INFLUENCE OF WATER TABLE MANAGEMENT ON RUNOFF LOSSES OF SOIL-APPLIED PESTICIDES

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INTRODUCTION

Pesticide and plant nutrient contamination of surface and subsurface water resources is a national concern. A growing number of farmers and agricultural researchers are looking for innovative ways to reduce production costs and protect human health and the environment (Schaller and Bailey 1983; National Research Council 1989). Part of this effort involves the development of Best Management Practices, including Integrated Pest Management systems that rely less on application of pest control chemicals. Part of the effort to reduce agricultural chemical contamination of surface waters involves the use of conservation tillage and grassed waterways to reduce the volume of water flowing off farm-land after rainfall.

Shallow water tables characterize the alluvial soils of the Mississippi River Delta, the agriculturally productive flood plain of the river from Cairo, Illinois, southward. Responding to rainfall, these water tables fluctuate considerably. Level aspect of the land and high rainfall lead to an abundance of streams, lakes, and wetlands. Shallow water tables, nearby wetlands, high agrichemical use, and high rainfall in the Delta suggest a significant potential for contamination of surface water and groundwater. Agrichemicals have been detected in Delta surface and subsurface water (Cavalier et al. 1989; Gambrell 1989; Cormier et al. 1990; Stuart and Demas 1990).

Subsurface drains not only make possible land preparation sooner in the spring, but also reduce the amount of surface runoff and sediment losses after rainfall. This aspect of subsurface drains therefore leads to reduced levels of agricultural chemical loss in runoff (Skaggs et al. 1994; Bengtson et al. 1995). By rerouting drainage outflow into surface water through the drains, leaching into groundwater can also be reduced. There is evidence that, in some cases, most of the reduction in pesticide runoff losses provided by subsurface drains becomes residual in the soil profile and, therefore, subject to microbial degradation processes, rather than passing into the drains to be discharged into the receiving surface waterway. In earlier work with atrazine and metolachlor, subsurface drains reduced runoff losses, but less than 10% of this reduction was detected in the drain outflow (Southwick et al. 1990a, 1990b).

Management of water table depths with subsurface drains may improve the utility of these drains for decreasing the amounts of agrichemicals lost from alluvial soils by way of surface runoff and leaching (Willis et al. 1991; Thomas et al. 1992; Skaggs et al. 1994). For example, if rain appeared imminent soon after pesticide or fertilizer application to the soil surface, the water table depth could be lowered to enhance infiltration and increase within-soil storage capacity, thereby decreasing runoff loss. Alternatively, if the pesticide and/or fertilizer were already incorporated into the soil surface, the water table could be maintained at some elevation above a subsurface drain line to retard agrichemical leaching below the root zone and thereby retain longer the chemical in the biologically active zone for utilization or degradation. The utility of water table management practices for reducing losses of nitrate nitrogen from agricultural fields has been shown in a few studies, but reports of the effect of such systems on pesticide losses seem not to have been published (Thomas et al. 1992; Skaggs et al. 1994).

This paper presents results from the 1995 season of a study on the effect of conventional subsurface drainage and of controlled water table on runoff losses of soil-applied pesticides from Mississippi River alluvial soil in southern Louisiana.

MATERIALS AND METHODS

The plot and field instrumentation layout is described in detail in Willis et al. (1991). Briefly, sixteen 0.21-ha plots are laid out on Commerce silt loam soil (fine-silty, mixed, nonacid, thermic, Aeric Fluvaquents) at the Louisiana Agricultural Experiment Station's Ben Hur Farms near Baton Rouge in East Baton Rouge Parish. The plots are instrumented for automatic, microprocessor-controlled measurement and sampling of surface runoff and subsurface drain outflow and water table management.

Four replications of four water table management treatments were imposed on the plots:

1. Surface drainage only (SUR).
2. Conventional subsurface drainage at 1.2 m or more below the soil surface (DRN).

3. Controlled water table depth at 45 cm below the soil surface (CWT45).

4. Controlled water table depth at 75 cm below the soil surface (CWT75).

The plots were planted to corn (*Zea mays* L.) on April 19-20, 1995, with conventional tillage. The chemicals were applied without incorporation on April 27, 1995, with the following rates (kg/ha a.i.): atrazine, 0.8; metolachlor, 1.0; pendimethalin, 0.5; chlorpyrifos, 0.9. After application of the chemicals, water table management treatments were imposed and all subsequent runoff and subsurface drain samples were analyzed for their chemical content. Samples were extracted and analyzed by gas chromatography by methods similar to those reported by Southwick et al. (1992). Sediment concentrations were determined from 10-mL aliquots of run-off samples.

