# Effects of Soil Scarification and Previous N Fertilisation on Pools of Inorganic N in Soil after Clear-Felling of a *Pinus sylvestris* (L.) Stand

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Previous analyses of soil water beneath mounds resulting from scarification have implied that this forestry measure increases leaching of inorganic N. However, more recent soil-water studies have not confirmed this assumption. The soil study presented here examined the pools of inorganic N in different microsites emanating from a simulated disc trenching, i. e. the mound with underlying soil, the furrow bottom and the undisturbed soil. The study was made five years after scarification. The mound itself with underlying soil had a larger pool of inorganic N than the undisturbed soil. This was mainly because of an increase in the embedded humus layer, thus implying a larger net N mineralisation and/or lower losses. However, when pools of inorganic N per hectare were calculated, taking into consideration that a scarified area comprises 25% mounds, 25% furrows and 50% undisturbed soil, there was no increase in pools of inorganic N when compared with an area not subjected to scarification. This observation supports the finding of the more recent soil-water studies mentioned, i. e., that leaching seems not to be influenced by soil scarification. The scarification was made as a split-plot treatment on main-plots in an old experiment with different N doses. Thus, the effect of the previous N fertilisation could also be evaluated. Two N doses were tested beside the unfertilised control: 720N (3 × 240 kg N $ha^{-1}$ $yr^{-1}$) and 1800N (3 × 600 kg N $ha^{-1}$ $yr^{-1}$). The last fertiliser application was made six years before the clearcutting and 13 years before the soil sampling. The previously fertilised main-plots had larger pools of inorganic N than the control plots.

**Keywords** boreal forest, furrow, mound, nitrogen mineralisation, podsol, Sweden

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# 1 Introduction

Efforts are undertaken in many countries to reduce the contamination of water with anthropogenic N. Land use significantly contributes to the N load on surface water and in Sweden, forested areas are the source of about 25% of this load (Löfgren and Olsson 1990). Of this part, one-fifth is because of forestry operations, mainly clear-felling. After clear-felling a forest stand, leaching of both organic and inorganic N often increases for a number of years (Grip 1982; Rosén et al. 1996).

Soil scarification is a common measure to improve survival and growth of planted or self-regenerated conifers. In Sweden, over a period at 1994–96, 70% (140 000 ha) of the regenerated area was annually subjected to scarification (Statistical yearbook... 1998). Several studies have indicated that N leaching is elevated because of soil scarification. This has been reported on the basis of high concentrations of inorganic N in soil water below mounds when measured by zero-tension lysimeters (Mälkönen 1986; Rosén and Lundmark-Thelin 1986; Lundmark-Thelin 1988). It has also been shown that mass loss and nutrient release from litter are larger when placed beneath mounds than when lying on an undisturbed soil surface (Johansson 1994; Lundmark-Thelin and Johansson 1997). In addition, a lowered amount of total N has been observed in soils earlier attributed to radical scarification, where a large part of the soil surface was disturbed (Lundmark 1977; Burgess et al. 1995; Örlander et al. 1996), which may be an indication of increased leaching losses.

In watershed studies, the effect of soil scarification has not been separated from the effect of clear-felling per se. The watersheds studied were most often both clearfelled and scarified. Scarification disturbs up to 50% of the soil surface (von der Gönna 1992). This means that a judgement of the effect of scarification on N leaching at the watershed scale cannot be based only on information from the situation beneath mounds. Nitrogen availability in furrows and undisturbed soil have also to be taken into account. A presumably low availability and leaching from furrows may counteract an elevated leaching from mounds.

Two recent soil-water studies tried to integrate on an areal basis the simultaneous effect of mounds, furrows and undisturbed soil (Ring 1996; Örlander et al. 1997). Their main result was that concentrations or leaching of inorganic N were not higher in areas that were both clearfelled and scarified, than in areas that were only clearfelled. Kubin (1995) studied the concentration of nitrate in ground water below a clear-cut with and without subsequent ploughing. There was no large difference between the two treatments, but a tendency for higher concentrations where ploughing had been made. The study comprised no true replicates and no details were given on the intensity of the ploughing.

