Spatial Variability of Deep Leached Nitrate as Related to Denitrification in a Prairie Landscape.

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ABSTRACT

Denitrification is an anaerobic process that converts NO_3^- to N_2 and N_2O, and is considered one of the most highly variable soil processes within a landscape. Moisture acting in response to hillslope hydrological processes controls rates of denitrification and leaching at the landform level. In 1991, a field study was conducted in the Black soil zone of an undulating landscape (3-5 % slope) at Blaine Lake, Saskatchewan to determine the amount of nitrate leached below the rooting zone and its possible relationship to denitrification.

Nitrate has been leached and translocated in the upper regolith in response to water movement where significant leaching of soluble components occurred in depressional areas to depths beyond 3 m. The amount of nitrate at depth was greatest in shoulder and upper level elements where it reached a maximum of 95 $\mu g\ g^{-1}$ at the 1.5 m depth. Footslope and lower level elements contained the lowest nitrate levels (<1 $\mu g\ g^{-1}$) within the 3 m sampled area. High rates of denitrification occurred in footslope and lower level elements, compared to significantly lower rates on divergent shoulder and upper level elements. Nitrate content at depth was inversely correlated with denitrification activity (-0.485 ***). High mean concentrations of nitrate were therefore, spatially related to low rates of denitrification activity in response to hydrological spatial variation.

INTRODUCTION

Losses of nitrate from agricultural systems can occur due to leaching and denitrification. Nitrate leached below a given depth has been related to the drainage volume and the lithological composition of the profile (Barraclough et al., 1983). Nitrate leachates are usually found at depths greater than soil development. Beke and Grahham (1991) found in a traditional field rotation (2-year fallow-crop) substantial quantities of nitrate within and below the rooting zone in low localized locations where zones of higher water infiltration had greater quantities of leached nitrate.

Denitrifying activity removes nitrate from the soil system and is considered one of the most highly variable processes within a landscape. Moisture acting in response to hillslope hydrological processes controls rates of denitrification at the landform level. Pennock et al. (1992) found that various landform elements reflect different rates of denitrification in which fundamental hydrologic and pedologic processes at the landscape-scale were present. A subsequent study by Van Kessel et al. (1993) at Blaine Lake, Saskatchewan, determined that large scale variations of denitrification were mainly controlled soil moisture content.

The interaction between denitrification and leaching of nitrate initiated a study to investigate the spatial variability of deep leached nitrate and its relationship to denitrification in a prairie landscape.

MATERIALS AND METHODS

Sampling procedure and field orientation

In 1991, a field study was conducted in the Black soil zone in an undulating landscape (3-5 % slope) near Blaine Lake, Saskatchewan, Canada. A 1.96 ha section of the landscape was selected to encompass a 140-m by 140-m study site (Fig. 1). A 10 meter grid matrix was placed upon the landscape. Landform elements within the study site were computed utilizing theodolite data in a computer surface interpolation program. Six landform elements were ascertained: Upper Level (UL), Convergent Shoulder (CSH), Divergent Shoulder (DSH), Lower Level (LL), Convergent Footslope (CFS), and Divergent Footslope (DFS). From each of the six landform elements, five replicates were randomly selected within the landscape. From the randomly selected 30 sites soil was sampled in 30 cm increments to a depth of 3.3 m by coring with a mounted hydraulic drill and described according to the Canadian System of Soil Classification (Canada Soil Survey Committee, 1978).

Soil samples from each 30 cm increment were analyzed for lithological composition according to the modified pipette method (Indorante et al., 1990) and nitrate concentration determined by copperized cadium reduction column and subsequent spectrophotometer analysis (Keeney and Nelson, 1982). Denitrification activity was measured concurrently in 1991, as described in detail elsewhere (Van Kessel et al., 1993).

RESULTS AND DISCUSSION

Site description, soil classification and lithological composition

The geomorphology of the study site is dictated by the deposition of glacial-lacusterine sediments. The highest topographic position occurs near the SW corner (2.0 m) alternately, in the NW position of the landscape a low lying area (0.6 m) can be identified. The low lying area in the NW portion of the landscape was previously influenced by an intermittent slough. This slough area had not been cultivated previously but in 1991 it was broken and brought into agricultural production. From the NW low lying area a trough runs to the SE corner between two localized high positions of the landscape.

