq 0.06$) in root length, surface area, projecting area, and volume (Table 2).

Discussion

Previous studies have reported omnivory, consumption of plant and soil-dwelling prey, by *S. borellii* and *S. vicinus* (Hayslip 1943, Taylor 1979, Matheny 1981, Fowler et al. 1985, Silcox and Brandenburg 2011). They also implied that *S. vicinus* should have greater pest status, because of its more herbivorous feeding habit, compared with the principally carnivorous *S. borellii.* Although *S. borellii* prefers a habitat of bare sand (Reinert 1983, Schuster and Price 1992) and primarily feeds on animal material even in grass habitat (Matheny 1981), there is potential for severe damage to turfgrass by its excessive tunneling activity if few or no alternative food sources are available (Schuster and Price 1992). In the current study, predation of earthworms by either species of mole crickets could not be verified. Recovery of earthworms, however, was similar when confined with *S. vicinus* but was significantly reduced when confined with *S. borellii.* A large *S. borellii* nymph (with wingpads) is able to cut off a living earthworm by using its mouthparts and immediately consume the prey (Y. X., unpublished data). We are therefore reasonably certain that *S. borellii* consumed the alternate prey but this isn't likely for *S. vicinus.*

The results of the current study indicate that the presence of prey does not affect top growth or root parameters of bermudagrass relative to mole crickets alone. Walker and Dong (1982) conducted similar

tests to quantify the damage to coastal bermudagrass (variety unnamed) and bahiagrass (*Paspalum notatum* Flueggé 'Pensacola') by adult *S. borellii* and *S. vicinus* over a 3-mo period. Neither adult *S. borellii* supplemented with dog food (21% protein) or starved (no alternative food provided) had significant effects on stand or forage production in either grass, even though extensive tunneling was observed in the coastal bermudagrass. Conversely, adult *S. vicinus* reduced the yield of bermudagrass slightly, especially when starved. With bahiagrass, however, 19% of plugs were lost when *S. vicinus* was provided supplemental food compared with 88% loss when no supplemental food was provided (Walker and Dong 1982). In the current study, however, neither mole cricket species had measurable effects on top growth of bermudagrass. Braman et al. (2000) observed similar results with *S. vicinus.* Under experimental conditions similar to our study, there was no significant reduction in top growth of various cultivars of bermudagrass.

Compared with the control plants, neither species of mole cricket negatively affected the various measured root parameters (Tables 1 and 2). This was unexpected, considering that mole crickets confined with turfgrass under similar conditions might reduce root dry weight relative to noninfested controls, particularly with *S. vicinus* (Braman et al. 2000). Also, bermudagrass in the southeastern United States is commonly damaged by mole crickets on golf courses and in home lawns (Potter 1998). *Scapteriscus borellii* and *S. vicinus* in captivity complete most of the excavation for their underground tunnel structure within ≈18 d. After that time, the tunnel structure typically was not expanded (Villani et al. 2002). When the grasses were harvested in the current study, both species had well-developed tunnels (Y. X., unpublished data). Root data were not collected over time to be able to determine if there were short-term reductions during the excavation of the tunnel system. However, this may explain the significant reduction in top

Table 2. Bermudagrass root measurements after 4-wk exposure to adult *S. vicinus* and earthworm prey treatments.

Treatment	Length (cm)	Avg diam (mm)	Surface area (cm²)	Projecting area (cm²)	Vol (cm³)	No. tips	No. forks	No. cross	Dry weight (g)
	Mean (± SEM) values of root measurements ($N = 6$)								
Earthworm	2,057.98 ± 222.4ab	0.46 ± 0.03a	292.96 ± 32.22a	93.25 ± 10.26a	3.37 ± 0.44a	13,671.5 ± 3,338.82ab	29,926 ± 3,301.16a	5,921.5 ± 713.08a	0.52 ± 0.05a
Mole cricket	1,612.95 ± 297.88ab	0.45 ± 0.02a	231.05 ± 47.33ab	73.55 ± 15.06ab	2.65 ± 0.61ab	11,747.67 ± 1,838.51ab	23,675.33 ± 4,515.23ab	4,490.17 ± 834.92ab	0.39 ± 0.09ab
Earthworm + mole cricket[a]	1,259.87 ± 177.35b	0.4 ± 0.02a	156.8 ± 21.49b	49.91 ± 6.84b	1.57 ± 0.24b	7,752.6 ± 1,974.06b	16,526.6 ± 2,052.44b	3,408.2 ± 394.6b	0.27 ± 0.04b
Control	2,238.04 ± 250.65a	0.43 ± 0.02a	300.05 ± 29.23a	95.51 ± 9.3a	3.24 ± 0.34a	15,382.33 ± 2,584.97a	31,139.83 ± 2,466.13a	6,122.5 ± 476.78a	0.52 ± 0.06a
F value	3.02	1.21	3.19	3.19	2.86	1.89	4.06	4.19	2.37
P value	0.0652	0.3421	0.0565	0.0565	0.0749	0.1782	0.0287	0.026	0.1143

