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Leaching of nitrate nitrogen into the groundwater after clear felling and site preparation

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The concentration of nitrate nitrogen in the groundwater was investigated one year before and during ten years after clear felling, collecting of logging residues and ploughing that took place in 1986 at the Pahalouhi and Hautala experimental sites at Kivesvaara, located in the middle boreal coniferous forest zone in the central part of Finland (64°28´N, 27°33´E). All the treatments caused a rise in nitrate nitrogen concentrations at both sites. Having been initially virtually zero, the concentrations of nitrate nitrogen continued to rise for 5–7 years, reaching 500–700 μg l^{-1} at their highest, after which they began to decrease. Concentrations were still high ten years after the treatments, a situation which has not been found earlier.

Introduction

Clear felling and soil preparation alter site conditions and affect run-off water quality. With the introduction of mechanization of site preparation to Finland in the mid-1960s (Turtiainen and Valtanen 1970), numerous field tests were conducted to determine its effects on the physical properties of the soil and on seedling growth (e.g. Leikola 1974, Pohtila 1977, Ritari and Lähde 1978, Kubin and Kemppainen 1991, 1994). It was for this purpose that the experimental site at Kivesvaara was established. This was also the first upland site in Finland where research on the leaching of nutrients after clear felling and site preparation was carried out (Kubin 1995), and where the leaching results can be combined with long-term research of soil temperatures (Kubin and Kemppainen 1991,1994). The increasing soil temperature makes the decomposition more effective and liberates more soluble nutrients to the soil compared with uncut forest.

As a background to this nutrient research, assessments of the amounts of nutrients removed from the forest site in the harvested timber and the amounts remaining in the residues were first made (Kubin 1977a). The main results indicated that a large amount of nutrients remained in the logging residues (branches, foliage, lop and top) relative to that removed with the stems. The highest proportions remaining on the site were recorded in the case of nitrogen, phosphorus and

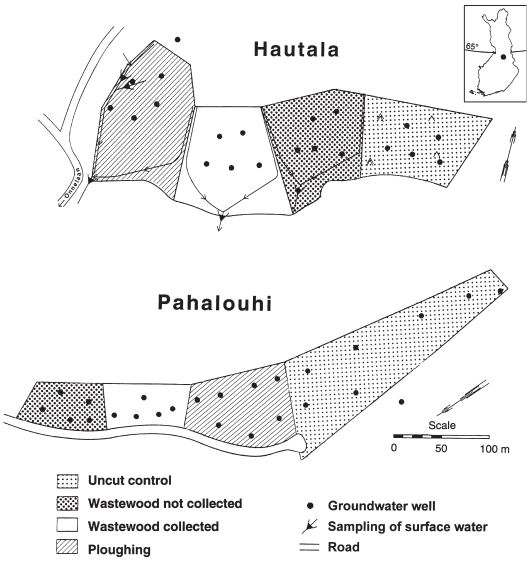

Fig. 1. The Hautala and Pahalouhi sites and location of the groundwater wells. The sites were set up in 1978 and clear felling, removal of the logging residues and site preparation took place in 1986.

base nutrients, the needles being the richest in nutrients of all the logging residues categories. Soil analyses showed that mineralization had started with particularly large increases in nitrate nitrogen in the humus layer (Kubin 1977b, 1979). A high concentration of nitrate could also be observed in the run-off water (Kubin 1995), which indicates nutrients leaching outside the biological cycle.

The pronounced mineralization of nutrients and their leaching by surface water led in turn to the assumption that nutrients may also be leach into groundwater. Results pointing towards such a possibility had already been reported in Sweden (Wiklander 1974), but they were not directly applicable to conditions in Central Finland. Consequently the research on surface water quality was extended into 1978 to cover groundwater quality as well. Such investigations on the effects of reforestation on the groundwater were utterly new in the 1980s, and indeed, no other experiments of this kind have been carried out in forest regeneration areas in Finland. General interest in groundwater quality has increased considerably, however, particularly regarding the effects of acid rain (Soveri 1985, Bergström and Lindström 1989, Soveri and Ahlberg 1990, Aastrup *et al*. 1995, Bertills and Hanneberg 1995, Maxe 1995). The present work provides new information on the duration of the effects of clear felling, whole tree harvesting and site preparation on groundwater nitrate nitrogen concentrations, especially under the conditions prevailing in the central part of Finland, where nitrogen deposition is small.