The main objective of this study was to examine the effects of a previous soil scarification on the amount of inorganic N in soil. Samples from mounds, furrows and undisturbed soil were analysed and from these data an integrated areal value was calculated. Soil scarification was a split-plot treatment in an old N fertilisation experiment. Thus, it was possible to evaluate also the effect of previous N fertilisation.

# 2 Material and Methods

The study was conducted in an earlier established N fertilisation experiment including several different doses. The experiment is described in detail by Nohrstedt (1988a). The experimental area is in a *Pinus sylvestris* L. forest in central Sweden (62°9' N, 14°9' E). The soil type was classified as a podzol (cf. Troedsson and Nykvist 1974) and had developed on an unwashed till.

In October 1987, the experimental stand was harvested. The original unfertilised stand that surrounds the experimental area was not clearfelled. In this stand, two reference plots were established. Four months prior to clear-felling, lysimeters had been established at 40–50 cm soil depth. On each plot, sized 40 × 40 m, four lysimeters were used.

No general soil scarification was performed in the experimental area. However, in the spring of 1989, a disc trenching that creates a mound on an inverted humus layer (cf. Sutton 1993), was simulated in the proximity of two of the four

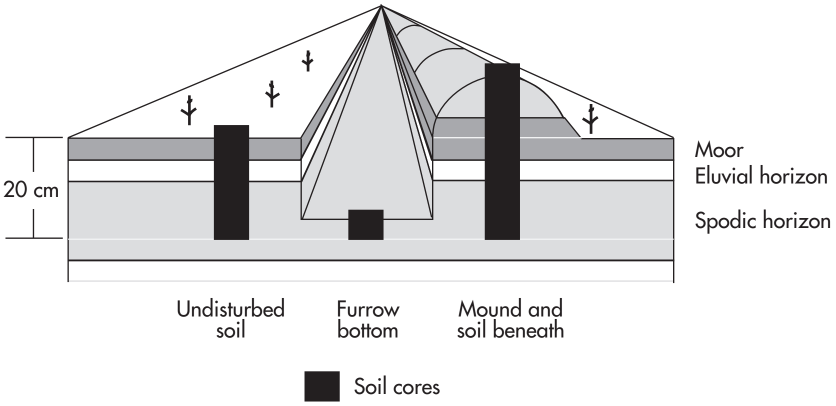

**Fig. 1.** Schematic view over the simulated soil scarification and the sampling.

lysimeters per plot. In a circle with a radius of 1.3 m and the lysimeter in the centre, furrows and mounds were created in a “piece-of-cake” manner by using a spade. Within the circle, there were two mounds and two furrows in opposite directions. Of the circular area, 50% consisted of undisturbed soil, 25% of furrows and 25% of mounds. The furrows were dug down to 10 cm in the mineral soil, which was about four cm down in the spodic horizon. Thus, the upper part of the mounds was covered by spodic material. For more details and an illustration, see Ring (1996). In the early summer of 1989, the experimental area was replanted with Scots pine.

In July 1994, which was five years after the simulated disc trenching, soil samples were taken in mounds, furrows and undisturbed areas. This was done in three main-plot treatments: 0N (control), 720N and 1800N, all in two replicates. The 720N and 1800N treatments had been given totally 720 and 1800 kg N ha$^{-1}$, respectively, in the form of ammonium nitrate, distributed on three occasions (1967, 1974 and 1981). Soil samples were also taken from the two uncut reference plots (without soil scarification as split-plot treatment). Altogether, eight study plots were examined.

Around an individual lysimeter without disc trenching, two soil cores were taken at a distance of 1.5 m from the lysimeter, one in each of two opposite directions. Around an individual lysimeter with disc trenching, two cores were taken from mounds and two from furrows, one in each of two opposite directions at a distance of 0.8 m from the lysimeter. Since there were two lysimeters per plot of each split-plot treatment, this means that four cores were taken per plot and microniche (mounds, furrows and undisturbed soil). These four cores were pooled within horizon before chemical analysis.

