RELEASE OF SOIL METALS AFFECTED BY EDAPHIC CONDITIONS IN COASTAL GEORGIA

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REFERENCE: *Proceedings of the 1989 Georgia Water Resources Conference,* held May 16 and 17, 1989, at The University of Georgia. Kathryn J. Hatcher, Editor, Institute of Natural Resources, The University of Georgia, Athens, Georgia, 1989.

Surface runoff water from cropped lands carries appreciable amounts of dissolved metals and particulate matter. Toxic metals such as cadmium and nickel released by soil into runoff water may adversely affect the water quality of lakes and streams. Vertical leaching resulting from heavy rains also transports considerable amounts of various metals to affect the groundwater quality, particularly in areas with shallow water tables. The release and transport of soil metals in erosion and runoff water depends on such factors as geology, soil type, vegetative cover, topography, agricultural practices, temperature and rainfall. Several workers have reported sediment concentrations and loads for a variety of drainage systems (McGuinness et al., 1971; Griffiths, 1982; Neff, 1982; Carling, 1983). Costa (1977) and Ostry (1982) provided information relating loads to rainfall intensity and duration, runoff amount and drainage area. Sheridan and Hubbard (1987) reported on solids transported in streamflow from watersheds in the Coastal Plain region of the southeastern USA. Price and Watters (1988) studied the water and chemical fluxes in a predominantly deciduous forest at Chalk River, Ontario.

The objective of this study was to determine the release of major and trace metals from coastal agricultural lands into the surface runoff water. Such a study was appropriate due to both the continuation of traditional soil loss studies (Wendt and Burwell, 1985) and the current interest in nonpoint source pollution (USEPA, 1984). The outcome of this study has a particular relevance to the quality of coastal water resources of Georgia and the management of soil fertility by the farmers.

MATERIALS AND METHODS

Two grass farmlands and their adjacent forest areas near the Chatham-Effingham County line in Coastal Georgia were selected as the study sites. For the collection of runoff water samples, four 16 sq. meter (4m x 4m) plots were blocked by inserting 10 cm wide flexscape edging around the perimeter of each plot. In one corner of each plot, the plastic edging was attached to a spillway weir leading to a 40 cm deep pit. A plastic bucket was placed in the pit to receive runoff water from the plot via spillway and the system was covered with aluminum foil. At site A, two plots on a sandy soil were under (1) Tifton grass, and (2) the adjacent forest trees. At site B, two plots on a loamy soil were under (3) Bazara grass, and (4) nearby forest cover. During the period August to November, 1988, four collections of runoff water from the plots were made, each after a measurable rain in the area. Total volumes of water collected in the buckets were measured each time and representative samples were taken in polyethylene bottles for analysis.

Estimation of Metals

Water samples were cleared of particulate matter by supercentrifuging and then passing through 0.45 μ Millipore filters. Filtered samples were acidified with nitric acid (1:1) to pH 2.0 and the metal concentrations were measured by atomic absorption spectroscopy. For the estimation of readily exchangeable metals in soil, 10 grams of air-dry samples (2 mm sieved) of 15-cm surface layer were treated with 100 ml of 1N ammonium acetate solution (pH 7.0). The mixture was shaken for 30 minutes, centrifuged and then passed through 0.45 μ Millipore filter to obtain a clear extract. Metals were determined in the extract after adjusting its pH to 2.0.

Concentrations of four major metals Ca, Mg, Na and K, and five trace metals Zn, Mn, Cd, Cu and Ni were determined in all four collections of water samples and ammonium acetate extract of surface soil samples. Other parameters such as pH of soil (1:1 soil-water paste) and water of all samples and total dissolved solids in water samples of 1st, 2nd and 3rd collections were also measured. Monthly temperature, dew point and precipitation data for the study area were recorded from the climatological data summaries published by the NOAA. Local weather station located at Travis Field in Savannah is only 2-4 km from the study sites.

RESULTS AND DISCUSSION

Four plots for the collection of runoff water were set up in the field on 6-28-88. There was only scattered and slight precipitation during June and July, but good rains fell belatedly in the months of August and September (Table 1).

Runoff water samples were collected from the field buckets on four dates shown in Table 2. Immediately preceding the sample collection days, rainfalls of sufficient amounts and intensities (Table 1) had occurred to produce runoff water from the enclosed plots.

