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TITLE: Mobility and Persistence of Turfgrass Pesticides in a USGA Green

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MOBILITY AND PERSISTENCE OF TURFGRASS PESTICIDES IN A USGA GREEN

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EXECUTIVE SUMMARY

During the first year of the project, the groundwork was laid for studies on the mobility and persistence of pesticides in a USGA green. Lysimeters were installed in a USGA green at the Ft. Lauderdale Research and Education Center (FLREC), and analytical methods were developed for determining pesticides in soil, thatch, plant tissue, and water in the Pesticide Laboratory at the Everglades Research and Education Center (EREC) in Belle Glade.

During the current reporting year, pesticide losses in percolate, retention in soil and thatch, and removal in clippings have been examined for two applications of fenamiphos (Nemacur), fonofos (Dyfonate), chlorpyrifos (Dursban), isazophos (Triumph), and isofenphos (Oftanol), and for one application of ethroprop (Mocap). In addition, an examination of the effect of material, moisture, pressure, and motion on the dislodgeability of chlorpyrifos and isazophos from bermudagrass turf was conducted, with supplementary funding from the Florida Turfgrass Association. In cooperation with Dr. Robin Giblin-Davis, an in vitro study was conducted on the effects of fenamiphos and fenamiphos metabolites on the survival of sting nematodes. Over 5,000 pesticide analyses were made on soil, thatch, water, cloth, and/or clippings during the current reporting year. Three papers on this work were submitted for publication in refereed journals. The Pesticide Lab was upgraded with $ 10,000.00 supplied by the EREC Center Director, and the IFAS Dean for Research granted $ 30,000.00 for the purchase of a new HPLC.

In the study involving fenamiphos and fonofos, residues of fenamiphos and fonofos were found to largely reside in the thatch layer, whereas the fenamiphos metabolites were found to a much greater degree in the soil. Considerable metabolite was detected in percolate water, especially following the first application of fenamiphos. An average of 17.7% of the applied fenamiphos was found as metabolites in the percolate water following the first application, whereas only 1.1% was found after the second application. Nevertheless, both percentages are high relative to the fenamiphos parent compound or fonofos, for which a maximum of 0.06 and 0.02% of applied, respectively, was obtained in percolate water following any one application. Excessive irrigation appeared to contribute to leaching of fenamiphos metabolites.

For the study on the effects of fenamiphos and the sulfone metabolite on the survival of the sting nematode Belonolaimus longicaudatus, the estimated LD_{50} for fenamiphos sulfone was 410 mg L^{-1}, compared to about 200 for fenamiphos itself. Comparisons of the sustained 14-day levels of these materials observed at three different depths in the USGA green with the LD_{50} data suggest that short term survival is not altered by the contact mode of action of either material when fenamiphos is applied at the currently labelled rate. Population supression of B. longicaudatus, when observed in the field, is probably due to temporary nematastasis or irreversible sublethal effects caused by contact action and/or the systemic action of the nematicide.

The data on the mobility and persistence of chlorpyrifos, isazophos, and isofenphos following two applications have not been fully analyzed, although some results can be reported. Chlorpyrifos leaching following the first application amounted to 0.15% of that applied. Leaching following the second application was only 1/10th that of the first. Generally, over 97% of the chlorpyrifos observed in the thatch-soil profile was found in the thatch. Approximately 0.014% of the applied isazophos and 0.008% of the applied isofenphos was found in the leachate following the 21 April application.

As much as 7.8% of the chlorpyrifos applied as a granular material was recovered with the clippings, whereas only 0.5% of that applied was found when a liquid formulation was used. Fonofos removal in clippings was 1.2% of applied for a granular material. Isazophos and isofenphos recovery in clippings amounted to 0.4 and 0.8% of that applied as a liquid.

In the study on the dislodgeability of pesticides applied to bermudagrass, for pressures of 10 kPa or greater, more chlorpyrifos and isazophos removal was obtained on wet cotton than on dry, and wet cotton removed more pesticide than wet polyester. There were no significant differences between dry cotton and dry polyester. Sliding wet cotton, leather, or polyester for 1 m over the turf surface resulted in more total removal of chlorpyrifos and isazophos than was obtained without sliding. However, when calculated on the basis of turf area contacted, motion had no significant effect on pesticide removal.

SUMMARY TABLE 1

Loss of pesticide in percolate waters obtained in lysimeters installed in a sand-soil USGA-green with 'Tifdwarf' bermudagrass (Cynodon dactylon X C. transvaalensis) turf, expressed as active ingredient (AI) on a unit area basis and as a percent of that applied.

Application date	Sampling duration	Pcpn/ irr.	Percolation	Pesticide	Formulation	Rate (AI)	Pesticide loss	
D/M/Y	days	- - mm - -				g m^{-2}	ug m^{-2}	%
13/11/91	75	350	340	Fenamiphos	10G	1.13	701	0.062
				Fen. metabolite		-	199038	17.69*
				Fonofos	5G	0.44	4	< 0.001
27/1/92	85	493	269	Fenamiphos	10G	1.13	419	0.037
				Fen. metabolite		-	12326	1.10*
				Fonofos	5G	0.44	103	0.023
				Chlorpyrifos	1G	0.12	176	0.150
21/4/92	66	407	253	Chlorpyrifos	2E	0.23	17	0.007
				Isazophos	4E	0.23	31	0.014
				Isofenphos	2E	0.23	18	0.008

* Expressed relative to the parent (fenamiphos) applied

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SUMMARY TABLE 2

Recovery of pesticide in 'Tifdwarf' bermudagrass (Cynodon dactylon X C. transvaalensis) clippings from a USGA green following pesticide application, expressed as a percent of that applied.

Application date	Sampling duration	Pcpn/ irr.	Percolation	Pesticide	Formulation	Rate (AI)	Pesticide recovery
D/M/Y	days	- - mm - -				g m^{-2}	%
27/1/92	85	493	269	Fenamiphos	10G	1.13	0.38
				Fen. metabolite		-	0.14*
				Fonofos	5G	0.44	1.17
				Chlorpyrifos	1G	0.12	7.87
21/4/92	66	407	253	Chlorpyrifos	2E	0.23	0.52
				Isazophos	4E	0.23	0.43
				Isofenphos	2E	0.23	0.79

* Expressed relative to the parent (fenamiphos) applied

SUMMARY TABLE 3

Chlorpyrifos and isazophos dislodged from 'Tifgreen' bermudagrass turf 24 hours after application as liquid formulations at 0.057 and 0.228 g active ingredient m^{-2}, respectively, followed by 5 mm irrigation.

