Report No. 04

CHLORDANE MOVEMENT DURING RAINFALL

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TABLE OF CONTENTS

FIGURES

TABLES

ABSTRACT

Indoor rainfall simulation experiments were conducted to quantify the mass of technical chlordane leaving an experimental soil box in runoff, splash and leachate. The initial mass of technical chlordane was uniformly distributed throughout the soil at concentrations equal to those recommended for termite control around basement and foundation walls. Two silt loam soils and one sandy soil were studied. The mass of chlordane in runoff adsorbed to organic matter was estimated to be 16 times the mass of chlordane in runoff adsorbed to clay. For a soil with a clay-to-organic-matter ratio as high as 66, the mass of chlordane in runoff appears to be predominantly a function of clay content. For a soil with a clay-to-organic-matter ratio as low as 2 to 5, the mass of chlordane in runoff appears to be predominantly a function of organic matter content. An increase in rainfall intensity from 51 to 102 mm/hr increased chlordane mass in runoff by 300 to 500 percent. This increase in rainfall intensity increased the chlordane-to-sediment mass ratio in the runoff by 7 to 18 percent. The chlordane mass in runoff was 5 to 9 times as great as the mass of bromide in runoff. The chlordane mass in splash was 25 percent of the chlordane mass in runoff. Only the sandy soil at the higher rainfall intensity produced leachate. The chlordane mass in this leachate during the rainfall period was 37 percent of the chlordane mass in runoff and 264 percent of the chlordane mass in splash. The total chlordane mass which left the soil box by runoff, splash and leachate was equivalent to 4 to 44 mg per square foot of treated surface. This amounted to 0.03 to 0.31 percent of the original chlordane mass applied to the experimental soil box.

This could potentially occur from previous legal surface applications in agriculture and turf management, from more recent illegal surface applications in agriculture and turf management, from proper use (according to label directions) as a subsurface termiticide but where depth of untreated cover soil was insufficient, from improper use as a subsurface termiticide where treated soil remained uncovered at the surface or from disturbance by new construction of large areas treated in previous years.

This type of horizontal movement of chlordane and other organochlorine pesticides has been documented. Bennett et al. (1974) measured 70 ppb of gamma chlordane in the top five inches of soil located 10 feet away from a foundation wall treated 21 years earlier. Lichtenstein (1958) found higher concentrations of the organochlorine insecticides aldrin, lindane and DDT on the downslope side than on the upslope side of treated test plots. Similarly, Peach et al. (1973) found surface movement of aldrin, lindane and heptachlor toward points of lower elevation in a sloping field. Haan (1971) conducted laboratory rainfall-runoff experiments following surface treatment with aldrin, dieldrin and DDT and found that sediment carried more than twice as much pesticide mass as the water. Wauchope (1978) reviewed the literature on pesticide losses in runoff water from agricultural fields. He found that organochlorine pesticides lose about 1% of the total mass applied to the field through runoff. This compared to other commercial pesticides which lose 0.5% or less unless severe rainfall conditions occur within 2 weeks after application.

Another important consideration is the mass of pesticide located within a few millimeters of the soil surface. Investigators have found that it is this zone from which pesticides are released during rainfall. Sharpley (1985) studied 5 soils and found the depth of this zone to range from 2 to 4 mm for 4 percent slopes under 50 mm/hr rainfall intensity to 13 to 37 mm for 20 percent slopes under 160 mm/hr rainfall intensity.

INTRODUCTION

In recent years, chlordane has been found in fish and sediments in Missouri and surrounding states (Luckey, 1985; Schmitt et al., 1985; Missouri Department of Conservation, 1986; Arruda et al., 1987). During 1984 and 1985, the Missouri Department of Health issued advisories against fish consumption in a number of lakes and rivers because of chlordane contamination (Crunkilton, 1986), and the commerical sale of fish from large portions of the Missouri and Mississippi Rivers within Missouri was banned in 1987.

These findings generate speculation as to the source of the chlordane. Its legal use during the 1980's was restricted to termite control. However, its availability to the public until 1988 presented the potential for improper use. It is not known whether present fish and sediment contamination is from proper use in the 1980's, improper use in the 1980's or previous use in rural agriculture and urban turf management during the 1950's through most of the 1970's. This question is important to address in determining the appropriate future use of this chemical and in determining planning and management alternatives to minimize future transport of existing chemical in the soil.

Several previous studies have shown that relatively little vertical movement of chlordane in soil occurs. Soil penetration of chlordane following initial surface application has been shown to vary from two to seven inches in various soils at concentrations recommended for termite control (Beal and Carter, 1968; Carter and Stringer, 1970a). Most of the long-term chlordane soil residue resulting from surface and shallow subsurface application has been shown to remain within the top few inches of soil (Fleming and Maines, 1954; Carter and Stringer, 1970b; Boyd, 1971; Wilson and Oloffs, 1973) with small amounts penetrating as deep as 20 inches after 21 years (Bennett et al., 1974).

Another possible route of chlordane movement is by runoff and erosion.

This study was undertaken to gain insight into off-site chlordane movement by runoff and erosion during a single rainfall event. The experiments were conducted in the laboratory using a rainfall simulator to more closely control experimental variables. The experiments were intended to simulate chlordane movement from soil adjacent and exterior to a basement or foundation wall recently treated for termite control. However, the variables controlling this type of movement are wide ranging. They include soil type, organic matter content, degree of vegetative cover, slope, rainfall intensity, hydraulic conductivity, antecedent soil moisture, depth of untreated cover soil and others. Furthermore, orientation and design of the building, roof and gutters could be important variables. For this study, three soil types and two rainfall intensities were examined. The soil types included a wide range in particle size distribution and organic matter content. The other variables remained constant.

In some respects, the experiments were designed for the worst-case scenario. That is, the soil surface was unvegetated as would be the case for new construction; this increased sediment transport compared to vegetated soil. The rainfall intensities were relatively large representing a 1-yr return period event and a 10-yr return period event for central Missouri. It was also assumed that the treated soil surface was not blocked or sheltered by a wall or roof. Furthermore, the experiments were conducted without the presence of untreated cover soil.

On the other hand, the surface slope was relatively mild to reduce erosion. Also, the rainfall intensities were less than would occur on windward walls. Likewise, the rainfall depths were less than would occur around gutter outfalls if roof gutters existed or directly below eaves if roof gutters did not exist.

Three soil types were examined--two Menfro silt loams and one Sarpy sand. The Menfro soils were selected because of their prevalence in the St. Louis metropolitan area and because of their similarity to the Knox soil series prevalent in the Kansas City metropolitan area. These locations represent large areas of intense development where termiticide use is concentrated. The two Menfro soils were collected at different depths to obtain a large range in organic matter content. The Sarpy soil was selected to provide an additional contrast in particle size distribution.

METHODS

Three soils were used in this study: Menfro silt loam collected from the top 10 cm of the Ap horizon, Menfro silt loam collected at depths between 75 and 90 cm from the Bt horizon and Sarpy sand collected from the top 10 cm of the A horizon. These soils produced a wide range of particle sizes and organic matter contents as shown in Table 1. Particle sizes were determined using the pipette method (Day, 1986). Organic matter content was determined gravimetrically after oxidation with hydrogen peroxide. All soils were air dried for one week and then passed through a 2-mm sieve prior to use.

