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Impact of harvesting and logging slash on nitrogen and carbon dynamics in soils from upland spruce forests in northeastern Ontario

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Abstract

The potential impact of timber harvesting in the boreal forest on aquatic ecosystem water quality and productivity depends in part on the production of nutrients within the soil of the harvested catchment. Nitrogen supplied by organic matter decomposition is of particular interest because of the important role that N plays in biotic processes in surface waters, and in forest nutrition in general. Logging slash quality and input to the forest floor has the potential to influence N availability after harvest on clearcut sites. Net production of organic and inorganic-N and microbial biomass C and N concentrations were determined during a 90-day laboratory incubation at constant temperature and moisture. Incubated soils included F horizon and shallow mineral soil horizons (0–5 cm) from unharvested and full-tree harvested (2 and 12 growing seasons since harvest) boreal forest sites at the Esker Lakes Research Area (ELRA), in northeastern Ontario, Canada. In an ancillary experiment, black spruce foliage was added to unharvested forest floor material after 30 days during a 90-day laboratory incubation to simulate the influence of logging slash from full-tree harvesting on C and N dynamics. Twelve-year old clearcut F horizon material released on average 75 and 5 times more NO_3^--N and 3 and 2 times as much inorganic-N than soil collected from unharvested and 2-year-old clearcuts, respectively. This increase in NO_3^--N accumulation during the incubation was accompanied by decreases in both exchangeable NH_4^+-N and microbial biomass C and N levels. Net daily changes in microbial biomass N were significantly related to organic and inorganic-N accumulation or loss within the F horizon. Mineral soil release of inorganic-N was lower than release from the forest floor. Nitrate-nitrogen accumulation was lower, and NH_4^+-N accumulation was higher in mineral soil from unharvested sites when compared to 12-year-old clearcuts. Calculated harvest response ratios indicated that incubated mineral soil from the 12-year-old clearcut sites released significantly greater amounts of NO_3^--N than 2-year-old clearcuts. Incorporation of black spruce needles into F horizon material reduced the production of organic and inorganic-N and increased microbial biomass N. Laboratory incubations of F horizon and shallow mineral soil from 12-year-old clearcuts suggested that these boreal soils have the capacity for increased inorganic-N production compared to uncut stands several years after harvesting. This has the potential to increase N availability to growing boreal forest plantations and increase N leaching due to greater NO_3^--N levels in the forest soil.

Keywords: Boreal forest; Net N mineralization; Immobilization; Logging slash; Microbial biomass; Potential aquatic impacts

1. Introduction

Forest harvesting has the potential to increase nutrient inputs to aquatic systems, which can have an eventual impact on surface water quality and biotic response. Increased nitrogen (N) movement from the terrestrial portion of the watershed is of critical importance as it influences productivity and nutrient cycling in aquatic systems (Putz et al., 2003). Whether there will be an increased export of N after harvesting to aquatic systems depends on the coincident occurrence of increased production and/or decreased uptake by plants and microorganisms within the terrestrial ecosystem and the ability to transfer these nutrients to adjacent receiving waters. The minimal surface water impacts of harvesting reported for

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the Canadian boreal forest region (Nicolson et al., 1982; Carignan et al., 2000; Lamontagne et al., 2000; Steedman 2000; Prepas et al., 2001), even in studies where no shoreline buffer zones had been established, may be partly explained by the limited potential of upland boreal forest soils to mineralize organic-N to inorganic forms. In general, unharvested boreal forest organic and mineral soils have been shown to have low net inorganic-N production, particularly NO_3^--N. This has been shown in Quebec (Brais et al., 1995; Smith et al., 2000) and Michigan (Stottlemyer and Toczydlowski, 1999) on the boreal shield and in Saskatchewan on the boreal plain (Walley et al., 1996).

