Biogeochemistry 2 (1986) 53–65

Nitrate increases in soil water following conversion of chaparral to grass

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Key words: Chaparral conversion, nitrogen, nitrate, soil water, stream water

Abstract. An Arizona watershed converted from chaparral to grass, released high concentrations of nitrate to stream water. The nitrate originated from the rooting zone of the decomposing shrubs. High nitrate concentrations (44–373 ppm) were found in soil solutions from 1.5-, 3.0-, and 4.6-m depths on the converted watershed as compared with low nitrate concentrations (0.2–6.2 ppm) found in an adjacent undisturbed area. Soil solution nitrate concentrations at the 0.3-m depth were generally low, especially in the untreated area. High nitrate concentrations were balanced mainly by relative decreases in bicarbonate anions in the soil solutions and in the stream water. Multiple stepwise regression analyses showed improvement in the regression of bicarbonate on nitrate when chloride and sulfate anions were entered as variables.

Introduction

Conversion of Arizona chaparral to grass cover as a method for augmenting water supplies can affect both quantity and quality of streamflow. Annual stream discharge can be increased about 10.2 cm when the annual precipitation is 55.9 cm (Hibbert et al., 1974; Hibbert et al., 1982), but an increase in the nitrate concentration of the stream water also occurs (Davis, 1984).

Converting from deep-rooted chaparral shrubs to more shallow-rooted grasses, by controlling the shrubs with herbicides, reduces transpiration losses from the vadose zone. Less precipitation is then needed to recharge the soil, and more of the precipitation is yielded to streamflow. Excavation of a mature shrub live oak bush (a dominant chaparral shrub) revealed a massive root system that extended down 6.4 m with an estimated root to top ratio of 3 (Davis and Pase, 1977). Mineralization of organic nitrogen from decomposing shrub roots and tops following herbicide treatment should make additional nitrogen available within a converted watershed that was not formerly available from the living stand of brush. The source of the large increases in nitrate concentrations that occur in streamflow following herbicide treatment of chaparral watersheds was considered to be the dead shrub biomass (Davis, 1984). If this is true then the soil water within converted chaparral areas should contain much higher nitrate concentrations than those within untreated chaparral areas.

This study was conducted to trace the origin of high nitrate concentrations in streamflow from the outlet of a treated chaparral watershed back up into the watershed. This was done by determining nitrate concentrations in soil-water samples collected within brush-controlled areas on the watershed, and by comparing them with soil-water samples from untreated chaparral areas. The hypothesis that the high nitrate concentrations and associated ionic balance changes found in streamflow from converted chaparral watersheds originate within the watershed soil mantle, in the root zone of decaying shrubs, was tested further by comparing the ionic balance changes that occurred in high-nitrate stream water with those that occurred in the soil solute collected within treated areas of the watershed. Soil-water samples from depths down to 4.6 m were collected from treated and untreated areas over a 4-year period.

Study site

The study was conducted on a 18.8-ha (46.5-acre) watershed under conversion from chaparral to grass on the Three Bar Wildlife Area in the Mazatzal Mountains of central Arizona at 914 m (3,000 ft). The chaparral was predominantly shrub live oak (*Quercus turbinella*) and birchleaf mountain-mahogany (*Cercocarpus betuloides*) with a mixture of other evergreen sclerophyllous species such as yellowleaf silktassel (*Garrya flavescens*), sugar sumac (*Rhus ovata*), desert ceanothus (*Ceanothus greggii*), hollyleaf buckthorn (*Rhamnus crocea*), Palmer oak (*Quercus chrysolepis* var. *palmeri*), and Emory oak (*Q. emoryi*).

