Variability of ammonium and nitrate in disturbed and undisturbed forest soils.

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ABSTRACT

The spatial distribution of NH_4^+- and NO_3^--N in forest soils, as affected by site disturbance, was studied at the landscape-scale. A sampling grid, consisting of 169 points, was established at an undisturbed site located in Prince Albert National Park. Additional grids, consisting of 36 and 49 sampling points, were established at a burned and a clear-cut site, respectively. Similar levels of inorganic-N at the undisturbed and disturbed sites suggests that management practices had little effect on the availability of inorganic-N. Similarly, the spatial distribution of inorganic-N was not related to landform element complexes, suggesting that hydrologic processes were not the primary factor controlling the distribution of inorganic-N at the scale studied. The occurrence of NH_4^+-N as the dominant inorganic-N form suggests that nitrification was strictly limited in these forest soils. This contrasts agricultural soils in which nitrification often proceeds swiftly in the presence of NH_4^+-N.

INTRODUCTION

There is an ever-increasing awareness and need for the development and implementation of management practices which will ensure the sustainable use of our forest resources. An understanding of nutrient cycling, and the factors that control nutrient cycling in forested soils, is critical to the development of successful management strategies. Available nitrogen is typically low in forest soils, implying a tight coupling between mineralization and immobilization. An uncoupling of these processes, due to the influence of pedogenic or anthropogenic factors, is likely to alter the soil N status. Although numerous studies have examined the impact of disturbance on forest soil quality (Vitousek and Melillo 1979; Fenn et al. 1993; Paré and Cleve 1993; Prieto-Fernandez et al. 1993), most studies are site specific and may not be reflective of the landscape as a whole. Landforms which comprise a landscape are known to play a critical role in modifying microclimatic and hydrologic conditions within a landscape, thereby influencing distribution and availability of critical soil nutrients (Pennock et al. 1987; Pennock et al. 1992; Sutherland et al. 1993). This study was initiated to (i) determine the spatial patterns of inorganic N within forested landscapes; and (ii) assess the impact of disturbance on these spatial patterns.

MATERIALS AND METHODS

Site and Soil Description- Three forest sites, representing three management systems (i.e., native, clear-cut, and burned) were located within, or associated with, the Prince Albert Model Forest, and were sampled during the summer of 1993. The undisturbed site, located within Prince Albert National Park (UTM coordinates 13U 425840 5968800 (SW corner of grid)), was a mature mixed-wood forest assemblage. Vegetation and understory correspond to a tA-wS/*Alnus*/*Cornus*-*Aralia*/*Linnaea* assemblage as listed in the Forest Site Classification for the Mid-Boreal Mixed Section of Saskatchewan (J.D. Beckingham, Geographic Dynamics Corp., June 1993). The general landscape was classified as a Loon

River-Bittern Lake soil landscape on a slope class 3-5 surface. Over 70% of the research site was dominated by Loon River (Orthic Gray Luvisolic) soils with significant inclusions of Bittern Lake soils (Brunisolic Gray Luvisols, Eutric Brunisolic soils, and gleyed variants of the Luvisolic and Brunisolic orders) in lower landscape positions.

The clear-cut site (UTM coordinates 13U 439950 5981100) had been trenched and planted to white spruce within the last five years. Aspen regeneration was significant. The site was classified as a Bittern Lake-Loon River assemblage on a slope class 3-4 surface. The dominant soil at the site was a Brunisolic Gray Luvisol with significant inclusions of Orthic Gray Luvisols, Eutric Brunisols, and gleyed variations of the Luvisolic and Brunisolic orders.

The burned site (approx. UTM coordinates 13 U 438000 6011000) was a former mixed-wood assemblage that had been burned in the past five years. The site was mapped as a Bittern Lake-Pine assemblage on a slope class 3 surface. More specifically, the research site was a mixture of Orthic Gray Luvisols, Brunisolic Gray Luvisols, Eutric Brunisols, and Gleysols. Although soil variability on the burned site was higher than at the other two sites, the same basic range of soils occurred.

