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Runoff and Leaching of Metolachlor from Mississippi River Alluvial Soil during Seasons of Average and Below-Average Rainfall

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The movement of the herbicide metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide] via runoff and leaching from 0.21 ha plots planted to corn on Mississippi River alluvial soil (Commerce silt loam) was measured for a 6-year period, 1995−2000. The first three years received normal rainfall (30 year average); the second three years experienced reduced rainfall. The 4-month periods prior to application plus the following 4 months after application were characterized by 1039 ± 148 mm of rainfall for 1995−1997 and by 674 ± 108 mm for 1998−2000. During the normalrainfall years 216 ± 150 mm of runoff occurred during the study seasons (4 months following herbicide application), accompanied by 76.9 ± 38.9 mm of leachate. For the low-rainfall years these amounts were 16.2 ± 18.2 mm of runoff (92% less than the normal years) and 45.1 ± 25.5 mm of leachate (41% less than the normal seasons). Runoff of metolachlor during the normal-rainfall seasons was 4.5−6.1% of application, whereas leaching was 0.10−0.18%. For the below-normal periods, these losses were 0.07−0.37% of application in runoff and 0.22−0.27% in leachate. When averages over the three normal and the three less-than-normal seasons were taken, a 35% reduction in rainfall was characterized by a 97% reduction in runoff loss and a 71% increase in leachate loss of metolachlor on a percent of application basis. The data indicate an increase in preferential flow in the leaching movement of metolachlor from the surface soil layer during the reduced rainfall periods. Even with increased preferential flow through the soil during the below-average rainfall seasons, leachate loss (percent of application) of the herbicide remained below 0.3%. Compared to the average rainfall seasons of 1995−1997, the below-normal seasons of 1998−2000 were characterized by a 79% reduction in total runoff and leachate flow and by a 93% reduction in corresponding metolachlor movement via these routes. An added observation in the study was that neither runoff of rainfall nor runoff loss of metolachlor was influenced by the presence of subsurface drains, compared to the results from plots without such drains that were described in an earlier paper.

KEYWORDS: Metolachlor; runoff; leachate; rainfall

INTRODUCTION

Soil-applied herbicides leave a field after rainfall both in runoff and via leaching through the soil profile. These routes of loss from the site of application have been intensively studied for numerous chemicals over the past 40 years (*1*−*3*). Most of these investigations have treated either the runoff or leaching loss pathway; rarely have both routes been investigated in the same study.

Richard and Steenhuis (*4*) and Kladivko et al. (*5*) have promoted the advantage of subsurface drains over suction cups and soil cores in soil profile leaching studies because of the integrating nature of leachate collection by these drains. Kladivko et al. (*5*), Schwab et al. (*6*), and Skaggs et al. (*7*) have investigated the leaching of soil-applied herbicides into subsurface drains.

Some studies have combined the investigation of runoff of soil-applied herbicides with collection of soil leachate samples by subsurface drains. In a four-year study (1987−1990) in Ohio on Hoytville silty clay, Logan et al. (*8*) observed runoff and tile drain losses of atrazine and alachlor (corn cultivation) and metolachlor and metribuzin (soybean). Most of the movement from site of application occurred in runoff. Runoff losses tended to be between 1 and 2 orders of magnitude greater than those in leachate. For example, in 1987, metolachlor losses from soybean plots (no-till) were 2.81 g/ha (runoff) and 0.17 g/ha (leachate); with the fall moldboard plow treatment, runoff was 1.15 g/ha and leachate was 0.22 g/ha.

Gaynor et al. (*9*) in Ontario, Canada, on Brookston clay loam observed atrazine and metolachlor movement from the field

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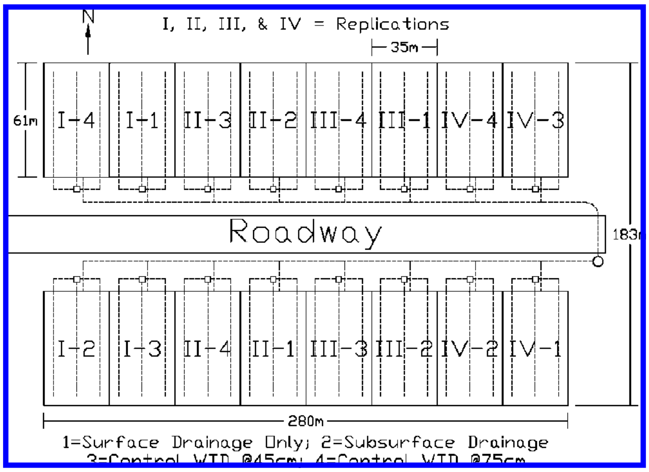

Figure 1. Plot layout at the Ben Hur Farms.

(corn) via surface runoff and subsurface drain tiles. For both herbicides, both routes produced losses of similar magnitude. For example, in 1987, atrazine was observed at 18.0 g/ha in runoff and 9.0 g/ha in tile drainage; in 1990, losses were 13.0 g/ha in runoff and 32.0 g/ha in leachate. Metolachlor in 1987 was measured in runoff at 10.0 g/ha and in leachate at 7.0 g/ha; in 1990 these values were 9.0 g/ha in runoff and 14.0 g/ha in tile drainage. In subsequent work on the same soil (*10*), these investigators again found similar magnitudes of atrazine, metolachlor, and metribuzin in runoff and tile drainage from various crop-tillage treatments. In the 1992−1993 season, for example, the moldboard plow treatment produced 3.33 g/ha of metolachlor in runoff and 7.02 g/ha in tile drainage. These workers have reported additional work on this soil (*11*).

