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Influence of Summer Storms on the Solution Geochemistry in a Coastal Plain Hydrosequence

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ABSTRACT

An understanding of factors which influence wetland soil solution chemistry is important for soil solutions are known to influence some chemical properties of surface waters. The influence of summer storms on the solution geochemistry in a South Carolina riverine wetland soil was evaluated by comparing pore water collected 24 hr after five summer storm events with pore water acquired during five nonstorm periods. Pore water was collected by tension lysimeters buried at 15 to 152 cm in two locations along a hydrologic gradient. Samples of rain, throughfall and stream water were also collected. Overall, summer storms had no significant influence on the concentrations of anions, cations, DOC, pH and electrical conductivity (EC) in soil pore water at both floodplain locations. There was a tendency for higher concentrations of dissolved NO_3-N, NH_4-N and PO_4-P in soil pore water after periods of high rainfall. In many situations, water chemistry was influenced by the degree of soil saturation. The seasonally wet soil of the floodplain had statistically higher mean concentrations of Ca, Fe, Na, Cl and EC values relative to the drier soil. Throughfall had a significant influence on the concentrations of K and DOC, whereas soil had a significant effect on some anions, cations, pH, and EC. These results suggest that pore water chemistry is primarily a function of the degree of soil saturation during nonstorm periods. Storms had little influence on soil pore water or stream water chemistry.

Key Words: Throughfall, wetland soil, stream water, floodplain, land-water interaction

INTRODUCTION

Floodplain soils directly link upland ecosytems and surface waters. Precipitation events can raise local water tables, causing the mobilization of previously unavailable nutrients (Meyer et al. 1988) and the transport of dissolved organic carbon (DOC) from floodplains to surface waters (Hemond 1990). Storm solute chemistry has been used to evaluate biogeochemical processes in watersheds (Johnson and Henderson 1979, Trudgill et al. 1981, Johnson et al. 1986, Jardine et al. 1990) and to quantify the hydrologic fluxes of nutrients to aquatic ecosystems (Johnson et al. 1969, Johnson and Swank 1973, Mulholland et al. 1981, Lawrence et al. 1988, Mulholland et al. 1990). Each of these studies illustrated that storm events caused sharp increase in the hydrologic fluxes in soils, catchments and watersheds. Thus, the chemistry of surface waters was significantly influenced by the process via the soil solution (Mulholland et al. 1990).

The Coastal Plain blackwater streams of South Carolina are commonly bordered by forested riverine floodplains. Many of these floodplains are wide, nearly-level to gently sloping, and contain very poorly drained, organic-enrich soils (Rogers 1990). Nearly-level sections of the floodplain adjacent to the streams are usually wet for long periods due to frequent flooding and a shallow water table. In this section of the floodplain, it is likely that anaerobic processes dominate nutrient turnover processes. Sloping sections of the floodplain near the upland edge are drier because the water table is deeper and flooding occurs less frequently. It is likely that aerobic processes dominate nutrient turnover processes here. A consequence of lateral differences in water table depth within a riverine floodplain is that there should be distinct differences in the signature of soil solutions. This condition could ultimately influence the chemistry of receiving waters.

The objective of this paper is to examine the influence of summer storms on the solution geochemistry in pore water from a South Carolina riverine wetland soil located along a hydrologic gradient. Chemical compositions of pore water rain, throughfall and stream water were compared during storm and nonstorm periods.

MATERIALS AND METHODS

Study Site

The study was conducted in the Upper Three Runs Creek (UTRC) watershed (Figure 1) on the U.S. Department of Energy's Savannah River Site (SRS) within the Aiken Plateau of the Upper Atlantic Coastal Plain physiographic region of South Carolina (Siple, 1967). The surface geology, vegetation and climate have been previously described by Novak and Bertsch (1991). Typical floodplain topography in the UTRC watershed exhibits a gradual change from being nearly level to gently-sloping with increasing distance from the stream. Soils adjacent to the stream are periodically flooded and usually saturated throughout the year. Soils further away are drier. Soil parent material near the stream is alluvium while soil parent materials in the floodplain interior are a mixture of alluvium and colluvium (Dennehy et al. 1989). Lysimeter nests were installed approximately 15 m (noted as B9) and 45 m from UTRC (noted as B7) (Figure 1). Physico-chemical analyses were made on soil samples that had been air-dried, ground to pass a 2-mm sieve, and stored in the dark at 4°C until analyzed (Table 1). The soil organic carbon (OC) content of each soil sample was measured using a N and C analyser (Carlo Erba/model NA 1500, Milan, Italy). Soil pH was measured using a pH meter with a combination electrode in Millipore Milli-Q H_2O at a solution to soil ratio of 2:1. Soil texture was measured using the micro-pipet method of Miller and Miller (1987). Prior to soil textural analyses, all soils with > 20 g OC kg^{-1} soil were pretreated with H_2O_2 to remove OC. Soils at the B7 and B9 sites are very poorly drained and have sandy texture, acidic pH, thick organic matter enriched surface horizon and a gleyed subsurface horizon (Table 1). Both soils were classified as the Pickney series, Sandy, siliceous, thermic Cumulic Humaquepts (Soil Survey Staff 1992), a common floodplain soil on the SRS.

