EVALUATION OF THE POTENTIAL MOVEMENT OF PESTICIDES FOLLOWING APPLICATION TO GOLF COURSES

1993 ANNUAL REPORT

SUBMITTED TO: United States Golf Association, Greens Section Research Committee.

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EXECUTIVE SUMMARY

The 1993 annual report includes a total file including the project proposal, 1991 and 1992 annual reports, the semi-annual reports, and publications that have been published, are in press, or have been submitted for review toward publication. This USGA funded project has been in progress for three years and is in the final year of funding. Much of the progress has been made in the development of a first class research facility for the determination of the potential movement of pesticides following application to golf course greens and fairways. We will submit the final report in February which will include final compiled data for the proposed research. Additional, information to be included in the final report will be the greenhouse analyses of chlorpyrifos and chlorothalonil treatments to the simulated golf course greens, additional data on dithiopyr, and data from the first runoff studies using the treatments of 2,4-D, dicamba, and mecoprop. The proposed research will be continued through next summer to allow for duplication of all experiments necessary for preparation of manuscripts toward publication and USGA will be acknowledged in all publications and copies of the publications will be forwarded to the Greens Committee. At this time, all objectives in the proposal will have been concluded and the data published or submitted for publication. In future years, the research will be further expanded to include other compounds if funding can be obtained past next year.

The 1993 annual report: 1) summarizes the mecoprop data obtained from the greenhouse and field lysimeters developed to simulate pesticide movement from USGA golf course greens; 2) describes methods developed in the laboratory for the simultaneous analyses of 2,4-D, mecoprop, and dicamba to be used for water samples obtained from the run-off plots; 3) describes a method developed in our laboratory for the analyses of chlorpyrifos, chlorothalonil and the respective hydroxy metabolites; and 4) describes the run-off plots developed during the summer of 1993. The data for the chloropyrifos and chlorothalonil treatments conducted during the summer 1993 are about 4 days from completion and are not included in this report. The major problem has been the development of a method for the sequential analysis of chloropyrifos, chlorothalonil, and the hydroxy metabolites of each analyte. This method is presently in use and the samples will be completely processed in ca. 1 week.

Mecoprop was found only in the leachate samples from the greenhouse lysimeters. There was no mecoprop detected in the leachate collected from the field lysimeters. The concentration of mecoprop in the leachate from the greenhouse lysimeters did not exceed 5 $\mu g\ L^{-1}$ and the total quantity of mecoprop found to exit the lysimeters over the 10 week treatment period was 5.5 and 3.1 μg for the 85:15 and 80:20 (sand:peat) soil mixture, respectively. This represented 0.2 and 0.1%, respectively, of the mecoprop applied to the sampled area on the sod in the growth box above the lysimeters. The magnitude of mecoprop elutriated from the treated lysimeters in the greenhouse were similar to the 2,4-D elutriated during the same period (data in 1992 annual report).

In summary, the results of the 1992 greenhouse and field lysimeter treatments with 2,4-D, dicamba, and mecoprop indicate that only a very small quantity of the analytes elutriated from the lysimeters. This would infer that the dynamics of the microorganisms in the sod surface is greater than the GLEAMS model predicts and that use of these herbicides on golf course greens should not result in analyte concentrations in water, moving from the greens, near the Minimum Contamination Level for these herbicides.

The dithiopyr concentration in the effluent water from the field lysimeters was extremely lot. Less than 0.3% of the herbicide applied to the surface of the bermudagrass and bentgrass lysimeters exited the lysimeters over the 10 week period. The concentration in the effluent water was below 3.0 ppb at all sample periods and would be considered negligible. The low water solubility and high K_{oc} for dithiopyr would indicate that very little would exit the lysimeters.

INTRODUCTION

The public demand for high quality turfgrass and uniform playing surfaces on golf courses often requires the use of intensive management to control pests. Additionally, the increasing interest by the general public for the environmental impact of certain management practices used at golf courses is a major concern for the research and regulatory institutions responsible for turfgrass management practices. A critical issue facing the golf course industry is the environmental fate and safety of pesticides used in management of recreation facilities. The enhanced interest in pesticide use is, in general, a response to the increased use of pesticides since the 1960's and the advancements in technology allowing scientists to detect pesticide contamination at very low concentrations. The major concern for the impact of pesticides on the environment is their potential entrance into drinking water sources which is facilitated by movement in surface water and groundwater from the treated site.

