Integrated Effects of Host Resistance and Insecticide Concentration on Survival of and Turfgrass Damage by the Fall Armyworm (Lepidoptera: Noctuidae)[1]

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Abstract The residual activity of six concentrations of chlorpyrifos, spinosad, and halofenozide on fall armyworm, *Spodoptera frugiperda* (J. E. Smith), as mediated by five warm-season turfgrass cultivars expressing varying levels of genetic resistance was evaluated in greenhouse trials. Similarly, varying concentrations of halofenozide were applied to six turfgrass cultivars in the field; mortality of neonate and third-instar fall armyworms was assessed. Reduced rates of chlorpyrifos resulted in lower fall armyworm survival on resistant zoysiagrass cultivars relative to that on bermudagrass or paspalum. In a separate trial when treated with spinosad, survival on the same zoysiagrasses was equal to or greater than that on more susceptible bermuda or paspalum. Reduced rates of halofenozide in another greenhouse trial resulted in lower survival on resistant zoysiagrasses at some concentrations at 7, but not at 14, days exposure compared to more susceptible grasses. In the field, at the full labeled rate of halofenozide, 100% mortality was observed regardless of turfgrass cultivar. Larval survival on the most susceptible turf, "TifEagle", was higher than that on the remaining turf cultivars at the intermediate rate applied. Larvae exposed to treated turf as third instars displayed a trend toward greater survival at intermediate rates on the two paspalums, "Sea Isle 1" and 561-79, while a trend toward lower survival was observed on "Palisades" and "Cavalier" zoysiagrasses. Factors potentially contributing to the variation in responses observed in the present study include different modes of action of insecticides, host plant resistance mechanisms, differential foliar consumption rates and insecticide dose in relation to body weight. Development of management guidelines for pest management practitioners must address the complexity of potential interactions and may require "case by case" evaluation.

Key Words Turfgrass, host plant resistance, integrated pest management, fall armyworm

Potential synergistic interactions between pest-resistant plants and reduced doses of insecticides offer benefits for agriculture and home landscapes that have yet to be fully realized. Failure to fully implement the strategy may, in part, be attributed to the inability to consistently predict the outcome of individual pest × host plant × insecticide interactions without empirical data. Different factors or combinations of factors such

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as pesticide mode of action, type and degree of host resistance, and insect feeding behavior may all affect the interaction (e.g., Verkerk and Wright 1996). In sod production, where narrow profit margins and dwindling pesticide availability make alternative pest management tactics increasingly attractive, unprecedented opportunities exist to implement truly integrated approaches that rely on information-intensive strategies. Currently, even integrated pest management strategies in use still rely primarily on single tactic technologies, mainly chemical. Effective integration of management approaches requires that more attention be given to the interaction and compatibility of various strategies (Wright and Verkerk 1995, Thomas 1999). Few studies have addressed the integrated effects of host plant resistance and pesticides for grasses. Green et al. (1999) determined that an increase in the proportion of Kentucky 31 (moderately resistant) tall fescue (*Festuca arundinacea* Schreb.) relative to Mojave (susceptible) and an application rate of the fungicide flutolanil acted additively to significantly suppress *Rhizoctonia* blight, but failed to limit the disease to acceptable levels. Hill et al. (1990) found that a three-quarter dose of chlorpyrifos, omethoate or triazophos resulted in a greater yield increase by an Italian ryegrass, *Lolium multiflorum* Lam., cultivar RvP compared with a more resistant perennial ryegrass (*L. perenne* L.) cultivar S24 reflecting the higher yield potential and susceptibility of RvP. Decision-making criteria and management plans that incorporate a thorough understanding of the tritrophic interactions characteristic of complex turfgrass systems (Braman et al. 2002a, Braman et al. 2003) will also require a case by case assessment of the potential host plant and insecticide interaction.

The fall armyworm, *Spodoptera frugiperda* (J. E. Smith), is an occasionally serious pest of turfgrass in the southeastern United States (Potter and Braman 1991). Nonpreference and antibiosis among warm season grasses has been observed for fall armyworm in varying turfgrass species and cultivars (Wiseman et al. 1982, Chang et al. 1985, 1986, Wiseman and Duncan 1996, Reinert et al. 1994, 1997, 1998, Braman et al. 2000a, Reinert and Engelke 2000, Braman et al. 2002b). Some turfgrass cultivars recently identified as demonstrating resistance to fall armyworm have also demonstrated antibiosis and/or tolerance to other turfgrass pests including two lined spittlebug, *Prosapia bicincta* (Say) (Shortman et al. 2002), zoysiagrass mite, *Eriophyes zoysiae* (Reinert et al. 1993) and mole crickets, *Scapteriscus* spp. (Braman et al. 1994, 2000b).

