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ABSTRACT Insecticides used on turf are sometimes applied to areas with flowering weeds that attract honey bees and native pollinators. We tested residual effects of such treatments on colony vitality and behavior of the bumble bees *Bombus impatiens* Cresson foraging on turf containing white clover, *Trifolium repens* L. Imidacloprid, a systemic chloronicotinyl used for preventive control of root-feeding grubs, was applied as granules, followed by irrigation, or sprayed as a wettable powder, with or without irrigation. Hives were confined on the plots in large field cages after residues had dried and colony vitality (i.e., numbers of brood, workers, and honey pots, and weights of queens, workers, and whole colonies with hives) was evaluated after 28–30 d. Workers' foraging activity and defensive response to an aggressive stimulus also were evaluated. In another test, weedy turf was sprayed with chlorpyrifos, carbaryl, or cyfluthrin at labeled rates for surface-feeding pests. Bee colonies were confined on the plots after residues had dried, with effects on colony vitality evaluated after 14 d. Finally, foraging activity of wild bumble bees was monitored on open plots to determine if insecticide-treated areas were avoided. Imidacloprid granules, and imidacloprid sprays applied with posttreatment irrigation, had no effect on colony vitality or workers' behavior, suggesting that such treatments pose little systemic or residual hazard to bumble bees. In contrast, exposure to dry nonirrigated residues of all of the aforementioned insecticides had severe impact on colony vitality. Foraging workers did not avoid insecticide-treated areas. Means by which turf managers can reduce hazards of insecticide applications to pollinators are discussed.

KEY WORDS *Bombus impatiens,* bumble bee, turfgrass, ecotoxicology, imidacloprid, cyfluthrin

HABITAT LOSS AND FRAGMENTATION, diseases and parasites, and exposure to broad-spectrum insecticides are factors contributing to declining populations of honey bees, native bee species, and other pollinators in the United States and worldwide (Watanabe 1994, Allen et al. 1998, Kearns et al. 1998). As urban areas grow, lawns, golf courses, and other managed landscapes continue to supplant natural bee habitat. Turfgrasses now cover >12 million hectares in the United States (Potter and Braman 1991). As pollinators adapt to their new urban environment, it is important their habitat include safe forage.

Lawns and out-of-play areas of golf courses commonly contain flowering weeds such as white clover (*Trifolium repens* L.), dandelions (*Taraxacum* spp.), plantain (*Plantago* spp.), and violets (*Viola* spp.). White clover, in particular, thrives on golf courses because it can flower and produce seed at mowing heights as low as 6 mm (Watschke et al. 1995). Sometimes it encroaches from roughs into fairways. When present, such weeds attract honey bees (Apidae), bumble bees (Bombinae), solitary bees (e.g., Andrenidae, Halictidae, Megachilidae), skippers (Hesperiidae), white and sulfur butterflies (Pieridae), and other pollinators (e.g., Shepherd and Tepedino 2000).

High esthetic standards for turf result in substantial insecticide usage on lawns and golf courses (Racke and Leslie 1993, Potter 1998, Racke 2000). Foliage-feeding pests typically are controlled with liquid applications of organophosphate, carbamate or pyrethroid insecticides, with residues allowed to dry on stems and leaves (Potter 1998). Root-feeding white grubs (Scarabaeidae) were traditionally controlled with organophosphates or carbamates applied after egg hatch and watered into the soil. During the 1990s, however, use patterns shifted to longer residual, less broadly toxic compounds, mainly imidacloprid and halofenozide (Potter 1998).

Imidacloprid, a chloronicotinyl, is now widely used for preventive control of white grubs, as well as billbug (*Sphenophorus* spp.) larvae, mole crickets (*Scapteriscus* spp), and other soil-inhabiting turf pests (Potter 1998). It is systemic, has relatively long residual effect when acting via soil, and has low mammalian toxicity (Elbert et al. 1991, Mullins 1993). In turf, it may be applied as a liquid spray, or as granules. The label recommends that for grub control, sufficient irrigation

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or rainfall be applied to move the residues into the soil. Although this usually is done on golf courses, in our experience, timely watering-in is less assured following treatments made by commercial lawn care firms or homeowners.