The soils are very gravelly sandy loams derived from granitic parent material. They are classified as loamy-skeletal, mixed, mesic Udic Ustochrepts with an A, C, R horizon sequence and they are well drained. Surface runoff is infrequent. Hydraulic conductivity is about 28 cm hr^{-1} for the surface horizon and 20.3 cm hr^{-1} for the gruss at the top of the R horizon. Seismic exploration on the Three Bar watersheds indicated weathering and fracturing 6- to 12-m deep. Observations at a root excavation site confirmed fractures to 6 m. The soils are slightly acidic; they have a moderate cation exchange capacity; exchangeable cations are predominately calcium followed by magnesium, with lesser amounts of potassium and sodium (Table 1). Organic matter content in the top 30 cm of the soil profile was about 3%, decreasing sharply to less than 1% below 30 cm.

Annual precipitation on the watershed averaged 64 cm over the past 27 years. Precipitation occurs during summer monsoon and winter rainy seasons with occasional snow; 75% of the precipitation was received from October through May.

Methods

Chaparral conversion treatments

Northeast-facing slopes comprising 40% (7.5 ha) of the watershed (Three Bar

Table 1. Chemical properties generally characteristic of the watershed soil but not specific to the soil-water collection sites*

Soil depth (cm)	pH	Cation exchange capacity (meq 100 g^{-1})	Organic matter (%)	NO_3-N (ppm)	Ortho PO_4-P (ppm)	Exchangeable cations (ppm)			
						K	Mg	Ca	Na
0–15	6.6	22.7	3.0	6	16	130	380	3800	40
15–30	6.7	20.6	3.4	2	9	90	390	3400	50
30–46	6.3	21.0	0.8	1	6	50	440	3400	40
46–61	6.2	22.3	0.5	1	3	50	480	3600	50
61–76	5.9	20.0	0.5	–	4	50	560	3000	40
76–91	5.6	16.9	0.5	–	3	60	120	3100	50

*Methods of analysis: pH was measured in water; organic matter, Walkley-Black method; NO_3-N, phenoldisulfonic acid method; ortho-phosphate phosphorus, Fiske-Subbarow method using Bray-1 extraction procedure; cations were extracted with ammonium acetate and analyzed by flame photometer or atomic absorption spectrophotometer methods.

B) were spot-treated with soil-applied fenuron pellets (20.5 kg active ingredient (ai) ha^{-1}) in 1965. Surviving shrubs were retreated with fenuron (6.8 kg ai ha^{-1}) in 1968 and with tebuthiuron pellets (0.9 kg ai ha^{-1}) in 1978. The remaining 60% (11.3 ha) of the watershed was spot-treated with karbutilate tablets (7.5 kg ai ha^{-1}) in 1972.

Soil water study

This study to trace the origin of the nitrate-release process within the watershed was begun in 1979 during the last stages of the water yield improvement and water quality studies on the watershed. Stream water nitrate concentrations were still high enough to warrant an investigation of the comparative chemical composition of soil water within the watershed and streamflow through the watershed outlet gaging station. The annual volume-weighted mean nitrate concentration in streamflow from the treated watershed for water year 1979 (October 1978 through September 1979) was 38.5 ppm (range, 14.9–44.9 ppm), whereas that from the untreated control watershed was only 0.3 ppm.

Soil water sites

Sites for sampling soil water 0.3-, 1.5-, 3.0-, and 4.6-m depths were established at 2 locations on the west side of watershed B, which had been treated last in 1978 to kill surviving shrubs. Brush control at the sites was greater than 90%. Two untreated control chaparral sites were established on an adjacent undisturbed area just outside the watershed boundary with depths of 0.3, 1.5, 3.0, and 4.6 m.

Holes were drilled with a portable General 31 Hole Digger[1] fitted with 7.62-cm (3-in) augers. After cleanout of the holes with a bucket auger, a 5- to 8-cm layer of sifted soil from the depth being worked on was added to the bottom of the hole as a bed for the ceramic cup of the water sampler. A 5.1-cm (2-in) diameter PVC casing was installed in the hole. Then a soil-water sampler (Soil Moisture Equipment Company) fitted with two plastic tubes was lowered into the hole and pressed into the bed of sifted soil. The casing was raised 15 cm and sifted soil was added around the outside of the casing and tamped. Additional sifted soil was added and tamped firmly in the space around the casing. Within 60 cm of ground level, surface soil was added and tamped to give a tight seal between casing and soil.