Turfgrasses showing varying levels of resistance to fall armyworm and other pests were also evaluated for extrinsic resistance characteristics where it was determined that occurrence and performance of predators was influenced by turfgrass type and resistance status (Braman et al. 2003). Research reported here examined the relationship between these same turfgrasses, reduced rates of three insecticides with differing modes of action, and survival of and plant damage by the fall armyworm.

Materials and Methods

Insects and plants used in experiments. *Spodoptera frugiperda* used in experiments described herein were from a colony maintained on commercial diet (Bioserv, Inc. Frenchtown, NJ). The armyworm colony was initiated with eggs obtained from the USDA/ARS Crop Protection and Management Research Unit (Tifton, GA) in 1994 and supplemented annually with new material from the USDA colony. Bermudagrasses, seashore paspalums and zoysiagrasses were maintained in a greenhouse in 15.2 cm diam. pots. Cultivars evaluated were "Palisades" and "Cavalier" zoysiagrasses (*Zoy-*

sia japonica von Steudel and *Z. matrella* (L.) Merrill); "TifSport" and "TifEagle" bermudagrasses (*Cynodon dactylon* (L.) × *C. transvaalensis* (Burtt-Davy)); and "Sea Isle 1" paspalum grasses (*Paspalum vaginatum* Swartz). Previous work demonstrated that fall armyworm survival should be greatest on "TifEagle" bermudagrass, followed by paspalum grasses and "TifSport" hybrid bermudagrass, and least on the two zoysiagrasses (Braman et al. 2000b, 2002a). Day length was 14 h, maintained using high intensity, metal halide light. Grasses were grown in granular calcinated clay (Turface™, Applied Industrial Materials, Corp., Deerfield, IL). Pots were watered daily and fertilized once per week with a solution containing 250 ppm NPK (Peters 20-20-20, Scotts-Sierra Horticultural Products Corp., Maryville, OH). Grasses were sheared weekly and maintained at 8cm height.

Effects of cultivar and insecticide concentration on survival of and damage by fall armyworm in the greenhouse. Individual tillers of each turfgrass cultivar were transplanted into 300- ml plastic containers of turface and allowed to establish for 3 wks prior to evaluation. Six concentrations of each of three insecticides were applied. Insecticides were chlorpyrifos (Chlorpyrifos Pro 2™, Micro Flo Company, Memphis, TN), halofenozide (Mach 2™, Dow AgroSciences, Indianapolis, IN) and spinosad (Conserve™, Dow AgroSciences, Indianapolis, IN). Applications were made using a CO_2 powered backpack sprayer with a Meter Jet Gun (Spray Systems Co., Wheaton, IL). Space constraints did not allow evaluation of all three insecticides simultaneously. Three separate sequential trials were conducted, one for each insecticide type. Larval survival and turfgrass top growth, measured as fresh and dry weights were compared among turfgrass cultivars for each of the six insecticide concentrations. Each turfgrass cultivar × insecticide concentration was replicated 18 times in a randomized complete block design. Pesticides were applied to grasses in cups at 0800 h. Four, 3-day-old fall armyworm larvae were placed in each cup between 1000 and 1200 h the same day and kept confined to the cups using opaque nylon screens. Numbers of larvae surviving in each cup were counted at days 3, 7 and 14 for chlorpyrifos and at days 7 and 14 for the slower-acting halofenozide and spinosad. After 14 days, plants were clipped at the base, weighed, placed in paper bags, oven-dried and weighed again.

Effects of cultivar and halofenozide concentration on survival of fall armyworm in the field. Turfgrass species and cultivars representing a range of resistance to fall armyworms 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; TifSport and TifEagle bermudagrasses; and 561-79 (*Paspalum vaginatum* Swartz) and Sea Isle 1 paspalum grasses. Turfgrass cultivars were arranged in a randomized complete block design with six replications. Plots were irrigated as neccessary to prevent wilt symptoms. Plots were fertilized using 13-13-13 (N-P-K) at 368.4 kilograms per ha. 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. Fifteen *S. frugiperda* larvae were introduced into 144 cages, each constructed from a length of 15.2 cm diam polyvinyl chloride (PVC) pipe inserted 5 cm into the soil in each turf plot. Halofenozide (Mach 2™) was applied at varying rates using a CO_2 powered backpack sprayer with a Meter Jet Gun 2 h prior to introduction of larvae. Larvae were confined to the cages using nylon screen. Cages were removed and plots were sampled after 10 d. Larvae were counted using a standard soap flush sampling method (30 ml liquid dishwashing soap per 3.8 1 water) to bring the larvae out of the thatch layer.

Data analysis. Data were transformed using a square root transformation prior to being subjected to analysis of variance using the GLM procedure of SAS (SAS Institute 1985). Mean separation was by Fisher's protected least significant difference test (Sokal and Rohlf 1981).