Exposure to organophosphate, carbamate, and pyrethroid insecticides has been associated with bee poisonings in food crops (Kevan 1975, Johansen 1977, Kearns et al. 1998). Such compounds could potentially intoxicate pollinators through direct contact, exposure to residues, or spray contamination of nectar and pollen (e.g., Burgett and Fisher 1980, Johansen et al. 1983). Certain systemic organophosphates and carbamates (e.g., dimethoate, aldicarb) also have the potential to contaminate nectar (Jaycox 1964, Waller et al. 1984, Johansen et al. 1983) and pollen (Ferguson 1987).

Imidacloprid, given direct exposure, also is inherently toxic to bees (Stark et al. 1995, Mayer and Lunden 1997, Schmuck et al. 2001). In some crops, the question has arisen whether soil-applied imidacloprid might be translocated into nectar and pollen at levels that pose a risk to pollinators or other insects that use floral resources. Schmuck et al. (2001) showed that residues of imidacloprid in nectar and pollen of seed-treated sunflower, *Helianthus annuus* L., plants in the field were negligible and that such treatments had no adverse effects on the development of exposed colonies of honey bees, *Apis mellifera* L. Imidacloprid seed coating of sunflowers also did not affect behavior or colony development of bumblebees, *Bombus terrestris* L. (Tasei et al. 2001). Smith and Krischik (1999), however, reported some adverse effects on mobility and fitness of the predatory coccinelid *Coleomegilla maculata* (DeGeer), which is a facultative pollen feeder, when beetles were confined with excised inflorescences from plants that had been treated with granular imidacloprid through the soil. Host foraging ability and longevity of the braconid *Microplitis croceipes* Cresson were reduced in wasps that had fed from extrafloral nectaries of imidacloprid-treated cotton (*Gossypium hirsutum* L.) plants (Stapel et al. 2000).

Lawn care professionals and homeowners often apply insecticides to lawns with flowering weeds, and many golf superintendents deliberately overlap the first cut of rough when treating fairways, aprons, putting greens, or tees. Potential hazards of such exposures to pollinators in weedy turf have not been evaluated. We applied imidacloprid to mixed stands of turf with flowering white clover, with or without post-treatment irrigation, and tested for residual and systemic effects on behavior and colony vitality of bumble bees, *Bombus impatiens* Cresson (Hymenoptera: Apidae) confined to foraging on the treated plots. Residual toxicity to the bees of three nonsystemic insecticides, carbaryl, chlorpyrifos, and cyfluthrin, also was examined. Finally, we tested whether or not foraging bumble bee workers avoid treated weedy turf in open field plots.

Materials and Methods

Exposure to Weedy Turf Treated with Granular Imidacloprid, Followed by Irrigation. This test was conducted on a mixed stand of tall fescue, *Festuca arundinacea* Schreber, with ≈25–50% flowering white clover cover at the University of Kentucky's Spindletop Research Farm, near Lexington. On 18 June 1999, 10 plots (3 by 5 m) were individually rated by three independent observers for percentage of surface area covered by clover. Plots were paired accordingly, and one of each pair was randomly selected for treatment the following day. Imidacloprid (Merit 0.5 G, Bayer, Kansas City, MO) was preweighed for application at the highest label rate for white grubs (0.4483 kg [AI]/ha). The granules were mixed with dry sand and evenly applied by gloved hand. The other plot of each pair was untreated. Shortly after treatment, all plots received 1.5 cm of irrigation from lawn sprinklers. Plots were then covered with pollination cages (4 by 2 by 1.3 m) consisting of a PVC frame draped with 1-mm mesh. The frames and screening were sealed at ground level using loose soil. The first rain (1.42 cm) was 24 June, 5 d after treatment. Total rainfall during the 30-d interval following treatment was 7.0 cm.

Similar-aged colonies of *B. impatiens* (Koppert Biological Supply, Romulus, MI) were paired according to their initial weights. Each colony was housed in a cardboard hive and contained a fertilized queen, 40–50 workers, and brood. Seven days after treatment (26 June), one randomly assigned hive was placed on a concrete block within each cage, facing west. A band of Tanglefoot (Tanglefoot, Grand Rapids, MI) was applied around the block to discourage invertebrate predators. Dry honey bee pollen, purchased from a health food store, was provided to ensure that the bees were not pollen-limited. The supplemental pollen (7 g, twice per week) was placed directly into the hive.

