Environmental Protection Technology Series

Herbicide Runoff From Four Coastal Plain Soil Types

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HERBICIDE RUNOFF FROM FOUR COASTAL PLAIN SOIL TYPES

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ABSTRACT

The movement of two herbicides in runoff and on sediment were studied as examples of pesticides in general use. Gas chromatography was used to determine the losses of atrazine (2-chloro-4-ethylamino-6-isopropylamino-s-triazine) and dichlobenil (2,6-dichlorobenzonitrile from fallow plots on four Coastal Plain soil types following the application of about 13 cm (5 in.) of rainfall in 2 hours.

The herbicides, as wettable powders, were surface-applied and incorporated. Simulated high intensity (a 100-year frequency storm) rainfall was started 1 hour after application.

Significant amounts of both compounds were transported. The percent loss was greater in all cases for atrazine, but because more dichlobenil was applied, its losses were greater on an absolute basis. Some of the herbicide in the sediment may have been transported as discrete particles rather than as an adsorbate.

The greatest combined (runoff plus sediment) losses of atrazine in all soils and of dichlobenil in two soils occurred during the first 40-50 minutes of runoff. During this time, the absolute amount of both herbicides was greater in runoff, but the concentrations were greater in the sediment. The preferential loss of certain clay-sized materials during the first 50 minutes of runoff may explain the high herbicide concentration in sediment relative to later times.

Over the entire event, 70-80% of the total herbicide loss occurred in the runoff.

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SECTION I

CONCLUSIONS

1. Runoff was the major transport mode for atrazine and dichlobenil (weakly basic, nitrogen-containing, chlorinated, aromatic herbicides) from sandy Coastal Plain soils under simulated high intensity rainfall. Although the herbicide concentration was greater in the sediment phase, the absolute amount of both herbicides was greater in runoff.
2. The combined, i.e., runoff plus sediment, losses of atrazine and dichlobenil were greatest during the first 40-50 minutes of runoff.
3. Such factors as pesticide type, soil type, rate and mode of application, and formulation properties influence the extent and distribution of pesticide transport from fallowed soil under simulated high intensity rainfall.
4. Field gas chromatographic analysis of extracts is a feasible procedure. However, best productivity would be attained were the samples separated, extracted, concentrated, and then sent to the home laboratory for analysis.

SECTION II

RECOMMENDATIONS

1. The following procedures are recommended to make future studies more fruitful.
   A. To assess the degree of pesticide downward movement, soil samples should be collected at 0.7 cm (0.3 in.), 7.5-15 cm (3-6 in.), and 15-30 cm (6-12 in.) depths (1) prior to pesticide application, (2) immediately after pesticide application and prior to starting the rainfall, and (3) at the end of the runoff event.
   B. To assess volatility losses, soil surface temperature should be measured (1) prior to pesticide application, (2) immediately after pesticide application, (3) at 0, 30, 60, 90, and 120 minutes after runoff has started, and (4) after runoff has stopped.
   C. To assess the possible occurrence of pesticide vapor loss during runoff, temperature measurement of runoff should be taken at 0, 30, 60, 90, and 120 minutes after initiation of rainfall and at the end of runoff.
   D. To correlate pesticide losses with physical processes occurring during runoff and erosion, a sequence of colored slides viewing the plot at various intervals should be taken (1) during soil preparation, (2) prior to pesticide application, (3) immediately after pesticide application, (4) at 0, 30, 60, 90, and 120 minutes after initiation of runoff, and (5) after runoff has stopped.
   E. To determine pesticide persistence, soil samples should be collected at 0.5, 1, 2, 3, 6, and 12 months after initial tests are complete.
2. Because the distances involved in the study gave rise to serious logistical problems, future field studies should be conducted closer

to the home laboratory or provisions made for quick shipment of samples, e.g., charter aircraft or express busses could be used.

3. A computer program should be written to calculate differential and integral sediment, runoff, and pesticide (in both runoff and sediment) losses.

SECTION III

INTRODUCTION

The use of pesticides in American agriculture has increased production efficiency, a benefit passed on to the consumer in the form of a lower cost for food and clothing than would otherwise be possible.

However, chemical control of agricultural pests may also create problems. Some pesticides applied to crops and soils do not remain on site, but through rainfall and erosion are carried into receiving waters in various ways--dissolved in the runoff, adsorbed on eroded soil particles, or transported as particulates. (Nicholson et al., 1962; Grzenda et al. 1964; Nicholson et al., 1964; Lauer et al., 1966; Nicholson et al., 1966; Barnett et al., 1967; White et al., 1967; Hall et al., 1972.) The environmental hazard created by such pollution has stimulated considerable research in the area of agricultural runoff.

Managerial and engineering techniques must be developed to prevent or control the pollution hazards resulting from agricultural runoff. The formulation of such techniques, however, requires an understanding of the influence on pollution potential of the following factors: soil properties, rainfall characteristics, pesticide type and formulation, agricultural practices, watershed characteristics, and pesticide attenuation processes. To this end, studies have been conducted on small well-characterized plots to which pesticide is applied in various specified manners.

The use of natural rainfall in runoff studies is very inefficient, since one cannot control the frequency, the intensity, and the duration of rain. Simulated rainfall, an important tool in erosion studies for over a decade (Meyer, 1965), has been shown to be of use in studying pesticide runoff from agricultural land (Barnett et al., 1967 and White et al., 1967).

A cooperative study between the Agro-Environmental Systems Branch,

SERL, NERC, Corvallis, EPA, and Southern Piedmont Conservation Research Center, ARS, USDA, was undertaken in the summer of 1970 because of a joint interest in the area of herbicide runoff. The objectives of the investigation were (1) to study the effect of soil type, pesticide type, and application rate of the amount and distribution of pesticide in runoff; (2) to evaluate field procedures for conducting future such studies; and (3) to evaluate the usefulness of the rainfall simulator in pesticide runoff studies and future modeling efforts.

SECTION IV

EXPERIMENTAL METHODS

FIELD PROCEDURES

Site Selection

The selection of four sites for the runoff study was based on (1) soil type, (2) slope of plot, (3) cropping and pesticide usage history, (4) future use of plot, and (5) effects of drainage on contiguous areas.

Surface samples were taken for analytical reference blanks from the prospective sites to determine herbicide background levels. Detailed information concerning the morphological character, physicochemical properties, and genesis of the four soil types is found in Appendix B.

One site (Site 2) located at Wiregrass Experiment Station, Headland, Alabama, was a Dothan sandy loam on a 2.2% slope near a "grady pond" (a pond typical of southern Alabama, that fills with water in the winter and dries out in the summer). Three sites were located at Gulfcoast Experiment Station, Fairhope, Alabama: Site 5, Red Bay sandy loam, 2.5% slope; Site 6, Malbis (Bowie) sandy clay loam, 3.6% slope; and Site 7, Malbis (Bowie) sandy loam, 5.7% slope. All sites were cropped to soybeans or corn. Site numbers were assigned in connection with a companion study and are therefore not consecutive.

Site Preparation

The major portion of foliage was removed from the soil surface by hand prior to tillage. Each site was divided into two plots, 1.83 m x 10.66 m (6 ft x 35 ft), separated by a 0.31 m (12 in.) walkway. One plot was used for the pesticide runoff experiment, the other for soil erodibility determination. Border material was placed to outline the experimental plots and the rainfall simulator was set up over the area.

The soil was fallowed with a rotary tiller and raked smooth to reduce surface irregularities and to remove any remaining plant residue. A control site, 1.83 m x 1.83 m (6 ft x 6 ft) was prepared in a similar manner near each of the test sites. For Site 2, one of the plots into which the site was divided was used a a suplicate plot. Pretreatment samples were taken of soil from each plot.

Pesticide Application

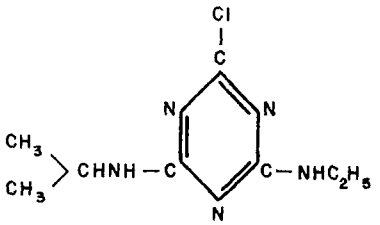
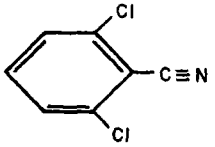
Atrazine (2-chloro-4-ethylamino-6-isopropylamino-s-triazine; Aatrex™) and dichlobenil (2.6-dichlorobenzonitrile; Casoron™) were selected as the test herbicides since background information was available on them from previous in-house research. Some properties of these two herbicides are given in Table 1.

Dichlobenil (DCBN) was applied at the recommended rate, 6.72 kg/ha active ingredient (6.0 lb/A), as a 50% wettable powder formulation to all four plots. Atrazine was applied at the recommended rate, 3.36 kg/ha active ingredient (3.0 lb/A) to Site 5 and Site 7 as an 80% wettable powder and at the rate of 1.68 kg/ha (1.5 lb/A) to Site 2 and Site 6. The two herbicides were applied simultaneously to both test and control plots 1 hour before the test storm in a volume of 590 l/ha (60 gal./A) with a precalibrated conventional CO_2 powered bi-wheeled applicator. This type of applicator had several advantages over a 3-gallon tank sprayer in that it could (1) apply test herbicides more uniformly over the area treated, (2) provide sufficient agitation for uniform mixing, and (3) more accurately apply predetermined dosages.

The herbicides were immediately incorporated to a depth of about 3 in. by harrowing parallel to the slope with a drag harrow to provide plot surfaces of uniform configuration and reproducibility.

To ensure that compound carry-over from plot to plot did not occur, gas chromatographic analyses were performed on samples of the water used to wash the sprayer.

Table 1. HERBICIDE PROPERTIES

Compound	Structural Formula	Properties	Application Rate of Active Ingredient
Common name: atrazine --- 2-chloro-4-(ethylamino) -6-(isopropylamino) -s-triazine --- Trade name: Aatrex 80W --- Formulation: 80% wettable powder		Molecular formula: $C_8H_{14}ClN_5$ Molecular weight: 215.7 Physical state and color: White, crystalline solid Melting point: 173° to 175°C Vapor pressure: Temperature °C — mm Hg 10 — 5.7×10^{-8} 20 — 3.0×10^{-7} 30 — 1.4×10^{-6} 50 — 2.3×10^{-5} Water solubility at 27°C: 33 ppm	2.24-4.48 kg/ha (2-4 lb/A) Geigy Agricultural Chemicals Research and Development Saw Mill River Road Ardsley, New York 10702
Common name: dichlobenil --- 2,6-dichlorobenzonitrile --- Trade name: Casoron W-50 --- Formulation: 50% wettable powder		Molecular formula: $C_7H_3Cl_2N$ Molecular weight: 172.0 Physical state, color: White, crystalline solid Melting point: 145° to 146°C Vapor pressure: Temperature °C — mm Hg 20 — 5.5×10^{-4} 50 — 1.5×10^{-2} 100 — 1.1×10^{-1} Water solubility at 20°C: 18 ppm	4.48-6.72 kg/ha (4-6 lb/A) Thompson-Hayward Chemical Co. P. O. Box 768 Kansas City, Missouri 64141

Rainfall Simulator

A rainfall simulator, "rainulator," described by Meyer and McCune (1958) and modified by Cobb et al. (1961), was used to provide erosional energy. Water for the simulator was obtained from local municipal water systems and stored in a tanker truck. Gas chromatographic analysis of the water was negative for both herbicides. The temperature of the "rainwater" and the washoff were measured (Table 2).

The rainfall amount was calculated by measuring the water collected on two U-shaped troughs placed diagonally across the plot. Rainfall at an intensity of 6.35 cm/hr (2.5 in./hr) with a storm duration of 2 hours was applied to the test sites only, beginning 1 hour after herbicide application. The simulated rainfall was comparable to a "100-year frequency storm" in the Alabama Coastal Plain Region, i.e., a storm that would occur once every 100 years, on the average (Hershfield, 1961).

Photographs illustrating the operation of the rainfall simulator are found in Appendix A.

Sampling Procedures

Sediment and runoff samples were collected in 1-quart containers from a runoff trough at the base of the plots at the beginning of runoff, then every 2 minutes for 10 minutes, every 3 minutes for 15 minutes, every 5 minutes for 25 minutes, and finally every 10 minutes until the end of runoff. All samples were sealed with a stopper, covered with aluminum foil, and refrigerated immediately after the run. Samples from Site 2 were iced down and transported to Fairhope.

Flow measurements to determine the runoff hydrograph, a plot of runoff rate versus time, were made at various time intervals during the runoff event by recording the length of time, to the nearest 0.1 sec, required to fill containers of known volume. Measurements were made using 1-qt and 1- and 2- gallon containers. As filling time for each smaller container

Table 2. HERBICIDE LOSS AND THE ACCOMPANYING RAINFALL, RUNOFF SOIL LOSS, HERBICIDE APPLICATION RATE, AND TEMPERATURE.

Site No.	Application Rate, Formulation, and Active		Herbicide Loss, Sediment, Water and Total						Total Water Applied cm	Total Water Loss cm	Total Sediment Loss,[a] kg/haX10^2	Temp., ^oC	
			Amount Lost kg/ha			Loss, %							
	Atrazine	DCBN		Atrazine	DCBN		Atrazine	DCBN					
Dothan	2.10[b]	13.5[b]	Sed.	0.03	0.02	Sed.	1.95	0.36				Air	30.0
Site 2	1.68[c]	6.72[c]	Water	0.07	0.16	Water	4.49	2.36	13.4	8.50	34.8	Water	30.9
			Total	0.10	0.18	Total	6.44	2.72				Runoff	----
Malbis	4.20[b]	13.5[b]	Sed.	0.10	0.17	Sed.	3.04	2.55				Air	32.2
Site 7	3.36[c]	6.72[c]	Water	0.23	0.14	Water	7.14	2.07	13.5	9.40	153	Water	28.6
			Total	0.33	0.31	Total	10.2	4.62				Runoff	32.8
Malbis	2.10[b]	13.5[b]	Sed.	0.04	0.20	Sed.	2.17	2.97				Air	----
Site 6	1.68[c]	6.72[c]	Water	0.16	0.40	Water	10.3	5.99	13.9	10.20	154	Water	28.6
			Total	0.20	0.60	Total	12.5	8.96				Runoff	30.6
Red Bay	4.20[b]	13.45[b]	Sed.	0.06	0.16	Sed.	1.90	2.33				Air	27.5
Site 5	3.36[c]	6.72[c]	Water	0.36	0.53	Water	11.4	7.61	14.6	10.50	89.4	Water	27.2
			Total	0.42	0.69	Total	13.3	9.94				Runoff	28.1

a Silt and Clay Only
b Formulation
c Active Ingredient

approached 10 sec, the next largest container was used to ensure adequate accuracy at higher runoff rates.

Soil core samples were taken for moisture and herbicide residue determination before the event and after rainfall and runoff had ceased. The core samples were taken at depths of 0 to 7.52 cm (0-3 in.), 7.52 to 15 cm (3-6 in.), 15 to 23 cm (6-9 in.), and 23 to 30 cm (9-12 in.). The moisture content was determined by oven-drying at 110°C.

LABORATORY PROCEDURES

Although analytical methods are available for the singular determination of atrazine (Benfield and Chilwell, 1964; Sheets and Kearney, 1964; and McClamery et al., 1967) and dichlobenil (Miller et al., 1966; Van Valin, 1966; and Briggs and Dawson, 1970), the extractions described were found to be inefficient in samples spiked with the formulated compound rather than the analytical grade material. An integrated method was therefore developed to permit simultaneous extraction and gas chromatographic analysis of the two admixed formulated grade herbicides from both the sediment and water fractions.

Apparatus and Reagents

(1) Gas chromatograph - A Packard Model 7620 Gas Chromatograph (Packard Instrument Company, Downers Grove, Ill.) equipped with dual Radium "D" (50 microcuries) electron capture detectors and dual 150-cm (5 ft) coiled glass columns (0.4 cm i.d.) packed with 10% DC-200 on 80-90 mesh Gas Chrom Q (Applied Science Labs, State College, Pa.). Injection port 230°C; column temperature 190°C for atrazine, 160°C for dichlobenil; detector temperature 220°C; nitrogen carrier gas flow 60-90 ml/min; (2) International Centrifuges, Model K - size 2; 4 place aluminum heads for 600-ml bottles; (3) Solvents - Burdick and Jackson pesticide grade chloroform, methylene chloride, acetone, and benzene; (4) Reagents - Sodium chloride and sodium sulfate anhydrous, A.C.S. Certified; and (5) Herbicides - Aatrex™ 80W (76% atrazine), CIBA-Geigy

Chemical Company; Casoron™ 50-W (50% dichlobenil), Thompson-Hayward Chemical Co.

Sediment-Water Separation

Refrigerated runoff samples were brought to room temperature and stirred, first vigorously to disperse the clay and silt and then slowly, to permit the sand fraction to settle to the bottom. While the suspension was still in motion, a 10 ml aliquot was removed for determination of the clay-silt content by drying and weighing. In all further discussion, the term "sediment" will refer only to the clay and silt fraction unless otherwise stated.

The suspension was drawn off into two 500 ml centrifuge bottles, filling one and partially filling the other. Following the addition of about 15 g of NaCl to each bottle, the clay-silt-sized particles were sedimented out by centrifuging at 2200 RPM for 10 minutes. The supernatants were decanted and combined.

The sediment from one centrifuge bottle was transferred into a small bottle containing 5 ml chloroform. The lid was lined with aluminum foil and sealed on the bottle with plastic tape. The sample was then frozen and sent to the Southeast Environmental Research Laboratory for analysis. The sediment from the second of the centrifuge bottles was analyzed on site. Comparison of the results from the frozen sediment with those obtained at Gulfcoast on the unfrozen samples indicated that volatilization and degradation of the residue during the freezing and transport steps were negligible.

Extraction and Analysis

The sediment was extracted for 4 hours in a Soxhlet apparatus with acetone. The extracting solution was concentrated to 100 ml and diluted to about 900 ml with distilled water. Further extraction of the resulting solution was performed with one 100-ml and three 50-ml portions of chloroform. The chloroform extracts were combined and passed through a

sodium sulfate column to remove traces of water. The chloroform was evaporated and the residue taken up in benzene for gas chromatographic analysis. A similar procedure was performed on the frozen sediment.

The supernatant was extracted with methylene chloride (one 100-ml and three 50-ml portions). The combined extracting solution was evaporated in a Kuderna-Danish apparatus and the residue taken up in benzene for gas chromatographic analysis.

Aliquots of the benzene-herbicide solutions were injected into the gas chromatograph onto the column previously described. The identification and quantitative determination of the herbicide were accomplished by comparison of retention times and peak heights with those of standards. The results reported are averages of the field and laboratory analyses.

The efficiency of the extraction technique was tested with water spiked with the herbicide formulations. The recovery levels of atrazine and dichlobenil from concentrations of 0.5 ppm were 99% and 80%, respectively. Corrections, however, were not made to the measured data.

Particle-size analysis of the soil from each plot and the eroded soil was done by the conventional hydrometer method (Day, 1965).

CALCULATIONS

Calculations of the runoff parameters were based on the following data: (1) the volume rate of runoff measured at specific times during the event, (2) measured weights of sediment for each 1-quart runoff sample taken at specified times during the event, and (3) atrazine and dichlobenil concentrations as measured on each sample by gas chromatography.

Manual integration of runoff data compared favorably with integrations done by computer.

1. Runoff Rate Data - The runoff rate data (in units of volume/time as measured by the time required to fill a container of known volume) were converted, by using the plot size, into units of inches of runoff (or

centimeters)/time to facilitate comparison with runoff data on any plot. The data were compiled on a computer. Volume rates were used in further calculations.

2. Runoff Volume - Manual interpolations were performed between data points to determine the average runoff rate at each minute in inches (or centimeters)/minute during the runoff event. Integrations of the resulting runoff rate data were performed over the entire event and over selected time periods to obtain runoff volume over the desired time period.

$$\sum_{\text{minute } x}^{\text{minute } y} \frac{\text{inches runoff}}{\text{time}} \times \text{time} = \text{inches runoff over interval } (y-x)$$

3. Sediment Delivery Rate - The sediment delivery rate was determined for each sampling time by using the total sediment weight for the sample, the liquid volume of the sample, and the volume rate of runoff at that time.

$$\frac{\text{sediment weight}}{\text{sample volume}} \times \frac{\text{runoff volume}}{\text{time}} = \frac{\text{sediment weight}}{\text{time}}$$

4. Sediment Weight - Interpolations and integrations analogous to those performed on water runoff data yielded the weight of soil eroded in pounds (or kilograms)/minute over the calculated intervals.

$$\sum_{\text{minute } x}^{\text{minute } y} \frac{\text{sediment weight}}{\text{time}} \times \text{time} = \text{sediment weight lost over interval } (y-x)$$

5. Herbicide Runoff Rates and Weights - The rate of herbicide runoff as a function of time in runoff water and sediment was calculated in a manner similar to that used for sediment rate calculations.

$$\frac{\text{herbicide weight in sample}}{\text{sample volume (or sediment weight)}} \times$$

$$\frac{\text{runoff volume (or sediment weight)}}{\text{time}} = \frac{\text{herbicide weight}}{\text{time}}$$

Interpolation and integration of the resulting data provided total weight data for herbicides over intervals calculated.

$$\sum_{\text{minute x}}^{\text{minute y}} \frac{\text{herbicide weight}}{\text{time}} \times \text{time} = \text{herbicide weight loss over interval (y-x)}$$

6. Pesticide Concentration Data - The concentration of herbicide in either water or sediment at any given time was calculated by using the calculated rate of herbicide loss at that time and the corresponding volume rate of water runoff (or weight rate of sediment loss).

$$\frac{\text{herbicide weight}}{\text{time}} \div \frac{\text{runoff volume (or sediment weight)}}{\text{time}} =$$

$$\frac{\text{herbicide weight}}{\text{runoff volume (or sediment weight)}}$$

7. Percent Herbicide Loss - The fractional loss of herbicide was based on the total amount lost over a given period (or over the whole event).

SECTION V

RESULTS AND DISCUSSION

Extensive research on the problem of runoff and soil erosion has shown it to be a complex phenomenon. Runoff is affected by such factors as rainfall characteristics (i.e., amount, duration, intensity, and frequency), antecedent soil moisture, watershed characteristics (i.e., area, shape, slope orientation, type of drainage, net extent of induced drainage, and presence of artificial drainage), and cultural and managerial practices. Soil loss is affected by rainfall, soil erodibility, slope length and gradient, crop management, and erosion control practices (Wischmeier and Smith, 1965). Pesticide attenuation behavior and persistence have been shown over the last decade to be governed by a combination of factors, such as adsorption-desorption, volatilization, organism uptake, vertical movement, and chemical, photochemical, and microbial degradation. The study of pesticide transport and movement from agricultural land is therefore a complex problem.

PROPERTIES OF SOILS IN RUNOFF STUDY

Physicochemical properties of the four soils studied are given in Table 3. All four soils are coarse-textured, moderately to well drained, highly acidic, moderately permeable, and relatively low in organic matter. They occur on gently sloping landscapes and are derived from unconsolidated marine sediments. Detailed morphological characteristics and genesis information are found in Apprendix B.

The soil erodibility factor, K, a part of the Universal Soil Loss Equation developed by USDA (Wischemeier and Smith, 1965), is a measure of the relative ease with which a soil will erode under standard conditions of 9 percent slope and 72.6 ft slope length. For a given set of rainfall, topographic, and management conditions, K is proportional to the degree of erosion. The studied soils in order of increasing K are Site 2, Site 5, Site 7, and Site 6 (Table 3).

Table 3. PHYSICOCHEMICAL PROPERTIES OF EXPERIMENTAL SITES

Experimental Site	Run No.	Site No.	Slope, %	Soil Type	Particle Size Distribution, %			Organic Matter, %	Soil pH	Soil Erodibility Factor, K
					Sand	Silt	Clay			
Wiregrass	1	2	2.2	Dothan Sandy Loam	79.9	4.3	15.3	0.80	5.2	0.26
Gulfcoast	4	5	2.5	Red Bay Sandy Loam	65.9	18.1	16.0	1.45	5.4	0.35
Gulfcoast	3	6	3.6	Malbis (Bowie) Sandy Clay Loam	53.9	25.7	20.4	1.60	5.6	0.60
Gulfcoast	2	7	5.7	Malbis (Bowie) Sandy Loam	71.3	16.0	12.7	2.55	5.6	0.56

SEDIMENT AND WATER LOSS

Sediment and water losses by time periods for each of the four soils are shown in Figures 1-4. Runoff rates, lowest during the early stages of rainfall, increased as a function of time, and stabilized about 20 minutes after the onset of rainfall. With the exception of Site 7, soil loss was greatest at the early stages of the runoff event and then decreased to a relatively constant value.

The sediment loss reported in Table 2, as explained previously, reflects only the combined clay and silt-size fractions; the total soil loss (i.e., sand, silt, and clay fractions) was generally greater by about a factor of two. The greatest overall sediment loss (sand, silt, and clay) occurred from the two Malbis soils, i.e., Sites 6 and 7 (15,270 and 15,400 kg/ha or 6.81 and 6.87 T/A); the Red Bay and Dothan soils lost significantly less at 940 kg/ha (3.99 T/A) and 3,480 kg/ha (1.56 T/A).

The particle size distribution of the sediment differed from that of the surface soil and varied with time during the runoff event (Figures 5-7). For all soils, the sand concentration increased and silt concentration decreased from onset of runoff; the concentration of clay was at its maximum near the onset of runoff and decreased to a relatively constant value by approximately 40 minutes after onset of rainfall. The leveling value for clay content of the total (including sand) sediment was about 40% for each of the two Malbis soils.

The fraction of the applied rainfall that appeared as runoff was less for the Dothan soil (63%) than for the other three soil types (Malbis, Site 7, 70%; Malbis, Site 6, 72%; and Red Bay, Site 5, 74%). A high infiltration rate, presumably due to the coarser texture of the soil, is proposed as an explanation. The soil with the greatest slope (Malbis, Site 7) would be expected to give rise to the maximum soil loss and runoff. However, the higher organic content and resulting higher infiltration rate apparently were sufficient to counteract the effect of the slope, giving Site 7 the second lowest runoff rate.

