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Modeling the Effectiveness of Bifenthrin for Reducing Populations of Japanese and Oriental Beetle Larvae in Nursery Containers[1]

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Abstract

Preplant potting mix incorporation of Talstar 0.2G (bifenthrin) can prevent root weevil and white grub infestations in container-grown nursery crops. Analysis of bifenthrin residues from potting media aged under northern nursery conditions indicated that this insecticide has a half-life of at least 3 years, irrespective of medium composition. Dose-response tests of bifenthrin for controlling Japanese and oriental beetle larvae indicated that the LD_{50} for these species is approximately 1.1 and 1.7 parts per million (ppm), respectively. These data suggest that >95% larval mortality of these scarab species can be expected up to three years following treatment of media with 10 ppm bifenthrin, and >99.9% larval mortality is expected for at least three years following treatment of media with 20 ppm bifenthrin.

Index words: Japanese beetle, *Popillia japonica* (Coleoptera: Scarabaeidae), oriental beetle, *Exomala orientalis* (Coleoptera: Scarabaeidae).

Chemicals used in this study: [1α,3α-(Z)]-(±)-(2 methyl[1,1'-biphenyl]-3-yl)methyl 3-(2-chloro-3,3,3-trifluoro-1-propenyl)-2,2-dimethylcyclopropanecarboxylate (bifenthrin; Talstar, FMC, Philadelphia, PA).

Significance to the Nursery Industry

Bifenthrin (Talstar 0.2G or Talstar F) used as potting mix incorporation or drench treatments can prevent the development of white grubs and black vine weevil larvae in container-grown nursery crops. The product label instructs growers to mix insecticide into the medium to achieve a concentration of 5–25 parts per million (ppm) for controlling various soil-dwelling insects. Chemical analysis of bifenthrin residues in various potting media determined that approximately half of the active ingredient is lost in three years, irrespective of medium composition. This long half-life allows preplant potting mix incorporation to provide continuous preventive control of soil-dwelling pests for several years. The relationship of Japanese beetle and oriental beetle larval mortality in response to bifenthrin concentration in potting media suggests that >95% mortality of these scarab species can be expected up to three years following media incorporation of 10 ppm bifenthrin, and >99.9% larval mortality is expected for at least three years in media initially loaded with 20 ppm bifenthrin. These species of white grubs are more sensitive to bifenthrin than are black vine weevil larvae (1).

Introduction

In 1999, the makers of a granular bifenthrin (Talstar 0.2G) product added control of white grubs and root weevil larvae to its label. This product previously had been used extensively for preventing fire ant infestations in container-grown nursery stock grown in southern states. Bifenthrin is now used widely in the Northeast for protecting container-grown ornamentals from root feeding insects, with the principal targets being the larvae of black vine weevil (*Otiorhynchus sulcatus* [Fabricius]) and oriental beetle (*Exomala orientalis* [Waterhouse]). Immediately following the report of bifenthrin's activity against white grubs (3), the preplant incorporation of bifenthrin to potting mix was added to the list of treatments qualified for certifying containers to be free of Japanese beetle (*Popillia japonica* Newman) in the Domestic Japanese Beetle Harmonization Plan (2). In this plan, the incorporation rate required for certification is 25 parts per million (ppm), and annual drenches with a flowable formulation of bifenthrin are required to maintain certification beyond one year.

The Talstar 0.2G label allows rates in potting media ranging from 5 to 25 ppm. Nielsen and Cowles (3) reported that their lowest tested incorporation rate for bifenthrin, 5 ppm, gave complete control of Japanese beetle for up to two years (the duration of their experiment) in potting media with moderate bulk density of 234–610 kg/m^3. Based on these extraordinary results, further tests were needed to determine the minimum dosage required for effective control and to determine the loss rate for the bifenthrin active ingredient from various potting media so that the duration of acceptable control could be predicted.

The work presented here addresses these issues by determining the dose-response of bifenthrin against two target pest species (Japanese and oriental beetle larvae), and the function that describes the loss of insecticide from various potting media over time. Together, these data can be combined into a model to predict the degree of control for each target pest based upon the initial concentration of insecticide loaded into the medium and the amount of time that the medium has been subjected to weathering.