Results

Effects of cultivar and insecticide concentration on survival of and damage by fall armyworm in the greenhouse. Significant turfgrass cultivar and concentration effects occurred on larval survival 3, 7 and 14 d after exposure to chlorpyrifos-treated grasses (Table 1).There was also a significant interaction at 7 and 14 d. Cultivar, pesticide concentration and the interaction were also significant for fresh and dry plant weights. By 14 days post-application, no significant cultivar effects were evident in larval survival on untreated plants, the two lowest or on plants treated with the highest concentration. Mortality was 97.5 to 100% at the highest concentration (Table 2). At 3 d post-treatment, intermediate concentrations resulted in enhanced mortality on cultivars previously demonstrating resistance to fall armyworm; Palisades and Cavalier zoysiagrasses and, to a lesser extent, TifSport bermudagrass (Table 2). Conversely, survival on the very susceptible TifEagle was significantly higher than on other grasses at the highest chlorpyrifos concentration at 3 d post-application. By 7 d post-application no significant effect of cultivar on larval survival was evident at the three highest concentrations; however, at the two lowest concentrations, the least fall armyworm survival was observed on the more resistant Cavalier and Palisades (Table 2). Grass top growth on untreated plants, measured as fresh and as dry weight of clippings at the end of the exposure period, was significantly greater for the two most resistant grasses Cavalier and Palisades zoysiagrasses (Table 3). These two resistant grasses also began to show enhanced growth relative to the untreated plants of the same cultivars in the second lowest chlorpyrifos concentration applied in fresh and dry weight comparisons.

When grasses were treated with spinosad, pesticide concentration and the concentration by cultivar interaction were significant at day 7 (Table 1). At day 14, cultivar concentration and the interaction were significant for larval survival, as well as fresh and dry weight of grasses. Spinosad applications resulted in 100% mortality at the highest concentration applied (Table 4): Fewer cultivar effects were evident within each pesticide concentration comparison than were observed in the prior trial with chlorpyrifos. In contrast with what was observed with chlorpyrifos, mortality at low concentrations of spinosad was not significantly higher on the more resistant grasses in comparison with the more susceptible TifEagle and Sea Isle 1. In fact, a slight trend occurred toward increased mortality on susceptible cultivars compared with the more resistant zoysiagrasses, possibly indicating greater ingestion of effective dose on more susceptible plant material (Table 4). Again, when plants were not treated, top growth was greatest for more resistant Cavalier and Palisades (Table 5). TifEagle, TifSport and Sea Isle 1 demonstrated greater fresh and/or dry weights at the three highest spinosad concentrations than Cavalier or Palisades in contrast to what was observed following chlorpyrifos application in the previous trial.

Application of halofenozide also resulted in significant cultivar, concentration and interaction effects for larval survival and grass weights (Table 1). In this greenhouse

Table 1. Analysis of variance table for *Spodoptera frugiperda* survival and grass top growth following exposure to varying concentrations of chlorpyrifos, spinosad or halofenozide applied to different turfgrass cultivars with varying resistance to fall armyworm

	3-Day post application			7-Day post application			14-Day post application			Grass fresh weight			Grass dry weight		
Source	F	DF	P	F	DF	P	F	DF	P	F	DF	P	F	DF	P
Chlorpyrifos															
Rep	3.52	17	0.0001	2.94	17	0.0001	8.12	17	0.0001	6.56	17	0.0001	5.46	17	0.0001
Cultivar	7.77	4	0.0001	6.81	4	0.0001	25.79	4	0.0001	23.24	4	0.0001	31.10	4	0.0001
Concentration	163.17	5	0.0001	147.91	5	0.0001	110.51	5	0.0001	95.52	5	0.0001	88.52	5	0.0001
Cultivar X concentration	1.11	20	.3399	2.15	20	0.0001	6.90	20	0.0001	7.30	20	0.0001	4.75	20	0.0001
Spinosad															
Rep				1.69	17	0.0418	1.80	17	0.0374	2.71	17	0.003	5.94	17	0.0001
Cultivar				0.23	4	0.9237	2.64	4	0.0367	17.32	4	0.0001	33.68	4	0.0001
Concentration				227.3	5	0.0001	75.40	5	0.0001	47.17	5	0.0001	136.69		0.0001
Cultivar X concentration				2.89	20	0.0001	1.67	20	0.0356	4.29	20	0.0001	14.47	20	0.0001
Halofenozide															
Rep				0.72	17	0.777	0.87	17	0.609	4.34	17	0.0001	1.69	17	0.0420
Cultivar				24.39	3	0.0001	5.14	3	0.0017	145.77	3	0.0001	42.38	3	0.0001
Concentration				41.47	5	0.0001	56.57	5	0.0001	144.47	5	0.0001	82.02	5	0.0001
Cultivar X concentration				1.54	15	0.089	2.27	15	0.0044	28.81	15	0.0001	10.64	15	0.0001