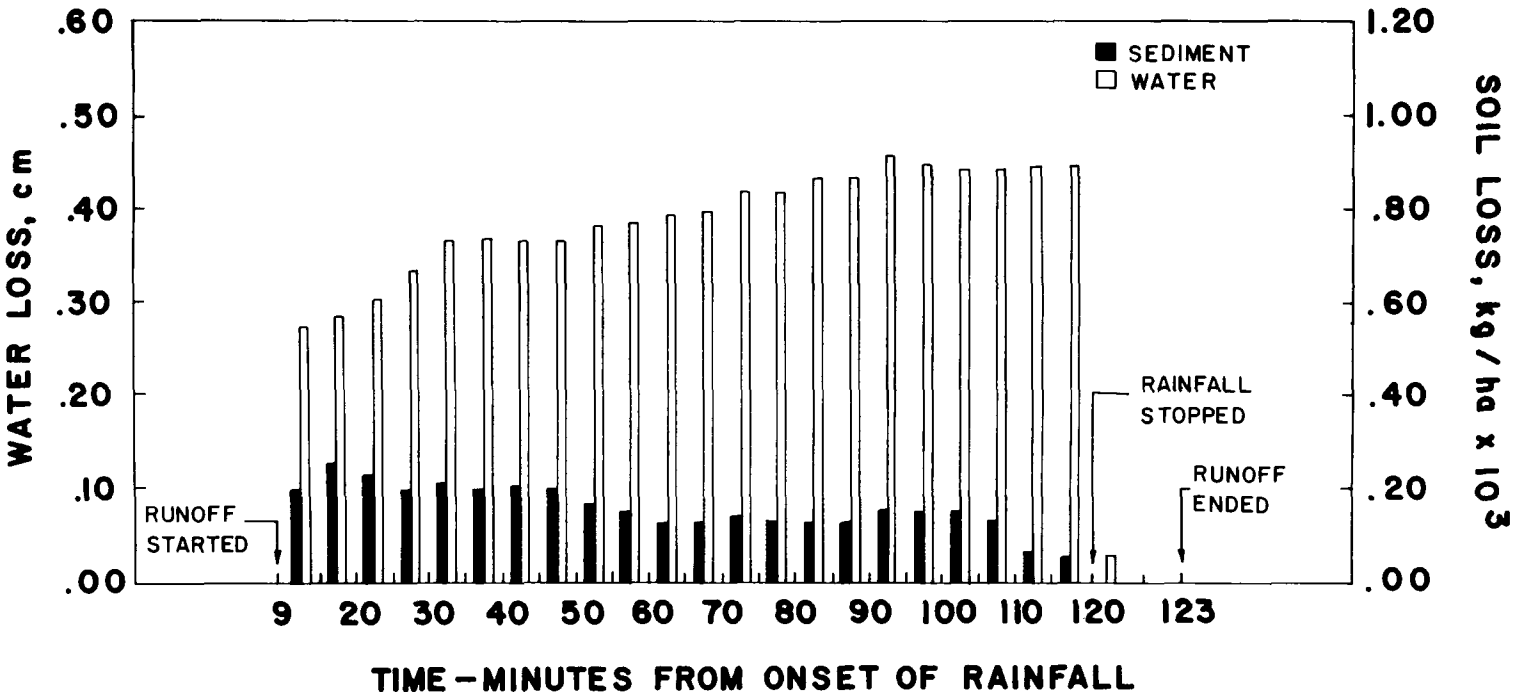


Figure 1. SEDIMENT AND WATER LOSSES BY TIME PERIODS ON DOTHAN, SITE 2.

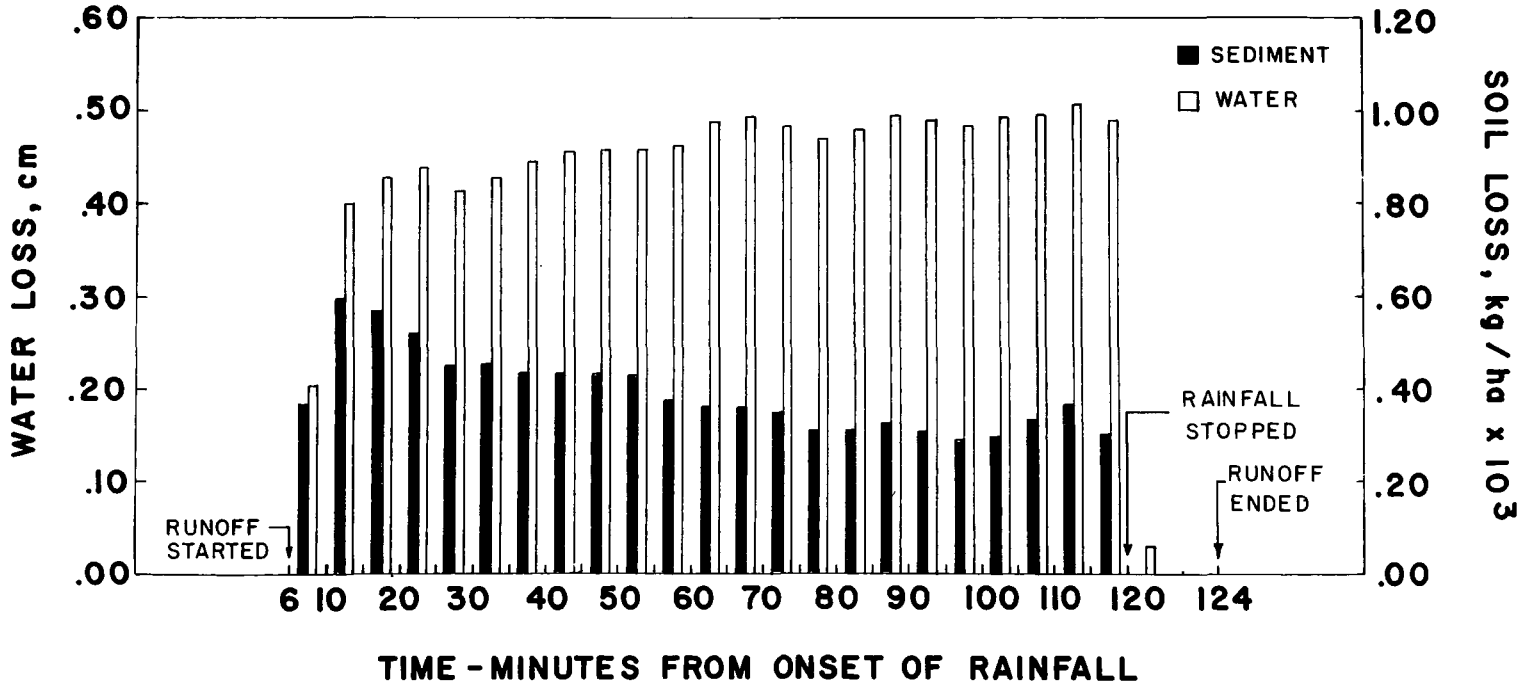


Figure 2. SEDIMENT AND WATER LOSSES BY TIME PERIODS ON RED BAY, SITE 5

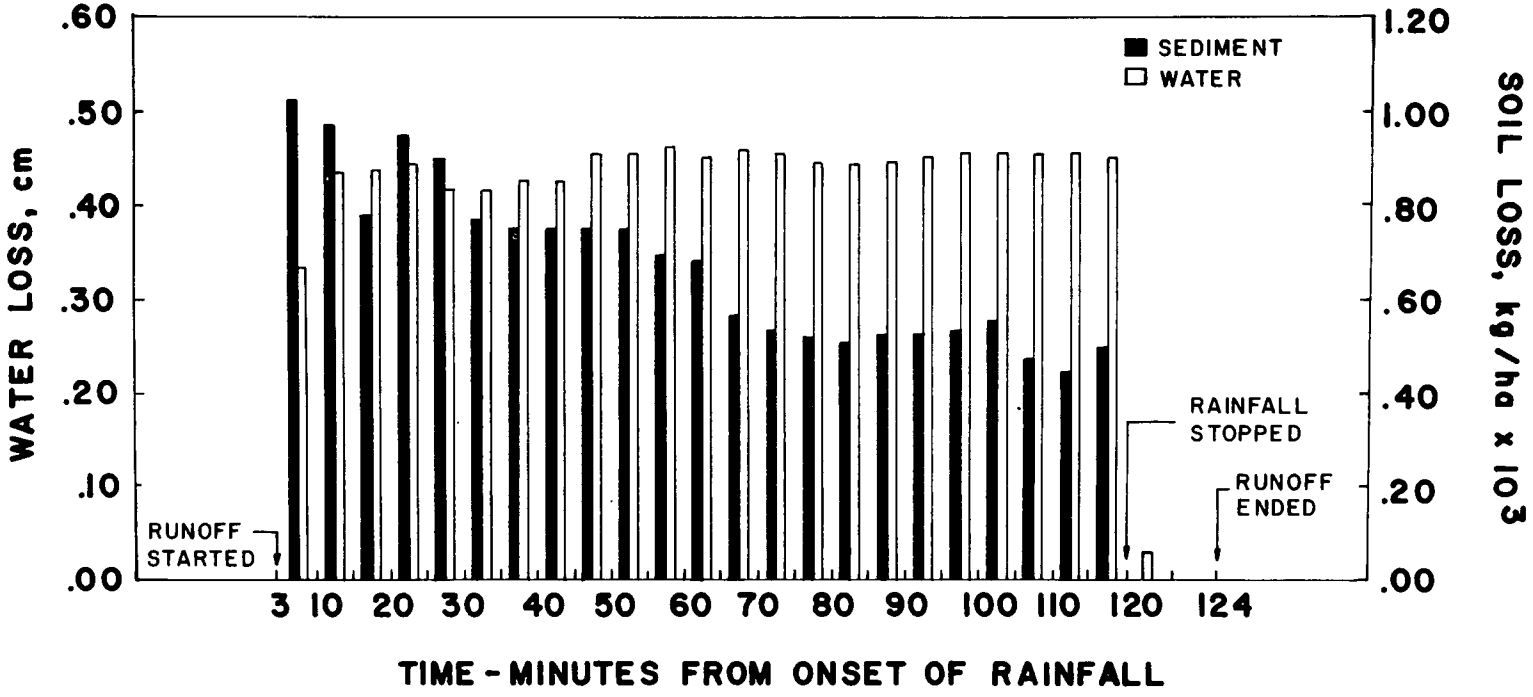


Figure 3. SEDIMENT AND WATER LOSSES BY TIME PERIODS ON MALBIS(BOWIE), SITE 6.

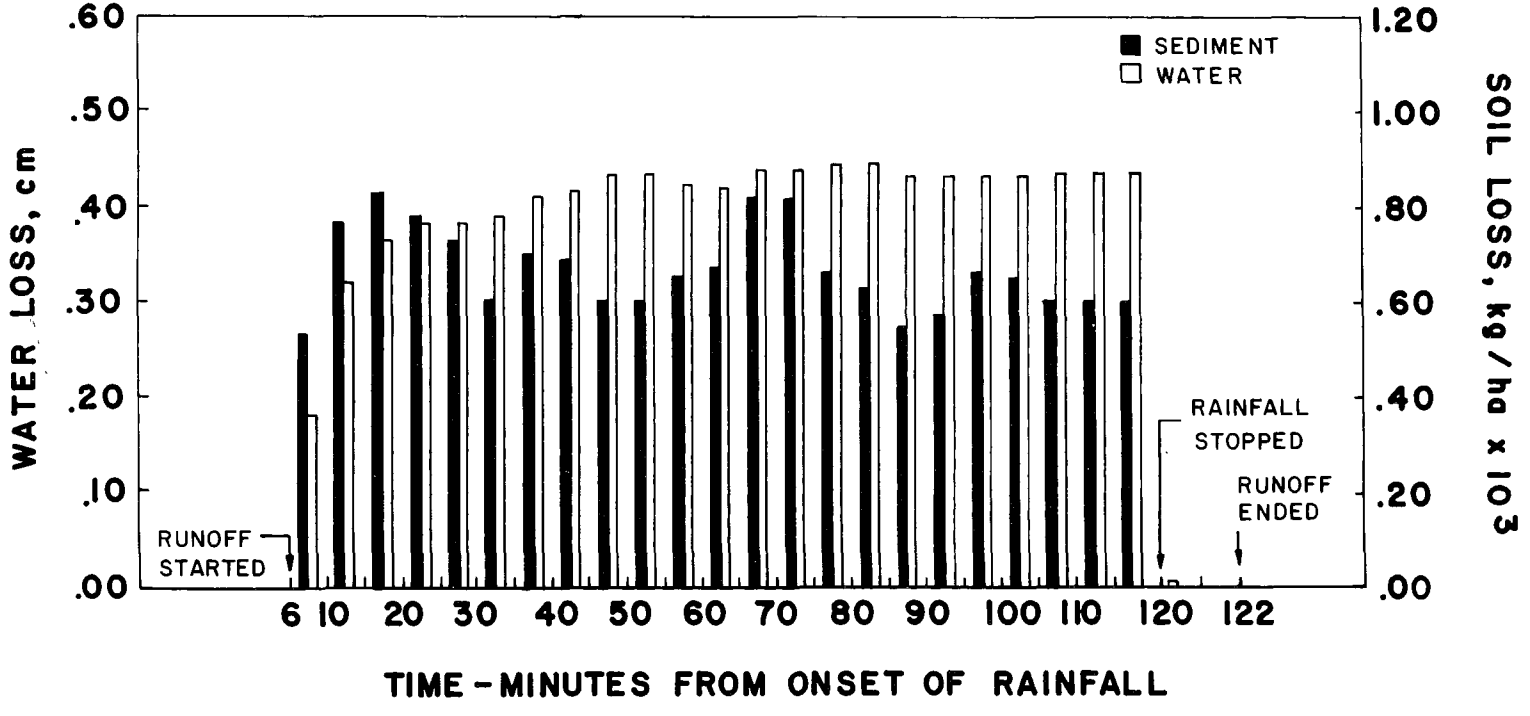


Figure 4. SEDIMENT AND WATER LOSSES BY TIME PERIODS ON MALBIS (BOWIE), SITE 7.

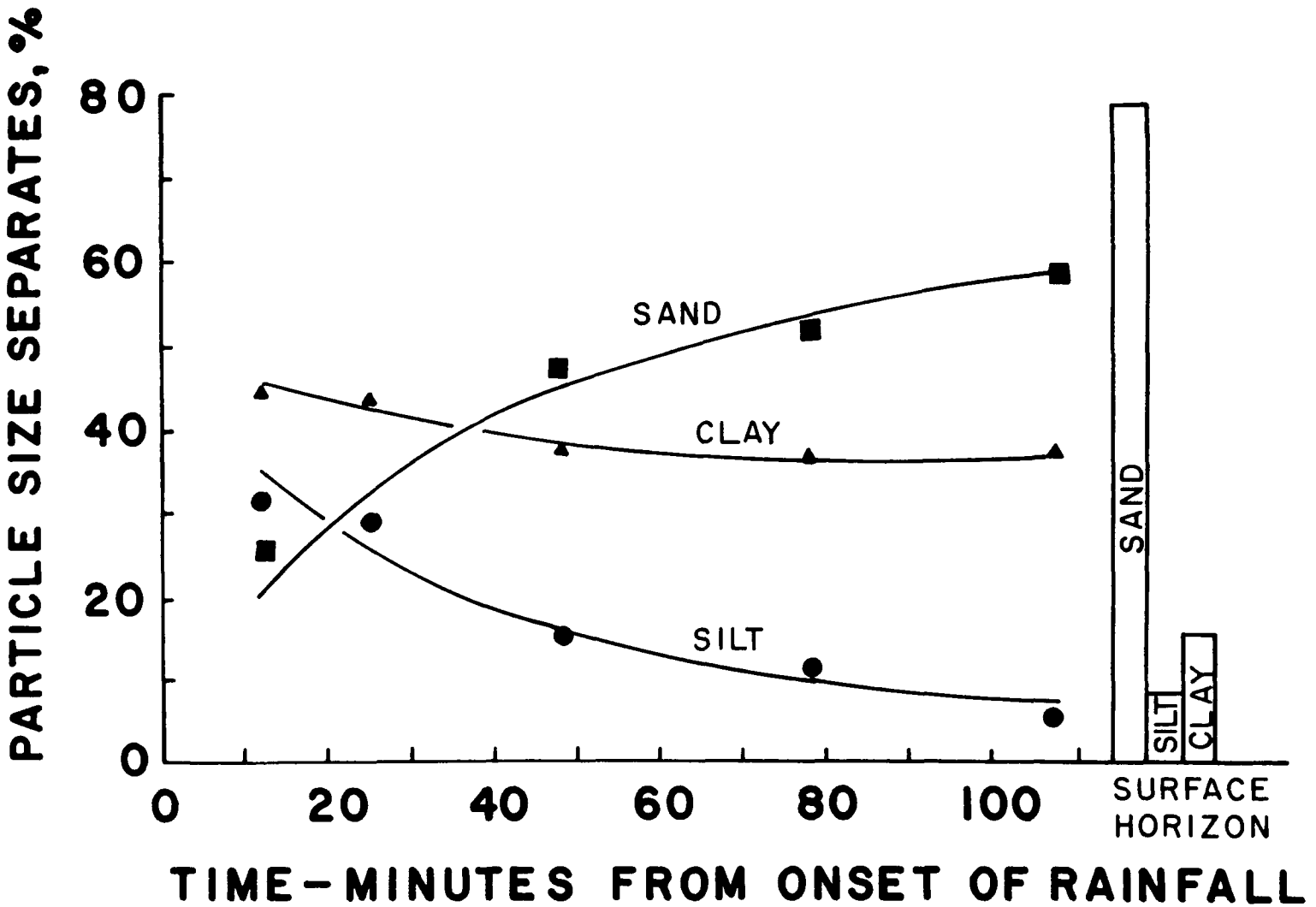


Figure 5. PARTICLE SIZE DISTRIBUTION IN RUNOFF FROM DOTHAN SANDY LOAM (AVERAGE OF 3 SITES).

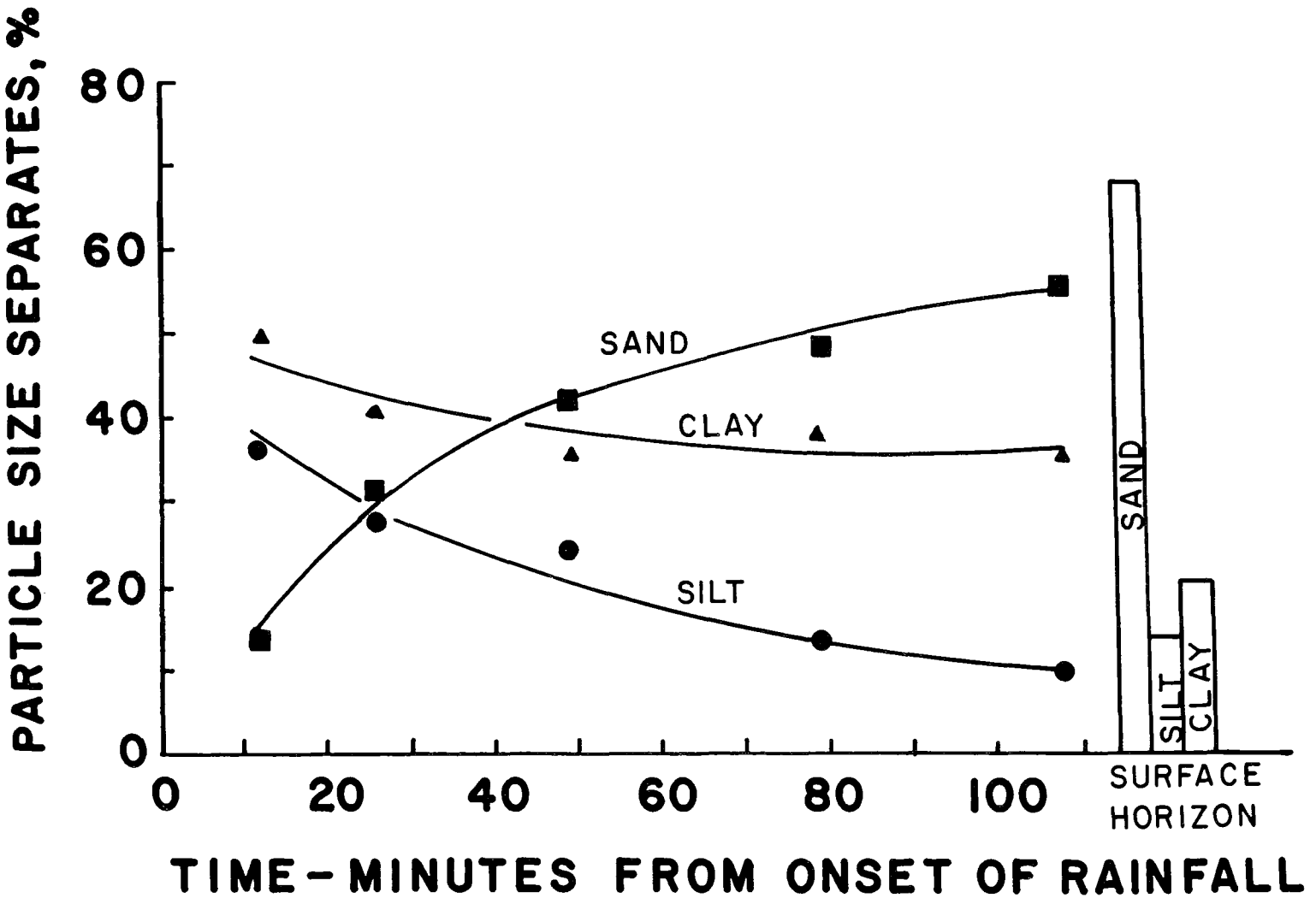


Figure 6. PARTICLE SIZE DISTRIBUTION IN RUNOFF AND SURFACE SOIL OF RED BAY SANDY LOAM (AVERAGE OF 3 SITES).

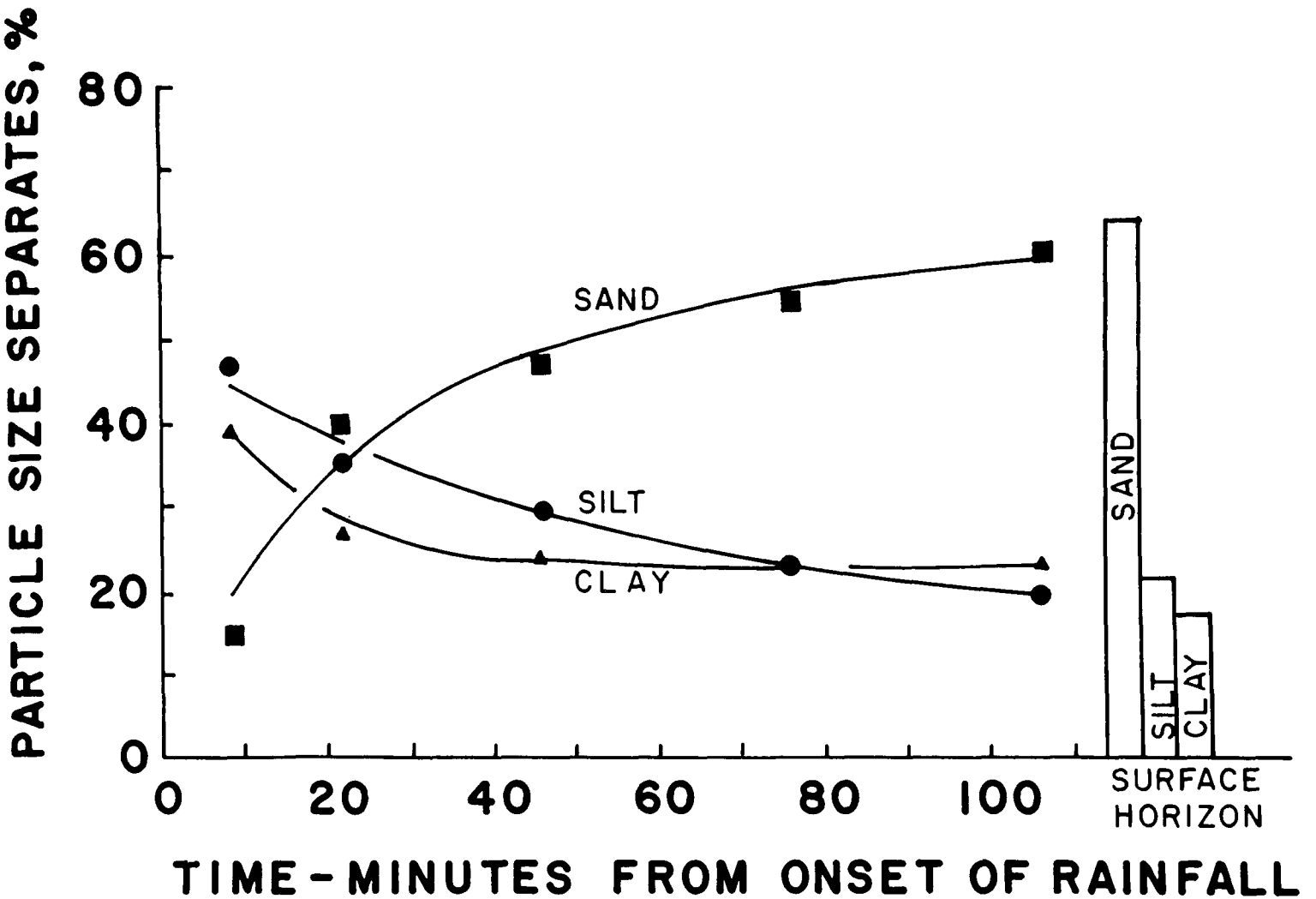


Figure 7. PARTICLE SIZE DISTRIBUITON IN RUNOFF AND SURFACE SOIL OF MALBIS (BOWIE) SANDY LOAM (AVERAGE OF 2 SITES).

The low infiltration rate and corresponding high runoff of the Red Bay soil relative to the Dothan may be due to the presence of a "plow pan" (see glossary) as indicated by soil moisture data (Table 4).

HERBICIDE LOSS

Several factors are discussed below with respect to their effect on herbicide loss from the four sites. Runoff data are presented in several forms: (1) herbicide loss per unit area as a function of time (Figures 8-13), (2) herbicide concentration in runoff and on sediment as a function of time (Tables 5-8), (3) total or percent herbicide lost for each event and runoff phase (Table 2), and (4) cumulative loss, i.e., the fraction of the total event loss that has occurred as a function of time.

Soil Type

The properties of soil that influence runoff and erosion would be expected to influence herbicide loss also. Although direct correlations were difficult to find, several comments may be made with respect to herbicide loss as it relates to soil and water loss data (Table 2).

The amount of dichlobenil lost in the sediment fraction did correlate roughly with the total sediment loss for the four soils and therefore with the soil erodibility factor. Atrazine loss data may be compared with soil loss data only among those soils receiving the same application rate. For each of the two application rates of atrazine, only two soils were tested; therefore atrazine loss/soil loss correlations are somewhat inconclusive, having been based on two points only. Indications are, however, that herbicide loss follows soil loss for atrazine also.

