THE MOVEMENT AND STORAGE OF WATER IN NORTH CAROLINA SOILS AND THE ROLE OF THE SOIL IN DETERMINING WATER QUALITY

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INTRODUCTION

Essentially all of the water used by agriculture and industry and for human consumption falls on the soil. In North Carolina, this amounts to approximately 50 inches per year. This will be lost from the soil in one of the three following ways: 1) by surface runoff, 2) by percolation to the groundwater, and 3) by evaporation and/or transpiration. The distribution among these three categories will be determined by the nature of the precipitation and, to a very large extent, by the properties of the soil. If the precipitation rate exceeds the infiltration capacity of the soil, runoff will occur. Under most conditions, runoff will carry some dissolved and undissolved material with it. This removal of materials from the soil usually is harmful at the point of origin by depleting soil fertility, and possibly again by causing water contamination and eutrophication.

There are two important facets to percolation. First, percolating waters dissolve some materials out of the soil and carry them to streams, lakes, and oceans where they may accumulate as undesirable salt concentrations. Second, many materials may be filtered out of the water as it percolates through the soil. The soil is the world's greatest natural filter. The suitability of any particular soil area as a filter is determined by its individual physical and chemical properties.

The amount of water lost from the soil by evaporation obviously is affected by the climatic conditions and, also, to a very large extent, by the properties of the soil. Evaporation in turn affects the properties

of the soil. When rain water soaks into the soil to a given depth, it dissolves certain materials. When the water moves back to the surface and is lost by evaporation, these dissolved materials precipitate at or near the surface leaving the soil salty. The vast areas of saline soils throughout the world are formed in this way.

It should be obvious from the above that water affects soil properties and that soil affects water quality. Some of the effects of soil on water are beneficial and some, perhaps, harmful. The nature and the extent of the effect is influenced by soil characteristics. It is, therefore, important to know something about the physical, chemical, and mineralogical properties of soils affecting the movement and storage of water in them.

PURPOSE AND SCOPE OF THE PROJECT

The land area of North Carolina is approximately 31 million acres. Of this, 14 million acres are in the Coastal Plain, 12 million in the Piedmont Plateau, and 5 million in the Mountain area. Included in the 31 million acres are sand dunes and swamp areas in the eastern part of the State, rock outcrops and rough, stony land in the Piedmont and Mountains, organic soils and mineral soils ranging from coarse sands to heavy clays. The mineral soils vary in depth from a few inches to many feet. The topography varies from flat, level lowlands to rough mountain terrain. Drainage varies from very poor in the lowlands of the east to excessive on the more sandy upland soils of the Coastal Plain and on the steep topography in parts of the Piedmont and in the mountains.

Almost all of the soils in the State have been classified and mapped, even though many of the county maps are old and out of date. The Soil Conservation Service Soil Survey Division, in cooperation with the North Carolina Agricultural Experiment Station, has continued to map the soils of the State, many on an individual farm basis but also by county units. The bulletins accompanying the soil survey maps give a description of the various soil types within the area mapped. These descriptions consist essentially of the visual observations made by the surveyor in the field. The major physical descriptions are texture, structure, and consistency. Data on water-holding characteristics, bulk density, compactness, hardness, etc. are usually given in very general terms, without data. It is common knowledge that sands have lower water-holding capacities than finer textured soils so textural descriptions are of value.

The 31 million acres of land in North Carolina has been classified into more than 200 soil series. Many of the series are subdivided into types on the basis of textural differences in the surface soil. While many of the more than 200 soil series are similar in some physical characteristics, there are wide differences in others. In fact, physical properties serve as a major basis for differentiation between series.

A few of the series have been studied in considerable detail with respect to their physical, chemical, and mineralogical properties; however, there has not been a systematic study of the water-holding and drainage soils of the State. The major purpose of this investigation was to make such a systematic study. Physical analyses have been made of 69 soil series representing approximately two-thirds of the total land area of the State. Those excluded represent relatively unimportant agricultural soils, the organic soils, and certain of the less extensive soil series.

Physical characteristics of both topsoil and subsoil have been studied. The analyses included bulk density, total porosity, pore-size distribution, total, available water-holding capacity, and hydraulic conductivity. The data are given in Tables 1, 2, and 3 for the Coastal Plain, Piedmont, and Mountain soils, respectively.

For those who desire more detailed descriptions of the various soils in the State, the following are recommended:

1. Lee, William D. 1955. The soils of North Carolina -- Their formation, identification, and use. North Carolina Agricultural Experiment Station. Technical Bulletin No. 115.

2. Goldston, E. F. et al. 1960. Soil survey of Alamance County, North Carolina. U. S. Department of Agriculture, Soil Conservation Service, in cooperation with the North Carolina Agricultural Experiment Station.

3. Goldston, E. F. et al. 1954. Soil survey of Buncombe County, North Carolina. U. S. Department of Agriculture, Soil Conservation Service, in cooperation with the North Carolina Agricultural Experiment Station and the Tennessee Valley Authority.

4. Goldston, E. F. 1959. Soil survey of Duplin County, North Carolina. U. S. Department of Agriculture, Soil Conservation Service, in cooperation with North Carolina Agricultural Experiment Station.

5. Goldston, E. F. et al. 1954. Soil survey of Haywood County, North Carolina. U. S. Department of Agriculture, Soil Conservation Service, in cooperation with the North Carolina Agricultural Experiment Station and the Tennessee Valley Authority.

6. Cawthorn, Joel W. et al. 1964. Soil survey of Iredell County, North Carolina. U. S. Department of Agriculture, Soil Conservation Service, in cooperation with the North Carolina Agricultural Experiment Station.

The above county soil surveys are listed because they are among the newer ones and because many of the soil samples studied were taken from the counties listed.

A second objective of the experiment was to determine the loss of certain herbicides as a function of soil water loss. This work was done by a graduate student, Mr. H. D. Scott, who completed his Master's thesis, copies of which have been supplied to the Water Resources Research Institute. A summary of his work appears later in this report.

A third objective of the project was to study the losses of certain inorganic ions (cations and anions) from soils as a function of previous treatment and as a function of soil water content. This phase of the project has been conducted by a graduate student, Mr. J. B. Hart, Jr., who is now in the process of preparing a Ph.D. thesis on the results. The data are summarized later. Copies of the Ph.D. thesis will be supplied to the Water Resources Research Institute when completed.

METHODS

Soil Physical Studies

Soil samples were collected from the topsoil and the subsoil of most of the major soil series in the Coastal Plain, Piedmont, and Mountain sections of the State. Undisturbed soil cores were taken with the Lutz Soil Sampler.[1] The cylinders were capped in the field to prevent loss of water in transport. In the laboratory, one end of the cylinder was covered with two layers of cheese cloth, and the samples were then placed in a water bath until completely saturated. They were then removed and the saturated weight determined. Following that, they were put on a tension table[2] and brought to equilibrium with fifty centimeters water tension. After weighing, they were placed in a pressure cooker[3] and subjected to pressures of 0.1, 0.35, 0.5, and 1 bar, the samples being weighed after equilibrium at each pressure. Later samples were taken from the cores and the water-holding capacity at 15 bars determined in the pressure membrane apparatus.[3]

Before disturbing the soil in the cylinders, hydraulic conductivity measurements were made using an apparatus especially designed by the author for this report.

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[1] Lutz, J. F. 1947. Apparatus for collecting undisturbed soil samples. Soil Science. 64:399-401.

[2] Leamer, Ross W. and Byron Shaw. 1941. A simple apparatus for measuring non-capillary porosity on an extensive scale. Jour. Amer. Soc. Agron. 33:1003-1008.

[3] Richards, L. A. 1949. Methods for measuring soil moisture tension. Soil Science. 68:95-112.

After the hydraulic conductivity measurements had been completed, the samples were oven dried and the total porosity and bulk density calculated.

The total water-holding capacity of the soil is considered as the percentage of water held between the 50-centimeter tension and oven drying. The "available" water-holding capacity is considered as the percentage of water held between the 50-centimeter and the 15-bar pressures. Thus, the difference between the total and the available water-holding capacities represents the percentage of water that is held so tightly by the soil that it is not available to plants (Tables 4, 5, and 6).

Herbicide Losses

This portion of the experiment consisted of treating clay suspensions with several different herbicides and studying the losses of the herbicides in increments of water removed at different pressures. Kaolinite and montmorillonite were used. X-ray diffraction and other analyses showed these to be relatively pure. Some of their physical and chemical properties are recorded in Table 7.

Kaolinite suspensions were prepared by mixing 50 grams of clay, one milliliter of potassium azide solution, a volume of herbicide stock solution to give the desired rate, and enough deionized water to make a total of 170 grams.

The montmorillonite suspensions were prepared by adding 25 grams of montmorillonite, one milliliter of potassium azide solution, enough herbicide stock solution to give the desired rate and deionized water to

make a total of 500 grams. Each of the suspensions was shaken on a mechanical shaker for one hour to insure thorough mixing.

Six herbicides were used. They were 2,4-D, simazine, atrazine, diuron, fluometuron, and CIPC. Each was added to each clay at the rate of 1 and of 4 ppm. All herbicides were C14 labeled.

A given volume of each herbicide suspension was poured onto the cellophane membrane in a pressure membrane extractor and brought to equilibrium in successive steps with the following pressures: .3, .5, 1, 5, 10, and 15 bars. The extract collected at each pressure increment was analyzed for herbicide using a nuclear-Chicago No. 6081 ambient temperature liquid scintillator. Each sample was counted for two 10-minute intervals with all totals being greater than four thousand counts per minute. Background counts were determined at each counting. From the volume of the extract and the counts per minute, the total amount of herbicide in each extract was calculated. A more detailed description of the procedure is found in the thesis prepared by Mr. H. D. Scott on this portion of the work.[4]

Cation and Anion Losses From Clay Minerals

Kaolinite and montmorillonite were saturated with sodium and potassium by treating suspensions of the clay with sodium or calcium chlorides and washing free of chloride. The clays were then freeze-dried and stored until ready for use. Suspensions were prepared using

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[4] Scott, Hubert Donovan. 1968. Release of herbicides from clay minerals as a function of soil moisture. Master of Science Thesis, Department of Soil Science, North Carolina State University.

deionized water and extracts secured at various pressures using the pressure membrane apparatus. Pressures of .05, .5, 1, 5, and 15 bars were used. Each extract was analyzed for sodium or calcium (depending upon the treatment), aluminum, and silicon. The pH of each extract was determined. A more detailed description of the procedure will be given in the thesis which is now being prepared by Mr. J. B. Hart, Jr. Copies will be made available to the Water Resources Research Institute.