Materials and Methods

Dose-response experiment. Potting medium, described as Medium 3 in Table 1, was obtained from a cooperating nursery. This experiment used seven dosages (including the untreated check) and eight replicates for each species (Japa-

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Table 1. Composition and physical characteristics of potting media used in the bifenthrin degradation experiment.

Mix no.	Component	Volume (%)	Organic matter (%)	Dry bulk density (kg/m^3)
1[z]	peat	77	65.8	102
	perlite	23		
2	fresh pine bark chips	67	65.3	203
	peat	26		
	porous ceramic[y]	7		
3	composted pine bark	65	77.5	250
	peat	30		
	6-mm stone	5		
4	composted hardwood bark	55	77.3	533
	sand	27		
	peat	18		
5	peat	50	3.5	728
	sand	50		

[z]TopGrow Mix-1, Lafaille Co., Coaticook, Quebec.
[y]Turface®, Profile Products, Buffalo Grove, IL.

nese beetle and oriental beetle), set up in a randomized complete block design (RCBD). Bifenthrin was incorporated at concentrations of 0.5, 1, 2, 4, 8, and 16 ppm in April 2000 and seeded with five seeds of *Briza maxima* L. (greater quaking grass) per pot. The plants were initially maintained in a greenhouse under automatic irrigation, and then moved to an outdoor site on June 19. To protect pots from overheating (from insolation or high ambient air temperatures), they were buried into the soil so that the top of the medium was level with the soil outside the pot. Drip irrigation was set up with an automatic timer and an individual emitter for each pot. A 9.5 × 3.3 × 0.6 m (height) field cage constructed with fiberglass window screen and 2 × 4 cm wooden furring strips prevented uncontrolled adult scarab access and egg laying, but could be removed to allow access for adding eggs to the pots.

Oriental beetle pupae (~200) were obtained from infested turf, and held in soil within a screened 20-liter bucket to obtain adults. Japanese beetles were collected from host plants as the adults fed. Adults of each species were fed grape foliage (changed every 2–7 days) in screened 20-liter buckets with damp sandy loam soil. Cages with adult beetles were held at 25C (77F) and 16:8 (L:D) hour conditions. Eggs were picked out from soil on a weekly basis with a moistened fine paintbrush. From late June to mid-July a total of 30 eggs per pot were placed at a depth of 3 cm (1.2 in), and then covered with media.

Scarab larvae were recovered from pots between November 20–28, 2000, by sifting through the media from each pot. Larval counts were subjected to analysis of variance following square root (x + 0.5) transformation to establish homogeneity of variance (5).

Bifenthrin degradation experiment. Five potting media were obtained from cooperating nurseries in an effort to obtain a representative sample of medium formulations. Media were also chosen to cover the spectrum of dry bulk density values. Dry bulk density was expected to be positively correlated with the percent composition of mineral amendments (such as sand or pea-gravel), which would not be expected to absorb (and retain) the bifenthrin active ingredient. The formula, organic matter content, and dry bulk density for these media are given in Table 1.

Talstar 0.2G was incorporated into potting media on May 28, 1999. Sufficient Talstar 0.2 G was weighed out to load 5, 10, or 20 ppm, based on the dry bulk density determined for each potting medium. Insecticide granules and 8.1 liters of media were combined in a cement mixer, the mixer was allowed to run for 2 min per batch, and three No. 1 pots were filled with each medium × concentration combination. Each pot was seeded with five seeds of *B. maxima* and placed in a RCBD under outdoor nursery conditions that included automatic daily overhead irrigation. During 1999, an effort was made to have high and low irrigation areas represented for different replicates. In 2000, pots were placed together and were exposed to similar irrigation intensities. Pots were placed in plastic-covered hoophouses without irrigation for overwintering (November–April).

