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SPRING DENITRIFICATION RATES IN SOILS OF FOUR EASTSIDE SIERRA NEVADA PLANT COMMUNITIES[1]

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ABSTRACT.—Denitrification rates in soils of four subalpine plant communities in the Sierra Nevada were determined by the acetylene blockage method. The study area included riparian, meadow, forest, and barren sites. Data were collected during dawn-to-dusk measurements in April 1987. Soil atmosphere samples were analyzed for N_2O content using gas chromatography. Generally, temporal variability in denitrification rate within each plant community was insubstantial. Denitrification rate and soil temperature were found to be significantly correlated only in the riparian and barren sites. Of the four communities, the riparian site was found to have the lowest rate of denitrification overall. However, differences among sites in denitrification rate could not be conclusively attributed to variation in soil temperature, moisture, organic matter, total C and N, C:N ratio, NO_3-N, or pH.

Past research has yielded conflicting conclusions regarding soil denitrification rates and the parameters affecting them. Nevertheless, several studies agree that spatial and temporal variability in denitrification rates exists (Burford and Stefanson 1973, Dowdell and Smith 1974, Biggar 1978, Ryden et al. 1978, Folorunso and Rolston 1984, Robertson and Tiedje 1984, Mosier et al. 1986a).

While denitrification is a process generally believed to be inhibited by the presence of oxygen, even very dry soils have anaerobic pockets in which denitrification occurs. Soil moisture is believed to affect denitrification rates by governing the diffusion of oxygen and thus the number of anaerobic sites (Alexander 1977, Rolston 1981). Soil temperature may alter the effect of soil moisture on denitrification rates (Mosier et al. 1986b) by modifying N_2O solubility in water (Blackmer et al. 1982).

Contrary to the data presented by Focht (1978) and Terry and Tate (1980), Hussey et al. (1985) suggested that there is a positive relationship between the number of denitrifying bacteria and denitrification rates. Soil organic matter content is often positively correlated with denitrification (Stefanson 1973, Dowdell and Smith 1974, Rolston et al. 1982, Parkin 1987). However, Muller et al. (1980) found no correlation between denitrification and organic C, total N, or exchangeable NH_4. Some studies have demonstrated that soil NO_3 concentration does not limit denitrification (Ryden and Lund 1980, Bremner and Blackmer 1981).

The acetylene blockage method has proven a feasible technique for measuring field denitrification rates (Balderston et al. 1976, Yoshinari et al. 1977, Yeomans and Beauchamp 1978, Ryden et al. 1979a, Ryden et al. 1979b). During denitrification, NO_3 is reduced to N_2 by the reaction

$$NO_3 \rightarrow NO_2 \rightarrow N_2O \rightarrow N_2.$$

The presence of acetylene (C_2H_2) inhibits the reduction of N_2O to N_2, thus permitting measurement of the soil atmosphere concentration of N_2O. Balderston et al. (1976) concluded that the effects of C_2H_2 are reversible and that measurement of N_2O is an acceptable method for the determination of denitrification rates and quantities in either soil or water.

Most research on denitrification rates has been conducted in the laboratory or on agricultural soils. This study was designed to provide baseline data on field denitrification rates in soils of four plant communities of a subalpine Sierra Nevada watershed. These measurements were concentrated during mid-April 1987 in order to quantify denitrification during seasonal snowmelt flushing of the soil profile.

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MATERIALS AND METHODS

Site Description

The study site containing the four plant communities is located at an elevation of 2,134 m near the base of an 80-ha watershed on the east slope of the Carson Range in Nevada immediately over the crest from the Lake Tahoe Basin (39°7′28″N, 119°52′47″W). The plant communities include a riparian, meadow, forest, and barren site. A dense stand of *Alnus tenuifolia* dominates the riparian site, but *Cornus stolonifera*, *Juncus* sp., *Agrostis* sp., and *Poa sandbergii* are also present. The principal vegetation of the meadow site consists of *P. sandbergii*, *Agrostis* sp., and *J. ensifolius*. *Abies concolor* and *Pinus jeffreyi* dominate the forest site, and the barren site is devoid of any vegetation.

Field Equipment and Procedures

Three soil chambers, constructed according to the design of Denmead (1979) as modified by Greenlee (1985), were installed in each of the four plant communities. Acetylene was supplied to the soil atmosphere through probes consisting of drip irrigation tubing perforated on one side at 5-cm intervals and inserted 1 m into the ground (Greenlee 1985). Four probes were installed per chamber. The 12 probes on each site were simultaneously supplied with C_2H_2.