RESULTS AND DISCUSSION

Soil Physical Properties

Data on the physical properties of soils from the Coastal Plain, Piedmont, and Mountain sections of the State are given in Tables 1, 2, and 3, respectively. These data are on the major soil series, and the ones listed cover approximately two-thirds of the total land area of the State. Some of the more important and more extensive series were sampled at several locations. Others were sampled at only one place. In all cases, however, the location sampled was typical and representative of the series. It must be recognized, however, that there is natural variation in each series and that the properties of any particular soil can and do change with season, with cultural practices, etc. These changes would be greater in the topsoil than in the subsoil. In fact under most conditions, subsoil changes would be relatively slight in all properties studied.

It is obvious that there are differences among the three physiographic provinces and among the individual soils in each province. No attempt has been made to group the soils on the basis of any individual characteristic since it appears that nothing would be gained by such a grouping insofar as this report is concerned.

Table 1. Hydraulic conductivity, bulk density, and porosity of Coastal Plain soils

Soil Series	Location (County)	Horizon	Depth (in)	k (in/hr)	B.D. (gm/cm^3)	Total Porosity (%)	Water lost between tensions of: (% by vol) 0-50 cm	50-100 cm	100-335 cm	335-1000 cm	1000-15000 cm
Barclay v.f.s.l.	Pasquotank	Ap	2-4	.29	1.50	41.2	4.6	6.6	9.5	2.5	5.6
		B2	15-17	9.59	1.65	38.9	5.2	3.4	4.7	3.1	13.7
Barclay v.f.s.l.	Pasquotank	Ap	3-5	.47	1.42	43.8	6.9	6.8	10.0	2.1	7.5
		B2	15-17	3.03	1.46	46.7	5.5	3.1	4.3	3.5	11.6
Bayboro si.l.	Pasquotank	Ap	2-4	10.06	1.33	45.5	8.3	2.4	3.5	1.8	16.9
		B22	13-15	1.80	1.44	43.4	8.9	.5	.9	.5	18.3
Bayboro si.l.	Pasquotank	Ap	3-5	25.20	.83	63.2	15.9	6.6	9.8	2.7	15.7
		B1	10-12	4.12	1.40	45.9	11.3	1.4	2.0	2.1	10.5
		B22	19-21	.51	1.58	40.0	8.8	.7	1.1	1.6	10.8
Bertie f.s.l.	Pasquotank	Ap	2-4	.45	1.49	41.6	8.2	5.1	7.5	1.1	5.5
		B1	8-10	2.42	1.77	31.7	6.1	2.3	3.2	2.4	8.0
		B2	19-21	.55	1.74	36.0	7.8	2.0	2.9	2.4	12.9
Bertie f.s.l.	Pasquotank	Ap	2-4	.53	1.60	37.4	9.0	5.6	8.4	3.2	3.3
		B2	12-14	.45	1.64	38.2	8.2	2.4	3.7	2.5	7.8
Bladen si.l.	Pasquotank	Ap	3-5	2.02	1.34	48.9	15.9	3.1	4.1	1.7	13.1
		B21	10-12	.43	1.57	40.8	8.1	.3	.3	.8	18.0
		B22	21-23	.54	1.58	42.1	5.1	0	.1	1.0	24.3
Caroline s.l.	Johnson	Ap	5-7	5.55	1.66	36.9	11.9	2.7	3.9	1.4	8.2
		B21	14-16	3.67	1.36	47.5	12.2	1.7	2.7	2.1	22.5
		B22	20-22	.19	1.54	42.9	6.4	1.4	1.9	1.5	24.6

Table 1. (Continued)

Soil Series	Location (County)	Horizon	Depth (in)	k (in/hr)	B.D. (gm/cm^3)	Total Porosity (%)	Water lost between tensions of: (% by vol.) 0-50 cm	50-100 cm	100-335 cm	335-1000 cm	1000-15000 cm
Chesterfield s.l.	Johnston	Ap	4-6	1.37	1.63	36.7	11.2	4.3	5.9	1.1	9.7
		A2	10-12	2.98	1.69	36.8	10.7	4.5	5.2	1.6	8.8
		B2	28-30	.42	1.55	41.9	5.6	2.2	3.4	1.9	9.0
Chesterfield f.s.l.	Johnston	Ap	3-5	8.52	1.45	43.4	12.8	3.1	4.2	1.0	7.9
		B		12.07	1.62	38.9	9.8	2.6	3.4	.7	10.5
Coxville si.l.	Duplin	Ap	3-5	.75	1.57	41.0	7.2	2.1	3.0	2.8	5.2
		B	9-11	.33	1.58	39.3	5.1	1.3	1.9	3.0	11.0
Craven f.s.l.	Duplin	A	3-5	4.2	1.53	43.1	11.1	4.5	4.7	3.5	11.2
		B	9-11	1.7	1.50	44.0	7.2	2.0	3.1	3.0	9.8
Dunbar v.f.s.l.	Duplin	Ap	3-5	1.86	1.63	38.3	9.5	3.2	4.7	1.3	9.1
		B	8-10	.34	1.68	35.6	4.4	1.8	2.3	1.9	12.0
Duplin v.f.s.l.	Duplin	Ap	3-5	2.27	1.52	41.5	13.5	3.2	4.6	2.2	6.2
		B	8-10	.40	1.54	40.5	6.9	1.8	2.1	2.1	14.7
Elkton si.l.	Pasquotank	Ap	3-5	1.23	1.68	36.9	5.9	2.0	3.1	.8	11.4
		B21	12-14	.83	1.72	34.5	7.4	2.6	3.6	1.0	7.7
		B22	24-26	.26	1.62	38.2	6.6	.8	1.1	.9	21.6
Elkton si.l.	Pasquotank	Ap	3-5	.34	1.44	44.3	7.8	5.0	6.7	.1	8.4
		B21	13-15	.40	1.49	43.5	5.2	1.3	1.7	.7	12.0
		B22	24-26	.71	1.47	45.6	4.7	1.2	1.7	.6	17.8

Table 1. (Continued)

Soil Series	Location (County)	Horizon	Depth (in)	k (in/hr)	B.D. (gm/cm^3)	Total Porosity (%)	Water lost between tensions of: (% by vol.) 0-50 cm	50-100 cm	100-335 cm	335-1000 cm	1000-15000 cm
Fuquay l.s.	Johnston	Ap	4-6	17.50	1.57	39.5	14.5	3.6	4.9	1.6	11.6
		A2	16-18	3.30	1.67	37.0	10.0	3.0	3.9	2.2	13.6
		B1	30-32	1.42	1.63	36.9	8.9	2.5	3.7	2.9	13.9
Klej l.s.	Duplin	Ap	3-5	100 +	1.26	50.9	33.8	1.9	2.6	1.3	3.3
		B	12-14	14.10 +	1.63	39.6	16.1	2.4	3.2	1.8	4.1
Lakeland s.	Duplin	A	3-5	100 +	1.52	43.5	28.0	3.5	4.9	1.7	2.1
		B	11-13	100 +	1.63	38.4	22.0	3.9	5.0	2.2	1.9
Leon s.	Johnston	Ap	6-8	20 +	1.39	46.8	22.2	6.3	5.2	3.7	4.2
		A2	16-18	40 +	1.64	38.4	17.2	5.8	4.8	3.0	1.7
		Bh	23-25	.1 -	1.61	39.8	5.6	2.7	2.5	1.1	3.5
		C	34-36	15 +	1.65	38.7	26.2	1.5	2.1	2.8	1.8
Lynchburg s.l.	Johnston	Ap	4-6	25 +	1.65	38.0	21.6	2.8	3.7	2.8	3.7
		A2	11-13	8.5	1.79	34.5	11.3	3.1	3.6	2.8	4.6
		B2	20-22	8.2	1.70	36.2	15.0	2.6	3.5	2.7	7.6
Marlboro s.l.	Duplin	A	3-5	4.54	1.55	42.2	14.6	5.5	7.5	2.2	4.7
		B	10-12	1.15	1.52	42.6	7.1	1.1	1.4	1.8	18.3
Nixonton v.f.s.l.	Pasquotank	Ap	3-5	2.26	1.36	48.3	9.3	7.1	8.4	2.0	9.1
		A2	8-10	8.50	1.42	46.2	7.3	3.3	4.4	3.4	10.5
		B2	18-20	1.40	1.45	45.6	7.8	7.6	9.8	4.0	6.7

Table 1. (Continued)

Soil Series	Location (County)	Horizon	Depth (in)	k (in/hr)	B.D. (gm/cm^3)	Total Porosity (%)	Water lost between tensions of: (% by vol.) 0-50 cm	50-100 cm	100-335 cm	335-1000 cm	1000-15000 cm
Nixonton si.l.	Pasquotank	Ap	3-5	.92	1.22	52.5	12.4	7.2	9.3	1.2	7.5
		A2	8-10	.64	1.53	41.7	5.7	1.4	1.9	3.7	11.4
		B2	17-19	.89	1.53	43.2	5.2	1.5	1.8	3.9	15.0
Norfolk s.l.	Johnston	Ap	3-5	3.48	1.49	42.8	21.8	2.1	3.1	1.5	4.8
		B	12-14	.81	1.70	35.0	10.4	1.6	2.4	2.0	11.4
Norfolk f.s.l.	Johnston	Ap	3-5	2.64	1.59	37.8	21.0	2.7	3.5	1.8	4.9
		B	9-11	.34	1.74	33.7	9.1	2.8	3.7	1.3	12.0
Norfolk s.l.	Scotland	Ap	3-5	5.1	1.56	40.7	16.8	5.4	6.9	3.1	6.8
		B1	10-12	2.2	1.58	39.5	10.1	5.2	7.7	3.7	9.3
Orangeburg s.l.	Johnston	Ap	2-4	10.7	1.45	45.2	20.4	2.9	3.7	2.4	4.8
		B21	10-12	2.4	1.48	44.1	7.5	4.0	5.7	3.5	12.6
Othella si.l.	Pasquotank	Ap	3-5	6.95	1.51	41.5	9.5	4.6	7.5	2.9	6.2
		B1	10-12	.28	1.43	44.5	8.6	1.6	2.4	1.7	10.5
		B22	23-25	.20	1.54	41.5	9.0	1.2	1.7	1.5	12.2
Othella si.l.	Pasquotank	Ap	2-4	1.85	1.50	42.1	6.3	1.1	2.5	3.9	12.1
		B2	11-13	.61	1.41	46.6	7.3	.4	.6	2.9	16.6
Pasquotank f.s.l.	Pasquotank	Ap	3-5	8.53	1.38	46.1	9.5	3.2	4.1	1.9	12.0
		B2	14-16	2.65	1.28	51.5	10.1	2.1	3.0	3.2	13.6
Pasquotank si.l.	Pasquotank	Ap	2-4	3.55	1.32	49.5	7.8	2.2	2.9	1.0	15.4
		B2	13-15	1.56	1.11	57.1	7.1	2.7	3.8	2.7	15.1