Many golf course greens are constructed for maximum infiltration and percolation of water through the rooting media. Root zone mixture composition generally includes at least 85% by volume and 98% by weight sand allowing for rapid water percolation and having an extremely low cation exchange capacity. Additionally, soil sterilization ultimately influences the soil microbial decomposition of applied pesticides. These characteristics of the root zone mixture could allow for the unimpeded movement of pesticides through the rooting mixture allowing for a potential source of contamination of the effluent water from the greens.

Additionally, fairways are intensively maintained and receive high rates of foot and golf cart traffic increasing the potential for these soils to become compacted. The close mowing regimen and soil compaction could allow for high rates of water runoff from these areas. However, the fibrous root system of turfgrass will allow for increased water infiltration compared to bare soil. Most pesticides will move with the water system following application.

The intense management strategies and the normal use of golf courses would suggest that there is a need for a close monitoring of pesticide movement from the treated site in order to develop strategies for minimizing that movement and to assure the public that golf courses are not a "toxic waste site".

The objectives of our research were to: 1) Determine the potential movement of pesticides from treated bermudagrass and bentgrass greens through effluent entry into surface runoff and groundwater; and 2) Determine the potential movement of pesticides from treated bermudagrass fairways by surface runoff and groundwater.

MATERIALS AND METHODS

Measurement of Potential Movement of Pesticides Through USGA Greens.
Greenhouse lysimeters: The greenhouse facility is described in the appended manuscript accepted for publication in the Journal of Environmental Science. The 1992 treatments included 'Pencross' bentgrass and 'Tifdwarf' bermudagrass. However, management problems of the bentgrass greens, in the greenhouse became insurmountable due to the disease pressure resulting from the high temperatures coupled with the high humidity and reduced light intensity. Therefore, we chose to conduct the greenhouse experiments using 'Tifdwarf'

bermudagrass in all growth boxes. The treatments of two soil mixtures, previously described (1992 annual report), were continued and for specifics on the 1992 treatments, for the 1992 data included in this report, refer to the 1992 annual report.

The bermudagrass sod was placed on the growth boxes during the first week in May and allowed to root into the rooting media until treatments. The growth boxes were mounted on the lysimeter tubes containing the respective rooting mixtures beneath the track watering system. The watering system was programmed to deliver an irrigation simulation of 0.625 cm water daily for 6 days and a rainfall simulation of 2.5 cm on the seventh day of the week. The turf was mowed to a stubble height of 0.4 cm thrice weekly and the clippings collected for analyses of pesticides remaining on the clipped foliage. The foliage samples were immediately frozen and stored until processed. The pesticide treatments were applied on July 19, 1993. Each pesticide treatment was in 3 replications for each rooting media. The pesticides were applied to the boxes, previously moved to a spray booth, in 204 L ha^{-1} water diluent at 18 psi under compressed air. The leachate was collected twice weekly, the samples were stored at 4°C, and the leachate volumes were determined on weekly intervals. Subsamples were taken from the collected samples for analyte extraction and quantification by electron-capture GLC.

<u>Field lysimeters:</u> The field lysimeter facility is described in detail in the 1992 annual report. This facility contains 10 lysimeters under each of the turfgrass cultivars. 'Pencross' bentgrass was seeded during September 1991 into the lysimeters filled with 85:15 (sand:peat v/v) rooting mixture and 'Tifdwarf' bermudagrass was sodded onto the lysimeters filled with 80:20 rooting mix during April 1992. The lysimeters were automatically covered with a rainout shelter during rain events.