A metal cylinder with a diameter of 6 cm was used to take soil cores of a specified volume. Samples were taken down to 15 cm below the original upper level of mineral soil and were separated into humus, 0–5 cm, 5–10 cm and 10–15 cm mineral soil (Fig. 1). This means that in the bottom of furrows sampling was made only to a depth of 5 cm. In mounds, cores were taken from the top mineral soil. The inverted humus layer was sampled together with the original humus layer.

The samples were kept cold awaiting further processing, which was done within few days after sampling. At the laboratory, the soil samples were passed through a sieve, 5.6 mm for humus samples and 4.0 mm for mineral soil. Thereafter, the samples were thoroughly homogenized. The water content of samples was determined gravimetrically after drying overnight in 80 (humus layer) or 105 (mineral soil) °C. For extraction of inorganic N later on, 100 ml aliquots of soil were frozen. Shortly before extraction, the samples were carefully thawed in a refrigerator. 40–100 g fresh weight of soil was extracted for inorganic N with 1 M KCl in an end-over-rotavator overnight. The ratio between soil and salt solution was 1:2.5 by volume. The suspension was cenrtifuged and filtered. The extract was colorometrically analysed for ammonium and nitrate by means of an AutoAnalayzer TRAACS 800. Ammonium forms, after a reaction at pH 13 with sodiumsalicylate in presence of prusside ions and hypochlorite, a green-coloured complex that was measured at 660 nm. Nitrate was first reduced to nitrite at pH 8 in a Cu-Cd reductor. At low pH, nitrite reacts with sulfanilamide to form a diazo-compound, which together with naphtylethylenediamine produces a red-lilac azo-compound which was measured at 520 nm.

Integrated areal amounts of inorganic N were calculated for a depth of 15 cm below the original mineral soil surface. On the split-plots with scarification, the integrated value took into account that 50% of the area consisted of undisturbed soil, 25% of mounds and 25% of furrows on all clear-cut plots. On the split-plots without scarification and on the uncut reference plots, the integrated value comprised only data from undisturbed soil.

The statistical analysis was made using SAS-GLM applying a split-plot model with soil scarification, previous fertiliser dose and block as independent, classified variables. Residuals were tested for normality (proc univariate). Differences between fertiliser doses were examined according to Tukey. For a few variables, for which the residuals did not represent a normal distribution, data were $^{10}$log-transformed. Data from the uncut reference plots were excluded from the statistical analysis, since no split-plot treatment had been established. However, data from these plots are presented to estimate the possible effect of clear-felling.

# 3 Results

## 3.1 Inorganic N – Effects of Scarification

The amount of total inorganic N (ammonium + nitrate) down to 15 cm below the original mineral soil surface is given in Table 1 for undisturbed soil profiles, furrows and mounds including the underlying soil. An effect of clear-cutting (0N vs Reference) on the amount of total inorganic N in the undisturbed soil profile was indicated, especially in block 1. On average for the two blocks, the amount was five times larger on the clear-cut and the increase was mainly because of ammonium.

Results from the ANOVA-test are given in Table 2, where data from specific soil layers are also presented. The amount of total inorganic N was larger in mounds and underlying soil than in the undisturbed soil profile (Table 1 and first variable in Table 2) . There was a similar tenden-

**Table 1.** Amount of total inorganic N (kg ha$^{-1}$), with nitrate-N given within brackets, down to 15 cm in mineral soil for individual replicates (blocks), site preparation microsites and fertiliser doses.

| Treatment | Block | Inorganic N | | | |
|---|---|---|---|---|---|
| | | Undisturbed soil | Furrow bottom* | Mound and soil beneath | Scarified soil; areally integrated |
| Reference | 1 | 2.1 (0.6) | | | |
| | 2 | 1.6 (0.2) | | | |
| 0N | 1 | 16 (1.1) | 0.6 (0.1) | 31 (3.7) | 16 (1.5) |
| | 2 | 4.3 (0.2) | 0.4 (0.1) | 18 (0.8) | 6.7 (0.3) |
| 720N | 1 | 46 (1.2) | 0.6 (0.1) | 36 (1.3) | 32 (0.9) |
| | 2 | 24 (1.6) | 0.5 (0.1) | 62 (4.6) | 28 (2.0) |
| 1800N | 1 | 45 (6.5) | 0.6 (0.1) | 121 (11) | 53 (6.1) |
| | 2 | 20 (5.2) | 0.4 (0.1) | 111 (22) | 38 (8.0) |