Material and methods

The experimental areas used for this purpose, Pahalouhi and Hautala (Fig. 1), are located in the central part of Finland (64°28´N, 27°33´E) near the town of Kajaani, representing prevailing conditions in the middle boreal coniferous forest zone (Hämet-Ahti 1981). The treatments applied were the same at both locations, i.e. clear felling, whole tree harvesting and ploughing. Surface runoff can be monitored in conjunction with groundwater at Hautala, by contrast with Pahalouhi, where no surface water was formed. The site types at both experimental areas varied from dryish to fresh upland forest. In the spring, following the felling and site preparation in 1986 the plots were planted with pine (*Pinus sylvestris* L.). The total amount of log and pulpwood harvested at Hautala was 127 m^3 ha^{-1}, of which pine (*P. sylvestris*) accounted for 11%, spruce (*Picea abies* Karsten) for 88% and birch (*Betula pendula* Roth., *Betula pubescens* Ehrh.) 1%. The corresponding figures at Pahalouhi were 141 m^3 ha^{-1}, of which pine made up 51%, spruce 46% and birch 3%. All the felling was carried out by harvester, the logging residues being collected manually.

A total of 49 groundwater wells were installed, five for each treatment area in the experiment. They consisted of plastic piping varying from 4–6 m in length with holes in the lowermost 1.5 m and with a plug to seal the bottom**.** The depth of the groundwater varied with the seasons; the mean being about 3 m. A low pressure pump was used to sample the groundwater. The soil consisted of sand or sandy till. There were no major differences in climate between the two sites.

Measurement of nutrient leaching commenced in 1985, the year before clear felling and site preparation, and water samples were taken from each well once a month from May to October. Surface water samples at Hautala (Fig. 1) were mostly collected twice a week in spring and early sum-