The turfgrass was mowed and the clippings were removed with a greens (reel-type) mower to a height of 0.4 cm three times per week. A complete fertilizer (20 N:20 P: 20 K) was applied in water to an N rate of 2.44 g m^2. Chlorpyrifos (1.14 kg ai ha^{-1}) was applied once per month as a general insecticide and as a treatment and chlorothalonil (9.53 kg ha^{-1}) was applied two times each month as a treatment and as a general fungicide. The herbicide treatments (dithiopyr g and ec) were applied on July 19, 1993. The ec formulation of dithiopyr was applied with a CO_2 backpack sprayer in 252.1 L ha^{-1} water diluent. Dithiopyr granules were spread evenly over the lysimeters. All pesticide treatments (Table 2) were replicated 3 times on each of the turfgrasses.

Irrigation and simulated rainfall events were applied on the same schedule as the greenhouse experiments through a horizontal moving track system similar to the greenhouse watering system (see publication in J. Environ. Qual). This system was installed in the spring of 1993 for improved distribution of the water over the lysimeter facility. All effluent water from individual lysimeters was collected in stainless containers the total sample was stored, following collection thrice weekly, in a 4°C cooler and the samples were quantified and subsampled for pesticide analyses in the laboratory. All subsamples were stored in a 4°C cooler until extracted and analyzed.

Table 1. Herbicide treatments applied to the growth boxes containing bermudagrass on 85:15 and 80:20 (soil:peat v/v) rooting media.

Herbicide	Rate (kg ha^{-1})	Total Herbicide over lysimeter[9] (μg)
2,4-D[1] + X77	0.56 + 0.56	2,044
dicamba[2] + X77	0.28	511
mecoprop[3] + X77	1.40	2,555
dithiopyr (g)[4]	0.56	1,022
dithiopyr (ec)[5]	0.56	1,022
chlorothalonil[6]	9.53 (twice monthly)	121,746
chlorpyrifos[7]	1.14 (monthly)	6,132

[1]2,4-D DMA; Weedar 64; 46.8% active ingredient dimethylamine salt of (2,4-dichlorophenoxy)acetic acid. EPA Reg. No. 264-2AA; EPA EST. No. 264-Mo-01 Rhone-Poulenc Ag. Co. RP-4500-148-000-031.
[2]Dicamba; Banvel 4S; 48.2% active ingredient dimethylamine salt of 3,6-dichloro-2-methoxybenzoic acid. Sandoz Crop Protection Corp.
[3]Mecoprop; Mecomec 4; 48.2% active ingredient potassium salt of 2-(2-methyl-4-chlorophenoxy)propionic acid. EPA Reg. No. 2217-674 EPA Est. No. 2217-KS-1. PBI/Gordon Corp. 841/1087.
[4]Dithiopyr; Dimension 175; granule formulation 0.175% active ingredient of 2-(difluoromethyl)-4-(2-methylpropyl)-6-(trifluoromethyl)-3,5-pyridine dicarbothioic acid, S,S-dimethyl ester. EPA Reg. No. 8378 EPA Est. No. 8378-IN-1. Monsanto Chemical Co.
[5]Dithiopyr; Dimension EC (emulsifiable concentrate) formulation.
[6]Chlorothalonil; Daconil 2787 flowable fungicide 'Turf Care' 40.4% active ingredient of tetrachloroisophthalonitrile. EPA Reg. No. 50534-9 EPA Est. No. 50534-TX-01. ISK Biotech Corp.
[7]Chlorpyrifos; Dursban Turf, 44.9% active ingredient 0,0-diethyl-0-(3,5,6-trichloro-2-pyridinyl)phosphorothioate. EPA Reg. No. 62712-38. DowElanco.
[8]Lysimeter surface area = 0.012 m^2.

Table 2. Herbicide treatments applied to 'Pencross' bentgrass (85:15 soil:peat v/v) and 'Tifdwarf' bermudagrass (80:20 soil:peat v/v) turf over lysimeters in the field lysimeter facility.