Bees were allowed to forage in the cages for 30 d. Foraging activity in each plot was monitored three times per week. Each time, the total number of bees foraging on each plot was counted for a 2-min interval between 1100 and 1300 hours. Counts were compared between treatments by multivariate analysis of variance (MANOVA for repeated measures using the Wilks lambda likelihood ratio test (SAS Institute 1997).

Observations early in the experiment suggested some bee colonies were more defensive than others. To test if imidacloprid was affecting colonies' defensive abilities, one person wearing a bee suit entered the cage and tapped the hive with a 30-cm wooden ruler three times from a striking distance of 20 cm. The time it took for the first three bees to leave the hive was recorded as the initial response time. A second measurement, the duration of response, was defined as the time elapsed from initial response until a 25-s lapse during which no more bees left the hive. In addition, the total number of bees that responded was recorded.

After dusk on the final day, each hive was closed and sealed within a dark plastic bag. Hives with colonies were brought back to the lab and frozen at −29°C.

Inspection of each cage the following day revealed no active bees, indicating that no workers had remained outside during the night and that the whole colony was accounted for.

Colonies were dissected to assess their relative vitality. Numbers of adult bees, honey pots (includes specialized wax cells filled with honey, together with smaller numbers of honey-filled, vacated adult cells), and brood chambers (i.e., individual cells containing one or more larvae) were counted, and weights of workers, queens, and whole colony plus hive were determined. Bees that had died on the ground could not be accounted for. Vacated cells were not a good indicator of number of adults that had emerged because such cells often were rebuilt and filled with honey, and were not distinctive unless the bee had just emerged.

Paired *t*-tests ($P = 0.05$) were used to compare colonies from treated versus untreated plots (Analytical Software 1996). All data are reported as means ± SE.

Exposure to Irrigated or NonIrrigated Spray Residues of Imidacloprid. Fifteen plots were established in a stand of tall fescue with ≈25–50% white clover coverage on a minimally maintained athletic field on the University of Kentucky campus, Lexington. Plots (3 by 5 m), marked and ranked as described earlier, were placed in five groups of three according to similar clover density. On 22 June 2000, two plots of each group were randomly selected for treatment with imidacloprid (Merit 75 WP, Bayer) at the label rate for grub control (0.336 kg [AI]/ha). Treatments were applied with a portable CO2 spray tank (R and D Sprayers, Opelousas, LA) with a spray volume of 468 liter/ha at pressure of 2,109 g/cm^2. The sprayer was equipped with a 1.8-m, hand-held boom with four Spraying System 8004 Tee Jet nozzles (Spraying Systems, Wheaton, IL). One sprayed plot within each group was randomly selected to receive 1.5 cm of irrigation immediately after treatment, as is recommended by the label. The third plot was left untreated. Plots were enclosed within individual pollination cages as before.

The following day, after residues had dried, a hive containing a *B. impatiens* colony was placed into each cage on a cement block, facing west. Each hive initially contained 20–25 workers, a fertile queen, and brood. The bees were fed 7 g of dry honey bee pollen once every 7 d. The first rainy period began 3 d after treatment (0.17, 0.15, and 3.45 cm on 25, 26, and 27 June, respectively) and total rainfall during the 4 wk following treatment was 10.1 cm.

Foraging activity and defensive response were assessed in the same manner as in 1999. Bees were allowed to forage inside the cages for 28 d. The hives and colonies were then collected and dissected as described for the previous test. Treatments were compared by a two-way analysis of variance (ANOVA) followed by the least significant difference test for mean separation (Analytical Software 1996).

Exposure to Nonirrigated Spray Residues of Nonsystemic Insecticides. On 24 May 2000, 16 plots were established on a different area of the same athletic field used in the previous imidacloprid experiment. Plot size and layout were the same as previously described. One plot of each replication was left untreated. The remaining plots were sprayed with either cyfluthrin (Tempo SC Ultra, Bayer) at 0.077 kg [(AI)]/ha, chlorpyrifos (Dursban 50W, Dow AgroSciences, Indianapolis, IN) at 1.12 kg [(AI)])/ha, or carbaryl (Sevin SL, Aventis, Montvale, NJ) at 6.10 kg [(AI)]/ha. Those rates are registered for control of foliage feeding turf pests. No posttreatment irrigation was applied.