In a study on Mississippi River alluvial soil (Commerce clay loam), Southwick et al. (*12, 13*) observed atrazine and metolachlor in both runoff and leachate through subsurface drain tiles. Atrazine was observed in runoff at 22.8 g/ha and at 0.62 g/ha in subsurface drainage. Metolachlor moved from the field in runoff at 23.1 g/ha and in subsurface drainage at 2.76 g/ha. Thus, runoff accounted for an order of magnitude greater loss for each herbicide than flow into the subsurface drains.

In 1995 we began studying runoff and leachate loss of soil-applied herbicides from Mississippi River alluvial soil (Commerce loam grading to silt loam) on a set of 16 plots that accommodated four treatments. These treatments (four replications) were (1) plots without the influence of subsurface drains, (2) conventional subsurface drainage at 1 m depth, (3) controlled water table at 45 cm depth, and (4) controlled water table at 75 cm (**Figure 1**). Runoff was collected from the entire plot (0.21 ha); leachate was collected from the middle subsurface drain, which received leachate from the middle half of the plot (0.105 ha). The plot design is described in detail by Willis et al. (*14*). We have reported runoff loss of atrazine and metolachlor from the plots without subsurface drains (treatment 1, **Figure 1**) during the 1995−1997 seasons (*15*).

After 1997, rainfall in the southeastern United States was below the 30 year average for the next several years. Consequently, runoff collection in our work at the Ben Hur Farms was much diminished. Here we report runoff and leaching of metolachlor from these plots for 1995−1997 (average or normal rainfall) and for 1998−2000 (reduced rainfall). The data were collected from those plots with conventional subsurface drainage (**Figure 1**, treatment 2). This multiple-year study allows a comparison between runoff and subsurface drainage loss of the same herbicide as influenced by two differing rainfall patterns.

Table 1. Metolachlor Application Rates and Formulations

year	application date	metolachlor rate, kg/ha (formulation)
1995	April 27	0.95 (Bicep 6 L)
1996	March 29	1.91 (Bicep)
1997	April 24	1.91 (Bicep II)
1998	April 13	1.91 (Bicep II)
1999	April 26	2.80 (Dual 8E)
2000	March 23	2.80 (Dual 8E)

EXPERIMENTAL PROCEDURES

The field work was conducted on 0.21 ha plots (four replications) at Louisiana State University's Ben Hur Farms (6 km south of Baton Rouge in East Baton Rouge Parish). The plots, precision graded to 0.2% slope, were laid out on Mississippi River alluvial soil [Commerce silt loam (fine-silty, mixed, nonacid, thermic, Aeric Fluvaquents)] and planted to corn. See **Figure 1** and Willis et al. (*14*) for details of the plot design. The plots with subsurface drains contained three 10.2 cm diameter plastic drain tubes 15 m apart and 1.0 m deep. Runoff was directed through 45 cm H-flumes, and 50 mL aliquots from every 1000 L of flow were collected by automatic samplers (1 L polyethylene bottles) that kept the samples at 5 °C until they could be removed to the laboratory, usually within 1 day of each runoff event. The outflow from the subsurface drains, which always began within 1 h (the minimum time division of the field instrumentation) of rainfall initiation, was likewise automatically collected and refrigerated until removal to the laboratory, usually within 1 day of a leachate event. Soil samples (10 subsamples per plot) were collected from the top 2.5 cm layer three times in the first 2 weeks and six to seven times within 5−6 months after application. Soils were allowed to air-dry in the laboratory, ground to pass a 2 mm sieve, and then frozen at −5 °C until analysis. Extraction and analysis of the samples are described in detail by Southwick et al. (*15*). Briefly, soils were extracted by Soxhlet with ethyl acetate for 24 h. Runoff and leachate samples were extracted with ethyl acetate for 4 h with magnetic stirrer. All extracts were analyzed by gas chromatography with electron capture detection. Limit of detection for metolachlor in runoff and leachate samples was 2 μg/L (250 mL sample); for soil the limit of detection was 25 ng/g (20 g sample).

Regression equations were developed with TableCurve 2D v. 5.01 and with SigmaPlot 2000 v. 6.10. Paired *t* test and correlation analysis comparisons were performed with Microsoft Excel 2003 with Analysis ToolPak. Metolachlor application information is listed in **Table 1**.

RESULTS AND DISCUSSION

Rainfall as deviation from normal (DFN, based on the 30 year average for 1961−1990) for the four months preceding application (December−March) and for the months of the growing season (April−July) is given in **Figure 2**. Rainfall during these periods most influenced runoff and leaching of

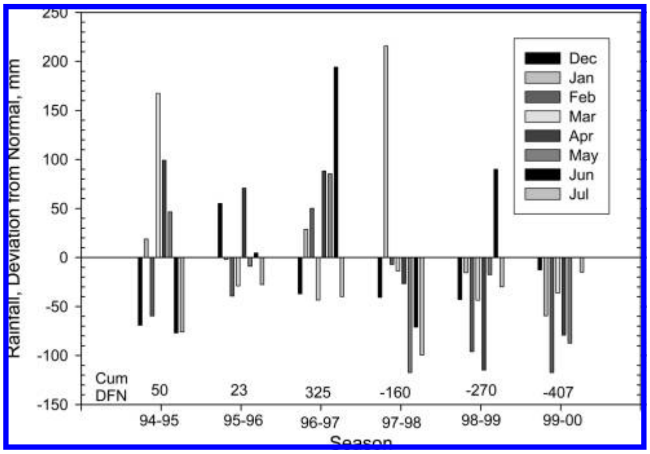

Figure 2. Rainfall, deviation from normal (DFN), December−July, for the study seasons, 1995−2000.