Particle size analysis indicated that the study area is mainly composed of glacio-lacusterine silty loam texture (56-72 % silt) spatially oriented over the landscape. The greatest depth of the silty loam material occurs in the depressional area and trough areas conversely shallow deposits are found on shoulder and upper level elements of the highest portions of the landscape in S and E locations. Soil classification of the Blaine Lake (Meota / Blaine Lake Association) is spatially oriented. Chernozemic soil covers 70 % of the study area in upper and shoulder positions in the landscape whereas gleysolic soils were found in the remaining 30 % of the area in depressional areas where water dominates the soil forming process.

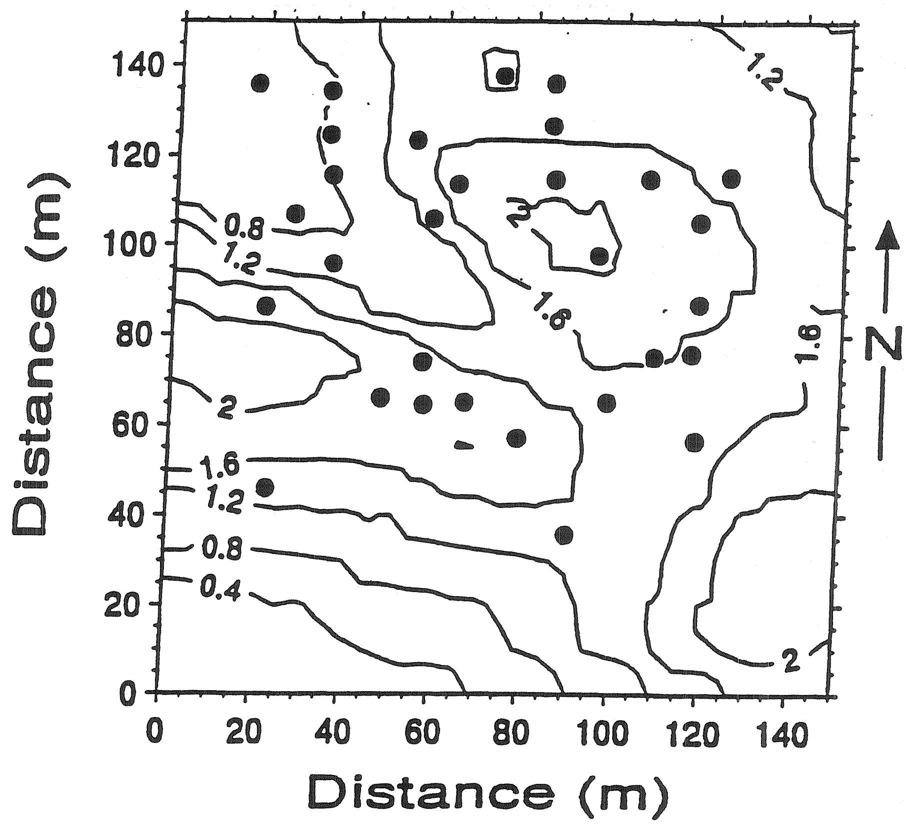

Figure 1. Sampling points (●) and topographic variation at Blaine Lake, Saskatchewan.

Landscape and landform element variations in soil nitrate

Nitrate has been leached and translocated in the upper regolith in response to water movement where significant leaching occurred in depressional areas to a depth of 3 m. Nitrate accumulation occurs in higher locations at depths below the rooting zone (120 cm +). At the landform element scale the lowest values of nitrate were formed on footslope and lower level elements in depressional areas in the northwest corner of the landscape. Conversely, the highest values were found in the shoulder and upper level elements.

Hillslope hydrological processes act to move nitrate from the upper and shoulder level elements slowly through the soil to depths where it becomes unavailable to plant roots (Fig. 2). In the upper positions a higher volume of water runs off the surface to lower lying locations, thus a smaller proportion of water is able to infiltrate through the soil column and moves nitrate vertically or laterally in response to topography and anisotropic variations. The lower level elements and the slough area also are influenced by the quantity of water which acts to leach nitrate through the soil column (Fig. 2). A high volume of water moving to lower locations infiltrates and moves soluble elements such as nitrate to very deep locations. It is therefore possible that great accumulations of nitrate could be found in the footslope and lower level positions below the 3 m sampling depth.