Herbicide losses in runoff, on both an absolute and percent basis, did correlate with water losses for both atrazine and dichlobenil. The deviation noted on the Malbis sandy loam, Site 7, may be caused by a higher organic matter content, which binds the herbicide more tightly

Table 4. MOISTURE CONTENT PROFILE

Soil Depth, cm.	Soil and Site No. Dothan, #2,% Dry[a]	Wet[b]	Red Bay, #5, % Dry	Wet	Malbis, #6, % Dry	Wet	Malbis, #7, % Dry	Wet
0-7.6 (0-3")	6.59	19.5	6.31	17.0	10.8	19.2	9.51	22.4
7.6-15 (3-6")	8.48	18.2	7.27	9.35	13.2	17.0	11.9	15.4
15-23 (6-9")	12.6	15.2	8.27	8.66	15.3	16.6	12.5	12.1
23-30 (9-12")	13.1	15.1	10.3	10.5	17.3	17.6	13.8	13.0

a Moisture content before application of simulated rainfall
b Moisture content after application of simulated rainfall

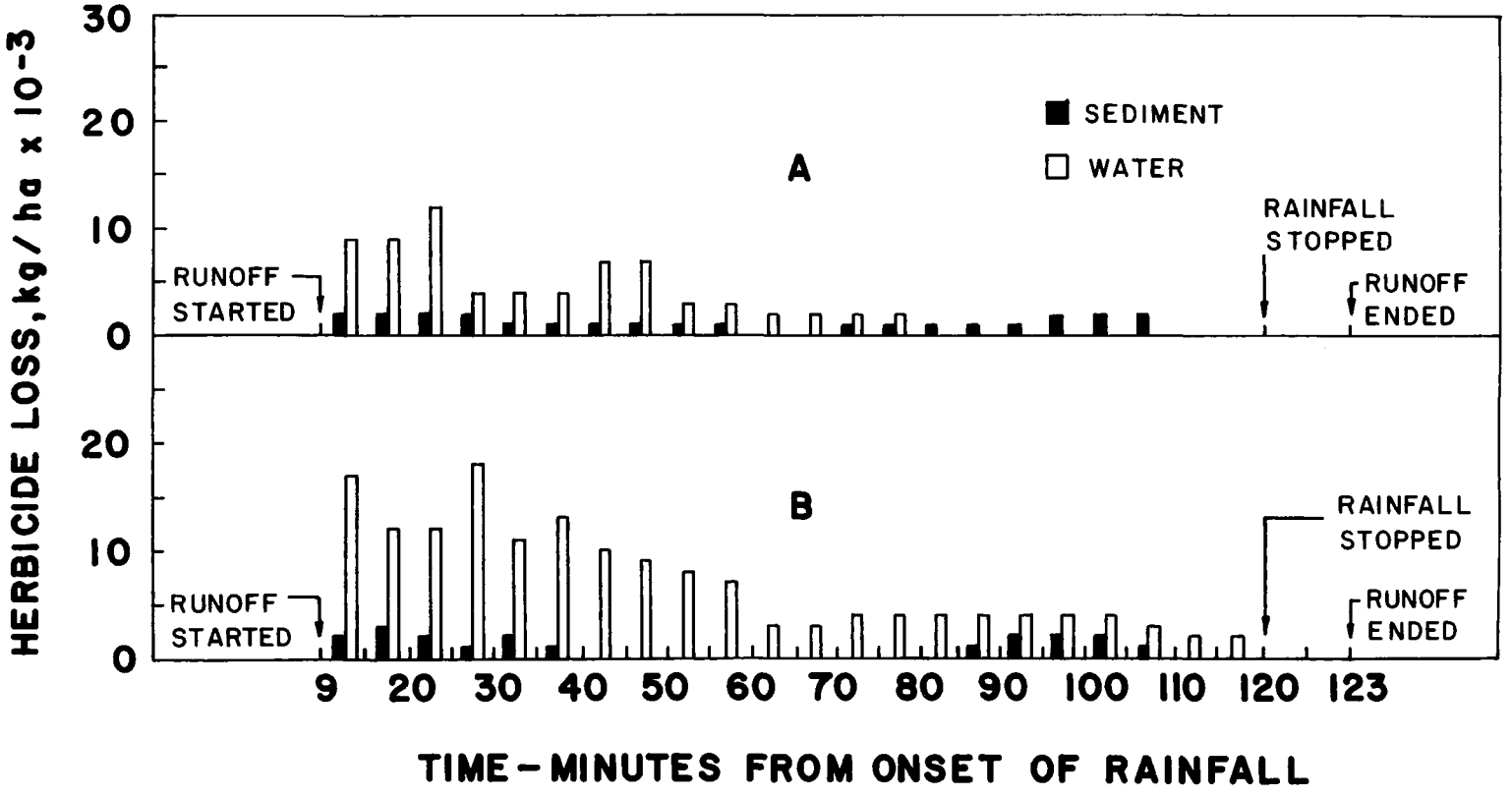


Figure 8. HERBICIDE LOSSES IN RUNOFF AND ON SEDIMENT FROM DOTHAN, SITE 2, (A) ATRAZINE, (B) DICHLOBENIL.

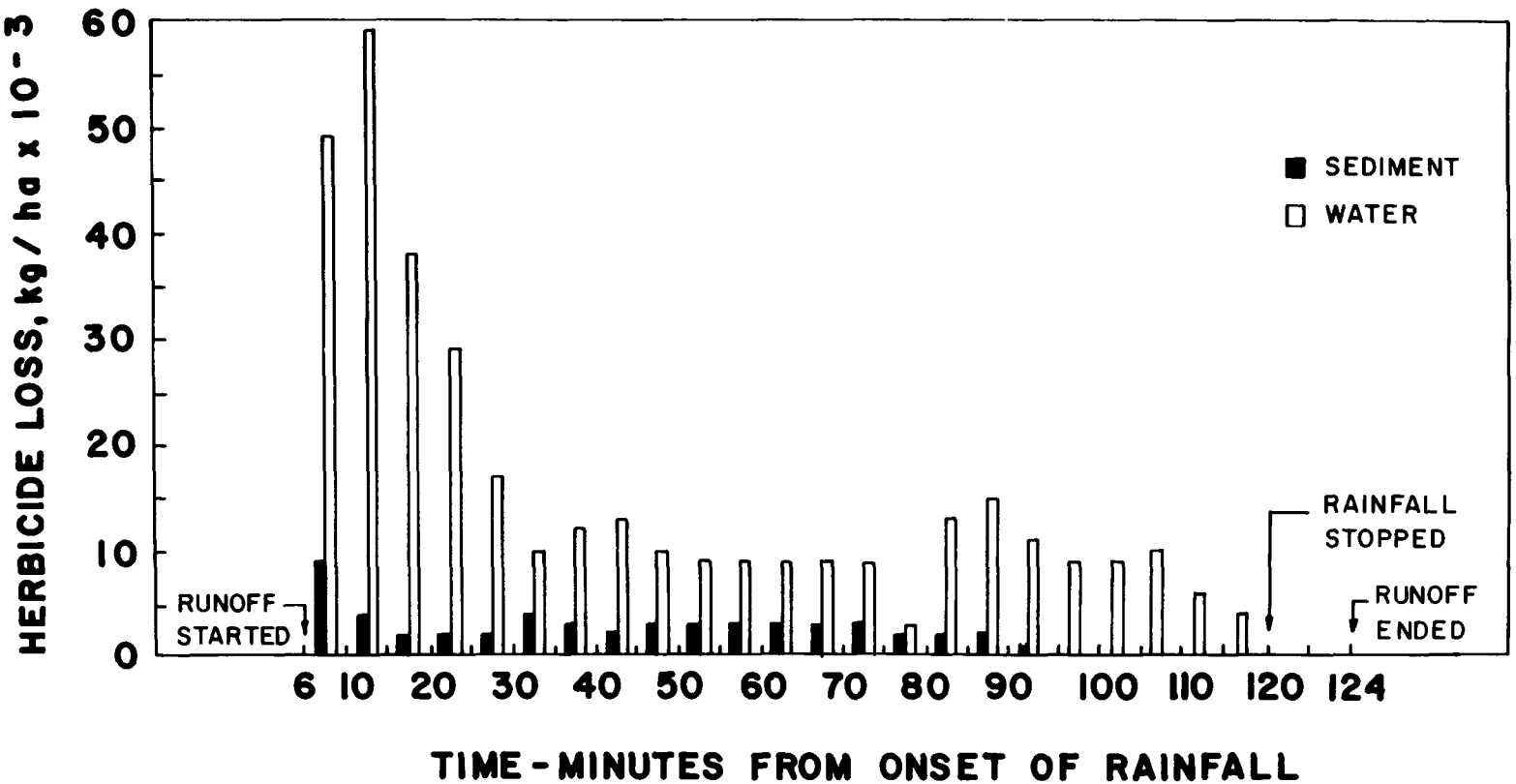


Figure 9. ATRAZINE LOSSES IN RUNOFF AND ON SEDIMENT FROM RED BAY, SITE 5.

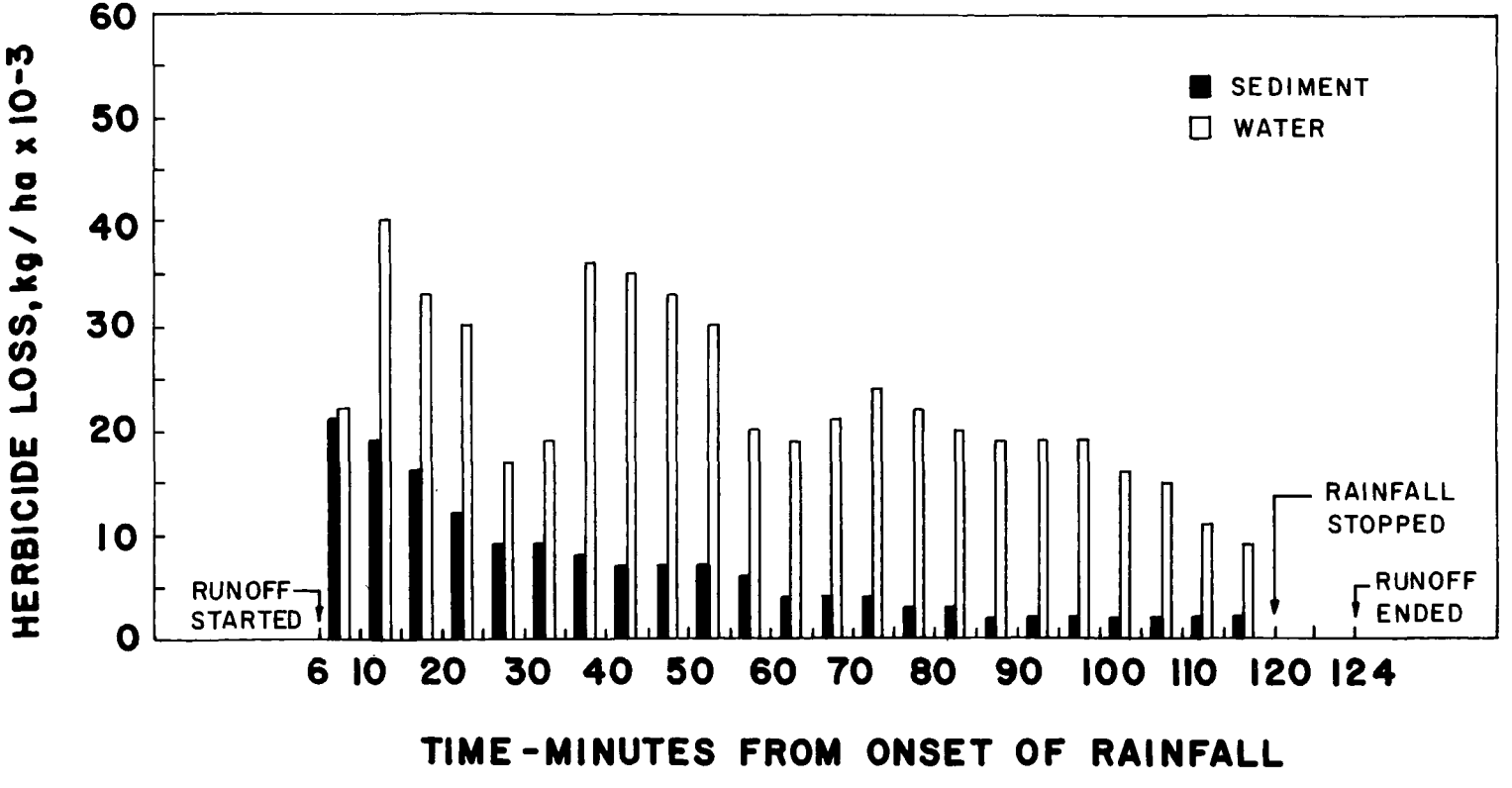


Figure 10. DICHLOBENIL LOSSES IN RUNOFF AND ON SEDIMENT FROM RED BAY, SITE 5.

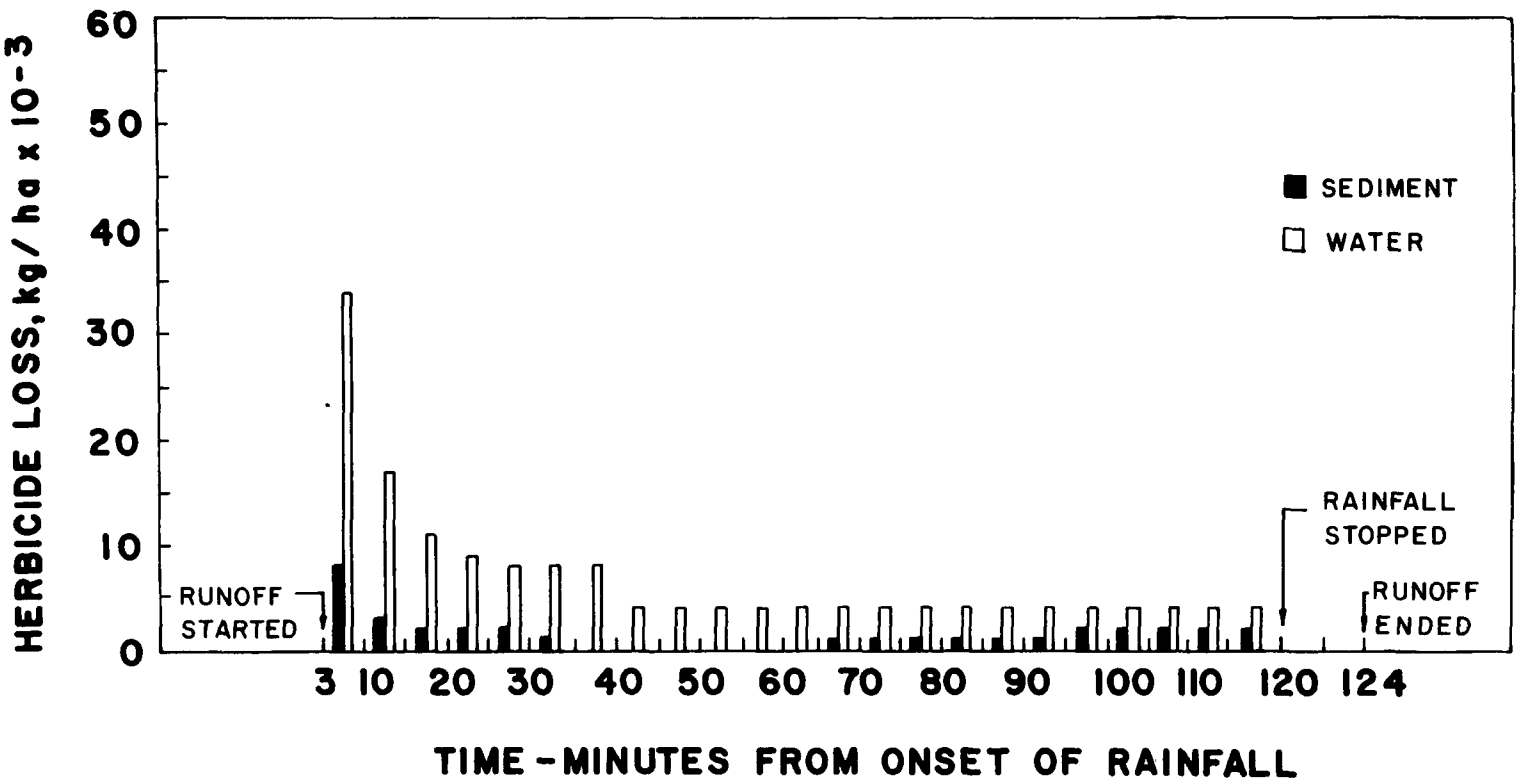


Figure 11. ATRAZINE LOSSES IN RUNOFF AND ON SEDIMENT FROM MALBIS (BOWIE), SITE 6.

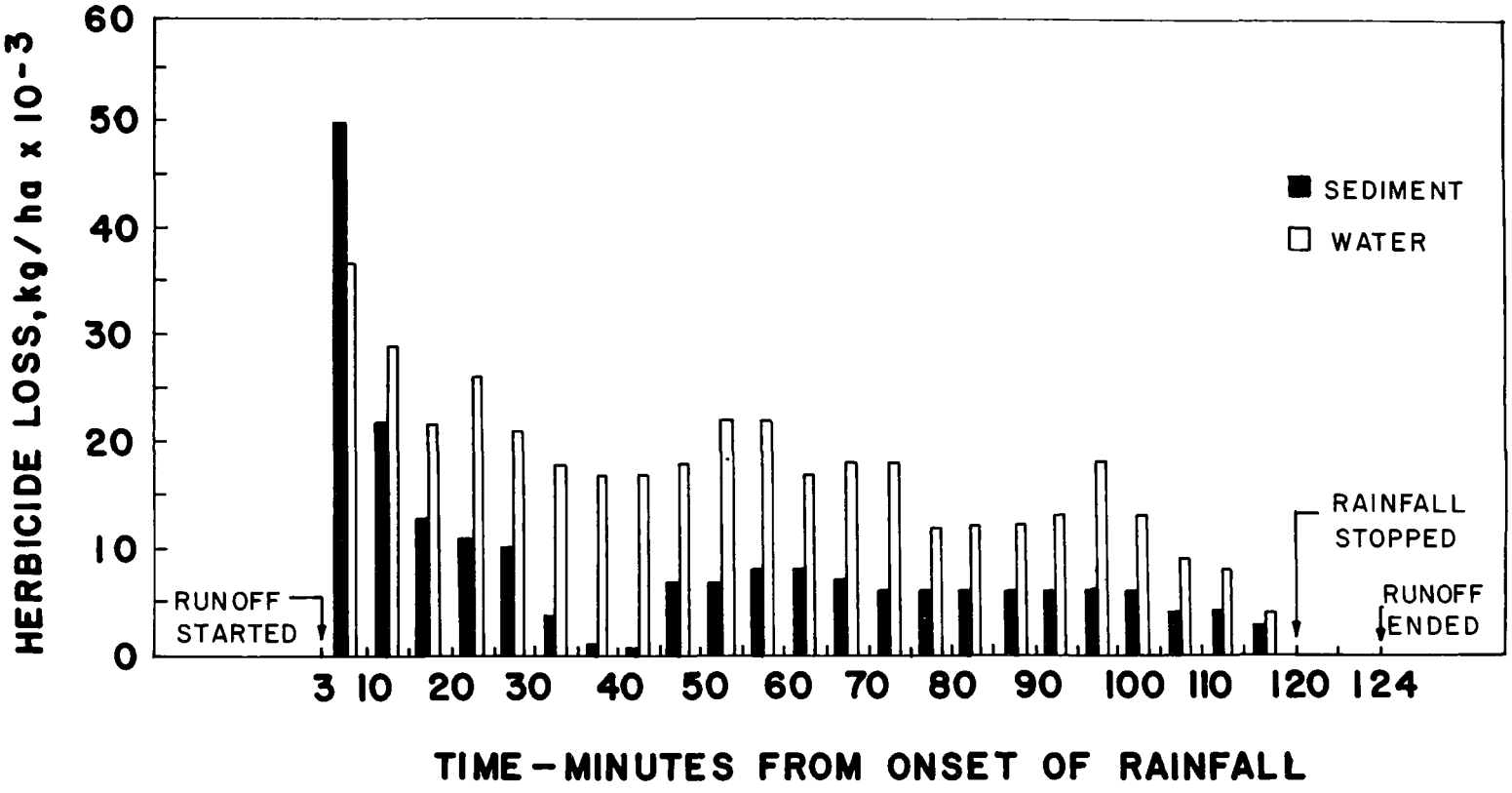


Figure 12. DICHLOBENIL LOSSES IN RUNOFF AND ON SEDIMENT FROM MALBIS (BOWIE), SITE 6

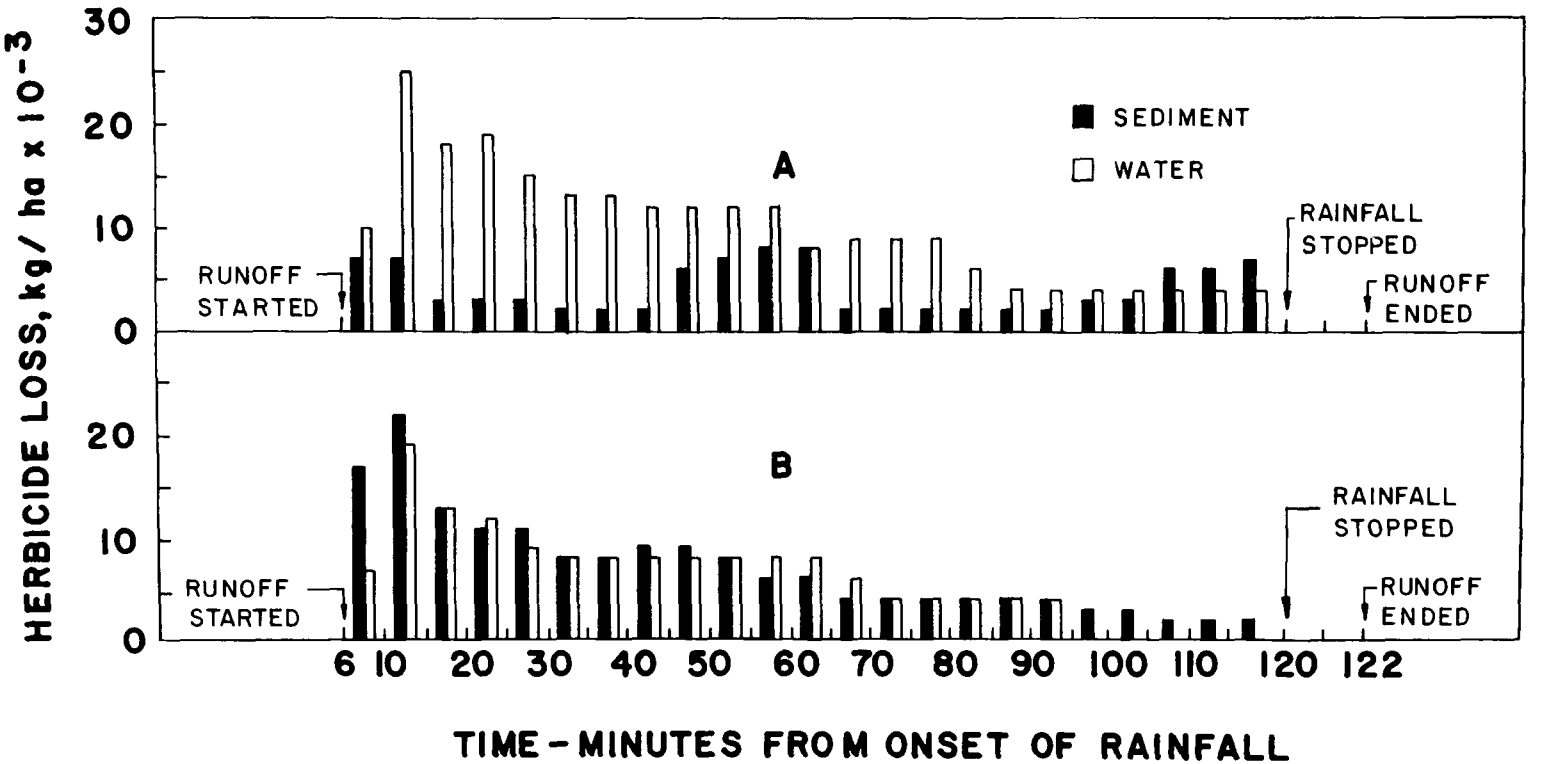


Figure 13. HERBICIDE LOSSES IN RUNOFF AND ON SEDIMENT FROM MALBIS (BOWIE), SITE 7, (A) ATRAZINE, (B) DICHLOBENIL.

Table 5. HERBICIDE CONCENTRATION (ppm) IN RUNOFF WATER AND ON SEDIMENT FROM DOTHAN, SITE 2

Time From Onset of Rainfall, Min	Sediment		Water	
	Atrazine	DCBN	Atrazine	DCBN
9	0.0	0.0	0.00	0.00
15	84.6	75.4	3.30	4.80
20	45.8	56.4	1.60	2.30
25	47.4	59.2	2.10	2.10
30	55.6	34.1	0.70	2.40
35	35.7	47.0	0.60	1.60
40	35.1	23.4	0.70	1.90
45	28.0	5.0	1.00	1.50
50	24.6	5.9	0.80	1.30
55	21.0	6.5	0.50	1.00
60	21.5	5.8	0.45	0.90
65	20.0	4.5	0.25	0.50
70	19.5	6.7	0.20	0.40
75	21.5	15.5	0.25	0.50
80	23.8	18.6	2.30	0.50
85	27.5	19.5	Negative	0.50
90	33.3	28.8	Negative	0.50
95	56.0	73.5	Negative	0.50
100	65.1	85.2	Negative	0.50
105	75.5	70.5	Negative	0.50
110	65.2	44.1	Negative	0.45
115	33.0	3.0	Negative	0.25
120	26.4	2.4	Negative	0.25
123	(Runoff stopped)			

Table 6. HERBICIDE CONCENTRATION (ppm) IN RUNOFF WATER AND ON SEDIMENT FROM RED BAY, SITE 5

Time From Onset of Rainfall, Min	Sediment		Water	
	Atrazine	DCBN	Atrazine	DCBN
7	0.0	0.0	0.0	0.0
10	137.7	308.0	11.1	5.2
15	33.8	160.2	7.8	5.3
20	24.7	136.6	4.6	4.0
25	20.5	116.4	3.4	4.0
30	25.3	95.5	2.1	2.8
35	44.3	97.7	1.2	2.3
40	44.1	90.0	1.5	4.2
45	44.5	83.0	1.5	4.0
50	44.8	83.0	1.1	3.7
55	45.0	83.0	1.0	3.5
60	44.0	70.5	1.0	2.3
65	42.5	68.0	1.0	2.0
70	42.5	68.3	1.0	2.3
75	42.5	68.5	1.0	2.5
80	39.1	58.2	1.0	2.5
85	38.5	50.5	1.4	2.2
90	29.1	39.2	1.5	2.0
95	22.2	38.5	1.2	2.0
100	8.4	39.6	1.0	2.0
105	5.3	37.2	1.0	1.6
110	5.5	29.4	1.0	1.5
115	5.5	27.2	0.5	1.1
120	5.3	29.2	0.5	1.0
123	(Runoff stopped)			

Table 7. HERBICIDE CONCENTRATION (ppm) IN RUNOFF WATER AND ON SEDIMENT FROM MALBIS (BOWIE), SITE 6

Time From Onset of Rainfall, Min	Sediment		Water	
	Atrazine	DCBN	Atrazine	DCBN
5	0.0	0.0	0.0	0.0
10	58.0	389.1	7.9	7.6
15	17.2	113.2	2.0	3.4
20	15.4	86.0	1.4	2.7
25	11.7	62.0	1.0	3.0
30	11.4	56.4	1.0	2.6
35	4.4	26.4	1.0	2.2
40	1.0	8.5	1.0	2.0
45	1.0	9.9	0.5	2.0
50	1.0	41.0	0.5	2.0
55	1.0	46.5	0.5	2.5
60	1.0	58.0	0.5	2.5
65	1.0	55.4	0.5	2.0
70	5.5	55.5	0.5	2.0
75	7.1	57.2	0.5	2.0
80	9.0	57.5	0.5	1.5
85	8.5	56.2	0.5	1.4
90	14.0	49.5	0.5	1.5
95	15.5	48.7	0.5	1.6
100	16.5	48.5	0.5	2.0
105	15.5	49.2	0.5	1.5
110	25.0	48.0	0.5	1.0
115	28.2	47.1	0.5	0.9
120	18.9	34.7	0.5	0.5
124	(Runoff stopped)			

Table 8. HERBICIDE CONCENTRATION (ppm) IN RUNOFF WATER AND ON SEDIMENT FROM MALBIS (BOWIE), SITE 7

Time From Onset of Rainfall, Min	Sediment		Water	
	Atrazine	DCBN	Atrazine	DCBN
6	0.0	0.0	0.00	0.00
10	67.2	164.8	2.40	2.10
15	42.6	146.7	4.00	3.10
20	18.5	82.6	2.60	1.90
25	19.3	75.7	2.50	1.60
30	19.8	79.3	2.00	1.20
35	22.6	67.8	1.80	1.00
40	17.6	62.9	1.50	1.00
45	18.0	67.0	1.50	0.60
50	51.5	74.7	1.50	0.90
55	59.5	71.5	1.50	1.00
60	64.7	43.0	1.50	1.00
65	56.0	40.0	1.00	1.00
70	13.3	26.6	1.00	0.60
75	13.5	27.0	1.00	0.50
80	18.8	35.4	1.00	0.50
85	20.4	37.4	0.60	0.50
90	24.1	37.9	0.50	0.50
95	23.5	36.0	0.50	0.50
100	25.4	26.5	0.50	Negative
105	26.5	26.5	0.50	Negative
110	45.9	23.3	0.50	Negative
115	49.5	22.5	0.50	Negative
120	53.1	21.7	0.50	Negative
122	(Runoff stopped)			

than the inroganic constituents. Less herbicide can be extracted by runoff, resulting in a lower loss.