Table 2. Regression Equations for Metolachlor in Top 2.5 cm Soil Layer[a]

year	equation	R^2	$t_{1/2}$, days
1995	$C_{met} = 1410 \exp(-0.0202t)$	0.84	34.3
1996	$C_{met} = 4450 \exp(-0.0468t)$	0.87	14.8
1997	$C_{met} = 3900 \exp(-0.0282t)$	0.75	24.6
1998	$C_{met} = 3760 \exp(-0.0175t)$	0.84	39.6
1999	$C_{met} = 3960 \exp(-0.0294t)$	0.79	23.6
2000	$C_{met} = 5590 \exp(-0.0146t)$	0.45	47.5
1995−2000	$C/C_0 = 0.996 \exp(-0.0235t)$	0.72	29.5

[a] C_{met}, metolachlor soil concentration, ng/g; *t*, days after application; C/C_0, metolachlor soil concentration at time *t* normalized with respect to the concentration at $t = 0$.

herbicides applied to the soil at planting time at the beginning of the growing season. Rainfall in excess of normal (30 year average) characterized the first three study years (1995−1997). This excess rain (the 8 month periods from December to July) varied from 23 mm (1995−1996) to 325 mm (1996−1997). The subsequent three years exhibited lower than normal rainfall. During 1998−2000, DFN became steadily more negative, reaching a value of −407 mm for the period December 1999−July 2000. Mean rainfall during the December−July periods of 1995−1997 was 1039 ± 148 mm; that for 1998−2000 was 674 ± 108 mm, a 35% decrease in rainfall, compared to the wetter earlier periods. The total annual rainfall at the Ben Hur site showed the following means: 1995−1997, 1712 ± 137 mm; 1998−2000, 1169 ± 148 mm. Thirty year mean rainfall for 1961−1990 at the Ben Hur site was 1496 mm; for 1971−2000 this figure was 1561 mm. The 1995−1997 period was characterized by rainfall 10−15% in excess of these two 30 year averages; the 1998−2000 seasons received rainfall 22−25% below these means. The rainfall−runoff patterns of the 1995−1997 seasons we refer to as normal in this paper; the 1998−2000 seasons we call below normal.

Metolachlor in the top 2.5 cm soil layer showed a slight trend toward longer persistence in the years (1998−2000) of below-normal rainfall (**Table 2**). The herbicide persisted with half-lives of 14.8−34.3 days (24.6 ± 9.8 days) for 1995−1997 (period of normal rainfall) and 23.6−47.5 days (36.9 ± 12.2 days) for 1998−2000. Presumably, lower microbial activity in the drier seasons was responsible for this trend; we do not have soil microbial activity measurements to support this suggestion. Smaller runoff and leachate loss (see below) would also have contributed in a minor way to greater soil persistence of metolachlor during the seasons of below-normal rainfall. Although intriguing, these differences were significant only at $P = 0.15$ (paired *t* test of metolachlor soil $t_{1/2}$ values for the 1995−1997 and 1998−2000 periods). Correlation analysis of $t_{1/2}$ versus rainfall afforded $P = 0.34$. The mean soil half-life of the herbicide for the six years was 30.7 ± 12.0 days. The 1995 regression predicts an initial concentration C_0 (1410 ng/g) that is different ($P = 0.05$) from the C_0 values of the other equations [the application rate for this year was 0.50 or 0.34 the rates of the subsequent years (**Table 1**)]; the remaining regression equations all have C_0s with overlapping 95% confidence limits, even though the application rate for the last two seasons (1999 and 2000) was 47% greater than that of the previous three seasons (1996−1998). The rate coefficients of the equations of **Table 2** have overlapping 95% confidence limits. To account for differing application rates and similar rate coefficients, the final equation of **Table 2** combines the normalized (with respect to initial concentration, C_0) data of each season (**Figure 3**).

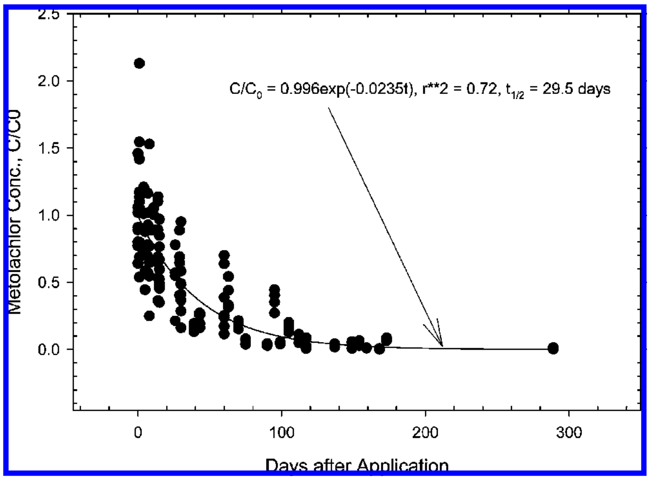

Figure 3. Pooled metolachlor soil concentrations (top 2.5 cm) for 1995−2000, normalized with respect to initial concentration C_0; t = days after application.

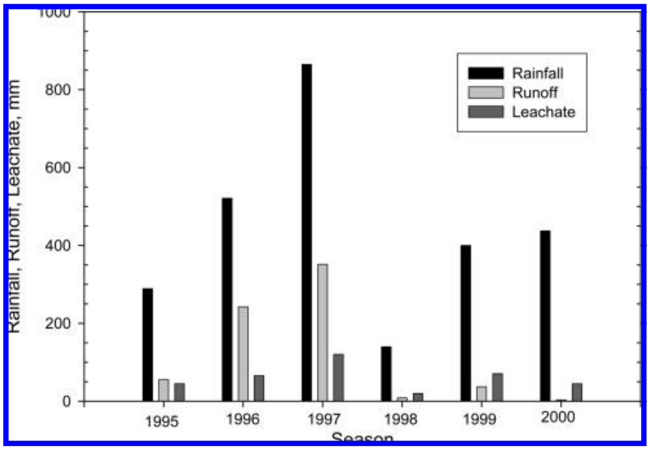

Figure 4. Rainfall, runoff, and leachate volumes for the four months after application, 1995−2000.

