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Alkaline Phosphatase Activity in Two Geologically Different Streams in Alabama, U.S.A.

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미국 알라바마에서 지질학적으로 다른 두 하천의 Alkaline Phosphatase 활성도

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ABSTRACT

Alakline phosphatase activity (APA) as a phosphorus deficiency measurement in flowing waters and of microhabitats (rocks, wood, leaves, and sediments) was measured and its relationship to flux of nutrients and response to rainfall events were determined for two geologically different streams in west Alabama from August to November. Results indicated water column APA in both streams had a low correlation with levels of orthophosphate, total organic phosphorus, nitrate, ammonia, dissolved organic carbon, and discharge ($r=0.075\sim0.583$; $n=9\sim11$). Communities on rock surfaces showed a higher APA level than those on wood and leaves. Sediment passed through a 106 μm sieve showed 2~9 times higher APA level than material passed through 425 μm sieve. The first storm after drought at Yellow Creek introduced substantial quantities of DOC (2.5 times baseflow concentrations) and NO_3-N (5.8 times baseflow concentrations) which did not affect APA significantly. The second storm at Little Schultz Creek caused minor changes in nutrient cocentrations; however NO_3-N levels and APA were drastically lower due to the dilution effect. Retention of stream water APA at Yellow Creek and Little Schultz Creek on 0.45 μm filter (54 and 43%, respectively) and 0.22 μm (83 and 77% of total APA, respectively) indicated more free dissolved portion of the enzyme was present at Little Schultz Creek. Little Schultz Creek (with carbonate and with a higher productivity and biomass) showed a consistantly greater APA activity (132 ± 54 $\mu M \cdot l^{-1} \cdot min^{-1}$; $n=9$) than Yellow Creek (41 ± 23 $\mu M \cdot l^{-1} \cdot min^{-1}$, with a sandstone substrate; $n=11$, $p\leq0.001$). Overall, a greater APA on all microhabitats and the presence of more dissolved enzyme in Little Schultz Creek during the study period may indicates it is more P deficient than Yellow Creek.

Key words: Alkaline phosphatase activity, Geology, Microhabitats, Streams

INTRODUCTION

In aquatic ecosystems, phosphorus frequently is a nutrient in most demand relative to supply. Phosphorus dynamics in lentic ecosystems in general have been well studied but only a few studies have focused on lotic ecosystems (Meyer and Likens 1979, Elwood *et al.* 1981). Algae and bacteria can respond to low inorganic phosphorus concentrations by producing alkaline phosphatases which supply inorganic phosphate groups by hydrolysis of organic phosphates (Wetzel 1981).

The use of alkaline phosphatase activity (APA) as an indicator of phosphorus (P) deficiency has been widely applied to lakes and marine systems (Wetzel 1981, Myklestad and Sakshaug 1983, Maura and Gorham 1985), but the applicability of these approaches to stream systems is still uncertain, in part because of the interaction of stream water velocity and nutrients. Some studies have identified a limiting role of P in streams by enriching orthophosphate experimentally (Elwood *et al.* 1981, Peterson *et al.* 1983), indicating that despite a continuous flow of water in streams, phosphorus limitation can occur.

Other than phosphorus concentrations, little is known about the factors controlling APA in lakes or streams. Stewart and Wetzel (1982a) showed that dissolved humic material of low molecular weight was stimulatory to ^{14}C assimilation and to the APA of natural algae-bacteria assemblages and suggested that interaction between dissolved humic material (DHM) and phosphorus cycling in aquatic systems may be important. An inverse relationship between light intensity and APA of *Selenastrum capricornutum* under stream conditions was demonstrated by Klotz (1985).

Two streams with different geological and chemical features were selected as sites in this study to compare APA. Seasonal patterns of nutrients and algal community dynamics have been studied previously (Lay and Ward 1987). Geological differences in the two streams (carbonate vs. sandstone /shale) contribute to differences in the mineral content and primary production. Levels of orthophosphate are at the analytical detection limits in both streams; however, dissolved organic carbon, nitrate, and alkalinity are significantly different. This study indicated a possible phosphorus demand in both streams because of consistently low levels of orthophosphate (PO_4-P) in the water column. However, instantaneous measurements of water column PO_4-P provide little insight into the actual degree of metabolic demand. Comparisons of APA between streams and between different microhabitats should provide better information of this type. Also, the physical similarities and potential phosphorus demand in both systems make these sites ideal for *in situ* studies. On the effects of different nutrient concentrations before, during, and after a storm event should provide information about the responsiveness of the microbial community to short term nutrient pulses.