The lowest total (sediment plus runoff) atrazine and dichlobenil losses occurred on the Dothan soil (Site 2) from which the soil and water losses were lowest.

The presence of the pan layer in the Red Bay soil (Site 5) discussed previously explains why, even though the soil loss was relatively low, the water loss and the herbicide loss were the highest of all soils.

For a given soil type, pesticide runoff could be decreased if (1) infiltration and percolation rates could be increased, and (2) soil detachability, transportability, and antecedent moisture content could be decreased. The latter could be done by increasing the aggregation character of the soil, e.g., by increasing organic matter content. Those conservation practices that decrease the intensity with which rainfall strikes the ground (decreasing detachability) and reduce runoff velocity (decreasing transportability) should decrease herbicide transport in runoff and on eroded soil particles.

Herbicide Type

The physical and chemical properties of the herbicide to a large extent influence its runoff characteristics. The nature of the herbicide determines the mechanism of adsorption, the adsorption-desorption equilibrium and kinetics, the rate of degradation and nature of degradation products, and the rate and extent of vertical movement. The adsorption-desorption properties influence the distribution of the pesticide between runoff water and sediment phases, an important factor from a toxicological standpoint in the aquatic ecosystem.

The proposed mechanism for bonding of the two studied herbicides to soil are different. Depending on the colloid type and its surface acidity, atrazine may be bound through one or more of the following five mechanisms: (1) protonation and subsequent ion exchange (Russel et al., 1968), (2) hydrogen bonding, (3) charge transfer, (4) coordination or

chemisorption, and (5) physical adsorption (Hayes, 1970). Dichlobenil has been shown by spectroscopy to be bound to montmorillonite principally by coordination either to the exchangeable cations or to the various spheres of ion hydration (Payne and Bailey, 1969). Because of the acidic conditions found in the soils under study, atrazine should be bound principally by protonation and subsequent ion exchange and therefore be held more tightly than dichlobenil. As a consequence, a larger fraction of the applied dichlobenil than of atrazine should have appeared in the runoff. However, although a larger absolute amount of dichlobenil was lost on all sites except Site 7 (presumably because of the larger application rate for dichlobenil), a larger fraction of the applied atrazine was lost on all sites (dichlobenil losses range from 2.7 to 9.9%, average--6.6%; atrazine losses range from 6.4 to 13.3%, average--10.7%). The adsorption characteristics, therefore, do not appear to be dominant in determining runoff in the cases studied.

In all cases, rainfall was started 1 hour after application. Possibly the time allowed was insufficient for the herbicides to reach equilibrium with the soils. A large portion of the herbicide in sediment may therefore have been in either the particulate or, in the case of dichlobenil, the vapor form instead of adsorbed on sediment (compare vapor pressures, Table 1). Also, the greater solubility of atrazine (Table 1) would make it more easily extracted by the impacting raindrops and moving water film. Pesticide mass transfer mechanisms have been discussed by Bailey, Swank, and Nicholson (1973).

In addition to pesticide solubility, the particle size distribution and density of the wettable powder also influence the facility of herbicide transport in runoff. Since dissolution rate is roughly inversely proportional to the square of the particle radius, the compound with the larger proportion of finer sized particles dissolves faster and is more available for transport in runoff water. For a given particle size, the ease of transport as a particle in water is proportional to the runoff velocity and inversely proportional to the particle density.

The greater loss of atrazine, on a percentage basis, is therefore attributed to the following combination of factors: (1) higher water solubility, (2) smaller average particle size, and (3) a lower particle density.

Other Factors

Various other factors influence the extent of pesticide loss in runoff and on sediment. Because the present study was a limited one, all such conditions could not be varied independently to draw conclusions or correlations.

Because the concentration of pesticide in the top layer of soil is a crucial factor, the mode of application would affect the availability for runoff. Surface application gives rise to a much higher concentration for a given rate of application than does incorporation.

As one would expect, more atrazine was lost from the sites receiving the greater application rate. However, since the soils were of different types, a direct correlation could not be drawn. For a more accurate measure of the relationship between the application rate and pesticide loss, varying amounts of the compound would have to be applied to the same soil type. In such a study, using simulated rainfall on a Cecil soil, Barnett et al. (1967) found a positive correlation between the concentration of 2, 4-D (2,4-dichlorophenoxyacetic acid) in runoff and the rate of application.

The rainfall intensity was not varied, but would be expected to greatly influence pesticide loss. The 100-year frequency storm simulated in the present study is an unusually intense rainfall, but indicates the magnitude of losses that could be expected. Lower losses would result from storms of shorter duration and lower intensity.

The time lapse between application and rainfall, as indicated previously, also has a significant effect on the pesticide loss. The various attenuation processes, dissolution, and adsorption all alter the availability of pesticide to runoff and erosion as a function of time.

The extent of adsorption is influenced by temperature largely through its effect on solubility and vapor pressure. High temperatures cause decreased adsorption and therefore an increase in the concentration of pesticide available for runoff. Soil temperatures in the present study, from measurements of runoff temperature, were estimated to be 50-60°C, common summer surface temperatures for the area studied.

Although its effect was not evaluated in the present study, the cropping history does significantly influence the magnitude of runoff and erosion. For the same soil and rainfall characteristics, less runoff and erosion occurs from a soil previously planted with a sod crop than from one planted with a row crop. The "memory" of the soil lasts from 2 to 3 years. Herbicide loss may be assumed to be affected in a similar manner.

Time Distribution of Runoff

The herbicide loss, in terms of both concentration and absolute amount, was not distributed evenly throughout the rainfall event. The runoff events were divided into 5-minute periods, and the amount of herbicide lost (summation of sediment and runoff loss) during each period was caluclated as a fraction of the total event loss. The logarithms of the resulting figures, termed "fractional losses," were plotted as a function of time (graphs not included).

For the first 40 minutes after onset of rainfall, the log fractional loss of atrazine decreased as a function of time on all soils. The Red Bay, Site 5, and Malbis, Site 6, had the highest initial loss. After 40 minutes, Sites 5, 6, and 7 exhibited a constant fractional loss as a function of time, within experimental error. The log fractional loss for Site 2 continued to decline until the end of the event. No explanation for this effect could be determined.

The Dothan, Site 2, and Malbis, Site 7, log fractional loss curves for dichlobenil were similar, showing the lowest percent of loss overall.

The higher percentage of sand in the surface horizon of these two soils may have provided better infiltration of water and therefore movement of water-borne dichlobenil into the soil, giving rise to the low loss levels. The greater losses occurring on Sites 5 and 6 may have been due to the greater percent of silt and clay in the surface soil and to a plow pan in Site 5. The resulting lower infiltration rate would give rise to a greater runoff rate. The silt and clay sediment fraction also provided a "piggyback" mode of transport for the herbicides.

The concentration of both compounds in the runoff was highest in the early part of the test storm and decreased with storm duration, stabilizing at a concentration of 0.5 ppm near the end. Barnett et al. (1967) observed the same behavior for 2,4-D in a runoff study using artificial rainfall.

The similarity of the total cumulative herbicide loss curves, Figures 14-17, for both herbicides and all soil types, suggests that the rate of total herbicide loss (i.e., water plus sediment) is independent of soil type, slope, and herbicide type. The rainfall characteristics may determine the rate of total loss. Failure to obtain a straight line for a semi-log plot of cumulative loss data versus time indicates that the herbicide loss is not a simple exponential function.

In cumulative loss plots (Figures 18-23), only 2 curves--dichlobenil on Site 7 and on Site 5, both on sediment fraction--follow a smooth, almost linear rate of increase. Most other curves exhibit a plateau region, a period of relatively low herbicide loss, somewhere in the middle of the event.

The following explanation is offered to explain the plateau formation. From the onset of rainfall, before runoff starts, the water infiltrates the soil forming a saturated front, which moved downward with time. The herbicide, whether surface applied or incorporated, moves downward with the waterfront, moving through and out of the "zone of erodibility," i.e., the layer of soil stripped away by erosion during the storm. The rate of movement of the herbicide through the soil is dependent upon its

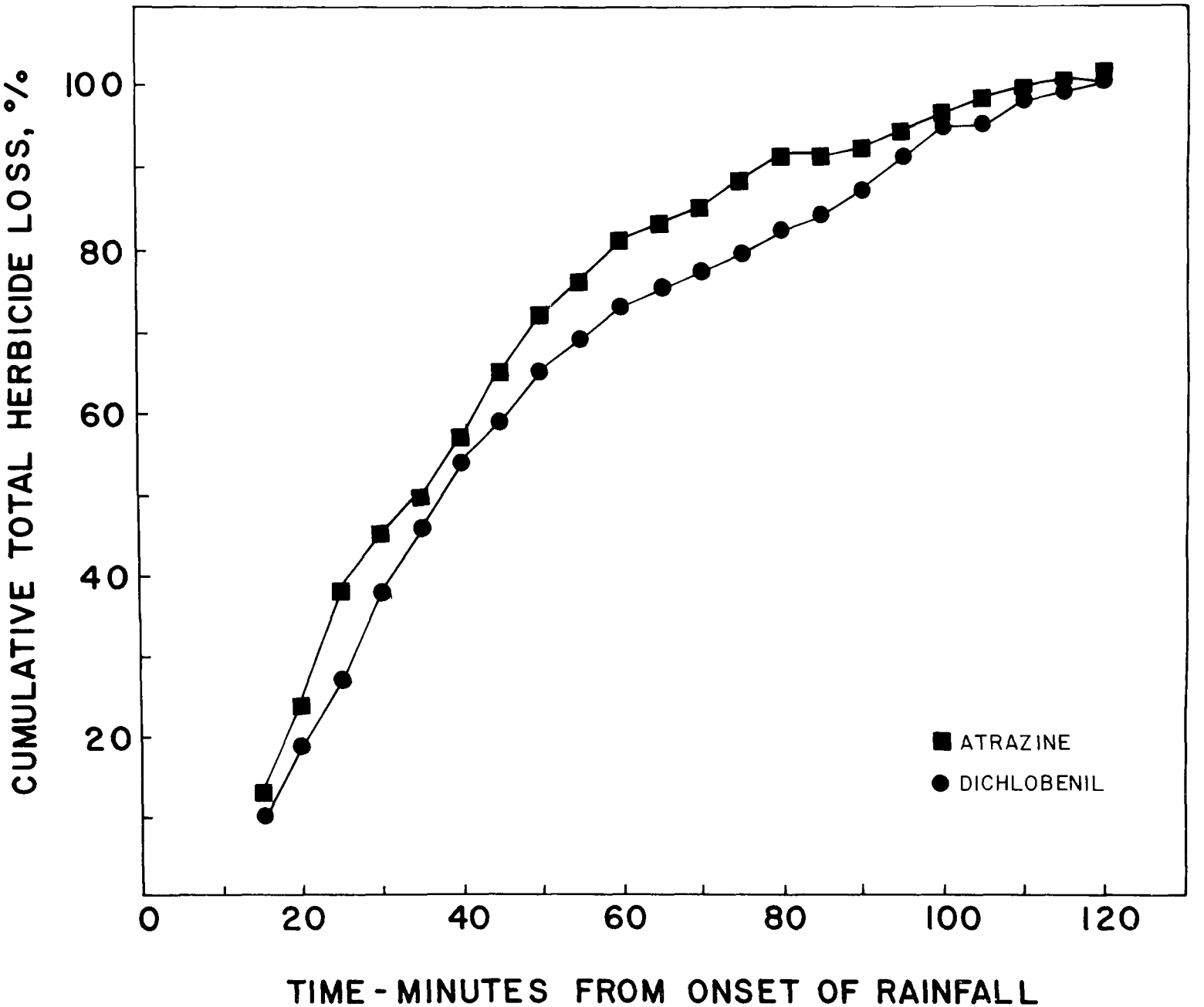


Figure 14. CUMULATIVE TOTAL HERBICIDE LOSS IN RUNOFF AND ON SEDIMENT FROM DOTHAN, SITE 2.

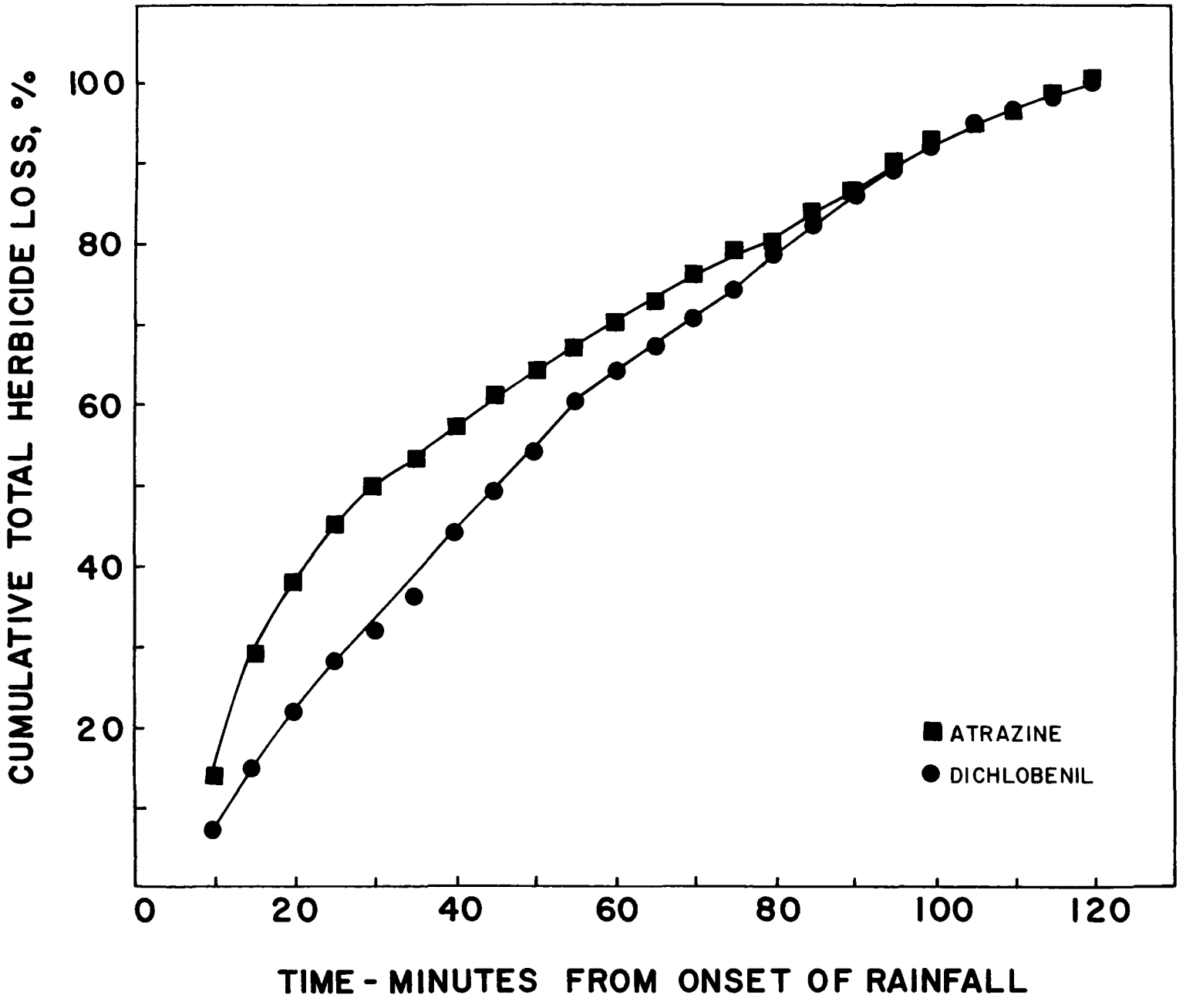


Figure 15. CUMULATIVE TOTAL HERBICIDE LOSS IN RUNOFF AND ON SEDIMENT FROM RED BAY, SITE 5.

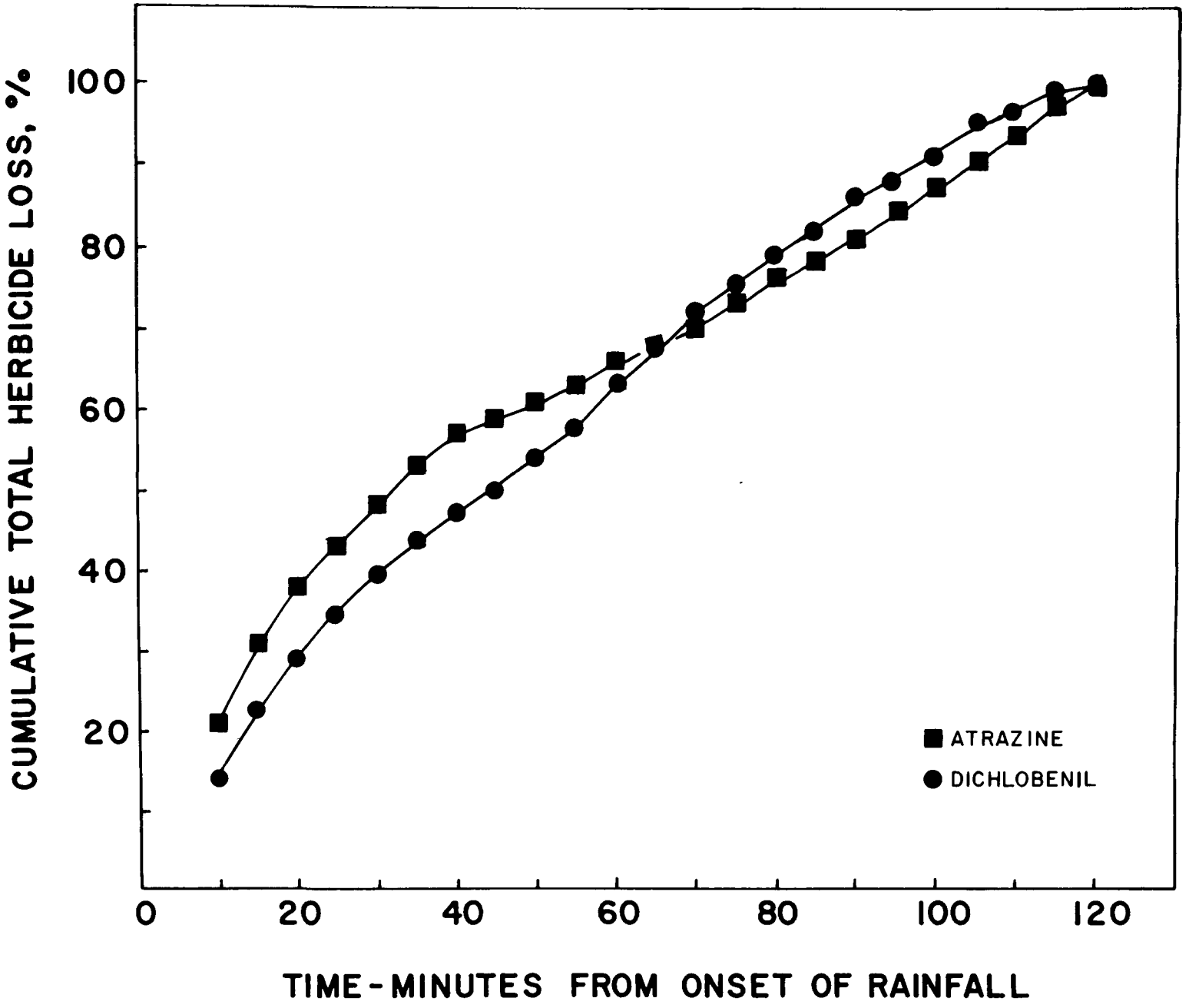


Figure 16. CUMULATIVE TOTAL HERBICIDE LOSS IN RUNOFF AND ON SEDIMENT FROM MALBIS (BOWIE), SITE 6.

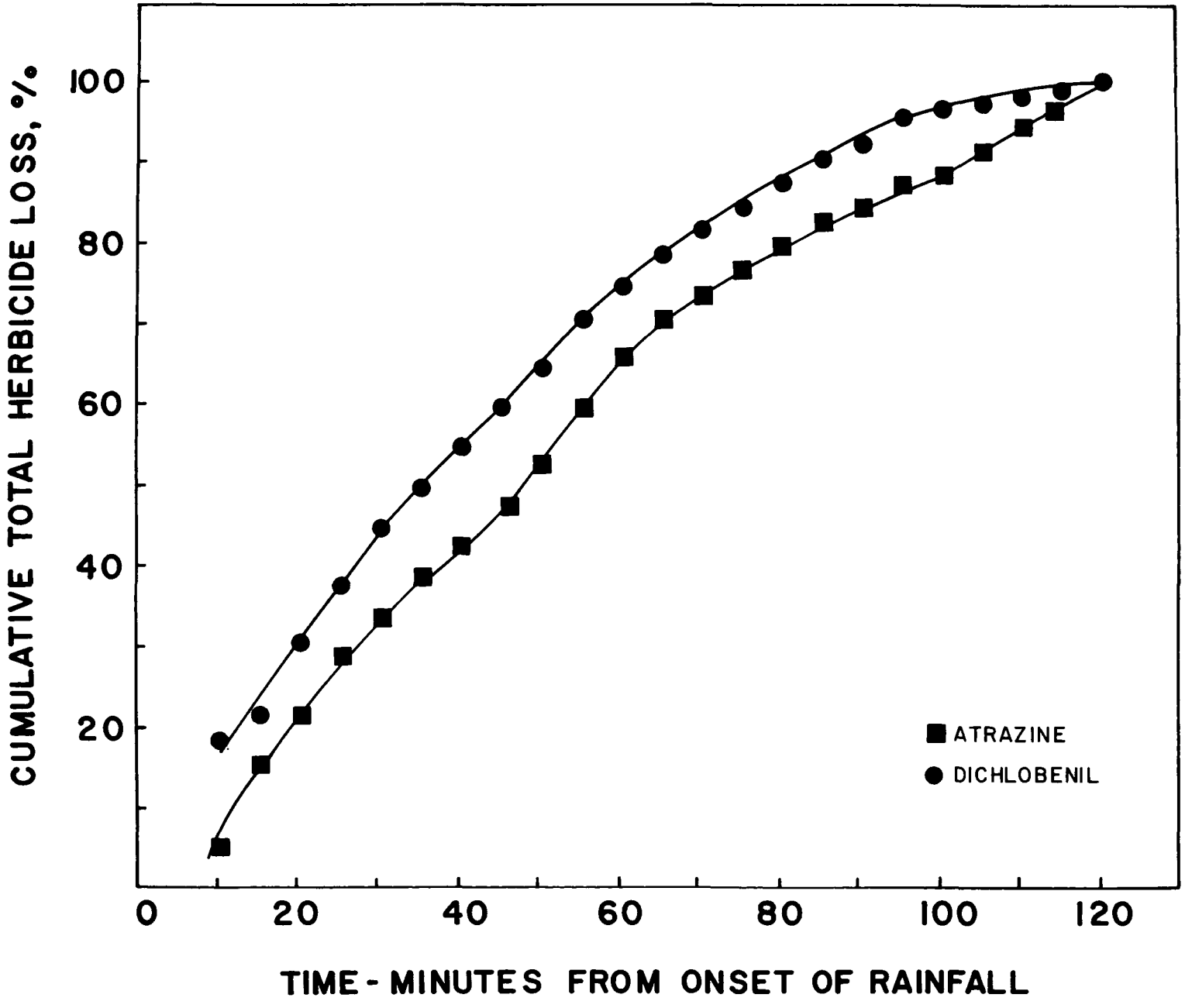


Figure 17. CUMULATIVE TOTAL HERBICIDE LOSS IN RUNOFF AND ON SEDIMENT FROM MALBIS (BOWIE), SITE 7.