A 1% solution (by volume) of technical chlordane in distilled water was prepared for application to the soil. This equals the concentration specified on chlordane labels for termiticide treatments. The amount of this solution applied to the soil was determined as follows: The volume of solution applied along a foundation wall is specified on termiticide labels in terms of volume of solution per area of wall. A volume to area ratio of 16.3 L/m^2 is specified for chlordane and is also typical for other termiticides. The ratio of volume of solution to volume of soil consistent with this specification was estimated to be 107 L/m^3 assuming a 0.15 m treatment zone extending outward from the foundation wall. This application rate was used for all chlordane rainfall-

TABLE 1

Particle Size Distribution and Organic Matter Content

Soil Type	Particle Size Distribution Clay (%)	Silt (%)	Sand (%)	Organic Matter (%)	Ratio of Clay to Organic Matter
Menfro Ap	10.5	71.2	18.3	5.08	2.1
Menfro Bt	21.8	65.4	12.8	0.33	66.1
Sarpy	2.5	2.4	95.1	0.55	4.5

runoff experiments.

Additional distilled water was added to the 1% chlordane solution to raise the volumetric soil moisture content to 33% of saturation. This mixture was then mixed with the soil by hand as uniformly as possible in a large pan. The soil was placed in a closed container, and the technical chlordane concentration and moisture content were allowed to equilibrate throughout the soil over a 24-hr period. For each experimental bromide run, a solution containing distilled water with 10,000 mg/l potassium bromide was added to the soil until the soil moisture content reached 33% of saturation. The soil was placed in a closed container, and the bromide concentration and moisture content were allowed to equilibrate throughout the soil over a 24-hr period.

A stainless steel box measuring 20 cm long by 20 cm wide by 13 cm high was used to contain the soil. A 1/2-in. diameter opening through the downstream side of the box at the bottom allowed for leachate drainage. The box was fitted with a detachable splash guard and perimeter collection trough to capture splash loss using the design of Bradford et al. (1987). Overland flow was collected in a separate trough at the downstream edge of the box and directed vertically downward into glass sample collection bottles. Immediately prior to an experimental run, the box was uniformly packed to a mean bulk density of 1.25 g/cm^3 for the Menfro soils and 1.60 g/cm^3 for the Sarpy soil. The soil was packed in layers by uniformly sprinkling soil into the box to a depth of 3 cm. A wooden block measuring 20 cm by 20 cm by 4 cm was placed on top of the soil and a 3-kg weight was dropped multiple times onto the block from a constant height. The number of drops varied between 7 for the bottom layer and 15 for the top layer to produce an approximately uniform bulk density. The soil surface between each layer was lightly scarified to minimize layering effects. The soil box was placed at a 3% slope for the rainfall simulation experiments.

A rainfall simulator equipped with an oscillating 80150 Veejet nozzle was used for all rainfall experiments. This nozzle operating at 62 kPa (9.0 psi) was shown by Meyer and Harmon (1979) to closely reproduce drop-size distributions and terminal drop velocities of natural rainfall. The rainfall intensity was controlled by varying the oscillation delay. The rainfall intensities used in the experiments were 51 and 102 mm/hr, and the rainfall duration was 0.5 hr. At Columbia, Missouri, these intensities at this duration correspond to 1-yr and 10-yr return period events, respectively.

Runoff and leachate drainage during each two-minute period were collected and analyzed for technical chlordane or bromide as applicable. Leachate drainage occurred only for the Sarpy soil. The entire splash volume was collected in one container, and three subsamples were collected from this container and analyzed. The average concentration of these three splash subsamples was used to estimate total chemical loss due to splash.

Technical chlordane was extracted from the samples by first placing the sample (plus dichloromethane used to rinse the sample bottle) into a 500-mL Erylenmeyer flask and adding additional dichloromethane to bring the total volume of dichloromethane to 150 mL. Runoff sample volumes placed in the flask ranged from 10 to 100 mL, leachate drainage sample volumes ranged from 40 to 109 mL, and splash samples were 100 mL. The mixture was shaken on a reciprocating shaker for 2 hr. The mixture (plus dichloromethane used to rinse the flask) was transferred to a separatory funnel. The organic phase passed through the separatory funnel and then directly through a filtering funnel filled with anhydrous sodium sulfate. The mixture remaining in the separatory funnel was rinsed twice with a total of 60 mL dichloromethane. This rinse also passed through the filtering funnel. The total volume of outflow from the filtering funnel was concentrated in a rotary evaporator to 2 mL and then was passed through a 14.5 mm x 254 mm chromatographic column filled with Florisil[R] using 200 mL of a 94:6 hexane:ethyl ether rinse. The volume of outflow from the chromatographic column was concentrated to 5 mL using a rotary evaporator and then diluted with hexane, if needed. The amount of dilution was anticipated based on results of previous experiments. This final mixture was analyzed using a Perkins Elmer Sigma 3B gas chromatograph with a 30-m-long capillary column and ^{63}Ni electron capture detector coupled with a Finnigan mass spectrometer. The gas chromatograph oven temperature was 180°C for the first minute after injection and was increased at 3°C/min to 245°C. Detector and injector temperatures were 300 and 250°C, respectively. Carrier gas was helium at a flow rate of 3 mL/min. The total mass of technical chlordane in the sample was estimated using the sum of the areas under the gas chromatograph curves for cis-chlordane, trans-chlordane, heptachlor, cis-nonachlor, trans-nonachlor, oxychlor and chlordene compared to a standard.

Bromide was analyzed with a Fisher solid-state bromide electrode with an Orion 90-02 double-junction reference electrode.

RESULTS AND DISCUSSION

Runoff

Technical chlordane in the runoff is shown in Figs. 1 and 2 for the 51 mm/hr rainfall intensity and in Figs. 3 through 5 for the 102 mm/hr rainfall intensity. The data points for concentration, mass flux and runoff rate in these figures represent mean values from two replicate experiments. The mean difference between replicate measurements was 0.9 mg/L for concentration, 0.12 mg/min for mass flux and 7.8 mL/min for runoff rate. The data points for sediment represent mean values from two to three replicate sediment experiments. These sediment experiments were conducted separately from the chlordane experiments because sediment could not be recovered when subjected to chlordane