Several general hypotheses concerning these streams and APA were: 1) the enzyme activity in the water column and on surfaces in Little Schultz Creek, which has a greater attached algal productivity, will be higher than Yellow Creek indicating more phosphorus demand, 2) levels of enzyme activity will be somewhat negatively correlated with water column PO_4-P concentrations in both streames, 3) increased DOC from terrestrial input will react with the enzyme in an inhibitory manner, 4) if major rain events introduce substantial quantities of phosphorous and other nutrients (such as dissolved organic carbon) into the stream, these substances will reduce APA compared to prerain levels.

The specific objectives of this study were: 1) to determine APA of flowing water and the microhabitats (rocks, wood, leaves, and sediments) and the enzyme activity of flowing water, depending on partide size fractionation, 2) to determine the enzyme activity at regular intervals after rain events in order to see the recovery mechanism of the stream ecosystem, 3) to determine the relationship between the enzyme activity and levels of nutrients, orthophosphate, dissolved inorganic nitrogen (NO_3-N, NH_4-N), total dissolved organic phosphorus and dissolved organic carbon.

MATERLALS AND METHODS

Sampling

Experiments were conducted during the summer and fall of 1984. Rainfall effects on nutrients and APA of both creeks were observed at the end of the study period. Samples were collected at irregular intervals before a rain event and more frequently (every 1 to 2 days) after rain events until the water level returned to normal.

Physico-chemical parameters

Temperature (mercury thermometer) and pH (Corning model 125) were determined on each sampling date. Nutrient concentrations (NO_3-N, NH_4-N, PO_4-P and total dissolved organic phosphorus) were determined after filtering (0.45 μm Whatman GF/F glass fiber filters, precombusted at 500℃ for 1 hr) water samples and freezing the filtrates, which were later analyzed on an Autoanalyzer 11 (Technicon Corp., Inc.). The cadmium reduction technique was used for nitrate (Wood *et al.* 1967), the phenate technique for ammonia (Harwood and Kuhn 1970), and the ascorbic acid technique for orthophosphate (Strickland and Parsons 1968) determinations. Water samples for dissolved organic carbon determination were also filtered using precombusted 0.45 μm glass fiber filters. Subsamples of the filtrate were then sparged with O_2, and phosphoric acid and potassium persulfate were added (Menzel and Vaccaro 1964). Three to four subsamples were ampoulated, autoclaved and analyzed by infrared determination of liberated CO_2 (Oceanography International).

APA measurement

Water samples were collected between 14:00~15:00 from both creeks where water samples were used to estimate total APA. Membrane filters (0.45 μm glass fiber filter and 0.22 μm Millipore) were used to partition APA into particle size classes. Water samples were filtered at a vacuum pressure of 0.5 atm. The measurement of APA was carried out by the fluorometric method of Perry (1972), using a Turner model 110 fluorometer by measuring rate of fluorescence increase resulting from enzymatic hydrolysis of non-fluorescent substrate 3-0-methyl fluorescein phosphate, to fluorescent 3-0-methyl fluorescein. 0 ml of sample containing 0.5 ml of substrate was incubated at 20~24℃ from 60 min to 90 min, depending on enzymatic activity.

Consistent linear relationships between fluorescence intensity and product concentration were observed, which allowed conversion from change in fluorescence per unit time to rate of orthophosphate liberated (μmols P released liter^{-1} · min^{-1}). In order to measure APA of microhabitats, rocks (7~12 cm diameter), gravel (2~3 cm), wood (4~6 cm), leaves and sediments were collected at the sampling sites and immediately brought back to the lab. Surface of rocks, gravel, wood leaves were scraped with a brush and diluted with 200 ml of whole water sample. For the sediment APA analysis, two size fractions (106 μm and 425 μm) were made to separate sand and clay using U.S.A. Standard Testing Sieves no. 40 and no. 140. After dilution with 200 ml of the whole water sample, the scraped natural assemblage was allowed to settle for 10~15 min. Four ml of water above the sediment were withdrawn and analyzed. For quantitative assay, several techniques such as ash free dry weight, wet volume, dry weight, and surface area can be applied. The determination of surface area is most appropriate for rock, leaves, wood, and can be easily compared across samples. Sediment samples (106 μm and 425 μm filtrate) were determined by wet volume. 425 μm samples in this study contained mostly sand and almost no organic matter. Due to heterogeneity of microhabitats, comparison between samples is difficult. Results were reported on the basis of wet volume, dry weight, and surface area.