Means presented are actual means. Within a column, means ± SEM followed by the same letter are not significantly different from each other ($P < 0.05$; GLM; LSmeans [SAS Institute 2008]).

[a] Only five observations were used (one observed mole cricket died after 3 wk in this treatment).

growth 2 wk after *S. vicinus* were introduced into the arenas, but not thereafter (Fig. 2).

The earthworm with mole cricket treatment interestingly had lower top growth than the earthworm only treatment at weeks 3 and 4 for *S. vicinus* and from week 2 to 4 for *S. borellii* (Figs. 1 and 2). However, this decrease in top growth cannot be attributed only to mole crickets because infestation with mole crickets can result in an increased top growth (Braman et al. 2000). On most of those same dates, top growth in the mole cricket treatment was not significantly different from the earthworm treatment. Coupled with this, the earthworm only treatment was often numerically or even significantly greater than the grass only controls. Likewise, several root parameters (length, surface area, number of forks, number of cross roots) were significantly reduced in grasses with mole crickets and earthworms compared with those with only earthworms. The difference may be exaggerated by the increase in root and shoot growth in the earthworm only control or perhaps there is an interaction when earthworms and mole crickets are combined. This synergy may have resulted from increased subsurface activity of mole crickets in the presence of another soil organism. Earthworms (Edwards 2004) and mole crickets (Potter 1998) both cause soil disturbance through their subterranean digging, and earthworm castings are known to increase growth responses of turfgrass (Potter 1998).

Since the late 1990s, new classes of turf insecticides have been released that are reduced-risk and have less impact on nontarget invertebrates, including earthworms (Potter et al. 1990, Kunkel et al. 1999). These new soil insecticides have more favorable toxicological profiles (Held and Potter 2012) resulting in a more active and diverse microfaunal community that potentially sustains alternative prey for mole crickets. Earthworms can be locally abundant in greens and tees, especially in the spring and fall (Potter 1998), and mole crickets may forage into these areas to access earthworm prey. The overlap of these two organisms in turfgrass can be completely coincidental; however, this study suggests a possible negative interaction. Although speculative, earthworm populations in bermudagrass may influence the abundance of mole crickets and the severity of root damage.

Acknowledgments

References Cited

Adjei, M. B., J. H. Frank, and C. S. Gardner. 2003. Survey of pest mole crickets (Orthoptera: Gryllotalpidae) activity on pasture in south-central Florida. Fla. Entomol. 86: 199–205.

Agrawal, A. A., C. Kobayashi, and J. S. Thaler. 1999. Influence of prey availability and induced host-plant resistance on omnivory by western flower thrips. Ecology 80: 518–523.

Braman, S. K., R. R. Duncan, W. W. Hanna, and W. G. Hudson. 2000. Evaluation of turfgrass for resistance to mole crickets (Orthoptera: Gryllotalpidae). Hort. Sci. 35: 665–668.

Coll, M., and M. Guershon. 2002. Omnivory in terrestrial arthropods: mixing plant and prey diets. Annu. Rev. Entomol. 47: 267–297.

Edwards, C. A. 2004. Earthworm ecology, 2nd ed. CRC, Boca Raton, FL.