Field Instrumentation and Sampling Techniques

Samples of rain, throughfall, soil pore water, and creek water were collected after five

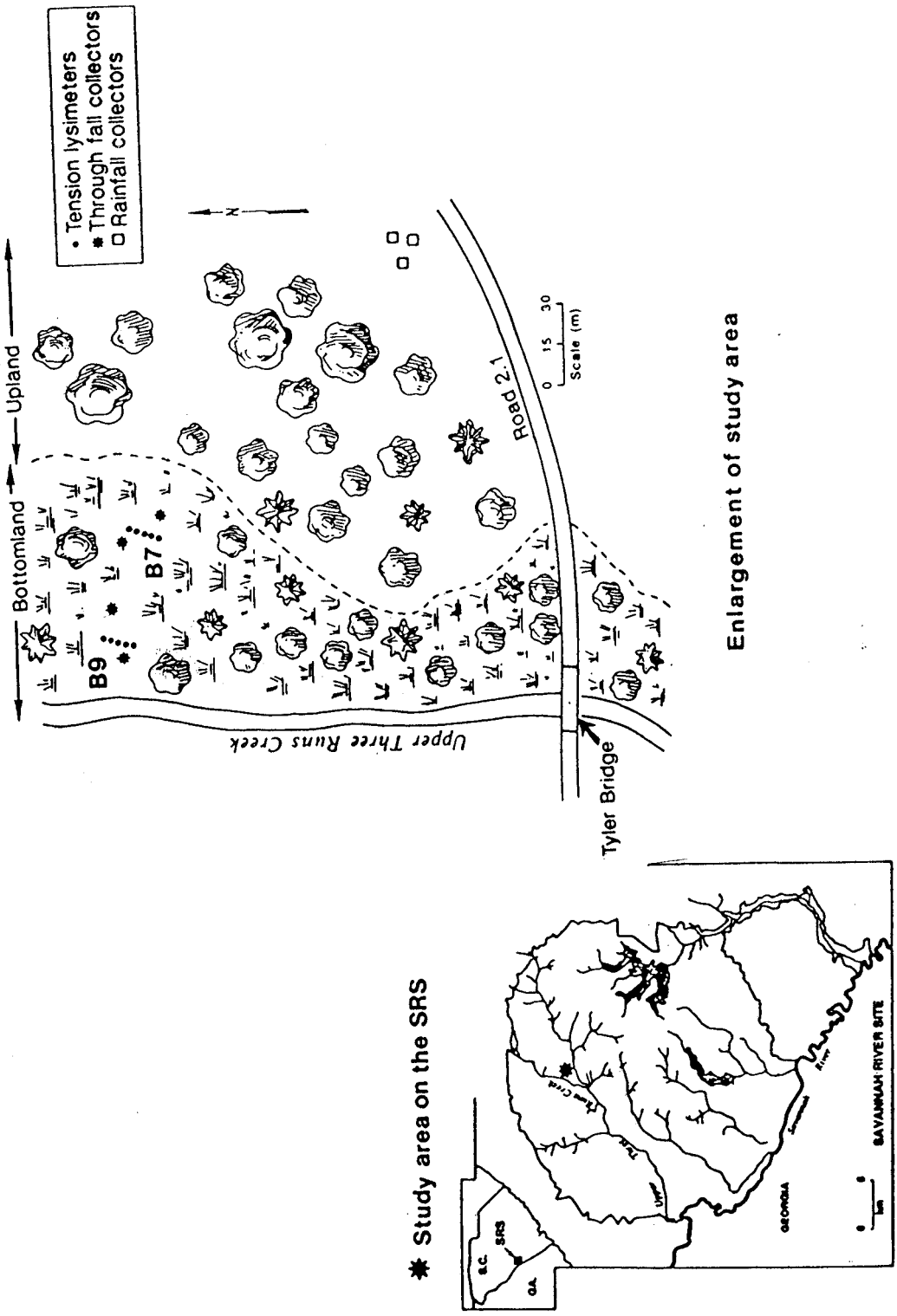


Figure 1. Location of Savannah River Site (SRS), study area and all tension lysimeters and collectors

Table 1. Soil physico-chemical properties and depth of lysimeters at both sampling locations

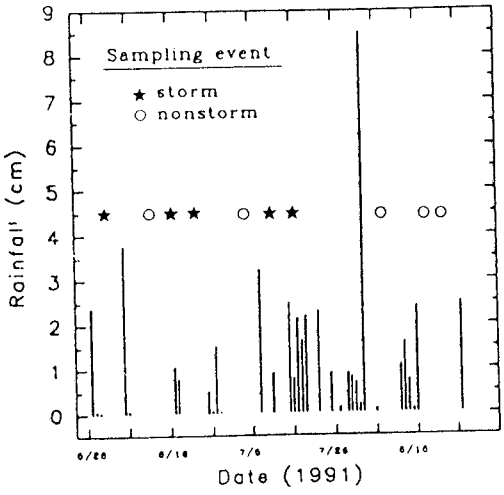
Location	Soil horizon	Horizon depth cm	Lysimeter depth cm	pH	OC g kg^{-1}	Soil texture sand %	silt %	clay %
B7	A1	0-15	15	5.3	32.9	91	6	3
	A2	15-38	30	5.2	19.7	88	7	5
	A3	38-66	61	5.6	7.3	93	5	2
	A4	66-122	102	5.0	4.8	97	1	2
	Cg	122-203	152	5.4	0.7	94	4	2
B9	A1	0-15	15	4.8	30.5	92	5	3
	A2	15-38	30	5.1	19.2	93	4	3
	A3	38-69	61	5.4	6.5	93	5	2
	A4	69-122	102	5.5	4.3	92	3	5
	Cg	122-203	152	5.6	4.4	97	1	2