Sampling Design- A representative 120- by 120-m area was selected at each site and a regularly spaced grid was laid out on the surface. Because the undisturbed site represented a key comparative landscape, an intensive sampling scheme was used; the grid was comprised of a square 13 by 13 (169 point) grid with a sample spacing of 7.5-m. A 7 by 7 (49 point) and a 6 by 6 (36 point) grid with 15-m sample spacing was used at the clear-cut and burned sites, respectively. A soil pit was dug and soils were sampled (15-cm increments to a depth of 45-cm) and described at each point.

Analysis- Soil samples were extracted immediately, on location, with 2 M KCl to inhibit further soil N transformations. Inorganic-N ($NH_4^+ + NO_2^- + NO_3^-$) was determined by steam distillation in the presence of MgO and Devarda alloy (Keeney and Nelson 1982). Soil pH (1:1 in water) and total organic carbon were determined using standard methods.

Landform Classification- Sample points on each grid, and a fringe area surrounding each grid, were surveyed using a Sokkisha SET5 Total Station. The topographical survey was used to generate a digital elevation model with a cell resolution of 5-m by 5-m. Using a quantitative classification system, landscapes were stratified into distinct segments sharing a defined range of gradient, plan (across-slope curvature), and profile (downslope) curvature, called landform elements (Pennock et al. 1987). The primary landform elements were denoted shoulders, backslopes, footslopes, and level. The former three elements were then further classified as convergent (concave plan curvature) and divergent (convex plan curvature). The basic landform element classification of each cell was used to derive larger landform complexes at each site, as described by Pennock and co-workers (1994). The following discussion is based on these larger landform element complexes.

Statistical Analyses- Boxplots, produced using SPSS for Windows, were used as an exploratory data analysis tool to identify the median and interquartile ranges, and to assess the nature of the frequency distribution for each variable. Outliers (i.e., measured value of variable $\geq$ median value + k) were defined using a k value > 1.5 and < 3 times the interquartile range whereas extreme outliers were defined using a k value > 3 times the interquartile range. Quartile maps were constructed as a qualitative exploratory approach to examine spatial patterns of inorganic N, and relationships with landform element complexes. Quartiles are defined so that one-quarter of the ranked values lie below the upper quartile limit.

RESULTS AND DISCUSSION

Total relief of the native site was 11 m (Fig. 1). Footslope complexes dominated the depressional area in NE corner of the native site and were also identified at a higher elevation in the landscape, having a NW-SE trending (Fig. 2). Qualitatively, these footslope complexes had no control on the distribution of total inorganic-N, NO_3^--N (Fig. 3a and b), and NH_4^+-N (data not shown) quartiles at the native site. Typically, topography is expected to exert a considerable control over basic hydrologic and pedogenic processes which, in turn, can influence nutrient cycling dynamics within a defined landscape (Pennock et al. 1987; Pennock et al. 1992; Sutherland et al. 1993). Others have noted clearly defined footslope-centered patterns of N accumulation in agricultural landscapes (Stevenson and van Kessel 1994).

Native Site (MF3)