Water discharge and precipitation data for the 1984 water year at Yellow Creek and daily precipitation data for Little Schultz Creek were obtained from the Alabama Geological Survey. Discharge from October to November at Yellow Creek was estimated by comparison with Turkey Creek which has a similar discharge pattern and is located 10km from the study site.

To determine if nutrients of Yellow Creek and Little Schultz Creek were statistically different, a Student's t-test was used. Pearson product-moment correlation coefficients were calculated between the APA and all nutrient parameters according to Sokal and Rohlf(1981).

Study sites

Two streams with different geological features, yet similar physical features, were chosen to compare APA. Yellow Creek and Little Schultz Creek are 2nd order streams and located in relatively undisturbed mixed deciduous and evergreen forests of northwest Alabama.

Yellow Creek is in a 491 hectare watershed within the Black Warrior River drainage. It is a soft water system and the stream bed consists mainly of sandstone, with gravel and sand. Little Schultz Creek is in a 117 hectare watershed within the Cahaba River drainage basin. The bed rock is limestone, resulting in a hard water system and the stream bed consists of bare rock, sand, and gravel. During periods of low flow, maximum water depth is both streams is 0.2~0.4 m. A detailed description of the sites and their water chemistry have been given elsewhere (Lay and Ward 1987). Both creeks have low levels of orthophosphate throughout the year with a mean concentration of 0.004 mg/l in Little Schultz Creek and 0.009 mg/l in Yellow Creek and a weight ratio of inorganic nitrogen (NH_4-N + NO_3-N) to (PO_4-P) of 16 and 3, respectively. A summary of biological and chemical parameters is shown in Table 1.

To determine the nutrient status in response to rainfall in different orders of Yellow Creek, two sites were selected. The first site is within the Creek itself (hereafter called main channel) and is 40 m upstream from the second site (hereafter called side channel), which is in a first order tributary.

Table 1. Biological and chemical characteristics of Little Schultz Creek and Yellow Creek. Monthly data collected from April 1983 through February 1984 (Lay and Ward 1987). Values are mean ± standard error (range)

Parameters	Little Schultz Creek	Yellow Creek
Primary productivity	91.16 ± 29.79	49.30 ± 32.10
(mgC m^{-2} d^{-1})	(23.5 ~211.08)	(4.12 ~237.0)
Biomass*	5.23 ± 1.09	0.64 ± 0.27
(mg chl a/㎡)	(2.16 ~10.10)	(0.00 ~2.30)
Temperature	17.33 ± 1.00	15.96 ± 1.33
(℃)	(9.24 ~23.00)	(8.00 ~23.00)
pH	7.20 ± 0.01	6.80 ± 0.02
	(6.83 ~7.68)	(6.13 ~8.52)
$CaCO_3$	103.75± 9.19	4.40 ± 0.53
(mg/l)	(55.00~148.60)	(0.30 ~7.20)
NO_3-N	0.056 ± 0.009	0.021 ± 0.010
(mg/l)	(0.014~0.098)	(0.002~0.131)
NH_4-N	0.008 ± 0.003	0.006 ± 0.001
(mg/l)	(0.002~0.038)	(0.001~0.012)
PO_4-P	0.004 ± 0.001	0.009 ± 0.005
(mg/l)	(0.002~0.010)	(0.001~0.065)
SiO_2	4.68 ± 0.12	4.70 ± 0.01
(mg/l)	(4.14 ~5.24)	(4.25 ~5.35)
DOC	1.56 ± 0.22	2.69 ± 0.26
(mg/l)	(0.97 ~ 3.35)	(1.39 ~3.35)

* natural substrate

RESULTS AND DISCUSSION

APA of microhabitats

The APA of the microhabitats on four dates in Little Schultz Creek showed a higher activity, compared to Yellow Creek (Table 2). The APA in the water column was about 2 times greater in Little Schultz Creek. Among microhabitats, rocks generally showed higher activity than leaves and wood. One high APA value occurred on 19 August in a Yellow Creek gravel sample due to development of green filamentous algae (2~3 cm in length) during low baseflow (Table 2), but filamentous algae on gravel disappeared during high discharge. In both streams, sediment which passed through 106 μm sieves showed a higher activity than 425 μm sieves. Sediment which passed through the 425 μm filter was collected from sand bottoms which usually contained no organic materials while 106 μm filter samples were largely collected from slow flowing pool sites with fine organic sediment. This phenomenon was observed throughout all experiments (11 at Yellow Creek and 9 at Little Schultz Creek) and may imply that fine sediment provides a more favorable habitat for microorganisms.