Table 2. Number of surviving *Spodoptera frugiperda* larvae of four initial larvae per rep (n = 18) when reared in a greenhouse on chlorpyrifos-treated turfgrasses expressing varying levels of host plant resistance

	Chlorpyrifos 2 concentration in ml formulation per 400 ml water					
Turf cultivar	0.000	0.001	0.030	0.090	0.270	0.810
	Mean number of surviving larvae per rep					
			3-day post-treatment			
TifEagle	3.3 ± 0.2a	3.0 ± 0.2a	2.8 ± 0.2a	1.8 ± 0.2ab*	1.2 ± 0.3a*	0.7 ± 0.3a*
TifSport	3.0 ± 0.2a	3.0 ± 0.2a	2.7 ± 0.2a	1.5 ± 0.2b*	0.8 ± 0.2a*	0.0 ± 0.0b*
Sea Isle 1	3.2 ± 0.1a	2.8 ± 0.2a	2.5 ± 0.3ab	2.2 ± 0.2a*	0.9 ± 0.3a*	0.1 ± 0.1b*
Cavalier	2.9 ± 0.2a	2.8 ± 0.2a	1.8 ± 0.3c*	1.2 ± 0.3b*	0.9 ± 0.3a*	0.0 ± 0.0b*
Palisades	2.7 ± 0.3a	2.6 ± 0.2a	1.9 ± 0.3bc	1.3 ± 0.3b*	0.7 ± 0.2a*	0.2 ± 0.2b*
			7-day post-treatment			
TifEagle	2.7 ± 0.2a	2.3 ± 0.2a	1.3 ± 0.2ab	0.4 ± 0.1a*	0.8 ± 0.2a*	0.2 ± 0.1a*
TifSport	1.6 ± 0.3b	2.0 ± 0.2a	1.8 ± 0.2a	0.4 ± 0.3a*	0.7 ± 0.2a*	0.0 ± 0.0a*
Sea Isle 1	2.0 ± 0.2b	2.3 ± 0.2a	1.3 ± 0.3ab*	0.9 ± 0.2a*	0.5 ± 0.1a*	0.1 ± 0.1a*
Cavalier	1.5 ± 0.2b	1.8 ± 0.2ab	0.8 ± 0.2b*	0.3 ± 0.1a*	0.3 ± 0.1a*	0.0 ± 0.0a*
Palisades	1.7 ± 0.2b	1.3 ± 0.2b	0.8 ± 0.2b*	0.3 ± 0.1a*	0.2 ± 0.1a*	0.0 ± 0.0a*
			14-day post-treatment			
TifEagle	1.0 ± 0.0a	0.9 ± 0.1a	0.9 ± 0.1a	0.4 ± 0.1bc*	0.3 ± 0.1a*	0.1 ± 0.1a*
TifSport	1.0 ± 0.1a	1.2 ± 0.1a	1.0 ± 0.1a	0.5 ± 0.1b*	0.2 ± 0.1ab*	0.0 ± 0.0a*
Sea Isle 1	1.1 ± 0.1a	1.0 ± 0.1a	0.7 ± 0.1a*	0.7 ± 0.1a*	0.1 ± 0.1ab*	0.1 ± 0.1a*
Cavalier	1.0 ± 0.1a	1.0 ± 0.1a	0.4 ± 0.1a*	0.3 ± 0.1c*	0.0 ± 0.0b*	0.0 ± 0.0a*
Palisades	1.1 ± 0.1a	1.0 ± 0.1a	0.8 ± 0.2a	0.1 ± 0.1d*	0.0 ± 0.0b*	0.0 ± 0.0a*

Means within a column followed by the same letter are not significantly different by Fisher's protected least significant difference test ($P > 0.05$).

* Significantly ($P < 0.05$) lower larval survival than in the untreated (0.000 concentration) group within the same cultivar (row) by Fisher's protected least significant difference test.

trial, fall armyworm larval survival on the more resistant Cavalier was significantly less than that on the more susceptible cultivars at day seven for each pesticide concentration (Table 6), but by day 14 few differences in survival were apparent. Concentration effects on larval survival were most evident for the partially resistant TifSport bermudagrass where a significant reduction in survival compared to the untreated grasses occurred by day 7 at the lowest concentration applied. Effects on plant topgrowth were, however, most evident for Sea Isle 1 paspalumgrass with a significant increase in plant weight observed at intermediate concentration levels (Table 7).