Suction of 30–50 centibars was applied with a vacuum-pressure pump (Soil Moisture Equipment Company) and the tubes were clamped off. The lower suctions were applied during periods of low soil moisture. After a 2- to 3-week absorption period, pressure was applied through the pressure line of the sampler and the soil water was collected in plastic bottles and stored at 2°C. Soil water samples were collected on 26 visits comprising 5 collection periods over 4 years (1980–1983). Sample collections were limited to periods with sufficient rainfall to permit collection of soil water. It was not always possible to collect water samples at all depths and sites. Frequently, samples could be obtained from the treated watershed when they could not be obtained from the control sites. Sample volumes ranged from a few ml to 500 ml. Because of the small volume of many samples, they were composited within collection periods for analysis; larger single samples were also analyzed (Table 2). Water samples were analyzed by atomic absorption spectrophotometric methods (for calcium, magnesium, sodium, and potassium) and with a Technicon AutoAnalyzer II (for nitrate, ammonium, chloride, sulfate, and ortho-phosphate. Technicon 1974). Carbonate and bicarbonate were analyzed by acid titration.

Results

Chaparral conversion responses

Streamflow was intermittent from watershed B prior to initiation of the chaparral conversion process. During a 9-year calibration period against the paired control watershed, an average of 223 days annually (ranging from 81 to 365 days) had no streamflow. Following the first-phase treatment, however, streamflow became continuous for the remaining 17 years of the study. Streamflow from treated areas on the watershed increased about 7.6 cm annually (Hibbert et al., 1982).

Increased nitrate concentrations accompanied the increased streamflow. Nitrate increased from the normal concentration of < 1 ppm, characteristic of undisturbed chaparral, to a maximum of 83 ppm in water year 1973 following the second-phase treatment. During water year 1973 the annual volume-weighted mean nitrate concentration was 34.7 ppm and the annual nitrate output in streamflow was 66.5 kg ha^{-1}, in contrast to the control

Table 2. Collection schedule for soil-water samples and the samples analyzed

Collection period	Dates	Samples analyzed
1 Winter–Spring, 1980	1/15/80–5/19/80	Composited, 6 collections
2 Spring, 1981	3/27/81	Single samples
3 Winter, 1982	1/25/82–3/29/82	Composited, 5 collections
4 Fall–Winter, 1982–1983	10/13/82–3/8/83	Composited, 5 collections
5 Spring, 1983	4/1/83–5/20/83	Composited, 5 collections

watershed which had a mean concentration of 0.5 ppm and an output of 1.4 kg ha^{-1}. The highest annual mean nitrate concentration for watershed B was 52.7 ppm in water year 1978, giving an annual nitrate output of 121.5-kg ha^{-1}; comparable data for the control watershed were 0.4 ppm and 0.8-kg ha^{-1}, respectively. During the first water year (1980) of the soil-water study, the annual weighted mean concentration of nitrate in streamflow from the converted watershed was 21.6 ppm, compared to 0.4 ppm for the control watershed.

Soil-water results

In 1980, the inorganic chemical composition of the treatment and control soil solutions at the 0.3-m depths was about the same (Table 3). Major differences occurred, however, at the 1.5- to 6.4-m depths, where ionic strengths of the cations in the treatment soil solutions were 2- to 7-fold greater than those in the control solutions, and nitrate was an average of 49-fold greater. Concentrations of the anions other than nitrate were about the same or slightly greater in the treatment solutions. The high nitrate concentrations (up to 373 ppm) in the soil water from the converted watershed are dramatic compared with the low nitrate concentrations ($<$ 6 ppm) in the control samples. The pH of all soil-water samples (treatment and control) remained essentially unchanged and nearly neutral.