Treatment factor				
Material	Pressure	Moisture	Chlorpyrifos	Isazophos
	- kPa -		- - - - - ug m^{-2} - - - - -	
Cotton	5	Dry	14.3	3.2
		Wet	22.9	17.7
	10	Dry	10.0	2.8
		Wet	89.4	24.4
	20	Dry	23.6	19.0
		Wet	85.6	50.4
Polyester	5	Dry	13.1	2.5
		Wet	16.3	6.9
	10	Dry	4.7	3.9
		Wet	25.1	9.7
	20	Dry	21.0	27.6
		Wet	27.8	29.4

SUMMARY TABLE 4

Chlorpyrifos and isazophos dislodged at 10 kPa pressure from 'Tifgreen' bermudagrass turf 24 hours after application as liquid formulations at 0.057 and 0.228 g active ingredient m^{-2}, respectively, followed by 5 mm irrigation.

Treatment factor			Chlorpyrifos		Isazophos	
Material	Motion	Moisture	ug[a]	ug m^{-2}	ug[a]	ug m^{-2}
Cotton	Fixed	Dry	0.10	10.0	0.03	2.8
		Wet	0.89	89.4	0.24	24.4
	Slide	Dry	0.60	5.5	0.46	4.2
		Wet	2.31	21.0	2.11	19.2
Leather	Fixed	Dry	0.12	11.6	0.36	36.4
		Wet	0.61	61.0	0.41	41.4
	Slide	Dry	0.28	2.5	0.75	6.8
		Wet	2.39	21.7	3.43	31.1
Polyester	Fixed	Dry	0.05	4.7	0.04	3.9
		Wet	0.25	25.1	0.10	9.7
	Slide	Dry	1.15	10.4	1.07	9.7
		Wet	1.67	15.1	1.70	15.5

INTRODUCTION

During the first year of the project, six lysimeters were installed and tested in a USGA-type green at the Ft. Lauderdale Research and Education Center (FLREC), and methods were developed and tested for performing organophosphate pesticide analyses on water, soil, and thatch in the Pesticide Lab at the Everglades Research and Education Center (EREC) in Belle Glade, FL. Thus, by November 1991, the start of the present reporting year, everything was in place to evaluate the mobility and persistence of several organophosphate pesticides in the green at the FLREC.

Mobility and persistence studies followed application of fenamiphos (Nemacur) and fonofos (Dyfonate) on 13 November, 1991, and 27 January, 1992, chlorpyrifos (Dursban) application on 27 Jan. 1992, and again on 21 April 1992, isazophos (Triumph) and isofenphos (Oftanol) application on 21 April, 1992, and isazophos, isofenphos, and ethroprop (Mocap) application on 15 September 1992 (Table 1). The effect of material, moisture, and

Table 1. Pesticides used on the USGA green in persistence and mobility studies.

TRADE NAME	COMMON NAME	DATES APPLIED	FORM	RATE
				g AI m^{-2}
Nemacur	fenamiphos	13 Nov. 1991	10G	1.125
		27 Jan. 1992	10G	1.125
Dyfonate	fonofos	13 Nov. 1991	5G	0.439
		27 Jan. 1992	5G	0.439
Dursban	chlorpyrifos	27 Jan. 1992	1G	0.117
		21 April 1992	2E	0.229
Triumph	isazophos	21 April 1992	4E	0.229
		15 Sept. 1992	4E	0.229
Oftanol	isofenphos	21 April 1992	2E	0.229
		15 Sept. 1992	2E	0.229
Mocap	ethroprop	15 Sept. 1992	10G	2.245

motion on the dislodgeability of chlorpyrifos and isazophos from bermudagrass followed application of these materials on 6 April, 1992. An in vitro study on the effects of fenamiphos or fenamiphos sulfone on the survival of sting nematodes was conducted during this reporting period in cooperation with Dr. Robin Giblin-Davis. In all, over 1,400 samples of water, soil, thatch, grass clippings, or cloth have been analyzed during the

past year for from three to six pesticides per sample. While data from some of these studies remains to be analyzed, the following can be reported at this time.

FENAMIPHOS AND FONOFOS MOBILITY AND PERSISTENCE

MATERIALS AND METHODS

On 13 Nov. 1991, fenamiphos (Nemacur) and fonofos (Dyfonate, as Crusade) were applied at the recommended rates (11.25 and 8.8 g m^{-2} of the fenamiphos 10G and fonofos 5G formulations, respectively) to the USGA-type green at the FLREC fitted with lysimeters for collecting percolate (described in the 1991 Annual Report) using a 1.07-m Gandy Turf Tender spreader. On 27 Jan., 1992, the same materials were applied at the same rate with a cone-type distributor that deposited a pre-weighed amount of granular pesticide over a 0.61-m swath. Both applications were designed to prevent overlapping in the vicinity of the lysimeters, which were centered in treated plot areas 3.21 x 4 m. Both applications began approximately 10:30 AM and were completed by noon.

Following application of the pesticides on each date, the green was irrigated to provide approximately 18 mm of water over a 22-minute period. Thereafter, irrigation and all other maintenance operations were controlled by an employee of the South Florida and Palm Beach Golf Superintendents Association, following instructions obtained from a committee of golf course superintendents.

Approximately 3:00 P.M. on the afternoon of the application days, soil and thatch samples were taken from the plot area using a 1.9 cm-diameter nickel-plated soil corer. Three sets of samples, each comprised of three thatch-soil cores composited over two plots, were collected and divided into the thatch, 0-5, 5-10, and 10-15 cm soil depths. The samples (three core sections each) were placed in 475-ml wide-mouth glass jars closed with metal lids. Thatch and soil samples were similarly collected 1, 3, 5, and 7 days after the first pesticide application and 3, 7, and 10 days after the second. Thereafter for each application, samples were taken at least weekly through 20 Apr. 1992. Soil samples were placed in a freezer (-20 C) until they could be transported on ice to a similar freezer in the Pesticide Lab in Belle Glade (generally within one week of sampling). Percolate water samples were collected from the lysimeters just prior to pesticide application, and again 1, 5, and 8 days after the first application and 7, 10, and 14 days after the second. Thereafter, water samples generally were collected from the lysimeters twice weekly; more often during rainy periods and less often during dry periods when no percolate could be expected. Pesticides were extracted from water samples within 24 hours of sampling

(generally on the same day) with methylene chloride. The extracts were stored in a refrigerator (4 C), or, later in the study, in a freezer, until they could be transported on ice to the Pesticide Lab for analysis.

In the laboratory, pesticides in the thatch and soil samples were extracted with a sulfuric acid - methanol mixture, which then was extracted with methylene chloride. The methylene chloride extracts of water, thatch, and soil were concentrated in a vacuum rotary-evaporator and analyzed by gas chromatography (GC) (Hewlett-Packard 5980A).

RESULTS AND DISCUSSION

The amount of fenamiphos in the combined thatch and soil declined rapidly following each application (Fig. 1A, 1B). Two metabolites of fenamiphos are known; a sulfoxide and a sulfone. These metabolites, determined as co-elutents, were detected in the thatch-soil column on the day of the first application, and their concentration increased rapidly during the following week. Thereafter, the combined concentration of these metabolites declined, but remained higher than that of the parent (fenamiphos) compound throughout most of the first-application study period (Fig. 1A). Peterson et al. (1986) also observed higher metabolite, relative to parent, concentration several weeks after fenamiphos application. Following the second application (Fig. 1B), the concentration of the metabolites increased somewhat, but did not reach the high levels that followed the first application. Fonofos in the thatch-soil column decreased rapidly for the first 5 days after each application, and then more slowly thereafter (Fig. 1A, 1B).