Rainfall was generally distributed throughout each season. Leaching events followed rainfall patterns, but runoff was generally limited to the first 45 days after application. (In four of the study seasons at least 98% of the runoff had occurred by this time.) After this duration, canopy closure and regrowth of grasses after the herbicide application ameliorated rainfall intensity and encouraged infiltration over runoff. This runoff pattern was not seen in 1997, the wettest study year (several runoff events from day 56 to day 108, and only 72% of the runoff on or before day 45), and in 1999, when no runoff had been measured by day 45. The details of rainfall, runoff, and leachate during the sample collection periods for 1995−2000 are available as Supporting Information.

During the normal rainfall years of the study (1995−1997), runoff volume predominated over volume of leachate through the subsurface drains (**Figure 4**). Runoff/leachate ratios varied from 1.2 (1995) to 3.7 (1996) during this period. During the drier years (1998−2000), leachate volumes predominated over runoff (**Figure 4**); the runoff/leachate ratios at this time ranged from 0.07 (2000) to 0.52 (1999). Runoff varied from 54.9 mm over 66 days (1995) to 352 mm over 110 days (1997) during the normal period and from 3.2 mm for 43 days (2000) to 37.1 mm for 61 days (1999) during the dry years. Leachate through the subsurface drains ranged from 44.8 mm in 123 days (1995) to 120 mm in 111 days (1997) during the normal years and from 19.9 mm for 56 days (1998) to 70.8 mm for 98 days (1999) during the below-normal periods. During the normal rainfall seasons runoff volumes were 2.81 times leachate volumes

Table 3. Mean Runoff and Leachate Volumes for the Study Periods during the Seasons of Normal (1995−1997) and Below-Normal (1998−2000) Rainfall and (1998−2000)/(1995−1997) Ratios

years	runoff, mm	leachate, mm	total, mm	runoff/leachate
1995−1997	216 ± 150	76.9 ± 38.9	293	2.81
1998−2000	16.2 ± 18.2	45.1 ± 25.5	61.2	0.36

	runoff/runoff	leachate/leachate	total/total
(1998−2000)/(1995−1997)	0.08	0.59	0.21

(average for the three seasons); for the drier periods, runoff was only 0.36 times the leachate volume (**Table 3**). Runoff volumes were more variable between the years of normal and below-normal rainfall than were leachate volumes. The below-normal years were characterized by a mean runoff that was 0.08 times the mean runoff of the normal years, whereas leachate mean of the below-normal years was 0.59 times the mean of the normal years (**Table 3**).

During the average rainfall seasons of 1995−1997 runoff volumes reported here for the plots with subsurface drains (**Figure 1**, treatment 2) were similar to the runoff volumes from those plots without subsurface drains (**Figure 1**, treatment 1) reported by Southwick et al. (*15*). Statistical comparison of the treatments for each year produced the following P values (paired t test): 1995, $P = 0.16$; 1996, $P = 0.19$; 1997, $P = 0.21$. For 1995 and 1997, treatment 1 flows were greater than those of treatment 2; for 1996, treatment 2 flow was larger than that for treatment 1. Comparing the surface flows reported here to those of our earlier paper (*15*) demonstrates that subsurface drains had neither a consistent nor a statistically significant effect on surface flows after rainfall.

Runoff metolachlor concentrations during the normal rainfall seasons were highest during the initial events (**Figure 5**). This standard observation [Leonard (*2*) cites a number of studies that report this effect; see Gaynor et al. (*10*) and Webster and Shaw (*16*), for example, for this observation in metolachlor runoff studies] reflects the decrease in runoff-available residues through degradation, volatilization, irreversible sorption onto the soil, and removal from the soil by runoff and leaching events (*17*, *18*). This observation has been reported (*15*) for the plots without subsurface drains (treatment 1, **Figure 1**). The concentration of metolachlor in the first runoff event of the season varied from 52.7 μg/L on day 11 of 1995 to 154 μg/L on day 1 of 1996. The first runoff event of 1995 occurred on day 11; first runoff events for 1996 and 1997 happened on days 1 (1996) and 4 (1997). The lower concentration of the first event of 1995 reflects the lower application rate of metolachlor and the later occurrence of the first event after application. During the low rainfall seasons, the first event concentrations of metolachlor ranged from 4.29 μg/L on day 53 for 1999 to 83.1 μg/L on day 15 for 1998 (**Figure 6**). The unusually low concentration of metolachlor in the first event of 1999 is due not only to the extended period after application (53 days) but probably more importantly to the preceding 140 mm of rainfall that did not produce runoff, but would have leached residue from the runoff-active zone of the soil surface (*2*). Gaynor et al. (*9*, *10*) have made similar field observations on the effect of non-runoff-producing rainfall on the amount of soil-applied herbicides in runoff from subsequent rainfall events. In 1998, 10 mm of rainfall fell before the first runoff, and in 2000, 54 mm of rainfall occurred before the first runoff event (see Supporting Information).