Changes that occurred in the nitrate concentrations of the soil water over 4 years are given in Table 4. To simplify the tabulation of data, and because the relationship among ions seen in Table 3 was consistent throughout the experiment, only the nitrate results are given. Remarkably high nitrate concentrations (up to 324 ppm) occurred during the third collection period (Winter, 1982), from which time concentrations gradually decreased. Nitrate concentrations in the control soil water from all depths remained low throughout the study. Mean nitrate concentrations indicate a general pattern of increasing nitrate concentrations with depth.

Mass balance changes that occurred between high- and low-nitrate soil solutions are given in Table 5. A low-nitrate water sample from 0.3 m is compared with a high-nitrate (199.8 ppm) sample from 4.6 m, collected at the same site and time. Milliequivalent percent changes that occurred in the

Table 3. Inorganic chemical composition of soil water collected during the winter and spring of 1980. Samples were collected at four depths down to 4.6 m on converted watershed B and on an adjacent untreated control area*

Location			Electrical conductivity	Soluble salts	Cations (ppm)					Anions (ppm)				
Site	Depth (m)	pH	mmho cm^{-1})	(ppm)	Ca	Mg	Na	K	NH_4	Cl	SO_4	HCO_3	PO_4	NO_3
Watershed B, treated														
1	0.3	7.1	0.08	69	13	2.4	1.8	0.17	0.08	6	5	39	0.28	1.5
	1.5	7.6	0.27	210	35	11.0	4.4	0.41	0.08	8	8	98	0.93	44.0
	3.0	7.6	0.28	172	22	10.1	10.5	0.73	0.06	6	2	59	0.31	61.6
	4.6	7.7	0.39	271	19	6.4	48.1	1.42	0.05	14	12	105	0.34	65.1
2	0.3	7.7	0.19	172	34	7.1	2.1	0.23	0.08	3	17	98	2.17	7.9
	1.5	7.6	0.49	437	62	32.0	9.4	0.56	0.19	16	17	132	0.40	167.2
	3.0	7.6	0.88	694	90	48.0	28.0	1.11	0.21	16	15	122	0.47	373.1
	4.6	7.5	0.53	365	41	24.0	16.0	0.87	0.09	15	9	59	0.31	199.8
Control area, untreated														
1	0.3	7.4	0.10	98	18	2.5	2.6	0.27	0.06	6	9	56	0.31	3.5
	1.5	7.6	0.18	162	30	5.4	4.9	0.43	0.13	8	9	98	0.28	6.2
	3.0	7.5	0.11	95	13	3.7	4.6	0.29	0.04	6	3	63	0.31	1.3
	4.6	7.4	0.16	110	10	1.0	19.4	0.51	0.10	15	4	59	1.24	0.2
2	0.3	7.2	0.05	43	7	1.0	1.8	0.28	0.01	4	2	24	0.22	2.2
	1.5	7.3	0.16	134	24	5.0	4.0	0.43	0.01	9	3	83	0.16	5.5
	3.0	7.4	0.11	96	13	2.2	4.2	0.31	0.01	6	2	63	0.22	4.8
	4.6	7.4	0.16	104	10	0.9	19.1	0.53	0.01	14	4	54	0.87	0.4

*Soil water from six collections during the period Jan. 15–May 19, 1980 were composited for analysis.

Table 4. Nitrate concentrations (ppm) in soil water collected during four years on converted watershed B and on an adjacent untreated control area