Turf	Treatment	Rate (kg a.i. ha^{-1})	Total chemical over lysimeter[2] (mg)
bentgrass	dithiopyr (g)[1]	0.56	16.4
	dithiopyr (ec)	0.56	16.4
	chlorpyrifos	1.14 (monthly)	131.2
	chlorothalonil	9.53 (twice monthly)	2,506.0
bermudagrass	dithiopyr (g)	0.56	16.4
	dithiopyr (ec)	0.56	16.4
	chlorpyrifos	1.14 (monthly)	131.2
	chlorothalonil	9.53 (twice monthly)	2,506.0

[1]See footnotes in table 1 for description of chemicals.
[2]Lysimeter surface area = 0.283 m^2

Runoff plots: Twelve individual plots (3.7 x 7.4 m) were developed in a grid (Fig. 1) with a 5° slope from the back to the front. A ditch was dug at the front of the plots to install a trough (B) for collecting the runoff water and a tipping-bucket sample collection apparatus (C). The slop was developed by removing the top soil from a level plot of land and forming the subsoil into the 5° slope and packing the subsoil before returning the top soil over the entire area. The subsoil is a clay loam and the top soil is a sandy loam. The individual plots are separated by landscape timbers (D) with the top edge located 2 cm above the soil surface to direct the runoff water within each plot. The plots were sprigged with 'Tifway 419' bermudagrass on May 17, 1993 and the plots were completely covered by August 1, 1993. These plots would be comparable to recently constructed fairways or lawns in the Piedmont Region of Georgia. The 5° slope is considered average for fairways and lawns in Piedmont Georgia.

The Wobbler™ off-center rotary action sprinkler heads (E) (Senninger Irrigation Inc.) were mounted 7.4 m apart and 3.1 m above the sod surface (Fig. 1). Research at the University of California, Berkley, has indicated that the droplets from these sprinkler heads are comparable to a typical rain droplet in size and intensity upon striking the ground. The system operated at 20 psi results in a very even distribution of the simulated rainfall over the total area and the rainfall intensity is 2.5 cm hr^{-1}.

At 1.23 m from the back and front of each plot, 0.6 m long stainless steel tube lysimeters (A) were placed into the ground to sample the soil solution at 0.6 m depths. The soil solution is removed from the tube lysimeters using a vacuum pump and routing the solution to sample bottles. The analytes in the soil solution can be determined by extracting the samples collected from the tube lysimeters.

