EFFECT OF CONTROLLED WATER TABLE ON RUNOFF LOSSES OF SOIL-APPLIED CHEMICALS

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INTRODUCTION

Pesticide and plant nutrient contamination of surface and subsurface water resources is a national concern that requires rational assessment and treatment. A growing number of farmers and agricultural researchers are looking for innovative ways to reduce 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 of farmland after rainfall.

An estimated 25% of US cropland needs drainage (Pavelis 1987). Much of this land is relatively flat and fertile and has no serious erosion problems. These potentially productive wet soils are primarily in the prairie and level uplands of the Midwest, the bottom lands of the Mississippi River Valley, the bottom lands of the Piedmont and hill areas of the South, the coastal plains of the East and South, and the irrigated areas of the West (Schwab et al. 1981). During part (sometimes most) of the year, these soils have shallow water tables that are potential sinks for pesticides that may leach below the root zone.

Shallow water tables characterize the alluvial soils of the Mississippi River Delta, the agriculturally productive flood plain of the river from Cairo, Illinois, southward. Water levels in the Delta are less than 9 m below the surface and are much closer to the surface during wet periods. 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. The conditions in the Delta of shallow water tables, nearby wetlands, high agrochemical use, and high rainfall suggest a significant potential for contamination of surface water and groundwater. There have been reports of detection of agrochemicals in Delta surface and subsurface water (Cavalier and Lavy 1987; 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 (Bengtson et al. 1995). By rerouting leachate flow into surface water through the drains, leaching into groundwater can also be reduced. There is evidence that, at least 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 (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 agrochemicals lost from alluvial soils by way of surface runoff and leaching (Willis et al. 1991; 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 agrochemical leaching below the root zone and thereby retain the chemical in the biologically active zone longer for utilization or degradation.

This paper presents results from the first two years of a study on the effect of controlled water table on runoff losses of soil applied chemicals from Mississippi River alluvial soil in southern Louisiana. Due to the generation of a soil compaction layer during the field installation work, the subsurface drains exhibited an erratic influence on water flow. Therefore, we report here data only from the plots without subsurface drains.

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

The plots were planted to corn (*Zea mays* L.). The planting dates and chemical application rates are listed in Table 1. (A faulty applicator setting gave half the intended rate for 1995.) 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).

RESULTS AND DISCUSSION

Rainfall (Table 2) for the 30-60 day periods after application was above the 30-year average (NOAA 1994). The June-July 1994 period accumulated 78 mm more rainfall than was typical, and May 1995 showed 46 mm more than the average. But after these initial above average rainfall periods, precipitation was below average. The 4-month period August-November 1994 accumulated 87 mm less than the average, and June-September 1995 showed 245 mm less than the average. The very low runoff values during these latter days of each season, however, was probably due more to a heavy grass cover that developed than to the low rainfall.

The concentration of pesticides in the top 2.5 cm soil layer (Table 3) showed rapid decreases. Levels of atrazine, metolachlor, and chlorpyrifos dropped by 50% in 16 days or less, and pendimethalin decreased by half in 20 days. In previous field work, we have measured soil half lives of 14-36 days for atrazine and 20-23 days for metolachlor (Southwick et al. 1990a, 1992, 1995). In the present study, atrazine showed the greatest soil persistence with a DT_{90} of 68 days.

Initial concentrations of the chemicals in runoff for the two years of the study (Table 4) fell into two groups, those greater than 60 ug/L and those less than 5 ug/L. 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 our 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 two seasons.

Disappearance times (Table 5) of the chemicals in runoff were similar in the two years of data we report herein. In addition, the 1994 data (1995 soil values are presently undetermined) show a trend that we have observed in our earlier studies with atrazine and metolachlor (Southwick et al. 1990a; 1990b): half lives of the pesticides (except for chlorpyrifos) in runoff are shorter than those in the soil that is the source of the chemicals in runoff. The 1994 runoff DT_{50}s are in the following ratios with their respective soil DT_{50}s: atrazine, 0.38; metolachlor, 0.43; pendimethalin, 0.60; similar (0.92) for chlorpyrifos. In our other investigation of atrazine and metolachlor runoff, these ratios were 0.25 for atrazine and 0,37 for metolachlor.