Table 1. (Continued)

Soil Series	Location (County)	Horizon	Depth (in)	k (in/hr)	B.D. (gm/cm^3)	Total Porosity (%)	Water lost between tensions of: (% by vol.) 0-50 cm	50-100 cm	100-335 cm	335-1000 cm	1000-15000 cm
Plummer f.s.	Duplin	Ap	3-5	90.0	1.52	42.5	21.5	4.5	5.5	1.8	3.8
		B	9-11	24.4	1.67	36.8	13.6	4.4	5.4	2.2	2.1
Portsmouth f.s.l.	Duplin	Ap	3-5	48.3	1.14	55.2	5.3	.8	1.1	1.4	14.8
		B	9-11	5.6	1.12	56.5	5.1	1.9	2.7	4.6	12.5
Ruston s.l.	Duplin	Ap	3-5	10.5	1.53	42.3	20.2	5.8	6.6	2.1	3.3
		B1	10-12	2.7	1.36	48.6	11.4	6.1	6.9	4.3	9.4
Rains l.s.	Duplin	A	2-4	109.0	1.65	37.8	12.8	3.4	4.3	2.1	5.9
		B	11-13	8.1	1.82	32.0	5.8	1.5	2.6	3.5	10.8
Rutledge l.s.	Duplin	A	6-8	99.0	1.29	50.1	15.4	3.2	3.9	3.2	7.4
		B	15-17	35.0	1.54	37.4	21.1	2.8	1.8	1.9	2.9
Varina l.s.	Johnston	Ap	4-6	14.2	1.69	36.6	11.1	3.1	3.8	2.3	3.0
		A2	12-14	8.5	1.77	33.3	9.2	2.4	4.3	2.6	5.3
		B2	20-22	14.6	1.69	36.3	9.3	2.5	3.0	2.5	16.7
Weeksville si.l.	Pasquotank	Ap	2-4	5.7	1.28	51.6	8.4	4.7	5.6	2.1	11.2
		B21	14-16	9.9	1.20	54.7	6.3	2.0	2.7	1.8	16.1
Weeksville si.l.	Pasquotank	Ap	2-4	15.6	1.23	53.6	12.1	3.2	4.2	5.1	14.9
		B2	11-13	14.0	1.20	52.8	8.4	2.6	3.0	2.8	12.9
Woodstown l.s.	Duplin	Ap	4-6	100 +	1.39	47.6	25.2	4.0	4.8	2.7	5.4
		B2	14-16	100 +	1.53	42.3	19.0	5.1	5.6	2.9	2.4

Table 2. Hydraulic conductivity, bulk density, and porosity of Piedmont soils

Soil Series	Location (County)	Horizon	Depth (in)	k (in/hr)	B.D. (gm/cm^3)	Total Porosity (%)	Water lost between tensions of: (% by vol.) 0-50 cm	50-100 cm	100-335 cm	335-1000 cm	1000-15000 cm
Alamance si.l.	Chatham	A	3-5		1.35	48.2	6.9	3.1	3.9	4.5	12.4
		B	7-9		1.40	46.5	4.2	2.9	3.1	5.1	11.8
Altavista f.s.l.	Rowan	Ap	2-4	7.4	1.54	42.1	12.0	3.6	6.7	1.3	6.7
		B	9-11	1.6	1.51	43.3	6.4	2.1	2.6	1.6	11.0
Appling s.l.	Wake	Ap	3-5	6.4	1.35	48.7	17.8	2.4	3.1	2.0	5.3
		B2	8-10	.6	1.38	47.8	4.9	.7	.9	1.5	16.7
Cecil c.l.	Davie	Ap	3-5	3.5	1.33	49.7	13.6	4.0	4.5	3.6	5.4
		B22	9-11	.8	1.42	46.4	9.1	2.3	3.2	2.4	11.4
Cecil f.s.l.	Wake	Ap	2-4	4.6	1.53	42.3	14.1	5.0	5.7	3.2	4.7
		B2	10-12	.7	1.48	44.2	11.8	1.8	2.3	2.7	10.5
Davidson c.l.	Rowan	Ap	2-4	8.5	1.47	45.5	16.7	3.1	3.3	1.9	13.2
		B	7-9	5.2	1.48	46.7	12.0	2.4	3.4	1.4	17.4
Davidson c.l.	Rowan	Ap	2-4	3.8	1.51	44.3	15.2	1.3	3.2	1.9	14.1
		B	8-10	3.2	1.48	45.4	9.8	3.1	3.7	1.7	16.8
Davidson c.l.	Davie	Ap	3-5	4.2	1.42	46.7	12.4	2.9	2.4	.8	16.1
		B	9-11	3.7	1.36	48.8	9.6	2.8	3.1	1.2	18.5
Davidson c.l.	Iredell	Ap	3-5	6.1	1.37	48.2	12.5	3.2	2.1	.7	17.3
		B	8-10	4.3	1.31	50.5	11.2	2.6	2.4	1.2	15.1
Durham s.l.	Wake	Ap	2-4	9.1	1.47	45.0	16.1	3.4	4.1	1.3	4.8
		B	8-10	.8	1.42	46.4	7.8	2.7	3.2	2.9	14.4

Table 2. (Continued)

Soil Series	Location (County)	Horizon	Depth (in)	k (in/hr)	B.D. (gm/cm^3)	Total Porosity (%)	Water lost between tensions of: (% by vol.) 0-50 cm	50-100 cm	100-335 cm	335-1000 cm	1000-15000 cm
Enon l.s.	Granville	Ap	3-5	8.6	1.49	43.1	16.6	3.0	3.4	1.8	3.9
		B	8-10	.3	1.40	46.3	8.1	2.5	2.8	2.0	13.7
Georgeville si.l.	Chatham	Ap	3-5	2.8	1.39	47.5	10.1	1.0	1.5	2.5	15.9
		B2	9-11	1.3	1.34	49.6	5.1	2.6	3.9	4.3	9.8
Granville s.l.	Wake	Ap	4-6	50 +	1.49	43.6	15.4	3.4	3.0	4.2	3.7
		A2	9-11	38.1	1.97	27.0	6.1	2.7	4.4	10.5	5.7
		B21	18-20	13.8	1.71	35.5	4.5	1.5	2.6	7.9	8.8
Helena s.l.	Alamance	A	3-5	5.6	1.60	39.5	7.2	3.4	4.5	4.0	8.5
		B	7-9	.4	1.62	37.9	3.4	2.0	2.5	3.5	13.1
Herndon si.l.	Chatham	Ap	3-5	3.1	1.41	47.1	10.9	2.2	2.8	3.3	14.1
		B21	10-12	.8	1.37	49.8	4.1	2.5	2.7	4.4	12.2
Iredell l.	Davie	Ap	3-5	2.9	1.62	38.9	10.3	6.2	1.1	2.1	9.7
		B1	7-9	.3	1.46	44.8	2.8	2.1	2.2	1.6	11.9
		B2	14-16	.2	1.45	45.2	1.6	2.4	2.4	1.2	9.8
Lloyd c.l.	Rowan	Ap	2-4	3.9	1.38	48.9	12.5	2.3	3.6	1.9	13.2
		B	8-10	2.3	1.32	51.3	9.0	1.3	2.0	1.8	17.1
Mecklenburg c.l.	Iredell	A	2-4	3.9	1.31	50.2	13.2	2.2	2.8	2.1	14.1
		B	8-10	1.4	1.28	50.7	5.4	2.7	1.9	3.2	15.0
White Store s.l.	Chatham	Ap	3-5	17.0	1.42	46.7	9.6	2.7	4.3	4.3	7.8
		B21	8-10	.4	1.47	44.4	2.9	1.2	2.0	1.4	5.2

Table 2. (Continued)

Soil Series	Location (County)	Horizon	Depth (in)	k (in/hr)	B.D. (gm/cm^3)	Total Porosity (%)	Water lost between tensions of: (% by vol.) 0-50 cm	50-100 cm	100-335 cm	335-1000 cm	1000-15000 cm
Wickham l.	Rowan	Ap	3-5	3.8	1.48	42.9	12.3	3.6	3.5	.8	9.4
		B1	8-10	2.1	1.40	47.0	7.1	1.8	1.9	1.4	11.9
Wickham s.l.	Rowan	Ap	2-4	5.3	1.50	43.4	16.1	4.9	5.0	2.2	7.6
		B1	7-9	2.3	1.51	43.0	9.9	1.3	2.1	1.2	9.8
Wilkes s.l.	Iredell	A	1-3	2.6	1.55	42.1	7.2	2.1	3.3	3.0	12.2
		B	5-7	.2	1.59	39.6	3.0	1.1	1.4	3.5	14.0

Table 3. Hydraulic conductivity, bulk density, and porosity of Mountain soils

Soil Series	Location (County)	Horizon	Depth (in)	k (in/hr)	B.D. (gm/cm^3)	Total Porosity (%)	Water lost between tensions of: (% by vol.) 0-50 cm	50-100 cm	100-335 cm	335-1000 cm	1000-15000 cm
Ashe l.	Buncombe	A	3-5	2.11	1.21	53.4	9.8	6.6	6.8	5.5	11.1
		B	7-9	.43	1.31	51.1	8.1	4.0	4.2	3.0	12.0
Ashe s.c.l.	Haywood	A	2-4	3.12	1.24	53.1	9.1	6.1	6.2	7.1	11.5
		B	7-9	.65	1.40	48.0	5.9	4.4	3.7	4.8	12.8
Balfour f.s.l.	Buncombe	A	2-4	4.22	1.39	48.5	12.5	7.5	8.0	5.4	5.5
		B	6-8	2.06	1.46	46.0	7.4	3.9	4.2	5.0	13.4
Balfour c.l.	Haywood	A	2-4	2.61	1.17	55.5	7.0	4.7	7.8	6.3	13.1
		B	5-7	1.28	1.32	50.3	6.1	2.8	3.7	4.9	14.2
Buncombe l.f.s.	Haywood	A	3-5	12.00 +	1.48	44.7	13.1	5.0	5.1	5.0	8.3
		B	9-11	8.50	1.42	46.9	24.6	4.1	4.2	3.9	3.5
Burton st.l.	Buncombe	A	4-6	2.24	1.24	54.2	12.1	5.5	8.5	5.2	11.4
		B	10-12	.80	1.38	47.6	5.6	2.8	3.9	7.1	12.6
Chandler l	Jackson	A	2-4	6.90	1.20	55.0	10.8	6.1	8.2	6.0	13.3
		B	6-8	4.78	1.32	51.2	9.4	6.5	6.2	5.8	12.1
Chester st.l.	Haywood	A	2-4	2.73	1.11	56.2	7.1	3.3	6.8	8.0	14.8
		B	7-9	1.61	1.15	55.1	5.8	4.7	2.9	7.3	12.1
Chester c.l.	Haywood	A	2-4	2.83	1.06	59.0	5.9	4.7	7.9	7.5	13.4
		B	7-9	.81	1.25	52.2	5.1	5.7	1.8	6.4	14.2
Clifton c.l.	Haywood	A	2-4	3.72	1.25	56.1	7.2	4.1	8.7	6.7	12.4
		B	7-9	.75	1.39	49.1	6.1	1.2	2.1	3.0	15.8

