EFFECT OF THE UNSATURATED ZONE ON THE MIGRATION AND RETARDATION OF A CONSERVATIVE TRACER AT THE PLAINS, GEORGIA, RESEARCH SITE

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ABSTRACT

Data collected at a 2-acre research plot (planting area) were used to define and evaluate the factors that control the fate and transport of conventionally applied agrichemicals. It was hypothesized that the heterogeneity in hydraulic conductivity of the unsaturated zone has a substantial effect on the rates of infiltration and in the transport pathways of solute.

The results of the investigation suggest that the lateral transport of a conservative tracer (potassium bromide solute) may be a substantial component of its dispersion in the unsaturated zone. Data from this investigation indicate that soil heterogeneity substantially affects the migration rates and pathways of surface-applied chemicals and that one-dimensional (vertical) transport in the unsaturated zone is rare and may be observed only where the soil column is homogeneous and permeable. The lateral migration of solute at the interface between permeable and less permeable material may account for a large part of the dispersion of agrichemicals in the unsaturated zone. Moreover, the lateral rate of movement may be greater than that observed in the vertical.

At the study site, atrazine, alachlor, carbofuran, and the conservative tracer were uniformly applied over the planting area in June 1989, and since application, more than 4,000 soil samples were collected for chemical analysis to evaluate the rates of degradation and transport. Analytical results indicate that, during the first 70 days after application, the center of mass of bromide infiltrated to a depth of about 48 inches in the planting area. From 70 to 350 days, the infiltration rate of the bromide mass was retarded at a depth of about 54 inches in the northeastern part of the area, but the tracer continued to infiltrate vertically to a depth of about 114 inches in the southwestern part of the area. In addition, the total bromide mass in the soil column progressively decreased over time in the northeast and increased in the southwest; thus indicating that the bromide mass within the planting area was migrating laterally from the upslope area.

The apparent anomolies in the migration of the bromide tracer are directly related to characteristics of hydrogeology in the planting area. The northeastern (upslope) part of the planting area is characterized by a shallow, 8-feet-thick layer of dense clay having an average vertical hydraulic conductivity of 0.36 feet per day. The upper part of the clay layer is extremely dense at a depth of about 4 to 5 feet, and in laboratory infiltration tests, would not allow water to pass (vertical hydraulic conductivity estimated to be 0.01 foot per day). Downslope, in the southwestern part of the area, the unsaturated zone is characterized by clean, quartz sand and a higher vertical hydraulic conductivity (1.02 - 5.03 feet per day). Between the northeastern and southwestern parts of the planting area is a transition zone having intermediate lithologies and vertical hydraulic conductivities.

INTRODUCTION

The vulnerability of ground water to contamination by agrichemicals is relatively high in several regions of the United States, particularly in the corn-belt region of the Midwest and the Coastal Plain of the Southeast. Heavy use of chemicals on farmlands in these regions increases the potential for nonpoint source contamination of the water resources. A cooperative, interdisciplinary research investigation in a ground-water recharge area near Plains, Ga., was initiated in 1986 by the U.S. Geological Survey (USGS), U.S. Department of Agriculture, Agricultural Research Service (ARS), and U.S. Environmental Protection Agency (USEPA) to improve current understanding of the complex processes that control the transport and fate of atrazine, alachlor, carbofuran, and a conservative tracer (potassium bromide) in the soil-root, unsaturated, and saturated zones. To develop this improved understanding, it was necessary to define the spatial variability of the hydrogeologic properties, to define environmental factors that control the transport and fate of agrichemicals, and to evaluate the physical and chemical processes that are important to the validation and testing of solute-transport models. This paper describes the results of a part of this investigation.

The heterogeneity in hydraulic conductivity of the unsaturated zone was hypothesized to have a substantial effect on the rates of infiltration and in the transport pathways of solute. The vertical position of the center of mass of a conservative tracer at a specific time is a relative indicator of the infiltration potential of the soil medium. Although other environmental and physical factors may affect the acceleration or retardation of the tracer, it should not be sorbed to soil particles because it is conservative. Thus, the vertical saturated hydraulic conductivity is assumed to be the predominant controlling factor for the migration of the tracer.

