ANNUAL PROGRESS REPORT

Concerning

EVALUATION OF BEST MANAGEMENT PRACTICES TO PROTECT SURFACE WATER QUALITY FROM PESTICIDES AND FERTILIZER APPLIED TO BERMUDAGRASS FAIRWAYS

For the Period

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Submitted by

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EXECUTIVE SUMMARY

The primary objective of the Oklahoma State University Turfgrass Environmental Research Program is to develop effective and practical management practices to protect surface water from runoff of pesticides and fertilizer applied to golf course fairways and other turf areas. A portable rainfall simulator is being used to simulate heavy precipitation events that may occur shortly after the application of pesticides and fertilizer, thus increasing the likelihood of water contamination from surface runoff. The simulator is capable of applying rainfall intensities of up to 5 in/h onto four plots each measuring 6 ft x 32 ft. In 1995, a preliminary study was conducted to evaluate the effectiveness of various combinations of buffer-strip: 1) length (0 vs. 8 ft. vs. 16 ft); 2) mowing height (0.5 in vs. 1.5 in); and 3) solid-tine aerification (vs. no aerification) in reducing pesticide and nutrient runoff. In July, an experiment was conducted at a location in Stillwater, OK consisting of common bermudagrass maintained under golf course fairway conditions. Within 24 hours of a simulated rainfall event, 2,4-D, mecoprop, and dicamba (formulated as Trimec™ Classic), chlorpyrifos (0.5G), nitrogen (urea) and phosphorus (triple superphosphate) were applied at normal rates recommended for fairway turf to designated areas on plots containing the buffer treatments. One of the treatments, containing no buffer-strip, was left untreated to determine the amount, if any, of pesticides and nutrients already present in the turf environment. The experimental design was an unbalanced, randomized incomplete block with 8 treatments 4 replications. The design insured that important treatment comparisons showed up in the same simulator set-up (block) at least twice. The experiment was repeated in August, whereupon the untreated control was substituted with a treatment consisting of no buffer-strip and application of identical rates of the 50WP formulation of chlorpyrifos and the sulfur-coated urea form of nitrogen fertilizer in addition to identical rates and formulations of the herbicides and phosphorus.

Soil moisture conditions prior to simulated rainfall were different between runs and affected the volume of runoff from plots and the total amount of pesticides and nutrients recovered therein. In the July run, no natural precipitation was detected within 12 days of simulated rainfall; by contrast, 6.51 inches of natural precipitation fell on the runoff site within 6 days of simulated rainfall in August. In July, percent recovery of pesticides and nutrients was less than 3% and 2%, respectively, based upon the total amount applied. Highest levels of nutrients and pesticides were recovered from the treatment containing no buffer-strip. In August, percent recovery of pesticides and nutrients was as great as 15% and 11%, respectively. Results from the July run indicated that buffer-strips were very effective in reducing pesticide and nutrient runoff. Although few treatment comparisons were statistically significant, numerical trends from the July data showed reduced pesticide and nutrient runoff from the 16-ft buffer length compared to the 8-ft buffer length, the 1.5-in mowing height compared to the 0.5-in mowing height, and solid-tine aerification compared to no aerification at the 0.5-in mowing height. At the 1.5-in mowing height, aerification resulted in greater pesticide and nutrient runoff. It is possible that the aerification process created channels in the higher-cut turf canopy thus causing expedited movement of the chemicals in surface runoff. In August, several of the trends observed in July were reversed, possibly indicating that the effectiveness of the buffer-strip treatments was overcome by the increased volume of surface runoff. Reduced pesticide and nutrient runoff occurred from the wettable powder formulation of chlorpyrifos compared to the granular formulation, and from the sulfur-coated urea form of nitrogen compared to urea. The correlation between the physico-chemical properties of pesticides and nutrients and their relative runoff potential was substantiated by this investigation.

Based upon the 1995 preliminary study, the following management practices are recommended to reduce pesticide and nutrient runoff: 1) incorporate a buffer-strip between surface water features and treated areas; 2) avoid application of pesticides and fertilizer

when high soil moisture conditions exist; 3) develop pest and nutrient management programs that utilize pesticide and fertilizer formulations with low runoff potential.

A manuscript describing the results of this study is currently being prepared for submission to Crop Science by the end of 1995. In 1996, research will focus on: 1) determination of critical soil moisture levels, buffer-strip lengths, and associated factors that result in reduced pesticide and nutrient runoff; and 2) continued examination of runoff potential of pesticides, nutrients, and their formulations.