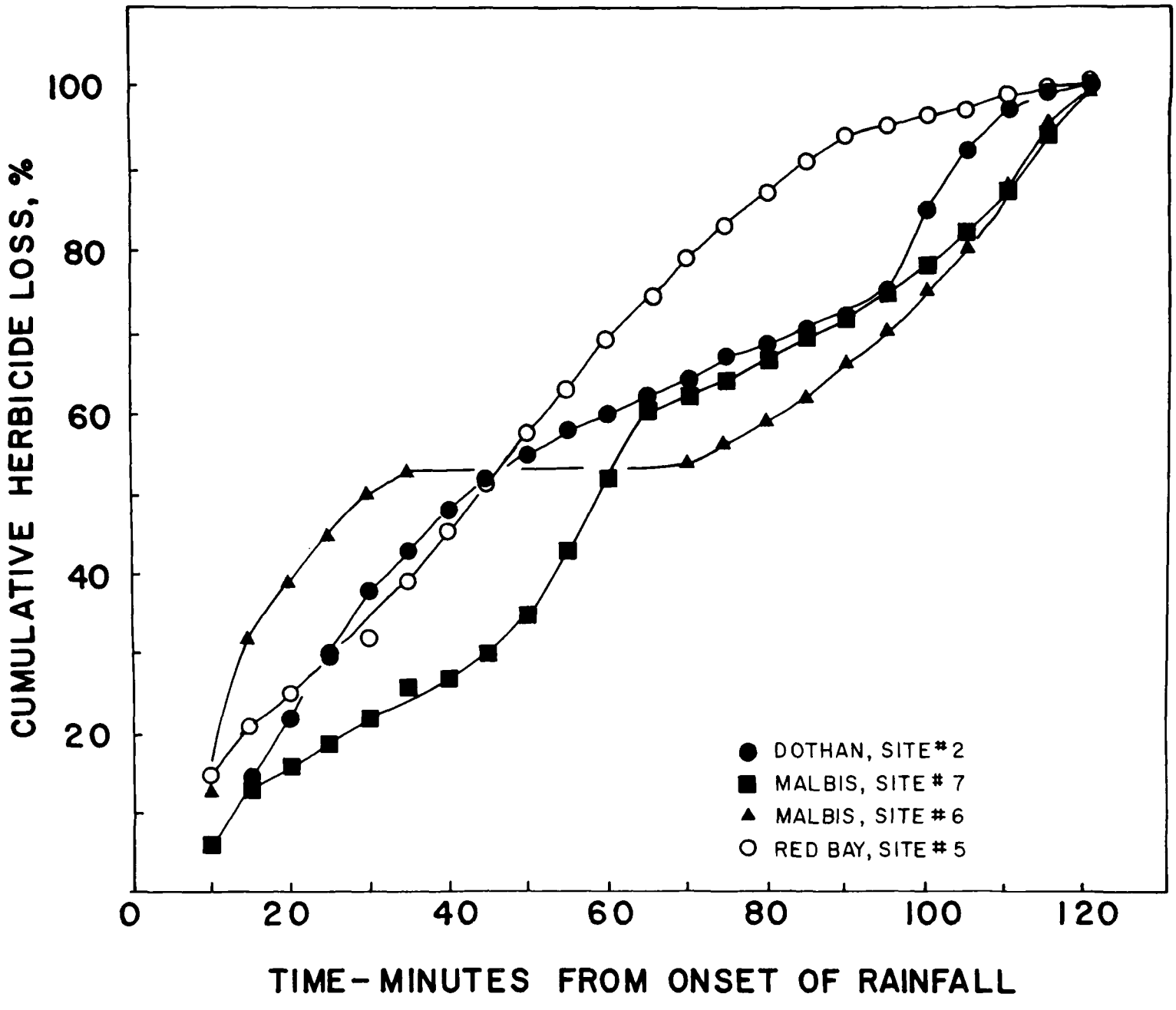


Figure 18. CUMULATIVE LOSS OF ATRAZINE ON SEDIMENT.

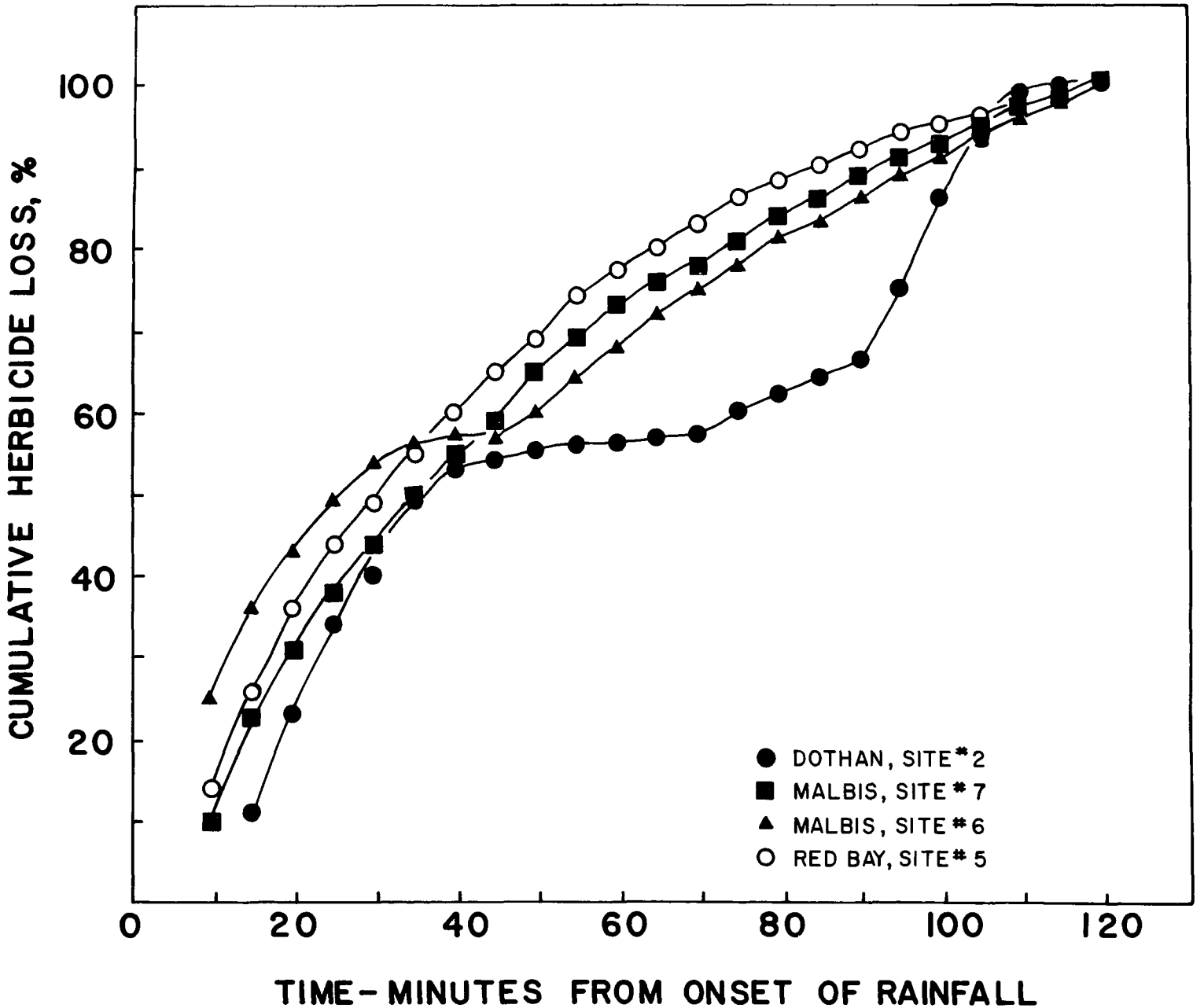


Figure 19. CUMULATIVE LOSS OF DICHLOBENIL ON SEDIMENT.

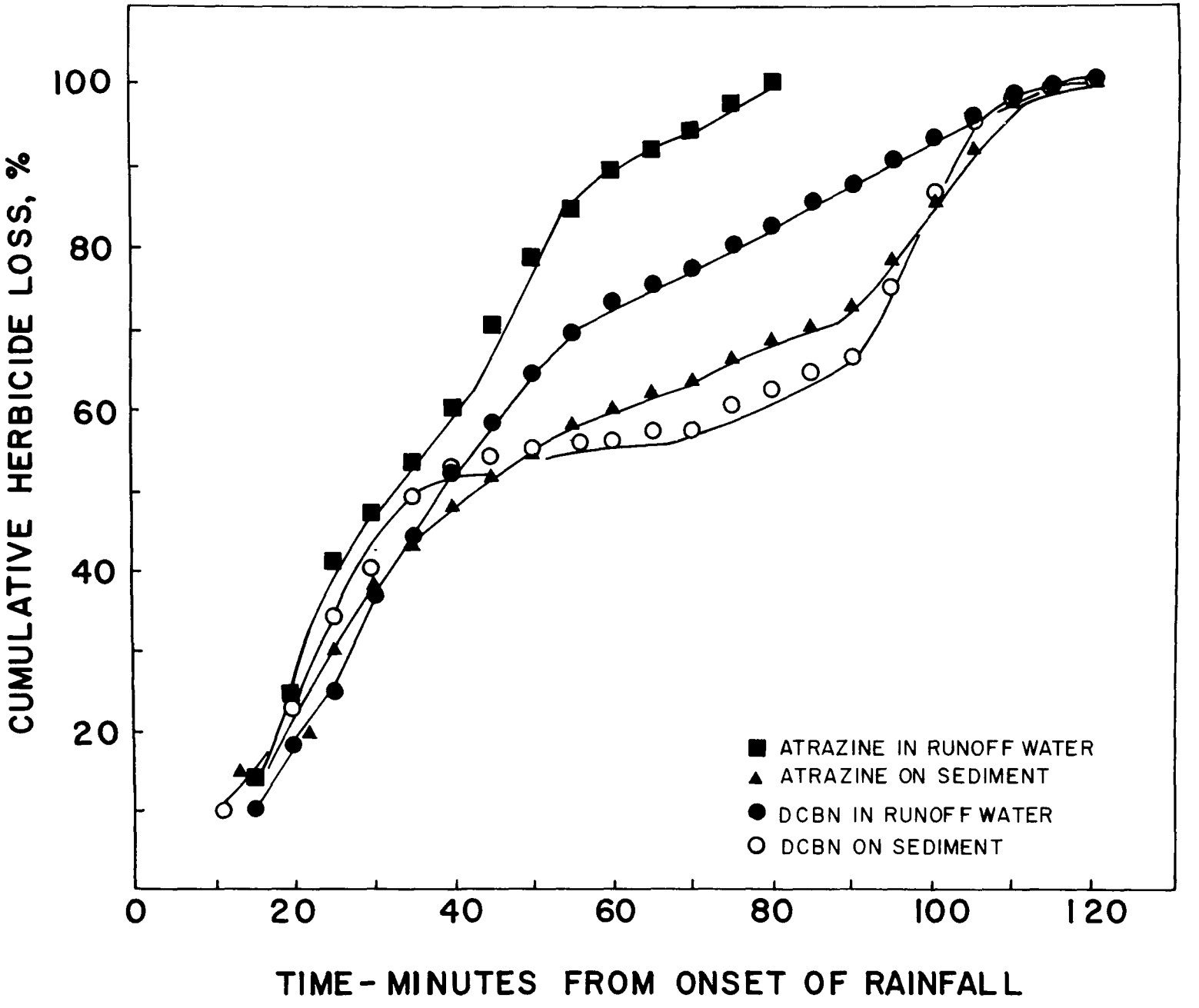


Figure 20. CUMULATIVE HERBICIDE LOSS IN RUNOFF AND ON SEDIMENT FROM DOTHAN, SITE 2.

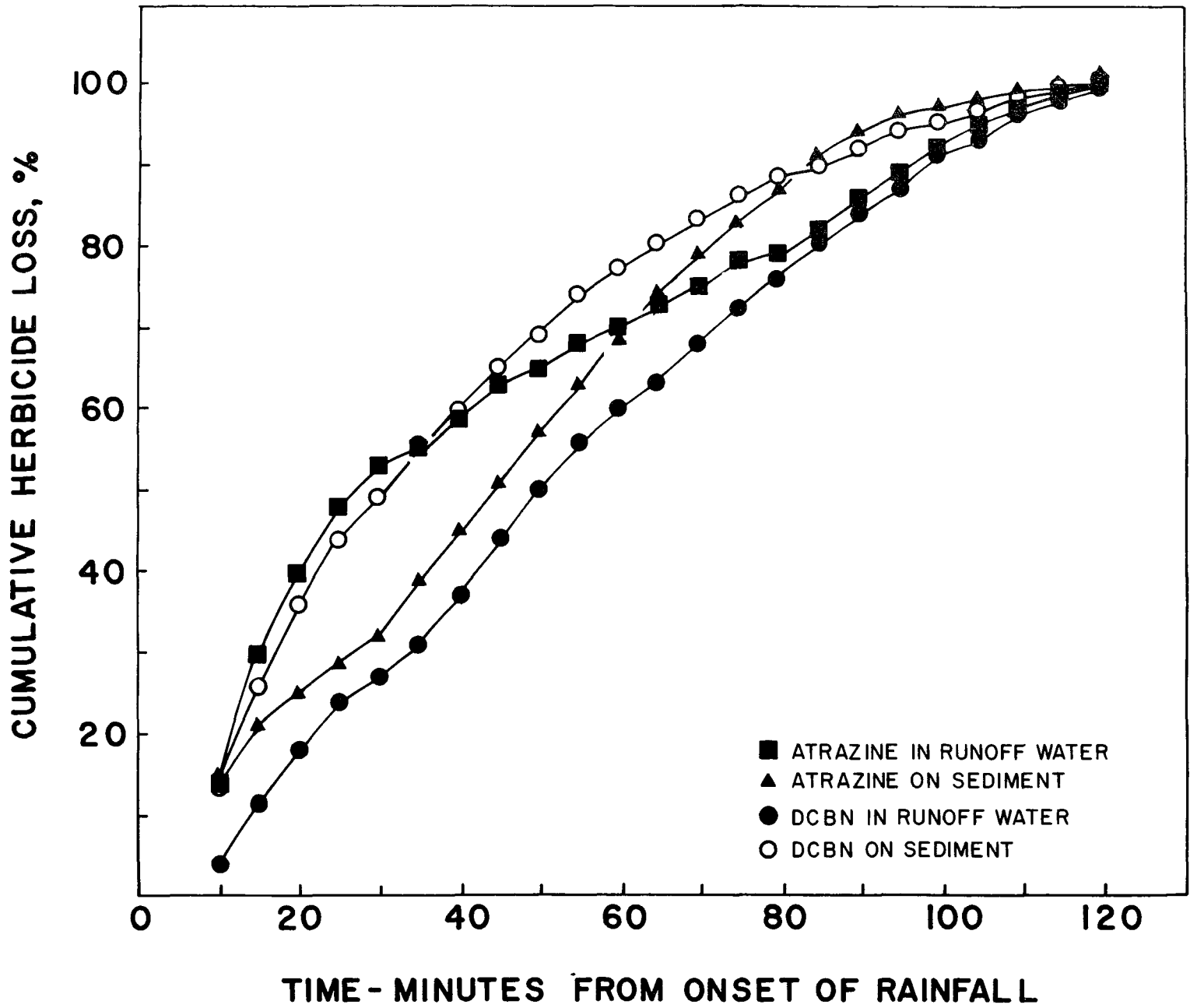


Figure 21. CUMULATIVE HERBICIDE LOSS IN RUNOFF AND ON SEDIMENT FROM RED BAY. SITE 5.

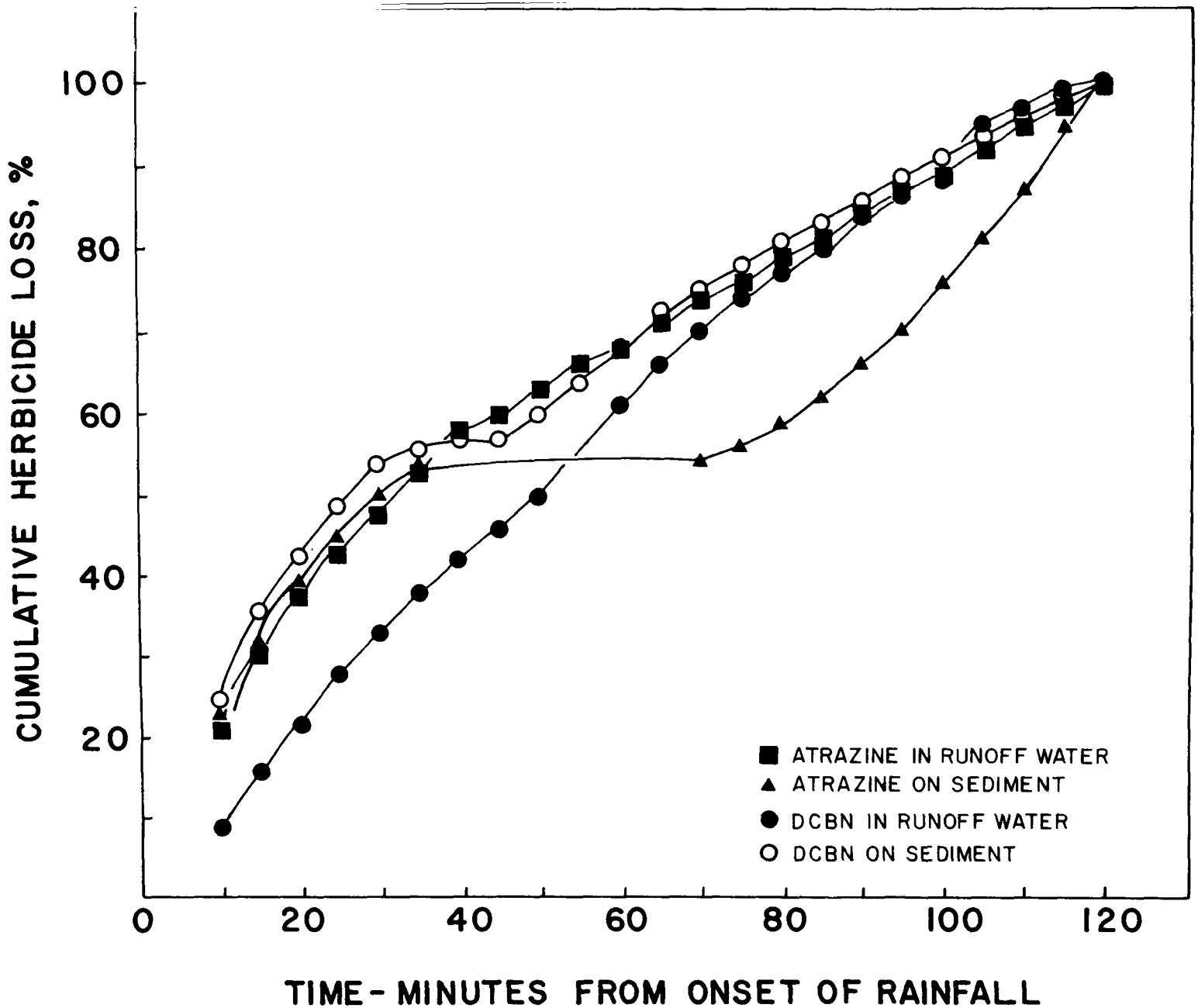


Figure 22. CUMULATIVE HERBICIDE LOSS IN RUNOFF AND ON SEDIMENT FROM MALBIS (BOWIE), SITE 7.

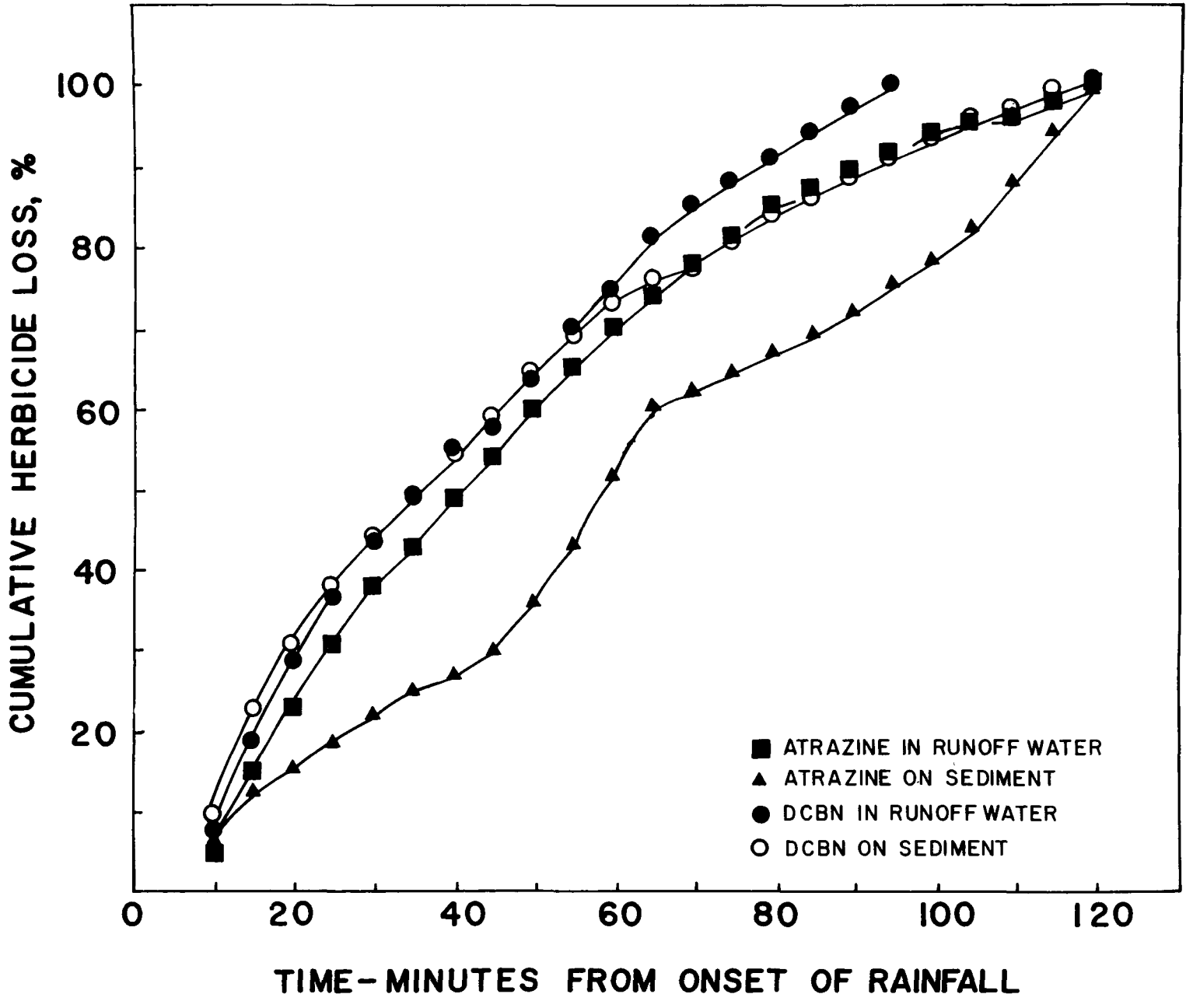


Figure 23. CUMULATIVE HERBICIDE LOSS IN RUNOFF AND ON SEDIMENT FROM MALBIS (BOWIE), SITE 7.

solubility, the adsorption-desorption equilibrium constant, and the rate constants of the adsorption-desorption reaction.

Rainfall throughout the event disperses and transports particulate matter, preferentially the clay and organic fractions, from the zone of erodibility in the runoff water. The rate of herbicide loss is constant, i.e., the cumulative loss curve increases, during that period in which the loss is largely due to the transport of sediment. However, when the leaching action of the infiltrating water depletes the erodibility zone of herbicide, the rate of herbicide loss decreases even though the rate of sediment loss stabilizes. A plateau region in the cumulative loss curve is a result. Herbicide loss in the runoff water during this time is due to upward diffusion from a pesticide-rich zone below the erodibility zone and through the pesticide-free zone into a film of laterally moving water.

The low herbicide loss rate in the sediment fraction continues until the pesticide-free zone is stripped away by erosion, exposing a layer of soil rich in the pesticide. The herbicide loss rate again increases, and the slope of the cumulative loss curve increases. The slope of the plateau region and its position on the curve is determined by the solubility of the herbicide, the extent and rate of adsorption onto and desorption from the sediment, the permeability of the soil, and the rate of infiltration. The plateau appears to be more pronounced, i.e., have a lesser slope, and the overall herbicide loss rate is lower under conditions of high pesticide solubility, high soil permeability, and high rate of infiltration, as indicated by the fraction of applied water appearing as runoff and by the depth of the wetting front (Table 4).

Another factor involved in the plateau phenomenon is the intermittent or wave-action phenomenon of sediment transport, especially of non-suspended and lightly suspended materials. As water begins to move across a sloping soil surface, certain of the soil particles are moved along in the flow. As flow continues, additional soil particles are

added until the kinetic forces involved are in balance. Beyond this point the system becomes overloaded and deposition begins to occur. Then, the relatively clear water or at least unloaded runoff proceeds downslope to begin again the process of entrainment, transport, and deposition. The process is readily observed in the field under natural conditions and also during simulated rainfall tests on fallow soils. Often during an event, sediment deposited at an earlier time in the event is re-entrained and moved downslope.

Since the greatest loss of herbicide coincides with the maximum loss of clay-sized particles, the herbicides evidently attach preferentially to the clay particles. The data do not permit further specification of the size of particles responsible for herbicide transport.

Phase Distribution

For both compounds on all soils, the concentration (ppm) of herbicide was greater in the sediment than in the runoff; however, since much more water ran off than sediment, the greater absolute loss (70-80% of total) was associated with the water fraction (Tables 5-8). Although a high concentration of herbicide in the sediment suggests that the compounds are adsorbed onto the clay and silt particles, the evidence is inconclusive. Since the equilibration time in the soil following application and incorporation was short (less than 1 hour) prior to onset of rainfall, a favorable condition existed for the mass transport of herbicide off the soil surface. A portion of the herbicide in the sediment may therefore have been in the form of wettable powder particles rather than adsorbed onto the eroded soil.

The concentrations of atrazine from Site 2 (after 80 minutes) and of dichlobenil from Site 7 (after 95 minutes) in the runoff were below the detection limit of the analytical method used. The respective sediment fractions, however, showed appreciable herbicide concentration. Apparently the herbicide in these cases was bound very tightly to the sediment.

The particle size distribution of the sediment changed with time during the runoff event and was at all times different from that of the surface soil. The degree of variation in particle size and its variation with time differ from soil to soil. In general, however, the fraction of the sediment represented by clay and silt decreased with time, leveling off at a constant value about 40-50 minutes after the onset of rainfall. The greatest proportion of the total herbicide loss in sediment occurred during this early period (Tables 9-12). The early preferential loss of clay and organic matter may account for the high rate of herbicide loss early in the runoff event. After 60 minutes, the particle size distribution in the sediment stabilized (Figures 5-7). In Sites 2 and 5 the clay content stabilized at a concentration about twice that present in the surface soil.

The percent herbicide loss increased as the total volume of runoff increased. However, more data are required to determine a relationship among the herbicide loss in runoff, the total herbicide loss, and the volume of runoff water.

ENVIRONMENTAL IMPLICATIONS

The runoff of agricultural pesticides presents an environmental hazard through the toxicity of such chemicals to natural aquatic organisms. The LD_{50} (lethal dose for 50% fatality) of dichlobenil ranges from 10 to 20 ppm for pumpkin seed (*Liopmis gibbosus*), bluegill (*L. macroberus*), redear sunfish (*L. microlophus*), and largemouth bass (*Micropterus salmoides*) (Walker, 1964). Vivier and Nesbet (1965) found that exposure of minnows to 0.5 ppm atrazine for 48 hours had no significant effects; concentrations of 5 and 10 ppm, however, were lethal to minnows at 48 and 6 hours, respectively.