Most of the fenamiphos, and especially the fonofos, in the thatch-soil column was found in the thatch, except that the proportion of fenamiphos in the thatch declined somewhat towards the end of the second study period (Fig. 1C, 1D). The fenamiphos metabolites (sulfoxide + sulfone), on the other hand, were found primarily in the soil portion one week or more after pesticide application, because these materials are more water soluble, and therefore more mobile, than the fenamiphos and fonofos. The time required for observation of the peak in metabolite concentration generally increased with soil-profile depth, whereas the magnitude of the peak concentration generally decreased with increasing depth (Fig 2A, 2B). That the metabolites are less-well adsorbed by organic residues, thatch in this case, than the parent compound or than fonofos is supported by the leachate data (Fig. 2C, 2D). Very little fonofos was detected in leachate. The maximum concentration of fenamiphos in leachate was 8 parts per billion (ppb). The combined sulfoxide and sulfone concentration in leachate, on the other hand, approached 2300 ppb three weeks after the first application of fenamiphos, and

remained over 200 ppb nearly seven weeks after that application. Less fenamiphos metabolite was detected following the second fenamiphos application (Fig. 1F), although once again, considerably more fenamiphos metabolite than fenamiphos-parent compound was found in leachate. Assuming that fenamiphos was applied at 1,125,000 ug M^{-2}, and using the data for total metabolite found in percolate (Table 2), then 17.7% of the applied fenamiphos was found as metabolites in percolate following the first application, whereas only 1.1% was detected in percolate after the second. It has been documented elsewhere that fenamiphos degradation is enhanced by even a single application, which may, along with reduced percolation, explain why less metabolite was found in percolate following the second application.

Because of imperfect distribution of irrigation water and various unknown factors, the total quantity of percolate measured in the six lysimeters over the study periods varied from 245 to 499 mm, averaging 340 mm of percolation in the first study, and from 190 to 420 mm, averaging 269 mm in the second. Since rainfall during the two periods totaled only 149 and 191 mm, respectively, excessive irrigation is indicated. There was a significant ($P < 0.05$) positive linear relationship between the quantity of metabolite leached and the quantity of percolate collected over each of the two study periods ($R^2 = 0.80$ and 0.83 for the first and second period, respectively).

Regarding the pesticides examined in this study, the metabolites of fenamiphos pose the greatest potential for off-site environmental contamination. Loss of the metabolites from the root zone also is likely to reduce the duration of nematicidal activity. The relationship observed between metabolite leaching and percolation suggests that leaching may be lessened by reducing percolation through the judicious use of irrigation.

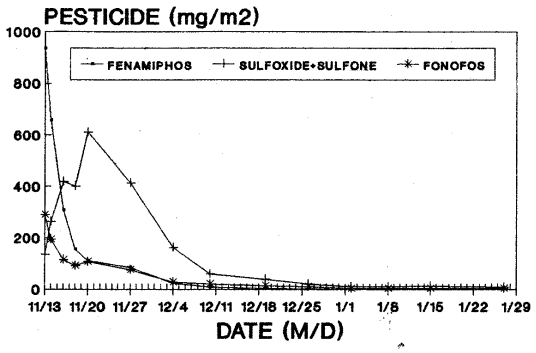
Table 2. Summary of hydrological data and pesticide leaching for the two pesticide application periods.

Item	Application 1	Application 2
Hydrologic data (mm)		
Rainfall	149	191
Irrigation*	201	302
Percolation	340	269
Pesticide leaching (ug M^{-2})		
Fenamiphos parent	701	419
Fenamiphos metabolites	199,038	12,326
Fonofos	4	103

*Based on irrigation time records, assuming 0.8 mm min^{-1}.

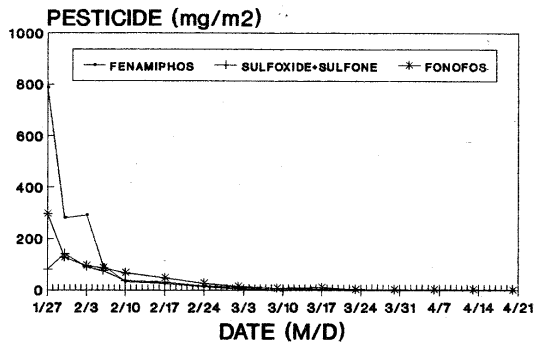
Fig. 1. Fenamiphos, fenamiphos metabolites, and fonofos in thatch and soil, following the first (A, C) and second (B,D) applications

TOTAL PESTICIDE IN THATCH AND SOIL



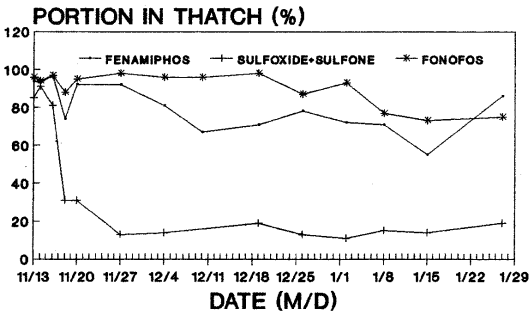
A.

TOTAL PESTICIDE IN THATCH AND SOIL



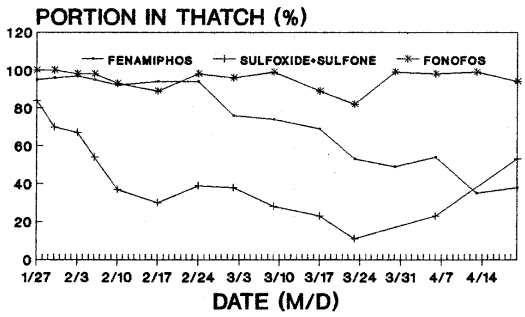
B.

PORTION OF PESTICIDE IN THATCH LAYER



C.

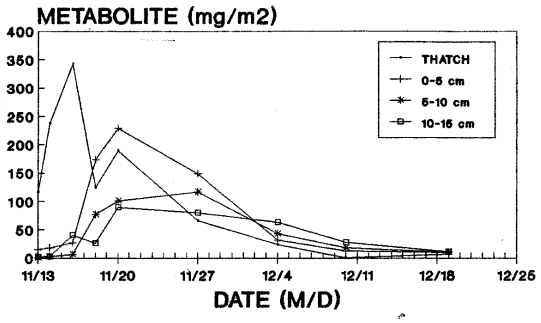
PORTION OF PESTICIDE IN THATCH LAYER



D.