INTRODUCTION

The increasing public concern over pesticide and nutrient usage, especially on golf courses, warrants further examination of their fate in the turfgrass environment and strategies to minimize their potential threat to environmental quality. The fate of a turf-applied pesticide or nutrient is one of transformation or dissipation. Transformation refers to all changes, degradative or bioactive, in the chemical structure of a pesticide or nutrient caused by photolysis, microbes, or other chemical reactions; dissipation involves redistribution of the pesticide or nutrient by volatilization, surface runoff, leaching, plant residue removal, or plant uptake (Leake, 1991). Surface runoff and leaching of pesticides and nutrients directly affect environmental water quality. On the finer-textured soils common to Oklahoma and many parts of the country, pesticides and nutrients are more likely to runoff the ground surface than leach through the soil profile. Runoff is determined by several factors related to the pesticide or nutrient, soil, plant, and surrounding environmental conditions. In general, surface losses of pesticides and nutrients are nominal with the exception of heavy precipitation events occurring shortly after application (Balogh and Anderson, 1992).

Approximately 80 percent (about 50 acres) of the total area of a typical 18-hole golf course is comprised of fairway (Watson et al., 1992). Water hazards such as a sea, lake, pond, river, stream, or ditch may border the edge of the fairway and thus are likely to receive surface runoff from the fairway. Best management practices (BMPs) that reduce surface runoff are well documented (Balogh et al., 1992). Grassed buffer-strips have been shown to provide an effective barrier between water supplies and areas of applied pesticides (Rohde et al., 1980; Wauchope et al., 1990). Although it is commonly known that buffer-strips help reduce runoff of pesticides and nutrients into water supplies, there is little, if any, research that has focused on the determination of buffer-strip lengths necessary to reduce or prevent surface runoff following application of pesticides or fertilizer to fine turf. Furthermore, little information was found on the effect of bermudagrass height of cut and turfgrass aerification practices on surface runoff potential. In 1995, a preliminary study was conducted to evaluate the effectiveness of various combinations of buffer-strip: 1) length (0 vs. 8 ft. vs. 16 ft); 2) mowing height (0.5 in vs. 1.5 in); and 3) solid-tine aerification (vs. no aerification) in reducing pesticide and nutrient runoff.

This report summarizes activities and progress for the period 1 February 1995 through 31 October 1995.

MATERIALS AND METHODS

Rainfall Simulator

A portable rainfall simulator was used to apply controlled precipitation on an area consisting of four 1.8-m x 9.8-m (6-ft x 32-ft) plots. The rainfall simulator is based on the Nebraska rotating-boom design (Swanson, 1979), and is capable of wetting a 15-m (50-ft) diameter area. The nozzles, located on a rotating boom 2.7 m (9 ft) above the ground, spray continuously and move in a circular pattern. By plugging selected nozzles, rainfall intensity was set at 51 mm/h (2 in/h) for the July experiment and 64 mm/h (2.5 in/h) for the August experiment. The boom was rotated at approximately 7 revolutions/min for both rainfall intensities. Figure 1 shows the simulator location and plots for each setup. A central alley, 3-m (10-ft) wide, allowed room for the simulator placement. Plot pairs were separated by 0.3 m (1 ft).

Plots

Plot borders were made using strips of 3.8-cm (1.5-in) i.d. plastic discharge hose (Amazon Hose and Rubber Co., Chicago, IL) filled with masonary sand. String lines were hung along plot ends and sides to mark placement of the hose strips. Once the plot borders were laid onto the turf, a sand:bentonite (5:1 v/v) mix was used to seal the outside edge of the hose to eliminate runoff from flowing underneath the borders.

The endplate at the lower end of each plot consisted of a 1.9-m x 75-mm x 75-mm x 5-mm (6.4-ft x 3-ft x 3-ft x 3/16-in) steel angle with a sheet of 22 gage galvanized steel spot welded onto one of the legs. The angle iron served as a shelf, while the galvanized strip channeled the the runoff into the collection trough. A 6-mm (0.25 in) deep lip and a 150-mm (6-in) deep trench was dug down slope of the plots to install the endplates and collection troughs. Melted paraffin was poured along the inside edge of the endplate to form a seal between the endplate and soil to insure that runoff would not flow underneath.

