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Nitrification: Importance to Nutrient Losses from a Cutover Forested Ecosystem

Abstract. *The nitrate concentration (weighted average) in stream water from an experimentally deforested watershed increased from 0.9 milligram per liter before removal of the vegetation to 53 milligrams per liter 2 years later. This nitrate mobilization, presumably due to increased microbial nitrification, was equivalent to all of the other net cationic increases and anionic decreases observed in the drainage water.*

Loss of nutrients in drainage water was greatly accelerated after the northern hardwoods vegetation was clear-cut in November and December 1965 on watershed 2 (15.6 hectares) of the Hubbard Brook Experimental Forest in central New Hampshire (*1*). Regrowth of vegetation has been retarded by the application of two herbicides, Bromacil ($C_2H_{13}BrN_2O_2$) and an ester of 2,4, 5-trichlorophenoxyacetic acid.

We have measured interactions between the hydrologic cycle and nutrient cycle in several undisturbed watershed ecosystems of the Hubbard Brook Experimental Forest since 1963 (*2*). These watersheds are characterized by a similar vegetation and geologic substrate. The latter forms a watertight basement, which makes it possible to determine quantitative nutrient budgets for these ecosystems from measurements of chemical input and output (*3*).

The chemical concentration in drainage waters from the cutover watershed did not increase significantly until June 1966, 5 months after the forest was cut (*1*). Therefore, milliequivalent values for the water year, 1 June 1965 to 31 May 1966, are equivalent to those for 1964–65 (Table 1), and to those obtained from undisturbed watersheds (*3*). Cations and anions in the drainage water greatly increased during 1966–67 and 1967–68 (*1*) (Table 1). Average concentrations (in milligrams per liter) in stream water increased from 0.9 for NO_3^-, 1.8 for Ca^{++}, 0.4 for Mg^{++}, 0.9 for Na^+, and 0.2 for K^+ in 1965–66 to 38, 6.5, 1.4, 1.5, and 1.9, respectively, during 1966–67, and 53, 7.6, 1.5, 1.5, and 3.0, respectively, during 1967–68. However, the weighted concentration of SO_4^{--} in drainage water decreased by about 45 percent. Because of the increased average concentration (Table 1) and increased streamflow from the cutover watershed, the net budgetary losses during 1966–67 for Ca^{++}, Mg^{++}, Na^+, K^+, and nitrate nitrogen were 9, 8, 3, 20, and 100 times greater, respectively, than those in comparable, undisturbed watersheds during the same period. The magnitude of these losses was great in relation to a comparative lysimeter study in a small cutover plot in a Douglas fir plantation in Washington (*4*). These changes may be accounted for by an increase in microbial nitrification.

Many microorganisms convert organic nitrogen into ammonia. The ammonia then may be oxidized to nitrite by bacteria of the genus *Nitrosomonas.* Nitrite may be further oxidized to nitrate by bacteria of the genus *Nitrobacter.* Our data on nutrient output from the undisturbed forest provide nothing definitive on the occurrence of nitrification (*1*). Others (*5, 6*) have questioned the occurrence of significant amounts of nitrification in climax forest ecosystems. At any rate, in the absence of vegetation, the microflora of the cleared watershed oxidizes ammonia to nitrate rapidly (*1*). The important end products of these reactions—in terms of nutrient losses from the ecosystem—are the increased amounts of nitrate and hydrogen ions. With decreasing *p*H, cations such as Ca^{++}, Mg^{++}, Na^+, and K^+ are more quickly dissolved and leached from the system. This may occur (i) as the hydrogen ions replace cations on the humic-clay ion exchange complexes of the soil, or (ii) as organic or inorganic compounds are decomposed. Since nitrification occurs in the humic layers of the soil, these base exchanges probably occur concurrently with the decay of organic substances.

In this regard, the ionic composition of the drainage water from the cutover watershed suggests that the predominant source for the surplus cations is the breakdown of humic substances from the upper layers of the soil. This is best shown by the changes in the ratio of Ca to Na in the drainage water of watershed 2 before and after deforestation. Before cutting, the ratio of Ca to Na in the stream water was 1.6:1.0, which is consistent with that observed in adjacent undisturbed watersheds, and has been attributed to the steady-state chemical weathering of bedrock and till (*7*). However, after clearcutting, the ratio climbed to an average of 4.8:1.0 for 1966–68. More significantly, the ratio for the excess ions of the stream (that is, the amount added above those present in the undisturbed condition) is 7.4:1.0. These ratios show that the net chemical effect of the deforestation was to differentially produce

Table 1. Ionic changes in stream water from watershed 2 of the Hubbard Brook Experimental Forest. The vegetation of the watershed was clear-cut during the winter of 1965–66. The water year for these studies extends from 1 June through 31 May. The hydrogen ion concentration was estimated from weekly measurements of *p*H. Milliequivalent values are based on weighted annual concentrations.