The herbicide concentrations measured in the runoff water in the present study were therefore below levels necessary to exert acute toxic effects for the above organisms. However, the concentrations on the sediment were such that the herbicides could produce toxic effects

Table 9. PERCENT CUMULATIVE AND FRACTIONAL LOSS OF HERBICIDES ON DOTHAN, SITE 2

Time From Onset of Rainfall, Min.	Cumulative, %						Fractional Loss in Sediment and Water	
	Atrazine			Dichlobenil				
	Sediment	Water	Total	Sediment	Water	Total	Atrazine	DCBN
9	0	0	0	0	0	0	0	0
15	14	12	13	11	10	10	0.77	0.28
20	22	24	24	23	18	19	0.66	0.23
25	30	41	38	34	25	27	0.87	0.23
30	38	47	45	40	37	38	0.39	0.29
35	43	53	50	49	44	46	0.34	0.20
40	48	60	57	53	52	54	0.38	0.21
45	52	70	65	54	58	59	0.49	0.16
50	55	78	72	55	64	65	0.44	0.14
55	58	84	76	56	69	69	0.26	0.11
60	60	89	81	56	73	73	0.26	0.10
65	62	91	83	57	75	75	0.14	0.06
70	63	94	85	57	77	77	0.14	0.06
75	66	97	88	60	80	79	0.15	0.07
80	68	100	91	62	82	82	0.18	0.07
85	70		91	64	85	84	0.04	0.07
90	72		92	66	87	87	0.05	0.07
95	78		94	75	90	91	0.09	0.10
100	85		96	86	93	95	0.11	0.10
105	92		98	94	95	95	0.13	0.09
110	97		99	99	98	98	0.08	0.08
115	99		100	100	99	99	0.03	0.03
120	100		100	100	100	100	0.02	0.03

123 (Runoff stopped)

Table 10. PERCENT CUMULATIVE AND FRACTIONAL LOSS OF HERBICIDES ON RED BAY, SITE 5

Time From Onset of Rainfall, Min.	Cumulative, %						Fractional Loss in Sediment and Water	
	Atrazine			Dichlobenil				
	Sediment	Water	Total	Sediment	Water	Total	Atrazine	DCBN
6	0	0	0	0	0	0	0	0
10	14	14	14	14	4	7	1.73	0.66
15	21	30	29	26	12	15	1.90	0.89
20	25	40	38	36	18	22	1.20	0.72
25	29	48	45	44	24	28	0.92	0.63
30	32	53	50	49	27	32	0.57	0.38
35	39	55	53	55	31	36	0.41	0.41
40	45	59	57	60	37	43	0.50	0.65
45	51	63	61	65	44	49	0.51	0.63
50	57	65	64	69	50	54	0.40	0.59
55	63	68	67	74	56	60	0.37	0.56
60	69	70	70	77	60	64	0.36	0.38
65	74	73	73	80	63	67	0.37	0.35
70	79	75	76	83	68	71	0.37	0.39
75	83	78	79	86	72	75	0.36	0.41
80	87	79	80	88	76	79	0.18	0.39
85	91	82	84	90	80	82	0.46	0.35
90	94	86	87	92	84	86	0.48	0.32
95	96	89	90	94	87	89	0.38	0.31
100	97	92	93	95	91	92	0.29	0.31
105	98	95	95	96	93	94	0.29	0.26
110	99	97	97	98	96	97	0.29	0.24
115	99	99	99	99	98	98	0.19	0.19
120	100	100	100	100	100	100	0.15	0.17
123 (Runoff stopped)								

Table 11. PERCENT CUMULATIVE AND FRACTIONAL LOSS OF HERBICIDES ON MALBIS (BOWIE), SITE 6

Time From Onset of Rainfall, Min.	Cumulative, %						Fractional Loss in Sediment and Water	
	Atrazine			Dichlobenil				
	Sediment	Water	Total	Sediment	Water	Total	Atrazine	DCBN
3	0	0	0	0	0	0	0	0
10	23	21	21	25	9	14	2.48	1.29
15	32	31	31	36	16	23	1.19	0.76
20	39	38	38	43	22	29	0.84	0.54
25	45	43	43	49	28	35	0.61	0.55
30	50	48	48	54	33	40	0.60	0.46
35	53	53	53	56	38	44	0.51	0.32
40	a	58	57	57	42	47	0.49	0.26
45	a	60	59	57	46	50	0.24	0.26
50	a	63	61	60	50	54	0.26	0.35
55	a	66	63	64	56	58	0.27	0.43
60	a	68	66	68	61	63	0.26	0.45
65	a	71	68	72	66	68	0.26	0.37
70	54	74	70	75	70	72	0.30	0.35
75	56	76	73	78	74	75	0.31	0.35
80	59	79	76	81	77	79	0.31	0.28
85	62	81	78	83	80	82	0.29	0.26
90	66	84	81	86	84	85	0.34	0.27
95	70	87	84	89	87	88	0.35	0.28
100	76	89	87	91	91	91	0.37	0.34
105	81	92	90	94	95	95	0.36	0.28
110	87	95	93	96	97	97	0.40	0.20
115	95	97	97	98	99	99	0.41	0.18
120	100	100	100	100	100	100	0.37	0.11
124 (Runoff stopped)								

a GC results are questionable due to interfering background material.

Table 12. PERCENT CUMULATIVE AND FRACTIONAL LOSS OF HERBICIDES ON MALBIS (BOWIE), SITE 7

Time From Onset of Rainfall, Min.	Cumulative, %						Fractional Loss in Sediment and Water	
	Atrazine			Dichlobenil				
	Sediment	Water	Total	Sediment	Water	Total	Atrazine	DCBN
6	0	0	0	0	0	0	0	0
10	6	5	5	10	5	8	0.50	0.36
15	13	15	15	23	19	21	0.92	0.62
20	16	23	21	31	29	30	0.61	0.40
25	19	31	28	38	37	37	0.65	0.35
30	22	38	33	44	44	44	0.53	0.30
35	25	43	38	49	49	49	0.48	0.23
40	27	49	42	54	55	54	0.43	0.25
45	30	54	47	59	58	59	0.43	0.21
50	36	60	52	65	64	64	0.55	0.24
55	43	65	59	69	70	70	0.58	0.25
60	52	70	65	73	75	74	0.61	0.20
65	60	74	70	76	81	78	0.46	0.20
70	62	78	73	78	85	81	0.32	0.14
75	64	81	76	81	88	84	0.31	0.13
80	67	85	79	84	91	87	0.33	0.13
85	69	87	82	86	94	90	0.23	0.13
90	72	89	84	89	97	92	0.20	0.12
95	75	91	86	91	100	95	0.20	0.12
100	78	93	88	93		96	0.22	0.05
105	82	94	91	95		97	0.23	0.05
110	88	96	94	97		98	0.29	0.04
115	94	98	97	99		99	0.30	0.04
120	100	100	100	100		100	0.31	0.04
122 (Runoff stopped)								

depending upon the following conditions: (1) the mode of uptake of the organism, (2) the bioactive threshold of the organism for the pesticide, (3) the rate with which the pesticide desorbs from the sediment surface, (4) the equilibrium distribution of the pesticide between the water and sediment, and (5) the site of adsorption (internal or external portion of the particle).

Although the major impact of herbicides in washoff from agricultural lands is the long-term chronic or sub-lethal effect on the aquatic ecosystem, the chemicals also affect other segments of the environment through the many uses of water.

Factors determining the environmental impact of pesticides in agricultural runoff are (1) the toxicity of the pesticide and its degradation products and metabolites; (2) the pesticide application rate and the extent of usage; (3) the runoff characteristics; and (4) the persistence, accumulation, and magnification in the aquatic ecosystem.

FIELD PROCEDURE EVALUATION

The rainulator provides an efficient means of studying pesticide runoff and soil erosion from agricultural land under conditions of high intensity. It may be transported easily by truck from site to site together with a 5,000-gallon tanker as a water supply. All variables of storm and soil conditions, including the time between pesticide application and the onset of the storm, can be controlled. Information that would take years to gather using only natural rainfall may be obtained in a relatively short period of time.

A field laboratory set up in a large shed proved sufficient for sample separation, extraction, and concentration. An air-conditioned facility, however, was required to house the gas chromatograph. A small trailer was provided for this purpose. Prior to any field study, the power requirements (especially voltage stability), ventilation, lighting, and work space should be thoroughly examined.

Analyses of samples at the field site closely correlated with those of samples sent to the home laboratory (SERL), demonstrating the feasibility of gas chromatographic analysis on site.

FUTURE NEEDS

A pesticide runoff mathematical model is vitally needed and must be formulated and used as a management tool to predict pesticide losses in runoff and on eroded soil. The basic variable in such a model would be (1) climatic factors, e.g., rainfall intensity, amount, frequency, and distribution, (2) soil properties, (3) physicochemical properties and formulation of the pesticide, (4) kinetics of the processes responsible for pesticide attenuation in the soil, (5) hydrologic and sediment transport submodels, and (6) watershed characteristics.

Using information from the model, the Pesticide Registration Branch will be able to determine the suitability of a given pesticide, as formulated, region by region. If adverse runoff behavior is predicted from a given formulation, registration could be denied until a suitable formulation is devised. This approach will permit selective registration of a pesticide for a given geographical region. Currently a pesticide proven to be environmentally detrimental in one region is denied registration throughout the country. Recommendation and clearance for selective pesticide use on small acreages would be possible with the availability of a viable pesticide runoff mathematical model.

SECTION VI

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SECTION VII

GLOSSARY

Control Site--herbicide treated plot without simulated (artificial) rainfall.

Erodibility Zone--portion of surface horizon, the thickness of which is measured from the surface downward, that will be eroded awary during a rainfall event.

Pesticide-Free Zone--the soil surface or an incremental layer between the soil surface and the pesticide-rich zone through which the downward moving pesticide has passed.

Pesticide-Rich Zone--the soil surface or incremental layer at some finite distance downward from the soil surface where all or the remaining amount of the applied pesticide resides.

Plow Pan--a compacted layer of soil semi-permeable to percolating water, resulting from repeated use of conventional agricultural equipment.

Runoff--water that moves over the soil surface.

Sediment--soil lost by the erosional process.

Soil Loss--synonomous with the term sediment.

Washoff--collective movement of water, sediment, and pesticide from the surface of agricultural soils.

Water Loss--synonomous with runoff.

SECTION VIII

APPENDICES

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A.	Photographs Showing Operation of the Rainfall Simulator	67
B.	Soil Classification descriptions	76
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Appendix A

Photographs Showing Operation of the Rainfall Simulator

Figure 1. General view of rainfall simulator during a soil erodibility-pesticide transport test on Dothan sandy loam soil.

Figure 2. A data collection center; instantaneous samples of runoff water and sediment are collected for analysis of soil and pesticide content.

Figure 3. Precision application of pesticides on a test plot after plowing (several weeks earlier), rotatilling, leveling, and smoothing by hand.

Figure 4. After raking by hand to stir pesticide into surface a section of a spike tooth drag harrow is pulled up slope to provide the final finished surface configuration.

Figure 5. Site 2 after 30 minutes of rain (3.2 cm), looking downslope. Runoff began in 9 minutes.

Figure 6. Site 2 after 60 minutes of rain (6.4 cm), looking downslope.

Figure 7. Site 2 after 90 minutes of rain (9.5 cm), looking downslope.

Figure 8. Site 2. Rainfall ending after 120 minutes (12.5 cm of rainfall); note smooth plot surface.

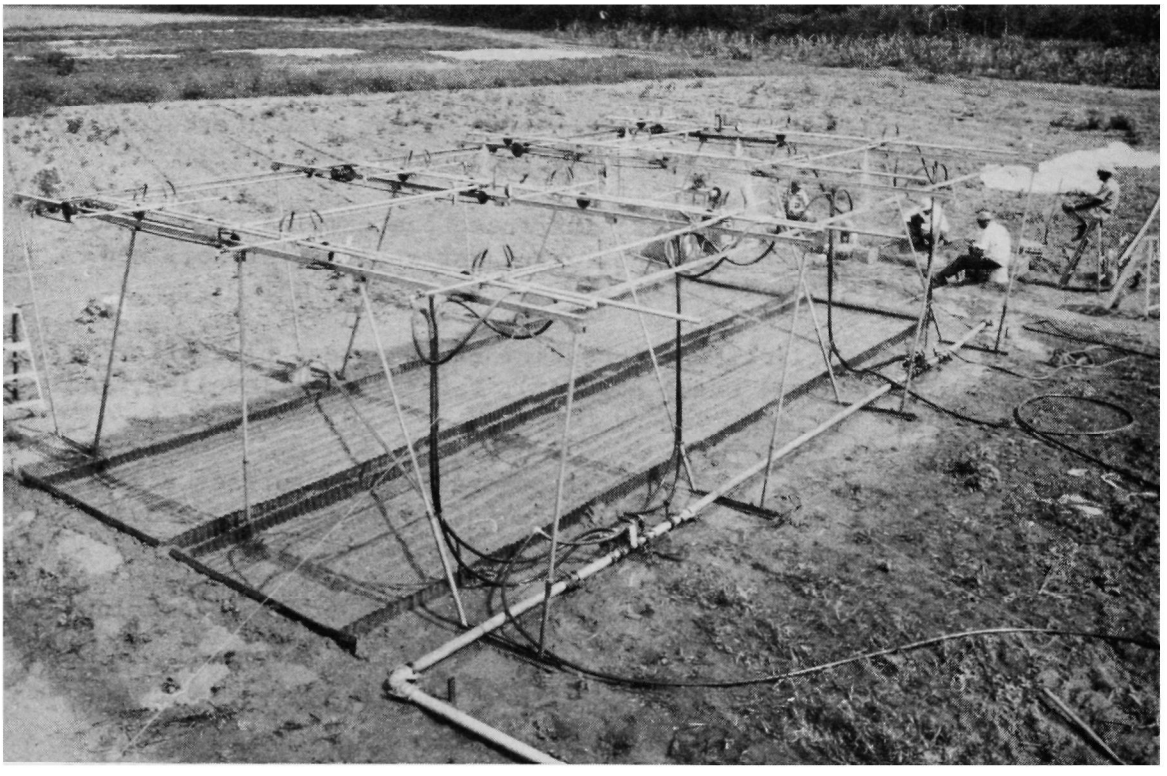

Figure 1. GENERAL VIEW OF RAINFALL SIMULATOR DURING A SOIL ERODIBILITY-PESTICIDE TRANSPORT TEST ON DOTHAN SANDY LOAM SOIL.

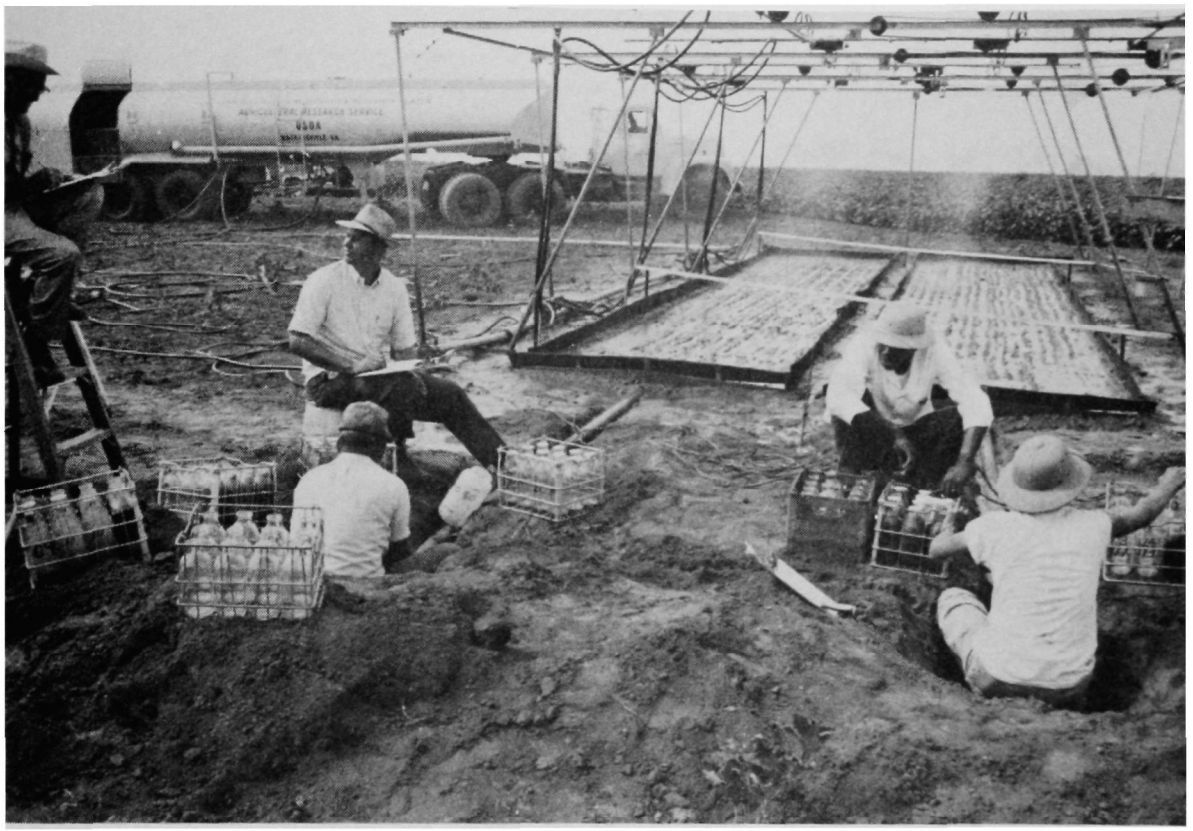

Figure 2. A DATA COLLECTION CENTER: INSTANTANEOUS SAMPLES OF RUNOFF WATER AND SEDIMENT ARE COLLECTED FOR ANALYSIS OF SOIL AND PESTICIDE CONTENT.

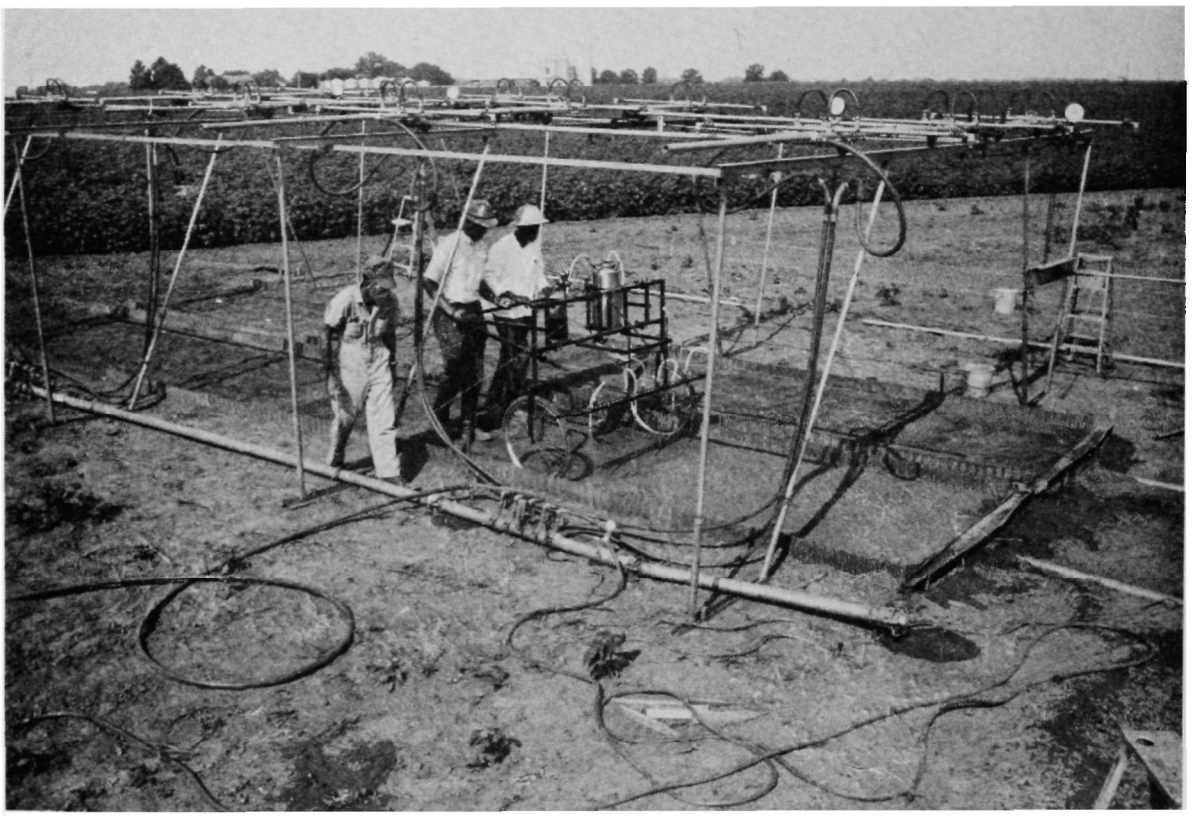

Figure 3. PRECISION APPLICATION OF PESTICIDES ON A TEST PLOT AFTER PLOWING (SEVERAL WEEKS EARLIER), ROTATILLING, LEVELING, AND SMOOTHING BY HAND.

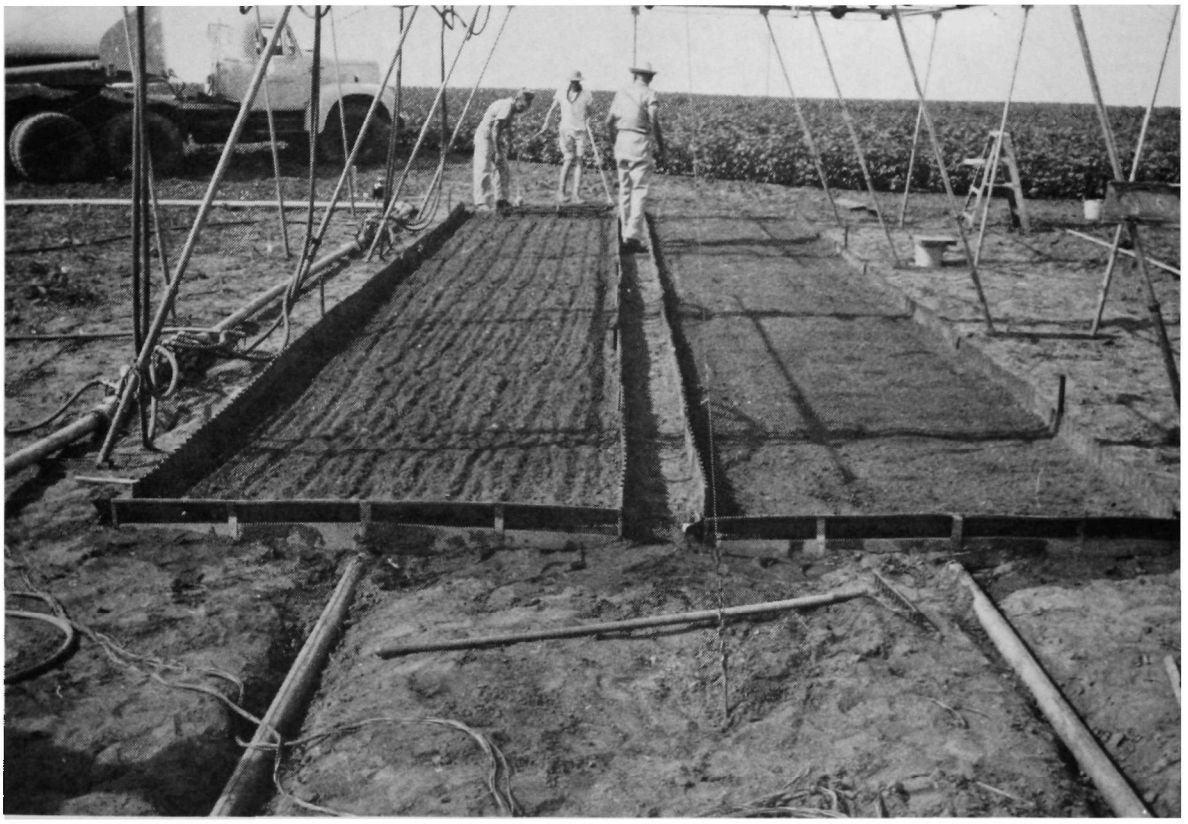

Figure 4. AFTER RAKING BY HAND TO STIR PESTICIDE INTO SURFACE A SECTION OF A SPIKE TOOTH DRAG HARROW IS PULLED UP SLOPE TO PROVIDE THE FINAL FINISHED SURFACE CONFIGURATION.

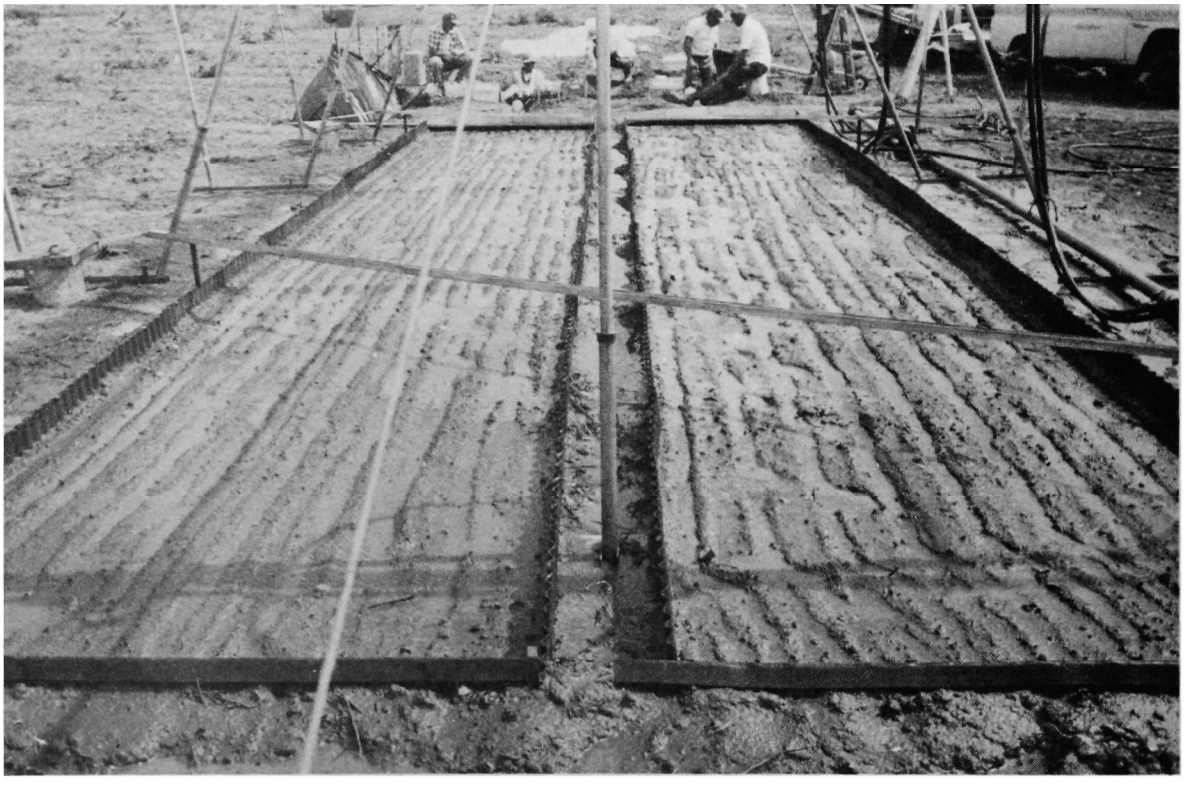

Figure 5. SITE 2 AFTER 30 MINUTES OF RAIN (3.2 cm), LOOKING DOWNSLOPE. RUNOFF BEGAN IN 9 MINUTES.