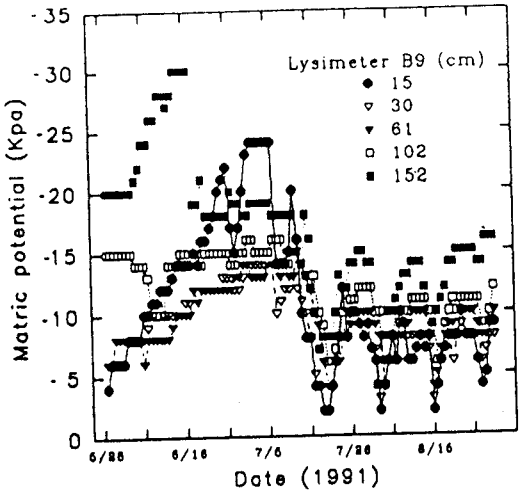
storm events and during five nonstorm periods. Soil pore water was collected at 15, 30, 61, 102 and 152 cm depths. Samples were collected approximately three times per month with sampling dates determined by incident precipitation. Storm samples were collected approximately 24 hr after storm events and nonstorm samples were collected 72 to 86 hr after the last recorded rainfall (Figure 2). Selection of the sampling dates was arbitrary.

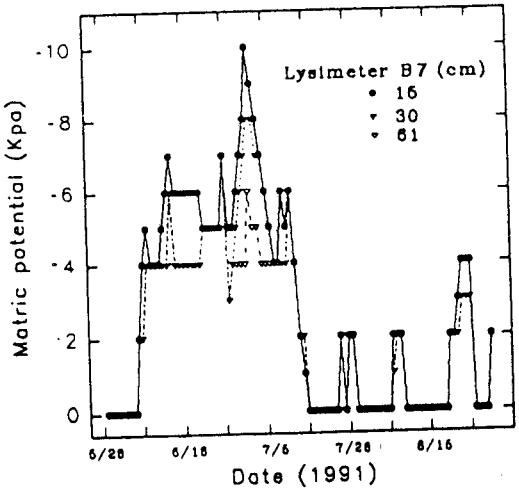
Incident rainfall was collected in triplicate using polyethylene funnels, covered with 1-mm nylon mesh and plugged with glass fiber, that drained into polyethylene containers. Collectors were clamped to a board so that the top of the funnel was 1 m above the soil surface. The rain collectors were located in an unforested area approximately 120 m southeast of sites B7 and B9 (Figure 1). Throughfall samples were obtained using collectors identical to those for rain collection. Two throughfall collectors were randomly placed near each site (Figure 1). Rainfall amounts were recorded with a raingauge placed in an open canopy area approximately 25 m from the lysimeter nests. All rain and throughfall collectors were initially cleaned using dilute HCl, rinsed with Millipore Milli-Q H_2O, and then cleaned in a similar manner once a week. Creek water was collected from two locations approximately midstream near B9 and combined for a single sample during each sampling period.

Tension lysimeters (Soil Moisture Corp. 1900 series) were installed in June of 1990 at B7 and B9 at approximately midpoint in each soil horizon (Table 1). Prior to installation, each lysimeter was leached first with 70 to 80 pore volumes of 1M HCl (about 1.5 L) and second with double deionized water until the input and output water had a similar pH (Creasy and Driess, 1988). The lysimeters were installed in auger holes with the ceramic cups embeded in a silica flour slurry (450 g silica flour to 125 ml double deionized water) to provide a good soil-cup contact (Rhoades and Oster 1986) and to minimize plugging of the cup tips (Everett et al. 1988). The hole was then backfilled with soil in the reverse

Figure 2. Incident precipitation, sampling events and soil matric potentials at both lysimeter locations during the study. ⟶


Sampling event
★ storm
○ nonstorm
Rainfall (cm)
Date (1991)


Lysimeter B9 (cm)
15
30
61
102
152
Matric potential (Kpa)
Date (1991)


Lysimeter B7 (cm)
15
30
61
Matric potential (Kpa)
Date (1991)

order from which it was removed. The lysimeters were allowed to equilibrate with soil pore water for one year, and were flushed twice before sampling commenced. Prior to sampling, each lysimeter was emptied and a vacuum of 13 to 30 Kpa was applied. Samples of soil pore water were then collected after 24 hr. Tensionmeters (jet-filled, Soil Moisture Corp.) with Bourdon vacuum gauges were installed at five depths at B7 and at three depths at B9 (Figure 2) for specific depths to provide water potential data. Each tensionmeter was tested and calibrated according to Reeve, 1965; and readings recorded daily. The soil matric potential at B7 ranged from -3 to -30 Kpa and for B9 from 0 to -10 Kpa. The very low soil matric potential (Figure 2) suggests that the water table was near the surface at B9 for a large period of time. In contrast, the soil profile at B7 was much drier as indicated by the higher soil matric potential (Figure 2). This suggests that the watertable at B7 was > 1.6m deep during the study.