Ion	Concentration (meq/liter) during:			
	1964–65	1965–66	1966–67	1967–68
H^+	0.010*	0.008	0.056	0.051
K^+	.005	.005	.050	.077
Na^+	.037	.037	.065	.066
NH_4^+	.003	.008	.004	.003
Ca^{++}	.069	.091	.323	.378
Mg^{++}	.030	.031	.112	.125
Al^{+++}	.022	.026	.167	.222
NO_3^-	.020	.015	.614	.846
Cl^-	.014†	.014†	.025	.022
HCO_3^-	.010	.013	.002	.000
SO_4^{--}	.134	.143	.080	.078
Total (+)	.176	.206	.777	.922
Total (−)	.178	.185	.721	.946

* Estimated. † Estimated from data for watersheds 4 and 6 of the Hubbard Brook Experimental Forest [Juang and Johnson (*3*)].

soluble calcium within the ecosystem. The fact that hardwood forest litter is rich in calcium relative to sodium (ratio of Ca to Na is greater than 20:1), in contrast to average bedrock in this system (ratio of Ca to Na is 0.9:1.0), suggests that the excess ions produced after deforestation, are derived mainly from bulk decomposition of humic materials rather than from accelerated decomposition of bedrock (*7, 8*). If the only source of excess ions were the chemical weathering of bedrock, roughly equal amounts of Ca^{++} and Na^+ would be expected in the stream water (*7*).

Table 2. Changes in milliequivalent values in stream water from watershed 2 after the vegetation was clear-cut.

Ion	Net change in concentration (meq/liter) during:	
	1965–66 to 1966–67 (1 year)	1965–66 to 1967–68 (2 years)
	*More negative**	
NO_3^-	0.599	0.831
Cl^-	.011	.008
NH_4^+	.004	.005
Total	.614	.844
	More positive†	
Ca^{++}	0.232	0.287
Al^{+++}	.141	.196
Mg^{++}	.081	.094
H^+	.048	.043
K^+	.045	.072
Na^+	.028	.029
SO_4^{--}	.063	.065
HCO_3^-	.011	.013
Total	.649	.799

* Increase in anion concentration or decrease in cation concentration. † Increase in cation concentration or decrease in anion concentration.

Increased biological nitrification seems to be the principal factor in producing this flush of ions from the system. The increase in the milliequivalent value for NO_3^- in the water years subsequent to cutting balances (within 10 to 15 percent error limits for the system) all of the net cationic increases and the net anionic decreases (Table 2). This relationship is improved in 1966–67 because the decrease in bicarbonate is accounted for by the decrease in *p*H and is offset by an increase in chloride (Table 2). The *p*H of the stream water from watershed 2 decreased from a weighted average of 5.1 during 1965–66 to 4.3 during 1966–67 and 1967–68 (Table 1).

Alexander (*9*) indicates that nitrification usually decreases greatly below *p*H 6.0 and becomes negligible at *p*H 5.0. This is not true of the cutover watershed, since the concentration of nitrate increased during 1966–68 (Table 1). Also, *Nitrosomonas* and *Nitrobacter* increased 18-fold and 34-fold, respectively, in the soil of watershed 2 (*10*). Others have shown nitrification at similarly low *p*H (*11*).

The explanation for the decrease in the sulfate concentration is more complicated. Precipitation is by far the major source of sulfate for the undisturbed watersheds (*3*). Since transpiration was eliminated in the cutover watershed, the runoff increased by some 40 percent in 1966–67 over that predicted (*1*). However, the amount of sulfate added by precipitation to the watershed did not change relative to previous years. Such indirect dilution nearly accounts for the 45 percent decrease in stream water concentration of sulfate. Thus the average weighted concentration of SO_4^{--} in drainage water from the cutover watershed during 1967–68 coincides with the concentration in precipitation after correction for evaporation.

Also, the normal release of SO_4^{--} by chemical weathering and microbial activity (*3*) became negligible subsequent to deforestation. This may be explained by two possible processes, operating simultaneously or separately: (i) There may be decreased oxidation of various sulfur compounds to SO_4^{--}. High concentrations of nitrate may be very toxic to sulfur oxidizing bacteria, such as *Thiobacillus thiooxidans* (*12*). This species is probably important in the cutover watershed since it can grow at low *p*H (*9*). Moreover, in the undisturbed watersheds and at nitrate concentrations less than 1 mg/liter, we have observed an inverse relationship between the concentration of nitrate and sulfate. Therefore, an intricate feedback mechanism between the toxicity of the nitrate concentrations and the microbial oxidation of sulfur compounds may exist. Alternatively the number of sulfur oxidizing bacteria may have been selectively reduced by the herbicides in the cutover watershed. (ii) There may be additional sulfate reduction induced by more widespread anaerobic conditions (see, for example, *12*), particularly in the lower water-saturated horizons of the soil of the cutover watershed.

The importance of anion mobilization in leaching nutrients from forest soils has been suggested previously (*4, 5*), but had not been demonstrated on a quantitative basis for an ecosystem.

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