Description of Study Area

The study area is in the Fall Line Hills district of the Coastal Plain physiographic province of southwestern Georgia in Sumter County (fig. 1). The area includes two, 16.7-acre farm fields and approximately 40 acres of adjacent woodland--a total of 73.4 acres (fig. 1). The fields are in an interstream area that separates two, small watersheds. The area is characterized by a relatively level cultivated tract having wooded midslope and toe-slope areas extending to the adjacent streams. Altitudes range from

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about 390 to 470 ft (feet) above sea level. Interior drainage is typical of the area, resulting from sandy, highly permeable, surface soils. A 2-acre planting area (300 by 290.4 ft) was delineated within one of the 16.7-acre fields and instrumented. Altitudes in the planting area range from about 458 to 462 ft above sea level.

Method of Study

Permanent monitoring stations are located randomly at 12 sites in the 2-acre planting area (fig. 1). At each of the 12 sites, continuous, undisturbed soil core were collected from land surface to the saturated zone. Saturated hydraulic

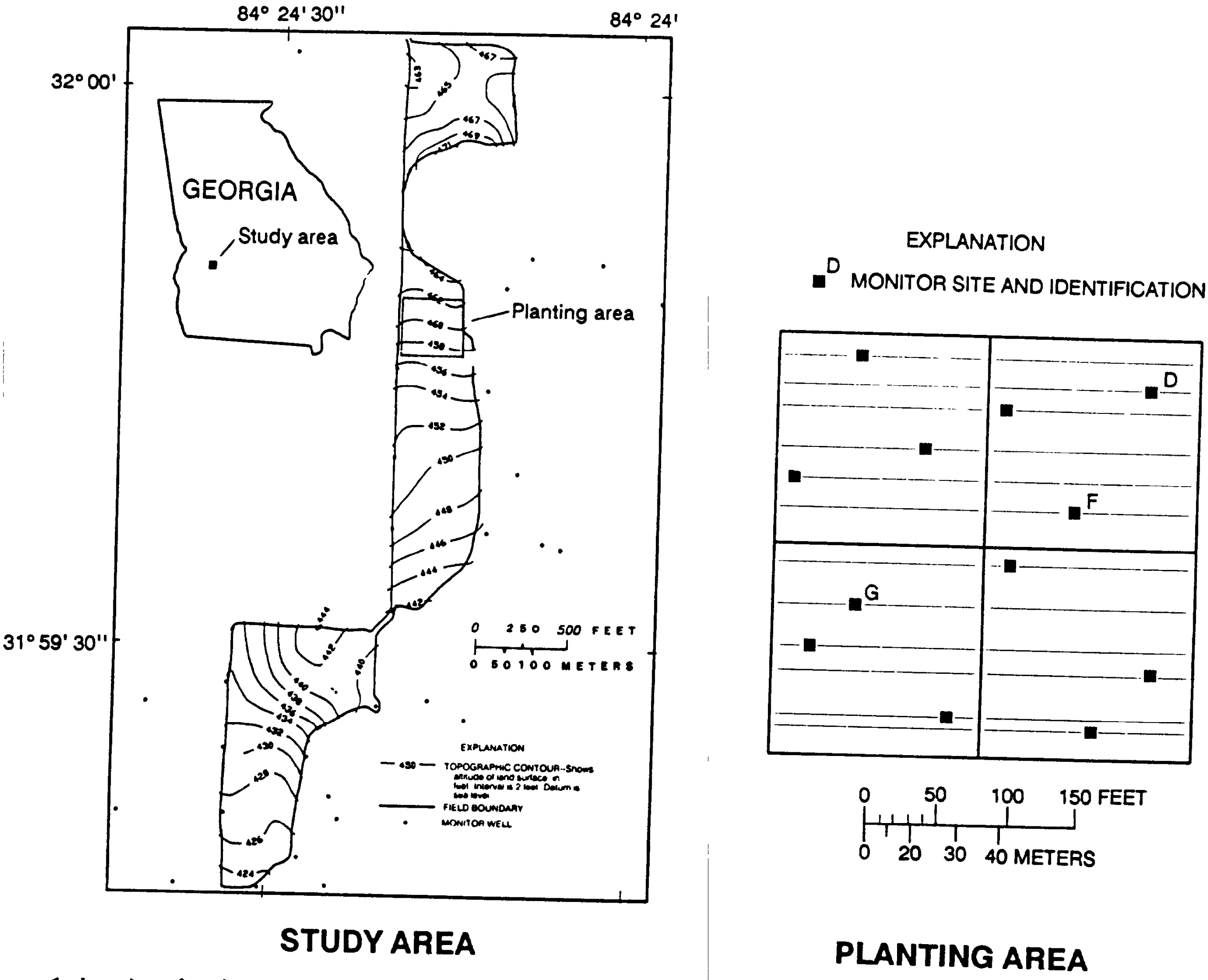

Figure 1. Location of study area, planting area, and monitor sites in the planting area.