Location		Collection periods					
Site	Depth (m)	1 Winter–Spring 1980	2 Spring 1981	3 Winter 1982	4 Fall–Winter 1982–83	5 Spring 1983	Mean
Watershed B, treated							
1	0.3	1.5	6.7	35.6	21.6	0.6	13.2
	1.5	44.0	29.1	3.6	2.9	2.8	16.5
	3.0	61.6	101.2	22.9	1.9	1.5	37.8
	4.6	65.1	152.6	172.0	15.0	20.1	85.0
	Mean	43.0	72.4	58.5	10.4	6.2	38.1 (n = 20)
2	0.3	7.9	30.5	2.2	3.9	1.1	9.1
	1.5	167.2	76.6	55.4	26.1	15.4	68.1
	3.0	373.1	201.4	151.4	99.7	74.8	180.1
	4.6	199.8	–	324.3	35.1	16.8	144.0
	Mean	187.0	102.8	133.3	41.2	27.0	98.0 (n = 19)
Control area, untreated							
1	0.3	3.5	–	0.4	0.8	0.7	1.4
	1.5	6.2	–	1.8	1.5	1.3	2.7
	3.0	1.3	–	3.1	0.9	0.9	1.6
	4.6	0.2	–	–	0.4	0.4	0.3
	Mean	2.8	–	1.8	0.9	0.8	1.6 (n = 15)
2	0.3	2.2	–	2.2	3.1	1.8	2.3
	1.5	5.5	–	2.2	–	1.5	3.1
	3.0	4.8	–	2.2	0.4	0.4	2.0
	4.6	0.4	–	–	–	–	–
	Mean	3.2	–	2.2	1.8	1.2	2.2 (n = 12)

paired samples indicate that the increase in nitrate was balanced mainly by a decrease in bicarbonate and by a lesser decrease in sulfate.

Comparisons of milliequivalent percent changes in Table 6 show the consistency of the mass balance shifts that accompanied the large release of nitrate into the soil solution. Comparisons of paired high- and low-nitrate soil solutions for each of the 5 collection periods over 4 years substantiate the inverse relationship between nitrate and bicarbonate. It is noted also from these comparisons that the milliequivalent percent composition of calcium declined in the high-nitrate solutions and that there was a proportional increase in magnesium plus sodium.

Correlation and multiple stepwise regression analyses were performed on all the milliequivalent percent data for each of the collection periods. In all of the correlation matrices the strongest relationship was the negative correlation of bicarbonate with nitrate ($r = -0.84$ to -0.97). Stepwise

Table 5. Changes in ionic concentrations and in relative proportions of ions in low- and high-nitrate composite soil solution samples from site 2 (winter and spring of 1980) on converted watershed B (ppm data is from Table 3)

	Low-nitrate sample 0.3-m depth			High-nitrate sample 4.6-m depth			Meq % changes that made the high-nitrate sample more-	
	ppm	meq l^{-1}	meq %	ppm	meq l^{-1}	meq %	negative*	positive**
Cations								
Ca^{2+}	34.0	1.697	71.24	41.0	2.046	43.14	− 28.10	
Mg^{2+}	7.1	0.584	24.52	24.0	1.974	41.62		+ 17.10
Na^+	2.1	0.091	3.82	16.0	0.696	14.67		+ 10.85
K^+	0.23	0.006	0.25	0.87	0.022	0.46		+ 0.21
NH_4^+	0.08	0.004	0.17	0.09	0.005	0.11	− 0.06	
Total		2.382	100.0		4.743	100.0		
Anions								
Cl^-	3.0	0.085	3.79	15.0	0.423	8.79	+ 5.00	
SO_4^{2-}	17.0	0.354	15.80	9.0	0.187	3.89		− 11.91
PO_4^{3-}	2.2	0.069	3.08	0.3	0.010	0.21		− 2.87
HCO_3^-	98.0	1.606	71.66	59.0	0.967	20.10		− 51.56
NO_3^-	7.9	0.127	5.67	199.8	3.223	67.01	+ 61.34	
Total		2.241	100.0		4.810	100.0	94.50	94.50

* Decrease in cation concentration or increase in anion concentration.
** Decrease in anion concentration or increase in cation concentration.

regression analysis of each of the 5 sets of data for maximum r^2 improvement for the variable nitrate showed that bicarbonate gave the best one-variable model in all cases. The regression of bicarbonate on nitrate for collection period 1 data (Fig. 1) shows the strong negative correlation that exists between nitrate and bicarbonate ($r^2 = 0.71$). The strongest partial correlation with the remaining ions was with chloride, giving the best two-variable model ($r^2 = 0.95$). Similarly, the best three-variable model was given by entering sulfate ($r^2 = 0.99$). For 3 of the 5 collection periods chloride was entered second, while in 2 cases sulfate was entered second.