The plots were caged as before, and hives with bumble bee colonies were placed on them 24 h after treatment. Observations on foraging activity were conducted as previously described. The first rain occurred 3 and 4 d after application (1.12 and 0.96 cm, respectively), followed by only a trace (0.2 cm) of additional rain through the remainder of the trial. The experiment ran for 14 d. The hives were then collected and their contents dissected as before. Colony vitality and behavioral parameters were compared between treatments by two-way ANOVA using Statistix for Windows, followed by the LSD means separation procedure ($P = 0.05$). Foraging activity was compared between treatments by MANOVA for repeated measures, as described before.

Test for Avoidance of Treated, Weedy Turf. To determine if bumble bees would avoid foraging in areas with irrigated residues of granular imidacloprid, another tall fescue stand with ≈25–50% clover cover on the University of Kentucky campus was used. Fourteen plots (3 by 6 m) were paired according to estimated percentage of the surface with flowering clover, as described before. On 7 July 1999, one plot of each pair was treated with imidacloprid (Merit 0.5 g) at 0.336 kg (AI)/ha, whereas the other plot was left untreated. Immediately thereafter, all plots received 1.5 cm of irrigation. Foraging activity was monitored 1 wk later (14 July), from 0800 to 1500 hours. The number of bees foraging on the clover within each plot was determined by walking the field and visually scanning the whole plot for 1 min, twice per hour, for 6 h. There was only a trace of rain (0.10 cm on 10 July) between the treatment and observation dates. Foraging activity was compared between treatments by MANOVA for repeated measures as described earlier.

To test for avoidance of nonirrigated spray residues of turf insecticides, four sets of five plots were established on a minimally maintained turf stand at the University Club golf course, near Lexington. Plots were blocked on the basis of similar clover cover, as before. Randomly selected plots were sprayed with carbaryl, chlorpyrifos, cyfluthrin, or imidacloprid, or left untreated. Formulations, rates, and application method were as described previously. Plots were treated on 17 August 2000. The following day, after residues had dried, the number of bees foraging on each plot was observed and recorded over 45-s intervals, twice per hour, as described above. Observations

Table 1. Colony vitality and defensive response of bumble bees confined for 30 d on plots with turf and flowering white clover that were untreated, or had been treated with granular imidacloprid followed by irrigation

	Control	Imidacloprid	*t*-statistic	*P*
Weight (g)				
Colony (with hive)	2,540 ± 52.0	2,690 ± 52.5	−1.54	0.20
Workers	27.4 ± 5.6	30.3 ± 4.9	−0.31	0.77
Queen	0.79 ± 0.02	0.73 ± 0.05	−0.86	0.44
No. in colony				
Workers	157.2 ± 37.1	116.6 ± 33.8	−0.86	0.44
Brood chambers	43.6 ± 11.5	76.2 ± 27.4	−1.68	0.17
Honey pots	131.6 ± 20.0	148.8 ± 11.0	−0.82	0.46
Defensive response				
Time to initial response (s)	7.5 ± 2.6	1.8 ± 0.6	−1.9	0.13
Duration of response (s)	46.6 ± 14.4	44.0 ± 12.7	−0.1	0.92
No. of bees responding	15.0 ± 2.2	6.2 ± 3.6	−0.9	0.74

began at 0800 and ended at 1500 hours. No rain fell at the site between treatment and the end of the observation period. Counts were analyzed by MANOVA for repeated measures as before.

Results

Exposure to Weedy Turf Treated with Granular Imidacloprid, Followed by Irrigation. Granular imidacloprid applied with posttreatment irrigation had no effect on vitality of *B. impatiens* colonies or on workers' defensive response to an aggressive stimulus (Table 1). In addition, these treatments did not affect foraging activity (Fig. 1).

Exposure to Irrigated or NonIrrigated Spray Residues of Imidacloprid. Spray applications of imidacloprid that were followed by irrigation did not adversely affect colony vitality or workers' defensive response (Table 2). However, colonies foraging on nonirrigated imidacloprid treated plots had fewer brood chambers, honey pots, and workers. Total biomass of workers was reduced on these plots, as was total colony weight.