All water samples were collected in acid-washed, amber-coloured jars and filtered through a prerinsed 0.4 μm polycarbonate filter unit (Nalgene Corp., Rochester, NY). The sample was then split into four portions. The pH of one portion was immediately measured in the field using an Orion model SA250 pH meter. A second portion was transferred into another amber coloured jar for DOC measurement. The last two portions were transferred into acid-washed plastic vials, one of which was acidified with two drops of Ultrex concentrated HNO_3. All samples were then transported under ice back to the laboratory and stored at 4°C until analysis. The electrical conductivity (EC) was measured on one portion (warmed to 25°C) using an Orion model 101 conductivity detector. The DOC content was determined in triplicate with a Shimadzu total organic carbon analyzer model 500 (Shimadzu Corp., Kyoto, Japan) usually within 48 hr. Cation concentrations, with the exception of K and NH_4, were determined on acidified samples using a Mark II Jarrell-Ash 965 Inductively Coupled Argon Plasma emission spectrometer (ICP). Potassium was determined using a Perkin-Elmer model 2380 atomic absorbance spectrophotometer. Automated determination of Cl, SO_4-S, PO_4-P, NH_4-N, NO_2-N and NO_2-N + NO_3-N were made using a Technicon Auto Analyzer. Chloride, SO_4-S and PO_4-P were measured by the ferric thiocyanate, barium-sulfate methylthymol blue and molybdenum blue methods, respectively (U.S. EPA, 1983). Ammonium was measured by a phenolate colorimetric technique and NO_2-N and NO_2-N + NO_3-N by a hydrazine reduction and diazotization technique (U.S. EPA, 1983). Because NO_2-N was not detected in any of our samples, the NO_2-N + NO_3-N measurements were attributed solely to NO_3-N. The minimum detectable concentrations of elements for ICP were 0.05 mg L^{-1} for Al, Ca and Fe; 0.25 mg and Na L^{-1}; and for atomic absorbance was 0.05 mg K L^{-1}. The minimum detectable concentrations for DOC measurement was 0.25 mg C L^{-1} and for the Technicon Auto Analyzer were 0.6 mg SO_4-S L^{-1}; 0.2 mg Cl L^{-1}; 6.1 μg PO_4-P L^{-1}; and 3.1, 2.4 and 4.4 μg NH_4-N, NO_2-N + NO_3-N and NO_2-N, respectively. Quality control procedures consisted of adding standard checks routinely for each analysis. Recovery rates for standard checks were between 95 to 105%. In addition, both filtered and unfiltered Millipore Milli-Q H_2O blanks were treated in a similar manner and all values corrected for trace amounts of material when necessary.

Statistical Analyses

Comparison of storm vs. nonstorm sample means were made with a paired Student's t-test (Minitab, Inc., State College, PA, 1986). The effects of floodplain location on means of

elements in SPW was determined using a one-way ANOVA (Minitab, Inc., State College, PA, 1986). The effects of water source were determined by comparing pooled variable means using the Newman-Kuels multiple range test (Zar 1974).

RESULTS

Chemical Properties of Water Samples

Except for pH at 15 and 102 cm within B7 (Table 2), there were no significant differences between storm and nonstorm periods ($P > 0.05$) with respect to EC, pH and DOC. There was no significant difference ($P > 0.05$) between storm and nonstorm cation and anion concentrations (Table 2) except for SO_4-S concentrations at B9 - 30cm.

Many of the water samples had PO_4-P, NH_4-N and NO_3-N concentrations that were below our detection limit. Thus, we were unable to statistically analyze the influence of storms on P and N dynamics in rain and throughfall and P dynamics in creek water. Concentrations of PO_4-P in rainwater were below the detection limit (< 6.1 $\mu g\ L^{-1}$), but became enriched after passage through the tree canopy (mean 179 $\mu g\ L^{-1}$, SD 128). Typically, creek water PO_4-P was below detection limits, but occasionally rose to measurable amounts (mean 10.0 $\mu g\ L^{-1}$, SD 2.9). Rainwater had a mean concentration of 27.3 μg of NH_4-N L^{-1} (SD 17.2) and 354 μg of NO_3-N L^{-1} (SD 117). Throughfall had a mean NH_4-N concentrations of 17.1 $\mu g\ L^{-1}$ (SD 8.8) and NO_3-N concentration of 292 μg of L^{-1} (SD 248).

Of all the forms of N quantified in creek water, only NO_3-N was consistently detected throughout the study. The mean NO_3-N concentrations during storm and nonstorm periods were 115 (SD 32) and 137 (SD 20) $\mu g\ L^{-1}$, respectively, and they were not significantly different ($P > 0.05$).

Most of the PO_4-P at the drier site (B7) ranged from 6 to 13 $\mu g\ L^{-1}$, with a high of 61 measured at 15-cm in B7 towards the end of the study (Figure 3). At the more saturated site (B9), PO_4-P concentrations in soil pore water from the 15-cm depth ranged from 6 to 10 $\mu g\ L^{-1}$ except during one sampling time, when it increased to a high of 50 $\mu g\ L^{-1}$. Deeper soil pore water samples (61 to 152 cm) at B9 were substantially higher in PO_4-P (note scale difference) compared to other sampling depths. The PO_4-P levels in soil pore water from the deeper horizons (61 to 152 cm) fluctuated greatly in June, then remained fairly constant.

Dissolved NH_4-N concentrations in soil pore water collected from 15- and 30-cm depths at B7 fluctuated widely over the sampling period, while NH_4-N levels in the subsurface horizons were consistently low (Figure 4). During the first and last sampling periods, soil pore water from B9 was enriched in NH_4-N. Nitrate-N levels in soil pore water collected from surface horizons were low but increased substantially (note scale difference) in subsurface horizons. In general, lower NO_3-N concentrations occurred in soil pore water from B9 than B7.

Variation in Soil Pore Water Chemistry Between Sites

With no statistically significant differences in soil pore water element concentrations during storm and nonstorm period, we pooled the element concentrations for each lysi-

Table 2. Chemical properties of rainfall, throughfall, Upper Three Runs Creek (UTRC) and soil pore water collected after storm and nonstorm events. Values are means with SD in parentheses.