Few studies have addressed comparison of biological processes on different substrata in streams. Heterogeneity of substratum type and history of substratum (i.e. residence time of wood, leaves, and gravel) make interpretations difficult. However, results from this study indicate that among the microhabitats, communities on large inorganic substrata may not be susceptible to physical disturbances compared to communities on organic

Table 2. APA of microhabitats in Yellow Creek main channel and Little Schultz Creek.
ND = Not Determined

Date		Flowing Water[1]	Rock[2]	Leaves[2]	Wood[2]	Gravel[3]	Sediments[4]	
							106 μm	425 μm
Yellow Creek								
12	Aug	14.30	1.05	0.60	8.62	1.43	ND	ND
19	Aug	36.10	5.22	3.41	1.89	20.21	ND	ND
12	Oct	60.15	1.00	0.79	1.00	6.00	0.05	0.03
31	Oct	36.10	9.12	1.02	1.18	ND	0.07	0.02
Average		36.66	4.09	1.50	3.19	9.21	0.06	0.03
Little Schultz Creek								
13	Aug	71.00	6.61	4.75	1.39	ND	ND	ND
22	Aug	23.60	23.60	16.40	ND	19.88	1.55	0.33
14	Oct	154.00	95.00	30.00	3.00	12.00	2.34	0.14
3	Nov	199.70	81.50	19.20	7.06	ND	2.33	0.20
Average		123.65	51.67	17.58	3.81	15.99	2.07	0.22

[1] unit : μM l^{-1} min^{-1}

[2] unit : μM cm^{-2} min^{-1} × 10^{-3} (surface area)

[3] unit : μM g^{-1} min^{-1} × 10^{-3} (dry weight)

[4] unit : μM ml^{-1} min^{-1} (wet volume)

substrata, since wood and leaves appear to be ephemeral habitats in both streams. In addition, communities on organic substata may utilize phosphate from the substratum itself.

Size fractionation of APA

Size fractionation of APA can be used to separate bacterial and algal APA. Stewart and Wetzel (1982b) indicated that non-algal APA may be an important component of the total APA and suggested that much of the particulate activity may be present in nannobacteria, capable of passing through a 0.5 μm filter. Therefore, separations of dissolved, bacterial-particulates, and algal particulates are accomplished by use of the 0.22 μm and 0.45 μm filters, respectively.

The data from size fractionation experiments on the main and side channels of Yellow Creek and Little Schultz Creek with a 0.45 μm membrane filter showed an average retention of 54, 50, and 43% of the whole water sample APA, respectively (Table 3). An average retention of 83, 78, and 77% was obtained with a 0.22 μm filter, respectively. The 0.45 μm filtrate showed a highly variable retention rate (13~87%) while the 0.22 μm filtrate was less variable (61~88%). Average retention rates for both filters on Yellow Creek samples showed slightly higher values than Little Schultz Creek samples. This may imply that more "dissolved" enzyme was present in Little Schultz Creek during the study period and also may indicate that a more severe phosphorus deficiency existed. This phenomenon was described by Healey (1973) for *Anabaena variabilis* in lab cultures and by Pettersson (1980) in moderately eutrophic lakes. The dissolved enzyme activity measured by Healey in the lab increased from 10% of the total to 50% as the algae became more P deficient under P limited conditions and similarly the field result of Pettersson's study showed that activity increased 2~3 fold as a lake became more P deficient.

This study, in general, agrees with previous size fractionation results in that retention of APA on filters is highly variable. About 50% of APA is retained on 0.45 μm filters, likely associated with algae and about 70% of APA is retained on 0.22 μm filters, likely associated with bacteria and algae.

Comparison of Yellow Creek and Little Schultz Creek APA with other studies

Many APA studies have been done in aquatic ecosystems, but the results have rarely been compared due to differences in methodology. The use of different enzyme substrates and specific enzyme units makes comparisons difficult. Comparisons with other studies indicate that results are highly variable, even when a similar analytical technique has been used. Hence, there is no absolute standard for comparison. However, the work of Sayler *et al.* (1979) on a first order stream in Tennessee shows that APA of aufwuchs (from rock scrapings) are generally higher than suspended paritcles (from water column). These results generally agree with this study in that the epilithic communities are more biologically active than other microhabitats. In addition, Jones (1972) has shown that the APA of lake ecosystems is correlated with the degree of eutrophication. This trend was

Table 3. Size fractionation of APA of flowing water from main and side channel of Yellow Creek and Little Schultz Creek. ND =Not Determined