The soil solution results were consistent with the mass-balance changes that occurred between high- and low-nitrate stream water samples at the outlet of the watershed. The comparison in Table 7 typifies many paired comparisons of high- and low-nitrate stream water samples. Here also the high nitrate concentration is balanced by a decrease in bicarbonate and by a lesser decrease in sulfate, and the milliequivalent percent composition of calcium decreased with a proportionate increase in magnesium plus sodium.

Discussion

Our results indicate that the high levels of nitrate in streams of converted chaparral watersheds in Arizona originate in the soil zone occupied by decaying shrub roots. Surprisingly high nitrate concentrations (up to

Table 6. Ionic balance comparisons of low- and high-nitrate composite soil solution samples from converted watershed B during five collection periods (1980–1983). Milliequivalent percent (meq %) changes in ionic composition of low-nitrate solutions from the 0.3-m depth were compared with the mean meq % changes of high-nitrate solutions from the 1.5, 3.0, and 4.6-m depths at the same site

	Ion meq % changes that made a high-nitrate solution more positive or negative than a low-nitrate solution in each collection period				
Ion	1 Winter–Spring 1980	2 Spring 1981	3 Winter 1982	4 Fall–Winter 1982–83	5 Spring 1983
			More positive *		
Mg^{2+}	+ 17.17	+ 4.81	+ 12.54	+ 7.09	+ 6.26
Na^+	+ 7.46	+ 24.86	+ 16.93	+ 20.98	+ 23.36
K^+	+ 0.08	+ 0.80	+ 0.25	+ 0.38	+ 0.76
PO_4^{3-}	– 2.86	– 0.23	– 0.45	– 1.18	– 2.26
Cl^-	–	– 12.87	–	– 0.05	– 2.32
SO_4^{2-}	– 11.24	– 1.39	–	–	–
HCO_3^-	– 44.70	– 17.12	– 63.06	– 30.79	– 26.77
Total	83.51	62.10	93.23	60.47	61.73
			More negative **		
Ca^{2+}	– 24.66	– 29.52	– 29.67	– 28.40	– 30.07
NH_4^+	– 0.05	– 0.95	– 0.05	– 0.05	– 0.32
Cl^-	+ 3.51	–	+ 1.86	–	–
SO_4^{2-}	–	–	+ 0.25	+ 2.25	+ 4.06
CO_3^{2-}	–	–	–	–	–
NO_3^-	+ 55.28	+ 31.63	+ 61.40	+ 29.77	+ 27.29
Total	83.50	62.10	93.23	60.47	61.74

* Decrease in anion concentration or increase in cation concentration.
** Decrease in cation concentration or increase in anion concentration.

373 ppm) were present in the soil solutions collected at the 1.5- to 4.6-m depths.

Low concentrations of nitrate in the soil water collected at the 0.3-m depth could be due to leaching of the nitrate produced through mineralization of organic nitrogen and to nitrogen utilization by the reestablished grasses and forbs.