The collection trough for each plot consisted of 2-m (6.5-ft) long sections of 150-mm (6-in) diameter PVC pipe split length-wise. Blocks were placed underneath the troughs as needed to provide a slope for movement of effluent toward the collection pits. A sheet metal frame was used to cover and protect the collection trough from rainwater and other contaminants. The collection pits were approximately 1-m (3-ft) wide by 1-m (3-ft) deep, and were reinforced with sheet metal. Runoff accumulating in the four pits was emptied by two sump pumps connected through a manifold to each pit. The manifold incorporated a valve for each pit, thus allowing manual balancing of each pit's pumping rate.

Water Supply

Each rainfall simulation experiment required approximately 14,500 l (3830 gal) to 21,600 l (5710 gal) of water, depending upon the rainfall intensity and length of the rainfall simulation event. A 19,000-l (5000 gal) tanker was used for storage of water supplied by a city fire hydrant. A 5.2-kW (7 hp) gasoline engine and pump, located at the tanker, pumped the water through a 5-cm high-pressure vinyl hose to the simulator. The pump provided a minimum mast-head pressure of approximately 207 kPa (30 psi).

Site Preparation

A 1.2-ha (3-acre) common bermudagrass runoff site in Stillwater, OK was managed under golf course fairway conditions beginning in August 1994. Differential leveling techniques were used to define contour lines in order to determine suitable locations for 8 simulator setups. Plot locations were surveyed and marked and then minor adjustments were made to insure that plots were parallel to the slope and that they contained no unusual surface conditions such as depressions. The average slope of the plots was 6% and the range was 5.4-6.6%.

Plot Preparation

All plots were irrigated, if necessary, prior to application of pesticides and fertilizer to ensure a more uniform initial soil water content between plots and setups. The simulator was placed between plots No. 2 and 3 with at least a 1.5 m (5 ft) boom overhang at all corners to ensure uniform rainfall coverage. The trailer was set parallel with the land surface with the boom held at a constant height rather than level. Three rain gauges were installed in the center alley, 2.4, 4, and 5.5 m (8, 13, and 18 ft) from the boom center to measure delivered rainfall. Soil moisture content of the plot region prior to rainfall simulation was determined by gravimetric analysis. Rainfall simulation events lasted between 75 and 140 min, depending upon the moisture content of the soil and subsequent volume of surface runoff from plots.

Pesticides and Fertilizer

Each area receiving pesticide and fertilizer measured 1.8 m x 4.9 m (6 ft x 16 ft) and was mowed at 0.5 in to represent a golf course fairway. The buffer area was considered to represent a golf course rough or, the area between the treated area (fairway) and runoff collection point (surface water feature). The buffer (rough) was mowed at 1.3 cm (0.5 in) to represent no rough or 3.8 cm (1.5 in) to represent the standard mowing height for bermudagrass rough in Oklahoma. Solid-tine aerification was performed on the buffer (rough) area only. The following fertilizers and pesticides were applied to the treated area (fairway): nitrogen at 49 kg ai/ha (1.0 lb N/1000 ft^2) from urea (46N-0P-0K) or sulfur-coated urea (39-0-0); phosphorus at 49 kg ai/ha (1.0 lb P/1000 ft^2) from triple superphosphate (0N-46P-0K); chlorpyrifos (Dursban™ 0.5G or 50WP) at 2.2 kg ai/ha (2 lbs ai/A); 2,4-D at 1.1 kg ai/ha (1.0 lb ai/A), mecoprop at 0.6 kg ai/ha (0.5 lb ai/A), and dicamba at 0.1 kg ai/ha (0.1 lb ai/A) formulated as Trimec™ Classic. The pesticides and fertilizer were chosen because of their widespread use by turf managers and greater potential for surface runoff based upon their physico-chemical properties. Pesticides and fertilizer were applied within 24 h of simulated rainfall. Fertilizer and insecticide were applied first and watered in with 5 mm (0.2 in) of water using the rainfall simulator. The herbicides were applied after the wetted turf had dried.

Experimental Design

Treatments are shown in Tables 1-3 and 4-6. Treatments A-G were repeated in August. Treatment H, an untreated control in July, was designated treatment I in August. The experimental design was an unbalanced, randomized incomplete block. The design insured that important treatment comparisons (shown in Tables 7 and 8) were contained in the same simulator setup (block) at least twice. Each treatment was replicated 4 times. Data were subjected to ANCOVA. The time to the start of runoff for each plot was used as a covariate in the analysis in order to account for differences in runoff among treatments that were due to soil moisture content prior to the start of the rainfall event.

Sample Collection

Two simulator runs were conducted per day. Two people were required to oversee the simulator and coordinate sample collection, while two others operated the pump and water storage tank. Four people measured flow and collected samples for chemical analysis, one for each plot.