Table 3. (Continued)

Soil Series	Location (County)	Horizon	Depth (in)	k (in/hr)	B.D. (gm/cm^3)	Total Porosity (%)	Water lost between tensions of: (% by vol.) 0-50 cm	50-100 cm	100-335 cm	335-1000 cm	1000-15000 cm
Edneyville f.s.l.	Buncombe	A	3-5	4.27	1.42	47.3	13.4	7.1	8.5	5.1	7.2
		B	10-12	3.01	1.36	48.7	6.9	4.2	5.1	4.8	12.3
Fannin c.l.	Haywood	A	2-4	2.16	1.22	53.8	8.2	6.1	9.4	6.8	11.5
		B	7-9	.94	1.38	48.4	4.3	3.9	6.7	6.1	12.1
Fletcher si.l.	Buncombe	A	2-4	4.70	1.32	50.1	9.3	5.6	7.1	7.3	10.5
		B	10-12	2.31	1.45	46.3	6.2	3.8	4.7	5.9	15.2
Hayesville c.l.	Haywood	A	2-4	1.92	1.33	51.1	7.6	6.5	8.1	6.0	12.8
		B	7-9	.41	1.38	47.6	4.7	4.5	2.3	5.1	15.1
Hiwassee c.l.	Haywood	A	2-4	3.60	1.15	56.2	6.5	5.7	7.9	8.1	14.6
		B	7-9	1.70	1.36	48.9	5.1	4.2	2.2	5.8	16.1
Porters c.l.	Haywood	A	2-4	1.10	1.40	49.2	9.2	5.6	6.8	7.6	12.2
		B	7-9	.47	1.59	39.7	7.8	4.9	3.7	6.9	13.8
Porters st.l.	Haywood	A	2-4	6.43	1.27	51.2	8.3	5.7	7.7	6.8	10.1
		B	7-9	3.28	1.31	50.7	6.7	4.1	4.0	5.8	14.7
Rabun c.l.	Buncombe	A	3-5	3.82	1.19	55.5	6.9	4.2	6.6	7.0	15.4
		B	10-12	2.60	1.47	44.3	5.4	1.1	2.0	4.1	18.3
Ramsey sh.l.	Haywood	A	2-4	5.48	1.26	52.0	10.1	5.3	6.1	6.3	12.1
		B	7-9	4.62	1.37	47.1	6.2	3.1	1.9	3.2	14.2

Table 3. (Continued)

Soil Series	Location (County)	Horizon	Depth (in)	k (in/hr)	B.D. (gm/cm^3)	Total Porosity (%)	Water lost between tensions of: (% by vol.) 0-50 cm	50-100 cm	100-335 cm	335-1000 cm	1000-15000 cm
Talladega si.l.	Jackson	A	2-4	5.38	1.24	52.3	9.4	6.1	6.2	8.0	9.4
		B	7-9	2.94	1.30	50.8	8.2	5.6	5.7	4.3	13.8
Tate si.l.	Buncombe	A	2-4	6.81	1.21	54.2	8.7	7.7	5.4	8.1	10.2
		B	9-11	2.79	1.33	49.6	6.8	3.4	5.0	6.1	14.5
Tusquitee si.l	Haywood	A	2-4	4.76	1.18	55.6	10.2	6.8	6.1	8.6	15.7
		B	8-10	4.51	1.32	47.4	8.1	5.2	4.9	6.7	12.4
Watauga c.l.	Haywood	A	2-4	.72	1.21	53.3	6.4	7.1	7.0	6.8	13.9
		B	5-7	.43	1.28	51.0	5.1	2.0	1.9	6.0	15.9

Table 4. Acreage, and water-holding properties of some Coastal Plain soils

Soil Series	Approx Acreage in state	Percent of total	Unavailable water (15 bar percent by volume)		Available water-holding capacity 50 cm - 15 bar ten. (vol %)		Ave. thickness (in)		Total water-holding cap. A + B (in)
			A	B	A	B	A	B	
Barclay	24,000	.077	11.5	13.8	25.3	23.7	9	26	8.44
Bayboro	165,000	.532	12.6	16.5	29.7	16.8	12	30	8.60
Bertie	80,000	.258	11.1	11.7	19.9	17.5	8	24	5.79
Bladen	350,000	1.130	11.0	13.3	22.0	22.8	6	30	8.16
Caroline	178,000	.575	8.8	6.3	16.2	29.2	8	40	12.97
Chesterfield	20,000	.064	8.3	15.9	19.1	16.9	16	30	8.12
Coxville	200,000	.644	20.7	17.0	13.1	17.2	8	34	6.89
Craven	450,000	1.450	8.1	18.9	23.9	17.9	6	28	6.45
Dunbar	450,000	1.450	10.5	13.2	18.3	18.0	10	32	7.58
Duplin	120,000	.384	11.8	12.9	16.2	20.7	9	48	11.40
Elkton	110,000	.355	15.0	15.4	18.8	19.1	6	30	6.86
Fuquay			3.8	5.0	11.7	17.9	23	48	8.87
Kelj	500,000	1.612	8.0	16.0	9.1	11.5	10	No B 40 +	5.50
Lakeland	800,000	2.580	3.3	3.4	12.2	13.0	8	No B 40 +	6.18
Leon	200,000	.644	5.6	24.4	11.4	9.8	18	20	4.08
Lynchburg	800,000	2.580	6.3	4.8	13.0	15.3	12	36	7.07
Marlboro	200,000	.644	7.7	12.9	19.9	22.6	8	50	12.89
Nixonton	5,000	.016	15.4	12.8	25.9	22.6	10	26	8.47

Table 4. (Continued)

Soil Series	Approx Acreage in state	Percent of total	Unavailable water (15 bar percent by volume) A	Unavailable water (15 bar percent by volume) B	Available water-holding capacity 50 cm - 15 bar ten. (vol %) A	Available water-holding capacity 50 cm - 15 bar ten. (vol %) B	Ave. thickness (in) A	Ave. thickness (in) B	Total water-holding cap. A + B (in)
Norfolk	1,100,000	3.547	5.0	5.2	15.5	21.0	14	48	12.27
Orangeburg	25,000	.081	11.0	10.8	13.8	25.8	10	48	13.76
Othella	31,000	.010	13.5	18.1	20.4	17.8	11	28	7.22
Pasquotank	25,000	.081	17.8	22.6	21.4	23.1	10	30	9.08
Plummer	200,000	.644	5.4	9.1	15.6	14.1	12	No B 30 +	6.10
Portsmouth	350,000	1.130	31.8	29.7	18.1	21.7	11	33	9.15
Ruston	300,000	.968	4.3	10.5	17.8	26.7	10	48	14.60
Rains	400,000	1.290	9.3	7.8	17.7	18.4	10	36	8.39
Rutledge	350,000	1.013	17.0	6.9	15.7	9.4	16	No B 30 +	5.33
Varina			11.4	2.3	13.4	24.7	8	52	13.91
Weeksville	25,000	.081	16.9	24.5	25.5	22.0	10	28	8.70
Woodstown	180,000	.580	5.5	7.3	16.9	16.0	12	24	5.87

Table 5. Acreage, and water-holding properties of some Piedmont soils

Soil Series	Approx Acreage in state	Percent of total	Unavailable water (15 bar percent by volume)		Available water-holding capacity 50 cm - 15 bar ten. (vol. %)		Ave. thickness (in)		Total water-holding cap. A + B (in)
			A	B	A	B	A	B	
Alamance	280,000	.903	17.4	19.4	23.9	22.9	6	32	8.75
Altavista	25,000	.081	12.1	19.6	18.3	17.3	10	36	8.07
Appling	740,000	2.382	18.1	23.1	12.8	19.8	9	40	9.07
Cecil	2,450,000	7.901	13.7	16.5	18.0	18.3	8	40	8.76
Davidson	130,000	.419	10.1	13.0	23.8	24.2	10	50	14.48
Durham	40,000	.129	15.3	15.4	13.6	23.2	12	36	9.98
Enon	80,000	.258	14.4	17.2	12.1	21.0	8	24	6.02
Georgeville	1,220,000	3.940	16.5	23.9	20.9	20.6	6	30	7.43
Granville	50,000	.162	5.8	10.2	18.8	20.8	10	34	8.95
Helena	330,000	1.064	11.9	13.4	20.4	21.1	10	36	9.64
Herndon	600,000	1.934	13.8	13.9	22.4	21.8	6	40	10.06
Iredell	270,000	.873	9.5	26.0	19.1	16.8	6	24	5.18
Lloyd	760,000	2.450	15.3	20.1	21.0	22.2	8	46	11.88
Mecklenburg	260,000	.839	15.8	22.5	21.2	22.8	6	34	9.03
White Store	200,000	.645	18.0	31.7	19.1	9.8	5	24	3.31
Wickham	80,000	.258	10.9	20.8	18.5	15.7	10	42	8.45
Wilkes	460,000	1.484	14.3	16.6	20.6	20.0	8	18	5.25