Table 1. Climatological Data for the Study Area.

1988	Temp. (C^{O}) Max.	Min.	Av.	Dew Point	Precipitation (cm)
JUN	31.9	18.8	25.4	18.2	6.7
JUL	33.7	22.7	28.2	21.1	4.6
AUG	32.9	23.2	28.1	22.9	27.1
SEP	29.5	20.9	25.2	21.3	24.4
OCT	24.0	11.7	17.9	11.1	7.1
NOV	22.3	10.2	16.3	10.9	3.6
8/11	-	-	-	-	6.4
8/13-8/17	-	-	-	-	4.3
9/17-9/26	-	-	-	-	4.2
10/3	-	-	-	-	3.4
11/4-11/5	-	-	-	-	2.3

Table 2. pH and Concentrations (in ppm) of Major Metals and Total Dissolved Solids in Runoff Water.

Plot* No.	pH	Ca	Mg	Na	K	TDS
1st collection (8-12-88)						
1A	6.9	1.280	0.840	4.35	8.70	77.2
2A	6.5	0.525	0.320	3.46	3.22	36.5
3B	7.5	4.370	9.780	77.50	195.00	n.d.
4B	7.5	4.700	4.780	63.50	77.90	n.d.
2nd collection (8-17-88)						
1A	7.2	0.652	0.535	2.91	5.01	62.8
2A	8.8	4.600	5.060	179.50	281.50	4643.7
3B	7.0	0.850	0.370	3.03	5.10	32.4
4B	7.0	0.222	0.145	6.85	4.82	79.1
3rd collection (9-30-88)						
1A	7.4	1.510	1.790	2.40	14.90	48.0
2A	6.6	1.010	0.465	1.60	3.33	198.0
3B	7.1	7.675	3.199	1.26	24.00	92.0
4B	6.4	1.730	0.965	1.36	5.90	76.0
4th collection (11-11-88)						
1A	7.7	1.600	2.680	11.20	59.60	n.d.
2A	7.5	6.535	9.440	34.00	43.10	n.d.
3B	7.3	5.947	4.368	5.00	29.50	n.d.
4B	7.4	3.950	4.460	56.50	64.20	n.d.

* Plots 1A and 3B were under grass. Plots 2A and 4B were forested. n.d. = not determined

The pH of runoff water samples from all four plots was in the range of 6.4 - 7.7 (Table 2). This neutral status of water is apparently due to the release of major basic metals from the surface soil. The concentrations of Ca, Mg, Na, K and total dissolved solids (TDS) seem to vary according to the volume of runoff water resulting from a rainfall event and the period of sampling. The metal concentrations and TDS vary in the ranges of: 0.222 - 7.675 ppm Ca, 0.145 - 9.780 ppm Mg, 1.36 - 179.5 ppm Na, 3.22 - 281.50 ppm K, and 32.4 - 4643.7 ppm TDS. These concentration variations are due to the solubilities of individual metals and their relative positions on the exchange complex of soil. The concentrations of Na and K are quite high as compared to Ca and Mg because these are rapidly released from the exchange complex of colloidal particles.

Table 3. Volumes of Runoff Water and Total Losses of Major Metals from Soil.

Plot No.	Volume (ml)	Ca	Mg	Na	K	Total
		(mg/sq.m. of each plot)				
1st collection (8-12-88)						
1A	131	0.168	0.110	0.570	1.140	1.988
2A	256	0.134	0.082	0.885	0.824	1.925
3B	11	0.049	0.109	0.862	2.169	3.189
4B	8	0.036	0.036	0.480	0.589	1.141
2nd collection (8-17-88)						
1A	52	0.034	0.028	0.151	0.260	0.473
2A	35	0.159	0.175	6.215	9.747	16.296
3B	186	0.069	0.069	0.562	0.947	1.647
4B	35	0.008	0.005	0.238	0.167	0.418
3rd collection (9-30-88)						
1A	469	0.708	0.839	1.125	6.984	9.656
2A	1063	1.073	0.494	1.700	3.538	6.805
3B	619	4.749	1.979	0.780	14.850	22.358
4B	296	0.513	0.286	0.403	1.748	2.950
4th collection (11-11-88)						
1A	28	0.045	0.075	0.315	1.676	2.111
2A	66	0.429	0.620	2.231	2.828	6.108
3B	463	2.751	2.020	2.313	13.644	20.728
4B	5	0.020	0.023	0.290	0.329	0.662
Totals of 4 collections from each plot						
1A	680	0.955	1.052	2.161	10.060	14.288
2A	1420	1.795	1.371	11.031	16.937	31.134
3B	1279	7.618	4.177	4.517	31.610	47.922
4B	344	0.577	0.350	1.411	2.833	5.171