Samples were collected at preset times after the start of runoff for individual plots using a nominal sampling schedule. Start of runoff was recorded when a continuous trickle of water was first observed at the collection pit. During the first few samples collected from each plot, sampling times were synchronized to a time selected by the coordinator. Most plots averaged at least 10 samples over the 75-140-min period. A sample of the rain water will be taken directly from a simulator nozzle during each run.

At predetermined intervals, sample collecting personnel were instructed to take 0.5-l samples. Immediately after sample collection, they measured the runoff rate by recording the time required to fill a calibrated 0.5-l sample bottle. Time was measured to within 0.1 s with a hand-held stopwatch. The accuracy of the runoff flow rate was estimated to be within 3%.

Efforts were made throughout the experiments to record data systematically using three prepared data sheets: Master Sheet, Sampler Sheet, and Field Analysis Sheet. One set of Master Sheets was maintained by the coordinator for each setup. One sheet was maintained for each plot by the sample taker. Discharge measurements, sample times, weather, precipitation, and plot conditions were recorded. Finally, the laboratory maintained one analysis sheet per plot.

Sample Preparation

Composite samples (1.0 l) were prepared in the laboratory to reduce sample preparation and laboratory expenses. These samples provided an average runoff quality for each run. Time and flow data for each plot were entered in a computer spreadsheet to calculate the volume-averaged portion of each sample needed for the composite. Composite samples were processed and analyzed for presence of pesticides and nutrients using laboratory facilities in the Agronomy Department.

Pesticide Analysis

The following procedures were adopted from Di Corcia and Marchetti (1992). Several minor modifications were made to decrease expenses and shorten analysis time. All organic solvents were high performance liquid chromatography (HPLC) grade or purer and deionized water was ≥ 15 MΩ.

Concentration and Extraction

Runoff samples were vacuum filtered through 0.45-μ nylon membrane filters and refrigerated at 4 °C until analysis. Total sample storage time was less than 48 h. Filtered samples (100 ml) were passed through Carbopack B solid phase extraction (SPE) columns. Air was drawn through each column for 1 min to exclude moisture. Acidic (2,4-D, dicamba, MCPP) and base/neutral (chlorpyrifos) pesticides were adsorbed by the SPE column. Bases followed by acids were eluted from the SPE column in sequence.

Chlorpyrifos was eluted with 1- x 2-ml then 2- x 1-ml solutions of 80:20 methylene chloride (MeCl): methanol (MeOH). Column eluates were combined in a 4-ml HPLC vial and placed in a water bath at 35 °C. Chlorpyrifos was concentrated by evaporation of the eluate to 1 ml under a gentle stream of ultra-high purity He gas. Eluate was reconstituted to 2 ml with 50:50 MeOH:H_2O and volume was determined by weight (2 ml MeOH = 1.841 g at 25 °C). Chlorpyrifos was determined by HPLC analysis as described below.

After chlorpyrifos was eluted, acidic pesticides were eluted from the SPE column by 3- x 1-ml of acidified 80:20 MeCl:MeOH (acidified to 0.17% trifluoroacetic acid, TFA). Column eluates were combined in a 4-ml HPLC vial and placed in a water bath at 35 °C under a stream of He until dry. The pesticide residue was reconstituted with 2.0 ml of 50:50 MeOH:H_2O. Acidic pesticides were determined by HPLC analysis described below.

Pesticides were determined using a Model 500 HPLC (Dionex). Components included a 50-μl injector, LC-18 HPLC column (Varian), and UV-VIS detector (Dionex). Chlorpyrifos and acidic pesticides were analyzed by two different HPLC methods.

Chlorpyrifos

The mobile phase flow rate was 1.5 ml/min. The mobile phase was 15% water containing 1 mM sodium phosphate buffer (pH 6.7) and 85% acetonitrile (ACN).

Chlorpyrifos had a retention time of 3.2 min and was measured at 230 nm. The detection limit was 0.1 μg/l chlorpyrifos in runoff water samples.

Acidic Pesticides (2,4-D, dicamba, mecoprop)

The mobile phase flow rate was 1.5 ml/min. The acidic pesticides were separated using premixed MeOH:ACN (82:18) as an organic eluent and water acidified with TFA (0.17% TFA, v/v). The initial mobile phase was 50% organic eluent and 50% acidified water, which was linearly increased to 62% organic eluent after 15 minutes. Acidic pesticides were measured at 220 nm. Retention times, in parentheses, were dicamba (5.7 min), 2,4-D (8.0 min), and MCPP (11.2 min). The detection limit was 0.1 μg/l of each acidic pesticide in runoff water samples.