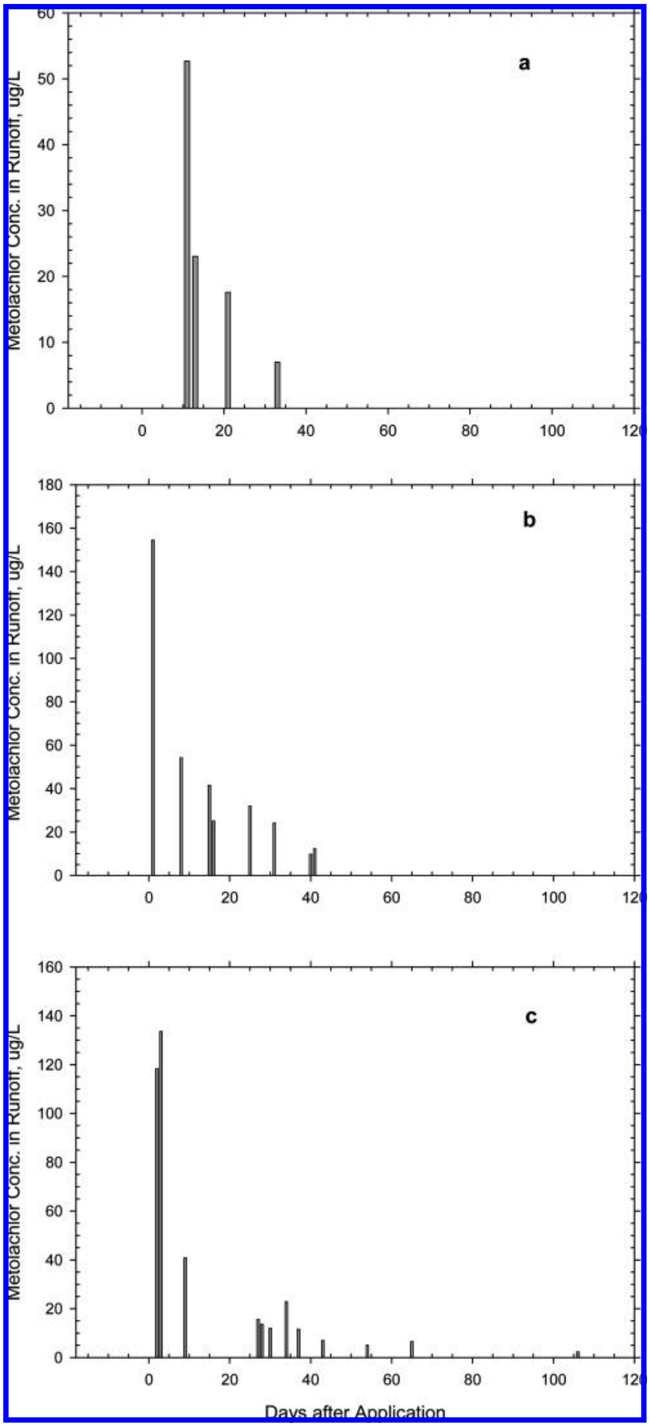

Figure 5. Metolachlor concentration in runoff, 1995−1997: (**a**) 1995; (**b**) 1996; (**c**) 1997.

The 95% confidence intervals for both initial concentration (C_0) and rate (k) were the same for the first-order regression equations of these metolachlor runoff concentration data for 1995−1997. Consequently, these years of normal rainfall were pooled to give the following equation for decrease in the concentration of metolachlor in runoff over time (**Figure 7**):

$$C_{\mathrm{met}} = 161\ \exp(-0.107t) \quad r^2 = 0.93,\ t_{1/2} = 6.5\ \text{days}$$

C_{met} is the concentration of metolachlor, and t is time in days after application. The half-life for metolachlor in runoff is about 0.2 times the half-life of metolachlor in the soil (see **Table 2**, combined equation, and **Figure 3**). This observation of a shorter persistence of a soil-applied herbicide in runoff compared to