Site	Date	Whole Water[1]	Filter retention (%)	
		APA	0.45 μm	0.22 μm
Yellow Creek (YC) main channel	1 Aug	13.2	41	ND
	12 Aug	14.3	46	ND
	19 Aug	36.1	62	ND
	13 Sep	81.2	75	88
	27 Sep	72.9	50	83
	30 Sep	18.3	27	ND
	8 Oct	45.3	49	76
	9 Oct	27.7	56	85
	10 Oct	48.1	53	83
	12 Oct	60.2	74	82
	31 Oct	36.1	60	ND
Yellow Creek side channel	8 Oct	37.7	52	83
	9 Oct	64.9	44	81
	10 Oct	57.7	13	61
	12 Oct	149.2	69	85
	31 Oct	111.9	72	ND
Little Schultz Creek(LSC)	13 Aug	71.0	46	ND
	22 Aug	69.9	32	ND
	24 Aug	205.4	87	ND
	14 Oct	154.0	35	78
	3 Nov	199.7	55	76
	4 Nov	185.3	35	ND
	6 Nov	102.2	19	ND
	8 Nov	117.9	47	ND
	16 Nov	89.0	36	ND
Averages:				
YC (main)		41.2	54	83
YC (side)		84.2	50	78
LSC		132.6	43	77

[1] unit: μM l^{-1} min^{-1}

also found in Little Schultz Creek and Yellow Creek with respect to productivity.

Effect of nutrient changes associated with rainfall on stream APA

1) Hydrology of the two streams

Both streams have a similar amounts of precipitation. Annual rainfall for Yellow Creek and Little Schultz Creek measured 142.5 and 153.0 cm in 1983, respectively, with both sites having high rainfall amounts in April, November, and December (Lay and Ward 1987). This pattern is typical for headwater systems in this area. Four year discharge and precipitation data indicate that the highest discharge occurs from December to April and low base flow occurs from August to early November. The 1984 hydrograph and rainfall of Yellow Creek and monthly rainfall of Little Schultz Creek represents this annual discharge pattern. However, slight changes can occur, depending on the frequency of rainfall and amounts of precipitation in each particular year. From December to April Yellow Creek maintained a high discharge (>20 ft^3/sec) while discharge fell below 8 ft^3/sec from August to September (Fig. 1-A, B). Stream velocity seems to change with discharge pattern. One measurement in early spring resulted in a range of $80\sim120$ cm/sec in the main channel of Yellow Creek. Direct measurement of discharge in Yellow Creek and Little Schultz Creek in mid-summer resulted in measurements of 0.036 m^3/sec and 0.088 m^3/sec, respectively (Lay and Ward 1987). The side channel of Yellow Creek was narrower (2.7 m) than the main channel (4.8 m) and only a few debris dams occur (0.5/100 m).