Acetylene was continuously supplied to the soil at a rate of 600 ml/min. The addition of C_2H_2 to the soil began 30 min prior to the start of the sampling period to permit its diffusion into the profile. The evacuation of N_2O from the chambers and its adsorption onto 5Å molecular sieve material was accomplished as described by Greenlee (1985). Nitrous oxide gas samples were suctioned from the chambers through vials containing the molecular sieve material. This occurred during alternate hours from 6:00 a.m. to 7:00 p.m. at a rate of approximately 300 ml/min (Ryden et al. 1979b). After each sampling period the vials of molecular sieve material were capped and replaced. Chamber covers were removed to facilitate aeration between each sampling period.

Soil moisture and soil and air temperatures were measured at the midpoint of each one-hour sampling period. Soil moisture was measured with a Campbell Pacific Neutron Model 503DR hydroprobe moisture depth gauge (CPN Corp., Pacheco, California). A neutron access tube, constructed of 0.13-cm thin-walled aluminum tubing with a 4.83-cm I.D., was installed near the chambers in each plant community by augering holes of slightly larger diameter and then backfilling. The probe was lowered down the tube, and readings were taken every 15 cm to a depth of 105 cm below the soil surface. Soil temperature was measured at depths of 5, 10, and 25 cm using three Reotemp Model H bimetal coil thermometers per chamber (Reotemp Instrument Corp., San Diego, California). Air temperature was measured 0.5 m above the ground.

Five soil subsamples were collected near each chamber to a depth of 20 cm and combined into one composite sample per chamber. These samples were kept on ice until arrival at the lab, oven-dried at 38 C for 48 hours, and ground to pass through a No. 10 (2-mm opening) sieve. Soil texture was determined by the hydrometer method; organic matter and total C by the Walkley-Black method, colorimetric and titration modifications, respectively; total N by macro-Kjeldahl digestion; NO_3-N by use of a specific ion electrode after extraction with $CaSO_4$; and pH by glass electrode on a 1:1 mixture (by weight) of soil and distilled water (American Society of Agronomy 1965). All analyses were done by A & L Agricultural Laboratories (Memphis, Tennessee). Total C and N values were used to calculate C:N ratios.

Soil water samples were collected at 10- and 25-cm depths from two lysimeters installed near the chambers in each plant community. These samples were transported on ice to the Desert Research Institute (Reno, Nevada), where $N0_3$ analyses were done using cadmium reduction (U.S. Environmental Protection Agency 1979).

Laboratory Equipment and Procedures

Laboratory procedures were based on those described by Ryden et al. (1978) as modified by Greenlee (1985). Nitrous oxide gas samples of 0.5 ml were injected into a gas chromatograph column of 80/100-mesh Porapak Q material (500 cm long by 0.21 cm I.D.) heated to 50 C. Argon was the carrier gas with a flow rate of 25 ml/min. Nitrous oxide was detected by a ^{63}Ni electron capture detector

heated to 350 C. Standards of 13.2 ppm N_2O were run after every sample. Each sample and each standard was injected at least twice, or until values were within 10%, and an average value calculated. Quantification of sample N_2O peak heights was based on comparison with standard peak heights. The field equipment set-up was duplicated in the lab using the standard N_2O tank as the gas source in order to calculate recovery rates. Recovery rates were approximately 70%.

Statistical Methods

All data were subjected to analyses of variance, and differences among means were evaluated using the LSD test ($\alpha = .10$). Log normal transformation was performed on all denitrification values as proposed by Parkin et al. (1988), and the arcsine transformation on soil organic matter, total C and N, and C:N ratio values. The analyses included comparisons among sampling periods within each plant community for denitrification rate and soil temperature at each measurement depth, and comparisons among plant communities for all variables. Also, a stepwise regression was performed to evaluate the relationship between denitrification rate and soil temperature within each plant community. The Statistical Analysis System (SAS Institute Inc., Cary, North Carolina) was used for all statistical analyses.

RESULTS

Overall, denitrification rates within each plant community did not vary appreciably among sampling periods. The lone exception was in the forest site, where a significantly lower rate was observed during the 6:00 to 7:00 p.m. sampling period. There was a positive correlation between denitrification rate and soil temperature at the 25 cm depth in the riparian site ($r^2 = .22$, $p = .03$), while denitrification rate and soil temperature at the 10 cm depth were negatively correlated in the barren site ($r^2 = .25$, $p = .02$). Denitrification rate and soil temperature were not significantly correlated in these two sites at any other depth of temperature measurement. Furthermore, there was no apparent relationship between these two parameters, regardless of temperature measurement depth, in the meadow or forest site.