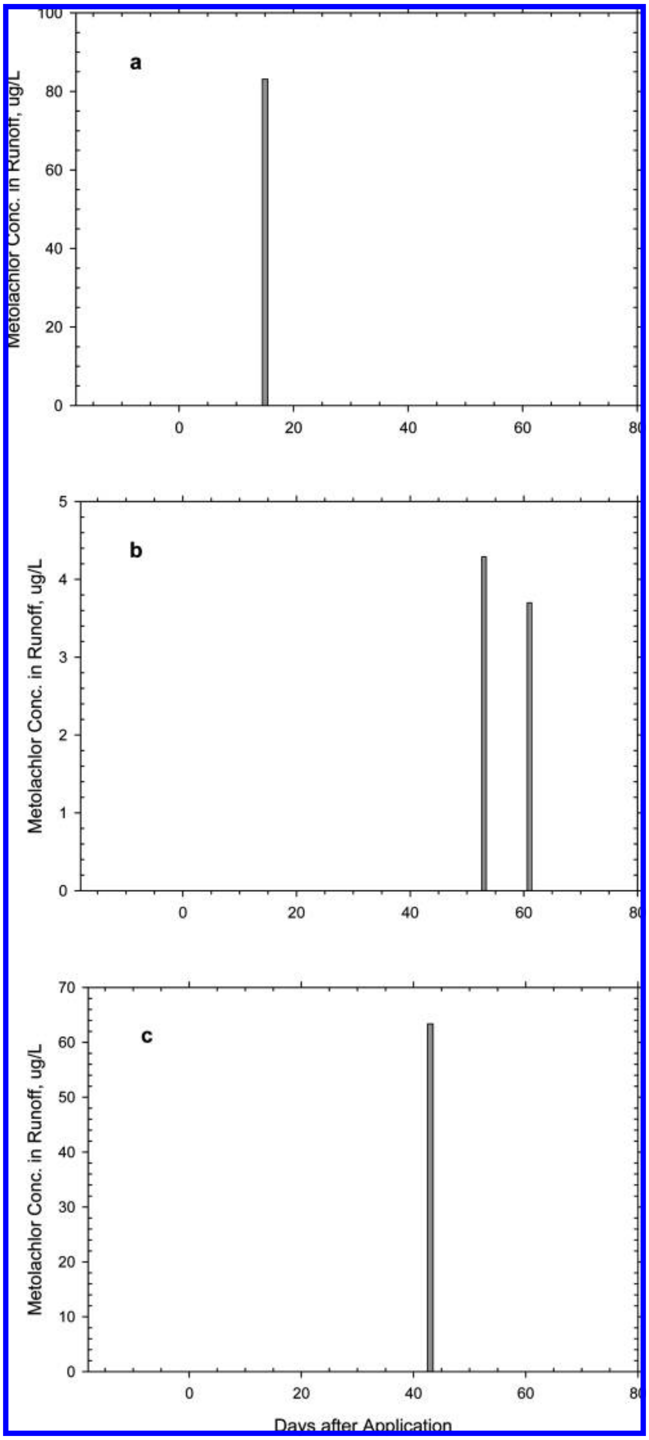

Figure 6. Metolachlor concentration in runoff, 1998−2000: (**a**) 1998; (**b**) 1999; (**c**) 2000.

its soil persistence has been reported by us and others (see ref *15* and Table 1 in that paper). The availability of the chemical in the top few millimeters of soil [“mixing zone” (*2*)] decreases at a faster rate [due to removal in runoff and leachate and to surface processes of volatilization and photolysis (*2*)] than does the residue in the deeper soil-sampling layer. Insufficient runoff data during the low-rainfall seasons (**Figure 6**) prevent development of regressions for these years. The four data points from these three years are plotted in **Figure 7**.

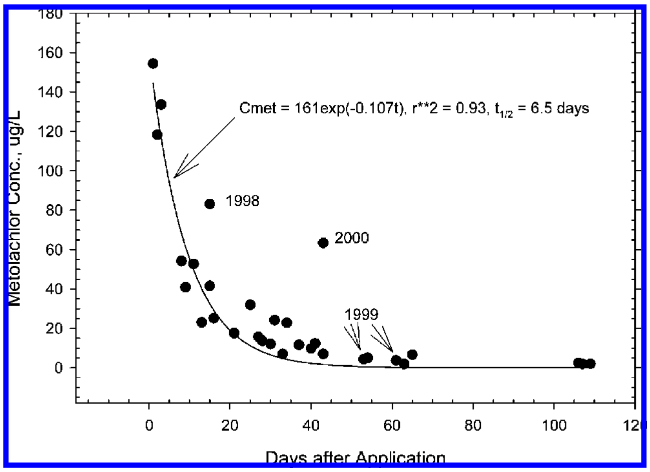

Figure 7. Pooled metolachlor runoff concentrations and regression line for 1995−1997; data for 1998−2000 added but not included in regression line. C_{met} = metolachlor concentration; t = days after application.

Table 4. Runoff and Leaching of Metolachlor, 1995−2000

year	runoff, g/ha (% of application)	leaching, g/ha (% of application)
1995	57.8 (6.1%)	1.70 (0.18%)
1996	111 (5.8%)	1.84 (0.10%)
1997	85.9 (4.5%)	2.70 (0.14%)
1998	7.10 (0.37%)	4.50 (0.24%)
1999	1.84 (0.07%)	6.04 (0.22%)
2000	2.16 (0.08%)	7.60 (0.27%)

Table 5. Mean Runoff and Leaching of Metolachlor for the Study Periods during the Seasons of Normal (1995−1997) and Below-Normal (1998−2000) Rainfall and (1998−2000)/(1995−1997) Ratios

years	runoff, % of application	leaching, % of application	total, % of application	runoff/leaching
1995−1997	5.5 ± 0.85	0.14 ± 0.04	5.6	39.3
1998−2000	0.17 ± 0.17	0.24 ± 0.03	0.41	0.71

	runoff/runoff	leaching/leaching	total/total
(1998−2000)/1995−1997	0.03	1.71	0.07

Loss of metolachlor in runoff (**Table 4**) during the seasons of average rainfall (1995−1997) ranged from 57.8 g/ha (6.1% of application) in 1995 to 111 g/ha (5.8% of application) for 1996. These values do not vary significantly from those of treatment 1 (**Figure 1**) without subsurface drains (*15*): P = 0.44−0.83 for treatment 1 and 2 comparisons within the 1995−1997 seasons (paired t test). During the low-rainfall years, runoff of metolachlor showed a drop of an order of magnitude, compared to that of 1995−1997, ranging from 1.84 g/ha (0.07%) in 1999 to 7.10 g/ha (0.37%) in 1998. By comparison of the means of runoff of metolachlor (percent of application) between the normal and below-normal seasons, runoff of the herbicide during the reduced-rainfall periods was 97% less than that during the seasons of normal rainfall (**Table 5**). Krutz et al. (*19*) also observed reduced runoff of metolachlor from another but closely related Mississippi River alluvial soil (Sharkey clay) during conditions of lower antecedent moisture in Mississippi.