Sample	Electrical conductivity $\mu S\ cm^{-1}$		pH		DOC $mg\ L^{-1}$		Ca $mg\ L^{-1}$		Fe $mg\ L^{-1}$	
	storm	nonstorm	storm	nonstorm	storm	nonstorm	storm	nonstorm	storm	nonstorm
I. Rainfall	16.1 (7.7)	nd	6.0 (0.6)	nd	6.0 (4.1)	nd	0.5 (0.2)	nd	0.0 (0.0)	nd
II. Throughfall	33.1 (11.7)	nd	6.0 (0.5)	nd	21.3 (10.1)	nd	2.0 (0.9)	nd	0.0 (0.0)	nd
III. UTRC	17.4 (1.0)	18.8 (2.7)	5.7 (0.2)	5.8 (0.1)	4.8 (2.8)	3.4 (0.4)	1.1 (0.4)	0.9 (0.3)	0.16 (0.0)	0.1 (0.0)
IV. Soil pore water										
Lysimeter (Loc., cm)										
B7-15	80.0 (14.5)	67.0 (14.0)	4.5 (0.0)	4.6 (0.1)*	44.5 (4.6)	43.2 (3.3)	9.6 (2.0)	8.0 (1.0)	0.78 (0.06)	0.86 (0.08)
B7-30	59.4 (7.7)	57.0+	4.8 (0.2)	4.9+	20.1 (4.6)	23.4+	6.5 (0.8)	5.8+	0.37 (0.05)	0.46+
B7-61	51.0 (8.5)	47.2 (4.4)	5.3 (0.2)	5.2 (0.1)	15.3 (2.9)	14.1 (5.2)	6.1 (0.6)	5.7 (0.6)	0.31 (0.11)	0.27 (0.06)
B7-102	38.4 (2.1)	46.8 (8.6)	5.3 (0.0)	5.2 (0.1)*	17.9 (10.6)	9.5 (3.0)	4.5 (0.3)	5.3 (0.8)	0.12 (0.04)	0.13 (0.05)
B7-152	64.4 (13.4)	55.6 (9.3)	5.4 (0.2)	5.3 (0.1)	12.1 (7.6)	15.8 (0.4)	7.8 (1.7)	6.5 (0.8)	0.06 (0.06)	0.48 (0.36)
B9-15	105.6 (26.7)	83.2 (22.5)	5.0 (0.1)	5.0 (0.2)	27.0 (16.6)	30.2 (13.9)	15.9 (3.8)	12.0 (3.7)	1.43 (1.58)	1.90 (1.1)
B9-30	80.4 (14.7)	80.0 (23.6)	5.0 (0.1)	5.0 (0.1)	23.5 (7.4)	20.5 (8.5)	10.5 (2.1)	9.9 (2.0)	1.45 (1.41)	1.05 (0.61)
B9-61	80.0 (4.9)	84.4 (9.5)	5.1 (0.1)	5.2 (0.1)	19.1 (4.0)	16.4 (4.6)	10.8 (0.4)	10.9 (0.5)	0.25 (0.06)	0.32 (0.12)
B9-102	108.4 (4.7)	115.0 (9.7)	5.4 (0.0)	5.4 (0.1)	20.0 (2.6)	18.2 (5.0)	13.3 (1.1)	13.2 (0.06)	4.20 (1.44)	3.85 (1.07)
B9-152	72.2 (5.9)	75.4 (13.4)	5.4 (0.1)	5.4 (0.0)	11.4 (4.9)	10.7 (3.9)	9.0 (0.06)	9.2 (0.4)	2.71 (1.26)	2.24 (1.21)

Table 2 (*continued*). Chemical properties of rainfall, throughfall, Upper Three Runs Creek (UTRC) and soil pore water

	Na		K		Al		SO_4		Cl	
	mg L^{-1}		mg L^{-1}		mg L^{-1}		mg L^{-1}			
Sample	storm	nonstorm	storm	nonstorm	storm	nonstorm	storm	nonstorm	storm	nonstorm
I. Rainfall	1.4 (1.0)	nd	0.40 (0.47)	nd	0.00	nd	0.68 (0.48)	nd	0.59 (0.20)	nd
II. Throughfall	1.3 (0.9)	nd	3.20 (1.50)	nd	0.00	nd	3.94 (7.25)	nd	2.10 (2.21)	nd
III. UTRC	1.3 (0.6)	1.1 (0.1)	0.28 (0.03)	0.28 (0.03)	0.00	0.00	0.82 (0.50)	0.62 (0.29)	2.31 (0.41)	2.20 (0.10)
IV. Soil pore water										
Lysimeter (Loc., cm)										
B7-15	1.6 (0.2)	1.4 (0.2)	0.23 (0.04)	0.22 (0.07)	0.86 (0.08)	0.92 (0.09)	10.3 (3.9)	6.7 (4.3)	6.4 (0.9)	4.5 (0.6)
B7-30	1.9 (0.5)	1.1+	0.21 (0.03)	0.16+	0.40 (0.10)	0.57+	6.3 (3.6)	2.2+	5.7 (1.6)	4.4+
B7-61	1.6 (0.3)	1.5 (0.1)	0.19 (0.06)	0.16 (0.05)	0.24 (0.09)	0.29 (0.07)	6.2 (4.8)	4.0 (4.0)	4.2 (0.4)	3.9 (0.3)
B7-102	1.4 (0.3)	1.6 (0.2)	0.10 (0.00)	0.09 (0.02)	0.18 (0.06)	0.25 (0.10)	3.4 (2.1)	2.6 (1.4)	3.3 (0.2)	3.8 (0.2)
B7-152	2.0 (0.3)	2.0 (0.1)	0.20 (0.06)	0.19 (0.01)	0.23 (0.08)	0.30 (0.10)	7.0 (3.6)	3.0 (1.5)	3.2 (1.4)	3.5 (0.4)
B9-15	1.9 (0.2)	2.0 (0.2)	0.17 (0.07)	0.24 (0.05)	0.32 (0.22)	0.45 (0.27)	12.7 (1.9)	7.8 (5.0)	6.2 (0.7)	6.0 (0.2)
B9-30	2.2 (0.2)	2.3 (0.5)	0.13 (0.05)	0.19 (0.02)	0.25 (0.14)	0.28 (0.07)	7.6 (2.4)	5.1 (1.8)*	8.1 (1.4)	7.8 (1.1)
B9-61	2.8 (0.03	3.0 (0.03)	0.12 (0.02)	0.16 (0.05)	0.19 (0.09)	0.28 (0.10)	4.8 (3.0)	3.7 (1.7)	10.4 (0.9)	8.9 (0.9)
B9-102	5.5 (0.5)	5.3 (0.5)	0.15 (0.05)	0.18 (0.03)	0.17 (0.07)	0.23 (0.05)	4.9 (3.4)	4.2 (3.5)	16.1 (1.3)	15.7 (0.4)
B9-152	2.4 (0.2)	2.5 (0.2)	0.11 (0.02)	0.18 (0.03)	0.25 (0.16)	0.13 (0.06)	5.2 (3.3)	3.9 (3.7)	8.2 (0.8)	9.0 (0.5)