On May 28, 1999, a single sample was removed for each medium × concentration group to confirm the initial bifenthrin rates. At 2, 3, 4, 5, 12, 24 and 28 months following bifenthrin incorporation, 60 ml of medium was removed from the interior of each pot with a core sampler. Along with the initial samples, there were 440 bifenthrin determinations. Each sample was air dried at room temperature for 1–2 weeks, then split into two subsamples. A preliminary methods development test determined that oven drying of potting media led to poorer bifenthrin recovery. Therefore, samples being extracted for bifenthrin determination had water present, and a bridge solvent (*n*-propanol) was combined with hexane to permit thorough interaction of the solvent system with particles of media. Because some water was retained in the media, a precise measure of moisture content was needed, both for determining the total solvent volume during the extraction procedure and for quantifying the bifenthrin concentration in the medium on a dry-weight basis. Ten to 15 grams of medium from Subsample 1 were used to determine the moisture content of the medium at the time of bifenthrin extraction. Media were weighed, placed in a drying oven at 60C overnight, and reweighed to determine water content. From Subsample 2, either 2.5 or 5 g of media (the smaller amount for low density media), was placed in a 60 ml glass vial with 20 or 30 ml of 4:1 hexane:propanol mixture and extracted overnight on a horizontal shaker. The sample was allowed to settle for 1–2 hr, and 0.1 ml removed and diluted with an additional 0.9 ml in a 1.5 ml autosampler vial (closed with a polytetrafluoroethylene-lined crimped lid) in preparation for analysis by gas chromatography.

An Agilent Model 6890 capillary gas chromatograph (GC) with an HP-5MS, 30 m × 250 µm i.d. with 0.25 µm film thickness column (Agilent Technologies, Palo Alto, CA) and electron capture detector was used to determine the bifenthrin concentrations of extracted samples. Conditions for the gas chromatograph were an injector temperature of 250C and detector temperature of 325C. The make-up gas was P-5 (5% methane, 95% argon), flowing at 60 ml/min. Hydrogen carrier gas flowed at a constant rate of 1.2 ml/min. A 1 µl pulsed splitless injection was made until 1 min, and then the inlet was purged at 50 ml/min for 20 min. The column temperature was initially 75C, ramped at 25C/min to 200C, then increased at 5C/min to 240C, then elevated at 25C/min to 280C, at which point the temperature was held constant for 5.4 minutes. Bifenthrin eluted at 12.7 min and the total run time was 20 min per sample. Bifenthrin standards of 10, 50, 100, 200, and 500 parts per billion (ppb) were prepared in isooctane from technical product (FMC, Philadelphia, PA), and

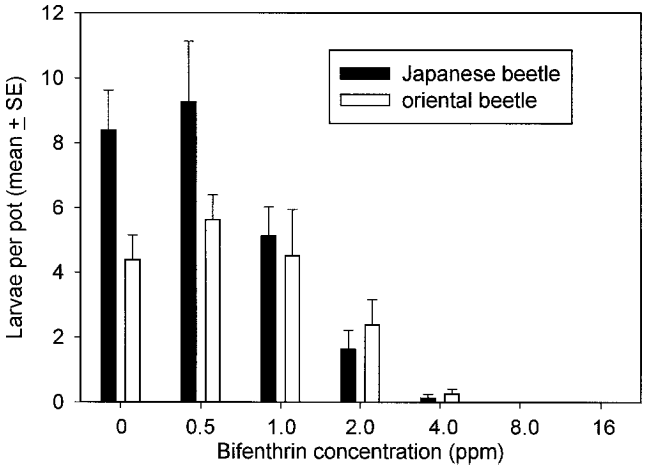

Fig. 1. Survival of Japanese and oriental beetle larvae in pots containing *Briza maxima* grown in potting media with preplant potting mix incorporated bifenthrin. Eggs (30 per pot) were infested in June–July, and larvae were counted in November 2000.