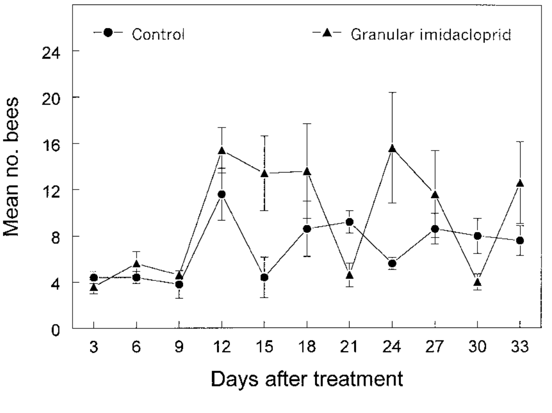

Fig. 1. Foraging activity of *B. impatiens* colonies confined on untreated plots of tall fescue mixed with flowering white clover, or similar plots that had been treated with granular imidacloprid followed by irrigation. Data are mean ± SE number of workers foraging within each cage based on 2-min counts taken every 3 d for 37 d. The overall treatment effect is not significant (MANOVA for repeated measures; $F = 1.91$; df = 1, 8; $P = 0.204$)

Queen weights were not affected, probably because queens already were mature. We observed a number of dead bees clinging to the sides of the cages on the nonirrigated, imidacloprid-treated plots, a phenomenon unique to this experiment. Colonies' defensive response to the aggressive stimulus also was reduced (Table 2). Colonies exposed to nonirrigated imidacloprid residues had reduced foraging activity (Fig. 2, MANOVA for repeated measures).

Exposure to Nonirrigated Spray Residues of Nonsystemic Insecticides. Exposure to dry spray residues of each of the surface-applied, nonsystemic insecticides adversely affected colony vitality of bumble bees (Table 3). Fewer worker bees, honey pots, and brood chambers were present in hives from treated plots. Worker biomass and colony weights were also reduced. For both carbaryl- and chlorpyrifos-treated plots, two of the four colonies had no live brood or adults. Colonies from chlorpyrifos-treated plots had significantly less brood than did plots from carbaryl- or cyfluthrin-treated plots (Table 3). Colonies from carbaryl-treated plots had less brood than those exposed to cyfluthrin. There also was reduced foraging activity on treated plots (Fig. 3).

Test for Avoidance of Treated, Weedy Turf. Endemic bumble bees neither avoided nor preferred plots that had been treated with granular imidacloprid relative to untreated control plots (MANOVA for repeated measures; $F = 0.89$, df = 1, 12; $P = 0.363$). Mean numbers of bee visits observed per plot, per 1-min observation period, were 5.5 ± 3.0 versus 5.1 ± 2.8, respectively. Likewise, bumble bees foraging on flowering white clover intermixed with turf did not avoid plots sprayed with imidacloprid, carbaryl, chlorpyrifos, or cyfluthrin, relative to untreated plots (MANOVA for repeated measures; $F = 1.62$; df = 4, 15; $P = 0.221$). Because there was relatively light foraging activity during this test, bee visits per plot were pooled across observation periods. Mean ± SE total numbers of workers observed per plot were 12.8 ± 1.3, 10.8 ± 0.9, 15.4 ± 1.5, 13.0 ± 1.3, and 12.1 ± 1.8, respectively.

Discussion

Our results suggest that regardless of formulation, imidacloprid applications that are followed by irriga-

Table 2. Colony vitality and defensive response of bumble bees confined for 28 d on untreated turf plots with flowering white clover versus plots with irrigated or non-irrigated imidacloprid residues

	Control	Irrigated	Non-irrigated	*F*	*P*
Weight (g)					
Colony (without hive)	86.4 ± 6.8a	80.6 ± 2.6a	39.6 ± 12.4b	11.81	0.004
Workers	7.2 ± 1.0a	7.9 ± 0.4a	3.2 ± 0.6b	18.63	0.001
Queen	0.7 ± 0.0a	0.7 ± 0.1a	0.7 ± 0.0a	0.00	0.999
No. in colony					
Adults	55.4 ± 7.0a	48.6 ± 4.4a	21.8 ± 2.3b	13.23	0.002
Brood chambers	28.6 ± 4.2a	25.0 ± 3.6a	3.6 ± 0.7b	18.65	0.001
Honey pots	24.0 ± 2.9a	24.2 ± 4.7a	6.8 ± 4.7b	6.37	0.022
Dead bees[a]	0.0 ± 0.0a	1.0 ± 0.7a	13.2 ± 2.3b	15.52	0.001
Defensive response					
Time to initial response (s)	9.8 ± 0.9a	9.2 ± 1.7a	3.2 ± 1.9b	14.24	0.002
Duration of response (s)	46.8 ± 1.0a	38.2 ± 7.0a	12.6 ± 7.2b	15.74	0.031
No. of bees responding	6.2 ± 1.9a	7.0 ± 0.7a	1.4 ± 0.8b	8.23	0.021