Effects of cultivar and halofenozide concentration on survival of fall armyworm in the field. When fall armyworm neonates were exposed to a ¼ X rate of halofenozide in field plots, turfgrass taxa influenced larval survival ($F = 2.88$; df = 5,5; $P = 0.03$; Table 8). At the full labeled rate, 100% mortality was observed regardless of turfgrass cultivar. Larval survival on the most susceptible turf, TifEagle, was higher than that on the remaining turf cultivars at the intermediate rate applied. Larvae exposed to treated turf as third instars displayed a trend toward greater survival at intermediate rates on the two paspalums, Sea Isle 1 and 561-79 ($F = 2.24$; df = 5,5; $P = 0.07$; Table 8), while a trend toward lower survival was observed on Palisades and Cavalier zoysiagrasses.

Table 3. Average fresh and dry weights of grasses expressing varying levels of host plant resistance to *Spodoptera frugiperda* larvae when treated with various concentrations of chlorpyrifos and infested with larvae for two weeks in a greenhouse

	Chlorpyrifos 2 concentration in ml formulation per 400 ml water					
Turf Cultivar	0.000	0.001	0.030	0.090	0.270	0.810
	Fresh weight of grasses in grams					
TifEagle	0.0 ± 0.0c	0.03 ± 0.01b	0.06 ± 0.04b	0.2 ± 0.05b	0.5 ± 0.1bc*	0.4 ± 0.1b*
TifSport	0.04 ± 0.2bc	0.03 ± 0.2b	0.05 ± 0.03b	0.2 ± 0.05b	0.4 ± 0.1c*	0.6 ± 0.1b*
Sea Isle 1	0.0 ± 0.0c	0.0 ± 0.0b	0.2 ± 0.1b	0.2 ± 0.1b	1.0 ± 0.1a*	1.1 ± 0.1a*
Cavalier	0.1 ± 0.04a	0.2 ± 0.04a	0.5 ± 0.1a*	0.6 ± 0.1a*	0.4 ± 0.1c*	0.9 ± 0.1a*
Palisades	0.09 ± 0.04ab	0.2 ± 0.04a	0.5 ± 0.1a*	0.5 ± 0.1a*	0.6 ± 0.1b*	0.6 ± 0.1b*
	Dry weight of grasses in grams					
TifEagle	0.0 ± 0.00b	0.01 ± 0.01b	0.03 ± 0.02b	0.06 ± 0.02b*	0.20 ± 0.03a*	0.10 ± 0.02c*
TifSport	0.01 ± 0.01b	0.01 ± 0.00b	0.02 ± 0.01b	0.05 ± 0.01b	0.10 ± 0.02a*	0.30 ± 0.03b*
Sea Isle 1	0.00 ± 0.00b	0.00 ± 0.00b	0.05 ± 0.02b	0.06 ± 0.02b	0.20 ± 0.03a*	0.20 ± 0.03b*
Cavalier	0.04 ± 0.01a	0.10 ± 0.02a	0.20 ± 0.04a*	0.20 ± 0.04a*	0.20 ± 0.04a*	0.40 ± 0.05a*
Palisades	0.02 ± 0.01ab	0.04 ± 0.01a	0.20 ± 0.03a*	0.20 ± 0.03a*	0.20 ± 0.03a*	0.30 ± 0.02b*

Means within a column followed by the same letter are not significantly different by Fisher's protected least significant difference test ($P > 0.05$).

* Significantly ($P < 0.05$) greater plant weight than in the untreated (0.000 concentration) group within the same cultivar (row) by Fisher's protected least significant difference test.

Table 4. Number of surviving *Spodoptera frugiperda* larvae of four initial larvae per rep (n = 18) when reared in a greenhouse on spinosad (Conserve)-treated turfgrasses expressing varying levels of host plant resistance

	Spinosad (Conserve) concentration in ml formulation per 400 ml water					
Turf cultivart	0.000	0.000375	0.00075	0.00375	0.0375	0.375
	Mean number of surviving larvae per rep					
	7-day post-treatment					
TifEagle	2.8 ± 0.2a	2.8 ± 0.3a	0.7 ± 0.2a*	0.4 ± 0.2a*	0.1 ± 0.1b*	0.0 ± 0.0a*
TifSport	2.8 ± 0.2a	1.8 ± 0.2a	0.9 ± 0.2a*	0.2 ± 0.1a*	0.2 ± 0.1b*	0.0 ± 0.0a*
Sea Isle 1	3.0 ± 0.2a	2.2 ± 0.3a	0.5 ± 0.1a*	0.0 ± 0.0b*	0.1 ± 0.1b*	0.0 ± 0.0a*
Cavalier	2.7 ± 0.3a	2.1 ± 0.3a	0.5 ± 0.2a*	0.2 ± 0.1a*	0.3 ± 0.1b*	0.0 ± 0.0a*
Palisades	2.5 ± 0.3a	2.0 ± 0.2a	0.7 ± 0.2a*	0.1 ± 0.1b*	0.5 ± 0.1a*	0.0 ± 0.0a*
	14-day post-treatment					
TifEagle	1.1 ± 0.1a	0.6 ± 0.1b*	0.4 ± 0.1a*	0.4 ± 0.1a*	0.1 ± 0.1a*	0.0 ± 0.0a*
TifSport	0.7 ± 0.1a	0.7 ± 0.1b	0.5 ± 0.1a*	0.1 ± 0.1a*	0.1 ± 0.1a*	0.0 ± 0.0a*
Sea Isle 1	1.0 ± 0.1a	1.0 ± 0.1a	0.4 ± 0.1a*	0.1 ± 0.1a*	0.1 ± 0.1a*	0.0 ± 0.0a*
Cavalier	1.0 ± 0.2a	0.9 ± 0.1ab	0.4 ± 0.1a*	0.1 ± 0.1a*	0.3 ± 0.1a*	0.0 ± 0.0a*
Palisades	1.3 ± 0.1a	0.9 ± 0.1ab*	0.3 ± 0.1a*	0.1 ± 0.1a*	0.3 ± 0.1a*	0.0 ± 0.0a*