*10–15 cm below the original mineral soil surface

**Table 2.** Effect of soil scarification on amounts of inorganic N (kg N $ha^{-1}$) – results from ANOVA. Mean values and SD of six replicates. Different letters following values within horizontal category denote a statistically significant difference ($p < 0.05$).

| Variable | Undisturbed soil | Soil scarification | p-value |
|---|---|---|---|
| 1. Inorganic N, soil profile* | 26±17a | 63±44b | 0.02 |
| 2. Nitrate N, soil profile | 2.6±2.6a | 7.2±7.9a | 0.11 |
| 3. Inorganic N, mineral soil 0–10 cm vs top of mound | 18±14a | 4.8±4.1b | 0.004 |
| 4. Nitrate N, mineral soil 0–10 cm vs top of mound | 0.97±0.84a | 0.43±0.49a | 0.08 |
| 5. Inorganic N, humus layer | 4.3±3.1a | 14.0±9.6b | 0.03 |
| 6. Nitrate N, humus layer | 0.03±0.02a | 0.31±0.35a | 0.07 |
| 7. Inorganic N, mineral soil# | 22±16a | 30±24a | 0.17 |
| 8. Nitrate N, mineral soil | 2.6±2.6a | 4.4±3.7a | 0.05 |
| 9. Inorganic N, soil profile areally integrated | 26±17a | 29±16a | 0.44 |
| 10. Nitrate N, soil profile areally integrated | 2.6±2.5a | 3.1±3.1a | 0.43 |

* Undisturbed soil down to 15 cm in mineral soil vs mound including 15 cm of mineral soil beneath
# 0–15 cm mineral soil below the undisturbed forest floor and the mound, respectively

cy for the amount of nitrate N, but this effect was not statistically significant.

The tops of the mounds consisted of mineral soil taken from 0–10 cm of the furrows. The amount of total inorganic N in this minerogenic top part of the mounds was compared with the amount in the 0–10 cm part of the undisturbed soil profile not covered by a mound (variables 3 and 4 in Table 2). With one exception among twelve comparisons (six plots and two species of inorganic N), amounts were lower in the mineral soil on the top of mounds. The difference between these two microsites was statistically significant for total inorganic N and close for nitrate N.

When forming the mounds, a double humus layer was formed by turning the humus from the furrow upside down on top of the humus layer of undisturbed soil. This means that if conditions otherwise are similar, the humus in the bottom of the mounds ought to have twice the amount of total inorganic N as the humus layer of the undisturbed soil profile. This was corrected for in the statistical analysis and data presentation of this comparison, by reducing the values of the mound by 50%. On an average over fertiliser doses, the corrected amounts were three (total inorganic N) and 10 (nitrate N) times higher in the humus layer in the bottom of mounds than in the humus layer of undisturbed soil (variables 5 and 6 in Table 2). The difference was statistically significant for total inorganic N and close to significant for nitrate N.

The 15 cm thick mineral soil layer underlying mounds tended to have an amount of total inorganic N about twice as large as the comparable layer underlying the undisturbed forest floor (variables 7 and 8 in Table 2). A higher value occurred in five out of six plots. However, the difference was not statistically significant, even though it was very close for nitrate N.

In Table 1, areally integrated values (last column) for site preparation may be compared with values for undisturbed soil (first column) on individual plots. Expressed in this way, the differences between the two groups were relatively small and not consistently larger for the group with site preparation. The average (over fertiliser doses) amount of total inorganic N in both groups was in the range 25–30 kg $ha^{-1}$, of which nitrate N was about 3 kg $ha^{-1}$ (variables 9 and 10 in Table 2).