* Significant at the 0.05 level of rejection.
\+ Data from one collection period only.

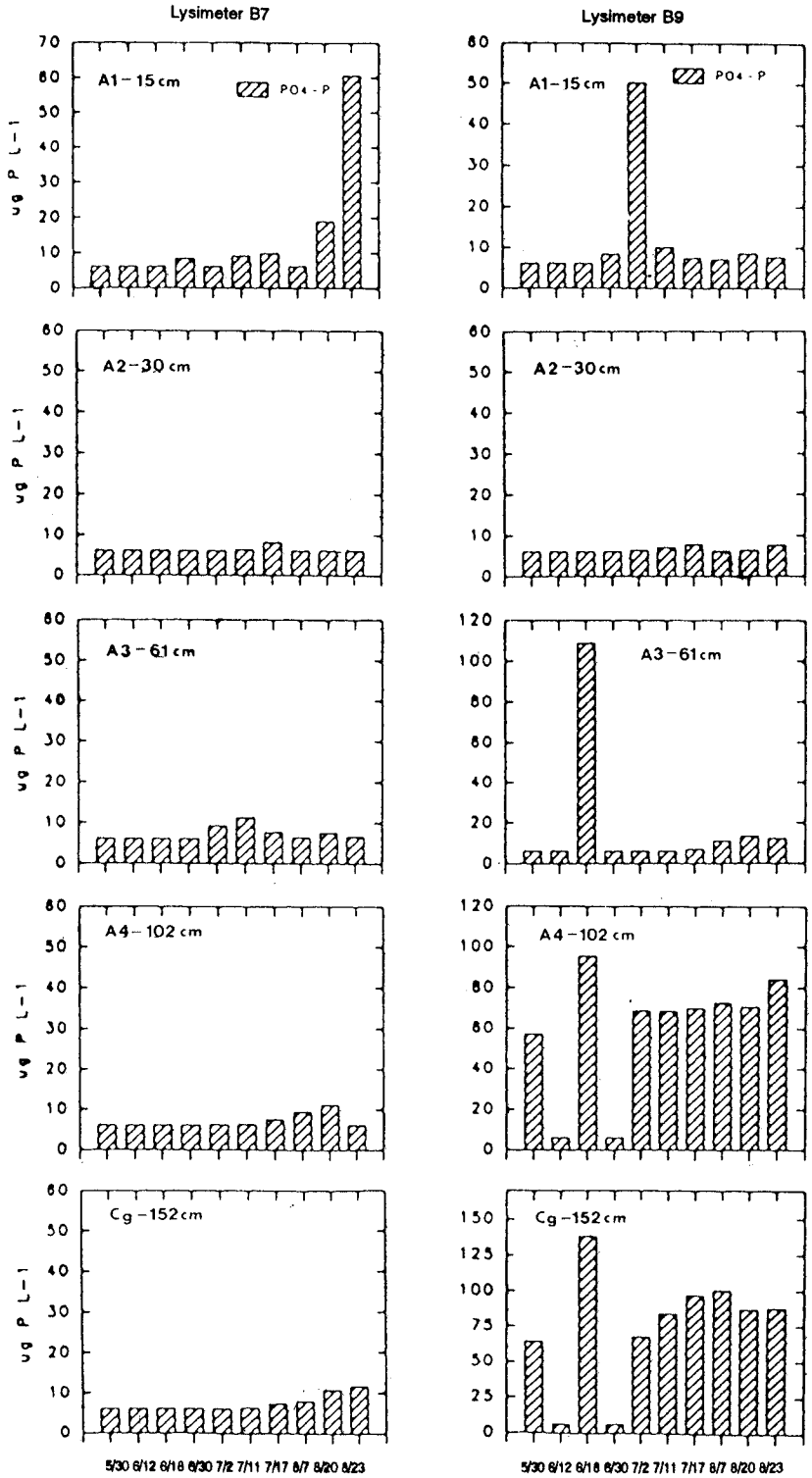


Figure 3. Concentrations of dissolved PO_4-P in soil pore water from each tension lysimeter.