Means within a column followed by the same letter are not significantly different by Fisher's protected least significant difference test ($P > 0.05$).

* Significantly ($P < 0.05$) lower larval survival than in the untreated (0.000 concentration) group within the same cultivar (row) by Fisher's protected least significant difference test.

Discussion

Insecticide types could not be directly compared in this study because each insecticide was evaluated in a separate trial. However, some conclusions regarding variation in larval response to turfgrass and pesticide type may be drawn based on observations. In the present study reduced rates of chlorpyrifos resulted in lower fall armyworm survival on resistant zoysiagrass cultivars relative to that on hybrid bermudagrass or seashore paspalum. In a separate trial when treated with spinosad, survival on the same zoysiagrasses was equal to or greater than that on more susceptible bermudagrass or paspalum. Reduced rates of halofenozide in another greenhouse trial resulted in lower survival on resistant zoysiagrasses at some concentrations at 7, but not at 14, days exposure compared to more susceptible grasses. More larvae tended to survive on susceptible grasses treated with reduced rates of halofenozide in field trials.

Chlorpyrifos is an organophosphate insecticide and an acetylcholinesterase inhibitor involving phosphorylation of the enzyme. It kills by both contact and ingestion. Chlorpyrifos has certainly been one of, if not the most widely used insecticides in sod production (Oetting et al. 1994, Braman et al. 2002c) and turfgrass maintenance (Braman et al. 1997, 1998). As a broad-spectrum insecticide it can be harmful to natural enemies. As a result of the Food Quality Protection Act review process, this insecticide also has been removed from use on residential turf although commercial and production uses are still permitted.

Spinosad and halofenozide are alternatives for fall armyworm suppression that have a narrower spectrum of activity and demonstrated improved margin of safety to many beneficial insects (e.g., Kunkel et al. 2001, Hill and Foster 2003). Spinosad is

Table 5. Average fresh and dry weights of grasses expressing varying levels of host plant resistance of *Spodoptera frugiperda* larvae when treated with various concentrations of spinosad (Conserve) and infested with larvae for two weeks in a greenhouse

	Spinosad (Conserve) concentration in ml formulation per 400 ml water					
Turf cultivar	0.000	0.000375	0.00075	0.00375	0.0375	0.375
			Fresh weight of grasses in grams			
TifEagle	0.1 ± 0.1b	0.8 ± 0.2a	1.5 ± 0.2a	3.0 ± 0.05a*	3.4 ± 0.3a*	2.4 ± 0.3ab*
TifSport	0.0 ± 0.0b	0.0 ± 0.0b	1.1 ± 0.2a*	1.6 ± 0.05b*	0.9 ± 0.1d*	2.3 ± 0.2b*
Sea Isle 1	0.0 ± 0.0b	0.5 ± 0.2a	1.9 ± 0.2a*	2.7 ± 0.1a*	2.1 ± 0.2b*	1.1 ± 0.1a*
Cavalier	0.5 ± 0.1a	0.7 ± 0.1a	0.6 ± 0.1a	1.2 ± 0.1bc*	1.5 ± 0.2c*	0.8 ± 0.1d*
Palisades	0.4 ± 0.1a	0.1 ± 0.1b	0.7 ± 0.2a	1.0 ± 0.1c*	0.5 ± 0.1d*	1.6 ± 0.2c*
			Dry weight of grasses in grams			
TifEagle	0.03 ± 0.01a	0.3 ± 0.1a*	0.2 ± 0.05c	1.1 ± 0.02a*	1.2 ± 0.1a*	0.9 ± 0.1a*
TifSport	0.00 ± 0.00a	0.00 ± 0.0d	0.4 ± 0.06b*	0.6 ± 0.01c*	0.4 ± 0.1c*	0.9 ± 0.1a*
Sea Isle 1	0.00 ± 0.00a	0.1 ± 0.01bc	0.6 ± 0.06a*	0.9 ± 0.02b*	0.7 ± 0.1b*	0.8 ± 0.1a*
Cavalier	0.2 ± 0.05b	0.3 ± 0.05ab	0.3 ± 0.05c	0.4 ± 0.04d*	0.6 ± 0.1bc*	0.4 ± 0.1b*
Palisades	0.2 ± 0.04b	0.06 ± 0.04cd	0.3 ± 0.1c*	0.3 ± 0.03d*	0.2 ± 0.1d*	0.6 ± 0.1b*