Means within rows that are not followed with the same letter differ significantly (two-way ANOVA, LSD, $P < 0.05$).
[a] These were the dead bees were found clinging to sides of the cage (see text).

tion, as is recommended by the label for optimum soil insect control, pose little or no residual hazard to bumble bees foraging on flowering white clover in weedy turf. Importantly, they suggest absence of systemic effects of soil treatment on colony vitality, even with prolonged exposure from bees having been caged on the treated plots for 28–30 d. Nonirrigated granular applications were not evaluated but they, too, would likely be nonhazardous because bees would not encounter granules that settle into grass or thatch. Residues from the irrigated spray application apparently did not bind to pollen, petals, and leaves, or else were dislodged by watering.

In contrast, bee colonies that foraged on imidacloprid-sprayed plots not receiving posttreatment irrigation experienced loss of workers, brood, and honey pots, as well as reduced worker biomass and colony weight. Foraging activity and aggressiveness of those colonies were also reduced. This likely resulted from acute toxicity to workers rather than sublethal impairment of their behavior. Similarly, exposure to dry, nonirrigated spray residues of chlorpyrifos, carbaryl, or cyfluthrin adversely affected all colony vitality parameters of bumble bees foraging on weedy, treated turf.

Our results with nonirrigated spray residues are not surprising considering that all four of the insecticides tested are inherently toxic to bees (Hays and Laws 1991, Extoxnet 2001). These tests represent a worst-case scenario in that the workers were caged on the sprayed plots for 2 or 4 wk. Whole-colony consequences of a smaller proportion of the workers foraging on insecticide-contaminated weeds in an open system likely would be less severe. Nevertheless, the fact that *B. impatiens* workers did not avoid treated plots suggests that insecticide residues on blooming weeds could adversely affect local, native bee colo-

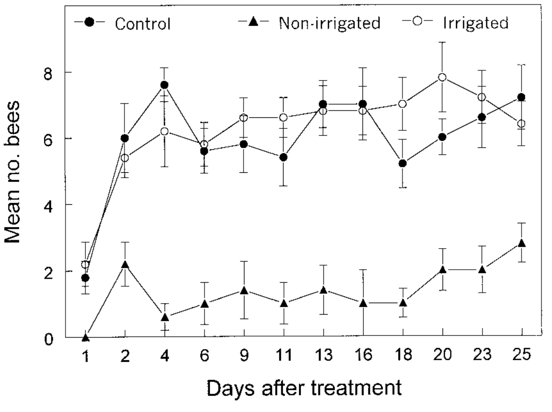

Fig. 2. Foraging activity of *B. impatiens* colonies confined on plots of tall fescue mixed with flowering white clover that were (1) untreated, (2) sprayed with a wettable powder formulation of imidacloprid with residues allowed to dry on the grass, or (3) sprayed with imidacloprid, with residues watered in. Data are mean ± SE number of workers foraging within each cage based on 2-min counts taken every 2–3 d. The overall treatment effect is significant (MANOVA for repeated measures; $F = 59.35$; df = 2, 12; $P < 0.0001$).

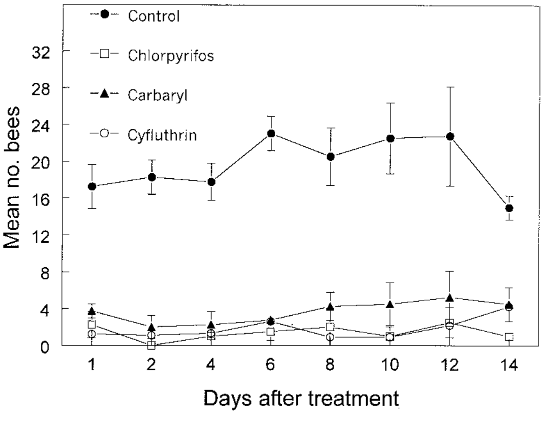

Fig. 3. Foraging activity of *B. impatiens* colonies confined on plots of tall fescue mixed with flowering white clover that had been treated with short-residual insecticides, with residues allowed to dry on the grass. Data are mean ± SE number of workers foraging within each cage based on 2-min counts taken every 3 d. The overall treatment effect is significant (MANOVA for repeated measures; $F = 40.34$; df = 3, 12; $P < 0.0001$)