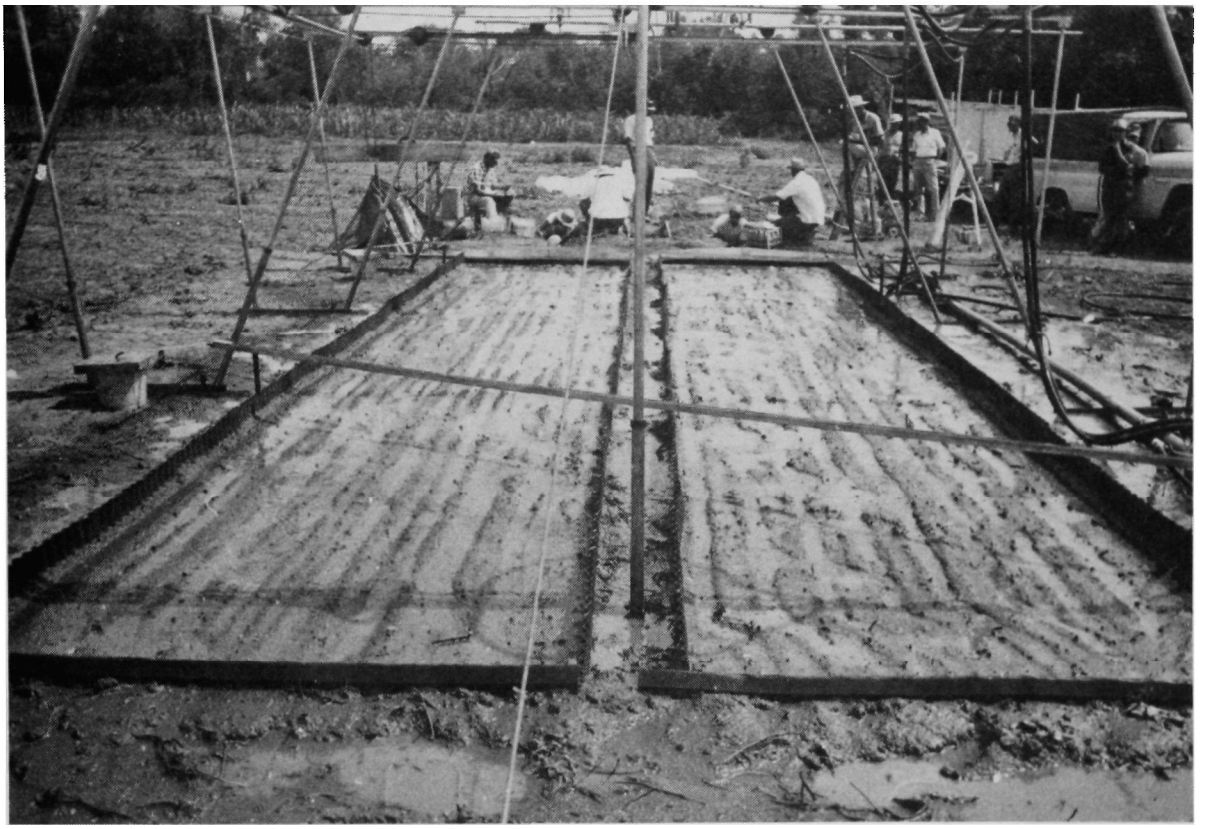

Figure 6. SITE 2 AFTER 60 MINUTES OF RAIN (6.4 cm), LOOKING DOWNSLOPE.

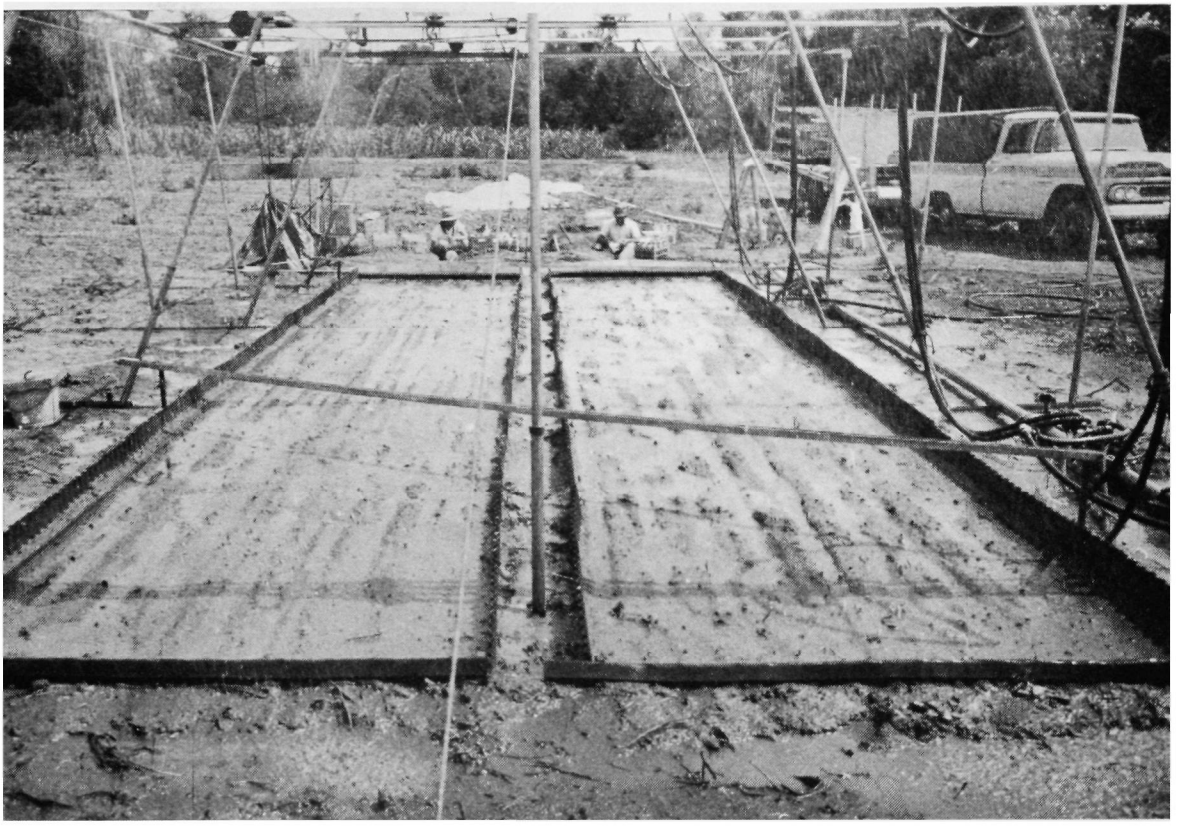

Figure 7. SITE 2 AFTER 90 MINUTES OF RAIN (9.5 cm), LOOKING DOWNSLOPE.

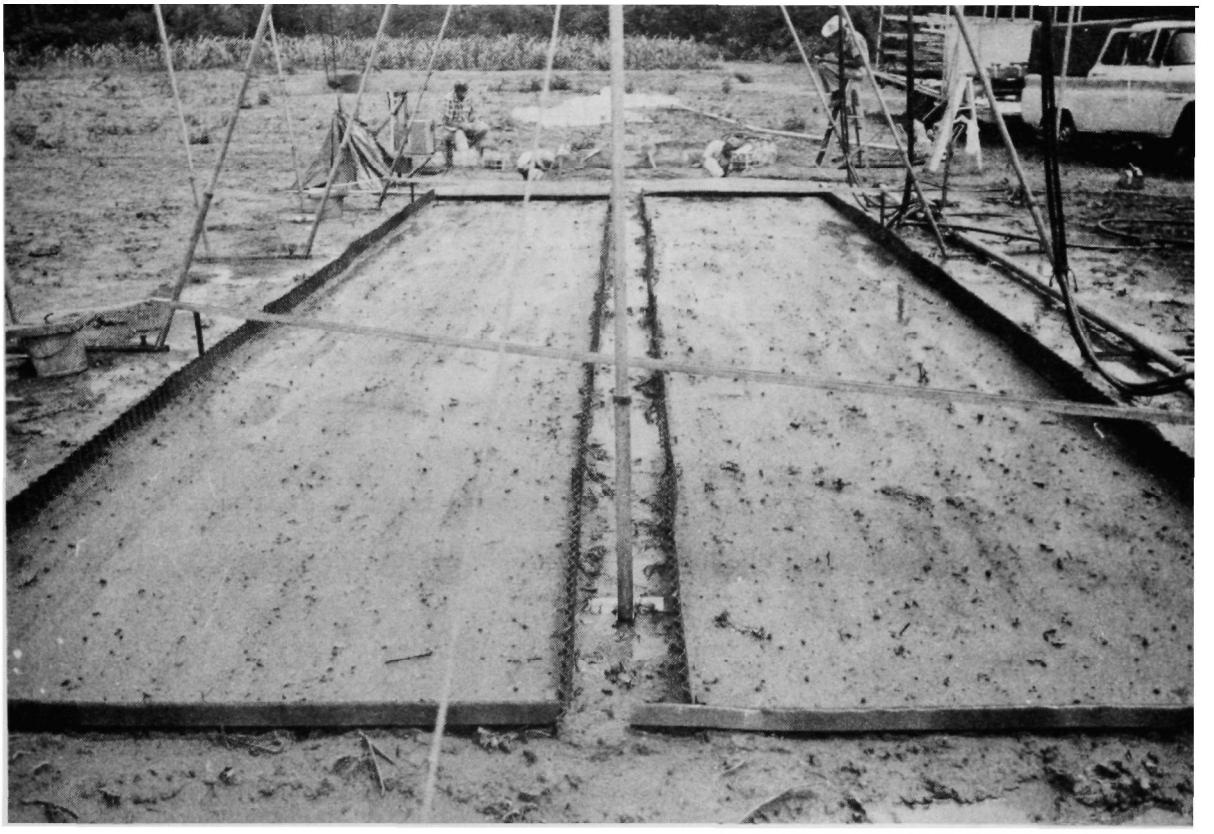

Figure 8. SITE 2. RAINFALL ENDING AFTER 120 MINUTES (12.5 cm of rainfall); NOTE SMOOTHED PLOT SURFACE.

APPENDIX B

SOIL CLASSIFICATION DESCRIPTIONS

A. Site #2.

Henry County, Wiregrass Substation, Headland, Alabama; northeast of headquarters, just north of field planted to cotton.

Typifying Pedon: Dothan sandy loam (lab analysis sandy loam).

Classification, Present: Plinthic Paleudult; fine-loamy, siliceous, thermic family.

Classification, Former: Red-Yellow Podzolic.

Use and Native Vegetation: Presently used as cropland (cotton and corn for silage). Native vegetation is longleaf pine and hardwoods.

Parent Rock or Regolith: Unconsolidated marine sediments.

Geomorphology: Region: Coastal Plain MLRA-133.
Position: Upland.
Elevation: Not recorded.

Drainage and Permeability: Well drained and moderately permeable.

Water Table and Duration: Below 6 ft throughout year except for occasional perched water table above layers with plinthite.

Slope: 2% (test plot 2.2%).

Effective Rooting Depth: 6 ft.

Described by: R.L. Guthrie. Date: October 23, 1970.

Pedon Descriptions:

A_p	0-7"	Brown (10YR 5/3) sandy loam; weak fine granular structure; very friable; few iron concretions; strongly acid; abrupt smooth boundary.
B_1	7-11"	Yellowish brown (10YR 5/6) sandy loam; weak fine subangular blocky structure; friable; very strongly acid; clear smooth boundary.
B_{21t}	11-36"	Yellowish brown (10YR 5/8) sandy clay loam;

		moderate fine subangular blocky structure; friable; thin patchy clay films on ped faces; very strongly acid; gradual boundary.
B_{22t}	36-48"	Yellowish brown (10YR 5/8) sandy clay loam with common medium distinct strong brown (7.5YR 5/8), yellowish red (5YR 5/8) mottles; moderate fine subangular blocky structure; friable, but firm around areas of plinthite; thin patchy clay films on ped faces; 2 to 5% plinthite nodules; few iron concretions; very strongly acid; gradual boundary.
B_{23t}	48-62"	Mottled yellowish brown (10YR 5/8), strong brown (7.5YR 5/8), light gray 10YR 7/2), and yellowish red (5YR 5/8) sandy clay loam; weak fine subangular blocky structure; friable but firm around areas of plinthite; thin patchy clay films on ped faces; 5 to 10% plinthite nodules; very strongly acid.

Mean Temperature: Not recorded.

Mean Precipitation: Not recorded.

B. Site #5.

Baldwin County, Alabama, Gulfcoast Substation, 0.2 miles south of office, 750 ft west of field road, 75 ft south of field border in the SE 1/4, NW 1/4, NE 1/4, Sec. 9, R2E, T6S.

Typifying Pedon: Red Bay fine sandy loam (lab analysis sandy loam).

Classification: Rhodic Paleudult; fine loamy, siliceous, thermic.

Use and Native Vegetation: Presently used for row crops (soybeans). Native vegetation is believed to have been longleaf and loblolly pine, dogwood, and various oaks.

Parent Rock or Regolith: Thick beds of unconsolidated sandy clay loams and sandy loams.

Geomorphology: Region: Coastal Plain MLRA-133.

Position: Upland.

Elevation: About 105 ft.

Drainage and Permeability: Well drained. Permeability is moderate.

Water Table and Duration: Below 10 ft throughout year.

Slope: 2% (test plot 2.5%).

Effective Rooting Depth: 50 in. plus.

Described by: M.G. Mattox. Date: October 21, 1970.

Pedon Descriptions:

A_p	0-9"	Dark reddish brown (5YR 3/3) fine sandy loam; weak fine granular structure; friable; slightly acid; abrupt smooth boundary.
B_1	9-14"	Dark reddish brown (2.5YR 3/4) light sandy clay loam; weak medium subangular blocky structure; friable; slightly acid; clear wavy boundary.
B_{21t}	14-62"	Dark red (2.5YR 3/6) heavy sandy clay loam; weak medium subangular blocky structure; friable; medium acid; gradual wavy boundary.
B_{22t}	62-70"	Dark red (10R 3/6) sandy clay loam; weak medium subangular blocky structure; friable; very strongly acid.

Mean Temperature: Annual 67°F.

Mean Precipitation: Annual 65 in.

C. Site #6.

Baldwin Country, Alabama, Gulfcoast Substation, 0.25 miles south of office, then 0.35 miles east-southeast to woods near pond and 425 ft north in field in the SW 1/4, NW 1/4, NE 1/4, Sec. 9, R2E, T6S.

Typifying Pedon: Malbis fine sandy loam (lab analysis sandy clay loam).

Classification: Plinthic Paleudult; fine loamy, siliceous, thermic.

Use and Native Vegetation: Present use is cropland (corn and silage--wheat winter cover). Native vegetation is believed to have been longleaf and loblolly pine, dogwood, and gallberry.

Parent Rock or Regolith: Thick beds of unconsolidated loams, sandy clay loams, and clay loams.

Geomorphology: Region: Coastal Plain MLRA-133

Position: Upland.

Elevation: About 110 ft.

Drainage and Permeability: Moderately well drained. Permeability is moderate in upper B_r and moderately slow in lower B_t.

Water Table and Duration: 30 to 50 in. for short periods in winter and spring months.

Slope: 2% (test plot 3.6%).

Effective Rooting Depth: 50 in. plus.

Described by: M.G. Mattox. Date: October 21, 1970.

Pedon Descriptions:

A_p	0-8"	Dark grayish brown (10YR 4/2) fine sandy loam; weak fine granular structure; friable, about 2% iron concretions; slightly acid; abrupt smooth boundary.
B_{21t}	8-26"	Yellowish brown (10YR 5/6) light clay loam; weak medium subangular blocky structure; friable, slightly sticky when wet; about 4% iron concretions; medium acid; gradual wavy boundary.
B_{22t}	26-40"	Strong brown (7.5YR 5/6) light clay loam with few medium prominent red (2.5YR 4/6)

		and few medium distinct yellowish brown (10YR 5/8) and light yellowish brown (10YR 6/4) mottles; weak medium subangular blocky structure; friable, slightly sticky when wet; about 4% iron concretions; about 5% plinthite; very strongly acid; gradual wavy boundary.
B_{23t}	40-52"	Mottled strong brown (7.5YR 5/6), yellowish brown (10YR 5/6), yellow (10YR 7/6) and red (2.5YR 4/6) light clay loam; weak medium subangular blocky structure; friable; plinthite nodules are firm; slightly sticky when wet; about 7% plithite nodules; very strongly acid; gradual wavy boundary.
B_{24t}	52-66"	Mottled yellowish brown (10YR 5/6), light yellowish brown (2.5Y 6/4), yellow (2.5Y 7/6), strong brown (7.5YR 5/6), red (2.5YR 4/6), and light gray (10YR 7/2) heavy sandy clay loam; weak medium subangular blocky structure; firm, friable in light gray and yellow areas; about 10% plinthite nodules; very strongly acid.

Mean Temperature: Annual 67°F.

Mean Precipitation: Annual 65 in.

D. Site #7.

Baldwin County, Alabama, Gulfcoast Substation, 225 ft east-northeast of silos at dairy barn in the SW 1/4, SW 1/4, Sec. 4, R2E, T6S.

Typifying Pedon: Malbis fine sandy loam (lab analysis sandy loam).

Classification: Plinthic Paleudult; fine loamy siliceous, thermic.

Use and Native Vegetation: Present use is cultivation (millet

for grazing--wheat cover crop). Native vegetation is believed to be longleaf and loblolly pine, dogwood, and gallberry.

Parent Rock or Regolith: Thick beds of unconsolidated loams, sandy clay loams, and clay loams.

Geomorphology: Region: Coastal Plain MLRA-133.
Position: Upland
Elevation: About 100 ft.

Drainage and Permeability: Moderately well drained. Permeability is moderate in upper B_t and moderately slow in lower B_t.

Water Table and Duration: 30 to 50 in. for short periods in winter and spring months.

Slope: 4% (test plot 5.7%).

Effective Rooting Depth: 50 in. plus.

Described by: M.G. Mattox. Date: October 21, 1970.

Pedon Descriptions:

A_p	0-7"	Brown (10YR 4/3) fine sandy loam; weak fine granular structure; friable; about 3% iron concretions; medium acid; abrupt smooth boundary.
B_{21t}	7-29"	Yellowish brown (10YR 5/6) sandy clay loam; weak medium subangular blocky structure; friable, slightly sticky when wet; about 4% iron concretions; strongly acid; gradual wavy boundary.
B_{22t}	29-39"	Yellowish brown (10YR 5/6) sandy clay loam with few medium distinct strong brown (7.5YR 5/6) and few medium prominent red (2.5YR 4/6) mottles; weak medium subangular blocky structure; friable, slightly sticky when wet; about 4% iron concretions; about 4% plinthite nodules; strongly acid; gradual wavy boundary.

B_{23t}	39-54"	Yellowish brown (10YR 5/6) sandy clay loam with common medium distinct strong brown (7.5YR 5/6), common medium prominent red (2.5YR 4/6), and few medium faint light yellowish brown (2.5Y 6/4) mottles; weak medium subangular blocky structure; friable, plinthite nodules are firm; about 4% iron concretions; about 8% plinthite nodules; very strongly acid; gradual wavy boundary.
B_{24t}	54-66"	Mottled yellowish brown (10YR 5/6), light gray (10YR 7/2), strong brown (7.5YR 5/6), yellowish red (5YR 4/8), red (2.5YR 4/6), and light yellowish brown (2.5Y 6/4) sandy clay loam; moderate medium subangular blocky structure; firm; about 15% plinthite nodules; very strongly acid.

Mean Temperature: Annual 67°F.

Mean Precipitation: Annual 65 in.

APPENDIX C

BASIC ANALYTICAL DATA

Wiregrass

Site #2, Plot #1: Dothan Soil Type, 2.2% Slope

Dothan, Alabama

Plot Size.....	1.83 m x 10.7 m (6.00 ft x 35.0 ft)
Application Rate:	
Casoron (50% dichlobenil)	13.4 kg/ha (12.0 lb/A)
Total Casoron applied	27.2 g
Total Dichlobenil (DCBN) applied	13.6 g (6.70 kg/ha)
Aatrex (80% atrazine)	2.11 kg/ha (1.88 lb/A)
Total Aatrex	4.26 g
Total Atrazine	3.24 g (1.60 kg/ha)

About 690 gallons of water was applied over 120 minutes. Runoff began at 9 minutes, samples were collected at specified time intervals during rainfall and after the rainfall had stopped (120 minutes); runoff ended at 123 minutes.

Results:

1. Total applied rainfall	13.2 cm (5.27 in.)
Total runoff (calculated)	8.64 cm (3.40 in.)
Total sediment runoff (calculated)	7.05 kg (15.5 lb)
2. Sediment runoff	
Sediment (SERL)	3.47×10^3 kg/ha (1.55 T/A)
Sediment and sandy (USDA)	7.35×10^3 kg/ha (3.28 T/A)
3. Atrazine recovered	
Total in sediment	62.2 mg
Total in water runoff	145 mg
Total recovered	207 mg

4.	Atrazine loss (% of applied)	
	In sediment	1.95%
	In water runoff	4.49%
	Total	6.44%
5.	Dichlobenil recovered	
	Total in sediment	48.6 mg
	Total in water runoff	321 mg
	Total recovered	370 mg
6.	Dichlobenil loss (% of applied)	
	In sediment	0.36%
	In water runoff	2.36%
	Total	2.72%

INCREMENTAL SOIL, WATER, AND HERBICIDE LOSSES IN SEDIMENT AND WATER
(English and Metric Units)

(Beginning with minute 9, first increment = 6 min,
subsequent increments = 5 min, final increment = 3 min)

Dothan Site #2

Minute	Soil Losses		Water Losses		Herbicide Losses							
					lb/acre				kg/ha			
					Sediment		Water		Sediment		Water	
	T/A	kg/ha	in.	cm	Atrazine	DCBN	Atrazine	DCBN	Atrazine	DCBN	Atrazine	DCBN
9	.000	0	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
15	.089	200	.107	.272	.002	.002	.008	.015	.002	.002	.009	.017
20	.114	256	.111	.282	.002	.003	.008	.011	.002	.003	.009	.012
25	.104	233	.120	.305	.002	.002	.011	.011	.002	.002	.012	.012
30	.087	195	.131	.333	.002	.001	.004	.016	.002	.001	.004	.018
35	.097	217	.144	.366	.001	.002	.004	.010	.001	.002	.004	.011
40	.090	202	.145	.368	.001	.001	.004	.012	.001	.001	.004	.013
45	.093	208	.145	.368	.001	.000	.006	.009	.001	.000	.007	.010
50	.090	202	.145	.368	.001	.000	.006	.008	.001	.000	.007	.009
55	.075	168	.150	.381	.001	.000	.003	.007	.001	.000	.003	.008
60	.066	148	.151	.384	.001	.000	.003	.006	.001	.000	.003	.007
65	.055	123	.155	.394	.000	.000	.002	.003	.000	.000	.002	.003
70	.057	128	.157	.399	.000	.000	.002	.003	.000	.000	.002	.003
75	.062	139	.165	.419	.001	.000	.002	.004	.001	.000	.002	.004
80	.060	134	.165	.419	.001	.000	.002	.004	.001	.000	.002	.004
85	.056	126	.170	.432	.001	.000	.000	.004	.001	.000	.000	.004
90	.056	126	.170	.432	.001	.001	.000	.004	.001	.001	.000	.004
95	.065	146	.180	.457	.001	.002	.000	.004	.001	.002	.000	.004
100	.066	149	.175	.444	.002	.002	.000	.004	.002	.002	.000	.004
105	.068	152	.175	.444	.002	.002	.000	.004	.002	.002	.000	.004
110	.060	134	.175	.444	.002	.001	.000	.003	.002	.001	.000	.003
115	.032	72	.175	.444	.000	.000	.000	.002	.000	.000	.000	.002
120	.026	58	.176	.447	.000	.000	.000	.002	.000	.000	.000	.002
123	(Runoff stopped)											

Wiregrass

Time Period Losses

Site #2, Plot #1: Dothan Soil Type, 2.27% Slope

Note: Runoff started at 9 min; first increment was 6 min (for 9-15 min period); following increments were 5 min for remainder of 120 min rainfall; because runoff ended at 123 min, final increment was 3 min.

Time (min)	Soil and Water Losses		Herbicide Losses (mg)			
	Soil	Water	Sediment		Water	
	lb	in.	Atrazine	DCBN	Atrazine	DCBN
9	.000	.000	0.00	0.00	0.00	0.00
15	.890	.107	5.33	5.18	18.29	33.20
20	1.144	.111	4.76	5.84	17.94	25.76
25	1.036	.120	4.45	5.58	25.02	25.22
30	.866	.131	4.35	2.68	8.87	36.92
35	.968	.144	3.13	4.13	8.52	22.90
40	.896	.145	2.84	1.90	10.17	27.31
45	.925	.145	2.35	0.41	14.37	21.56
50	.900	.145	2.01	0.49	12.98	18.78
55	.750	.150	1.44	0.45	7.44	14.87
60	.657	.151	1.28	0.36	7.71	13.43
65	.550	.155	1.00	0.23	3.84	7.68
70	.570	.157	1.01	0.35	3.89	7.78
75	.620	.165	1.21	0.87	4.09	8.18
80	.596	.165	1.28	1.00	4.91	8.23
85	.555	.170	1.39	0.99	0.00	8.43
90	.563	.170	1.73	1.53	0.00	8.52
95	.650	.180	3.30	4.33	0.00	8.92
100	.655	.175	3.94	5.13	0.00	8.67
105	.675	.175	4.53	4.32	0.00	8.67
110	.597	.175	3.74	2.68	0.00	7.80
115	.320	.175	0.96	0.09	0.00	4.34
120	.264	.176	0.77	0.07	0.00	3.47
123	(Runoff stopped)					

Gulfcoast

Site #5, Plot #2: Red Bay Soil Type, 2.5% Slope

Mobile, Alabama

Plot Size.....	1.83 m x 10.7 m (6.00 ft x 35.0 ft)
Application Rate:	
Casoron (50% dichlobenil	13.4 kg/ha (12.0 lb/A)
Total Casoron applied	27.2 g
Total Dichlobenil (DCBN) applied	13.6 g (6.7 kg/ha)
Aatrex (80% atrazine)	4.21 kg/ha (3.76 lb/A)
Total Aatrex	8.53 g
Total Atrazine	6.48 g (3.22 kg/ha)

About 753 gallons of water was applied over 120 minutes. Runoff began at 6 minutes, samples were collected at specified time intervals during rainfall and after the rainfall had stopped (120 min); runoff ended at 123 minutes.