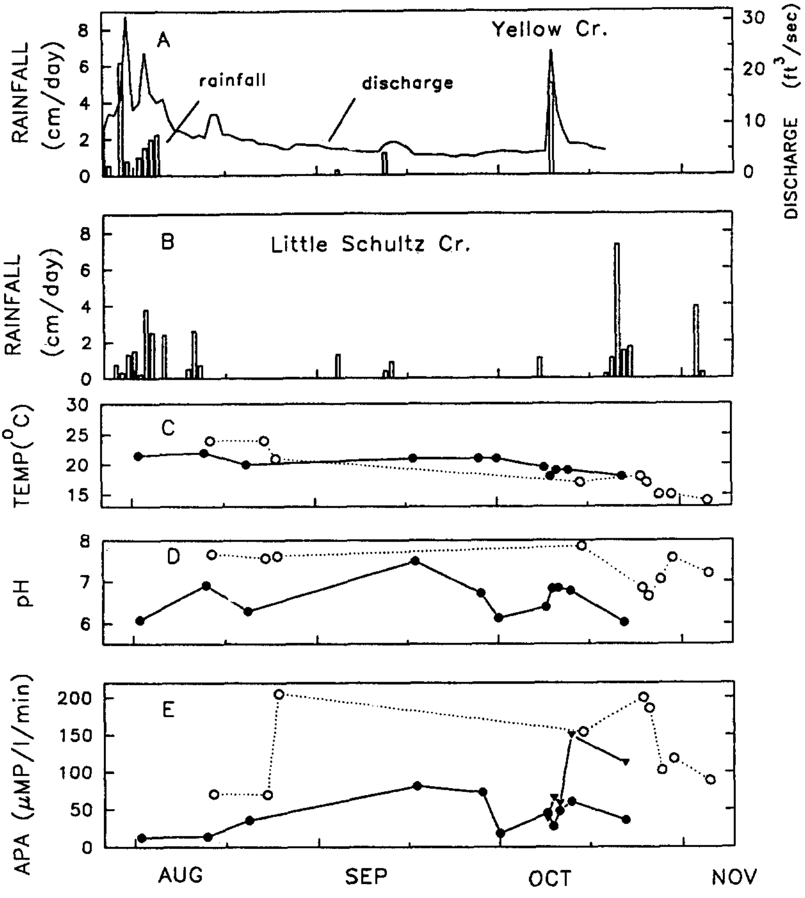

Fig. 1. A, Rainfall and discharge of Yellow Creek during the study period. B, Rainfall in Little Schultz Creek during the study period. C, Temperature. D, pH. E, Alkaline phosphatase activity for main (---●---) and side (---▲---) channel of Yellow Creek and Little Schultz Creek (- -O- -).

2) Changes in nutrients before the rain events

Before the major rainfall events on 8 October (Yellow Creek, Fig. 1-A) and 3 November (Little Schultz Creek, Fig. 1-B), nutrients of both creeks were relatively constant throughout the study period.

Higher nitrate, DOC concentration, and pH occurred in Little Schultz while ammonium concentration was similar to that in Yellow Creek prior to the rain events (Fig. 1-C, D, E ; Fig. 2-A, B, C, D, E). Nitrate concentrations of the two streams were significantly different ($p<0.01$). The nitrate concentrations increased with falling water levels and decreased

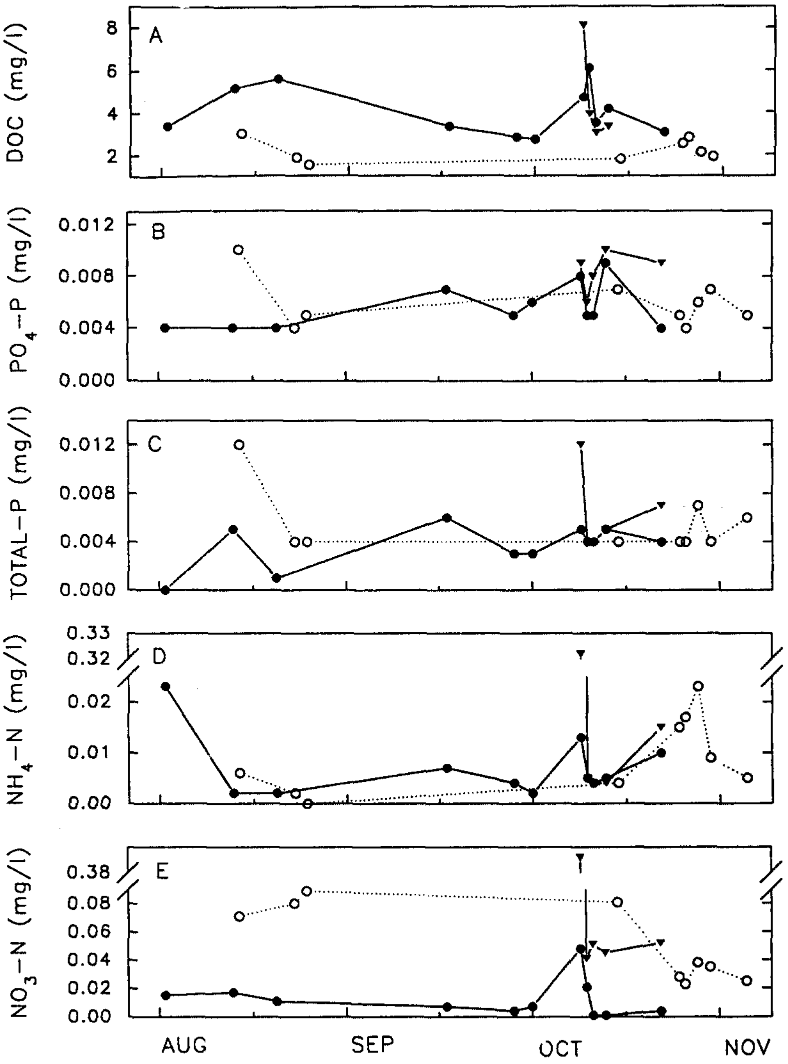

Fig. 2. A, Concentration of dissolved organic carbon (DOC). B, Orthophosphate (PO_4-P). C, Total dissolved organic phosphorus (Total P). D, Ammonia (NH_4-N). E, Nitrate (NO_3-N) for main (---●----) and side (- -▲ - -) channel of Yellow Creek and Little Schultz Creek(---O---).

with rising water levels. pH levels in both creeks were similar, however there was more variability in Yellow Creek. Annual mean alkalinity (mg $CaCO_3$/1) of Little Schultz and Yellow Creek were 103.75 and 4.40 mg/1, respectively.