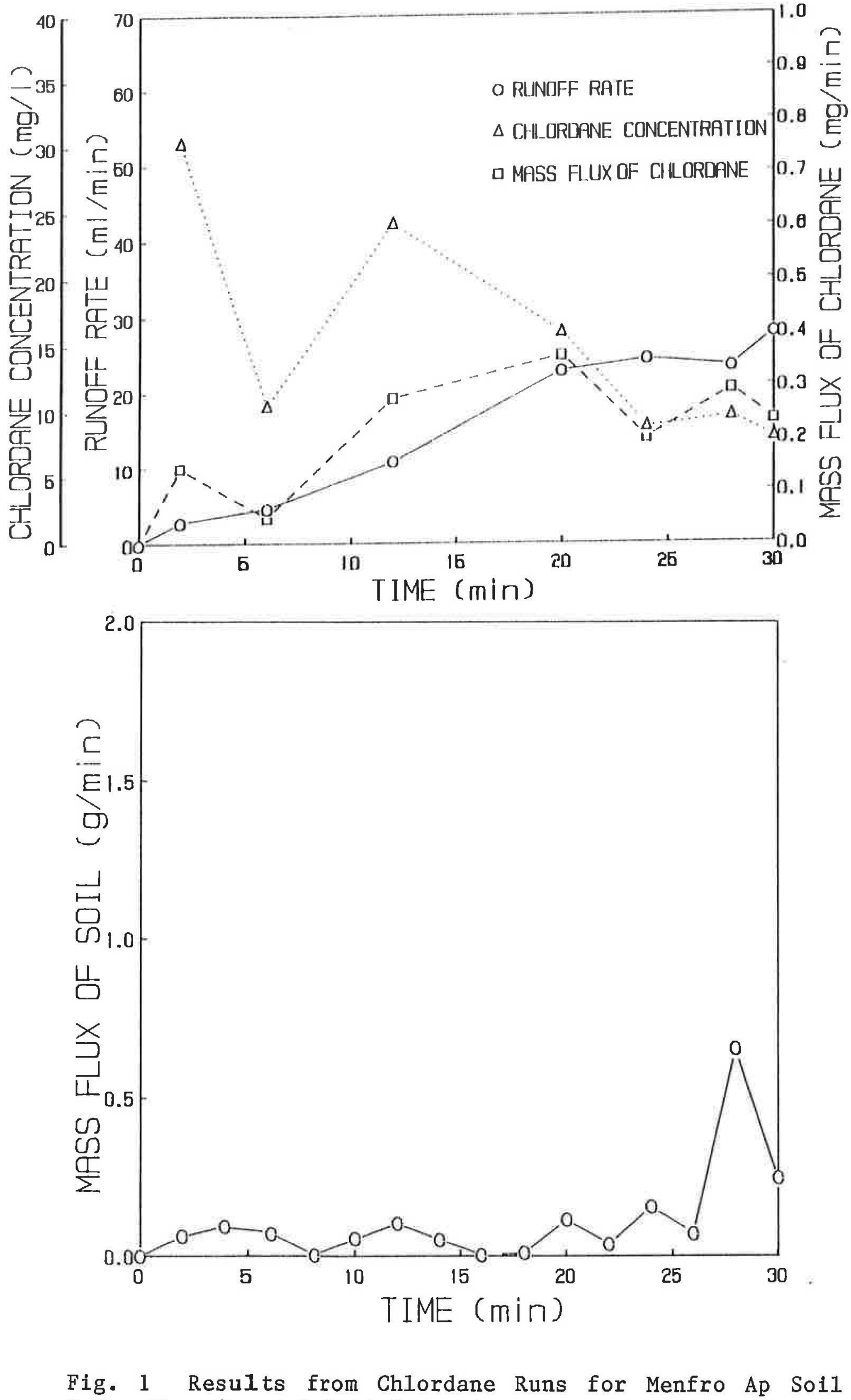


Fig. 1 Results from Chlordane Runs for Menfro Ap Soil Under 51 mm/hr Rainfall Intensity

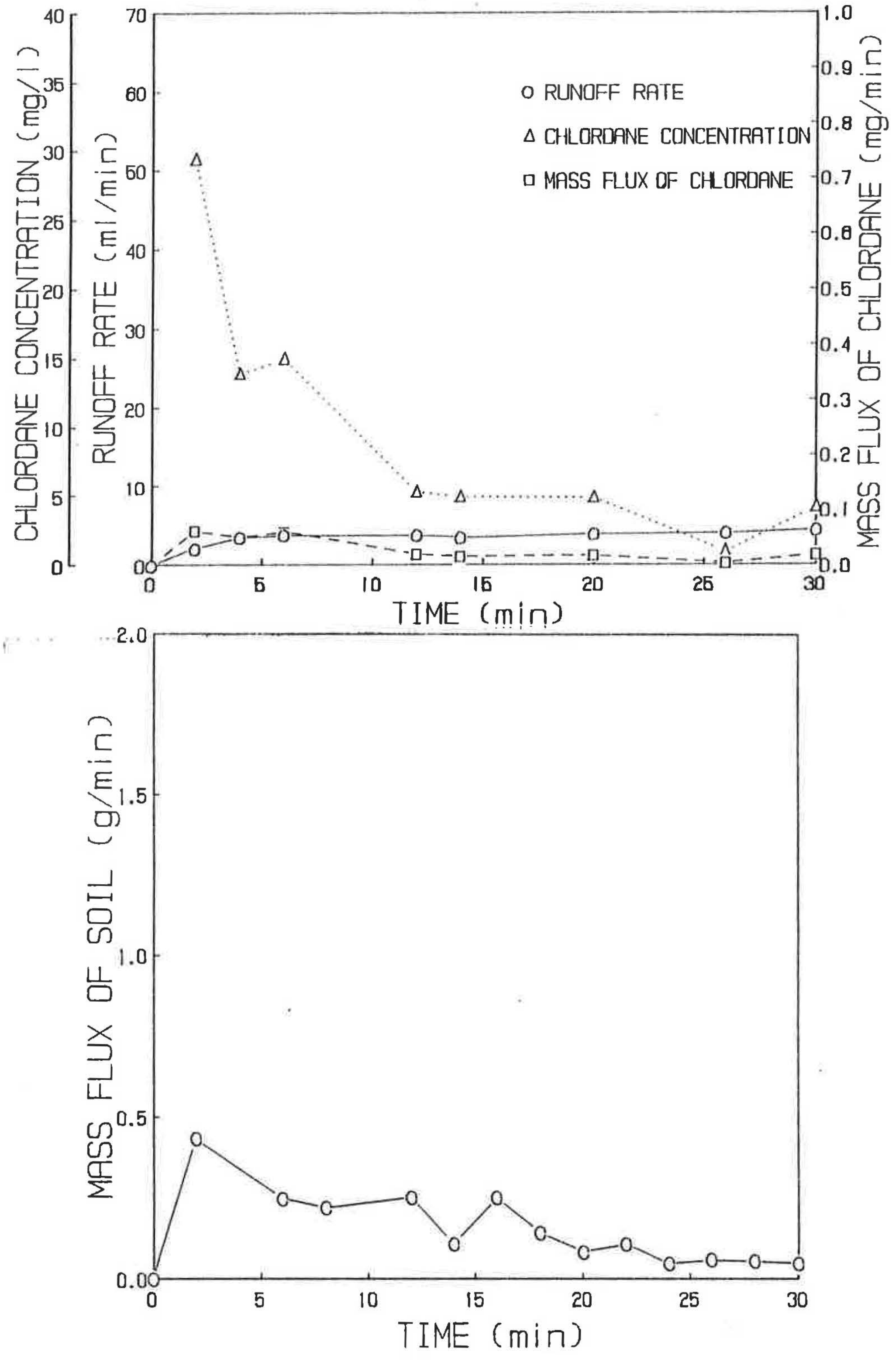
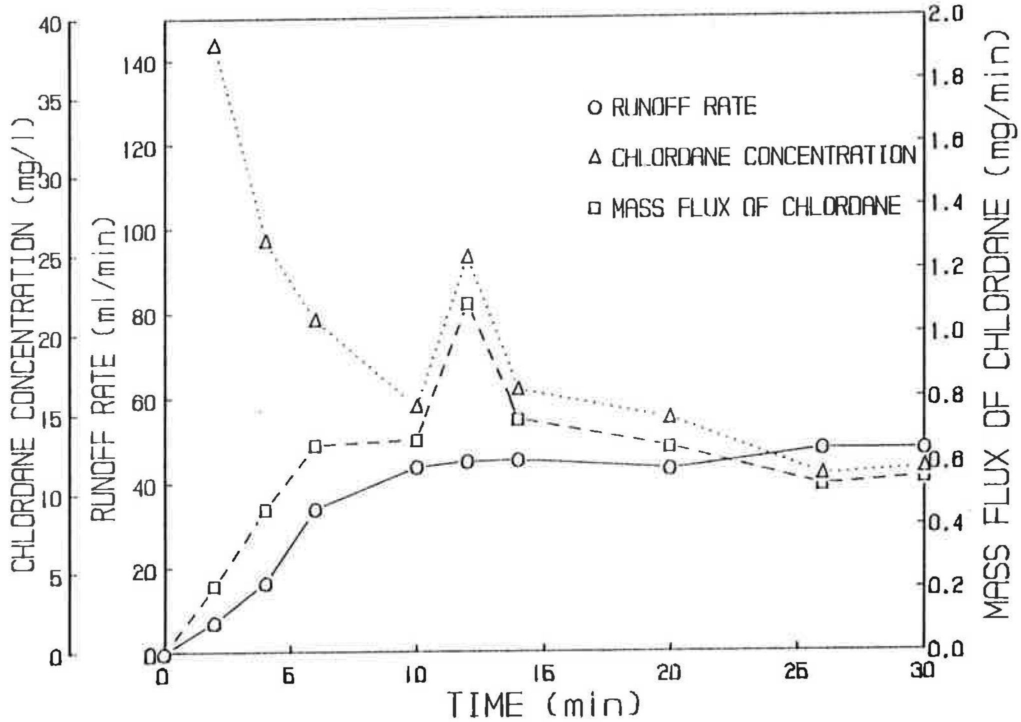