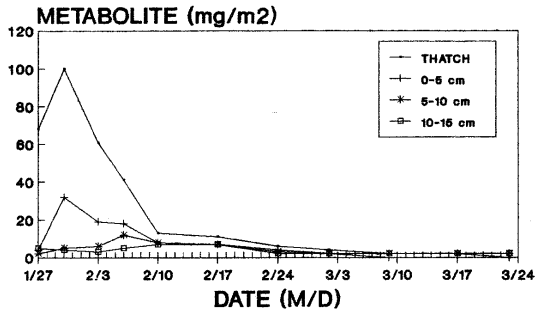
Fig. 2. Fenamiphos metabolites in the soil profile, and fenamiphos, fenamiphos metabolites, and fonofos in percolate water, following the first (A, C) and second (B, D) applications.

FENAMIPHOS METABOLITE IN VARIOUS SOIL LAYERS



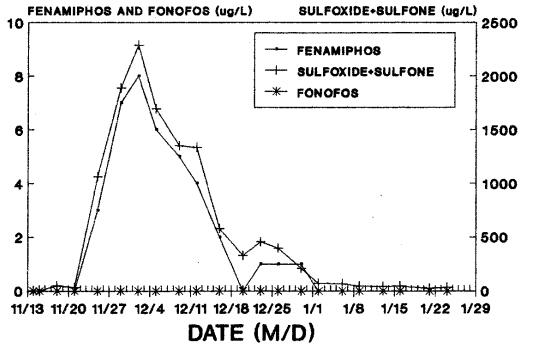
A.

FENAMIPHOS METABOLITE IN VARIOUS SOIL LAYERS



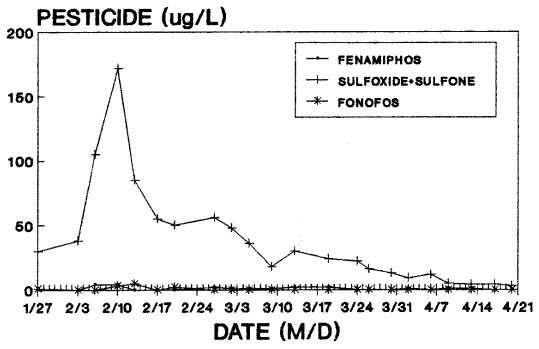
B.

PESTICIDE IN PERCOLATE



C.

PESTICIDE IN PERCOLATE



D.

EFFECTS OF FENAMIPHOS OR FENAMIPHOS SULFONE ON THE SURVIVAL OF THE STING NEMATODE Belonolaimus longicaudatus IN VITRO

Because of the observation that fenamiphos was rapidly converted to metabolites and the high level of metabolite that was measured in the USGA green, Dr. Robin Giblin-Davis of the FLREC conducted a study of the effect of parent and metabolite concentrations on the survival of sting nematodes. The Pesticide Lab at Belle Glade produced fenamiphos sulfone for this study, and determined the concentration of fenamiphos parent and metabolite in the treatments.

METHODS AND MATERIALS

Fenamiphos was obtained as technical grade 10G from Mobay Chemical Corp., Kansas City, MO. A starting solution of 350 ppm of fenamiphos, representing maximum solubilty in deionized water, was prepared by acetone extraction of the technical grade material, rotary evaporative removal of the solvent, and resuspension in deionized water with two centrifugations at 10,000X for 15 min each. The supernatant was checked for final concentration of fenamiphos by extraction with methylene chloride, and analysis with gas chromatography (GC) on a Hewlett-Packard 5890A gas chromatograph with dual column dual NP detector. A dilution series was done resulting in test concentrations of 350.00, 85.00, 8.50, 0.85, 0.09, and 0.00 ppm of fenamiphos.

Fenamiphos sulfone was synthesized by permanganate oxidation of fenamiphos and the permanganate was removed as follows; 1 ml of the above mentioned fenamiphos supernatant was diluted to 50 mls with acetone, 500 mls of 0.1 M $KMnO_4$ and $MgSO_4$ were added and incubated at room temperature for 2 h, extracted with methylene chloride, rotary evaporated to dryness, resolubilized in 5 mls of acetone and rotary evaporated to dryness three times, and solubilized in deionized water as described for fenamiphos. The starting concentration of fenamiphos sulfone was checked as described above. A dilution series was done resulting in 410.00, 100.00, 10.00, 1.00, and 0.10 ppm of fenamiphos sulfone.

Belonolaimus longicaudatus was cultured on FX-313 St. Augustinegrass, Stenotaphrum secundatum (Walt.) Kuntze, in square tapered pots (8.0 cm wide at the top, 6.0 cm wide at the bottom, and 7.5 cm deep) filled with autoclaved Margate fine sand (siliceous, hyperthermic, Mollic Psammaquent, pH 6.5, 3.8% OM) for 126 days. Nematodes were harvested from the soil using the centrifugal-flotation method and 48-53 nematodes (mostly adult males and females [1:1 sex ratio]) were handpicked and placed into 2000 ul of a test concentration of fenamiphos or

fenamiphos sulfone in small glass dishes with lids. After 14 days at 22-26 C, nematodes were handpicked from each solution into deionized water and examined for appearance and movement. Nematodes not responding to probing or lifting from the water several times with a minuten pin probe were counted as dead. There were four replicates in time for each compound and each dose. After the nematodes had been removed from each dish, a 1000 ul aliquot of each solution was removed for verification of concentration. Samples for each concentration of each compound were sequentially pooled and mixed with methylene chloride and kept frozen at -20 C until final analysis with GC.

Based upon data obtained in the study in which fenamiphos was applied to the USGA green at the FLREC, the concentrations (ppm) of fenamiphos and fenamiphos sulfone/sulfoxide present at 0-5, 5-10, and 10-15 cm depths in a USGA-type green after treatment with the maximum labelled rate of fenamiphos 10G (11.25 kg a.i./ha) were estimated (Fig. 3). Several assumptions were made in preparing these estimates. The mean volumetric water contents (%) at 20, 30, and 45 cm pressure for both 5 and 10 cm sample depths were pooled to calculate a mean volumetric water content of 11% for the soil of the USGA-type green receiving frequent irrigation. The average bulk density of the green for both 5 and 15 cm soil depths (1.70 g/cm3) was used, and calculations were based upon means of soil dry weight and total extractable pesticide from each soil depth for each sample time period. The amount of pesticide that was available in the soil water may have been somewhat overestimated because total extractable pesticide is not necessarily available in the aqueous phase. However, it appears that presentation of the ppm of pesticide relative to the available soil water under adequate irrigation is more biologically relevant than presentation of the ppm of pesticide relative to soil volume. The reader can quickly convert ppm soil water in Fig. 3 to ppm soil by dividing by 9.09.