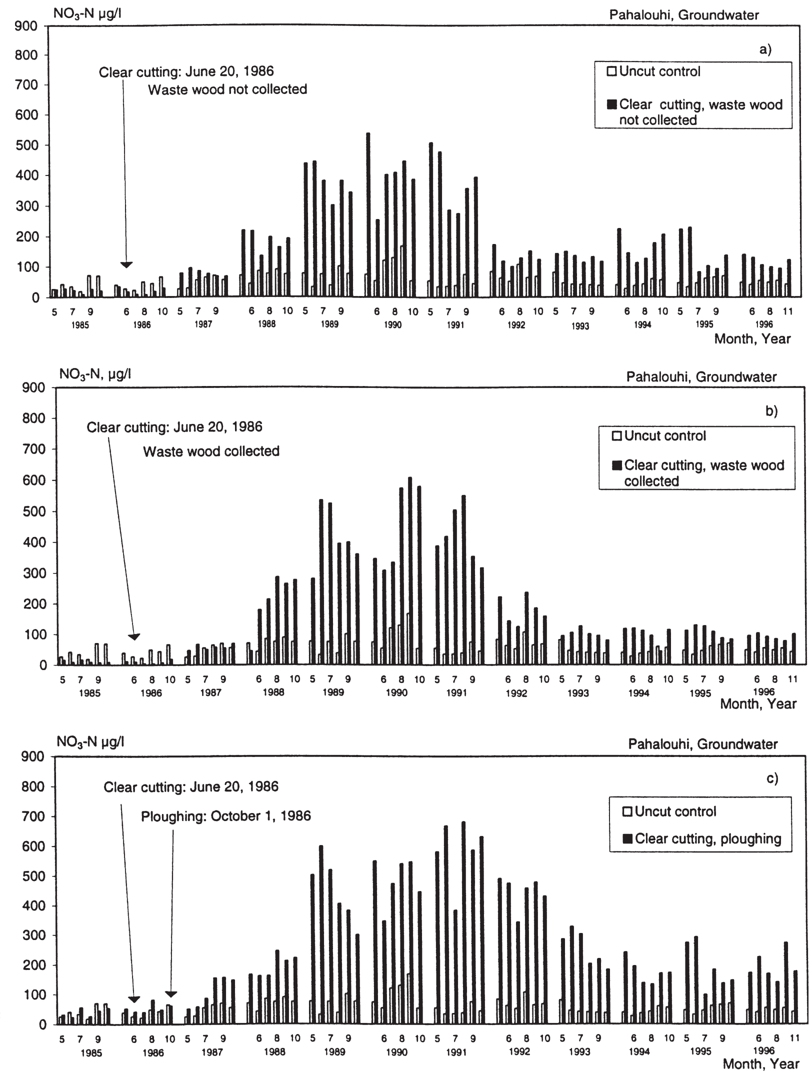

Fig. 2. Effects of clear felling, removal of logging residues and ploughing on nitrate nitrogen concentrations in the groundwater of the Pahalouhi site. The column shows the mean of wells sampled.

mer. Chemical analyses were carried out following standard methods. This paper presents the results for nitrate nitrogen concentration measurements over the period 1985–1996.

Results

Pahalouhi

Nitrate nitrogen concentrations at the site were initially 30–50 µg l^{-1} and they continued to rise for 4–5 years following clear felling, reaching their peak of over 500 µg l^{-1} in 1990 (Fig. 2a). They were still well above the initial level ten years after felling.

Removal of the logging residue had a similar effect to felling alone (Fig. 2b), the rise of nitrate nitrogen concentrations being remarkably similar. The same rise was true for the ploughed area, except that the concentrations fell more slowly from the peak levels and were slightly higher at the end of the period than in the unploughed treatments (Fig. 2c).

Hautala

The effect of clear felling was similar to that at the Pahalouhi site, except that maximum concen-

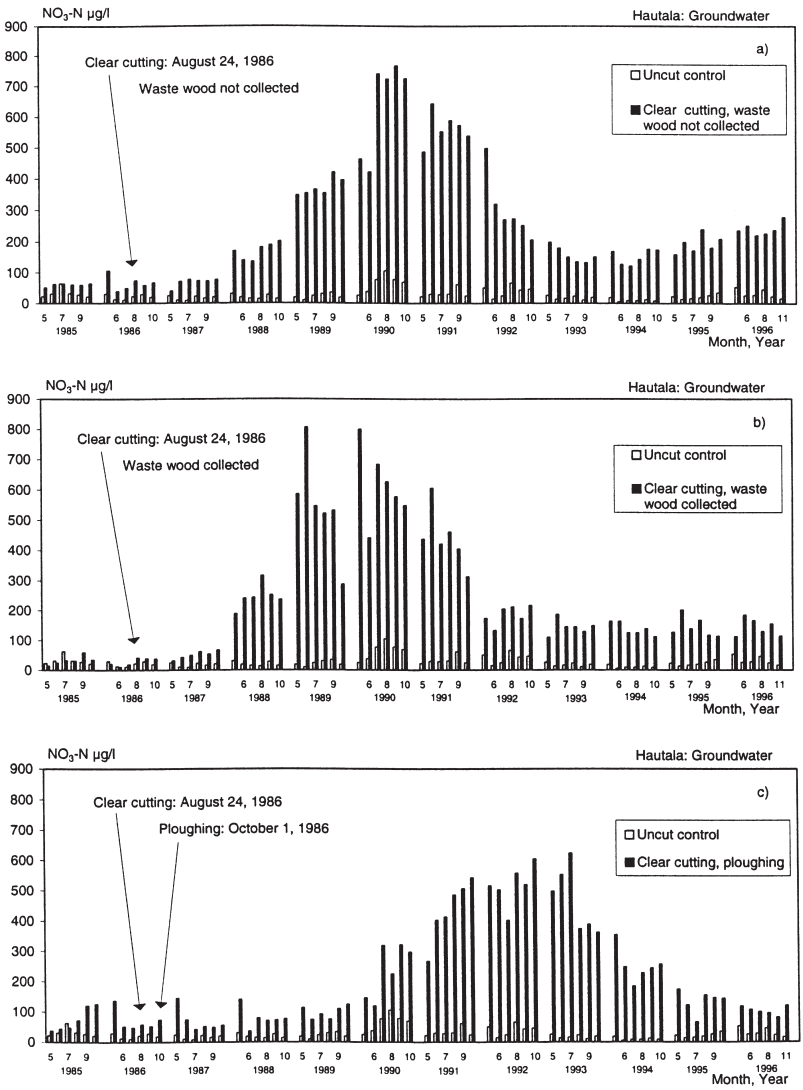

Fig. 3. Effects of clear felling, removal of logging residues and ploughing on nitrate nitrogen concentrations in the groundwater of the Hautala site.

trations were slightly higher (Fig. 3a). The effect of harvesting the logging residue was somewhat similar, but again the maximum concentrations were slightly higher than at Pahalouhi (Fig 3b).