For both the seasons of normal (**Figure 8**) and below-normal rainfall (**Figure 9**), as for runoff in the normal years, concentrations of metolachlor in the leachate were highest in the events soon after application [Kladivko et al. (*5*) and Gaynor et al. (*10*) have reported similar observations of concentrations of soil-applied herbicides in subsurface drains]. The highest concentrations observed during the low-rainfall years (46.2−70.6 μg/L) were 2−3 times those of the years of average rainfall (16.8−22.4 μg/L). Malone et al. (*20*) reported highest concentrations of

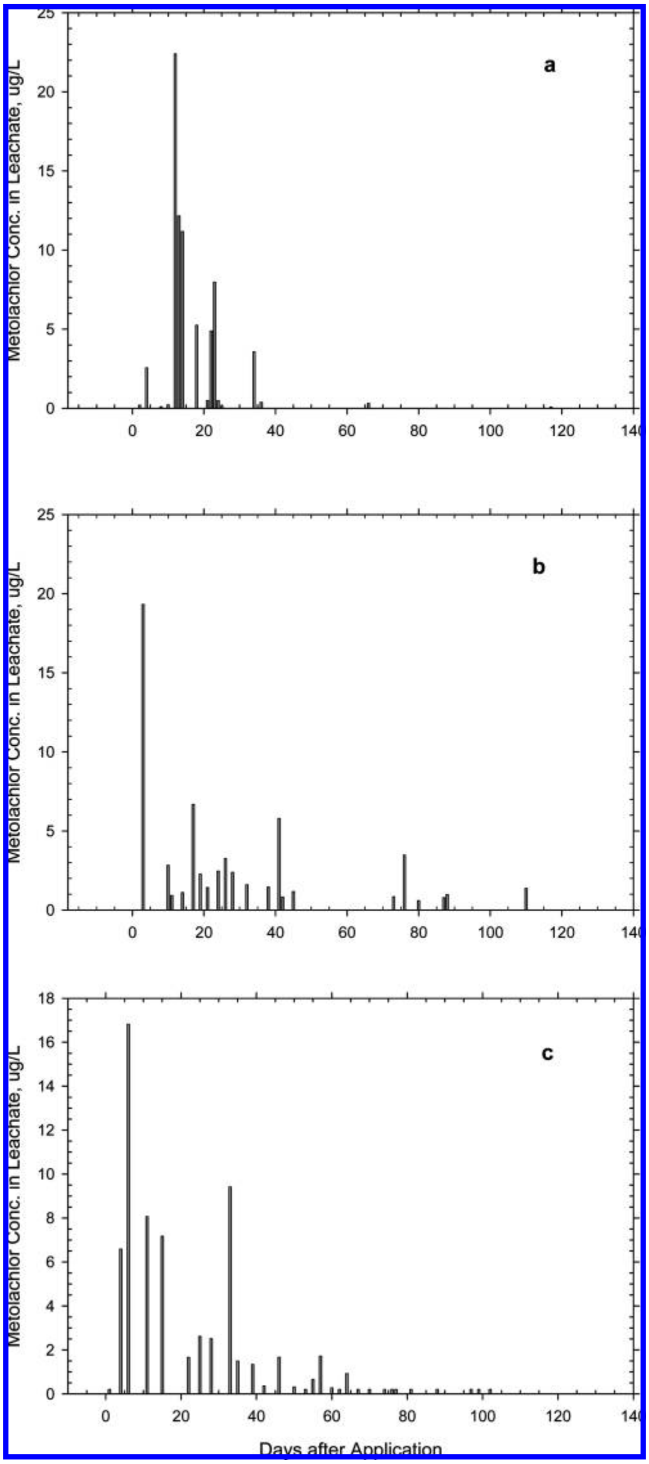

Figure 8. Metolachlor concentration in leachate, 1995−1997: (**a**) 1995; (**b**) 1996; (**c**) 1997.