Nutrient Analysis

Runoff samples were vacuum filtered through 0.45-μ nylon membrane filters and refrigerated at 4 °C until analysis. Total sample storage time was less than 48 h. Samples were analyzed for PO_4-P in a 0.348 M (2%) CH_3COOH extract. Concentration was determined after filtration through Whatman No. 2 paper by the phosphomolybdate colorimetric procedure employed by Murphy and Riley (1962). Duplicate samples were extracted using 2 M KCl (Bremner, 1965) and analyzed for NH_4-N and NO_3-N using automated flow injection analysis (Lachat, 1989, 1990). The detection limit was 1.0 mg/l of each nutrient in runoff water samples.

RESULTS AND DISCUSSION

Soil moisture conditions prior to simulated rainfall were different between runs and affected the volume of runoff from plots and the total amount of pesticides and nutrients recovered therein. In the July run, no natural precipitation was detected within 12 days of simulated rainfall; by contrast, 6.51 inches of natural precipitation fell on the runoff site within 6 days of simulated rainfall in August. Mean concentrations and mass of pesticides and nutrients recovered from runoff in July are shown in Tables 1 and 2, respectively. Percent recovery of pesticides and nutrients was less than 3% and 2%, respectively, based upon the total amount applied (Table 3). Highest levels of nutrients and pesticides were recovered from the treatment containing no buffer-strip. Mean concentrations and mass of pesticides and nutrients recovered from runoff in August are shown in Tables 4 and 5, respectively. Pesticide and nutrient runoff was much greater in August compared to July, indicating a negative effect of increased soil moisture content on surface runoff. In August, percent recovery of pesticides and nutrients was less than 15% and 11%, respectively (Table 6). Results from the July run indicated that buffer-strips were very effective in reducing pesticide and nutrient runoff (Table 7). Although few treatment comparisons were statistically significant, numerical trends from the July data showed reduced pesticide and nutrient runoff from the 16-ft buffer length compared to the 8-ft buffer length, the 1.5-in mowing height compared to the 0.5-in mowing height, and solid-tine aerification compared to no aerification at the 0.5-in mowing height (Table 2). At the 1.5-in mowing height, aerification resulted in greater pesticide and nutrient runoff. It is possible that the aerification process created channels in the higher-cut turf canopy, thus causing expedited movement of the chemicals in surface runoff. In August, several of the trends observed in July were reversed, possibly indicating that the effectiveness of the buffer-strip treatments was overcome by the increased volume of surface runoff (Tables 4, 5, 6, and 8). Although no significant differences were found, aerification did appear to positively contribute to reduction in runoff under high soil moisture conditions. Reduced pesticide and nutrient runoff occurred from the wettable powder formulation of chlorpyrifos compared to the granular formulation, and from the sulfur-coated urea form of nitrogen compared to urea

(Tables 4, 5, 6, and 8). The correlation between the physico-chemical properties of pesticides and nutrients and their relative runoff potential was substantiated by this investigation.

Based upon the 1995 preliminary study, the following management practices are recommended to reduce pesticide and nutrient runoff: 1) incorporate a buffer-strip between surface water features and treated areas; 2) avoid application of pesticides and fertilizer when high soil moisture conditions exist; 3) develop pest and nutrient management programs that utilize pesticide and fertilizer formulations with low runoff potential.

A manuscript describing the results of this study is currently being prepared for submission to Crop Science by the end of 1995. In 1996, research will focus on: 1) determination of critical soil moisture levels, buffer-strip lengths, and associated factors that result in reduced pesticide and nutrient runoff; and 2) continued examination of runoff potential of pesticides, nutrients, and their formulations.