After the release of mobile nitrate anions from organic matter through the processes of ammonification and nitrification, many ionic balance adjustments occur in the soil solution. The most highly correlated change that electrochemically balanced the increased nitrate concentrations was a decrease in the relative proportion of bicarbonate ions. The relative proportions of calcium ions decreased while those of magnesium and sodium increased. The following chemical mechanism is a possible explanation for the results.

$$(1)\ NH_4^- + 2O_2 \longrightarrow NO_3^- + 2H^+ + H_2O$$

$$(2)\ Ca^{2+}(HCO_3)_2^- + (Mg^{2+}, Na^+, H^+, \ldots .)[Soil]^{n-} \longrightarrow$$

$$Ca^{2+}[Soil]^{n-} + (Mg^{2+}, Na^+, H^+, \ldots .) + 2\ HCO_3^-$$

$$(3)\ HCO_3^- + H^+NO_3^- \longrightarrow NO_3^- + H_2O + CO_2$$

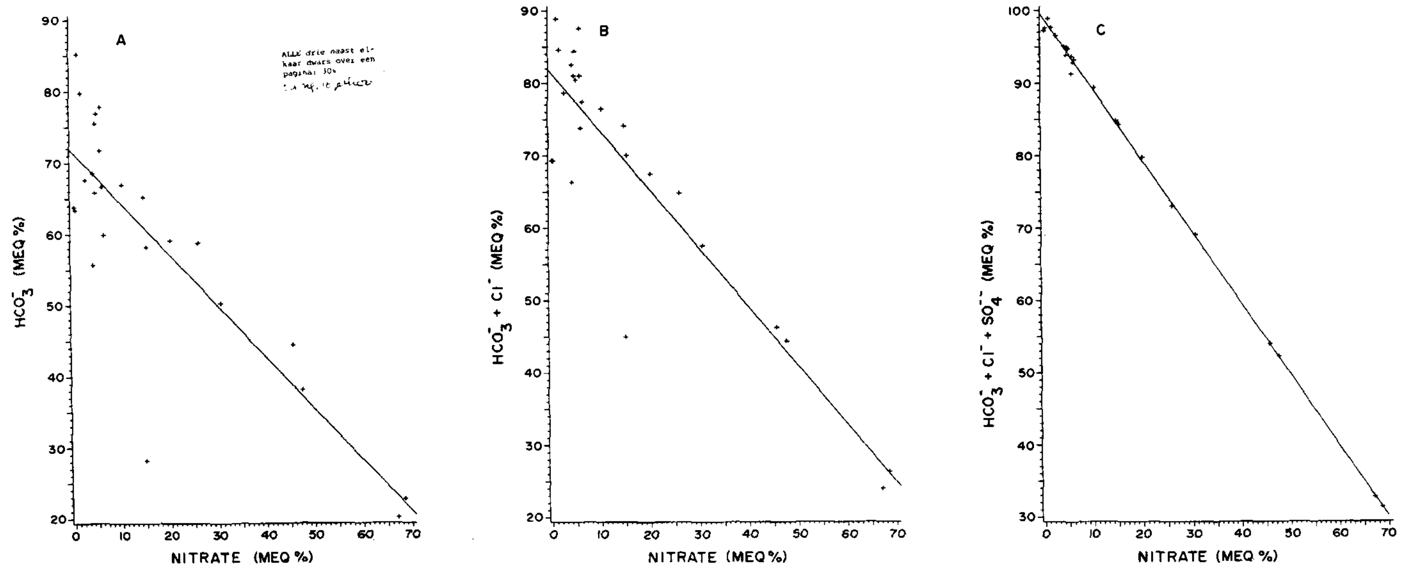

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Figure 1. Stepwise linear regressions of soil solution milliequivalent percent composition for those ions which when regressed on nitrate gave the best one-, two-, and three-variable models: (A) bicarbonate, $r^2 = 0.71$; (B) chloride entered, $r^2 = 0.95$; (C) sulfate entered, $r^2 = 0.99$.

The end result of these reactions is an increase in nitrate and a decrease in the relative proportion of bicarbonate and calcium ions in the soil solution. The lyotropic series, or the relative replaceability of ions from soil colloids, is $Na > K > Mg > Ca$ (Bohn et al., 1979), which could account for the relative decrease in calcium.