## 3.2 Inorganic N – Effects of N Fertilisation

Results from the ANOVA-tests are given in Table 3, where data from specific soil layers are also presented. On average for the two blocks, taking both undisturbed soil as well as mounds

**Table 3.** Effect of N fertilisation on amounts of inorganic N (kg N ha$^{-1}$) down to a depth of 15 cm in mineral soil for all variables except the humus layer – results from ANOVA (Tukey test). Mean values and SD of four replicates. Different letters following values within horizontal category denote a statistically significant difference ($p < 0.05$).

| Variable | 0N | 720N | 1800N | p-value (N dose) |
|---|---|---|---|---|
| 1. Inorganic N, soil profile* | 17±11a | 42±16ab | 74±49b | 0.03 |
| 2. Nitrate N, soil profile* | 1.5±1.5a | 2.2±1.6a | 11±7.4a | 0.08 |
| 3. Inorganic N, soil profile areally integrated | 11±6a | 32±10b | 39±14b | 0.03 |
| 4. Nitrate N, soil profile areally integrated | 0.8±0.6a | 1.4±0.5a | 6.4±1.2b | 0.02 |
| 5. Inorganic N, humus layer | 3.3±1.8a | 11±7a | 14±12a | 0.10 |
| 6. Nitrate N, humus layer | 0.02±0.01a | 0.13±0.15a | 0.36±0.43a | 0.28 |
| 7. Inorganic N, mineral soil | 9.8±5.9a | 23±9a | 45±22b | 0.02 |
| 8. Nitrate N, mineral soil | 1.3±1.5a | 1.9±1.3a | 7.4±2.0a | 0.07 |

*Average of undisturbed soil and mound with soil beneath

with underlying soil into consideration, the previously N-fertilised plots (720N and 1800N) had about two to four times larger amounts of total inorganic N than the unfertilised plots (0N) (first variable in Table 3). The effect of N fertilisation was statistically significant, but only the highest N dose (1800N) differed from the control. The relative increase was slightly larger for nitrate-N (second variable in Table 3) but, at the same time, variation within treatments was larger which is why the effect of fertilisation was not statistically significant. The amount of total inorganic N in mounds and in the underlying soil increased with N dose (Table 1). The amount of total inorganic N in the 5 cm thick layer of the bottom of the furrows was very low and independent of fertiliser dose (Table 1).

As regards the area-integrated values for the soil profile, there were statistically significant effects of fertilisation on both total inorganic N and nitrate-N (variables 3 and 4 in Table 3). Both fertiliser doses had more total inorganic N than the control, but they were not statistically separated themselves. The amount of nitrate-N was larger for the highest dose than for the control and the lower dose.

There were tendencies that both total inorganic N and nitrate N increased with fertiliser dose in the embedded humus (variables 5 and 6 in Table 3). However, the differences between N doses were not statistically significant. There was an evident effect of previous fertiliser dose on the amount of total inorganic N in the 15 cm thick mineral soil layer underneath the forest floor (variable 7 in Table 3). The highest N dose deviated significantly from the lowest N dose and the control. For nitrate N there was a similar tendency for an increase with N dose (variable 8 in Table 3) but, as for the embedded humus, the effect of fertilisation was not statistically significant.

### 3.3 Soil Moisture

Mostly there was no statistically significant influence of microsite (undisturbed soil – furrow – mound) on moisture in comparable soil layers. In the humus layer and in the three studied mineral soil layers below the original forest floor, soil moisture was nearly identical among microsites. On average, it was 54% of fresh weight in humus and 17–19% in the mineral soil. The only statistically significant effect was that the mineral soil on top of the mound was clearly drier than the corresponding mineral soil layers from where the top of the mound originated (0–10 cm depth). The water contents were 9% and 18%, respectively.

# 4 Discussion

## 4.1 Effects of Soil Scarification

The increase in the soil pool of total inorganic N following clear-felling is probably a transient phenomenon. This study was made seven years after clear-felling at a time when the pool of total inorganic N was elevated (cf. Table 1). This was also evident from continuously ongoing soil-water studies (cf. Ring 1996).