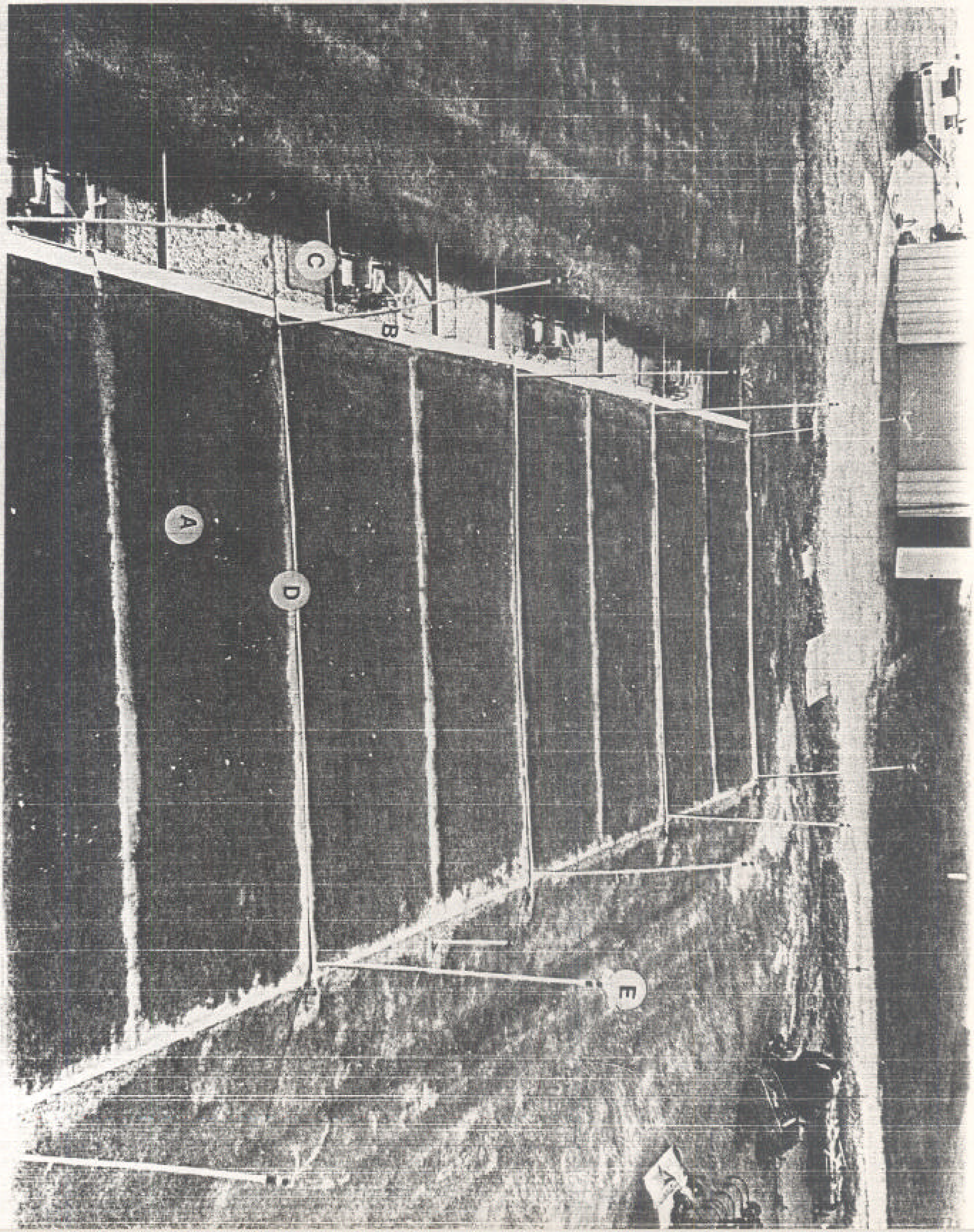
The plots will be treated with 2,4-D (1.2 kg a.e. ha^{-1}), dicamba (0.3 kg a.e. ha^{-1}), and mecoprop (1.2 kg a.e. ha^{-1}) on November 15 for control of winter broadleaf weeds. Rainfall will be simulated at 24, 48, and 96 hours after treatment. Following these 3 simulated rainfall periods normal rainfall events will be monitored for a 15 week period. The runoff water will be quantified and subsamples will be collected by the tipping-bucket apparatus. Soil solution will be sampled from the tube lysimeters at sequential periods following the simulated and normal rainfall events.

Additional treatments to include dithiopyr, chlorpyrifos, chlorthalonil, and MSMA will be made in the summer of 1994.

Analytical methods: The analytical methods used for the analytes in this research were modified from existing methods or developed in our laboratory. Generally the published methods resulted in additional cleanup procedures to remove interfering contaminants or did not allow for the sensitivity that we require for the minimum detectible concentration (MDC) for the analytes in water. We set our goals to be able to accurately and consistently determine all analytes at a MDC of 1 ppb in water. Therefore, we had to improve on the methods presently used for these analytes.

Dithiopyr: The method used for dithiopyr extracted from water, soil, and plant material is included in the manuscript accepted for publication in Chromatographic Science and was developed by a graduate student (S. Hong). The method includes Solid Phase Extraction for concentrating the analyte and

Fig. 1. Photograph of the pesticide runoff plots: A-Lysimeter tubes, B-runoff water collection troughs, C-tipping bucket, D-landscape timber dividers, and E-Wobbler sprinkler head.



excluding interfering compounds and analyses by gas-chromatography equipped with electron capture detector. The method is sensitive over a range of 0.01 to 150 $\mu g\ L^{-1}$.

Mecoprop: The data from the mecoprop treatments made in 1992 were not included in the 1992 annual report since the accepted method for analyzing this analyte did not allow for a MCD of 1 ppb in water. The Research Associate, whose funding is included in the USGA grant, developed an improved method for the esterification of MCPP. This method increased the sensitivity for detection on capillary GC-MS and GC-ECD (manuscript is accepted for publication in the JAOAC). Historically, mecoprop was methylated using diazomethane in preparation of analyses by GC-ECD. The detector response to the methyl ester of mecoprop is much less than for dicamba and 2,4-D. Additionally, diazomethane is not stable and the Laboratory Safety Officer for the University of Georgia is critical of storing diazomethane. Therefore, based on efficiency, convenience, worker safety, and least sample contamination; the triflouroethanol esterification method was developed and used for analyzing mecoprop at a MCD of 1 ppb.