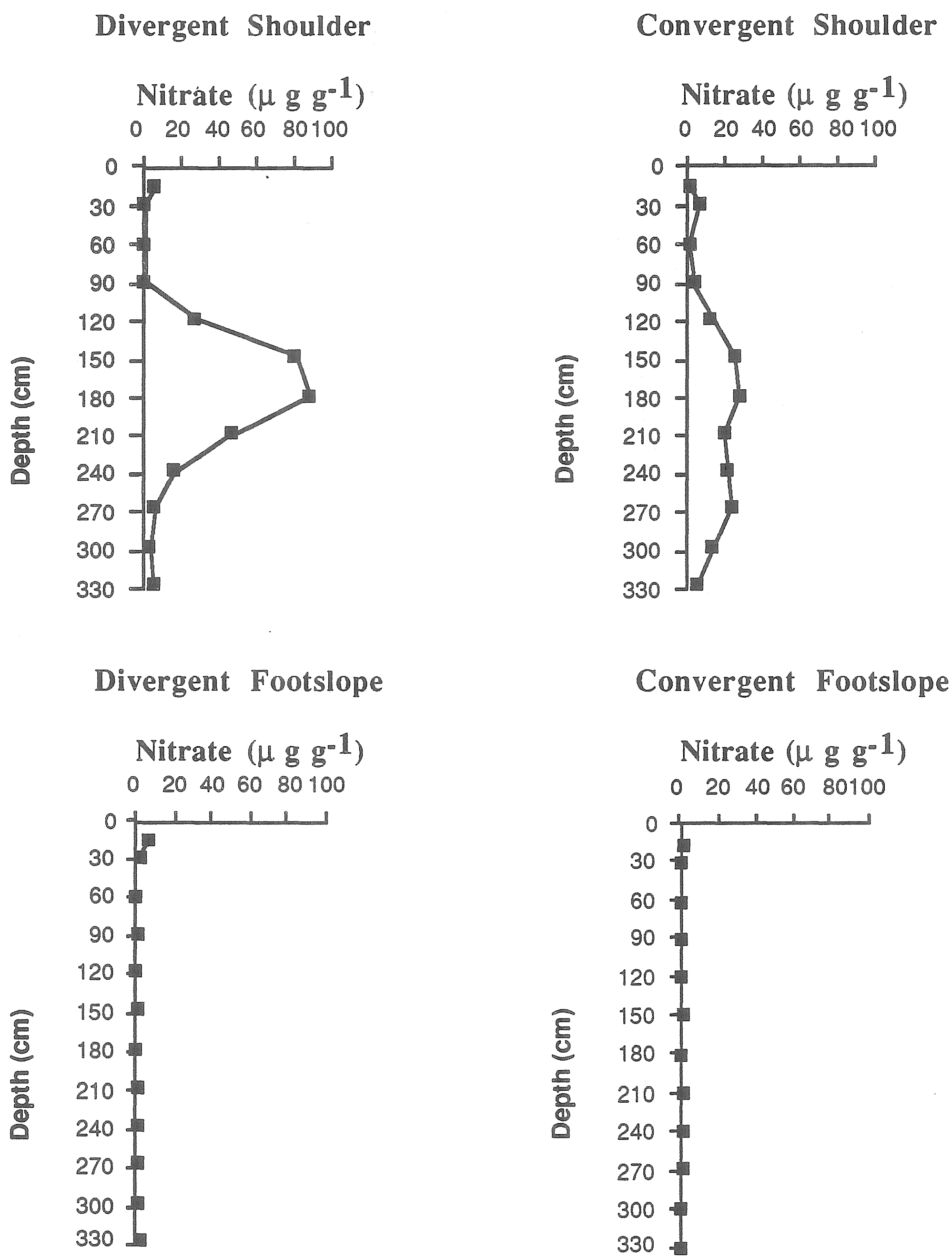

Figure 2. Leaching of nitrate as affected by landscape position.