Table 6. Acreage, and water-holding properties of some Mountain soils

Soil Series	Approx Acreage in state	Percent of total	Unavailable water (15 bar percent by volume)		Available water-holding capacity 50 cm - 15 bar ten. (vol. %)		Ave. thickness (in)		Total water-holding cap. A + B (in)
			A	B	A	B	A	B	
Ashe	450,000	1.450	13.1	17.6	30.5	24.5	10	18	7.46
Balfour	70,000	.226	13.1	15.4	29.2	26.1	10	36	12.32
Buncombe	25,000	.081	8.2	6.6	23.4	15.7	10	No B 30 +	7.05
Burton	10,000	.032	11.5	15.6	30.6	26.4	14	18	9.04
Chandler	160,000	.516	10.6	11.2	33.6	30.6	6	18	7.53
Chester	420,000	1.353	17.9	20.7	33.2	27.6	10	36	13.26
Clifton	80,000	.258	17.0	20.9	31.9	22.1	10	30	9.83
Edneyville	7,000	.023	6.0	15.4	27.9	26.4	10	24	9.12
Fannin	75,000	.243	11.8	15.3	33.8	28.8	8	26	10.20
Fletcher	21,000	.068	10.3	10.5	30.5	29.6	8	32	11.90
Hayesville	270,000	.871	10.1	15.9	33.4	27.0	8	30	10.77
Hiwassee	17,000	.049	13.4	15.5	36.3	28.3	12	48	17.92
Porters	1,075,000	3.475	10.2	9.0	31.3	29.0	12	20	9.57
Rabun	17,000	.049	13.4	13.4	33.2	25.5	10	24	9.45
Ramsey	650,000	2.095	12.1	18.5	29.8	22.4	8	18	6.42
Talladega	220,000	.710	13.2	13.2	29.7	29.4	8	16	7.07
Tate	40,000	.129	14.1	13.6	31.4	29.0	12	42	15.95
Tusquitee	110,000	.355	8.2	10.1	37.2	29.2	14	50	19.81
Watauga	40,000	.129	12.1	20.1	34.8	25.8	10	24	9.67

In Tables 4, 5, and 6 are given some calculations based on the data in Tables 1, 2, and 3. These summary figures show wide differences in the water-holding characteristics of the soils studied. The data should be valuable in planning water control, erosion control, irrigation, or other management practices. With these data and a soil map of any particular area, such as a watershed, the total water-holding capacity of the A and B horizons of the area can be calculated. Such calculations were not made for this report, but the data are presented for the many uses that may be made of them.

Herbicide Losses From Kaolinite

As shown in the preceding section, soils vary tremendously in hydraulic conductivity and in water-holding capacity. Those with a high hydraulic conductivity usually have a low water-holding capacity, and vice versa. Most of the herbicides applied to soils are soluble in water and their disposition in the soil usually is a function of water content or water movement. It was the purpose of this part of the investigation to determine the amount of applied herbicide lost in water extracted from the soil at various pressures. As indicated in the section on methods, radioactive C14-labeled herbicides were used.

The data obtained may be summarized in three major categories: 1) the amount of applied herbicide recovered in the various pressure extracts; 2) the total percentage of the applied herbicide recovered; and 3) the concentration of the herbicide in each of the pressure extracts.

Data on the percentage of applied herbicide recovered in the various pressure extracts are shown in Table 8. Water held in soils at pressures below 0.3 of a bar is easily moved under a potential gradient. It

Table 7. Summary of physical and chemical properties of clays

Clay	Sand (%)	Silt (%)	Clay (%)	pH	CEC (me/100g)	Exchangeable Cations		
						H (me/100g)	Al (me/100g)	Na (me/100g)
Kaolinite	20.3	5.1	74.6	4.1	2.68	.55	1.58	.93
Montmorillonite	23.6	3.6	72.8	9.3	50.00	.00	2.00	85.56

Table 8. Percent of added herbicide recovered from Kaolinite

Rate Applied (ppm)	Pressure Increment (bars)	Herbicides					
		2,4-D	Simazine	Atrazine	Diuron	Fluometuron	CIPC
1	0.0-0.3	49.2	16.0	33.3	10.5	57.4	41.2
	0.3-0.5	18.4	11.1	8.3	2.9	10.5	3.0
	0.5-1.0	2.8	1.9	4.4	0.4	4.0	1.4
	1.0-5.0	4.9	3.3	3.8	0.9	5.0	1.4
	5.0-10.0	2.2	2.1	1.6	0.4	2.7	1.0
	10.0-15.0	3.3	2.9	1.6	0.3	1.9	0.3
Totals →		80.8	37.3	53.0	15.4	81.5	48.3
4	0.0-0.3	53.1	14.7	34.6	15.4	52.1	48.6
	0.3-0.5	10.3	6.7	6.0	2.9	10.1	6.8
	0.5-1.0	2.9	1.2	2.6	0.4	4.9	1.7
	1.0-5.0	4.1	4.0	2.9	0.4	4.7	2.8
	5.0-10.0	2.5	1.5	1.6	0.3	2.1	1.3
	10.0-15.0	2.6	2.3	1.9	0.1	1.3	1.0
Totals →		75.5	30.4	49.6	19.5	75.2	62.2

may be lost by percolation (particularly that held at a pressure below .05 bars) or it may be readily available to plants. The amount of herbicide in this loosely-held fraction of the water, therefore, becomes very important. As shown in the table, more than half of the fluometuron and approximately half of the 2,4-D was recovered in this loosely-held water. However, only 10 percent of the diuron was recovered. The order of recovery in the loosely-held water for the 1 ppm application was: fluometuron > 2,4-D > CIPC > atrazine > simazine > diuron.

When applied at the rate of 4 ppm the percentage recovery in the loosely-held water was of the same order of magnitude with approximately half of the 2,4-D and of the CIPC being recovered. The order of recovery was: 2,4-D > fluometuron > CIPC > atrazine > diuron > simazine.

In addition to that lost in the lowest pressure increment, additional amounts were lost at the increasing pressure increments up to 15 bars. These totals are shown in Table 8. When applied at the rate of 1 ppm, approximately 81 percent of the fluometuron and 2,4-D were recovered; however, only 15 percent of the diuron was recovered. This means that only 19 percent of the fluometuron and 2,4-D remained in the tightly-held water, whereas approximately 85 percent of the diuron remained. The order of total recovery of the 1 ppm was: fluometuron $\cong$ 2,4-D > atrazine > CIPC > simazine > diuron.

The total percentage recovery of the 4 ppm from kaolinite ranged from 75 percent of the 2,4-D and fluometuron to less than 20 percent of the diuron. The order of total recovery was 2,4-D = fluometuron > CIPC > atrazine > simazine > diuron.

The concentration of the chemicals in the various pressure extracts is an indication of whether they would be easily lost by leaching, whether they would be readily available to plants in the available water, or whether large percentages of the applied herbicide would be held in the soil in the unavailable water. These concentration data are shown in Figures 1, 2, 3, 4, 5, and 6. The figures show that simazine concentration was greater in the higher pressure increments and that the concentration of all the other herbicides used decreased in the higher pressure increments, even though in several instances the decreases were very slight. The same general trends existed for both rates of application. Since relatively small percentages of the simazine and diuron were recovered at pressures up to 15 bars, it was concluded that there would be a high concentration of them in the tightly-held water. These two chemicals especially would be lost from the soil very slowly in percolation from subsequent rains or irrigation. The concentrations in percolating water would never be high.

Herbicide Losses From Montmorillonite

Data on the recovery of the various herbicides from montmorillonite are shown in Table 9. More than half of all the herbicides, except diuron, when applied at 1 ppm was recovered in the lower pressure increment. This means that all except diuron would be easily lost by leaching or would be readily available to plants. The order of recovery was: CIPC > fluometuron ≒ atrazine > simazine ≒ 2,4-D > diuron.

Total recovery at pressures up to 15 bars followed essentially the same order except that simazine and atrazine reversed positions. Total recovery amounted to as high as 96 percent of the CIPC but only

Table 9. Percent of added herbicide recovered from Montmorillonite

Rate Applied (ppm)	Pressure Increment (bars)	Herbicides					
		2,4-D	Simazine	Atrazine	Diuron	Fluometuron	CIPC
1	0.0-0.3	51.9	52.9	62.3	22.2	62.6	73.1
	0.3-0.5	3.5	10.0	2.9	3.7	14.0	7.8
	0.5-1.0	2.1	10.2	1.2	0.6	6.8	8.7
	1.0-5.0	3.0	7.0	2.0	1.3	5.3	4.3
	5.0-10.0	0.5	1.5	0.8	0.3	1.1	2.1
	10.0-15.0	0.2	0.9	0.5	0.1	0.5	0.4
Totals →		61.2	82.5	69.7	28.2	90.3	96.4
4	0.0-0.3	80.8	44.8	78.3	25.1	62.7	20.2
	0.3-0.5	13.8	7.4	9.0	2.9	5.4	0.8
	0.5-1.0	2.3	9.3	4.1	0.6	3.7	1.0
	1.0-5.0	7.8	3.8	3.6	1.2	3.8	0.0
	5.0-10.0	0.6	1.3	0.9	0.2	0.9	0.1
	10.0-15.0	0.2	0.5	0.6	0.1	0.3	0.1
Totals →		105.5*	67.1	96.5	30.1	76.8	22.2

* Unexplained high counts on one replication.