1 - m contour interval

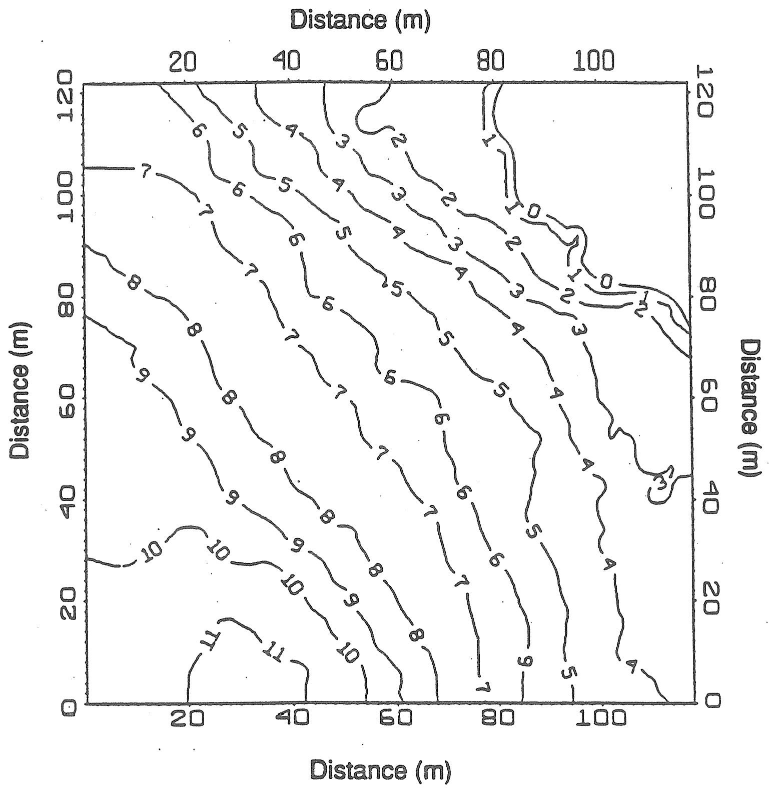

Fig. 1. Contour map for the native (undisturbed) site, located in Prince Albert National Park (Note: elevations are relative to the lowest point in the grid, which was assigned an elevation of 0.0 m).

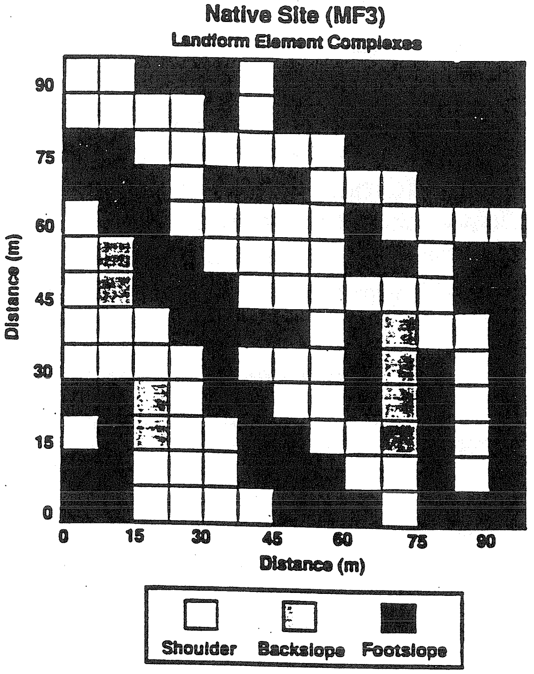

Fig. 2. Spatial distribution of landform element complexes at the native (undisturbed) site.