The amount of total inorganic N was larger in the mound and underlying soil than in the undisturbed soil. The increase was mainly located in the embedded humus, but also in the underlying mineral soil. The increase may be the net result of changes in both input processes (net mineralisation, transport from above) and output processes (denitrification, plant uptake and leaching downwards).

The major reason behind the increased pool of inorganic N in the embedded humus is most probably an increase in net N mineralisation. An increase in the pool of inorganic N and N mineralisation in embedded humus has earlier been shown by Lundmark and Nömmik (1984). The reason for this effect may be a more even temperature and moisture from which microbial activity may benefit, when compared with the original humus layer that is more exposed to light, precipitation and wind (cf. Örlander et al. 1990). A common explanation is also that the water content usually is higher and more optimal in the mound. In the present study, there was no difference in the water content between the embedded humus and the original humus layer. However, this information is only from one occasion and conditions may be different in other situations (cf. Kauppila and Lähde 1975). Another suggested cause of the increased amount of inorganic N and nitrate in the embedded humus is that it has a higher pH than the original humus layer (Lundmark and Nömmik 1984), a factor that normally stimulates the actual processes (Persson 1988, 1995). The reason for a higher pH would be that the humus layer is mixed with some mineral soil during scarification and that the mineral soil has a higher pH than the humus layer. In the present case there was an opposite tendency. The pH($H_2O$) was 0–0.3 units lower in the embedded humus than in the original humus layer (pH 4.5–4.8). In a Canadian study by Burgess et al. (1995), there was no difference in pH between scarified and undisturbed soil. In my case, there was a clear tendency for more nitrate in the embedded humus than in the undisturbed humus layer, even though the variation was so large that the difference was not statistically confirmed (cf. variable 6 in Table 2). The reason for such an increase, if true, obviously could not be a rise in pH as the pH was in fact somewhat lower. The lower pH might be an effect of the acidity produced through nitrate formation. A possible primary trigger of nitrification in the mounds would be a long-term elevation of ammonium, a factor known to be decisive for induction of nitrification even at rather low pH-values (cf. Nilsson et al. 1988; Persson and Wirén 1995).

A higher input from mineral soil on top of the mound seems less likely as a major explanation of the larger pool of inorganic N in the embedded humus. From Table 2 it appears that the amount of inorganic N in that particular microsite is low, pointing to a slow net mineralisation which might be the result of the conditions being dry (cf. results in this paper and by Kauppila and Lähde (1975)) and with a rapidly changing temperature (cf. Örlander et al. 1990).

Differences in the deposition of atmospheric inorganic N between scarified and undisturbed soil surfaces might be a result of differences in vegetation cover. The covers of the field layer and regeneration plants at the actual site have not been systematically studied with regard to the effect of scarification. Since the presence of a vegetation canopy in this part of Sweden normally means that N is partially retained in it, a larger amount of inorganic N in mounds would imply that plant cover is less on scarified microsites than on undisturbed microsites. This is in contrast to the subjective impression from the study clear-cut and a nearby operational clear-cut, which suggests that the scarification improves the vegetative response. This improvement is probably, to some extent, a secondary effect following an increase in N availability in the mounds. Such a response would rather decrease the inorganic N pool in the mound.

An accumulation of inorganic N in the embedded humus layer might also be the result of a reduced downward transport with percolating water. Such a decrease in transport could be caused if infiltration on top of the mound is decreased, thus causing the superficial water flow on the sides of the mound to increase. However, this explanation is, at least to some extent, contradicted by the fact that the water content was the same in the embedded humus as in the undisturbed humus layer. This similarity suggests that there are no major differences in water pathways between the mound and its surroundings.

In the mineral soil underlying the mound, a 50% increase in both inorganic N and nitrate-N was indicated. Such an increase could be caused either by a larger downward transport from the overlying humus material or increased microbial activity in the layer in question (cf. Voss-Lagerlund 1976; Palmgren 1984).