The change of nitrate nitrogen concentrations following ploughing was quite different, however, for where these had been elevated in the third summer following site preparation at Pahalouhi, i.e. in 1989, no sign of any rise was observed at Hautala (Fig. 3c). Eventually 1992 the concentrations at Hautala did rise to the levels measured at Pahalouhi in 1989. Concentrations were still high in the last year of the observations. It is significant that the rise at Hautala occured only after leaching into the surface water had come to an end (Fig. 4).

Discussion

Nitrate nitrogen is the most essential of the nutrients that are leached into the groundwater as a consequence of forestry practices. In the studied area, the effect of leaching lasted for at least ten years, i.e. somewhat longer than has previously been reported for instance in Sweden (Wiklander 1974, 1983). However, in the nutrient-poor northerly conditions the peak concentrations of nitrate

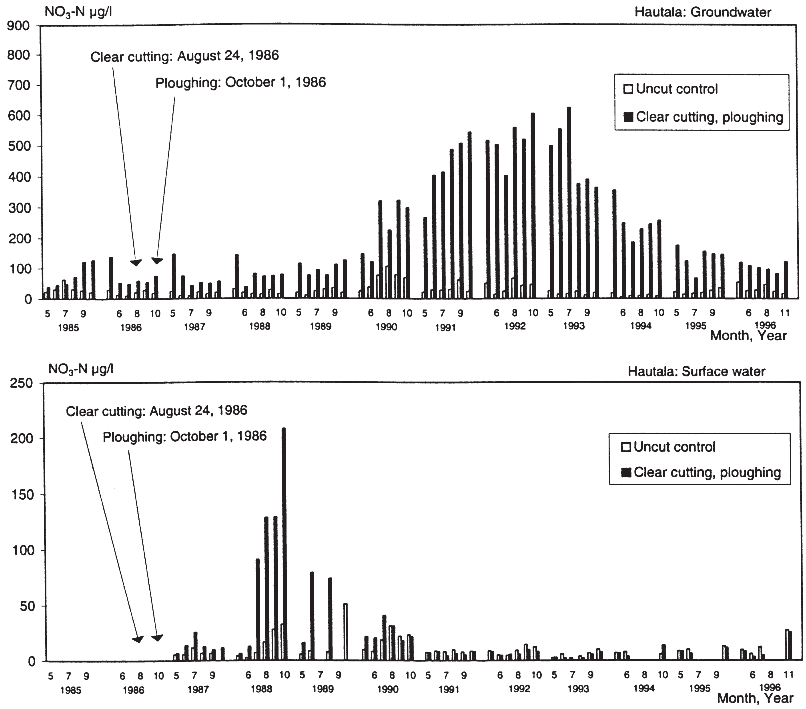

Fig. 4. Effects of ploughing of the Hautala site on the leaching of nitrate nitrogen into the surface water and groundwater. Surface water sampling was started after site preparation. The control is the water flowing above the treatment area.

nitrogen were lower than in the case of fertile forest soils in southern Sweden (Wiklander 1983). Change to the nitrate nitrogen concentration did not exceed the values set for drinking water.

The effects of clear felling on nitrogen concentrations in surface water have been shown to last only a few years (Tamm *et al.* 1974, Haveraaen 1981, Ahtiainen 1988, Kubin 1995), and this is confirmed by the present results, but the long-term nature of the increasing groundwater concentrations, which have persisted for over 10 years, could not have been deduced from the earlier surface water studies. For this reason when regeneration practices are carried out, the site properties including the binding effect of nutrients by ground vegetation and seedling stand (Borman and Likens 1979) should be taken into account in greater detail than before.

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