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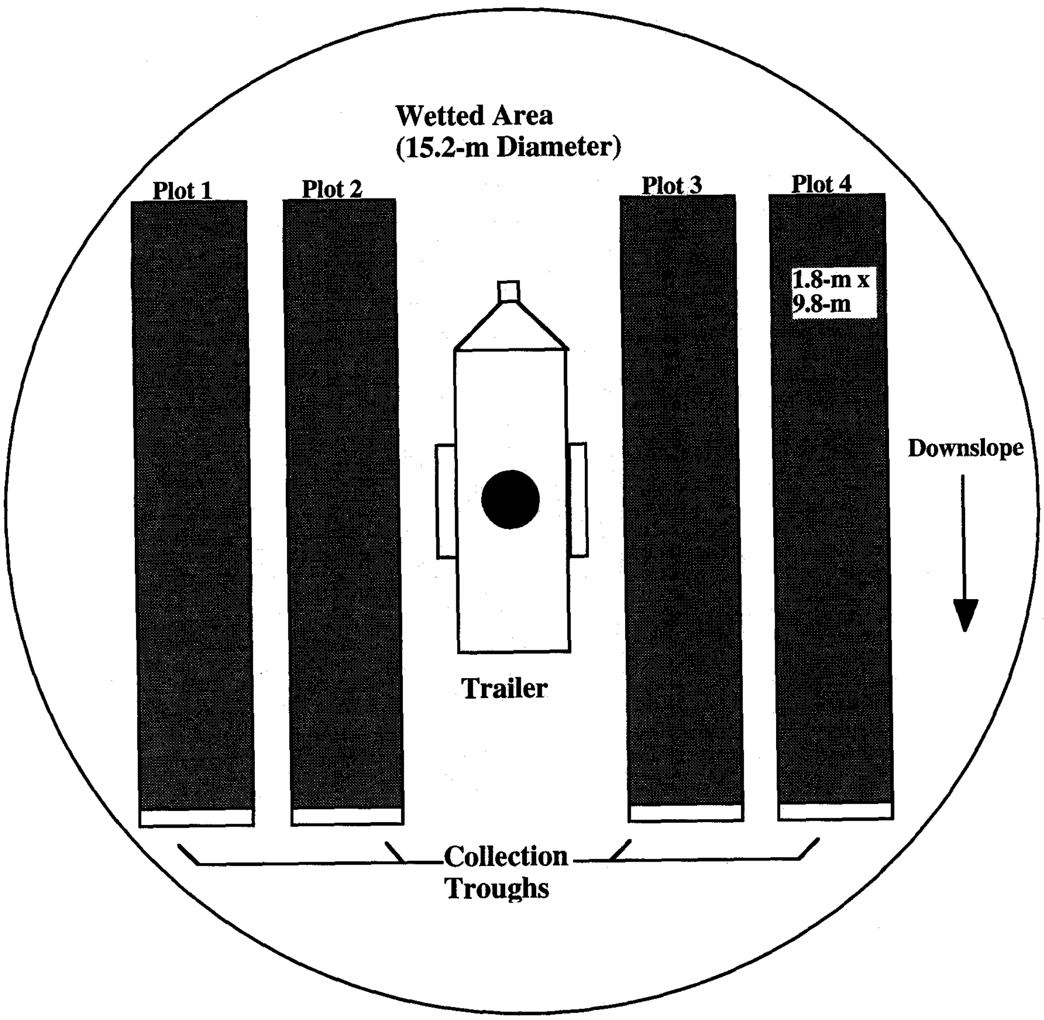

Figure 1. Rainfall simulator and plot layout. Ten booms with staggered nozzles not shown.

Table 1. Concentration of pesticides and nutrients recovered from runoff in July.

Treatment	Buffer Length	Buffer Height	Aerification	Dicamba	2, 4-D	Mecoprop	Chlorpyrifos	NH4-N	NO3-N	PO_4
				CONCENTRATION						
	(m)	(cm)		(µg/L)				(mg/L)		
A	4.9	1.3	No	1.00	14.39	6.30	5.73	3.47	3.44	1.02
B	4.9	3.8	No	4.79	26.92	15.51	4.64	5.33	3.99	1.35
C	0	-	-	16.48	313.92	164.36	34.84	7.40	2.49	9.57
D	2.4	1.3	No	3.69	76.85	44.90	4.49	4.94	2.74	2.36
E	2.4	3.8	No	1.34	30.99	15.32	0.00	4.85	3.93	1.94
F	4.9	1.3	Yes	0.00	15.84	14.39	20.47	2.82	3.05	0.78
G	4.9	3.8	Yes	0.00	13.16	6.38	7.25	4.50	3.45	1.25
H	0	-	-	0.00	0.00	0.00	0.00	2.41	2.56	0.42

Table 2. Mass of pesticides and nutrients recovered from runoff in July.