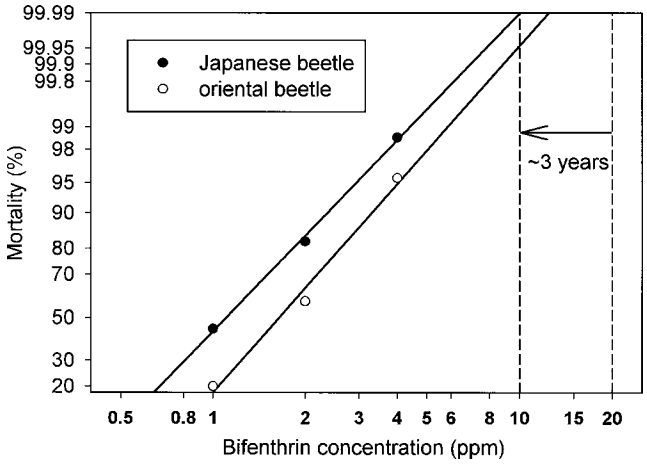

Fig. 2. Graphical model for estimating the percent control for Japanese and oriental beetles following preventive incorporation of bifenthrin into potting media. The log of bifenthrin concentration vs probability of mortality for Japanese and oriental beetles gives a linear dose-response relationship, permitting estimation of LC values (e.g., LC_{50}) and extrapolation to values of interest for quarantine-level protection ($LC_{99.997}$). The dashed lines and arrow represent the expected shift in efficacy over one half-life (~3 years) for a potting medium initially treated with 20 ppm of bifenthrin.

injected on GC once before and four times intermittently during every run of 60 samples to construct a standard calibration curve. The detection limit for this system was approximately 2 ppb.

Results and Discussion

Dose-response experiment. Preplant potting mix incorporation of Talstar 0.2G significantly controlled Japanese and oriental beetle larvae ($F_{[6,49]}$ = 29.9 and 14.1, respectively, $P < 0.0001$), and prevented all larval development at concentrations of 8 ppm or greater. The lowest concentration tested, 0.5 ppm, was ineffective and had more larvae (though not statistically significant) than the untreated check (Fig 1.). Therefore, this concentration was used as the standard against which percent mortality in the remaining treatments was calculated. The three concentrations for which there was partial control, 1, 2, and 4 ppm, provided sufficient data for determining the linear dose-response on a log (concentration) vs. probability mortality plot (Fig. 2). Results for oriental and Japanese beetle have similar slopes in their dose-responses. Japanese beetle larvae were somewhat more susceptible to bifenthrin than oriental beetle larvae, with graphically estimated LC_{50} values of 1.1 and 1.7 ppm, respectively.

Bifenthrin degradation experiment. Bifenthrin was recovered at measurable concentrations from all treated potting media through the duration of the experiment (Table 2). All media had similar variation in bifenthrin concentration measured over time, represented by Mix 5 sample results in Figure 3. However, some of this variation apparently was influenced by extraction efficiency on different sampling or extraction dates. For example, results for the second sampling date were consistently higher than those of the first sampling date, pointing to more efficient extraction from the second

Table 2. Bifenthrin degradation in treated potting media as determined with solvent extraction and gas chromatography. The half-life estimates are based on an exponential decay model, using the measured 1999 and 2001 bifenthrin concentrations.

Mix no.	Target concentration (ppm)	Bifenthrin concentration (ppm)			Half-life (years)
		1999	2000	2001	
1	5	7.3	3.7	3.0	1.6
	10	12.0	10.7	7.3	2.8
	20	27.0	16.2	11.0	1.5
2	5	4.8	2.4	3.9	6.2
	10	9.0	5.9	8.3	16.4
	20	22.7	13.4	15.0	3.3
3	5	5.4	2.8	2.0	1.4
	10	10.6	10.0	8.6	6.6
	20	19.8	15.8	9.7	1.9
4	5	3.9	2.7	2.5	3.0
	10	7.8	5.7	5.5	4.0
	20	18.0	11.3	13.6	4.9
5	5	5.3	5.0	3.5	3.4
	10	12.7	9.2	7.3	2.5
	20	24.1	15.9	15.4	3.1