Means within a column followed by the same letter are not significantly different by Fisher's protected least significant difference test ($P > 0.05$).

* Significantly ($P < 0.05$) greater plant weight than in the untreated (0.000 concentration) group within the same cultivar (row) by Fisher's protected least significant difference test.

Table 6. Number of surviving *Spodoptera frugiperda* larvae of four initial larvae per rep (n = 18) when reared in a greenhouse on halofenozide (Mach 2)-treated turfgrasses expressing varying levels of host plant resistance

	Halofenozide (Mach 2) concentration in ml formulation per 400 ml water					
Turf	0.000	0.001	0.010	0.100	1.000	2.000
Cultivar	Mean number of surviving larvae per rep					
	7-day post-treatment					
TifEagle	1.9 ± 0.2a	2.3 ± 0.2a	2.0 ± 0.2a	1.7 ± 0.2a	0.7 ± 0.1ab*	0.7 ± 0.2a*
TifSport	2.5 ± 0.2a	1.4 ± 0.2b*	1.5 ± 0.2b*	1.9 ± 0.2a*	0.8 ± 0.1a*	0.8 ± 0.1a*
Sea Isle 1	1.9 ± 0.2a	2.0 ± 0.2a	1.7 ± 0.bab	2.1 ± 0.2a	0.3 ± 0.1c*	0.6 ± 0.2ab*
Cavalier	1.2 ± 0.2a	0.9 ± 0.1b	0.8 ± 0.2c	1.2 ± 0.2b	0.1 ± 0.1c*	0.2 ± 0.1b*
	14-day post-treatment					
TifEagle	1.1 ± 0.2a	1.3 ± 0.2a	1.0 ± 0.2a	0.9 ± 0.2b	0.5 ± 0.1a*	0.3 ± 0.1ab*
TifSport	1.4 ± 0.2a	1.4 ± 0.2a	1.8 ± 0.3a	1.6 ± 0.2a	0.3 ± 0.1a*	0.4 ± 0.2a*
Sea Isle 1	1.6 ± 0.2a	1.8 ± 0.2a	1.6 ± 0.2a	2.1 ± 0.2a	0.2 ± 0.1a*	0.0 ± 0.0c*
Cavalier	0.9 ± 0.2b	0.9 ± 0.3a	0.8 ± 0.2a	1.2 ± 0.3ab	0.1 ± 0.1a*	0.05 ± 0.05bc*

Means within a column followed by the same letter are not significantly different by Fisher's protected least significant difference test ($P > 0.05$).

* Significantly ($P < 0.05$) lower larval survival than in the untreated (0.000 concentration) group within the same cultivar (row) by Fisher's protected least significant difference test.

a naturalyte, derived from a soil-dwelling actinomycetes bacteria, *Saccharopolyspora spinosa*. It is a mixture of the two metabolites spinosyn A and D produced by the bacteria. The unique mode of action involves excitation of the insect nervous system by affecting the nicotinic acetylcholine receptors, and also affects the GABA (gamma-aminobutyric acid) receptor function. Spinosad acts as a contact and stomach poison. Halofenozide is a diacylhydrazine molting accelerator that acts as an agonist of the insect steroidal hormone 20-hydroxyecdysone required for the molting process. Ingestion causes larvae to attempt a premature, lethal molt. It also has some systemic and considerable residual activity.