RESULTS AND DISCUSSION

There were acute mortality differences between fenamiphos and fenamiphos sulfone on B. longicaudatus after 14 days in vitro. A preliminary estimate of the LD_{50} for fenamiphos sulfone in the 14 day bioassay was 410 ppm compared with about 200 ppm for fenamiphos (Fig. 4). This supports the assumption that both fenamiphos and fenamiphos sulfone are pesticidal. Concentrations of fenamiphos were low (generally <1 ppm) during the first field application of fenamiphos and even lower during the second application (Fig. 3). These levels would have had no acute survival effects for B. longicaudatus (Fig. 4). The fenamiphos oxidative metabolites were in much higher abundance in the first application cycle compared with the fenamiphos parent compound with sustained periods (14 days) of >25 ppm for the 0-5

cm depth, and levels of >15 ppm for the 5-10 and 10-15 cm depths (Fig. 1.). These levels were sufficiently high for possible nematastasis or some irreversible effects, but not for acute toxicity (Fig. 4). It has been reported that short term (24 h) exposure to fenamiphos between 10 and 100 ppm caused irreversible effects on the ability of the stem and bulb nematode, Ditylenchus dipsaci (Kuhn), to penetrate bean stems and that a 24 h exposure to 64 ppm caused a significant reduction in the reproduction of D. dipsaci. The ability of the nematodes used in this 14-day in vitro assay to grow on FX-313 St. Augustinegrass is currently being investigated. The second application cycle yielded much lower concentrations of fenamiphos and its oxidative metabolites (Fig. 3) suggesting enhanced biodegradation. These low levels of fenamiphos and its metabolites probably would have had only minor contact effects on B. longicaudatus.

In a previous study, 'Tifgreen' bermudagrass grown in Ft. Lauderdale, FL which was kept at a 0.65 cm mowing height had >99% of its root biomass (dry weight) in the top 0-5 cm. Twenty-six percent of the sting nematodes recovered came from the top 0-5 cm, 28% from 6-10 cm, 32% from 11-20 cm, and 14% from 21-30 cm. Considering the vertical distribution of the roots relative to B. longicaudatus, the vertical distribution of fenamiphos sulfone/sulfoxide in the first application cycle (Fig. 3), and our acute toxicity data (Fig. 4), the acute contact effects of pesticide exposure would have probably lasted for a maximum of about 14 days and would have been minimal during the second application cycle.

A major limitation to an in vitro assay with B. longicaudatus is that it only measures acute contact activity of a nematicide. Fenamiphos is a systemic and contact nematicide and population suppression of a target nematode may be due to sublethal or lethal effects caused when a nematode contacts residues during interactions with plant fluids or surfaces (Bunt, 1975). It has been reported that total residues of fenamiphos in turfgrass (Poa annua L.) clippings peaked at 7 days (200 ppm on a dry weight basis) and that fenamiphos sulfone and sulfoxide peaked at 14 days with 200 and 800+ ppm, respectively when fenamiphos 15G was applied at a rate of 22.7 kg a.i./ha. Assuming a linear rate-related decrease in concentration, wet to dry weight ratio of 10:1, and equal distribution of the pesticide in the clippings and roots, these peak levels of fenamiphos and its metabolites would have ranged from 10 to 40+ ppm which might be high enough for potential irreversible effects on nematodes, depending upon the length of exposure. However, even if these levels were available to nematodes in the roots there still could have been about 74% of the population of B. longicaudatus (those in the 6-30 cm soil depth) that might not have been affected systemically because 99% of the roots are in the top 5 cm of soil. Thus, most of the B. longicaudatus might not have been in a position to be seriously impacted by contact or systemic

activity from an application of fenamiphos at the rate used in this study, especially after a prior treatment with fenamiphos. It has been reported that mineralization of fenamiphos was significantly enhanced after one field application and that enhancement lasted at least three years.

There are environmental risks to the use of fenamiphos for management of phytoparasitic nematodes because of the relatively low LD_{50} values for mammals, birds, and fish (rat; oral: 2-3 mg/kg) and the possibility for misapplication or groundwater contamination. Lower rates of application, enhanced biodegradation, and improper turfgrass management, such as overirrigation, appear to limit the potential efficacy of this material for managing B. longicaudatus in turfgrass in Florida. Alternative management strategies are needed for the control of phytoparasitic nematodes in turfgrass.

Fig. 3. Fenamiphos and fenamiphos sulfone/sulfoxide concentrations recovered at different depths in the soil profile.