RESULTS AND DISCUSSION

Soil concentrations of the applied chemicals were not generally significantly different with respect to treatment, so they were combined to give the concentrations reported in Table 1. Initial concentrations on the soil surface roughly reflected the application rate ratios: atrazine : metolachlor : pendimethalin : chlorpyrifos, 3.4 : 2.9 : 1.0 : 1.7 (day 0 soil concentration); 1.6 : 2.0 : 1.0 : 1.8 (application rate). The high atrazine soil level on day 0 is probably due at least in part to the 30-100 fold lower vapor pressure of this compound compared to the other pesticides (Wauchope et al. 1992). The soil data of Table 1 were regressed to give the modified first order equations of Table 2. These equations provide DT_{50} values ranging from 5.1 (chlorpyrifos) to 55.2 days (pendimethalin).

Rainfall (Table 3) for the 30-day period after application was above the 30-year average (NOAA 1995). May 1995 showed 46 mm more than the average. But after this initial above average rainfall period, precipitation was below average for the next four months. June-September 1995 showed 290 mm less than the average. October rainfall was 66 mm above the long-term average. The very low runoff values during June-September, however, were due not only to low rainfall, but also to a heavy grass cover that developed under the corn canopy.

Sediment concentrations in runoff were generally in the range 1500-7000 mg/L (data not shown), leading to sediment losses of 1400-3300 kg/ha for the first 33 days of the season (Table 4). For all treatments, greater than two-thirds of this erosion occurred in the first runoff event on day 11. The subsurface drains reduced erosion by 39-59%; there was no significant difference among the subdrain treatments in erosion reduction. Bengtson et al. (1995) reported an average 31% reduction in erosional losses due to uncontrolled subsurface drainage (the DRN treatment of this report) in ten years of investigations on the soil (but different plots) of the present study.

Initial concentrations (days 11 and 13) of the chemicals in runoff (Table 5) fell into two groups: those greater than 20 μg/L (atrazine and metolachlor), and those less than 2 μg/L (pendimethalin and chlorpyrifos). These categories correspond to the two groups of water solubility (S_w) represented by the chemicals: > 3 mg/L (atrazine, S_w = 33 mg/L; metolachlor, S_w = 530 mg/L) and < 3 mg/L (pendimethalin, S_w = 0.3 mg/L; chlorpyrifos, S_w = 0.4 mg/L). Pesticides with S_w > 3 mg/L tend to leave a field in runoff mostly (> 50%) in the water phase; those with lower S_w tend to move in runoff attached to sediment (Wauchope 1978). In an earlier study of runoff losses of atrazine and metolachlor (Southwick et al. 1990b), we observed levels of these herbicides in the water phase usually in excess of 75%. At the end of sample collection in the two seasons, atrazine concentrations were still > 3 ug/L, the lifetime health advisory (LHA) for drinking water for this herbicide (USEPA 1991). The LHA for metolachlor of 100 ug/L (USEPA 1991) was not exceeded at any time during the study season.

Generally, differences in concentrations of the chemicals in runoff with respect to treatment on a sample day (even on the first runoff event on day 11) were not significant at the 0.05 level. In our earlier study of runoff of atrazine and metolachlor (Southwick et al. 1990b), we observed significantly higher concentrations of these herbicides from the plots without subsurface drains on day 12 (1.6 times higher from plots without drains). In small plot work, Baldwin et al. (1975a, 1975b) observed large differences in concentrations of prometryn and fluometuron in the first 6.5 mm of runoff as a function of antecedent soil moisture (concentrations 7-9 times higher from wet soil).

Concentrations of atrazine and metolachlor in runoff exhibited smooth trends toward low values with time (Table 5). These trends were regressed (Table 6) using a modified first order decay equation [$C = a + b\exp(-t/c)$]. This equation permitted calculation of a 50% disappearance time (DT_{50}) and in most cases a DT_{90} (starting from the first runoff event on day 11). The DT_{50} values of Table 6 are in the range 2-8 days and show no trend with treatment; DT_{90} times range between 9 and 26 days . Our earlier work with atrazine and metolachlor in runoff (Southwick et al. 1990b) afforded DT_{50}s of 8-9 days after the first runoff event on day 12.