Fall armyworm in our trials responded differently to reduced rates of insecticide depending on turfgrass cultivar and, apparently insecticide type (although these could not be directly compared). Numerous factors play a role in the complex interactions between plant resistance, insecticides and herbivores (e.g., as outlined in Verkerk and Wright 1996). Factors potentially contributing to the variation in responses that were observed in the present study include different modes of action of insecticides, host plant resistance mechanisms, differential foliar consumption rates, age of target pest, and insecticide dose in relation to body weight. In relation to the development of management guidelines for pest management practitioners the complexity of the interactions must be stressed. An understanding of the variable responses requires "case by case" evaluation. The shift from single-tactic pest management technologies to a more integrated approach that incorporates both extrinsic and intrinsic host plant resistance factors and optimizes novel chemical technologies will be information-intensive and require data-based solutions. Turfgrass host plant mediated response to insecticides was evaluated in the present study. Previous work using the same turfgrass cultivars evaluated turfgrass host plant mediated responses of predators to fall armyworms (Braman et al. 2003). Further study will be required to define the

Table 7. Average fresh and dry weights of grasses expressing varying levels of host plant resistance to *Spodoptera frugiperda* larvae when treated with various concentrations of halofenozide (Mach 2) and infested with larvae for two weeks in a greenhouse

Turf Cultivar	Halofenozide (Mach 2) concentration in ml formulation per 400 ml water					
	0.000	0.001	0.010	0.100	1.000	2.000
	Fresh weight of grasses in grams					
TifEagle	0.0 ± 0.0b	0.0 ± 0.0a	0.0 ± 0.0b	0.1 ± 0.1b	1.1 ± 0.2b*	0.3 ± 0.1b*
TifSport	0.0 ± 0.0b	0.0 ± 0.0a	0.0 ± 0.0b	0.0 ± 0.0b	0.6 ± 0.1b*	0.6 ± 0.1b*
Sea Isle 1	0.1 ± 0.1ab	0.1 ± 0.1a	0.2 ± 0.1a	1.1 ± 0.2a*	2.8 ± 0.3a*	4.0 ± 0.3a*
Cavalier	0.2 ± 0.1a	0.1 ± 0.1a	0.2 ± 0.1a	0.1 ± 0.1b	0.7 ± 0.1b*	0.5 ± 0.1b*
	Dry weight of grasses in grams					
TifEagle	0.0 ± 0.0b	0.0 ± 0.0a	0.0 ± 0.0a	0.03 ± 0.01b	0.4 ± 0.1ab	0.01 ± 0.01c
TifSport	0.0 ± 0.0b	0.0 ± 0.0a	0.0 ± 0.0a	0.0 ± 0.0b	0.3 ± 0.1c	0.01 ± 0.01c
Sea Isle 1	0.01 ± 0.01b	0.02 ± 0.01a	0.01 ± 0.01a	0.3 ± 0.04a*	0.5 ± 0.1a*	0.7 ± 0.1a*
Cavalier	0.1 ± 0.04a	0.01 ± 0.01a	0.01 ± 0.01a	0.0 ± 0.0b	0.3 ± 0.1bc*	0.2 ± 0.03b*

Means within a column followed by the same letter are not significantly different by Fisher's protected least significant difference test ($P > 0.05$).

* Significantly ($P < 0.05$) greater plant weight than in the untreated (0.000 concentration) group within the same cultivar (row) by Fisher's protected least significant difference test.

Table 8. Percent survival of *Spodoptera frugiperda* larvae per rep when exposed in the field to halofenozid-treated turfgrasses expressing varying levels of host plant resistance

	Halofenozide concentration expressed as a fraction of the labeled rate X*		
Turf Cultivar	0.000	¼X***	½X***
		Percent ± s.e. survival Exposed as first instar larvae	
TifEagle	34.4 ± 9.3a	15.6 ± 5.0a	7.8 ± 2.7a
TifSport	31.1 ± 9.4a	5.6 ± 2.6b	3.3 ± 2.3ab
Sea Isle 1	25.3 ± 8.9a	0 ± 0b	1.3 ± 1.2b
561-79	28.9 ± 3.7a	3.3 ± 1.4b	1.1 ± 1.1b
Cavalier	10.0 ± 5.4a	4.4 ± 2.8b	2.2 ± 2.2b
Palisades	22.2 ± 10.4a	5.6 ± 2.0b	0 ± 0b
		Percent ± s.e. survival Exposed as third instar larvae	
	0.000	1/16X**	¼X
TifEagle	20.0 ± 6.8a	8.3 ± 4.8abc	3.3 ± 2.1a
TifSport	16.7 ± 7.6a	11.7 ± 6.0abc	3.3 ± 3.3a
Sea Isle 1	33.3 ± 5.5a	20.0 ± 6.8ab	3.3 ± 2.1a
561-79	30.0 ± 5.7a	22.0 ± 3.8a	2.0 ± 2.0a
Cavalier	11.7 ± 7.9a	6.7 ± 3.3bc	0 ± 0a
Palisades	22.0 ± 1.3a	1.7 ± 1.7c	5.0 ± 3.4a

Means within a column followed by the same letter are not significantly different by Fisher's protected least significant difference test ($P > 0.10$**; $P > 0.05$***).

*Full labeled rate X resulted in 100% mortality of larvae regardless of turfgrass cultivar.

response of predators and parasitoids to novel pesticide technology within particular plant/pest systems of interest.

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