The TFE method was extended to include the simultaneous analyses of dicamba, 2,4-D and mecoprop for use in analyzing these analytes in the water collected from the runoff plots following treatment on November 15, 1993. This will allow for treating the plots with the three herbicides and analyzing the water samples for the three analytes in the same sample. This method has been submitted for review toward publication in the J. of Agric. and Food Chem. (copy included in the publication section of this report).

The chlorpyrifos and chlorothalonil samples from the 1993 treatments were analyzed by a method that was recently developed in our laboratory and is being compiled for submission for review toward publication in JAOAC. The method is presently in use in our laboratory. Our method is developed for the sequential analyses of chlorothalonil, 2,5,6-trichloro-4-hydroxyisophthalonitrile (SDS) (first order metabolite of chlorothalonil), clorpyrifos, and 3,5,6-trichloro-2-pyridinol (TCP) (first order metabolite for clorpyrifos). The leachate water samples are collected from lysimeters and runoff water will be collected from the runoff plots treated with chlorothalonil and chlorpyrifos and the four analytes are extracted and analyzed from the same sample.

The acidified water subsamples are extracted with diethyl ether and the dried ether extracts are reduced in volume using a rotary evaporator under a vacuum. The analytes are dissolved in ethyl acetate and TCP and SDS are methylated using diazomethane. This method of methylation does not interfere with the parent compounds, chlorpyrifos and chlorothalonil, included in the same sample. TCP is methylated at two molecular locations (N and O esters) resulting in two peaks on the chromatogram. Each is analyzed separately and the final concentrations added together for TCP concentration. The five peaks are easily separated by capillary chromatography and the ECD is sensitive enough to result in a MDC of 1 ppb in water.

RESULTS AND DISCUSSION

Mecoprop movement through simulated greens: The data for the 1992 mecoprop treatments to the greenhouse and field lysimeters was not included in the 1992 annual report due to the need for the development of a more sensitive analytical method for quantifying mecoprop in water samples at a MDC of 1 ppb. An acceptable method was developed during the winter of 1992-1993 and the samples were analyzed during the spring of 1993. The samples were maintained at 4°C until analyzed. A standard sample containing 100 ppb mecoprop in soil leachate was stored to determine the loss of mecoprop during storage in soil leachate. The data from the analyses of the standard sample indicated less than 10% (8.76%) loss of mecoprop over the 9 months of storage.

The data from the greenhouse lysimeter treatments indicate that the mecoprop movement through the simulated greens occurred during the first 5 weeks of sampling (Tables 3 and 4). More water moved through the lysimeters containing the 85:15 soil mixture compared to the 80:20 soil mixture. Mecoprop concentrations in the soil leachate exiting the lysimeters was less than 5 ppb for the two rooting mixtures. The mecoprop concentrations were highest in the 2nd and 3rd weekly samples from the lysimeters containing the highest sand content and total mecoprop exiting the greenhouse lysimeters was highest in the lysimeters containing the highest sand content (Table 1). However, only 0.2 and 0.3% of the total mecoprop applied to the lysimeters exited in the effluent water from the 85:15 and 80:20 soil mixtures, respectively.

Table 3. Weekly water elutriated and herbicide transported from greenhouse lysimeters containing bentgrass in 85:15 (sand:peat) rooting media and treated with mecoprop. Data are averages for 3 replications.

Week	Weekly water volume (ml)	Herbicide transported ($\mu g\ L^{-1}$)	Total (μg)
1	960	<1	-
2	960	3.75	3.6
3	667	2.83	1.9
4	400	<1	-
5	783	ND	-
6	870	ND	-
7	943	ND	-
8	663	ND	-
9	860	ND	-
10	900	ND	-
Total mecoprop exiting lysimeters			5.5 (0.2% applied)

Table 4. Weekly water elutriated and herbicide transported from greenhouse lysimeters containing bermudagrass in 80:20 (sand:peat) rooting media and treated with mecoprop. Data are averages for 3 replications.