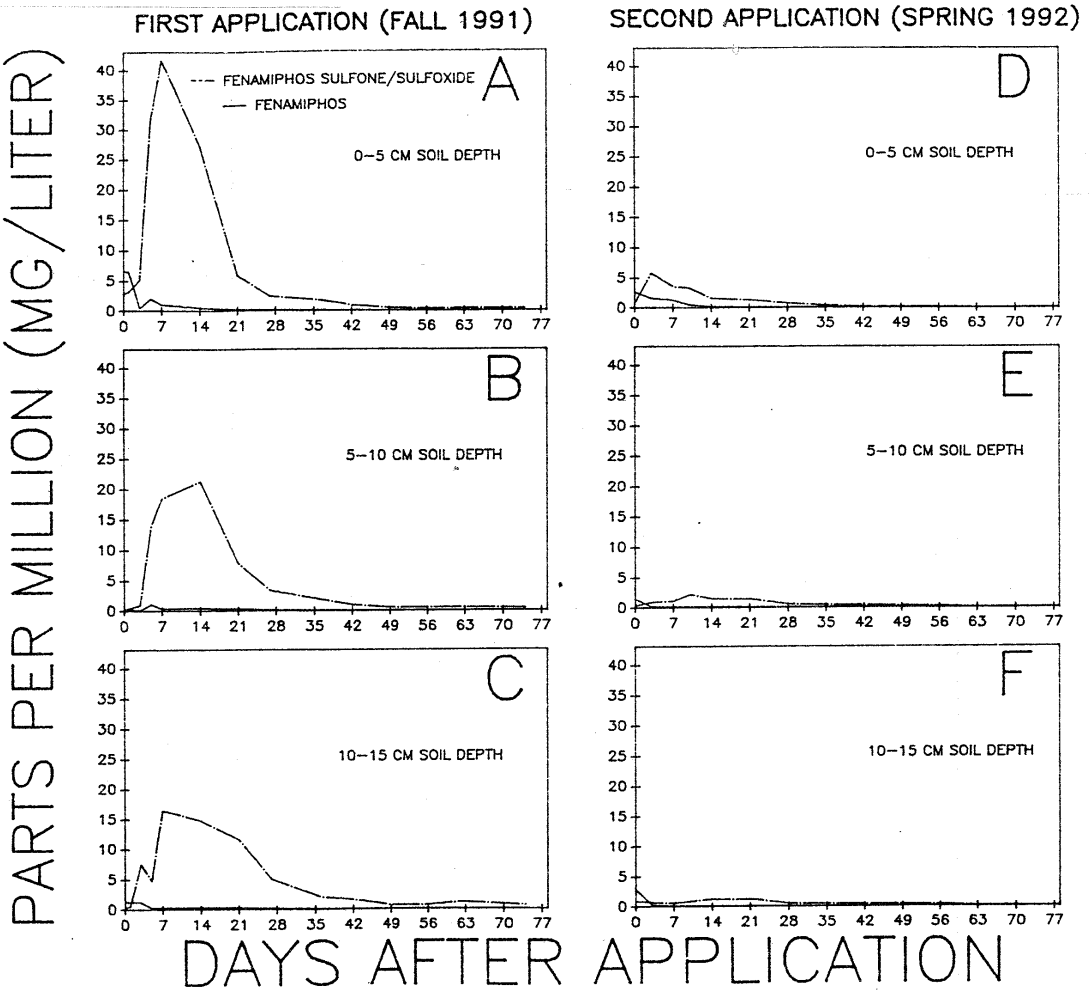
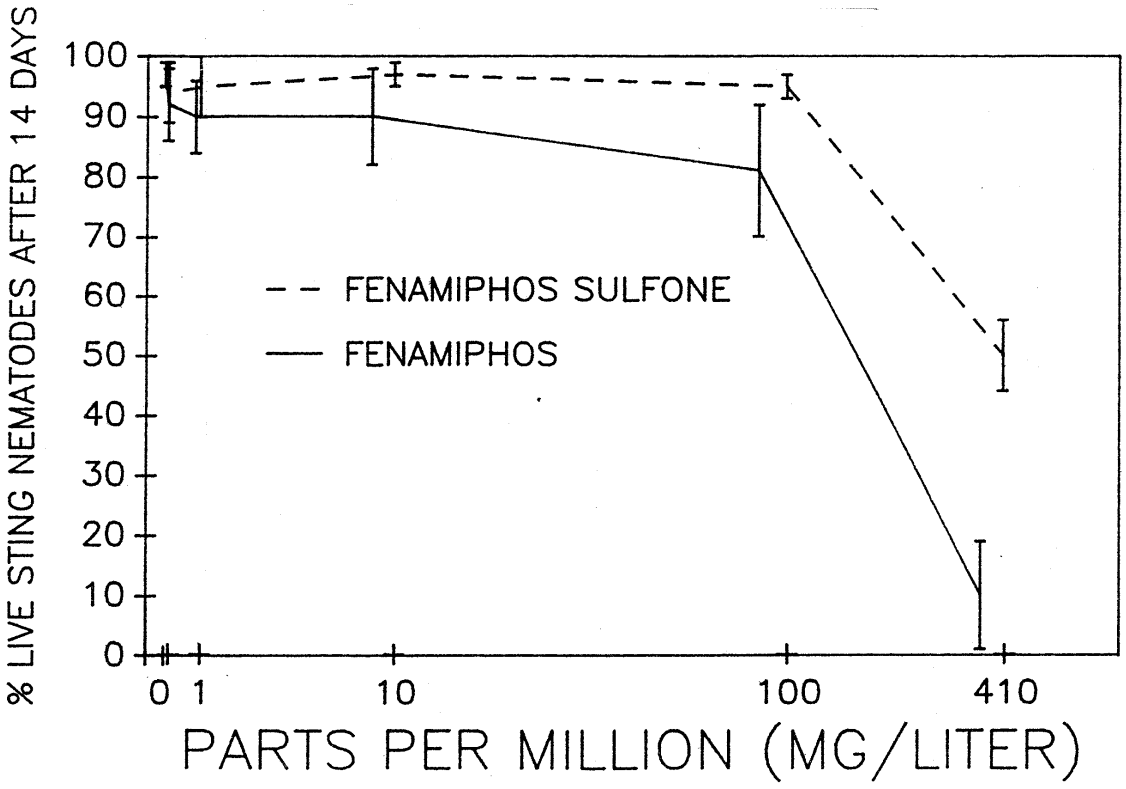

FIRST APPLICATION (FALL 1991)
SECOND APPLICATION (SPRING 1992)
PARTS PER MILLION (MG/LITER)
--- FENAMIPHOS SULFONE/SULFOXIDE
— FENAMIPHOS
A
0–5 CM SOIL DEPTH
B
5–10 CM SOIL DEPTH
C
10–15 CM SOIL DEPTH
D
0–5 CM SOIL DEPTH
E
5–10 CM SOIL DEPTH
F
10–15 CM SOIL DEPTH
0 7 14 21 28 35 42 49 56 63 70 77
0 5 10 15 20 25 30 35 40
DAYS AFTER APPLICATION

Fig. 4. Percentage survival of Belonolaimus longicaudatus after 14 day exposures to different concentrations of fenamiphos or fenamiphos sulfone.


% LIVE STING NEMATODES AFTER 14 DAYS
100
90
80
70
60
50
40
30
20
10
0
FENAMIPHOS SULFONE
FENAMIPHOS
0 1
10
100
410
PARTS PER MILLION (MG/LITER)

CHLORPYRIFOS, ISAZOPHOS, AND ISOFENPHOS MOBILITY AND PERSISTENCE

MATERIALS AND METHODS

Chlorpyrifos (Dursban) was applied to the green as a 1G material at 0.117 g A.I. m^{-2} on 27 Jan. 1992, along with the fenamiphos and fonofos application that was described above, and again on 21 April 1992 as a 2E liquid at 0.229 g A.I. m^{-2}, along with Isazophos (as Triumph 4E) at 0.229 g A.I. m^{-2} and Isofenphos (Oftanol 2E) at 0.229 g A.I. m^{-2}. Soil and water samples were taken and processed as has been previously described. The data have been completely analyzed for the first chlorpyrifos application, and the percolate data have been analyzed through 5 June 1992 for the second chlorpyrifos application and for the isazophos and isofenphos application.

RESULTS AND DISCUSSION

Chlorpyrifos leaching following application on 27 Jan. 1992, was low (Table 3), and was even lower following the second application (21 April 1992). Leaching of isazophos and isofenphos following the 21 April 1992 application was even less (Table 3). Generally, over 97% of the chlorpyrifos observed in the thatch-soil column following the 27 Jan. application was found in the thatch, which helps explain the general lack of this pesticide in the leachate.

Table 3. Summary of hydrological data and pesticide leaching for applications on 27 Jan and 21 April 1992,.

Item	27 Jan - 20 April	21 April - 5 June
Hydrologic data (mm)		
Rainfall	191	46
Irrigation*	302	361
Percolation	269	253
Pesticide leaching (ug M^{-2})		
Chlorpyrifos	176	17
Isazophos	-	31
Isofenphos	-	18

*Based on irrigation time records, assuming 0.8 mm min^{-1}.

REMOVAL OF FENAMIPHOS, FENAMIPHOS METABOLITES, FONOFOS, CHLORPYRIFOS, ISAZOPHOS, AND ISOFENPHOS IN CLIPPINGS

METHODS AND MATERIALS

Following the application of fenamiphos, fonofos, and chlorpyrifos on 27 Jan. 1992, and chlorpyrifos, isazophos, and isofenphos on 21 April 1992, as has been described above, a clipping sample was retained from each mowing of the treated area. A 20 g (fresh weight) portion of each sample was placed in a 475-ml wide-mouth jar and frozen until it could be transported on ice to the Pesticide Lab for analysis. The balance of the sample was weighed, oven dried, and re-weighed to determine the moisture content. The area sample was noted (generally 23.47 m^{-2}).