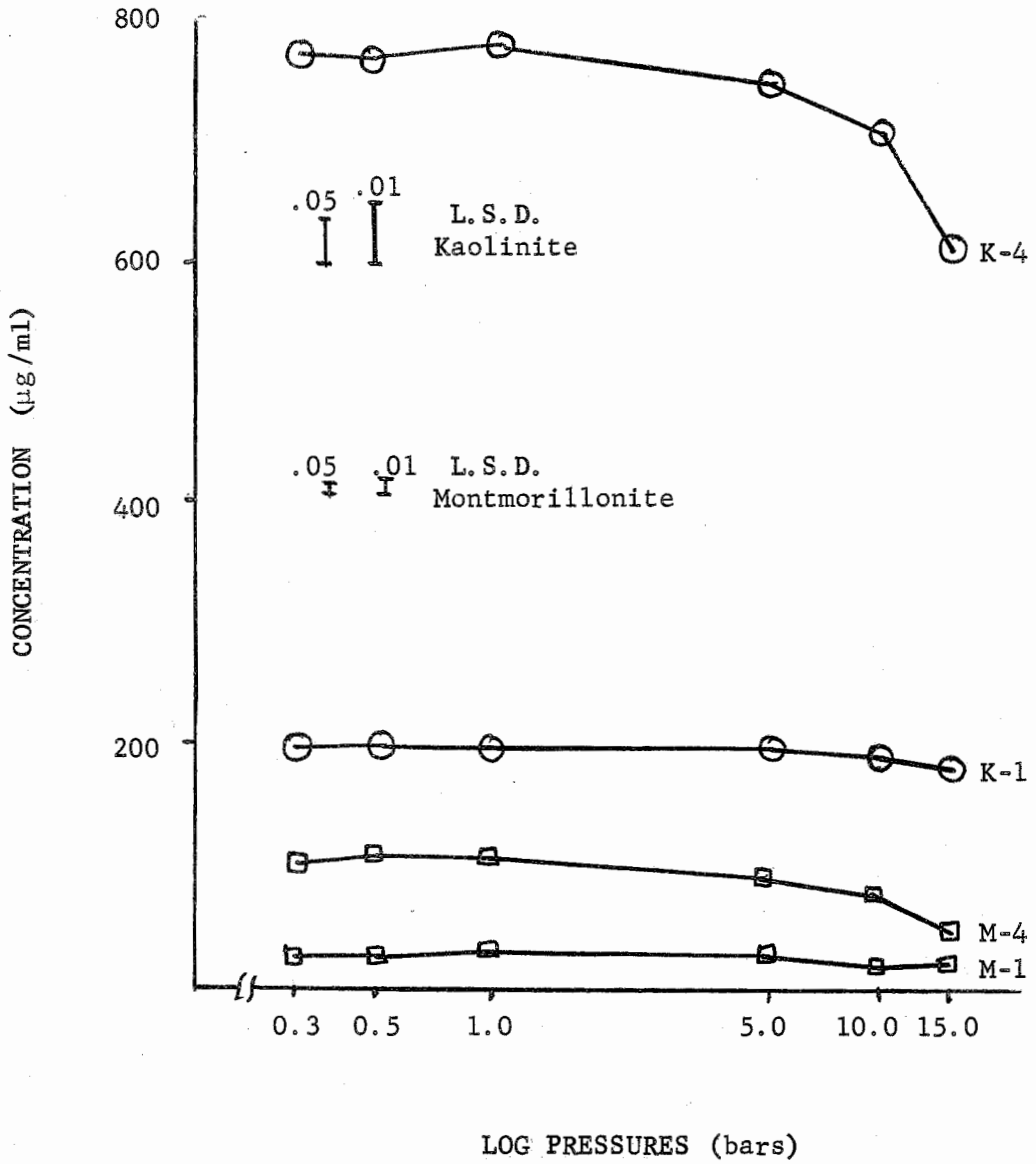

Figure 1. Concentration of 2,4-D in the various pressure extracts.

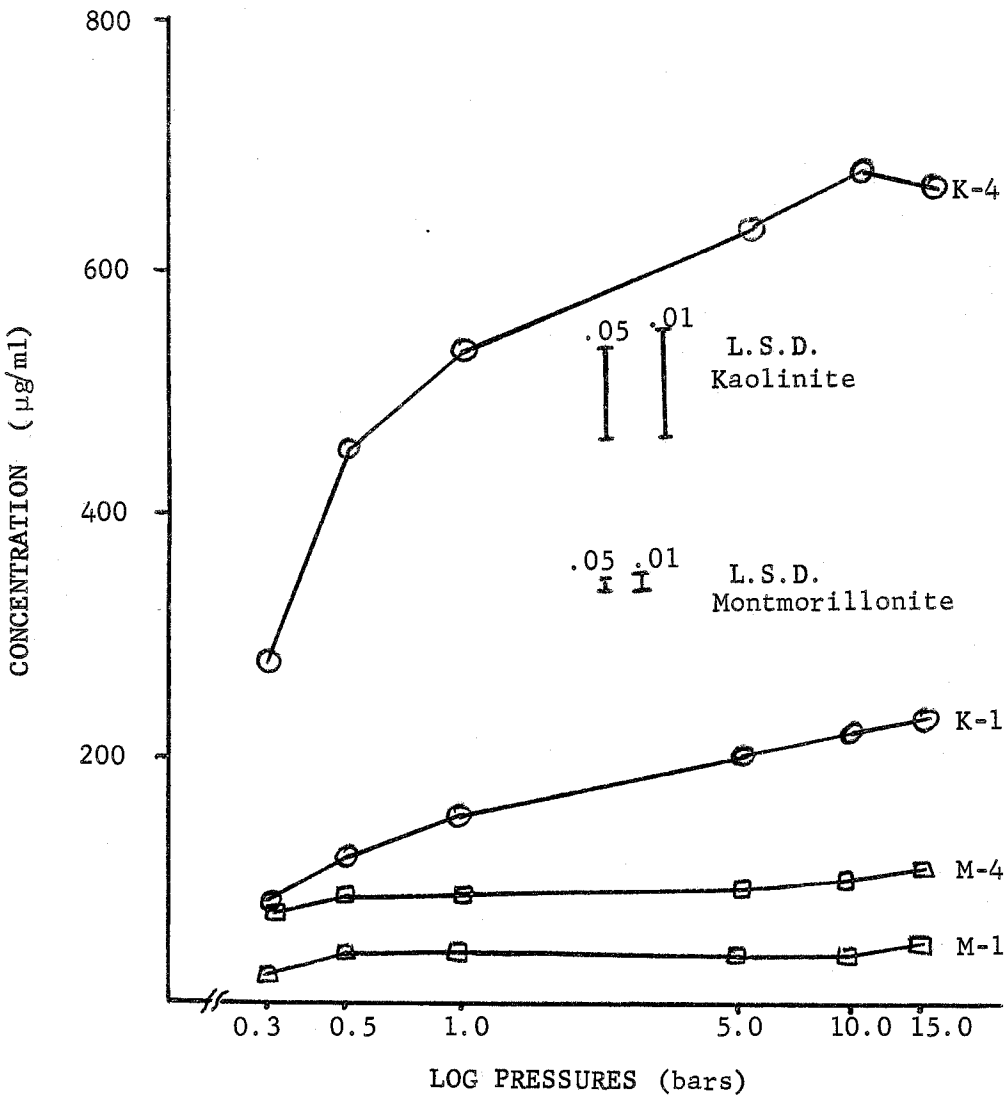

Figure 2. Concentration of Simazine in the various pressure extracts.

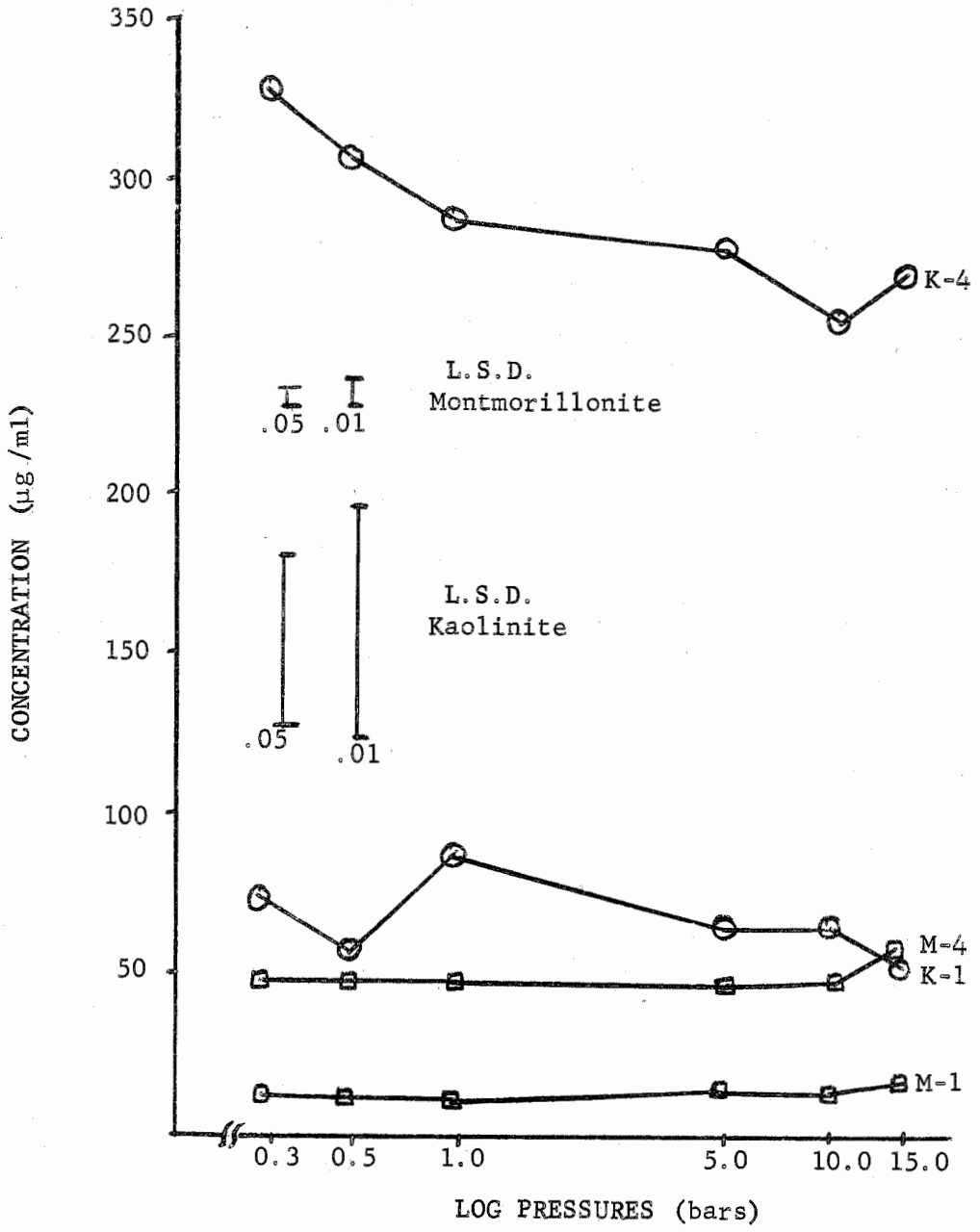

Figure 3. Concentration of Atrazine in the various pressure extracts.