Table 3. Colony vitality of bumble bees following 2-wk exposure to dry residues of surface insecticides on mixed stands of turf and flowering white clover

Colony parameters	Treatment				F	P
	Control	Chlorpyrifos	Carbaryl	Cyfluthrin		
Weight (g)						
Colony (without hive)	193.4 ± 26.3a	107.8 ± 7.2b	127.0 ± 11.4b	142.6 ± 13.8b	7.04	0.010
Workers	23.1 ± 4.9a	7.5 ± 1.1b	11.0 ± 2.5b	11.8 ± 2.3b	6.22	0.014
Queen	0.78 ± 0.05a	0.78 ± 0.08a	0.74 ± 0.06a	0.66 ± 0.03a	1.04	0.422
No. in colony						
Workers	132.8 ± 19.6a	56.8 ± 6.5b	67.3 ± 11.9b	76.8 ± 9.3b	9.07	0.004
Honey pots	41.8 ± 12.9a	5.5 ± 3.6c	29.7 ± 8.2b	38.5 ± 6.9a	6.05	0.015
Brood chambers	56.0 ± 5.1a	3.5 ± 1.3d	10.3 ± 2.4c	20.5 ± 2.7b	19.70	0.0003

Means within rows that are not followed with the same letter differ significantly (two-way ANOVA, LSD, $P < 0.05$)

nies. Honey bees, solitary bees, and other pollinators foraging in treated, weedy turf could similarly be at risk

The extent to which an insecticide is hazardous to pollinators is determined by its inherent toxicity as well as the formulation and manner in which it is applied (Stark et al. 1995). For example, pollen contamination, which can decimate honey bee colonies, may be exacerbated by wettable powder or microencapsulated formulations that have high affinity for binding to pollen (Johansen et al. 1983). Conversely, posttreatment irrigation may decrease exposure or dilute active ingredient concentration thereby reducing hazards to beneficial insects (e.g., Kunkel et al. 2001).

Our results suggest that, at least for imidacloprid, posttreatment irrigation will greatly reduce hazard to bees from liquid applications targeting soil pests. Other tactics likely to alleviate hazards of turf insecticides to pollinators include use of products with target-selective or low residual toxicity, granular formulations, mowing flower heads before treatment, weed management with herbicides, and avoiding treatment when weeds are in bloom. Although these tactics have long been advocated for agricultural crops (e.g., Kevan 1975, Johansen 1977, Kearns et al. 1998), increasing awareness of them among turf managers may help to conserve pollinators in urban and suburban landscapes.

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References Cited

Allen, W. G., P. Bernhardt, R. Bitner, A. Burquez, S. Buchmann, J. Cane, P. A. Cox, V. Dalton, P. Feinsinger, M. Ingram, and others. 1998. The potential consequences of pollinator declines on the conservation of biodiversity and stability of food crop yields. Conserv. Biol. 12: 8–17.

Analytical Software. 1996. Statistix for Windows. Analytical Software, Tallahassee, FL.

Burgett, M., and G. C. Fisher. 1980. Recovery of Penncap-M from foraging honey bees and pollen storage cells. Environ. Entomol. 9: 430–431.

Elbert, A., B. Becker, J. Hartwig, and C. Erdelen. 1991. Imidacloprid– a new systemic insecticide. Pflanzenschultz-Nachr. Bayer 44: 113–136.

Extoxnet. 2001. The extension toxicology network. University of California-Davis, Oregon State University, Michigan State University, Cornell University, University of Idaho (http://ace.orst.edu/info/extoxnet/ghindex.html).

Ferguson, F. 1987. Long term effects of systemic pesticides on honey bees. Australas. Beekeep. 89: 49–54.