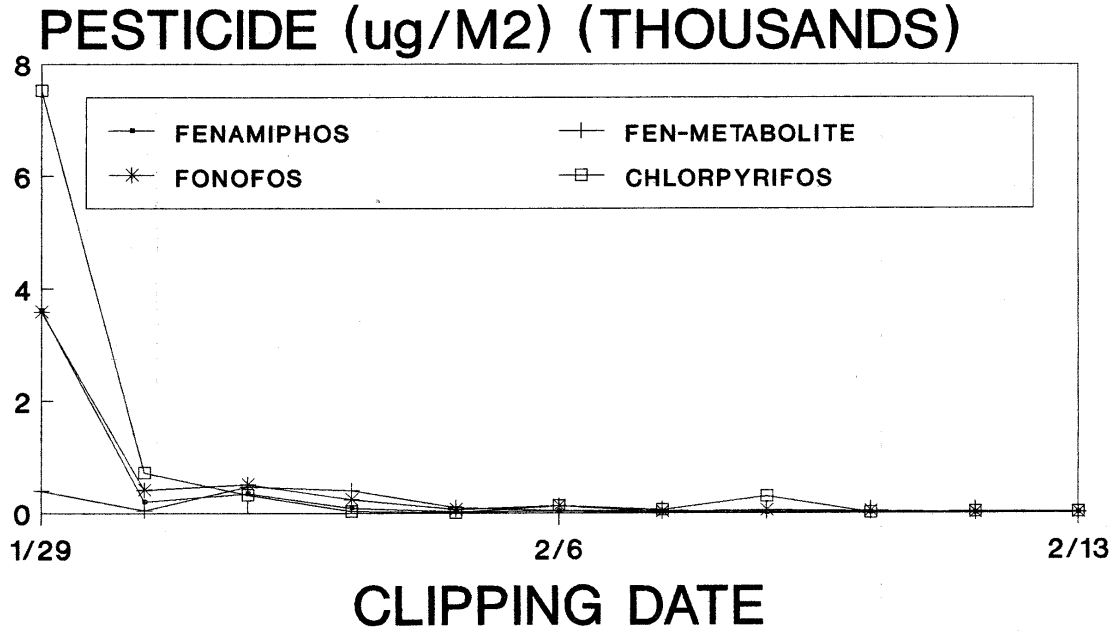
In the lab, the clipping sample was macerated three times in a blender in the presence of a methanol-sulfuric acid solution, and filtered. The combined filtrates were extracted three times with methylene chloride. The extract was reduced in volume by rotoevaporating, and the sample was analyzed by GC for the pesticides of interest. Pesticide amounts were calculated on a weight basis and on an area basis.

RESULTS AND DISCUSSION

As would be expected, the quantity of pesticide removed with the clippings was greatest for the first clipping after application, and decreased rapidly thereafter (Fig. 5, 6). In some cases, an appreciable amount of pesticide was removed in the clippings over the sampling period following pesticide application (Table 4). The higher value for the first application of chlorpyrifos may have been the result of granules having been removed with the clippings. Chlorpyrifos was applied as a liquid on the second application (21 April). Clippings removed the day after application of fonofos and chlorpyrifos as granules contained 0.87 and 1.82 mg kg^{-1} of these pesticides, respectively, expressed on a dry weight basis, whereas following application of chlorpyrifos, isazophos, and isofenphos as liquids the next-day clippings contained 0.12, 0.14, and 0.29mg kg^{-1} of the pesticides, respectively.

Fig. 5. Quantity of fenamiphos, fenamiphos metabolite, fonofos, and chlorpyrifos in clippings following application on 27 January 1992.

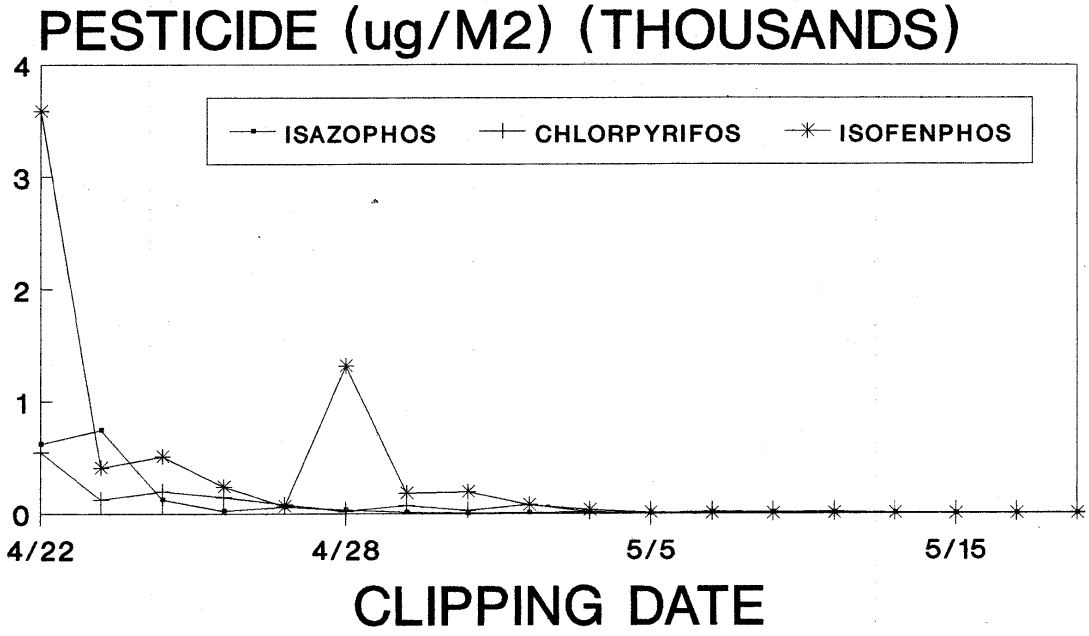
PESTICIDE REMOVED WITH CLIPPINGS



1992

Fig. 6. Quantity of chlorpyrifos, isazophos, and isofenphos in clippings following application of 21 April 1992.

PESTICIDE REMOVED WITH CLIPPINGS



1992

Table 4. Accumulative quantity of pesticide removed with clippings during two application cycles.

Study period	Pesticide	Application rate	Amount removed
		g A.I. m^{-2}	% of applied
27 Jan. - 21 Apr.	Fenamiphos	1.125	0.38
	Fenamiphos metabolite	-	0.14*
	Fonofos	0.439	1.17
	Chlorpyrifos	0.117	7.87
21 Apr, - 5 June	Chlorpyrifos	0.229	0.52
	Isazophos	0.229	0.43
	Isofenphos	0.229	0.79

* Calculated as a percent of fenamiphos applied.