The losses of major metals were calculated from the volumes of runoff water of each plot and the corresponding metal concentrations (Table 3). Data indicate that the total losses of K were the greatest, but decreased for Na, Ca and Mg in all plots. Considering all four major metals, the maximum elution of 47.922 mg /sq.m. for the four collection events occurred in plot 3B under Bazara grass, followed by forested plot

2A, and Tifton grass Plot 1A while forested Plot 4B lost the least amounts. Among the sampling events, total flux of major metals was largest for plot 3B on 9-30-88 and the next largest for Plot 2A on 8-17-88.

In general, Plot 4B released the lowest amounts of major metals, which may be due to its compacted soil surface and relatively well-drained topography resulting from an adjacent drainage channel. The lowest chemical flux from Plot 4B may also be attributed to the decreased runoff water yields (Table 3) as compared to the yields from other plots. According to Price and Watters (1988), a chemical flux is defined as the amount of chemical per square meter in one rain event and is calculated as the product of chemical concentration (mg/liter) and equivalent water depth (mm). In this study, chemical fluxes are expressed as mg/l square meter plot per collection event which includes the runoff water from one or more rains. It is noteworthy that the fluxes of Ca and Mg are almost equal in sandy soil plots 1 and 2 of site A, while in the loamy soil plots 3 and 4 of site B, Ca flux exceeds the Mg flux by a factor of two.

Patrice (1980) reported annual losses of 3.8-8.5 kg/ha for Ca and 1.9-3.4 kg/ha for Mg in a forested watershed, which are far greater than the values found in this study. However, results of this study support the findings of Lowrance and Leonard (1988) who observed the highest nutrient loads in streams of watersheds that had the lowest percentage of cropland.

Losses of Trace Metals in Runoff Water

Concentrations of trace metals in the runoff water samples vary within the ranges of: 11-328 ppb Zn, 18-612 ppb Mn, 8-15 ppb Cd, 29-86 ppb Cu, and 0.0-175 ppb Ni (Table 4). Data reveal minimum variations in the concentrations of Cd and Cu and wide variations in the concentrations of Zn, Mn and Ni. Chemical fluxes of Zn, Mn, Cd and Cu were the maximum in forested Plot 2A for the 3rd collection, in which Ni turned out to be zero. Nickel flux was the highest in the 4th collection of Bazara grass Plot 3B. Loamy soil and relatively low-level position of Plot 3B reflecting poor drainage have contributed to high fluxes of trace metals. In the forested Plot 4B, despite the low volumes of runoff water collected (Table 3) and its good drainage, the amounts of trace metals released, particularly Zn, Cu and Ni, compare favorably with those released from grassy Plot 1A. Thus the high fluxes of trace metals in forested Plot 2A and the comparable fluxes of these metals in the forested Plot 4B, indicate a pronounced effect of leaf litter in the release of heavy metals. It may be seen that the effect of organic carbon in the dissolution and release of Mn from the soil is consistent in all four collections of runoff water samples. Manganese concentrations in the water samples of forested plots are greater than those of grassy plots.

Table 4. Concentrations of Trace Metals in Runoff Water and Their Total Losses from Soil.