Fig. 2 Results from Chlordane Runs for Sarpy Soil Under 51 mm/hr Rainfall Intensity



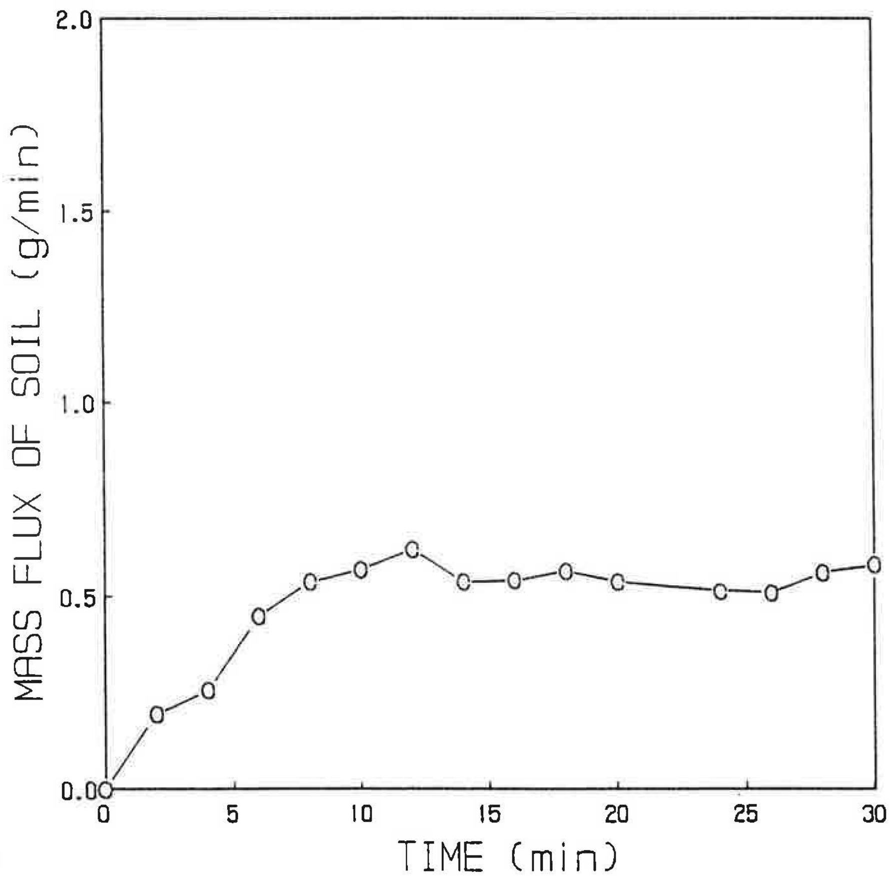


Fig. 3 Results from Chlordane Runs for Menfro Ap Soil Under 102 mm/hr Rainfall Intensity

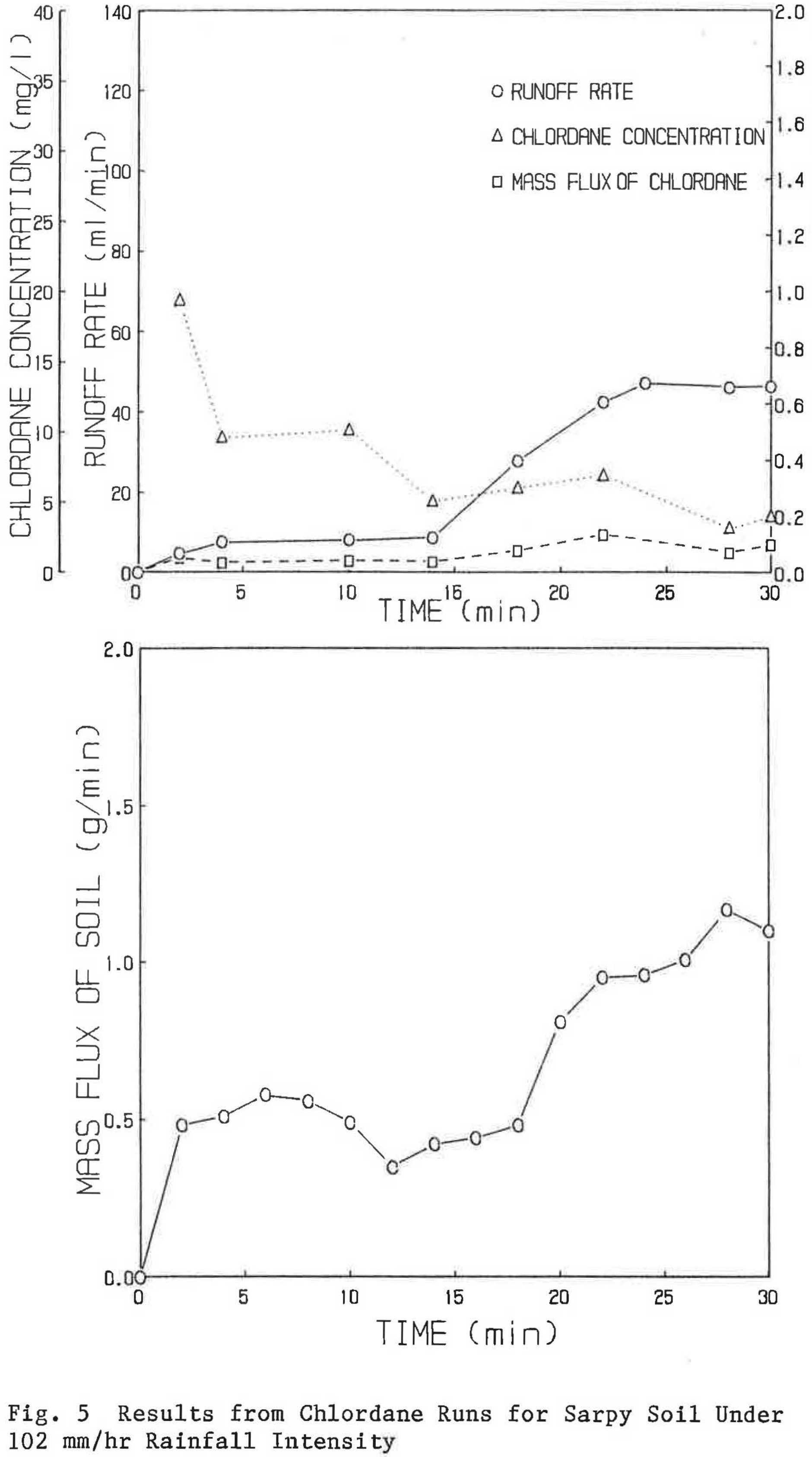


Fig. 5 Results from Chlordane Runs for Sarpy Soil Under 102 mm/hr Rainfall Intensity

extraction procedures. The mean difference between the highest and lowest replicate sediment concentration for all sampling periods was 0.37 g/min.