The mean denitrification rate in the riparian site was significantly lower than those of the forest or barren sites by approximately 9% in either comparison (Table 1). The meadow site exhibited an intermediate rate that did not differ significantly from that of any other site. The soil of the forest site was frozen during these measurements, but the effect on denitrification was negligible. Soil temperature differences were substantial between the forest and barren sites, but the denitrification rates were essentially equivalent. Percent soil moisture by volume differed significantly among all sites. Lower denitrification rates were generally associated with higher soil moisture contents, but no conclusive relationship could be established from these data. Mean air temperatures ranged from 5 C at the barren site to 9 C at the meadow site, while intermediate values were observed at the other two sites.

Soil content of organic matter and total C and N were significantly greater in the riparian site than in the other sites examined (Table 2). Conversely, the values for these three parameters were generally lowest in the barren site. Among the four plant communities, C:N ratios generally paralleled denitrification rates, with the C:N ratios and denitrification rates being lower in the riparian and meadow sites and higher in the forest and barren sites. Soil NO_3-N differences among sites, although in some cases significant, were small. Nevertheless, sites with higher NO_3-N concentrations exhibited lower denitrification rates overall. The soil of the forest site was significantly more acidic than that of the other sites, but soil reaction within the range of values observed had no apparent effect on denitrification. Soil texture in all four plant communities was classified as either loamy sand or sandy loam. Soil water analyses for NO_3 indicated low concentrations in all sites of ≤ 0.002 mg/l.

DISCUSSION AND CONCLUSIONS

Many studies have shown soil denitrification rates to be affected by soil temperature, soil moisture, or both (Black 1968, Blackmer et al. 1982, Fillery 1983, Greenlee 1985, Mosier et al. 1986b). This study reveals a site-dependent relationship between soil denitrification and temperature with a positive

TABLE 1. Soil denitrification rate, temperature, and moisture in four subalpine Sierra Nevada plant communities.[a]

Site	Denitrification rate ug/m²/hr	Soil temperature °C 5 cm	10 cm	25 cm	Soil moisture % by volume at 45 cm
Riparian	88.6b	7a	6a	4b	50a
Meadow	90.9ab	8a	7a	5a	42b
Forest	97.2a	−1b	0b	0c	18d
Barren	97.8a	6a	6a	5a	21c

[a]Means sharing a common letter do not differ significantly according to the LSD test at $\alpha = .10$.

TABLE 2. Selected chemical properties of soils in four subalpine Sierra Nevada plant communities.[a]

Site	Organic matter %	Total C %	Total N %	C:N ratio	NO_3-N ppm	pH
Riparian	8.0a	4.9a	0.29a	18.5b	3a	6.5b
Meadow	4.0b	2.5b	0.13b	20.3b	3a	6.8b
Forest	3.0b	1.8b	0.05bc	36.5a	2b	5.6a
Barren	3.0b	1.5b	0.04c	33.7a	2b	6.3b

[a]Means sharing a common letter do not differ significantly according to the LSD test at $\alpha = .10$.

correlation and a negative correlation in the riparian and barren sites, respectively, but no apparent relationship between these two parameters in the meadow and forest sites. Mosier et al. (1986b) found that relatively low soil temperatures (12–24, 8–19, and 6–16 C for 5-, 10-, and 20-cm depths, respectively) contributed to low N_2O emission rates even when soil moisture conditions were near or above field capacity. Soil temperatures in the four plant communities examined here may have been below the threshold at which temperature predictably influences denitrification. Furthermore, the effects of soil moisture may have also been suppressed by these low temperatures. Thus, at these temperatures denitrification occurred, but it is unlikely that the variation in rates is solely attributable to soil temperature or moisture differences within or among sites.

Among the four plant communities, only the riparian site differed significantly in denitrification rate, but none of the other soil parameters investigated could be conclusively identified as a causal factor in the lower rate measured at this site. Studies by Ryden (1981) and Haider et al. (1987) suggest that plant absorption of NO_3 may limit denitrification. In this study, however, the lower denitrification rate of the riparian community could not be logically attributed to NO_3 uptake by the dense mountain alder stand occupying this site since soil NO_3-N concentration was not lower than those of the other sites.

The results presented here suggest that soil parameters other than those examined may have a significant impact on denitrification in wildland soils. Denitrifying bacterial populations may have been a factor of importance in the four plant communities investigated in this study, although other studies (Focht 1978, Terry and Tate 1980, Hussey et al. 1985) have presented conflicting conclusions regarding this parameter. It is obvious from the disparity in the results of denitrification studies that further research is necessary to delineate the causal relationships in the temporal and spatial denitrification variability of wildland soils.

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