Treatment	Buffer Length	Buffer Height	Aerification	Dicamba	2,4-D	Mecoprop	Chlorpyrifos	NH4-N	NO3-N	PO_4
				MASS						
	(m)	(cm)		(µg)				(mg)		
A	4.9	1.3	No	3	2734	1383	963	480	381	136
B	4.9	3.8	No	156	1861	1046	27	264	170	71
C	0	-	-	1583	30775	16196	2778	642	147	911
D	2.4	1.3	No	876	17217	10012	984	813	363	471
E	2.4	3.8	No	341	6010	3049	0	410	186	276
F	4.9	1.3	Yes	0	768	847	1065	125	143	37
G	4.9	3.8	Yes	0	3515	1727	877	672	462	246
H	0	-	-	0	0	0	0	401	340	51

Table 3. Percent recovery of pesticides and nutrients from runoff in July based upon the total mass applied.

Treatment	Buffer Length	Buffer Height	Aerification	Dicamba	2,4-D	Mecoprop	Chlorpyrifos	NH4-N	NO3-N	PO_4
				% Recovery						
	(m)	(cm)								
A	4.9	1.3	No	0.003	0.3	0.3	0.05	0.2	0.09	0.2
B	4.9	3.8	No	0.2	0.2	0.2	0.001	-0.3	-0.4	0.05
C	0	-	-	1.5	3.0	3.0	0.14	0.6	-0.4	2.0
D	2.4	1.3	No	0.8	1.7	1.9	0.05	0.9	0.05	1.0
E	2.4	3.8	No	0.3	0.6	0.6	0	0.02	-0.04	0.5
F	4.9	1.3	Yes	0	0.08	0.2	0.05	-0.6	-0.5	-0.03
G	4.9	3.8	Yes	0	0.4	0.3	0.05	0.6	0.3	0.5
H	0	-	-	-	-	-	-	-	-	-

Table 4. Concentration of pesticides and nutrients recovered from runoff in August.

Treatment	Buffer Length	Buffer Height	Aerification	CONCENTRATION Dicamba	2, 4-D	Mecoprop	Chlorpyrifos	NH4-N	NO3-N	PO_4
	(m)	(cm)		(µg/L)				(mg/L)		
A	4.9	1.3	No	5.58	83.77	48.31	0.00	3.01	2.19	3.35
B	4.9	3.8	No	9.65	160.25	90.56	9.11	3.16	2.17	3.87
C	0	-	-	10.76	173.87	97.85	37.24	5.08	2.02	6.52
D	2.4	1.3	No	9.70	154.25	89.43	7.48	3.86	1.92	6.06
E	2.4	3.8	No	8.26	99.80	59.71	0.00	4.11	2.01	4.83
F	4.9	1.3	Yes	5.67	77.80	43.45	0.00	2.89	2.16	4.01
G	4.9	3.8	Yes	7.32	106.80	62.09	0.00	3.27	2.21	4.47
I	0	-	-	9.82	166.32	88.09	20.73	1.83	1.62	8.14

Table 5. Mass of pesticides and nutrients recovered from runoff in August.

Treatment	Buffer Length	Buffer Height	Aerification	MASS Dicamba	2,4-D	Mecoprop	Chlorpyrifos	NH4-N	NO3-N	PO_4
	(m)	(cm)		(µg)				(mg)		
A	4.9	1.3	No	4449	67898	39350	0	2534	1799	2666
B	4.9	3.8	No	8581	142295	80453	3240	2448	1645	3029
C	0	-	-	6175	97540	56527	18701	2774	1069	3598
D	2.4	1.3	No	6643	105549	61096	4919	2713	1447	4193
E	2.4	3.8	No	5480	72898	44393	0	2344	1061	2886
F	4.9	1.3	Yes	4422	60187	32864	0	1940	1419	2771
G	4.9	3.8	Yes	4793	72479	42001	0	2234	1533	3063
I	0	-	-	4942	86478	45880	10259	933	791	4611

Table 6. Percent recovery of pesticides and nutrients from runoff in August based upon the total mass applied.

Treatment	Buffer Length	Buffer Height	Aerification	% Recovery Dicamba	2,4-D	Mecoprop	Chlorpyrifos	NH4-N	NO3-N	PO_4
	(m)	(cm)								
A	4.9	1.3	No	4.2	6.7	7.3	0	5.8	4.1	6.1
B	4.9	3.8	No	8.2	14.0	14.9	0.2	5.6	3.8	6.9
C	0	-	-	5.9	9.6	10.5	1.0	6.4	2.5	8.3
D	2.4	1.3	No	6.3	10.4	11.3	0.3	6.2	3.3	9.6
E	2.4	3.8	No	5.2	7.2	8.2	0	5.4	2.4	6.6
F	4.9	1.3	Yes	4.2	5.9	6.1	0	4.5	3.3	6.4
G	4.9	3.8	Yes	4.6	7.1	7.8	0	5.1	3.5	7.0
I	0	-	-	4.7	8.5	8.5	0.5	2.1	1.8	10.6

Table 7. Tests of significance for comparisons of the effect management practices on concentration and mass of pesticides and nutrients recovered from runoff in July.