Denitrification is another N transformation process that might affect pools of inorganic N in soil, both in terms of depleting the nitrate pool and thus indirectly affecting net N mineralisation through the influence of nitrate on that process (Persson 1995). However, a previous study during the two first years after clear-felling indicated a very low denitrification at the actual site, even in cases of large N fertilisation (Nohrstedt et al. 1994). Another previous study in a N-fertilised coniferous forest also confirmed low denitrification in soil (Nohrstedt 1988b).

In conclusion, my findings as regards the effect of soil scarification support the view presented by Ring (1996) that scarification does not influence soil-water concentrations of inorganic N. Areally integrated soil pools of inorganic N, calculated over mounds, furrows and undisturbed soil, were nearly similar for partially scarified areas and areas not at all subjected to scarification. The larger pools of inorganic N, that were indicated for mounds and the underlying mineral soil, were obviously counteracted by smaller pools in furrows where the humus layer had been removed (cf. Schmidt et al. 1996).

## 4.2 Effects of N Fertilisation

On the studied clear-cut, previously N-fertilised plots had larger amounts of inorganic N in the soil than control plots. Probably, this is foremost because of the larger pool of total-N in the soil of these plots (cf. Nohrstedt 1990) and thus a larger net N mineralisation per unit area. This is more likely than qualitative changes in net N mineralisation per unit mass. Popovic (1985) and Martikainen et al. (1989) found no long-lasting effect of previous N fertilisation on net N mineralisation in humus of a fertilised stand when calculated per gram of material. However, they did not consider the fact that the amount of humus might have been elevated because of N fertilisation. If so, net mineralisation per unit of area might have been enlarged because of previous N fertilisation. This idea was supported by results in a previous report by Andersson (1997). In the present study, and considering the whole profile, there was no statistically significant difference in the amount of inorganic N between the two N doses studied. This observation is consistent with the fact that the amount of total-N in soil did not increase linearly with the amount of fertiliser N added, but rather levelled off at the highest doses (cf. Nohrstedt 1990).

There was also a tendency that the previous N fertilisation had resulted in larger amounts of nitrate-N in soil on the clear-cut. This was at least evident for the highest N dose. Nitrification may be elevated in the humus layer of forest stands where N fertiliser has been added (Popovic 1985; Aarnio and Martikainen 1992). There are few reports on the effect of previous N fertilisation on N transformations after the stand has been cut. However, Ring (1996) and Berdén et al. (1997) report on elevated N leaching, mainly in the form of nitrate, after clear-felling of previously heavily N-fertilised coniferous stands in central Sweden. Contradictory to these findings, Paavolainen and Smolander (1998) found in studies on a clear-cut in south Finland that the potential nitrification (per volume) was lower in humus that had previously been N fertilised (860 kg N ha$^{-1}$) than in control humus. For net N mineralisation, the rate was, however, slightly higher in N-amended humus. The Finnish study was made on a more fertile forest site (*Oxalis-Myrtillus*-type) than the two Swedish studies (lichen type and dwarf-shrub type, respectively) and this difference in site fertility might influence the effect of the previous N addition.

The clear-cut was replanted in 1989, which was five years prior to this study. The growth of these plants might significantly affect the pools of inorganic N in soil and contribute to differences between N treatments. However, during the years between planting and this study the plants had developed very slowly and there was no effect of the previous N fertilisation (Nohrstedt and Lundström 1995). That study only considered plants growing in undisturbed soil, and not on the mounds or in the furrows created locally around the lysimeters. The field-layer vegetation might also possibly affect pools of inorganic N and contribute to differences between N treatments. The ground vegetation was analysed before clear-felling. The field-layer was found to be dominated by *Vaccinium*-species and their cover increased with increasing previous N dose (Kellner 1993). Shortly after clear-felling, the ground vegetation of the closed forest totally vanished. Later on, the clear-cut has only very slowly been revegetated by field-layer and bottom layer species. Their abundance has not been systematically examined, but a subjective impression at the time of this study was that there were no obvious differences between N treatments.

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