Results:

1. Total applied rainfall	14.6 cm (5.75 in.)
Total runoff (calculated)	10.5 cm (4.13 in.)
Total sediment runoff (calculated)	18.1 kg (39.9 lb.)
2. Sediment runoff	
Sediment (SERL)	8.95×10^3 kg/ha (3.99 T/A)
Sediment and sandy (USDA)	1.52×10^4 kg/ha (6.79 T/A)
3. Atrazine recovered	
Total in sediment	125 mg
Total in water runoff	739 mg
Total recovered	864 mg
4. Atrazine loss (% of applied)	
In sediment	1.93%
In water runoff	11.4%
Total	13.3%

5. Dichlobenil recovered

Total in sediment	317 mg
Total in water runoff	1.04×10^3 mg
Total recovered	1.35×10^3 mg

6. Dichlobenil loss (% of applied)

In sediment	2.33%
In water runoff	7.61%
Total	9.94%

INCREMENTAL SOIL, WATER, AND HERBICIDE LOSS IN SEDIMENT AND WATER
(English and Metric Units)

(Beginning with minute 6, first increment = 4 min,
subsequent increments = 5 min, final increment = 3 min)

Red Bay, Site #5

Minute	Soil Losses		Water Losses		Herbicide Losses							
					lb/acre				kg/ha			
					Sediment		Water		Sediment		Water	
	T/A	kg/ha	in.	cm	Atrazine	DCBN	Atrazine	DCBN	Atrazine	DCBN	Atrazine	DCBN
6	.000	0	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
10	.164	368	.080	.203	.008	.019	.044	.020	.009	.021	.049	.022
15	.266	596	.157	.399	.004	.017	.053	.036	.004	.019	.059	.040
20	.251	563	.168	.427	.002	.014	.034	.029	.002	.016	.038	.033
25	.231	518	.173	.439	.002	.011	.026	.027	.002	.012	.029	.030
30	.199	446	.163	.414	.002	.008	.015	.015	.002	.009	.017	.017
35	.201	451	.168	.427	.004	.008	.009	.017	.004	.009	.010	.019
40	.194	435	.175	.444	.003	.007	.001	.032	.003	.008	.012	.036
45	.193	433	.179	.455	.003	.006	.012	.031	.002	.007	.013	.035
50	.193	433	.180	.457	.003	.006	.009	.029	.003	.007	.010	.033
55	.192	430	.180	.457	.003	.006	.008	.027	.003	.007	.009	.030
60	.167	374	.182	.462	.003	.005	.008	.018	.003	.006	.009	.020
65	.160	359	.192	.488	.003	.004	.008	.017	.003	.004	.009	.019
70	.160	359	.194	.493	.003	.004	.008	.019	.003	.004	.009	.021
75	.156	350	.190	.483	.003	.004	.008	.021	.003	.004	.009	.024
80	.137	307	.185	.470	.002	.003	.003	.020	.002	.003	.003	.022
85	.139	312	.189	.480	.002	.003	.012	.018	.002	.003	.013	.020
90	.144	323	.195	.495	.002	.002	.013	.017	.002	.002	.015	.019
95	.137	307	.193	.490	.001	.002	.010	.017	.001	.002	.011	.019
100	.128	287	.190	.483	.000	.002	.008	.017	.000	.002	.009	.019
105	.133	298	.194	.493	.000	.002	.008	.014	.000	.002	.009	.016
110	.151	338	.195	.495	.000	.002	.009	.013	.000	.002	.010	.015
115	.163	365	.200	.508	.000	.002	.005	.010	.000	.002	.006	.011
120	.135	303	.192	.488	.000	.002	.004	.008	.000	.002	.004	.009
123	(Runoff stopped)											

Gulfcoast

Time Period Losses

Site #5, Plot #2: Red Bay Soil Type, 2.5% Slope

Note: Runoff started at 6 min; first increment was 4 min (for 6-10 min period); following increments were 5 min for remainder of 120 min rainfall; because runoff ended at 123 min, final increment was 3 min.

Time (min)	Soil and Water Losses		Herbicide Losses (mg)			
	Soil	Water	Sediment		Water	
	lb	in.	Atrazine	DCBN	Atrazine	DCBN
6	0.000	.000	0.000	0.000	0.000	0.000
10	1.635	.080	17.852	44.032	99.852	45.791
15	2.655	.157	8.157	38.567	121.168	82.348
20	2.510	.168	5.605	31.208	76.305	66.645
25	2.306	.173	4.291	24.349	58.321	61.642
30	1.990	.163	4.554	17.301	34.040	34.037
35	2.007	.168	8.065	17.786	19.967	38.549
40	1.938	.175	7.757	15.884	26.015	72.839
45	1.929	.179	7.791	14.529	26.611	70.958
50	1.928	.180	7.835	14.514	19.624	66.003
55	1.920	.180	7.835	14.450	17.840	52.435
60	1.665	.182	6.669	10.705	18.038	41.427
65	1.601	.192	5.174	9.877	19.028	38.056
70	1.602	.194	6.181	9.931	19.226	44.099
75	1.560	.190	6.015	9.695	18.830	47.075
80	1.365	.185	4.858	7.195	7.334	45.836
85	1.393	.189	4.869	6.386	26.263	41.178
90	1.440	.195	3.852	5.094	28.990	38.650
95	1.371	.193	2.773	4.787	22.993	38.254
100	1.279	.190	0.996	4.571	18.830	37.660
105	1.333	.194	0.642	4.500	19.226	30.724
110	1.514	.195	0.757	4.010	19.325	28.990
115	1.630	.200	0.813	4.023	11.892	21.801
120	1.354	.192	0.665	3.540	9.515	19.028
123	(Runoff stopped)					

Gulfcoast

Site #6, Plot #2: Bowie Soil Type, 3.6% Slope

Mobile, Alabama

Plot Size.....	1.83 m x 10.7 m (6.00 ft x 35.0 ft)
Application Rate:	
Casoron (50% dichlobenil)	13.4 kg/ha (12.0 lb/A)
Total Casoron applied	27.2 g
Total Dichlobenil (DCBN) applied	13.6 g (6.97 kg/ha)
Aatrex (80% atrazine)	2.11 kg/ha (1.88 lb/A)
Total Aatrex	4.26 g
Total Atrazine	3.24 g (1.66 kg/ha)

About 720 gal. of water was applied over 120 minutes. Runoff began at 3 minutes, samples were collected at specified time intervals during rainfall and after the rainfall had stopped (120 min); runoff ended at 124 minutes.

Results:

1. Total applied rainfall	13.9 cm (5.47 in.)
Total runoff (calculated)	10.2 cm (4.02 in.)
Total sediment runoff (calculated)	31.2 kg (68.7 lb)
2. Sediment runoff	
Sediment (SERL)	1.54×10^4 kg/ha (6.87 T/A)
Sediment and sand (USDA)	2.55×10^4 kg/ha (11.4 T/A)
3. Atrazine recovered	
Total in sediment	70.2 mg
Total in water runoff	334.0 mg
Total recovered	404.0 mg
4. Atrazine loss (% of applied)	
In sediment	2.17%
In water runoff	10.3%
Total	12.5%

5. Dichlobenil recovered

Total in sediment	404 mg
Total in water runoff	816 mg
Total recovered	1.22×10^3 mg

6. Dichlobenil loss (% of applied)

In sediment	2.97%
In water runoff	5.99%
Total	8.96%

INCREMENTAL SOIL, WATER, AND HERBICIDE LOSS IN SEDIMENT AND WATER
(English and Metric Units)

(Beginning with minute 3, first increment = 7 min,
subsequent increments = 5 min, final increment = 4 min)

Malbis, Site #6

Minute	Soil Losses		Water Losses		Herbicide Losses							
					lb/acre				kg/ha			
					Sediment		Water		Sediment		Water	
	T/a	kg/ha	in.	cm	Atrazine	DCBN	Atrazine	DCBN	Atrazine	DCBN	Atrazine	DCBN
3	.000	0	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
10	.456	1022	.131	.333	.007	.045	.030	.033	.008	.050	.034	.037
15	.434	973	.171	.434	.003	.020	.015	.026	.003	.022	.017	.029
20	.348	780	.172	.437	.002	.012	.010	.020	.002	.013	.011	.022
25	.422	946	.174	.442	.002	.010	.008	.023	.002	.011	.009	.026
30	.401	899	.165	.419	.002	.009	.007	.019	.002	.010	.008	.021
35	.344	771	.164	.417	.001	.004	.007	.016	.001	.004	.008	.018
40	.337	755	.168	.427	.000	.001	.007	.015	.000	.001	.008	.017
45	.334	749	.168	.427	.000	.001	.004	.015	.000	.001	.004	.017
50	.336	753	.180	.457	.000	.006	.004	.016	.000	.007	.004	.018
55	.333	746	.180	.457	.000	.006	.004	.020	.000	.007	.004	.022
60	.311	697	.182	.462	.000	.007	.004	.020	.000	.008	.004	.022
65	.300	672	.178	.452	.000	.007	.004	.015	.000	.008	.004	.017
70	.252	565	.181	.460	.001	.006	.004	.016	.001	.007	.004	.018
75	.238	534	.179	.455	.001	.005	.004	.016	.001	.006	.004	.018
80	.222	498	.175	.444	.001	.005	.004	.011	.001	.006	.004	.012
85	.226	507	.175	.444	.001	.005	.004	.011	.001	.006	.004	.012
90	.235	527	.176	.447	.001	.005	.004	.011	.001	.006	.004	.012
95	.234	525	.178	.452	.001	.005	.004	.012	.001	.006	.004	.013
100	.239	536	.180	.457	.002	.005	.004	.016	.002	.006	.004	.018
105	.247	554	.180	.457	.002	.005	.004	.012	.002	.006	.004	.013
110	.210	471	.180	.457	.002	.004	.004	.008	.002	.004	.004	.009
115	.198	444	.180	.457	.002	.004	.004	.007	.002	.004	.004	.008
120	.220	493	.177	.450	.002	.003	.004	.004	.002	.003	.004	.004
124	(Runoff stopped)											

Gulfcoast | Time Period Losses

Site #6, Plot #2: Bowie Soil Type, 3.6% Slope

Note: Runoff started at 3 min; first increment was 7 min (for 3-10 min period); following increments were 5 min for remainder of 120 min rainfall; because runoff ended at 124 min, final increment was 4 min.

Time (min)	Soil and Water Losses		Herbicide Losses (mg)			
	Soil	Water	Sediment		Water	
	lb	in.	Atrazine	DCBN	Atrazine	DCBN
3	0.000	.000	0.000	0.000	0.000	0.000
10	4.564	.131	16.302	102.003	68.387	74.235
15	4.340	.171	6.752	44.364	33.868	57.975
20	3.476	.172	4.895	27.141	23.860	46.035
25	4.217	.174	3.743	23.588	17.245	51.732
30	4.012	.165	4.152	20.488	16.301	42.388
35	3.435	.164	1.376	8.024	16.204	35.628
40	3.369	.168	0.000	2.600	16.600	33.200
45	3.337	.168	0.000	2.994	8.300	33.200
50	3.360	.180	0.000	12.505	8.920	35.680
55	3.327	.180	0.000	13.962	8.920	44.595
60	3.105	.182	0.000	16.340	9.045	45.220
65	2.993	.178	0.000	15.071	8.795	35.185
70	2.522	.181	1.256	12.687	8.970	35.679
75	2.375	.179	1.492	12.269	8.870	35.481
80	2.215	.175	1.805	11.545	8.670	26.015
85	2.263	.175	1.733	11.507	8.670	24.281
90	2.346	.176	2.983	10.538	8.695	26.090
95	2.344	.178	3.261	10.289	8.759	28.149
100	2.390	.180	3.575	10.505	8.895	35.581
105	2.471	.180	3.465	11.038	8.920	26.760
110	2.100	.180	4.760	9.135	8.920	17.840
115	1.975	.180	4.958	8.460	8.920	16.056
120	2.197	.177	3.689	6.851	8.826	8.826
124	(Runoff stopped)					

Gulfcoast

Site #7, Plot #1: Bowie Soil Type, 5.7% Slope

Mobile, Alabama

Plot Size.....	1.83 m x 10.7 m (6.00 ft x 35.0 ft)
Application Rate:	
Casoron (50% dichlobenil)	13.4 kg/ha (12.0 lb/A)
Total Casoron applied	27.2 g
Total Dichlobenil (DCBN) applied	13.6 g (6.7 kg/ha)
Aatrex (80% atrazine)	4.21 kg/ha (3.76 lb/A)
Total Aatrex	8.53 g
Total Atrazine	6.48 g (3.32 kg/ha)

About 700 gal. of water was applied over 120 minutes. Runoff began at 6 minutes, samples were collected at specified time intervals during rainfall and after the rainfall had stopped (120 min); runoff ended at 122 minutes.

Results:

1.	Total applied rainfall	13.5 cm (5.32 in.)
	Total runoff (calculated)	9.37 cm (3.69 in.)
	Total sediment runoff (calculated)	30.9 kg (68.1 lb)
2.	Sediment runoff	
	Sediment (SERL)	1.53×10^4 kg/ha (6.81 T/A)
	Sediment and sandy (USDA)	3.07×10^4 kg/ha (13.7 T/A)
3.	Atrazine recovered	
	Total in sediment	197 mg
	Total in water runoff	463 mg
	Total recovered	660 mg
4.	Atrazine Loss (% of applied)	
	In sediment	3.04%
	In water runoff	7.14%
	Total	10.2%

5. Dichlobenil recovered

Total in sediment	347 mg
Total in water runoff	281 mg
Total recovered	628 mg

6. Dichlobenil loss (% of applied)

In sediment	2.55%
In water runoff	2.07%
Total	4.62%

INCREMENTAL SOIL, WATER, AND HERBICIDE LOSS IN SEDIMENT AND WATER
(English and Metric Units)

(Beginning with minute 6, first increment = 4 min,
subsequent increments = 5 min, final increment = 2 min)

Malbis, Site #7

Minute	Soil Losses		Water Losses		Herbicide Losses							
					lb/acre				kg/ha			
					Sediment		Water		Sediment		Water	
	T/A	kg/ha	in.	cm	Atrazine	DCBN	Atrazine	DCBN	Atrazine	DCBN	Atrazine	DCBN
6	.000	0	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
10	.238	534	.071	.180	.006	.015	.009	.009	.006	.007	.010	.007
15	.342	767	.126	.320	.006	.020	.022	.017	.007	.022	.025	.019
20	.371	832	.143	.363	.003	.012	.016	.012	.003	.013	.018	.013
25	.347	778	.150	.381	.003	.010	.017	.011	.003	.011	.019	.012
30	.326	731	.150	.381	.003	.010	.013	.008	.003	.011	.015	.009
35	.268	601	.152	.386	.002	.007	.012	.007	.002	.008	.013	.008
40	.311	697	.162	.411	.002	.008	.012	.007	.002	.008	.013	.008
45	.307	688	.165	.419	.002	.008	.011	.007	.002	.009	.012	.008
50	.265	594	.170	.432	.005	.008	.011	.007	.006	.009	.012	.008
55	.263	590	.170	.432	.006	.007	.011	.007	.007	.008	.012	.008
60	.292	655	.166	.422	.007	.005	.011	.007	.008	.006	.012	.008
65	.302	677	.165	.419	.007	.005	.007	.007	.008	.006	.008	.008
70	.365	818	.172	.437	.002	.004	.008	.005	.002	.004	.009	.006
75	.364	816	.172	.437	.002	.004	.008	.004	.002	.004	.009	.004
80	.295	661	.174	.442	.002	.004	.008	.004	.002	.004	.009	.004
85	.280	628	.175	.444	.002	.004	.005	.004	.002	.004	.006	.004
90	.243	545	.170	.432	.002	.004	.004	.004	.002	.004	.004	.004
95	.254	569	.170	.432	.002	.004	.004	.004	.002	.004	.004	.004
100	.294	659	.170	.432	.003	.003	.004	.000	.003	.003	.004	.000
105	.290	650	.170	.432	.003	.003	.004	.000	.003	.003	.004	.000
110	.266	596	.172	.437	.005	.002	.004	.000	.006	.002	.004	.000
115	.266	596	.172	.437	.005	.002	.004	.000	.006	.002	.004	.000
120	.264	592	.172	.437	.006	.002	.004	.000	.007	.002	.004	.000
122	(Runoff stopped)											

Gulfcoast — Time Period Losses

Site #7, Plot #1: Bowie Soil Type, 5.7% Slope

Note: Runoff started at 6 min; first increment was 4 min (for 6-10 min period); following increments were 5 min for remainder of 120 min rainfall; because runoff ended at 122 min, final increment was 2 min.

Time (min)	Soil and Water Losses		Herbicide Losses (mg)			
	Soil	Water	Sediment		Water	
	lb	in.	Atrazine	DCBN	Atrazine	DCBN
6	0.000	.000	0.000	0.000	0.000	0.000
10	2.375	.071	12.701	33.570	21.057	14.623
15	3.418	.126	12.944	45.009	49.453	38.800
20	3.705	.143	6.227	27.910	35.562	26.925
25	3.472	.150	6.083	23.858	37.680	24.117
30	3.256	.150	5.799	23.405	30.145	18.086
35	2.683	.152	5.461	16.380	27.187	15.106
40	3.108	.162	4.954	17.670	24.154	16.103
45	3.070	.165	5.010	18.650	24.525	9.810
50	2.645	.170	12.328	17.944	25.270	15.111
55	2.625	.170	14.180	17.040	25.270	16.845
60	2.924	.166	16.866	11.305	24.674	16.449
65	3.020	.165	15.345	10.960	16.350	16.350
70	3.654	.172	4.406	8.811	17.095	10.259
75	3.635	.172	4.450	8.900	17.095	8.550
80	2.945	.174	4.960	9.375	17.295	8.646
85	2.800	.175	5.184	9.504	10.405	8.670
90	2.427	.170	5.286	8.275	8.425	8.425
95	2.543	.170	5.426	8.313	8.425	8.425
100	2.939	.170	6.755	7.066	8.425	0.000
105	2.895	.170	6.960	6.960	8.425	0.000
110	2.659	.172	11.065	5.623	8.525	0.000
115	2.655	.172	11.920	5.420	8.550	0.000
120	2.635	.172	12.666	5.194	8.525	0.000
122	(Runoff stopped)					

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ATHENS, GEORGIA 30601

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15. Supplementary Notes

Environmental Protection Agency report number, EPA-660/2-74-017, April 1974.

16. Abstract

The movement of two herbicides in runoff and on sediment were studied as examples of pesticides in general use. Gas chromatography was used to determine the losses of atrazine (2-chloro-4-ethylamino-6-isopropylamino-s-triazine) and dichlobenil (2,6-dichlorobenzonitrile) from fallow plots on four Coastal Plain soil types following the application of about 13 cm (5 in.) of rainfall in 2 hours.

The herbicides, as wettable powders, were surface-applied and incorporated. Simulated high intensity (a 100-year frequency storm) rainfall was started 1 hour after application.

Significant amounts of both compounds were transported. The percent loss was greater in all cases for atrazine, but because more dichlobenil was applied, its losses were greater on an absolute basis. Some of the herbicide in the sediment may have been transported as discrete particles rather than as an adsorbate.

The greatest combined (runoff plus sediment) losses of atrazine in all soils and of dichlobenil in two soils occurred during the first 40-50 minutes of runoff. During this time, the absolute amount of both herbicides was greater in runoff, but the concentrations were greater in the sediment. The preferential loss of certain clay-sized materials during the first 50 minutes of runoff may explain the high herbicide concentration in sediment relative to later times.

17a. Descriptors

*Runoff, *Herbicides, *Simulated rainfall, *Soil types, Coastal Plains, Gas Chromatography

17b. Identifiers

*Pesticide movement, *Preferential herbicide loss, Atrazine, Dichlobenil, Fallow plots.

17c. COWRR Field & Group 05B

18. Availability

19. Security Class (Report)

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EPA Report 660/2-74-017 ERRATA SHEET

Tables Number 5 through 9 are in error. The attached Tables (5-9) should replace the Tables 5-9 in the report at pages 34, 35, 36, and 56, respectively.

Page 42, line 11 should read: stabilizing at a concentration of 0.1 ppm near the end.

Any questions regarding the report should be directed to Dr. George W. Bailey, telephone number 404/546-3149.

Table 5. HERBICIDE CONCENTRATION (ppm) IN RUNOFF WATER AND ON SEDIMENT FROM DOTHAN, SITE 2

Time From Onset of Rainfall, Min	Sediment		Water	
	Atrazine	DCBN	Atrazine	DCBN
9	0.0	0.0	0.00	0.00
15	10.7	8.3	0.3	0.6
20	7.8	13.9	0.4	0.4
25	11.5	10.7	0.3	0.5
30	9.7	5.8	0.1	0.4
35	7.3	7.3	0.1	0.4
40	5.6	1.0	0.2	0.3
45	5.6	1.0	0.2	0.3
50	4.2	1.3	0.1	0.2
55	4.2	1.3	0.1	0.2
60	4.0	0.9	0.05	0.1
65	4.0	0.9	0.05	0.1
70	4.3	3.1	Negative	0.1
75	4.3	3.1	0.05	0.1
80	5.5	3.9	0.1	0.1
85	5.5	3.9	Negative	Negative
90	11.2	14.7	Negative	Negative
95	11.2	14.7	Negative	Negative
100	15.1	14.1	Negative	Negative
105	15.1	14.1	Negative	Negative
110	6.6	0.6	Negative	Negative
115	6.6	0.6	Negative	Negative
120	Negative	Negative	Negative	Negative
123	(Runoff Stopped)			

Table 6. HERBICIDE CONCENTRATION (ppm) IN RUNOFF WATER AND ON SEDIMENT FROM RED BAY, SITE 5

Time From Onset of Rainfall, Min	Sediment		Water	
	Atrazine	DCBN	Atrazine	DCBN
7	0.0	0.0	0.0	0.0
10	10.8	37.1	2.1	0.4
15	6.1	32.5	1.3	0.9
20	5.7	23.2	0.5	0.9
25	3.8	23.5	0.6	0.6
30	7.3	17.5	0.3	0.3
35	9.0	20.1	0.3	0.7
40	8.9	16.6	0.3	0.8
45	8.9	16.6	0.3	0.8
50	9.0	16.6	0.2	0.7
55	9.0	16.6	0.2	0.7
60	8.5	13.6	0.2	0.4
65	8.5	13.6	0.2	0.4
70	8.5	13.7	0.2	0.5
75	8.5	13.7	0.2	0.5
80	7.7	10.1	0.2	0.5
85	7.7	10.1	0.3	0.4
90	4.5	7.7	0.3	0.4
95	4.4	7.7	0.2	0.4
100	1.0	7.5	0.2	0.4
105	1.7	7.4	0.2	0.3
110	1.1	5.5	0.2	0.3
115	1.1	5.4	0.1	0.2
120	1.1	6.5	0.1	0.2
123	(Runoff Stopped)			

Table 7. HERBICIDE CONCENTRATION (ppm) IN RUNOFF WATER AND ON SEDIMENT FROM MALBIS (BOWIE), SITE 6

Time From Onset of Rainfall, Min	Sediment		Water	
	Atrazine	DCBN	Atrazine	DCBN
5	0.0	0.0	0.0	0.0
10	5.5	27.4	0.6	0.8
15	4.1	17.7	0.3	0.6
20	2.6	16.5	0.2	0.6
25	2.3	11.1	0.2	0.6
30	2.2	12.0	0.2	0.5
35	0.2	0.8	0.2	0.4
40	0.2	1.7	0.2	0.4
45	0.2	2.7	0.1	0.4
50	0.2	8.2	0.1	0.4
55	0.2	13.7	0.1	0.5
60	0.2	11.6	0.1	0.5
65	0.2	4.4	0.1	0.4
70	1.1	11.1	0.1	0.4
75	2.3	12.8	0.1	0.4
80	1.8	11.5	0.1	0.3
85	1.3	10.2	0.1	0.2
90	2.8	9.9	0.1	0.3
95	4.3	9.5	0.1	0.4
100	3.3	9.7	0.1	0.4
105	2.3	10.0	0.1	0.3
110	5.0	9.6	0.1	0.2
115	7.8	9.1	0.1	0.1
120	1.1	5.5	0.1	0.1
124	(Runoff Stopped)			

Table 8. HERBICIDE CONCENTRATION (ppm) IN RUNOFF WATER AND ON SEDIMENT FROM MALBIS (BOWIE), SITE 7

Time From Onset of Rainfall, Min	Sediment		Water	
	Atrazine	DCBN	Atrazine	DCBN
6	0.0	0.0	0.00	0.00
10	9.2	17.5	1.0	0.3
15	4.7	20.5	0.6	0.6
20	3.7	15.0	0.5	0.3
25	4.1	15.9	0.4	0.3
30	4.4	16.0	0.4	0.2
35	4.3	12.9	0.3	0.2
40	3.6	13.4	0.3	0.2
45	3.6	13.4	0.3	0.1
50	11.9	14.3	0.3	0.2
55	11.9	14.3	0.3	0.2
60	11.2	8.0	0.3	0.2
65	11.2	8.2	0.2	0.2
70	2.7	5.4	0.2	0.1
75	2.7	5.4	0.2	0.1
80	4.0	7.4	0.2	0.1
85	4.1	7.5	0.1	0.1
90	4.7	7.2	0.1	0.1
95	4.7	7.2	0.1	0.1
100	5.3	5.3	0.1	Negative
105	5.3	5.3	0.1	Negative
110	9.9	4.5	0.1	Negative
115	9.9	4.5	0.1	Negative
120	13.5	3.7	0.1	Negative
122	(Runoff Stopped)			

Table 9. PERCENT CUMULATIVE AND FRACTIONAL LOSS OF HERBICIDES ON DOTHAN, SITE 2

Time From Onset of Rainfall, Min.	Cumulative,%						Fractional Loss in Sediment and Water	
	Atrazine			Dichlobenil				
	Sediment	Water	Total	Sediment	Water	Total	Atrazine	DCBN
9	0	0	0	0	0	0	0	0
15	9	13	12	11	10	10	0.77	0.28
20	18	25	23	23	18	19	0.66	0.23
25	26	43	38	34	25	27	0.87	0.23
30	33	49	44	40	37	37	0.39	0.29
35	39	55	50	49	44	44	0.34	0.20
40	44	62	57	53	52	52	0.38	0.21
45	48	72	65	54	58	58	0.49	0.16
50	51	81	72	55	64	63	0.44	0.14
55	54	86	76	56	69	67	0.26	0.11
60	56	91	81	56	73	70	0.26	0.10
65	58	94	83	57	75	73	0.14	0.06
70	60	97	85	57	77	75	0.14	0.06
75	62	99	88	60	80	75	0.15	0.07
80	64	100	91	62	82	77	0.18	0.07
85	67		91	64	85	82	0.04	0.07
90	70		92	66	87	88	0.05	0.07
95	76		94	75	90	88	0.09	0.10
100	82		96	86	93	92	0.11	0.10
105	90		98	94	95	95	0.13	0.09
110	97		99	100	98	98	0.08	0.08
115	99		100	100	99	99	0.03	0.03
120	100		100	100	100	100	0.02	0.03

123 (Runoff stopped)