Week	Weekly water volume (ml)	Herbicide transported ($\mu g\ L^{-1}$)	Herbicide transported Total (μg)
1	763	2.66	2.0
2	563	1.31	0.7
3	230	1.60	0.4
4	87	ND	-
5	327	ND	-
6	400	ND	-
7	390	ND	-
8	144	ND	-
9	450	ND	-
10	560	ND	-
Total mecoprop exiting lysimeters			3.1 (0.3% applied)

Mecoprop was not detected in the leachate from the field lysimeters (Tables 3 and 4). The horizontal moving track irrigation system resulted in a more even distribution of leachate exiting the lysimeters at each weekly interval compared to the 1992 experiments (data not shown). The improvement in the consistency of water exiting the lysimeters is attributed to the better control of the water spray pattern on windy days. The distribution of the irrigation water across the top of the lysimeters, for the greenhouse and field lysimeters, has a coefficient of variation of less than 0.1.

Table 5. Weekly water elutriated and herbicide transported from field lysimeters containing bentgrass in 85:15 (sand:peat) rooting media and treated with mecoprop. Data are averages for 3 replications.

Week	Weekly water volume (L)	Herbicide transported ($\mu g\ L^{-1}$)	Herbicide transported Total
1	10.3	ND	-
2	11.1	ND	-
3	12.6	ND	-
4	14.0	ND	-
5	12.0	ND	-
6	10.1	ND	-
7	12.0	ND	-
8	15.7	ND	-
9	13.4	ND	-
10	12.2	ND	-

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Table 6. Weekly water elutriated and herbicide transported from field lysimeters containing bermudagrass in 80:20 (sand:peat) rooting media treated with mecoprop. Data are averages for 3 replications.

Week	Weekly water volume (L)	Herbicide transported ($\mu g\ L^{-1}$)	Total
1	6.8	ND	-
2	6.8	ND	-
3	11.0	ND	-
4	10.0	ND	-
5	9.0	ND	-
6	5.9	ND	-
7	9.8	ND	-
8	11.4	ND	-
9	10.3	ND	-
10	9.2	ND	-

Similar results have been reported for 2,4-D and dicamba 1992 treatments in the greenhouse and field lysimeters (1992 annual report). Slightly higher concentrations of 2,4-D were found in the effluent from the greenhouse lysimeters containing the higher sand content. However, the effluent water concentrations were always below 5 ppb and total amounts of 2,4-D found to move from the bottom of the lysimeters was less than 6 µg. There was no detectible concentration of 2,4-D in the effluent water exiting the field lysimeters during the 10 week period.

The herbicides used in this study are reported to have very short half-life periods in agricultural soils (Table 7). We would consider these very short half-life periods as probable for the upper 7.5-15 cm of the rooting media for the lysimeters due to the high organic matter content and the potentially high microbial activity. Although the rooting media were sterilized prior to establishing the turf sod, the sodding of the bermudagrass and the 8 month period for establishing the bentgrass sod allowed for ample microbial development prior to treatment.

The results of the 1992 experiments conducted in the greenhouse and field lysimeters would indicate that the concentrations of 2,4-D, dicamba, and mecoprop in the effluent water exiting the lysimeters is at least a factor lower than the MCL established for these herbicides by EPA. The analytes in samples resulting in concentrations greater than 5 ppb, in the effluent water, were confirmed by GC-MS.

Table 7. Properties of herbicides used in the greenhouse and field lysimeters during 1992 and 1993. Wauchope, 1992.