Plot No.	Zn	Mn	Cd	Cu	Ni
		Conc. parts/billion (ppb)			
1st collection					
1A	16.0	18	12	43	50
2A	11.0	41	15	50	75
3B	328.0	129	15	57	75
4B	200.0	141	15	86	75
2nd collection					
1A	11.0	18	10	43	30
2A	35.0	176	12	43	-0-
3B	11.0	29	8	36	1
4B	18.3	35	10	36	175
3rd collection					
1A	17.5	47	15	50	-0-
2A	35.0	71	15	64	-0-
3B	24.5	35	12	43	40
4B	36.5	47	12	79	-0-
4th collection					
1A	100.0	71	12	43	1
2A	84.2	612	12	36	75
3B	63.2	71	12	29	150
4B	220.0	171	15	86	40
		Total losses (micrograms/sq.m.)			
1st Collection					
1A	2.09	2.36	1.58	5.63	6.55
2A	2.81	10.49	3.84	12.79	19.18
3B	3.65	1.44	0.17	0.63	0.84
4B	1.51	1.07	0.11	0.65	0.57
2nd collection					
1A	0.57	0.93	0.52	2.23	1.56
2A	1.21	6.09	0.41	1.49	-0-
3B	2.04	5.38	1.49	6.68	0.19
4B	0.64	1.21	0.35	1.25	6.07
3rd collection					
1A	8.21	22.03	7.03	23.44	-0-
2A	37.19	75.44	15.94	68.00	-0-
3B	15.16	21.66	7.42	26.61	24.75
4B	10.81	13.93	3.56	23.41	-0-
4th collection					
1A	2.81	2.00	0.34	1.21	0.03
2A	5.53	40.16	0.79	2.36	4.93
3B	29.23	32.84	5.55	13.41	69.38
4B	1.13	0.88	0.08	0.44	0.21
Totals of 4 collections/sq.m.					
1A	13.68	27.32	9.47	32.51	8.14
2A	46.74	132.18	20.98	84.64	24.11
3B	50.08	61.32	14.63	47.33	95.16
4B	14.09	17.09	4.10	25.75	6.85

Table 5. pH and Concentrations of Exchangeable Metal Ions of Soil in Experimental Plots.

Plot* No.	pH (1:1)	Ca	Mg	Na	K
		(ppm in air dry soil)			
1A	4.7	330	58.3	2.99	120.0
2A	5.3	120	48.3	4.98	49.5
3B	5.4	360	67.5	3.72	122.5
4B	4.8	75	45.3	7.02	62.5
	Zn	Mn	Cd	Cu	Ni
1A	1.217	1.39	0.077	0.318	0.075
2A	0.538	4.70	0.077	0.227	0.010
3B	1.472	3.20	0.096	0.136	0.245
4B	0.840	1.14	0.096	0.227	0.205

* Surface soil samples (0-15 cm) collected on 6-28-88.

The pH of soil samples from four runoff experimental plots is definitely acidic, varying within a narrow range of 4.7-5.4 (Table 5). It is remarkably clear that the concentrations of exchangeable Ca, Mg and K in the forested soil of Plots 2A and 4B are less than half as compared to the concentrations of these metal ions in the soils of grass-covered Plots 1A and 3B. This indicates that the grass cover permits greater conservation of metals in the soil. The decomposition of leaf-litter in the forested plots induces greater dissolution of major metals from the soil and their elution from the system by rain water (Table 3). Relatively high losses of major metals in the runoff water of forested plots may be due to a combination of releases from both the soil and the leaf-litter.

Concentrations of ammonium acetate extractable trace metals are low for Zn, Cu and Ni, particularly in forested Plot 2A. Exchangeable Mn levels are quite high in the soils of forested Plot 2A and loamy soil grass-covered Plot 3B, which may be due to the reducing conditions prevalent in these plots, and the resulting release of Mn is reflected in the concentrations of runoff water (Table 4). Exchangeable Cd in the soil of all plots is low and it seems to be unaffected by the hydrologic conditions of plots.

CONCLUSIONS

A definite pattern of rain-soil cover interaction and other edaphic conditions emerges from these data. Study suggests that the soil texture, compaction, and drainage conditions modify the ion-exchange reactions and release of metals from the soil complex. Salient observations we have made are as follows: (i) removal of major and trace metals from the soil is greater under forest canopy than under grass covered soil; (ii) losses of K and Na far exceed the losses of Ca and Mg; (iii) exchangeable metals of soil are diminished due to leaf-litter interaction; and (iv) drainage conditions modify the effects of soil texture and canopy-atmosphere. This study suggests some areas that are worth further investigation. Among these correlation studies between organic carbon content of soil and the amounts of release of major and trace metals as well as the determination of total metal concentrations of soil seem to be quite important.

ACKNOWLEDGEMENTS

We are grateful to the Environmental Resources Center, Georgia Institute of Technology for supporting this research project (June 1, 1988 - March 31, 1989) under the Water Research Institute Program funded by the U.S. Geological Survey. We are also thankful to Mr. Gene Hart whose farm was used for experimental plots.

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