3) Flux of nutrients after rainfall events and effect on APA

Levels of DOC and NH_4-N in the main channel of both streams changed only slightly after the 8 October rainfall. Levels of NO_3-N dropped to half of prerain levels. In the main channel of Yellow Creek, the NO_3-N concentration increased 5.8 times over prerainfall levels, then quickly returned to normal(Fig. 2-A, D, E, Table 4). Accelerated decomposition of organic matter followed by nitrification may be responsible for the increased concentrations of NO_3-N just after the rainfall events. Similarly, in a small first order Cascade Mountain stream of Oregon, nitrate concentration reached a maximum value of 0.268 mg/1 during the early stages of a storm in late February of a drought year (Dahm 1980).

PO_4-P and total P concentrations in both channels of Yellow Creek did not change significantly with increasing discharge after the rainfall events(Fig. 2-B, C). Meyer and Likens (1979) also found no relationship between dissolved phosphorus concentration and discharge in a New England forested stream after storm events, although fine particulate phosphorous increased dramatically.

DOC concentration changes in both the side and main channels of Yellow creek were slightly different from the other nutrients. In the side channel, the concentration of DOC increased within a few hours, then quickly returned to the normal low level. However, in

Table 4. Chemical parameters for Little Schultz and Yellow Creek from 1 August to 16 November, 1984. Results are expressed as the mean ± standard error (s.e.) and are in mg/l. Sample sizes are Little Schultz Creek, n=9; Main channel of Yellow Creek, n=11; and side channel of Yellow Creek, n=5. t-values are calculated for differences between Little Schultz Creek and the main channel of Yellow Creek

Parameters	Little Schultz Creek	Yellow Creek		t-value
		Main Channel	Side Channel	
	Mean ± s.e. (range)	Mean ± s.e. (range)	Mean ± s.e. (range)	
Total P	0.0054 ± 0.0026 (0.004~0.012)	0.0036 ± 0.0018 (0.001~0.006)	0.0064 ± 0.0033 (0.004~0.012)	1.83^{ns}
DOC	2.1 ± 0.55 (1.50~3.05)	4.10 ± 1.13 (2.76~6.01)	4.25 ± 2.06 (3.06~7.89)	4.55^{**}
PO_4-P	0.0058 ± 0.0019 (0.004~0.010)	0.0055 ± 0.0017 (0.004~0.009)	0.0078 ± 0.0021 (0.005~0.010)	0.416^{ns}
NO_3-N	0.0522 ± 0.0273 (0.023~0.089)	0.0123 ± 0.0135 (0.001~0.048)	0.1014 ± 0.1503 (0.001~0.368)	4.268^{**}
NH_4-N	0.0090 ± 0.0077 (0.000~0.023)	0.0070 ± 0.0063 (0.002~0.013)	0.0700 ± 0.1409 (0.004~0.322)	0.639^{ns}

** = $p \leq 0.01$

ns = not significant

the main channel, the highest DOC concentration (6.01 mg/1) occured after 24 hours. This difference in response of DOC may be due to the size of the watershed of each channel. Previous studies have shown DOC concentrations decline sharply as rain water passes through the soil profile: from about 1 mg DOC/1 in precipitation, 10 mg/1 as water passes throught the forest canopy, 90 mg/1 in the upper portion of the soil profile, and decrease to 2~3 mg/1 in the lower soil horizons and the streams (Likens 1984). However, this generalized DOC flux between the terrestrial and aquatic ecosystems may vary depending on the intensity of rainfall and the size of the watershed, as shown in this study. Under similar precipitation patterns in the Oregon Cascade Mountains, the peak DOC concentrations were 25 and 9 mg/1, in first and second order streams, respectively, in response to storm events (Dahm 1980). This difference in DOC flux supports the idea that the flux in low order streams is more dynamic than in higher order streams.

Hobbie and Likens (1973) concluded that since concentrations of DOC did not change appreciably with discharge of season, monthly sampling would not be much improved. However, the sampling intervals in this study, which were one or two days or less after rainfalls, enable the precise evaluation of storm induced DOC flux. Manny and Wetzel (1973) found that DOC concentrations after autumn rain were double the annual average. Two first order Oregon streams responded to small storm events after dry low discharge periods with rapid increased in episodic pulses of high DOC concentrations up to ten times the baseline levels (Dahm 1980).