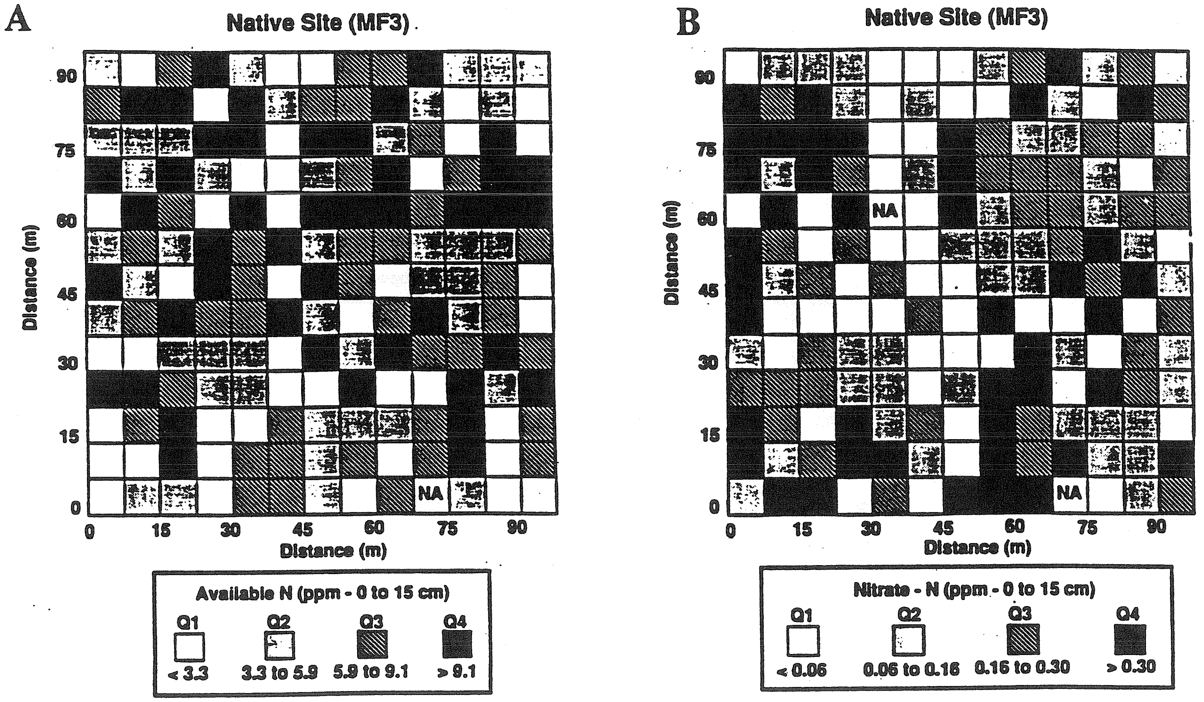

Fig. 3. Quartile maps of available-N (inorganic) (A) and nitrate-N (B) at the native (undisturbed) site.

Lack of topographic control over distribution of inorganic-N was likely related to the dominant form of inorganic-N. The relatively immobile cationic NH_4^+ form dominated at all sites (Fig. 4a), whereas levels of the mobile anionic NO_3^- form remained very low, irrespective of management treatment (Fig. 4b). As a consequence, inorganic-N assumed a random pattern of distribution, unrelated to landscape element complex, at each of the study sites (data not shown). Typically the process of nitrification, during which NH_4^+-N is converted to NO_3^--N, is favoured in soils because nitrifying microorganisms (i.e., *Nitrosomonas* and *Nitrobacter*) obtain their energy from this process. In fact, nitrification occurs so readily in agricultural soils that most soil testing laboratories limit their tests of inorganic soil N to NO_3^--N, ignoring the negligible contribution of NH_4^+-N.