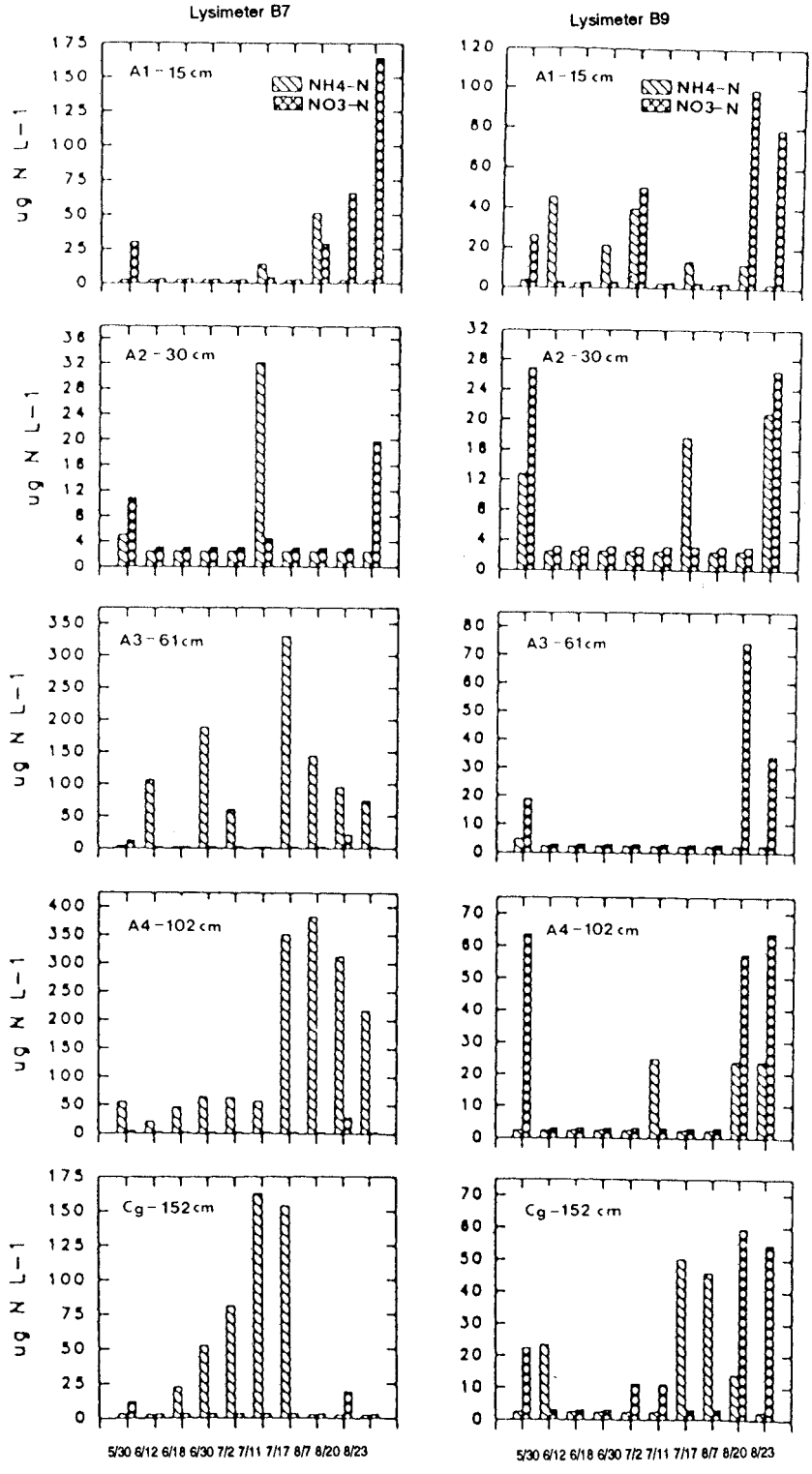


Figure 4. Concentrations of dissolved NH_4-N and NO_3-N in soil pore water from each tension lysimeter.

meter depth at B7 and B9 to assess the effects of floodplain location on pore water chemistry (Table 3). In general, statistically higher concentrations of Ca, Fe, Na, Cl and EC values occurred at B9 than at B7 ($P < 0.05$, Table 3). On the other hand, B7 had significantly higher concentrations of A1 than B9. Overall, no significant differences were observed between locations with respect to SO_4-S, DOC (except at 15 cm in B7) and pH. Soil pore water EC values were typically greater at site B9 than at B7.

Table 3. Summary of significant difference at the 0.05 level# between means of soil pore water collected from lysimeters at different depths

	Lysimeter depth (cm)				
Measurement	15	30	61	102	152
pH	-	0	+	-	0
EC	0	-	-	-	-
DOC	+	0	0	0	0
Ca	-	-	0	-	-
Fe	0	0	0	-	-
Al	+	+	0	0	0
Si	-	0	0	+	+
Na	-	0	-	-	-
K	0	0	0	-	-
SO_4	0	0	0	0	0
Cl	0	-	-	-	-

Analysed using a one-way ANOVA
+ indicates lysimeter nest B7 higher,
- indicates lysimeter nest B9 higher, and
0 indicates no significant difference

Rainfall, Throughfall and Creek Water Chemistry

There were no significant differences ($P < 0.05$) between rain, throughfall and creek water with respect to EC values, and concentrations of H, Ca, Na, SO_4-S, or Cl (Table 2). On the other hand, throughfall had a significant influence on the concentrations of K and DOC. Soil pore water had significantly higher pH and EC, and mean concentrations of Ca, Na SO_4-S, Cl than rain, or creek water. It was interesting that throughfall and soil pore water had statistically similar pooled mean DOC concentrations (Table 2).

Soil pore water collected from the surface horizons at both sites typically had the highest concentrations of Ca, Al, Fe, DOC, SO_4-S, and the lowest pH ($P < 0.05$). Except for Fe at B9, the concentrations of these elements usually decreased with increasing soil depth. Typically, the highest Fe concentrations measured in SPW were collected from the deepest lysimeters at B9 (Table 2). The decrease in DOC concentrations with depth parallels the decrease of soil organic carbon content (Table 1).