The hydrogeologic units of importance to this study are, in descending order (1) the undifferentiated overburden, consisting of alternating and intermittent layers of sand, clayey sand, and clay; (2) the Tallahatta Formation (in the Claiborne Group), composed of fine-to-coarse, quartz sand; and (3) the Tuscahoma Formation, which consists of homogeneous, well sorted, glauconitic, very fine-to-fine, argillaceous, quartz sand.

The unsaturated zone includes the undifferentiated overburden and the upper part of the Tallahatta Formation, and ranges in thickness from about 26 to 30 ft. The saturated zone (Claiborne aquifer) is restricted to the lower part of the Tallahatta Formation and ranges in thickness from about 8 to 15 ft in the planting area. It is underlain by the Tuscahoma Formation and generally is unconfined.

conductivity was determined for sections of the soil core in the laboratory by using a falling-head, flexible-wall permeameter. Subsamples of the soil core were analyzed to determine pretreatment concentrations of agrichemical residues and potassium bromide.

Subsequent to tilling and fertilization, corn was planted during June 1989, and atrazine, alachlor, carbofuran, and potassium bromide were applied, in liquid form. The pesticides were applied in accordance with recommended rates provided by each manufacturer. A quantity of 277 lbs (pounds) of potassium bromide salt, or 186 lbs of bromide, was uniformly applied over the planting area as a conservative tracer.

To evaluate the rate of migration and the fate of the compounds applied in the planting area, more than 4,000 soil samples were collected since June 1989. Soil/pore water extracts were removed from the samples and bromide determinations were made by using an ion chromatograph. For each sampling period, a vertical profile of the bromide distribution was developed as well as a computation of the center of mass and total of mass. Thus, a record has been maintained since application of the relative position of the bromide mass and total bromide in the soil column at selected time periods over the entire plot area.

RESULTS

Results of soil-core analyses, borehole geophysical logging, and ground-penetrating radar surveys indicate that the lithology and hydraulic characteristics of the unsaturated zone are heterogeneous and vary substantially over a small area. The northeastern part of the planting area occupies the topographic high position and is the crest of the drainage divide separating the two watersheds. This part of the planting area is underlain by unconsolidated sediments that are dominated by an 8-ft-thick layer of dense clay that extends from a depth of about 3 to 11 ft below land surface. At site D, in the northeastern part of the planting area, the saturated vertical hydraulic conductivity of the clay layer averages about 0.36 ft/d (feet per day). In this area, the saturated vertical hydraulic conductivity ranges from 0.01 ft/d at a depth of about 5 ft, to 4.91 ft/d at a depth of about 26 ft. Downslope in the southwestern part of the planting area at site G, the clay layer is absent and the sediments are characterized by relatively clean, medium quartz sand. In this area, the vertical hydraulic conductivity ranges from 1.02 ft/d at a depth of about 7 ft, to 5.03 ft/d at a depth of about 23 ft. Between the northeastern and southwestern parts of the planting area is a transition zone with intermediate lithologies and vertical hydraulic conductivities.

Analyses of bromide concentrations indicate that during the first 70 days after application the center of mass of the bromide tracer migrated to a uniform depth of about 48 in. (inches) below land surface at sites D, F, and G (fig. 2). The total mass of bromide was uniform in the soil columns (table 1).

Table 1. *Total bromide mass in the soil columns during the 350-day period since application*

[µg, micrograms; NS, not sampled]

Site	Time since application (days)	Bromide, in soil column (µg)
D	70	948
	145	938
	225	473
	350	258
F	70	860
	145	784
	225	1,543
	350	NS
G	70	899
	145	1,302
	225	785
	350	1,423

From 70 to 145 days after application, the bromide remained at about the same depth in the northeastern part of the plot at site D and progressively increased in depth during migration downslope (fig. 2). After 145 days, the center of mass of bromide in the southwestern part of the planting area at site G was at a depth of 72 in. Total mass of bromide remained nearly uniform.