Total losses of these chemicals in runoff (Table 7) amounted to 33-52 g/ha for atrazine and metolachlor and to 0.02-0.4 g/ha for pendimethalin and chlorpyrifos. In relation to application rates, these losses were 3-7% for atrazine and metolachlor and 0.005-0.04% for pendimethalin and chlorpyrifos. The DRN and CWT45 treatments gave 22% reductions in runoff losses of atrazine and metolachlor and 51-68% reductions in pendimethalin and chlorpyrifos runoff losses. The CWT75 treatment generally did not perform as well. At the 0.05 level, differences for DRN and CWT45 are not significant, neither are they significant between atrazine and metolachlor or between pendimethalin and chlorpyrifos. But cumulative losses (g/ha and % of application) are significantly different ($P = 0.05$) between the atrazine-metolachlor pair and the pendimethalin-chlorpyrifos pair of chemicals. As with water solubilities, runoff losses are therefore separable into two categories: greater than 30 g/ha (3% of application) and less than 1 g/ha (0.2% of application). For the study season, greater than 94% of runoff losses had occurred by day 14, except for pendimethalin (36-82% by this day). In a previous study of atrazine and metolachlor runoff losses from nearby plots on the soil of the present report (Southwick et al. 1990b), losses of about 52 g/ha (2.4-3.2% of application) over a 130-day season were reduced 56% by uncontrolled subsurface drainage (DRN treatment of the present investigation).

Not only are runoff losses of pendimethalin-chlorpyrifos absolutely less than atrazine-metolachlor (Table 7), the treatment effect on the losses of this pair with low (<3 mg/L) water solubility is greater than the effect on the pair with high (> 3 mg/L) water solubility (Table 8). The data indicate roughly twice the effect of the DRN and CWT45 treatments on losses of pendimethalin-chlorpyrifos compared to their influence on runoff losses of atrazine-metolachlor. This greater influence is consistent with the greater effect of the treatments on soil erosional losses than on water runoff from the plots (Tables 3 and 4). This observation is compatible with the general observation that stream suspended sediment load increases faster than discharge (Johnson and Moldenhauer 1970; p. 15). For reducing runoff losses of pesticides such as atrazine and metolachlor, the lowering of water loss in runoff is important; but for chemicals such as pendimethalin and chlorpyrifos, the reduction of soil erosional losses in runoff is equally or more important. Conservation tillage and grassed waterways act to reduce water and sediment losses in runoff. Subsurface drains also reduce both water and soil erosional losses in runoff. In addition, subsurface drains with controlled water table capability have the theoretical potential of increasing the time soil leachate and its associated chemicals spend in the soil profile and thus lengthening the time these chemicals have to exert their action in the root zone and to undergo soil degradation processes. The data reported herein reveal trends, generally without statistically significant differences ($P = 0.05$), that indicate the potential usefulness of not only conventional subsurface drains but also of controlled water table for reduction of runoff losses of pesticides. The lack of statistical significance was due at least in part to the low runoff volumes being compared. In this study, the 45-cm water table treatment provided more consistent runoff loss reductions that did the water table held at 75 cm. Additional study seasons will be required before the general usefulness of the technique can be evaluated.

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Table 1. Pesticides in Soil, Top 2.5 cm.

Day after Appl.	Atrazine	Metolachlor	Pendimethalin	Chlorpyrifos
	μg/kg			
	(s.d.)[a]			
0	1370 (577)	1200 (247)	409 (136)	702 (168)
4	864 (254)	1310 (267)	426 (182)	335 (208)
11	742 (248)	1270 (152)	386 (127)	219 (41.2)
26	593 (229)	612 (212)	274 (102)	123 (68.7)
70	157 (74.9)	212 (99.8)	182 (61.2)	23.8 (11.2)
112	167 (84.4)	107 (36.3)	164 (46.0)	20.3 (5.7)
154	87.2 (36.4)	63.2 (26.0)	76.8 (19.5)	25.0 (5.6)

[a]s.d. = standard deviation

Table 2. Regression Equations, Pesticides in Soil, Top 2.5 cm[a]

$$C = a + b\exp(-t/c)$$

Pesticide	a	b	c	r^2	DT_{50}
Atrazine	127	1117	22.5	0.65	18.3
Metolachlor	1.36	1361	42.0	0.85	29.2
Pendimethalin	68.4	359	61.2	0.58	55.2
Chlorpyrifos	48.4	636	6.55	0.81	5.1

[a]C = pesticide concentration in soil, μg/kg; t = time, days after application.