Technical chlordane concentration was greatest during the first 5 min when the runoff rate was small. It then decreased to a relatively narrow range when the runoff rate and mass flux of soil reached steady rates. Mass flux of technical chlordane gradually increased to a relatively narrow range when the runoff rate and mass flux of soil reached steady rates.

The results are summarized in Tables 2 and 3. As shown in Table 2, the Menfro silt loam with the higher clay content produced more runoff than the Sarpy sand. Yet the Sarpy sand produced the most sediment loss and the highest sediment concentration. On a per runoff volume basis, the Sarpy soil produced 6 to 7 times as much sediment loss as the Menfro Ap soil and almost 3 times as much as the Menfro Bt soil. Table 2 also presents an estimate of organic matter content in the sediment assuming the soil analysis presented in Table 1 is also valid for the sediment. Using this assumption, the organic matter concentration in the runoff is shown to be similar for the Menfro Ap and Sarpy soils.

Table 3 presents an analysis of technical chlordane lost in runoff. These losses ranged from 1 to 7 mg with the low rainfall intensity and 4 to 19 mg with the high rainfall intensity. Mean chlordane concentrations in the runoff did not vary significantly with rainfall intensity and ranged from 8 to 16 mg/L.

It was expected that technical chlordane would be lost primarily with the sediment rather than in the aqueous phase due to its low solubility in water. As seen in Table 3, the ratio of technical chlordane loss to total sediment loss is highly variable (0.17 to 2.41 mg/g) indicating that total sediment loss does not adequately explain the technical chlordane loss. The technical chlordane had been uniformly applied to the soil at a rate of 1.00 mg technical

TABLE 3

Technical Chlordane in Runoff

Soil Type	Rainfall Intensity (mm/hr)	Chlordane Loss[1] (mg)	Mean Chlordane Conc.[1] (mg/L)	Ratio of Chlordane Loss to Sediment Loss[2]		Ratio of Chlordane Loss to Organic Matter Loss[4] (mg/g)	Ratio of Chlordane Loss to Clay Loss[5] (mg/g)
				(mg/g)	(% applied)[3]		
Menfro Ap	51	6.87	16.1	2.25	224	43	21.5
Sarpy	51	0.90	7.9	0.17	22	30	6.9
Menfro Ap	102	18.76	14.6	2.41	240	48	23.2
Menfro Bt	102	15.24	12.2	0.74	74	218	3.4
Sarpy	102	4.27	8.6	0.20	26	36	7.9

(1) Mean of two replicate chlordane runs.

(2) Ratio computed using sediment loss in Table 2.

(3) Percent of chlordane mass applied per mass of soil.

(4) Ratio computed using estimated organic matter loss in Table 2.

(5) Ratio computed using estimated clay loss in Table 2.

chlordane per g Menfro soil (1.25 g/cm^3 bulk density) and 0.78 mg technical chlordane per g Sarpy soil (1.60 g/cm^3 bulk density).

Karickhoff (1981) indicated that the primary factor in sorption of hydrophobic pollutants on soil is organic carbon and that a secondary factor is the fraction of fine particles. Based on the organic matter contents in Table 1, the ratios of technical chlordane loss to organic matter loss are estimated in Table 3. These ratios fall within a relatively narrow range (30 to 48 mg/g) as one might expect from the narrow range in estimated organic matter concentrations in the runoff (0.24 to 0.37 g/L) shown in Table 2. The exception to this is the Menfro Bt soil which was found to transport a much larger mass of technical chlordane per mass of organic matter than the other two soils. However, the estimated clay content of the Menfro Bt sediment was 5 to 8 times that of the other two soils. This implies that perhaps the fine particles were substantially contributing to the technical chlordane loss for this soil.

The relative influence of organic matter and clay in transporting technical chlordane was estimated using the following equation:

$$M_{tc} = S_{om}M_{om} + S_cM_c + M'_{tc} \qquad (1)$$

where M_{tc} = total mass of technical chlordane in the runoff, S_{om} = mass of technical chlordane adsorbed to organic matter per mass of organic matter, M_{om} = mass of organic matter, S_c = mass of technical chlordane adsorbed to clay per mass of clay, M_c = mass of clay and M'_{tc} = mass of technical chlordane in runoff from all other sources (dissolved, adsorbed to silt and sand, nonadsorbed organic phase). Estimated values for M_{tc}, M_{om} and S_c were taken from the experimental results presented in Tables 1 through 3 and used in a regression analysis to numerically fit S_{om}, S_c and M'_{tc} in Equation 1 to the combined experimental data for all three soils. The best-fit values for S_{om}, S_c and

M'_{tc} were 46.1 mg/g, 2.8 mg/g and -1.9 mg, respectively, with $r^2 = 0.99$. The negative sign for M'_{tc} indicates that S_{om} and S_c are probably somewhat over-predicted. The fact that the absolute value of M'_{tc} is the smallest of the three best-fit values implies that transport by organic matter and clay are the most important mechanisms. The resulting S_{om} to S_c ratio of 16 (combined effect of all three soils) provides insight into the dominant influence of organic matter over clay in the transportation of technical chlordane by adsorption to sediment in these experiments.

The ratio of chlordane to organic matter in Table 3 is equivalent to S_{om} assuming that all chlordane is adsorbed to organic matter, while the ratio of chlordane to clay in Table 3 is equivalent to S_c assuming that all chlordane is adsorbed to clay. The Menfro Ap and Sarpy soils have relatively low clay-to-organic matter ratios of 2.1 and 4.5, respectively. The range of chlordane-to-organic-matter ratios for these soils in Table 3 is 30 to 48 whereas the calibrated S_{om} value is 46.1. For the Menfro Bt soil with a relatively high clay-to-organic-matter ratio of 66.1, the chlordane-to-clay ratio in Table 3 is 3.4 whereas the calibrated S_c value is 2.8.