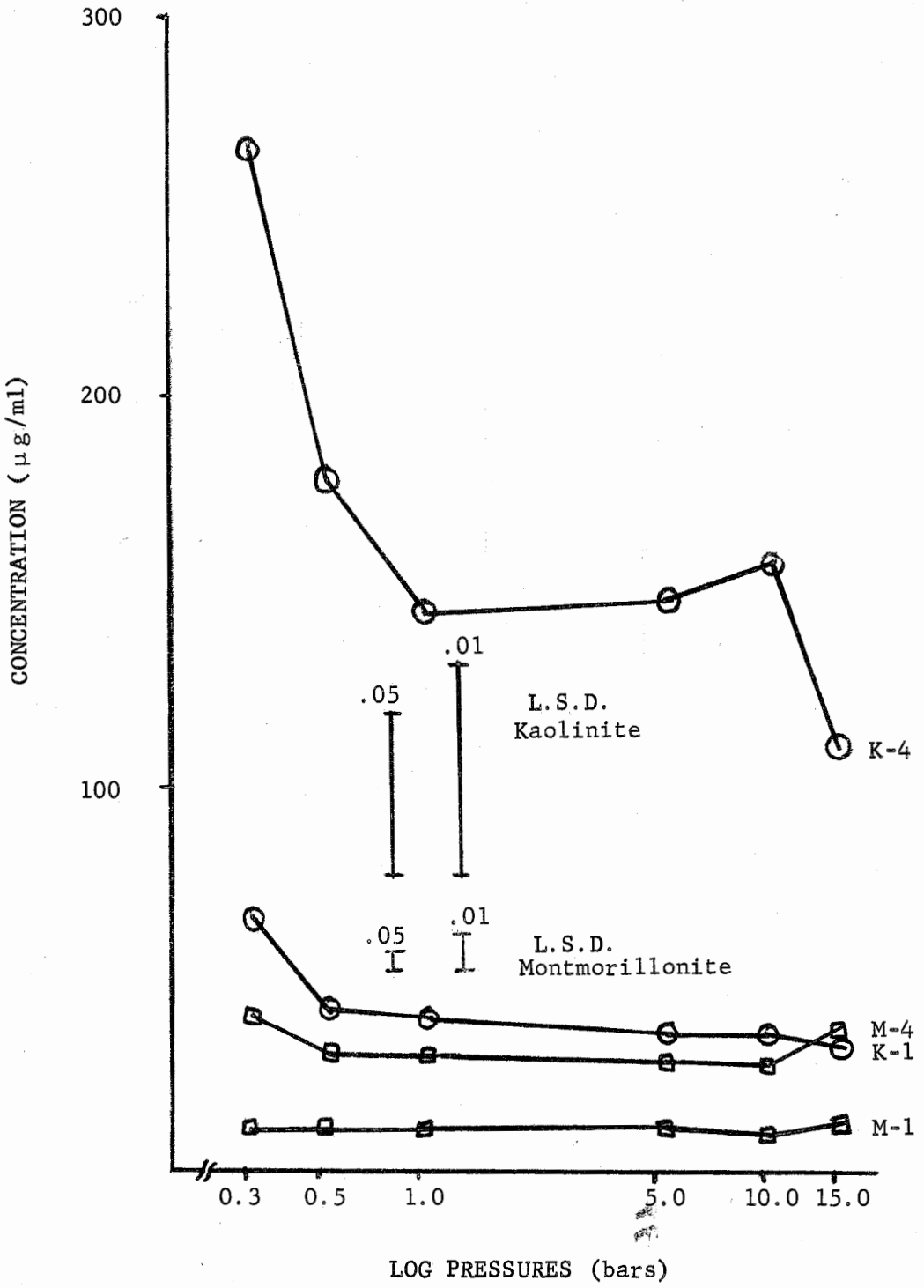

Figure 4. Concentration of Diuron in the various pressure extracts.

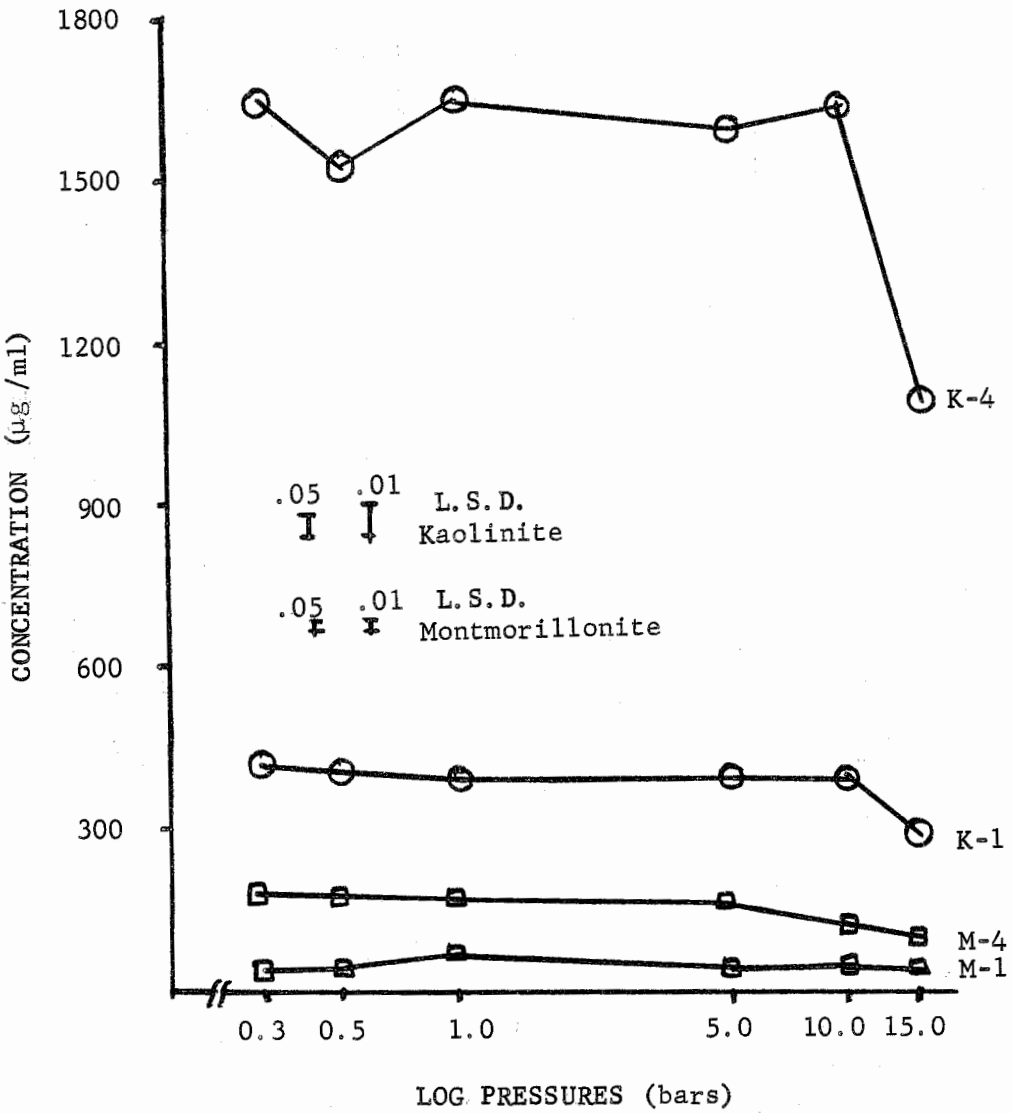

Figure 5. Concentration of Fluometuron in the various pressure extracts.

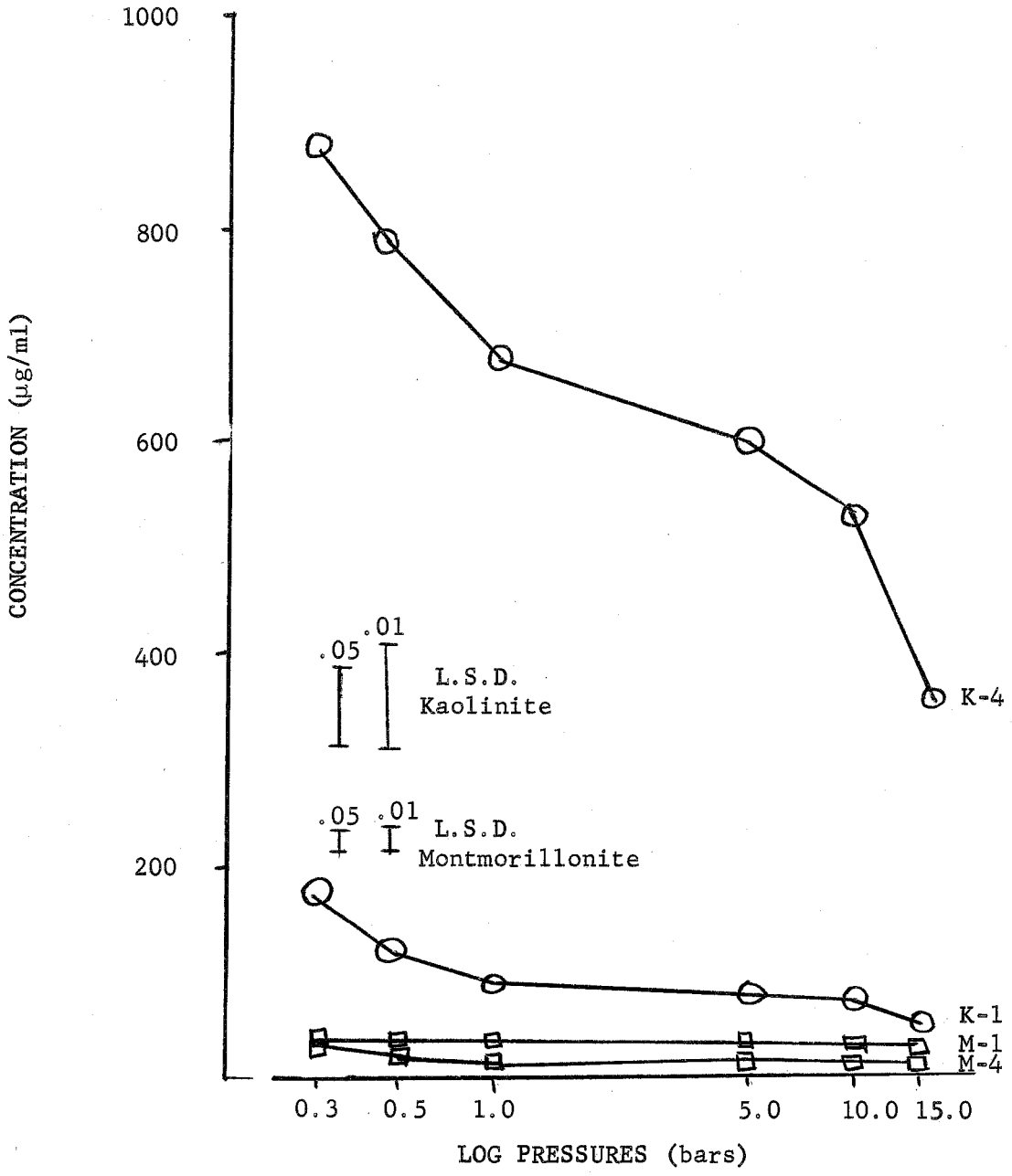

Figure 6. Concentration of CIPC in the various pressure extracts.