Analysis of ionic changes in composition of soil water and stream water following chaparral conversion gave concordant results. This agreement suggests that the ionic balance changes that occurred in streamflow from the converted watershed originated within the watershed soil mantle, and supports the nitrate-bicarbonate balancing mechanism. The fact that the same relationship occurred in the stream water from another chaparral watershed (Davis, unpublished) suggests that the response was not site-specific but may be a general response to chaparral conversion in Arizona.

Vitousek et al. (1979) reported a nitrogen cycling study of 19 forest ecosystems in 7 states (USA) in which soil was collected at a depth of 55–70 cm within small, trenched and plastic-lined plots ($1\,m^3$) beneath the forest canopy. The highest soil-water nitrate concentration reported was 133 ppm for an Indiana maple-beech ecosystem. The lowest nitrate concentration was 0.3 ppm for Pacific silver fir; the median concentration was 38 ppm. In other studies, low soil-water nitrate concentrations occurred beneath clearcut or deadened forest stands (McColl, 1978; Edwards and Ross-Todd, 1979; Sollins and McCorison, 1981; Sollins et al., 1981).

Table 7. Changes in ionic concentrations and in relative proportions of ions in low- and high-nitrate stream water samples collected at the outlet of watershed B

	Stream water samples						Meq % changes that made the high-nitrate sample more-	
	Low-nitrate 7/22/71			High-nitrate 4/28/78				
	ppm	meq l^{-1}	meq %	ppm	meq l^{-1}	meq %	negative*	positive**
Cations								
Ca^{2+}	74	3.693	48.29	40	1.996	40.11	− 8.18	
Mg^{2+}	26	2.138	27.96	20	1.645	33.05		+ 5.09
Na^{+}	41	1.784	23.32	30	1.305	26.23		+ 2.91
K^{+}	0.55	0.014	0.18	1.10	0.028	0.57		+ 0.39
NH_4^{+}	0.34	0.019	0.25	0.04	0.002	0.04	− 0.21	
Total		7.648	100.00		4.976	100.00		
Anions								
Cl^{-}	16	0.451	5.80	10	0.282	5.68		− 0.12
SO_4^{2-}	62	1.291	16.60	29	0.604	12.16		− 4.44
PO_4^{3-}	0.03	0.001	0.01	0.03	0.001	0.02	+ 0.01	
HCO_3^{-}	366	5.999	77.16	176	2.885	58.10		− 19.06
NO_3^{-}	2.0	0.032	0.41	74	1.194	24.04	+ 23.63	
Total		7.774	100.00		4.966	100.00		

*Decrease in cation concentration or increase in anion concentration.

**Decrease in anion concentration or increase in cation concentration.

Nitrate concentrations in the soil water of the converted chaparral watershed reported here are also high compared to nitrate concentrations found in groundwater beneath 4 feedlots in Colorado that contained concentrations ranging from 0.4 to 88 ppm (Stewart et al., 1968). Groundwater under irrigated croplands in California typically contain 25–30 ppm nitrate (National Research Council, 1978). Also, a survey of 855 wells in Arizona showed that only 34 contained nitrate concentrations ⩾ 40 ppm, and of those the 3 highest concentrations were 107, 123, and 202 ppm, probably the result of runoff from agricultural areas (Dutt and McCreary, 1970).

Four of the most important processes that could delay or prevent nitrate losses from disturbed ecosystems are nitrogen uptake by regrowing vegetation, nitrogen immobilization by decomposer organisms, lags in nitrification, and lack of percolating water for nitrate transport (Vitousek et al., 1979). None of these processes were effective in the long term in preventing nitrate losses following the conversion of chaparral to grass, although processes which promoted nitrogen immobilization and lags in nitrification may have been at work. One way to reduce possible undesirable environmental effects of the release of high nitrate concentrations from converted chaparral watersheds would be to plan projects so that streamflow from converted areas is diluted by streamflow from undisturbed areas upstream from reservoir systems.

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Note

1. The use of trade and company names is for the benefit of the reader; such use does not constitute an official endorsement or approval of any service or product by the US Department of Agriculture to the exclusion of others that may be suitable.