Temporal and landform element variations in denitrification

In a previous study at Blaine Lake (Van Kessel et al. 1993) determined that large scale variations of denitrification are mainly controlled by an adequate supply of moisture. Other soil factors such as nitrate concentration was found to play a secondary role in the denitrification process. The spatial variability of denitrification observed at the Blaine Lake research site showed that: i) the highest rates of denitrification occurred in the footslope and lower level elements in which an estimated 13.7 kg N ha^{-1} (72% of denitrification activity) was lost to denitrification during the growing season, ii) the lowest denitrification rates occurred in the divergent shoulder and upper level landform elements.

Van Kessel et al. (1992) performed multiple comparisons between landform elements (shoulder, footslopes, upper level, and lower level elements) which indicated that denitrification rates associated with the shoulders were consistently lower than those associated with footslopes. Different rates of denitrification at different landform elements were associated with topographic controls. Low rates of denitrification in upper-level and divergent shoulder elements reflect the effects of hillslope flow processes and better internal drainage at these sites.

Relationship between denitrification and deep leached nitrate

The spatial diversity of nitrate variation and denitrification activity in the landscape in response to hydrological characteristics provides the basis for statistical analysis. Nitrate and denitrification are both very highly skewed data sets thus initiating the implementation of non-parameteric statistical analysis. There is an inverse relationship between denitrification and unused nitrate (Spearman Correlation coefficient -0.485 ***) (Fig. 3). The highest nitrate levels were found in shoulder and upper level elements which also contain the lowest denitrification rates. High rates of denitrification occurred in footslope and lower level elements, with concurrent low levels of nitrate. In contrary high values of nitrate were spatially related with low rates of denitrification activity in response to the spatial variation of water within the landscape.

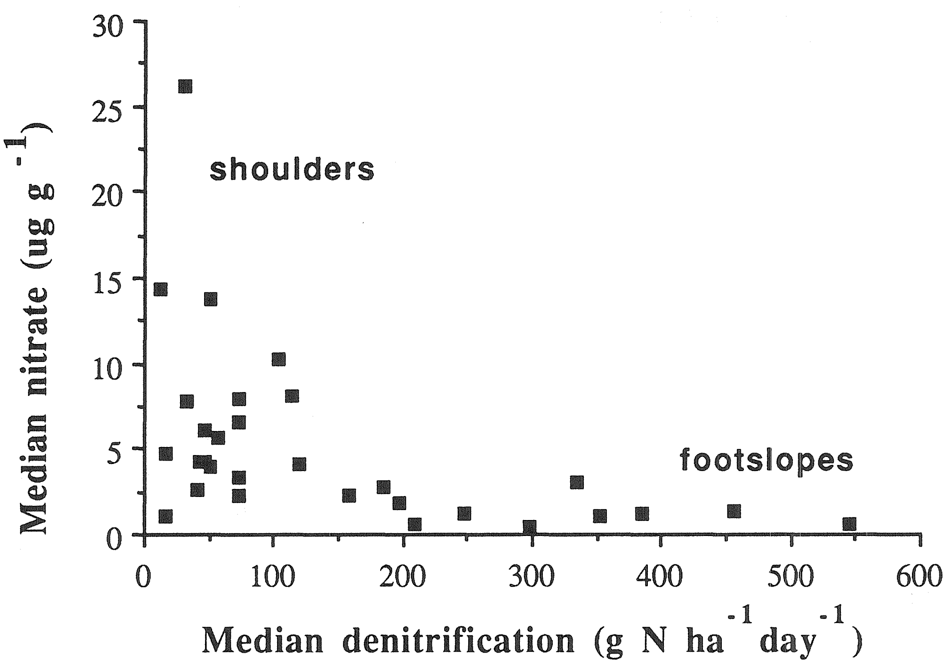

Figure 3. Median nitrate at depth verse median denitrification.

CONCLUSIONS

1) A significant amount of leaching occurred in the upper and shoulder landscape positions.

2) An inverse relationship occurs between the rate of denitrification and the concentration of nitrate in the soil.

3) Spatial variation of nitrate and denitrification is controlled by landscape morphology which regulates the impact of water runoff and infiltration.

ACKNOWLEDGEMENTS

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