	CONCENTRATION							MASS						
COMPARISONS	Dicamba	2,4-D	Mecoprop	Chlorpyrifos	NH4-N	NO3-N	PO_4	Dicamba	2,4-D	Mecoprop	Chlorpyrifos	NH4-N	NO3-N	PO_4
<u>Buffer Mowing Height (1.3 vs. 3.8 cm)</u>	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
A vs B	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D vs. E	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
F vs. G	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
<u>Buffer Length (2.4 vs. 4.9 m)</u>	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
A vs. D	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
B vs. E	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
<u>Buffer Length (0 vs. 2.4 m)</u>														
C vs. D	**	**	**	**	*	NS	**	NS	NS	NS	NS	NS	NS	*
C vs. E	**	**	**	**	NS	NS	**	*	*	*	*	NS	NS	*
<u>Buffer Length (0 vs. 4.9 m)</u>														
C vs. A	**	**	**	**	**	NS	**	**	**	**	NS	NS	NS	**
C vs. B	**	**	**	**	*	NS	**	**	**	**	**	NS	NS	**
C vs. F	**	**	**	NS	**	NS	**	*	*	*	NS	NS	NS	**
<u>Aerification (+ vs. 0)</u>	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
A vs. F	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
B vs. G	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
<u>Control</u>														
H vs. C	**	**	**	**	**	NS	**	**	**	**	**	NS	NS	**
H vs. A	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
H vs. B	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
H vs. E	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
H vs. F	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
H vs. G	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
<u>Other Comparisons</u>														
A vs. G	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
B vs. D	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D vs. F	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D vs. G	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
E vs. F	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
E vs. G	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

*, ** Significant at P = 0.05 and 0.01, respectively.

Table 8. Tests of significance for comparisons of the effect management practices on concentration and mass of pesticides and nutrients recovered from runoff in August.

	CONCENTRATION							MASS						
COMPARISONS	Dicamba	2,4-D	Mecoprop	Chlorpyrifos	NH4-N	NO3-N	PO_4	Dicamba	2,4-D	Mecoprop	Chlorpyrifos	NH4-N	NO3-N	PO_4
Buffer Mowing Height (1.3 vs. 3.8 cm)	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS
A vs. B	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	**	NS
D vs. E	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS
F vs. G	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	**
Buffer Length (2.4 vs. 4.9 m)	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	**	NS
A vs. D	NS	NS	NS	NS	*	NS	*	NS	NS	NS	NS	NS	*	NS
B vs. E	NS	NS	NS	NS	NS	NS	NS	*	*	*	NS	NS	*	NS
Buffer Length (0 vs. 2.4 m)														
C vs. D	NS	NS	NS	**	**	NS	NS	NS	NS	NS	**	NS	NS	NS
C vs. E	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	**	NS	NS	NS
Buffer Length (0 vs. 4.9 m)														
C vs. A	NS	NS	NS	**	**	NS	*	NS	NS	NS	**	NS	**	NS
C vs. B	NS	NS	NS	**	**	NS	NS	NS	NS	NS	**	NS	NS	NS
C vs. F	NS	NS	NS	**	**	NS	**	NS	NS	NS	**	NS	NS	*
Aerification (+ vs. 0)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
A vs. F	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
B vs. G	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Formulation														
I vs. C	NS	NS	NS	*	**	*	NS	NS	NS	NS	*	**	NS	NS
I vs. A	NS	NS	NS	**	**	*	**	NS	NS	NS	**	**	**	NS
I vs. B	NS	NS	NS	NS	**	**	**	**	NS	NS	*	**	*	NS
I vs. E	NS	NS	NS	**	**	NS	**	NS	NS	NS	**	NS	NS	*
I vs. F	NS	*	*	**	NS	NS	**	NS	NS	NS	**	NS	NS	**
I vs. G	NS	NS	NS	**	**	*	**	NS	NS	NS	**	**	*	NS
Other Comparisons														
A vs. G	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
B vs. D	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D vs. F	*	NS	*	NS	**	NS	**	NS	NS	NS	NS	NS	NS	NS
D vs. G	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
E vs. F	NS	NS	NS	NS	**	NS	**	NS	NS	NS	NS	NS	NS	**
E vs. G	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	*	**

*, ** Significant at P = 0.05 and 0.01, respectively