Herbicide	Water Solubility (mg L^{-1})	K_{oc} ml g^{-1}	Foliar Half-life (days)
2,4-D (dimethylamine salt)	8.0×10^5	20	8.3
2,4-D (butoxyethyl ester)	100	100	0.8
dicamba (dimethylamine salt)	4.0×10^5	2	8.3
mecoprop (dimethylamine salt)	6.6×10^5	20	5.0
dithiopyr	138	1638	8.3

Dithiopyr movement through field lysimeters: The MDC (minimum detection concentration) for dithiopyr was set at 0.05 ppb by concentrating the extract prior to analyzing by gas chromatography. Therefore, very low concentrations of this anaylte are reported for the field lysimeters treated with the EC and granule (g) formulations (Tables 8-11). The analyte concentrations in the water elutriated from the lysimeters are less than 3.0 ppb and the total amounts elutriated from the lysimeters is less than 0.3%.

Table 8. Weekly water elutriated and herbicide transported from field lysimeters containing bentgrass in 85:15 (sand:peat) rooting media and treated with dithiopyr (g)

Week	Weekly water Volume (L)	Herbicide Transported (μg L^{-1})	Total (μg)
1	1.39	1.03	1.4
2	5.73	0.29	1.6
3	6.20	0.75	4.5
4	11.80	0.25	3.0
5	9.23	0.07	0.6
6	9.67	0.41	4.0
7	7.20	1.61	12.0
8	9.37	1.04	9.7
9	4.87	1.49	7.1
10	9.07	0.43	3.6
Total			47.5 μg

Table 9. Weekly water elutriated and herbicide transported from field lysimeters containing bermudagrass in 80:20 (sand:peat) rooting media and treated with dithiopyr (g)

Week	Weekly water Volume (L)	Herbicide Transported ($\mu g\ L^{-1}$)	Total (μg)
1	0.82	1.07	0.8
2	4.50	0.67	3.9
3	5.60	0.04	0.5
4	11.80	0.19	1.6
5	8.13	0.67	5.7
6	8.47	2.17	13.2
7	5.90	1.90	15.2
8	7.64	1.20	5.6
9	4.77	0.90	6.8
10	7.80	2.37	1.3
Total			54.6

Table 10. Weekly water elutriated and herbicide transported from field lysimeters containing bentgrass in 85:15 (sand:peat) rooting media and treated with dithiopyr (EC)

Week	Weekly water Volume (L)	Herbicide Transported ($\mu g\ L^{-1}$)	Total (μg)
1	1.42	0.17	0.2
2	5.33	0.26	1.4
3	6.57	0.03	0.2
4	13.13	0.20	3.2
5	8.83	0.24	2.0
6	9.40	0.23	2.0
7	5.47	1.33	7.7
8	10.63	1.65	17.5
9	6.07	1.23	7.4
10	9.80	1.12	11.0
Total			52.6

Table 11. Weekly water elutriated and herbicide transported from field lysimeters containing bermudagrass in 80:20 (sand:peat) rooting media and treated with dithiopyr (EC)

Week	Weekly water Volume (L)	Herbicide Transported ($\mu g\ L^{-1}$)	Total (μg)
1	0.8	0.39	0.3
2	5.0	0.60	3.1
3	5.1	0.32	1.6
4	10.5	0.09	0.9
5	8.7	0.29	2.4
6	8.5	0.79	6.6
7	4.6	2.27	9.6
8	9.6	2.06	20.0
9	5.1	0.52	2.6
10	8.1	0.67	5.1
Total			52.2

PUBLICATIONS

BOOK CHAPTERS AND JOURNAL ARTICLES:

1. Smith, A. E. and W. R. Tillotson. 1993. Potential leaching of herbicides applied to golf course greens. In. eds. K. D. Racke and A. R. Leslie. "Pesticides Urban Environments". Amer. Chem. Soc. Washington, DC pp 168-171.

2. Smith, A. E., O. Weldon, W. Slaughter, H. Peeler, and N. Mantripragada. 1993. A greenhouse system for determining pesticide movement from Golf Course Greens. J. Environ. Qual. 4:In Press.

3. Hong, S., A. S. Lee, and A. E. Smith. 1994. Gas chromatographic analysis of dithiopyr in soil leachate. Chromatographic Sci. In Press.

4. Lee, A. S., M. K. Hong, and A. E. Smith. 1994. Improved exterification of MCPP for sensitive detection on capillary GC-MS and GC-ECD. JAOAC. In Press.

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