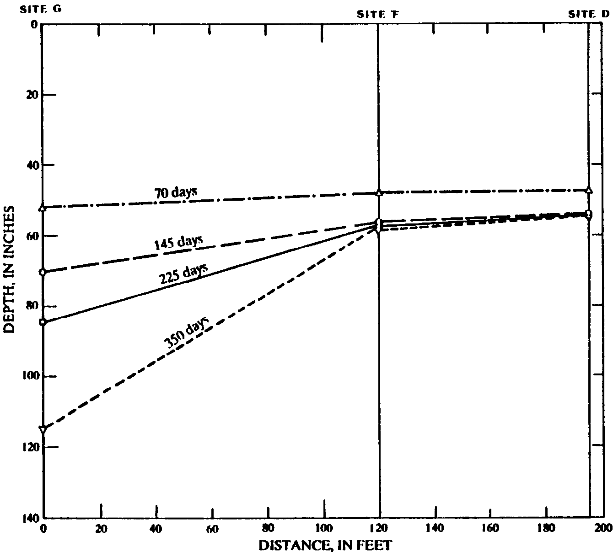

Figure 2.--Bromide distribution in the unsatureted zone 70, 145, 225, and 350 days after applicetion.

Figure 2. Bromide distribution in the unsaturated zone 70, 145, 225, and 350 days after application.

Samples collected 225 days after application indicated that the center of mass had moved slightly downward at site D, but had moved significantly downward at site G. More importantly, the total bromide mass had decreased at site D from about 950 µg (micrograms) to less than 500 µg. In the transition zone at site F, the total bromide mass had increased from 860 µg to more than 1,500 µg (table 1).

Analyses of samples collected 350 days after application indicated that the vertical position of the bromide at site D was nearly unchanged (approximately 60 in. below land surface); however, the total mass of bromide had decreased to about 250 µg (fig. 2 and table 1). At site G, the center of mass had migrated to a depth of about 120 in., but, more importantly, the total mass of bromide in the soil column at that site had nearly doubled since the previous samples were collected.

SUMMARY AND CONCLUSIONS

This study was conducted as a part of a cooperative research project underway since 1986 near Plains, Ga., in the Fall Line Hills district of the Coastal Plain physiographic province of southwestern Georgia in Sumter County. The USGS, ARS, and USEPA instrumented a 2-acre research plot (planting area) to define and evaluate the factors that control the fate and transport of conventionally applied agrichemicals. It was hypothesized that the heterogeneity in hydraulic conductivity of the unsaturated zone has a substantial effect on the rates of infiltration and in the transport pathways of solute.

The hydrogeology of the unsaturated zone is heterogeneous and varies substantially over a small area. The northeastern part of the planting area is characterized by a shallow, 8-ft-thick, layer of clay having relatively low vertical hydraulic conductivity (average, about 0.36 ft/d). The southwestern part of the area is characterized by clean, medium quartz sand. Here, the vertical hydraulic conductivity ranges from 1.02 to 5.03 ft/d. Between the northeastern and southwestern parts of the planting area is a transition zone having intermediate lithologies and vertical hydraulic conductivities.

Subsequent to tilling and fertilization, corn was planted during June 1989, and atrazine, alachlor, carbofuran, and a conservative tracer (potassium bromide) were applied, all in liquid form, and since application, more than 4,000 soil samples have been collected for chemical analysis to evaluate the rates of degradation and transport of the applied chemicals. The results indicate that, during the first 70 days after application, the center of mass of bromide infiltrated to a depth of about 48 in. From 70 to 350 days, the infiltration rate of the bromide mass was retarded at a depth of about 54 in. in the northeastern part of the area. However, in the southwestern part of the area, the tracer continued to infiltrate vertically and was at a depth of about 114 in. In addition, the total bromide mass in the soil column progressively decreased with time in the northeast and increased in the southwest.

Preliminary results suggest that the lateral transport of the bromide solute may be a substantial component of its dispersion in the unsaturated zone and that soil heterogeneity significantly affects the migration rates and pathways of surface-applied chemicals. Moreover, one-dimensional transport in the un saturated zone is rare and may be observed only where the vertical soil column is homogeneous and permeable. The lateral migration of solute at the interface between permeable and less permeable material may account for a large part of the dispersion of agrichemicals in the unsaturated zone. Also, the rates of movement may be greater in the lateral than observed in the vertical.