Disturbance by forest harvesting causes increases in soil temperature, which, if soil moisture remains adequate, would be expected to increase microbial activity, leading to enhanced organic matter decomposition and increases in inorganic-N production. However, production and immobilization of N may vary during the time after harvest due to changes in soil organic matter quantity and quality, and microbial activity. Knowledge of the silvicultural plan of a given site (harvest type, site preparation, regeneration approach, vegetation control) and the timing when each component of the plan was executed can assist in the interpretation of changes to substrate characteristics and N mineralization rates after harvest. In the boreal region of Ontario, large amounts of logging slash are removed from cutovers after harvest and placed in roadside slash piles. These piles are burned, usually during the fall, to clear areas for forest regeneration. In spite of this removal, significant amounts of slash remain on site and this material has the potential to influence N transformations in cutover soils.

Due to the varied interactions of environmental conditions and composition of substrate, results from several studies in the boreal forest demonstrate that it is not possible to make broad generalizations concerning relationships between clearcut harvesting and net N mineralization. For example, growing season net forest floor mineralization was greater in 9-year-old full-tree harvested sites when compared to uncut stands in northwestern Quebec (Brais et al., 2002). However, 15 years after harvest the uncut stands in this study had higher net mineralization rates than the harvested sites. Forest harvesting has increased, decreased or resulted in no change to forest floor and mineral soil horizon ammonification and nitrification rates when compared to unharvested boreal stands (Gordon and Van Cleve, 1983; Walley et al., 1996; Smith et al., 1998, 2000; Simard et al., 2001; Carmosini et al., 2002, 2003). The results from these studies agree with the main conclusion of Grenon et al. (2004) in their examination of forest floor N dynamics in coniferous ecosystems in British Columbia. In their research they recognized responsive and non-responsive sites, and determined that the many factors and mechanisms that control production and consumption of mineral N will determine the spatiotemporal response of a given N variable to harvesting. A comprehensive review of soil N mineralization research by Schimel and Bennett (2004) suggested that research that seeks to provide explanations for differences in terrestrial N cycling must address the linkages between biotic processes (e.g., depolymerization, mineralization, microbial uptake, root uptake), the role of microsite level dynamics in regulating macroscale N response, and the contribution of roots and mycorrhizae in creating variable microsites and mediating soil processes.

In this study we assessed N dynamics in soils from unharvested stands and from two different aged, full-tree harvested sites. We hypothesized that substrate quality, that is the chemical composition of organic residues in the soil, would be modified by silvicultural practices and time since harvest and that this would affect organic matter decomposability and soil N mineralization. Through the use of standardized incubation conditions we attempted to isolate changes in N transformation rates due to substrate differences rather than soil physical environment. Our purpose was to determine whether forest harvesting could alter soil N production, thereby assessing one aspect of the potential susceptibility of boreal aquatic ecosystems to increased N loading. Our objectives were to determine: (1) the potential rates of soil ammonification, nitrification and net N mineralization after full-tree harvesting, (2) the influence of logging slash (fresh black spruce needles) on N transformations in boreal clearcut soils, and (3) relationships between soil microbial biomass and C and N dynamics. Specifically, we tested the hypotheses that modifications to substrate quality, resulting from full-tree harvesting, silvicultural practices, clearcut age, and logging slash would influence microbial biomass cycling and N dynamics.

2. Materials and methods

2.1. Study site description

The study sites were located at the Esker Lakes Research Area (ELRA) located approximately 75 km north of Cochrane in northeastern Ontario (49°38′N, 81°00′W) (Fig. 1). The sites were located on a 15 km north-south transect along an esker formation that had variable soil textures including up to 40% clay content in some horizons (Hazlett et al., 2005). The ELRA is located within the Northern Clay Section of the Boreal Forest Region (Rowe, 1972). The soil has a podzolic profile (Soil Classification Working Group, 1998) with a pH of 4.5 in the forest floor and >7.0 at 75 cm depth in the soil profile. Forest floor horizons stored between 10 and 20% of the total soil N to a depth of 75 cm (Hazlett et al., 2005). The natural forest is typical of undisturbed fire-origin boreal forest, dated at 95 years of age at the time of the study. Dominant tree species include black spruce (*Picea mariana* (Mill.) BSP), white spruce (*Picea glauca* (Moench) Voss), balsam fir (*Abies balsamea* (L.) Mill) and white birch (*Betula papyrifera* Marsh.). Dominant understory shrub species are mountain maple (*Acer spicatum* Lamb.), speckled alder (*Alnus rugosa*