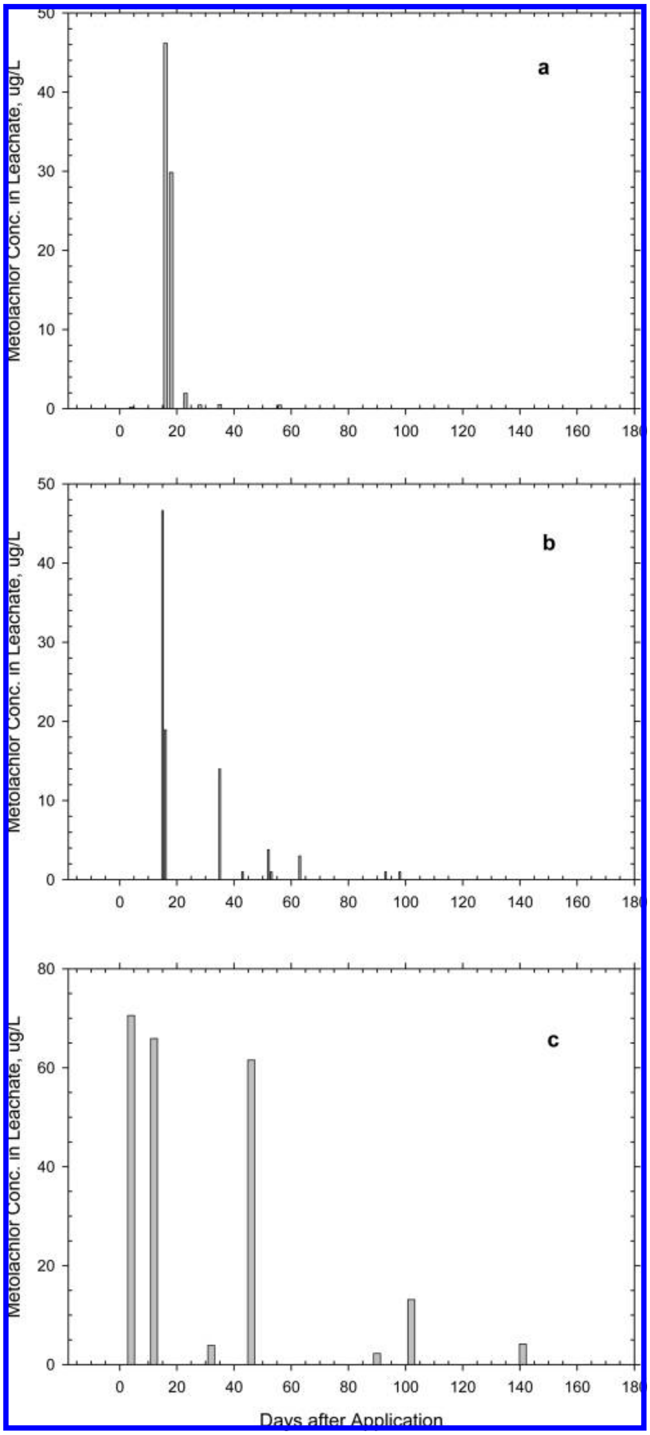

Figure 9. Metolachlor concentration in leachate, 1998−2000: (**a**) 1998; (**b**) 1999; (**c**) 2000.

several herbicides soon after application in leachate (lysimeter) samples from simulated rainfall. Kladivko et al. (*5*) stated that initiation of subsurface drain flow soon after the beginning of rainfall is evidence of preferential flow into the drains. We observed in the present work initiation of drain flow soon (within 1 h) after the beginning of rainfall. In our work reported here both runoff and leachate pathways of metolachlor movement generated highest concentrations of the herbicide in the first events after application. We suggest that these concentration observations are additional evidence for preferential flow through the soil of our study. The statement by Van Es et al. (*21*), that direct drainage (preferential flow) reflects the chemical composition of residues on the soil surface, whereas general (matrix) flow reflects the composition in the lower soil profile, is consistent with the observations we make here.

For 1995−1997 (average rainfall), leaching of metolachlor into the subsurface drains (**Table 4**) varied from 1.70 g/ha (0.18% of application) in 1995 to 2.70 g/ha (0.14%) in 1997; for the period 1998−2000 (below-normal rainfall), leaching ranged from 4.50 g/ha (0.24%) in 1998 to 7.60 g/ha (0.27%) in 2000. During the years of average rainfall, loss (percent of application) of metolachlor in runoff was 39.3 times that leaving the field through the subsurface drains (**Table 5**). During the years of below-normal rainfall, runoff of the herbicide (percent of application) was 0.71 times that of the corresponding leachate loss. Movement of metolachlor into the subsurface drains during the drier seasons was 71% greater than during the normal rainfall periods. The below-normal rainfall of 1998−2000 compared to the rain of 1995−1997 led to an order of magnitude reduction in runoff and to a slight increase in leaching. During the normal rainfall seasons, mean runoff of metolachlor was ≤6.1% and leaching was <0.2% of application (**Table 4**). During the reduced-rainfall periods, mean runoff of the herbicide was <0.4% and leaching was <0.3%.

The absence of a difference between runoff flows and loss of metolachlor between treatment 1 (**Figure 1**, no subsurface drains), results reported by Southwick et al. (*15*), and the results reported here for treatment 2 (**Figure 1**, subsurface drains without water table control) are in contrast to the findings we reported in Southwick et al. (*12*), where runoff was reduced 44% by a subsurface drain treatment. These earlier results were consistent with the general influence of subsurface drains toward increased infiltration and reduced runoff (*22*), an effect most pronounced in reduction of runoff loss of soil-applied herbicides when runoff occurs within a few weeks of application, when the runoff mixing zone is highest in available herbicide. The previous results (*12*) were collected on plots that were subjected to periodic deep tillage (*23*−*25*). The plots of the present study were not subjected to deep tillage. The implication is that the surface layer of the heavy soil of our work is not susceptible to the influence of subsurface drains without an additional infiltration aid. Clark et al. (*26*) observed significantly increased water infiltration rates on a Cecil clayey kaolinitic soil in Georgia if deep tillage (30 cm depth) was conducted at least annually. Truman et al. (*27*) reported on the effectiveness of deep tillage (40 cm depth) of a coastal plain soil (coarse-loamy, siliceous) of Alabama on reduction of runoff water: with both conventional tillage and no-till plots, deep tillage resulted in increased infiltration and reduced runoff from simulated rainfall.

In summary, during the seasons of normal rainfall (1995−1997), an average of 216 mm of runoff and 76.9 mm of leachate corresponded to metolachlor in runoff of 5.5% and in leachate of 0.14% of the amount applied. The periods of below-normal rainfall (1998−2000) produced an average runoff volume of 16.2 mm and an average leachate volume of 45.1 mm. These lower levels of runoff and leachate corresponded to 0.17% of applied metolachlor in runoff and to 0.24% in leachate. Consequently, a 92% reduction in runoff volume corresponded to a 97% reduction in metolachlor loss in runoff (percent of application); a 41% reduction in leachate volume was related to a 71% increase in leaching movement of the herbicide (percent of application). The reduced flow through the soil profile carried more metolachlor residue because of the order of magnitude reduction in runoff of the chemical and to the increase in preferential flow potential in the soil profile; but even with increased preferential flow, leaching of the herbicide through the heavy alluvial soil of our study did not exceed 0.3% of application. The seasons of below-normal rainfall (1998−2000), compared to the average-rainfall period (1995−1997), were characterized by a 79% reduction of runoff and leachate flow and by a corresponding 93% reduction (percent of application) in movement of metolachlor via these routes.

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Supporting Information Available: Ben Hur Farms rainfall, runoff, and leachate data. This material is available free of charge via the Internet at http://pubs.acs.org.

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