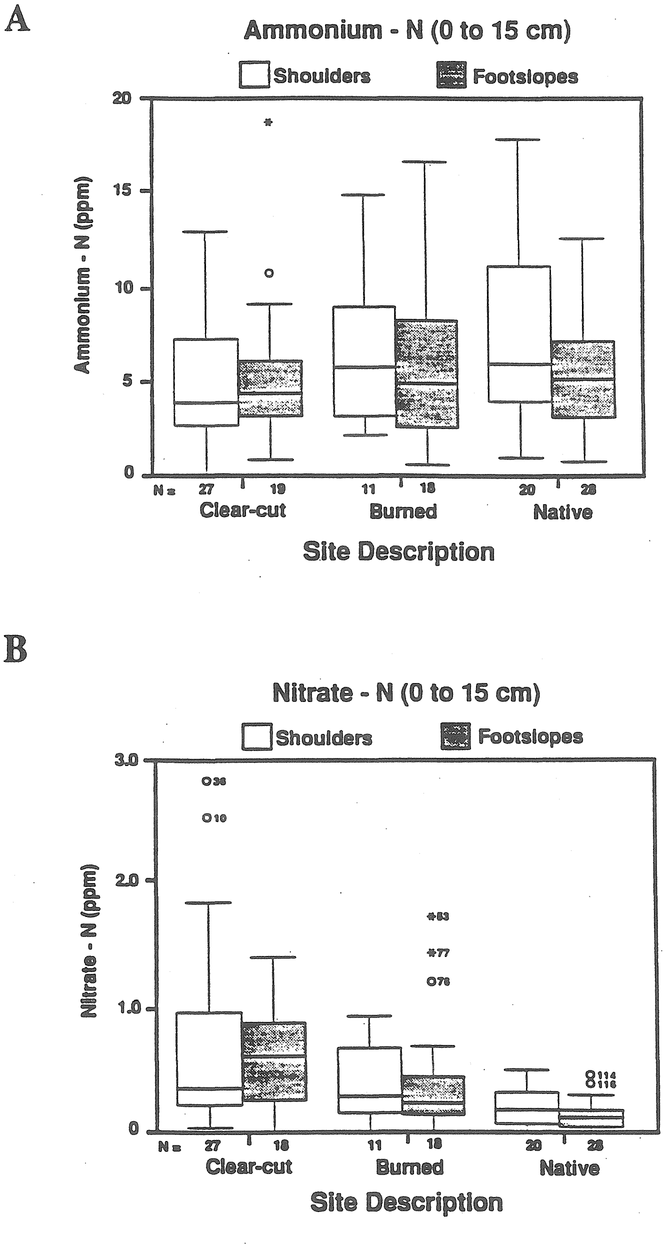

Fig. 4. Boxplots of ammonium-N (A) and nitrate-N (B) in shoulder and footslope landform element complexes at the clear-cut, burned and native sites.

Inhibition of nitrification in forested soils has been attributed to low soil pH (see review by Killham 1990); however, pH was not considered to be inhibitory at any of the study sites (Fig 5). Because the NO_3^--N form is favoured for plant uptake, it is possible that the vegetation at the native site provided a strong NO_3^--N sink which served to limit the detection of available NO_3^--N. It follows that removal of this sink would result in an increase in NO_3^--N levels; however, NO_3^--N levels were not appreciably higher at either the clear-cut or the burned site (Fig 4b). It is possible that profuse regrowth of aspen at the disturbed sites replaced the sink associated with the mature forest. However, even when soils from each of the sites were incubated under laboratory conditions designed to promote nitrification, the conversion of NH_4^+- to NO_3^--N was strictly limited (data not shown). Thus, it is suggested that nitrification was inhibited by a naturally occurring compound, or compounds, characteristic of forest soils. Others have reported total or selective allelopathic inhibition of nitrification in forest soils (see review by Killham 1990).

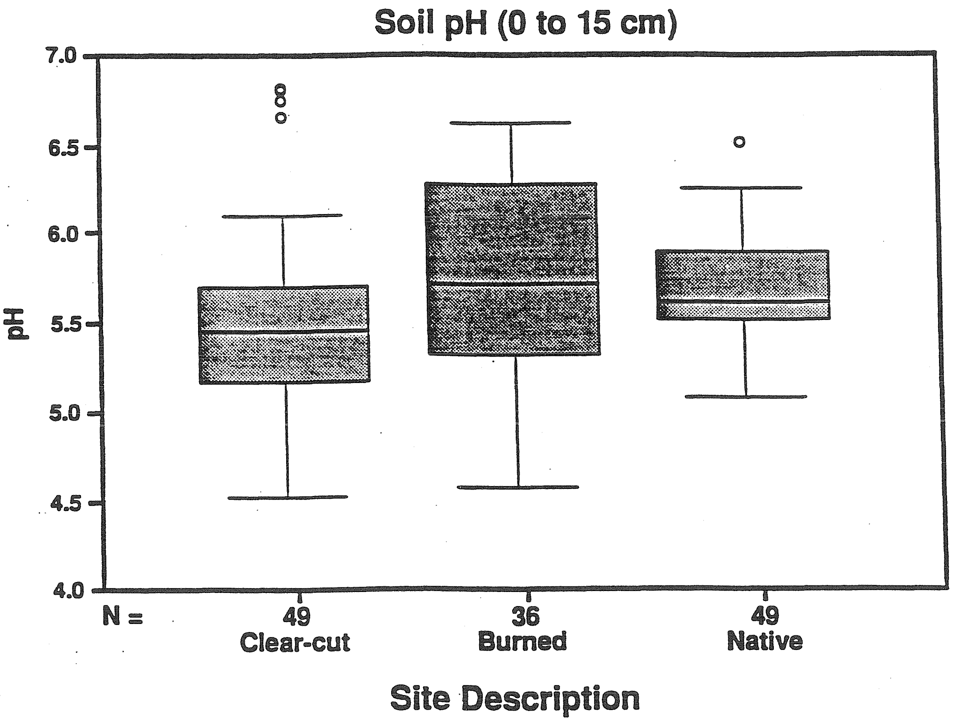

Fig. 5. Boxplot of soil pH at the clear-cut, burned and native (undisturbed) sites.