Table 3. Rainfall and Runoff, mm

Month	Days After Appl.	Rainfall		Runoff							
				SUR		DRN		CWT45		CWT75	
		month total	cum[a]	month total	cum[a]	month total	cum[a]	month total	cum[a]	month total	cum[a]
Apr	0-3	0	0	0	0	0	0	0	0	0	0
May	4-34	158	158	69.4	69.4	53.5	53.5	52.8	52.8	66.7	66.7
Jun	35-64	54	212	0	69.4	0	53.5	0	52.8	0	66.7
Jul	65-95	71	283	0	69.4	0	53.5	0	52.8	0	66.7
Aug	96-126	81	364	0	69.4	0	53.5	0	52.8	0	66.7
Sep	127-156	47	411	0	69.4	0	53.5	0	52.8	0	66.7
Oct	157-187	136	547	6.9	76.3	4.4	57.9	5.1	57.9	2.6	69.3
% Reduction in Runoff[b]							24.1		24.1		9.2

[a]Cumulative rainfall and runoff
[b]With respect to SUR

Table 4. Sediment in Runoff.

Days After Appl.	Sediment, kg/ha (s.d.)[a] SUR	DRN	CWT45	CWT75
11	2730 (2069)	924 (320)	1213 (196)	1534 (1292)
13	164 (20.8)	89.5 (12.9)	112 (71.4)	159 (71.6)
21	93.8 (17.2)	114 (62.7)	97.6 (54.8)	107 (2.3)
33	321 (204)	238 (36.1)	194 (106)	217 (72.0)
Total	3309 (2311)	1366 (432)	1617 (428)	2017 (1438)
% Reduction[b]		59	51	39

[a]s.d. = standard deviation
[b]With respect to SUR

Table 5. Concentrations of Pesticides in Runoff.

Days After Appl.	Concentration, µg/L (s.d.)[a]							
	SUR		DRNC		WT45		CWT75	
Atrazine								
11	71.8	(21.3)	60.9	(17.6)	63.5	(24.7)	70.8	(34.3)
13	38.4	(8.4)	35.3	(8.4)	38.5	(11.8)	40.2	(5.0)
21	23.5	(12.1)	30.6	(10.1)	23.5	(10.0)	23.2	(8.1)
33	7.7	(3.6)	2.5	(2.7)	6.7	(3.3)	8.0	(3.9)
170	8.3	(16.1)	1.1	(0.7)	4.3	(4.6)	5.8	(8.0)
Metolachlor								
11	64.7	(17.4)	52.7	(7.3)	61.4	(7.5)	48.2	(10.9)
13	29.0	(1.8)	23.0	(11.6)	27.0	(3.9)	29.6	(2.7)
21	19.3	(5.7)	17.6	(5.4)	14.8	(7.8)	18.9	(7.7)
33	6.1	(3.9)	7.0	(1.8)	6.2	(2.5)	6.6	(2.9)
170	0.9	(1.6)	0.1	(0.0)	0.1	(0.0)	0.3	(0.4)
Pendimethalin								
11	0.13	(0.06)	0.10	(0.0)	0.20	(0.18)	0.12	(0.05)
13	0.91	(0.19)	1.12	(0.37)	1.18	(0.72)	1.39	(0.45)
21	0.10	(0.0)	0.10	(0.01)	0.15	(0.10)	0.12	(0.03)
33	0.2	(0.07)	0.40	(0.22)	0.27	(0.22)	0.36	(0.32)
170	0.72	(1.07)	0.10	(0.0)	0.29	(0.32)	0.10	(0.0)
Chlorpyrifos								
11	0.08	(0.03)	0.07	(0.02)	0.11	(0.09)	0.04	(0.02)
13	0.43	(0.35)	0.44	(0.28)	0.43	(0.22)	0.48	(0.28)
21	0.04	(0.02)	0.0	(0.09)	0.15	(0.20)	0.10	(0.04)
33	0.04	(0.02)	0.07	(0.04)	0.06	(0.03)	0.11	(0.12)
170	0.02	(0.0)	0.02	(0.0)	0.02	(0.0)	0.27	(0.30)

[a]s.d. = standard deviation

Table 6. Regression Equations for Atrazine and Metolachlor Concentrations in Runoff $C = a + b\exp(-t/c)$[a]