Total losses of these chemicals in runoff (Figure 1) amounted to 21-40 g/ha for atrazine and metolachlor and to 0.04-1.1 g/ha for pendimethalin and chlorpyrifos. In relation to application rates (Table 1), these losses were 1.1-3.5% for atrazine and metolachlor and 0.004-0.13% for pendimethalin and chlorpyrifos. As with water solubilities, runoff losses are therefore separable into two categories: greater than 20 g/ha (1% of application) and less than 2 g/ha (0.1% of application). In 1994, 91-93% of runoff losses occurred by day 18, except for chlorpyrifos (80% by this day); in 1995, 97-100% of losses had happened by day 13, except for pendimethalin (71%).

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 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.

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Table 1. Application Dates and Rates

Application Dates		
1994: May 25		
1995: April 27		
Application Rates, kg/ha	1994	1995
Atrazine	1.5	0.8
Metolachlor	1.9	1.0
Pendimethalin	0.9	0.5
Chlorpyrifos	1.7	0.9

Table 2. Rainfall and Runoff, SUR Plots

Month	Days After Appl.	Rainfall		Runoff	
		mm	Cum mm[a]	mm	Cum mm[a]
1994					
May	0-6	24	24	0	0
Jun	7-36	197	221	81.1	81.1
Jul	37-67	159	380	19.0	100
Aug	68-97	98	478	0.9	101
Sep	98-127	62	540	0	101
Oct	128-158	80	620	0	101
Nov	159-188	53	673	0	101
Dec	189-193	73	746	7.7	109
1995					
April	0-3	0	0	0	0
May	4-34	166	166	40.3	40.3
Jun	35-64	54	220	0	40.3
Jul	65-95	71	291	0.1	40.4
Aug	96-126	81	372	0	40.4
Sep	127-156	47	419	0	40.4
Oct	157-159	42	461	0.2	40.6

a Cumulative rainfall and runoff.

Table 3. Pesticides in Soil, 1994

Days After Appl.	Concentration, ug/kg			
	Atrazine	Metolachlor	Pendimethalin	Chlorpyrifos
1	1700	3920	2100	1010
23	588	823	917	95.6
69	70.7	183	a	45.3
76	49.1	202	a	14.0
DT_{50} (DT_{90})[b]	16 (68)	14 (57)	20	12 (24)

a Questionable results.

b Time in days to 50% (90%) disappearance of starting level.

Table 4. Pesticides in Runoff from SUR Plots.

Days After Appl.	Concentration, ug/L			
	Atrazine	Metolachlor	Pendimethalin	Chlorpyrifos
1994				
11	129	69.6	2.00	0.26
15	116	59.8	1.78	0.24
18	32.8	18.8	1.18	0.19
30	9.12	7.76	0.71	0.10
46	11.0	5.71	0.38	0.06
47	13.3	7.17	0.19	0.02
70	8.68	8.40	0.19	0.00
72	2.82	1.64	0.18	0.03
193	4.72	0.46	0.08	0.18
1995				
11	81.4	66.2	0.81	0.25
13	38.4	26.2	0.91	0.29
14	65.0	50.0	3.52	1.04
21	20.2	18.9	0.17	0.20
33	9.39	5.92	0.42	0.08
62	4.81	0.72	0.30	0.30
64	7.86	2.65	0.00	0.27
66	15.0	1.26	0.95	0.24
159	9.03	1.44	0.37	0.82

Table 5. Disappearance Times (50% and 90%) of Pesticides in Runoff

Pesticide	DT_{50} (DT_{90}), days	
	Runoff, 1994[a]	Runoff, 1995[a]
Atrazine	6 (35)	8 (30)
Metolachlor	6 (19)	8 (22)
Pendimethalin	12 (35)	b
Chlorpyrifos	11 (36)	b

a Values measured from first runoff event on day 11.

b Not determined because of erratic runoff concentrations.

FIGURE 1
CHEMICALS IN RUNOFF FROM SUR PLOTS
BEN HUR STATION
1994-1995