Although site disturbance had little effect on levels and/or patterns of inorganic-N within the landscape, boxplots suggest that the variability associated with some soil parameters increased with increasing levels of disturbance (i.e., clear-cut > burned). In particular, whereas little variability was associated with levels of soil NO_3^--N and soil organic carbon at the native site, variability was increased at both the burned site and clear-cut sites (Fig. 4b and 6). Limited variability associated with some soil parameters at the native site likely reflects the relatively conservative nature of this ecosystem.

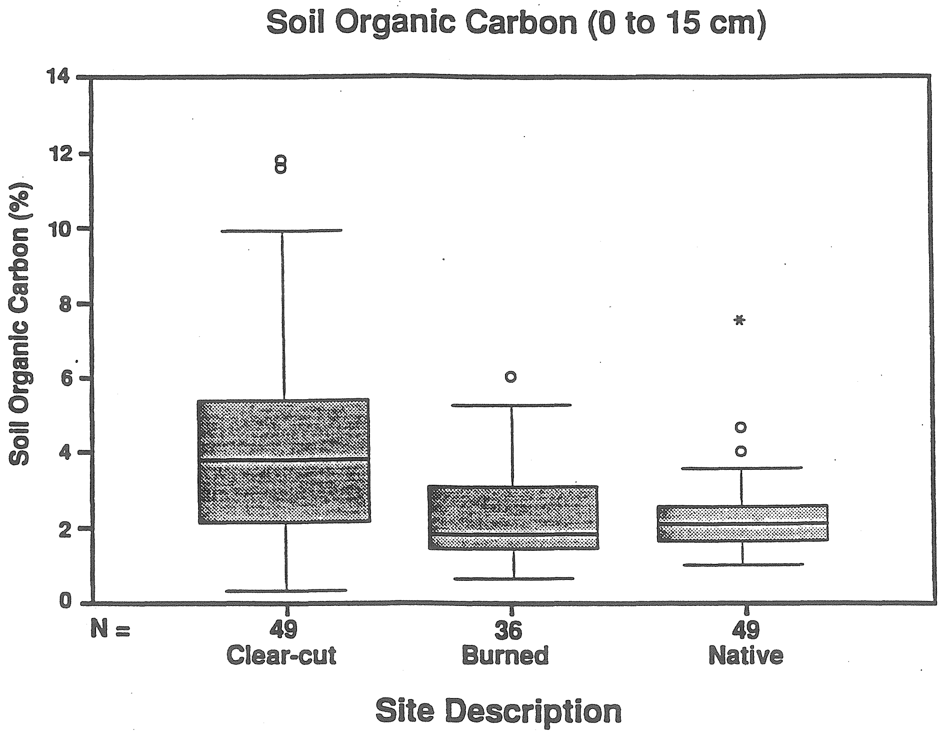

Fig. 6. Boxplot of soil organic carbon at the clear-cut, burned and native (undisturbed) sites.

SUMMARY

Spatial distribution of inorganic-N was not controlled by landform element complexes at any of the study sites, suggesting that hydrologic processes had a limited impact on N cycling. This observation is in direct contrast to agricultural soils in which accumulation of inorganic-N typically is footslope-centered. It is likely that the redistribution of inorganic-N within the forested sites in response to landscape-directed water movement was limited, in part, by the dominance of the relatively immobile NH_4^+ cation. The presence of NO_3^--N was strictly limited at all sites and it is suggested that nitrification was controlled by a compound, or compounds which occurred naturally in these soils. Although disturbance had little effect on the concentration or pattern of inorganic-N within the landscape, variability associated with some soil parameters increased in response to an increasing degree of site disturbance. This observation suggests that factors controlling the conservative nature of N-cycling within forested landscapes may be disrupted as a consequence of changing management practices.

ACKNOWLEDGEMENTS

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