DISCUSSION

Our results show that summer storms had no significant influence on the concentrations of K, Ca, Na, SO_4-S, Cl, DOC, pH or EC in soil pore water collected from a relatively wet and dry soil in a South Carolina riverine floodplain. This suggests that the geochemical properties of the floodplain soils are fairly constant throughout the summer and are buffered to disturbances such as storms. The lack of a significant change in concentration of elements in the soil solution (except N and P) may be due to the long residence time of pore water in poorly drained soils, which minimizes the flushing effects of storms (Trudgill 1988). The hydraulic gradient associated with the nearly level terrain of the floodplain (0 to 1% slopes) may act to increase soil pore water residence time and minimize the flushing of solutes. We speculate that the long residence time of pore water would also promote soil pore water-soil mineral equilibrium, which would buffer the pore water against geochemical changes.

By comparison, concentrations of PO_4-P, NH_4-N and NO_3-N in soil pore water highlight the influence of biotic processes on P and N dynamics. In several instances, increases in PO_4-P concentrations were measured in soil pore water samples during mid-July and August after periods of high rainfall. We also measured the highest PO_4-P concentrations in pore water collected from the deepest lysimeters (102 to 152 cm) in the wet soil (B9). These trends are probably related to the high rainfall (mid-July to early August), shallow water table and poor drainage which may have created a reducing environment. Under reducing conditions, increased solubility of PO_4-P may occur due to Fe-reduction and subsequent release of P. Enhanced dissolution of P-containing minerals may occur in saturated soils due to elevated CO_2 partial measures (Ponnamperuma 1972, Patrick et al. 1985, Walters et al. 1992). Similarly, the high rainfall and poor drainage may have promoted anaerobic conditions, minimized nitrification, and allowed mineralized N to accumulate as NH_4. During the same period, soil pore water collected from 30 to 152 cm in the drier soil (B7) had higher NO_3-N concentrations than the wet soil (B9). This is thought to be due to NO_3 leaching from surface horizons to the deeper horizons of B7.

Although storms did not significantly influence the concentrations of most anions, cations, DOC, pH and EC in soil pore water, some element concentrations did vary with floodplain and water source. In general, the seasonally wet soil (B9) of the floodplain adjacent to the stream had a higher mean concentration of Ca, Fe, Na, Cl and EC values when compared to B7 (Table 3). We believe the generally drier conditions present in B7 have resulted in increased leaching losses of these soil pore water components relative to the generally wet B9. This is especially relevant for Ca, Na and Cl, which are very soluble components. Higher concentrations of these elements may explain why EC was higher in B9 than in B7 soil pore water.

Significantly higher Fe concentrations at 152 cm in B9 relative to B7 reflects the permanently saturated conditions in B9 (Table 2). Soil saturation causes reducing conditions and promotes dissolution of Fe minerals (Ponnamperuma 1972, Daniels et al. 1978, Waltxs et al. 1992). The low soil water matrix potentials (0 to -10 kPa) measured throughout the study period are evidence for permanent saturated conditions in B9.

Aluminum concentrations in SPW collected from the surface horizons in B7 were significantly higher (Table 2, $P < 0.05$) than B9. There was a close linear relationship ($r^2 = 0.8$) between DOC and Al concentrations, which suggests that Al may be chelated by dissolved organic ligands, thereby increasing Al dissolution rates.

Surprisingly, there was no significant difference between floodplain locations with respect to SO_4-S concentrations (Table 3). Sulfate reduction should occur at B9 because it was saturated and had a C source (Hemond 1990). Because there was no influence of floodplain location on SO_4-S concentrations, other factors (i.e., quality of C source, absence of sulfate reducers) may be regulating S dynamics. At both sites, the highest SO_4-S concentrations occurred in surface horizons and decreased with depth. The high SO_4-S concentrations in the surface horizon soil pore water may be related to mineralization of S-containing material associated with the DOC and/or sorbed organic matter and by washing of dry fallout from leaf sources (Feller 1977). A similar decrease in SO_4-S concentrations with depth was reported by Feller (1977) who attributed it to anion exchange and/or adsorption reactions of the associated cation.

Throughfall had significantly higher mean DOC and K concentrations (Table 2) relative to rain and creek water and was probably due to leaching of leaf tissue (Feller 1977, Brinson et al. 1980, Dalva and Moore 1991).

As indicated in Table 2, soil pore water typically had the highest EC, lowest pH and higher concentrations of DOC, Ca, Na, SO_4-S, and Cl relative to other soures of water. The enrichment of soil pore water% with inorganic anions and cations probably originates from weathering of minerals, and additions from rain and throughfall. The low soil pore water pH may be related to the high organic carbon content of the soils, which are a source of DOC compounds containing acidic functional groups (Stevenson 1982). Overall, the highest soil pore water DOC concentrations occurred in surface horizons and progressively decreased with depth. This is a common condition in soils and may be attributed to the mineralization of DOC from organic matter in surface horizons and sorption of DOC by minerals in subsurface horizons (Cronan 1990, Dalva and Moore 1991). In comparison to the literature, the DOC concentrations in rainfall samples were high, but DOC in throughfall and soil pore water are within the ranges reported by Cronan (1990).

In conclusion, this study showed that summer storms had a minor impact on the biogeochemistry of pore water in a riverine wetland soil. It is hypothesized that the poor drainage associated with the relatively level terrain of the floodplain minimized solute leaching by increasing the residence time of rain water. The lack of solute leaching would therefore allow the pore water to approach equilibrium with the overall soil minerals and the atmosphere.

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