EFFECT OF MATERIAL, PRESSURE, AND MOTION ON THE DISLODGEABILITY OF CHLORPYRIFOS AND ISAZOPHOS FROM BERMUDAGRASS

INTRODUCTION

Dislodgeability refers to movement of pesticide from leaf surfaces following application. While pesticides designed for soil application need to be dislodged from the foliage, transfer of pesticides to persons utilizing the turf generally is undesirable. In the present study, for which supplemental funding was received from the Florida Turfgrass Association, transfer of pesticide from leaf surfaces to materials frequently used as wearing apparel was studied as a function of pressure, moisture, and motion.

METHODS AND MATERIALS

Chlorpyrifos and isazophos were applied to a 2.25 by 4.0 m (7.4 by 13 feet) area of 'Tifgreen' bermudagrass approximately 100 m WSW of the USGA green that was mowed at 1.25 cm (0.5 inch) height. Chlorpyrifos and isazophos were applied as Dursban 2E and Triumph 4E, respectively, at the label rates of 0.24 and 0.48 ml m^{-2} (0.75 and 1.5 oz. per 1000 ft^2) of product, respectively, followed by an irrigation of approximately 0.5 cm (0.2 in.). Twenty-four hours later, an attempt was made to dislodge the pesticides onto cotton, polyester, or leather that was either wet or dry. There were two replications. The methods used for dislodging the pesticides were pressure, either with or without motion. Pressure at 5, 10, and 20 kPa (0.73, 1.45, and 2.90 lb. in^{-2}) was applied for 10 sec. over a 10 cm square metal plate. The cloths, wrapped around the metal plate and attached on the top side with magnets, were separated from the plate by a layer of aluminum foil to prevent contamination of the plate. Leather was tested only at 10 kPa pressure. Motion consisted of sliding the plates at 10 kPa pressure for 1 m over a 10 sec. period.

Following the dislodgeability treatment, the cloths and aluminum foil were removed from the metal plate, placed in 500 ml (1 pint) glass jars which were capped, transported to the laboratory in Belle Glade, and placed in a freezer (-20 C) prior to analysis.

For each sample, the cloth and foil were removed from the glass container, sliced with scissors into pieces approximately 1 cm square, and returned to the container. Pesticides were extracted from the cloths with three portions of a methanol-sulfuric acid solution, and the combined extracts were themselves extracted three times with methylene chloride. The combined

methylene chloride extract was roto-evaporated to 10 ml volume and analyzed for chlorpyrifos and isazophos by gas chromatography.

RESULTS AND DISCUSSION

All three treatment factors, i.e., material (cotton and polyester), pressure (5, 10, and 20 kPa), and moisture (wet or dry), significantly affected the quantity of chlorpyrifos dislodged, whereas only pressure and moisture affected the quantity of chlorpyrifos dislodged (Table 5). Moist cloth generally dislodged more pesticide than dry cloth. More pesticide was dislodged at the higher pressures. Some significant interactions were observed among the treatment factors. For example, wet cotton generally dislodged more pesticide than did wet polyester, whereas only a similar, but less distinct, trend was observed for the dry materials.

Interpretation of the experiment involving fixed and sliding pressure depends on how dislodged pesticide is calculated. Sliding motion generally increased the total amount of pesticide transferred to the material (Table 6). However, since sliding increased by a factor of 11 the turf area contacted by the material, on a turf area basis sliding reduced the amount of pesticide transferred (Table 6). As in the first experiment, some treatment interactions were observed. It should be noted that very little pesticide was dislodged onto materials by any of the treatments. For example, chlorpyrifos was applied at the rate of 0.057 g active ingredient m^{-2}, or 57,000 ug m^{-2}. The maximum amount dislodged was 89 ug m^{-2} by wet cotton, i.e. 0.16% of that applied.

The experiments reported herein were conducted to obtain preliminary information on the major factors affecting pesticide dislodgeability. Future studies will concentrate on a limited range of these factors imposed over an extended time period after pesticide application. Not reported here are the results of several preliminary studies designed to mimic "real life" situations such as walking, kneeling, and putting a golf ball on pesticide-treated turf. These studies will be continued and expanded.

Table 5. Effect of material, pressure, and moisture on chlorpyrifos and isazophos dislodged from turfgrass 24 hours after application.

Treatment factor				
Material	Pressure	Moisture	Chlorpyrifos	Isazophos
	- kPa -		- - - - - ug m^{-2} - - - -	
Cotton	5	Dry	14.3	3.2
		Wet	22.9	17.7
	10	Dry	10.0	2.8
		Wet	89.4	24.4
	20	Dry	23.6	19.0
		Wet	85.6	50.4
Polyester	5	Dry	13.1	2.5
		Wet	16.3	6.9
	10	Dry	4.7	3.9
		Wet	25.1	9.7
	20	Dry	21.0	27.6
		Wet	27.8	29.4
$LSD_{0.05}$			22.2	20.5

Statistical significance of main factors and their interactions		
Material	**	NS
Pressure	**	**
Moisture	**	**
Material x pressure	*	NS
Material x moisture	**	*
Pressure x moisture	**	NS
Material x pressure x moisture	*	NS

**, *, and NS refer to $P < 0.01$, 0.05 and $P > 0.05$, respectively.

Table 6. Effect of material, motion, and moisture at 10 kPa pressure on chlorpyrifos and isazophos dislodged from turfgrass 24 hours after application.

Treatment factor			Chlorpyrifos		Isazophos	
Material	Motion	Moisture	ug[a]	ug m^{-2}	ug[a]	ug m^{-2}
Cotton	Fixed	Dry	0.10	10.0	0.03	2.8
		Wet	0.89	89.4	0.24	24.4
	Slide	Dry	0.60	5.5	0.46	4.2
		Wet	2.31	21.0	2.11	19.2
Leather	Fixed	Dry	0.12	11.6	0.36	36.4
		Wet	0.61	61.0	0.41	41.4
	Slide	Dry	0.28	2.5	0.75	6.8
		Wet	2.39	21.7	3.43	31.1
Polyester	Fixed	Dry	0.05	4.7	0.04	3.9
		Wet	0.25	25.1	0.10	9.7
	Slide	Dry	1.15	10.4	1.07	9.7
		Wet	1.67	15.1	1.70	15.5
$LSD_{0.05}$			1.51	28.0	1.51	20.0
Statistical significance of main factors and their interactions						
Material			NS	NS	NS	**
Motion			**	**	**	NS
Moisture			**	**	**	**
Material x motion			NS	NS	NS	*
Material x moisture			NS	NS	NS	NS
Motion x moisture			NS	**	*	NS
Material x moisture x moisture			NS	NS	NS	NS

[a] Per sample cloth, regardless of turf area contacted. **, *, and NS refer to $P < 0.01$, 0.05 and $P > 0.05$, respectively.