The biological importance of these transient, high DOC concentrations has not been investigated extensively. For example, the higher DOC may provide and increased supply of labile energy rich compounds which stimulate stream microbial activity or it may simply represent a flushing of stored refractory material with little biological utilization. One study (Kaplan and Bott 1985) in a Piedmont stream showed the influence of storm and DOC on bacterial activity. During the storm, bacterial activity was reduced, but at the end of the storm when discharge was near baseflow, but DOC still elevated, there was higher specific growth rate. Due to lack of prerain APA data on the side channel of Yellow Creek, it is hard to conclude that microbial activity follows a similar trend as stated above. However, the APA response to changes in DOC at both sites in Yellow Creek after storm events showed a clear pattern. The lowest APA coincided with the storm induced peak in DOC concentration and APA recovered in 2~3 days as DOC levels returned to near prerain levels(Fig. 1-E, 2-A). This suggests that increased DOC reacts with the enzyme in an inhibitory manner.

Surfaces of particulate matter and suspended solids in water column represent potential sites of nutrient exchange. A study by Grobbelaar (1983) indicates that suspended solids can be important factors in phosphorus dynamics. He found more than 95% of absorbed NO_3-N and more than 84% of absorbed PO_4-P in the Amazon River suspended soils were available to algae. This suggests that water column measurements of dissolved orthophosphate in streams may result in underestimation of available phosphorus to algae.

This suggests that water column measurements of dissolved orthophosphate in streams may result in underestimation of available phosphorus to algae. Therefore, water column nutrients alone do not provide a full picture of the nutrient exchange or biological response.

Low correlation between APA and water column PO_4-P suggest that complex mechanisms control P dynamics in these streams, including abiotic sorption and subsequent biological utilization on surfaces. Sorption of dissolved phosphorus by sediments is a likely mechanism in low order stream ecosystems which have a high sediment surface area for interaction with the water column. Klotz (1985) found phosphorus limitation using APA of stream benthos was correlated with phosphorus absorption by sediments and not with phosphorus concentration of water. Phosphorus sorption has been shown to increase as sediment particle size decreased and as organic matter content increased (Meyer 1979). Increases in DOC, POC and clay material after rainfall at both stream sites may absorb P and keep water column P levels low. If so, the further characterization of stream surfaces with regard to their nutrient sorptive capacities and mechanisms by which attached biota can utilize these nutrients appears to be a logical next step in understanding nutrient exchange in small stream ecosystems.

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적 요

두개의 다른 지질대에 위치한 알라바마 하천에서 8월부터 11월 사이 하천수와 미세서식처 (암석, 나무가지, 나뭇잎 및 저질)에서 인의 결핍의 척도로서 alkaline phosphatase 활성도 (APA)를 측정하고, 강우 후 영양물질 증감에 따른 효소 활성도의 반응정도를 조사하였다.

두 하천에서 하천수의 APA는 인산염인, 총유기인, 질산성질소, 암모니아성 질소, 용존유기탄소 및 유량과 낮은 상관을 보였다 (r=0.075~0.583: n=9~11). 암석표면의 부착생물에 의한 APA는 나뭇가지 및 잎에서 보다 높았다. 106 μm 체를 통과한 저질의 APA가 425 μm 체를 통과한 저질보다 2~9배 높았다. Yellow Creek에서 가뭄후 첫 강우로 상당히 많은 양의 DOC (강우전에 비해 2.5배)와 질산성 질소 (강우전에 비해 5.8배)가 증가되었으나 APA에는 크게 영향을 미치지 않았다. Little Schultz Creek에서의 두번째 강우는 영양염류의 농도변화에 영향을 적게 미쳤으나, 질산성질소와 APA는 하천수의 희석으로 매우 낮았다. Yellow Creek과 Little Schultz Creek에서의 하천수의 APA 잔류정도는 0.45 μm 여과지에서 각각 54와 43%였으며,

0.22 μm 여과지에서 각각 83과 77%로 Little Schultz Creek에서의 용존정도가 더 큼을 알 수 있었다. Little Schultz Creek (석회암 지질, 높은 일차생산력과 생물량)의 APA (132±54 $\mu M \cdot l^{-1} \cdot min^{-1}$; n=9)는 Yellow Creek (사암지질) (41±23 $\mu M \cdot l^{-1} \cdot min^{-1}$) 보다 항상 높았다. Little Schultz Creek에서 전체적으로 높은 APA와 더 많은 용존 효소 활성도가 나타난 것은 인의 결핍이 Yellow Creek 보다 더 심할 가능성을 보인 것이다.

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