28 percent of the diuron. This indicates, of course, that the diuron would be concentrated in the tightly-held, unavailable water.

When applied at the rate of 4 ppm, as compared to 1 ppm, there was a greater percentage recovery of 2,4-D, atrazine, and fluometuron and a lower percentage recovery of simazine, diuron, and CIPC in the lowest pressure increment. The values ranged from approximately 81 percent for 2,4-D to 20 percent for CIPC, with the order being: 2,4-D > atrazine > fluometuron > simazine > diuron > CIPC.

Total recovery followed the same order with all of the 2,4-D and 22 percent of the CIPC being recovered.

Attention should be called to several interesting observations concerning the behavior of the several herbicides in the montmorillonite systems. When applied at the rate of 1 ppm, a high percentage of CIPC was recovered in the lowest pressure extract and in the total pressure extracts. There was a much lower percentage recovery of 2,4-D in the low pressure extract and in the total. When applied at 4 ppm, the order was reversed, with 2,4-D showing the greatest recovery and CIPC the lowest. Apparently montmorillonite can adsorb only so much -- approximately 50 percent of 1 ppm -- and any greater application will be readily lost. The total amount of CIPC recovered at the two different rates was almost the same (73 percent of 1 ppm and 20 percent of 4 ppm). Two possible explanations for the behavior have been offered. First, only a given amount of CIPC is soluble under the existing conditions and that amount was recovered. Second, at the higher rates the CIPC polymerized in the soil system forming particles larger than the openings in the membrane.

In terms of concentration in the various extracts, the data in Figures 1 to 6 show that in all cases the concentration of the herbicides in the extracts from the montmorillonite were lower than those from the kaolinite. Furthermore, the general trend in concentration from the lower to the higher pressure extracts was essentially the same as for kaolinite. The extracts from CIPC added at 4 ppm had a lower concentration than when added at 1 ppm. Again this indicates either the insolubility or the polymerization of CIPC at the higher rate.

Under the conditions of this experiment, it would have been almost impossible for any of the herbicides to have been lost by volatilization. Under field conditions, some might be lost by volatilization. Also, in this experiment steps were taken to prevent biodegradation which would not be done under natural field conditions. The low percentage recovery of some of the herbicides would indicate a high concentration remaining in the soil. Under natural conditions, these might be decomposed or they might tend to accumulate in the soil with repeated applications. Some of the herbicides used, especially 2,4-D, are readily decomposable and would not accumulate in the soil. Those that were recovered in high concentrations in the low pressure extracts would be subject to loss in the percolating waters and could possibly serve as sources of contamination for streams. The amounts that might get into streams would depend upon the total amount of herbicide applied to a given area and the amount of water leaving the area. This latter point is the major portion of a separate project currently being conducted by the author under natural watershed conditions.

Cation and Anion Losses From Clay Minerals

The primary function of this segment of the work was to study the concentration of several cations as a function of distance from the clay surface, using clay suspensions with and without added electrolyte present. Sodium- and calcium-saturated kaolinite and montmorillonite were used. Water was extracted from the clay suspensions at the pressures indicated in Table 10 and the concentrations of the extracts studied. If no decomposition of the clay occurred, theoretically, only hydrogen, and calcium or sodium, should be present as cations in the extracts. It is known that H-saturated clays will revert to Al-saturated clays upon standing in water. Preparation of the clays by freeze-drying reduces the amount of aluminum which is replaced from the crystal lattice. During the short time which the clays were in water suspension, practically no aluminum was replaced from the clay and removed in the extracts as shown in Table 10.

The pH and total salt concentration of the extracts are essentially as might be expected except that the pH values of the Na-montmorillonite in sodium chloride solution seem too high. The sodium and calcium concentrations in the extracts are as would be expected. With Na-montmorillonite in water, the sodium concentrations increased as the extract came from nearer and nearer the soil surface (that is, as the pressure with which it was removed increased). When excess sodium chloride was added, giving a total concentration of sodium greater than the cation exchange capacity of the clay, the sodium content was highest in the intermediate range pressure extracts. This indicates that it was more concentrated as the distance from the particle

Table 10. Chemical properties of extracts obtained at various pressures

Clay System	Electro-lyte	Extraction Pressure Internal (bars) 0-.25	.25-.50	.50-1.0	1.0-2.0	2.0-4.0	4.0-8.0	8.0-16.0
				pH				
Na-Mont. in water	4.3	8.2	8.6	8.5	8.4	8.2	8.2	8.5
Na-Mont. in NaCl	4.4	9.9	10.8	10.9	10.9	10.9	10.4	10.0
Ca-Mont. in water	4.6	8.0	8.3	8.3	8.3	8.3	8.2	8.1
Ca-Mont. in $CaCl_2$	5.3	8.5	7.7	7.5	7.2	7.2	7.2	6.7
Ca-Kaol. in water	6.1	7.6	7.8	7.9	7.9	7.8	8.1	7.5
Ca-Kaol. in $CaCl_2$	5.6	7.1	7.5	7.4	7.3	7.2	7.4	7.2
				Total Salt Concentration (meq/1)				
Na-Mont. in water	0.0	1.02	1.34	1.39	1.40	1.36	2.00	2.68
Na-Mont. in NaCl	10.0	13.66	27.55	35.18	30.99	23.45	14.32	9.43
Ca-Mont. in water	0.0	.98	1.58	1.75	1.88	2.14	2.65	3.05
Ca-Mont. in $CaCl_2$	10.0	10.50	9.22	8.59	7.52	6.91	6.36	5.73
Ca-Kaol. in water	0.0	.57	.95	1.02	1.01	1.08	1.22	1.29
Ca-Kaol. in $CaCl_2$	10.0	10.39	9.47	7.50	6.66	6.28	5.75	5.80
				Na (or Ca) Concentration (meq/1)				
Na-Mont. in water	0.0	1.80	2.41	2.20	2.43	2.40	3.33	4.35
Na-Mont. in NaCl	10.0	14.27	31.63	37.13	33.55	25.39	17.18	11.60
Ca-Mont. in water	0.0	1.24	2.09	2.32	2.54	2.93	3.63	4.13
Ca-Mont. in $CaCl_2$	10.0	10.40	9.25	8.37	7.47	6.84	6.25	4.76
Ca-Kaol. in water	0.0	.75	1.11	1.16	1.14	1.18	1.30	1.79
Ca-Kaol. in $CaCl_2$	10.0	10.16	8.74	7.80	6.83	6.32	5.91	5.94

Table 10 (Continued)

Clay System	Electro-lyte	Extraction Pressure Internal (bars) 0-.25	.25-.50	.50-1.0	1.0-2.0	2.0-4.0	4.0-8.0	8.0-16.0
			Cl Concentration (meq/l)					
Na-Mont. in water	0.0	.18	.07	.03	.02	.02	.02	.07
Na-Mont. in NaCl	10.0	10.47	6.87	4.77	3.04	1.45	.42	.21
Ca-Mont. in water	0.0	.08	.02	.05	.02	.04	.05	.03
Ca-Mont. in $CaCl_2$	10.0	9.80	8.75	8.04	7.20	6.56	6.04	5.24
Ca-Kaol. in water	0.0	.00	.04	.09	.10	.13	.16	.68
Ca-Kaol. in $CaCl_2$	10.0	.96	8.09	7.42	6.49	6.07	5.55	5.18
			Al Concentration (meq/l)					
Na-Mont. in water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Na-Mont. in NaCl	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca-Mont. in water	0.00	0.00	0.00	0.01	0.00	-	-	-
Ca-Mont. in $CaCl_2$	0.01	0.01	0.00	0.02	0.01	0.03	0.01	0.01
			Si Concentration (ppm)					
Na-Mont. in water	0.26	12.77	16.56	16.99	16.01	16.76	16.69	18.00
Na-Mont. in NaCl	0.43	34.47	182.20	183.62	182.20	181.14	166.67	106.64
Ca-Mont. in water	0.30	10.56	14.97	10.83	12.03	10.56	12.51	10.51
Ca-Mont. in $CaCl_2$	0.67	11.63	17.02	14.98	20.43	17.40	14.90	16.31

decreased; but as the extracts came from nearer and nearer the particle, the sodium was held by the particle in what has been described by various authors as salt sieving; hence, the decrease in sodium concentration in the higher pressure extracts. For the clay systems in water, the ion distributions appear to be in accord with the diffuse theory.

It is well established that soils in temperate to tropical regions lose Si and gain Fe and Al during the processes of rock weathering and soil formation. Early work by Clark[5] indicates that large quantities of Si appear in most streams and in other bodies of water. More recent studies by the Tennessee Valley Authority show that high concentrations of Si occur in the streams of the Tennessee Valley area.[6]

The data in Table 10 show that extremely high concentrations of Si occurred in the extracts from the Na-montmorillonite in sodium chloride, the values being as high as 183 ppm. It is not definitely known what the form of the Si was but quite likely it appeared as the $HSiO_3$ anion. The high concentration in the high pressure extract from Na-montmorillonite in water would indicate that it is not as an anion. However, with the other three systems, the decrease in concentration from the intermediate to the high pressure extracts indicates that it was present as an anion, and hence was negatively adsorbed. With the

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[5] Clark, F. W. 1920. The Data of Geochemistry. 4th Edition. United States Geological Survey Bulletin 695.

[6] Mineral quality of surface waters in the Tennessee River basin. Report No. 0-6392. The Tennessee Valley Authority, Division of Water Control Planting, Hydraulic Data Branch, Knoxville, Tennessee. October, 1963.

Ca-montmorillonite system in calcium chloride, there is an alternating increase and decrease in concentration in the pressure extracts. This was not true of either the calcium or the chloride concentrations in the various extracts and thus it is difficult to draw conclusions concerning the form of the Si. It could be present as a silicic acid or as sodium or calcium silicate.

The distribution and concentration of these various ions, particularly the Ca, Al, and Si could have many implications concerning the movement of other ions such as phosphate in the soil. It usually has been assumed that most of phosphorus lost from the soils, and which is important in eutrophication, is carried with the soil sediment; that is, as a part of the soil particles. No phosphorus studies were included in this particular investigation, but a similar study to which phosphorus is added would be extremely interesting and valuable.