Karickhoff (1984) discusses the significance of the ratio of clay to organic matter in controlling the partition coefficient, K_p, defined as adsorbed chemical mass per sediment mass divided by dissolved chemical mass per volume of solution. He presents sorption data for several organic chemicals to support the existence of a threshold value for the clay-to-organic matter ratio. Above the threshold, the mineral contributions to K_p become increasingly significant, and below the threshold, mineral contributions are masked due to organic and inorganic coatings on the mineral surfaces. Because surface area is one of the most important variables affecting chemical adsorption and because clay has large surface area, the mineral contributions to K_p are primarily clay contributions. Karickhoff (1984) showed that for biquinoline and

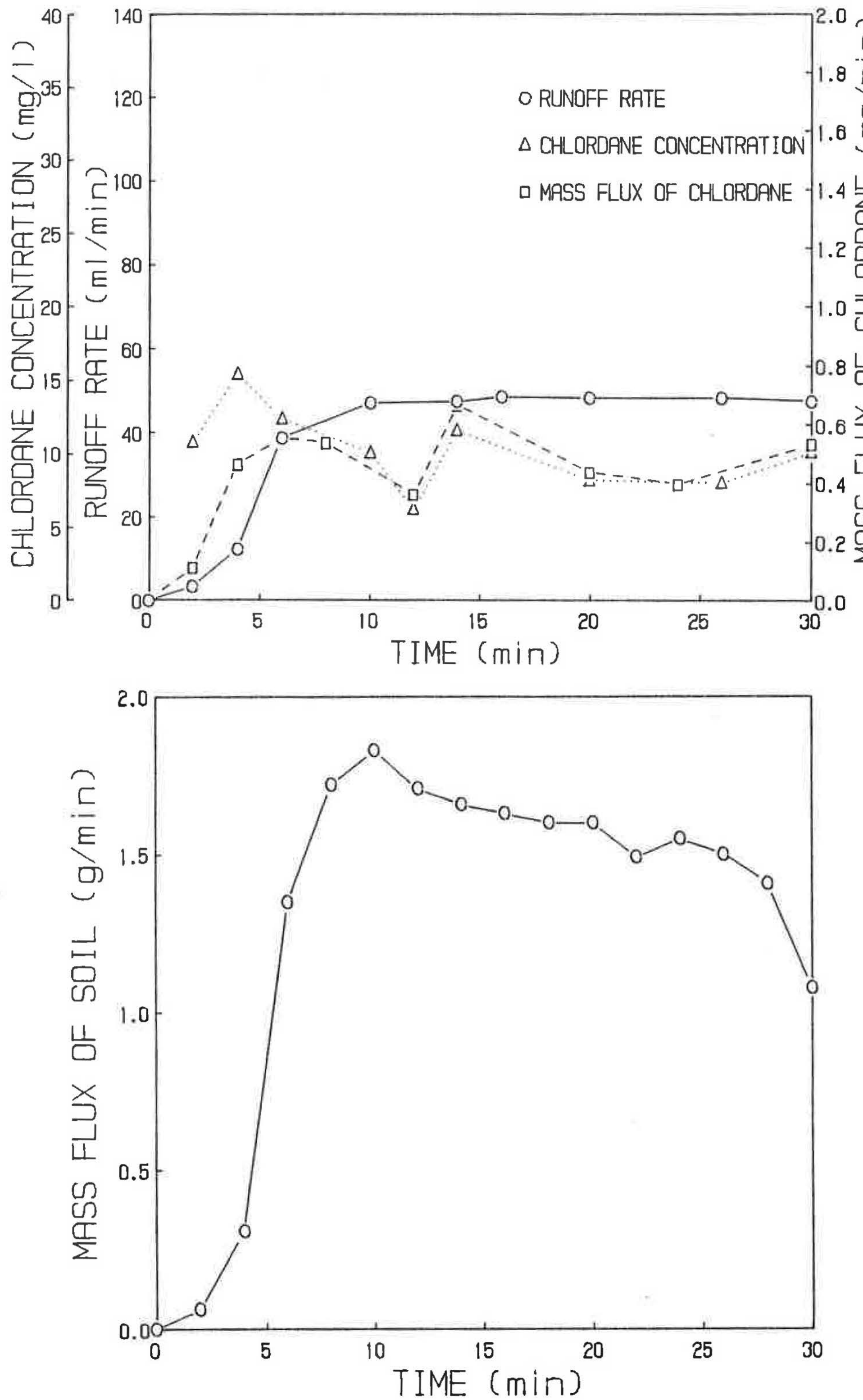


Fig. 4 Results from Chlordane Runs for Menfro Bt Soil Under 102 mm/hr Rainfall Intensity

TABLE 2

Runoff Volume and Sediment Loss in Runoff

Soil Type	Rainfall Intensity (mm/hr)	Runoff Volume[1] (L)	Sediment Loss[2] (g)	Mean Sediment Conc. (g/L)	Estimated Organic Matter Loss[3] (g)	Mean Estimated Organic Matter Conc. (g/L)	Estimated Clay Loss[4] (g)
Menfro Ap	51	0.43	3.05	7.1	0.16	0.37	0.32
Sarpy	51	0.11	5.23	47.5	0.03	0.27	0.13
Menfro Ap	102	1.29	7.77	6.0	0.39	0.30	0.81
Menfro Bt	102	1.25	20.50	16.4	0.07	0.06	4.47
Sarpy	102	0.49	21.58	44.0	0.12	0.24	0.54

(1) Mean of two replicate chlordane runs.

(2) Mean of three sediment runs for Menfro Ap and two sediment runs for Menfro Bt and Sarpy.

(3) Estimated by applying organic matter percentage in Table 1 to sediment loss in Table 2.

(4) Estimated by applying clay percentage in Table 1 to sediment loss in Table 2.

pyrene the threshold ratio was about 30, whereas for simazine the threshold ratio was about 15. This threshold theory appears to be consistent with the calibrated values for S_{om} and S_c and the data in Table 3. That is, the ratios of clay to organic matter of 2.1 and 4.5 for the Menfro Ap and Sarpy soils, respectively, appear to be below the threshold for chlordane so that sorption is dominated by organic matter. The ratio of clay to organic matter of 66.1 for the Menfro Bt soil appears to be above the threshold for chlordane so that sorption by clay is a dominant factor.

Additional rainfall-runoff runs were made with a uniform distribution of 1.29 mg bromide ion per g of Menfro soil and 1.09 mg bromide ion per g of Sarpy soil. The runoff results are plotted in Figures 6 through 8 and summarized in Table 4. Bromide is a conservative tracer. Its movement in soil simulates the movement of other dissolved chemicals which do not adsorb to soil. In this study it was used as a relative measure of the first flush of the small initial mass of technical chlordane that remains dissolved or suspended in the soil water at the beginning of the experiment. Figures 6 through 8 show the rapid attenuation of the chemical concentration with time.

A comparison of these bromide losses to chlordane losses in runoff is shown in Table 5. The comparison is in terms of percent mass of chemical applied in the top 1.0 cm of soil which was transported off the soil surface in runoff. The top 1.0 cm of soil has been found to be the approximate zone of rainfall-soil interaction which influences the movement of solute from soil into overland flow (Havis, 1986). Table 5 implies that only 0.13 to 0.60 percent of the technical chlordane which was dissolved or suspended in the soil water at the beginning of the experiment was actually transported off the soil surface in runoff. The total mass of technical chlordane (including dissolved, suspended and adsorbed) which was transported off the soil surface in runoff