Fowler, H. G., M. T. Vieira De Camargo, and L. Crestana. 1985. Feeding habits of Brazilian mole crickets (Orthoptera: Gryllotalpidae: *Scapteriscus spp.* and *Neocurtilla sp.*). J. Econ. Entomol. 78: 1076–1078.

Gillespie, D. R., and R. R. McGregor. 2000. The functions of plant feeding in the omnivorous predator *Dicyphus hesperus:* water places limits on predation. Ecol. Entomol. 25: 380–386.

Hayslip, N. C. 1943. Notes on biological studies of mole crickets at Plant City, Florida. Fla. Entomol. 26: 33–46.

Held, D. W., and D. A. Potter. 2012. Prospects for managing turfgrass pests with reduced chemical inputs. Annu. Rev. Entomol. 57: 329–354.

Hertl, P. T., and R. L. Brandenburg. 2002. Effect of soil moisture and time of year on mole cricket (Orthoptera: Gryllotalpidae) surface tunneling. Environ. Entomol. 31: 476–481.

Kunkel, B. A., D. W. Held, and D. A. Potter. 1999. Impact of halofenozide, imidacloprid, and bendiocarb on beneficial invertebrates and predatory activity in turfgrass. J. Econ. Entomol. 92: 922–930.

Matheny, E. L. 1981. Contrasting feeding habits of pest mole cricket species. J. Econ. Entomol. 74: 444–445.

Potter, D. A. 1998. Destructive turfgrass insects: biology, diagnosis, and control. Ann Arbor Press, Chelsea, MI.

Potter, D. A., M. C. Buxton, C. T. Redmond, C. G. Patterson, and A. J. Powell. 1990. Toxicity of pesticides to earthworms (Oligochaeta: Lumbricidae) and effect on thatch degradation in Kentucky bluegrass turf. J. Econ. Entomol. 83: 2362–2369.

Reinert, J. A. 1983. Foraging sites of the southern mole cricket, *Scapteriscus acletus* (Orthoptera: Gryllotalpidae). Proc. Fla. State Hortic. Soc. 96: 149–151.

Rosenheim, J. A., R. E. Goeriz, and E. F. Thacher. 2004. Omnivore or herbivore? Field observation of foraging by *Lygus hesperus* (Hemiptera: Miridae). Environ. Entomol. 33: 1362–1370.

SAS Institute. 2008. SAS/STAT(R) 9.2 user's guide, 2nd ed. SAS Institute, Cary, NC.

Schuster, D. J., and J. F. Price. 1992. Seedling feeding damage and preference of *Scapteriscus spp.* mole crickets (Orthoptera: Gryllotalpidae) associated with horticultural crops in west-central Florida. Fla. Entomol. 75: 115–119.

Silcox, D. E., and R. L. Brandenburg. 2011. Gut content analysis of southern and tawny mole crickets (Orthoptera: Gryllotalpidae). Fla. Entomol. 94: 117–118.

Taylor, T. R. 1979. Crop contents of two species of mole crickets, *Scapteriscus acletus* and *S. vicinus* (Orthoptera: Gryllotalpidae). Fla. Entomol. 62: 278–279.

Thompson, S. R., and R. L. Brandenburg. 2004. A modified pool design for collecting adult mole crickets (Orthoptera: Gryllotalpidae). Fla. Entomol. 87: 582–584.

Ulagaraj, S. M. 1975. Mole crickets: ecology, behavior, and dispersal flight (Orthoptera: Gryllotalpidae: *Scapteriscus*). Environ. Entomol. 4: 265–273.

Villani, M. G., L. L. Allee, L. Preston-Wilsey, N. Consolie, Y. Xia, and R. L. Brandenburg. 2002. Use of radiography and tunnel castings for observing mole cricket (Orthoptera: Gryllotalpidae) behavior in soil. Am. Entomol. 48: 42–50.

Walker, T. J., and N. Dong. 1982. Mole crickets and pasture grasses: damage by *Scapteriscus vicinus*, but not by *S. acletus* (Orthoptera: Gryllotalpidae). Fla. Entomol. 65: 300–306.

Walker, T. J., and D. A. Nickle. 1981. Introduction and spread of pest mole crickets: *Scapteriscus vicinus* and *S. acletus* reexamined. Ann. Entomol. Soc. Am. 74: 158–163.