Pesticide	Treatment	Parameter				Disappearance Time, days[b]	
		a	b	c	r^2	DT_{50}	DT_{90}
Atrazine	SUR	7.23	617	4.73	0.94	3.9	c
	DRN	0.078	146	11.2	0.92	7.8	26.0
	CWT45	3.27	218	8.02	0.96	6.1	24.5
	CWT75	4.86	347	6.31	0.95	4.7	22.6
	Combined	3.46	233	7.84	0.93	5.9	24.2
Metolachlor	SUR	7.29	7700	2.24	0.94	1.9	c
	DRN	3.81	458	4.63	0.89	3.6	18.2
	CWT45	4.93	6600	2.30	0.95	1.8	8.9
	CWT75	0.75	128	10.1	0.96	7.2	25.0
	Combined	5.58	2320	2.87	0.90	2.3	22.5

[a]C = concentration, µg/L; t = time, days.
[b]Values are measured from first runoff event on day 11.
[c]Equation does not allow calculation of a DT_{90}.

Table 7. Losses of Pesticides in Runoff.

Days After Appl.	Cumulative Loss, g/ha (s.d.)[a] [Cumulative % of Application Loss (s.d.) at 170 Days]			
	SUR	DRN	CWT45	CWT75
	Atrazine			
11	50.1 (18.0)	38.4 (13.0)	39.1 (18.8)	49.0 (25.5)
13	50.3 (18.1)	38.5 (13.2)	39.2 (18.9)	49.3 (25.7)
21	51.3 (18.4)	39.7 (13.4)	40.0 (19.0)	50.2 (26.0)
33	51.9 (18.8)	40.2 (13.6)	40.2 (19.1)	50.6 (26.2)
170	52.0 (18.9)	40.3 (13.7)	40.3 (19.1)	50.8 (26.4)
	[6.5 (2.4)]	[5.0 (1.7)]	[5.0 (2.4)]	[6.4 (3.3)]
	Metolachlor			
11	42.0 (10.9)	32.8 (6.8)	37.3 (10.2)	32.1 (11.7)
13	42.1 (11.0)	32.9 (7.0)	37.4 (10.3)	32.3 (11.9)
21	43.0 (11.2)	33.6 (7.3)	37.8 (10.4)	33.1 (12.2)
33	43.3 (11.4)	34.0 (7.4)	38.1 (10.5)	33.4 (12.2)
170	43.4 (11.4)	34.0 (7.4)	38.1 (10.6)	33.4 (12.2)
	[4.3 (1.1)]	[3.4 (0.74)]	[3.8 (1.1)]	[3.3 (1.2)]
	Pendimethalin			
11	0.045 (0.078)	0.006 (0.001)	0.006 (0.001)	0.007 (0.0004)
13	0.049 (0.080)	0.010 (0.006)	0.010 (0.004)	0.019 (0.014)
21	0.050 (0.080)	0.011 (0.008)	0.012 (0.008)	0.022 (0.017)
33	0.059 (0.086)	0.027 (0.019)	0.020 (0.016)	0.034 (0.028)
170	0.060 (0.086)	0.028 (0.019)	0.023 (0.020)	0.034 (0.028)
	[0.012 (0.017)]	[0.006 (0.004)]	[0.005 (0.004)]	[0.007 (0.006)]
	Chlorpyrifos			
11	0.056 (0.022)	0.042 (0.016)	0.057 (0.033)	0.030 (0.016)
13	0.338 (0.225)	0.101 (0.094)	0.161 (0.117)	0.310 (0.319)
21	0.339 (0.226)	0.104 (0.096)	0.165 (0.121)	0.314 (0.320)
33	0.341 (0.227)	0.107 (0.097)	0.167 (0.122)	0.319 (0.327)
170	0.342 (0.228)	0.108 (0.097)	0.168 (0.123)	0.327 (0.338)
	[0.038 (0.025)]	[0.012 (0.011)]	[0.019 (0.014)]	[0.036 (0.038)]

[a]s.d. = standard deviation

Table 8. Effect of Treatments on Runoff Losses of Applied Pesticides.[a]

Pesticide	Treatment			
	SUR	DRN	CWT45	CWT75
	% Reduction			
Atrazine	0	22	22	2
Metolachlor	0	22	12	23
Pendimethalin	0	53	62	43
Chlorpyrifos	0	68	51	4

[a]With respect to SUR.