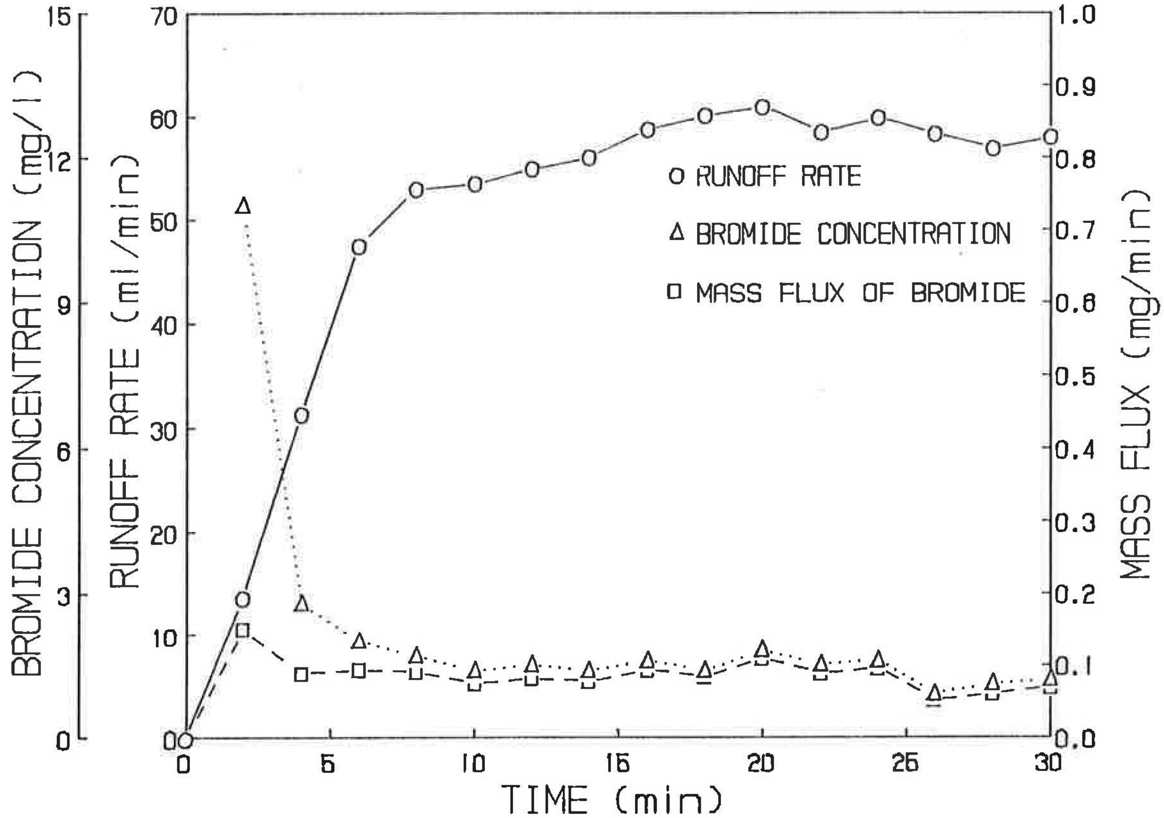


Fig. 6 Results from Bromide Runs for Menfro Ap Soil Under 102 mm/hr Rainfall Intensity

TABLE 4

Bromide in Runoff

Soil Type	Rainfall Intensity (mm/hr)	Runoff Volume (L)	Bromide Loss (mg)	Mean Bromide Conc. (mg/L)
Menfro Ap	102	1.56	2.63	1.49
Menfro Bt	102	1.29	4.21	3.24
Sarpy	102	0.55	0.54	1.03

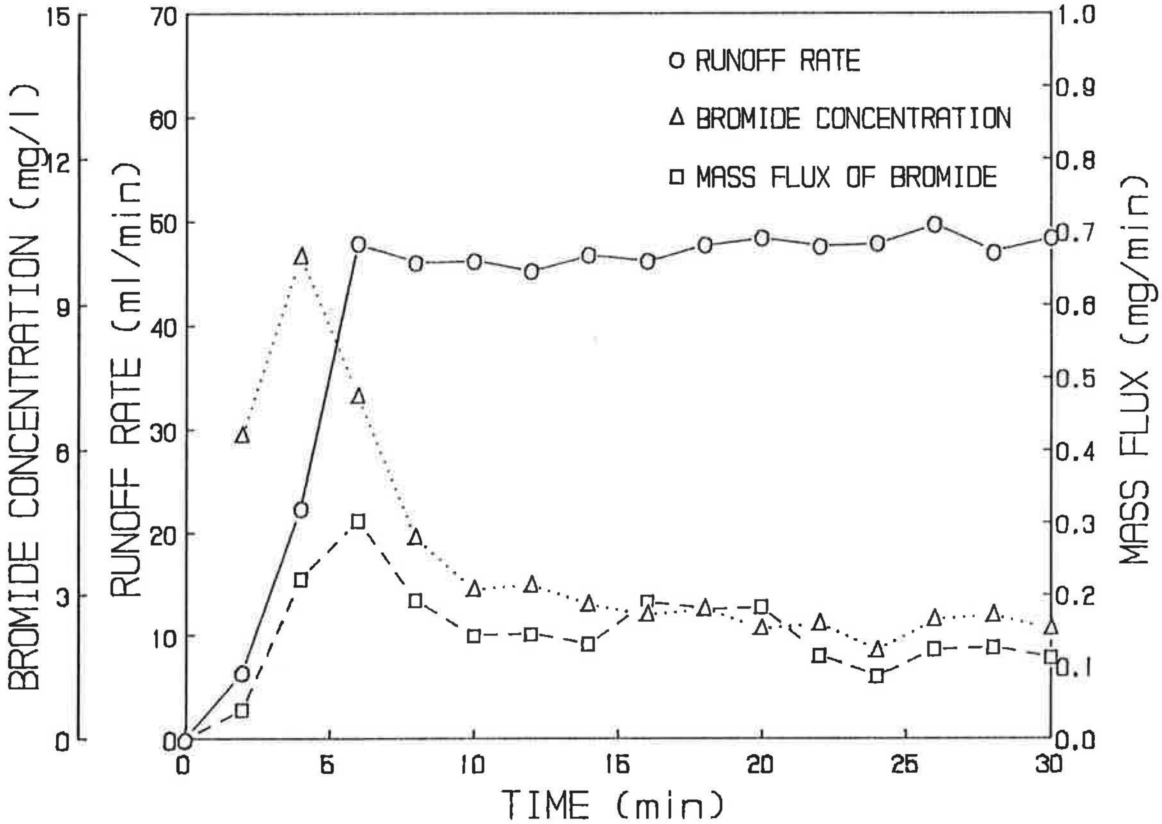


Fig. 7 . Results from Bromide Runs for Menfro Bt Soil Under 102 mm/hr Rainfall Intensity