Hays, W. J., Jr., and R. R. Laws, Jr. (eds.). 1991. Handbook of pesticide toxicology. Academic, New York

Jaycox, E. R. 1964. Effect on honeybees of nectar from systemic insecticide-treated plants. J. Econ. Entomol. 57:31–35.

Johansen, C. A. 1977. Pesticides and pollinators. Annu. Rev. Entomol. 22: 77–92.

Johansen, C. A., D. F. Mayer, J. D. Eves, and C. W. Kious. 1983. Pesticides and bees. Environ. Entomol. 12: 1513–1518.

Kearns, C. A., D. W. Inouye, and N. M. Waser. 1998. Endangered mutualisms: the conservation of plant pollinator interactions. Annu. Rev. Ecol. Syst. 29: 83–112.

Kevan, P. G. 1975. Pollination and environmental conservation. Environ. Conserv. 2: 293–298.

Kunkel, B. A., D. W. Held, and D. A. Potter. 2001. Lethal and sublethal effects of bendiocarb, halofenozide, and imidacloprid on *Harpalus pennsylvanicus* DeGeer (Coleoptera: Carabidae) following different modes of exposure in turfgrass. J. Econ. Entomol. 94: 60–67.

Mayer, D. F., and J. D. Lunden. 1997. Effects of imidacloprid insecticide on three bee pollinators. Hortic. Sci. 29: 93–97.

Mullins, J. W. 1993. Imidacloprid: a new nitroguanidine insecticide, pp. 183–198. *In* S. O. Duke, J. J. Menn, and J. R. Plimmer [eds.], Challenges of pest-control with enhanced environmental safety. ACS Symposium Series 524. American Chemical Society, Washington, DC.

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

Potter, D. A., and S. K. Braman. 1991. Ecology and management of turfgrass insects. Annu. Rev. Entomol. 36: 383–406.

Racke, K. D. 2000. Pesticides for turfgrass pest management: Uses and environmental issues, p. 45–63. *In* J. M. Clark and M. P. Kenna (eds.), Fate and management of turfgrass chemicals. ACS Symposium Series 743:American Chemical Society, Washington, DC.

Racke, K. D., and A. R. Leslie (eds.). 1993. Pesticides in urban environments. Fate and significance. ACS Symposium Series 522:American Chemical Society, Washington, DC.

SAS Institute. 1997. SAS STAT users' guide for personal computers, version 8.0 ed. SAS Institute, Cary, NC.

Schmuck, R., R. Schoning, A. Stork, and O. Schramel. 2001. Risk posed to honeybees (*Apis mellifera* L., Hymenoptera) by an imidacloprid seed dressing of sunflowers. Pest Manag. Sci. 57: 225–238.

Shepherd, M. D., and V. J. Tepedino. 2000. The birdies and the bees: native pollinators on your golf course. U.S. Golf Assoc. Green Sec. Rec. 38(4): 17–21.

Smith, S. F., and V. A. Krischik. 1999. Effects of systemic imidacloprid on *Coleomegilla maculata* (Coleoptera: Coccinellidae). Environ. Entomol. 28: 1189–1195.

Stapel, J. O., A. M. Cortesero, and W. J. Lewis. 2000. Disruptive sublethal effects of insecticides on biological control: altered foraging ability and life span of a parasitoid after feeding on extrafloral nectar of cotton treated with systemic insecticides. Biol. Control 17: 243–249.

Stark, J. D., P. C. Jepson, and D. F. Mayer. 1995. Limitations to use of topical toxicity data for predictions of pesticide side effects in the field. J. Econ. Entomol. 88: 1081–1088.

Tasei, J. N., G. Ripault, and E. Rivault. 2001. Hazards of imidacloprid seed coating to *Bombus terrestris* (Hymenoptera: Apidae) when applied to sunflower. J. Econ. Entomol. 94: 623–627.

Waller, G. D., B. J. Erickson, J. Harvey, and J. H. Martin. 1984. Effects of dimethoate on honeybees (Hym.: Apidae) when applied to flowering lemons. J. Econ. Entomol. 77: 70–74.

Watanabe, M. E. 1994. Pollination worries rise as honey bees decline. Science 265: 1170.

Watschke, T. L., P. H. Dernoeden, and D. J. Shetlar. 1995. Managing turfgrass pests. Lewis, Boca Raton, FL.

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