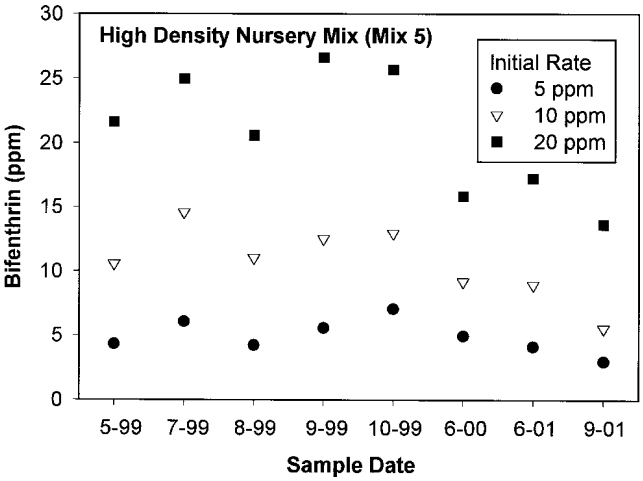

Fig. 3. Bifenthrin concentrations in a potting medium initially dosed with 5, 10, or 20 ppm, and then measured at several time points. Pots containing *Briza maxima* were held under irrigated nursery conditions during the growing season and overwintered in an unheated hoop-house. One sample was collected for the May 1999 sample date; all other data points represent the average of three samples. Samples were extracted overnight with a hexane:*n*-propanol mixture (4:1), followed by 1:10 dilution in hexane, and subjected to gas chromatography.

sample. Furthermore, potting media, with the exception of Mix 5, included large particles (>10 mm diameter) that may have increased the heterogeneity of sample particle distribution. This could contribute to variation in bifenthrin measurements. Chance inclusion of unusually large particles in a sample being extracted for bifenthrin determination could be expected to contribute to lower than average bifenthrin values because these particles would exclude bifenthrin from their interiors. In spite of these variations, concentrations of bifenthrin did decrease over the two years.

To minimize the effects of sampling variation on the estimation of bifenthrin's half-life in media, the 2nd, 3rd, 4th, 7th and 8th sampling dates were chosen as the best representative samples to compare 1999 with 2001 concentrations. These values were averaged within each year and used with the exponential decay model, $C_t = C_0 e^{-rt}$, to provide estimates on the half-life for each potting medium × concentration combination. In this model, C_0 and C_t represent the initial and subsequent concentrations after time in years 't' has elapsed, where 'r' is the exponential decay coefficient. Values of bifenthrin concentration used for this calculation and the resulting half-life estimates are given in Table 2. Statistical evaluation of half-life estimates from all concentrations and media indicated that there were no significant differences between media or initial concentrations (Kruskal-Wallis ANOVA on Ranks, $P = 0.15$). The median estimate for bifenthrin's half-life was 3.1 years, similar to the mean of 3.3 years calculated after excluding the 16.4 year datum as an outlier. The median half-lives were 3.0, 3.4, and 3.1 years, respectively, for initial bifenthrin concentrations of 5, 10, and 20 ppm.

The resulting model could be used to improve treatment guidelines for commercial nurseries. For nurseries wanting the greatest amount of benefit at the least expense, a lower concentration of insecticide (even 5 ppm) may be acceptable, whereas a nursery shipping plants to a state or Canada, which require that plants be free of Japanese beetle, the required concentration would be greater (at least 10 ppm, although the current Japanese Beetle Domestic Harmonization Plan requires a 25 ppm loading rate for bifenthrin).

Potting medium treatments to permit certification of pots as being free of Japanese beetle could be fine-tuned to prevent excessive insecticide application while still providing quarantine-level protection against this pest. Extrapolating the dose-response relationships to a level of 99.999% control, which is slightly better than the quarantine standard Probit 9 level of control (4), provides estimates for potting medium concentrations of 14 and 17 ppm being required for Japanese beetle and oriental beetle, respectively. Incorporating 20 ppm of bifenthrin into potting media can be expected to provide at least 99.9% control of Japanese beetle larvae for 3 years (Fig. 2). Treatment guidelines should be revised to take into account this more complete understanding of the dynamics of bifenthrin in potting media and the sensitivity of this pest to bifenthrin. As long as a plant is moved into a larger container with similarly treated medium, the long half-life of bifenthrin in potting media ensures that effective control of Japanese beetle larvae is feasible for at least three years without necessitating an additional annual bifenthrin drench.

For those growers not requiring quarantine level control of white grubs, concentrations of bifenthrin in potting media exceeding 10 ppm can be expected to provide >95% control of Japanese beetle or oriental beetle larvae for the first three years. However, previous work with black vine weevil on highly susceptible plant material demonstrated that potting mix incorporation of bifenthrin granules could require 25 ppm or higher concentrations to achieve 95–100% control (1). Therefore, growers may want to consider the benefits of controlling black vine weevil when deciding the optimum bifenthrin incorporation rate for protecting each crop.

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