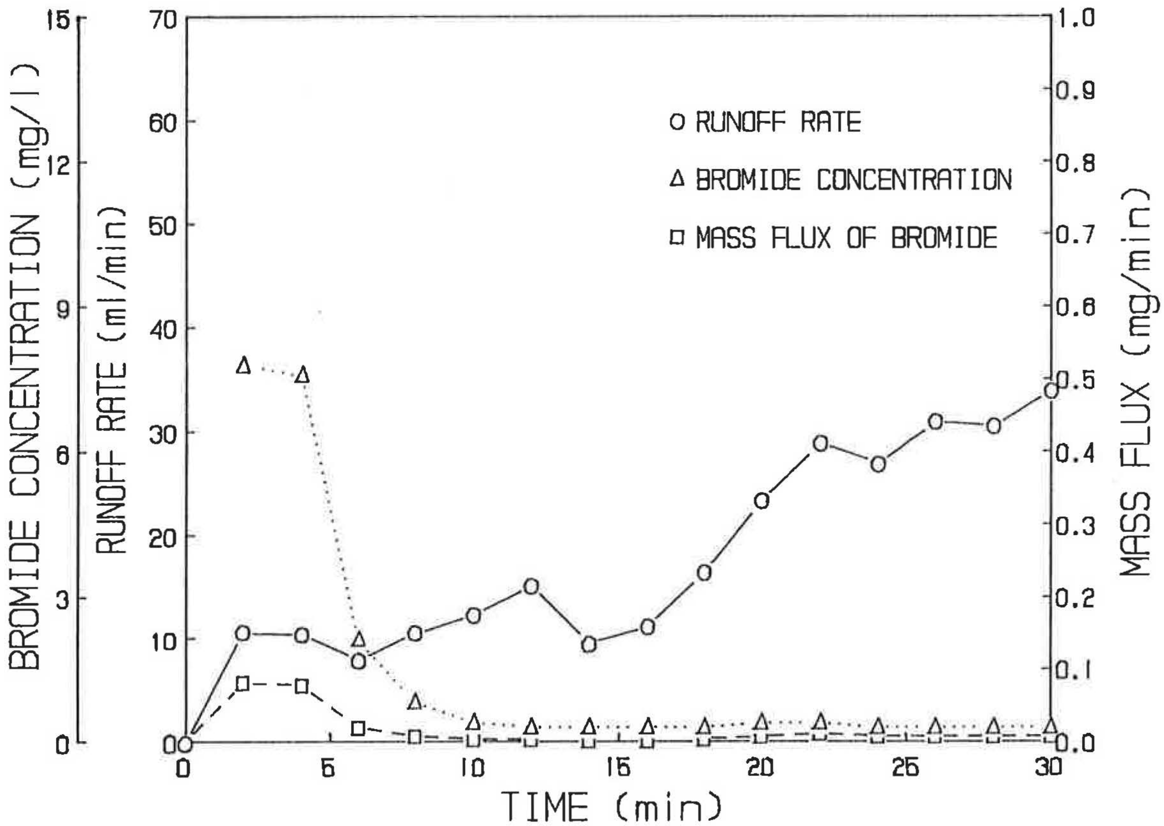


Fig. 8 Results from Bromide Runs for Sarpy Soil Under 102 mm/hr Rainfall Intensity

TABLE 5

Comparison of Technical Chlordane and Bromide Losses in Runoff

Soil Type	Rainfall Intensity (mm/hr)	Percent Loss in Top 1.0 cm by Runoff During First 30 min	
		Bromide	Chlordane
Menfro Ap	102	0.38	3.38
Menfro Bt	102	0.60	2.75
Sarpy	102	0.13	0.77

ranged from 0.77 to 3.35 percent of the total mass of technical chlordane applied in the top 1.0 cm of soil.

Splash

The chlordane loss in splash is summarized in Table 6. In all cases, the total chlordane loss in splash was less than the loss in runoff, ranging between 4 and 14 percent of the loss in runoff except for the Sarpy soil under the smaller rainfall intensity which averaged 88 percent. The ratio of chlordane loss to sediment loss in splash was also small compared to this ratio in runoff except for the Sarpy soil under the smaller rainfall intensity which was larger. The chlordane mass in splash per mass of sediment in splash ranged from 3 to 33 percent of the chlordane mass applied to the soil per mass of soil. The bromide concentration in the splash was diluted below the detectable limit of the bromide ion electrode by the additional rainfall intercepted by the splash guard.

Leachate

Only one experimental condition produced leachate during the 30-min rainfall period--the Sarpy soil under 102 mm/hr rainfall intensity. This outflow began between 18 and 20 min after the rainfall began. Table 7 summarizes the leachate results for technical chlordane and bromide. The technical chlordane concentration during the first 2-min sampling period (18 to 20 minutes after rainfall began) was 14.7 mg/L. This reduced to 1.4 mg/L during the final sampling period (28 to 30 minutes after rainfall began). The concentrations for bromide were significantly larger than for technical chlordane, ranging from 2200 mg/L at the beginning to 1100 mg/L at the end of the sampling period. The mass of bromide in the leachate was many times greater than the mass in the runoff, whereas the mass of technical chlordane in the leachate was less than the mass in the runoff. The percent of the total mass of bromide in the soil

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TABLE 6

Technical Chlordane and Sediment in Splash

Soil Type	Rainfall Intensity (mm/hr)	Sediment Loss[1] (g)	Chlordane Loss[2] (mg)	Chlordane Loss[2] (% runoff)[3]	Ratio of Chlordane Loss to Sediment Loss (mg/g)	Ratio of Chlordane Loss to Sediment Loss (% runoff)[4]	Ratio of Chlordane Loss to Sediment Loss (% applied)[5]
Menfro Ap	51		0.99	14			
Sarpy	51	3.05	0.79	88	0.259	152	33
Menfro Ap	102	13.3	0.86	5	0.065	3	6
Menfro Bt	102	22.2	0.63	4	0.028	4	3
Sarpy	102	26.7	0.59	14	0.022	11	3

[1] Mean of three sediment runs.

[2] Mean of two replicate chlordane runs.

[3] Percent of chlordane loss in runoff.

[4] Percent of the ratio of chlordane loss to sediment loss in runoff.

[5] Percent of chlordane mass applied per mass of soil.

TABLE 7

Technical Chlordane and Bromide in Leachate

Soil Type	Rainfall Intensity (mm/hr)	Chemical	Leachate Volume (L)	Chemical Loss (mg)	Mean Chemical Conc. (mg/L)	Percent of Chemical Loss in Runoff	Percent of Chemical Loss in Splash	Percent of Chemical Mass Applied Originally to Entire Soil Column
Sarpy	102	Chlordane	0.231	1.56	6.75	37	264	0.02
Sarpy	102	Bromide	0.271	402.	1483.	74,444		4.55

column which was lost in the leachate was 4.55 percent compared to 0.02 percent for technical chlordane.

CONCLUSIONS

The mass of chlordane leaving the soil surface in runoff is closely related to the mass of the sediment in runoff and to the organic matter and particle size characteristics of the soil. By assuming as a first approximation that the sediment characteristics in runoff were the same as the bulk soil, the mass of chlordane in runoff adsorbed to organic matter was estimated to be 16 times the mass of chlordane in runoff adsorbed to clay. For a soil with a clay-to-organic-matter ratio (on a mass basis) as high as 66, the mass of chlordane in runoff appears to be predominantly a function of clay content of the sediment. For a soil with a clay-to-organic-matter ratio as low as 2 to 5, the mass of chlordane in runoff appears to be predominantly a function of organic matter content. An increase in rainfall intensity from 51 to 102 mm/hr had a large effect on the total chlordane mass in runoff (increase of 173 to 374 percent). However, this increase in rainfall intensity had only a slight effect on the chlordane-to-sediment mass ratio in the runoff (increase of 7 to 18 percent). Under these experimental conditions, the chlordane mass in runoff was 5 to 9 times as great as the mass in runoff of a water soluble, nonadsorbed chemical (bromide).

The chlordane mass in splash averaged 25 percent of the chlordane mass in runoff. The ratio of chlordane mass to sediment mass in splash was also less than in runoff (averaging 6 percent of the ratio for runoff) except for the sand at low rainfall intensity which had a larger ratio.

Only the sand at the higher rainfall intensity produced leachate. Over the 30-min rainfall period, the chlordane mass in this leachate was much less than the chlordane mass in runoff (37 percent of the mass in runoff) but much greater than the chlordane mass in splash (264 percent of the mass in splash).

The total chlordane mass which left the experimental soil box by runoff, splash and leachate during the 30-min rainfall period ranged from 2 to 20 mg. This is equivalent to 4 to 44 mg per square foot of treated surface area. This total loss of chlordane ranged from 0.03 to 0.31 percent of the original chlordane mass within the experimental soil box at the beginning of rainfall.

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