# Respiration in a Forest Soil 27 Years after Fertilization with Different Doses of Urea

Hans-Örjan Nohrstedt and Gunnar Börjesson

**Nohrstedt, H.-Ö. & Börjesson, G.** 1998. Respiration in a forest soil 27 years after fertilization with different doses of urea. Silva Fennica 32(4): 383–388.

A number of previous studies have shown that N fertilization often reduces respiration in forest soils. However, the durability of this effect has not been fully explored. In this study, the response of soil respiration to a single fertilization with urea, applied 27 years earlier, was examined in a field experiment located in a stand of *Pinus sylvestris* in central Sweden. The doses that had been added were 120, 240 and 600 kg N $ha^{-1}$. Samples were taken from the humus layer and the upper 7.5 cm of the mineral soil. Sieved samples were incubated in the laboratory. No effect of the previous fertilization on soil respiration was found, thus indicating that the reduction shown in earlier studies is not persistent. There was a tendency that the highest N dose had caused a higher N concentration and a lower C/N-ratio in the humus layer and a higher C concentration in the mineral soil.

**Keywords** carbon mineralization, humus, mineral soil, *Pinus sylvestris* L., podzol
**Authors' addresses** *Nohrstedt*, The Forestry Research Institute of Sweden, Uppsala Science Park, S-751 83 Uppsala, Sweden; *Börjesson*, Department of Microbiology, Swedish University of Agricultural Sciences, P.O. Box 7025, S-750 07 Uppsala, Sweden
**Tel** +46 18 188 546 **E-mail** hans-orjan.nohrstedt@skogforsk.se
**Received** 14 April 1998 **Accepted** 5 October 1998

## 1 Introduction

Fertilization of forests with N causes a long-lasting reduction in soil respiration (Bååth et al. 1981, Nömmik and Möller 1981, Söderström et al. 1983, Martikainen et al. 1989, Nohrstedt et al. 1989). This has been shown for most N fertilizers that have been used in forestry. Urea may cause increases in soil respiration initially (Salonius and Mahendrappa 1975, Söderström et al. 1983), but the long-lasting effect is a reduction of the same size as for ammonium nitrate (Bååth et al. 1981, Nohrstedt et al. 1989). The size of the reduction in activity decreases with site productivity and may be absent on the most productive sites (Martikainen et al. 1989, Arnebrant et al. 1996).

The cause behind the reduction has not yet been revealed. The turnover rate of organic matter is regulated by the environment, organisms and substrate quality. Important environmental conditions, such as moisture and pH do not differ substantially between fertilized and unfertilized soil (Nohrstedt 1990, 1992). The ratio between C and N is often somewhat lower in the fertilized soil (Popovic 1985, Nohrstedt 1990), but such a difference ought to cause higher activity in this soil compared with the control soil (cf. Nohrstedt 1985). A lower availability of phosphorus following fertilization (Nohrstedt 1992, Jacobson and Nohrstedt 1993) may reduce microbial activity (cf. Amador and Jones 1993). It has also been suggested that the lower respiration in fertilized soil may be caused by a lower outflow from tree roots of easily decomposable exudates (Nohrstedt et al. 1989). This hypothesis was, however, questioned by Persson and Wirén (1989). Changes in the saprophytic microfungal community following fertilization have been reported (Arnebrant et al. 1990) and may hypothetically influence the turnover rate of organic matter.

In earlier studies, different periods of time have elapsed between fertilizer application and activity measurement, ranging from immediately after, to several years later. The studies by Martikainen et al. (1989) and Nohrstedt et al. (1989) are those considering the longest time between fertilization and measurement. In the first study, 7 or 14 years had elapsed, and in the second study 11 years. Despite the pronounced number of years, the biological activity in soil was most often reduced. Is there a possibility that the reduction is irreversible? Such an effect would be especially important when assessing the environmental consequences of N fertilization. The study presented below was aimed as a contributing answer to this question and used a field experiment in which N fertilization was done only once 27 years earlier.

## 2 Material and Methods

The field experiment is situated at 395 m a.s.l. about 20 km NW from the municipality of Sveg, in the province of Härjedalen, central Sweden (62°9'N 14°9'E). The stand is 120 years old and consists of *Pinus sylvestris* L. regenerated after a forest fire. The site index according to Hägglund and Lundmark (1988) is T18. The ground vegetation is dominated by dwarf shrubs and reindeer lichens. The soil type is a podzol (national classification, cf. Troedsson and Nykvist 1974) that has developed on an unwashed sandy-silty till. The humus layer is 3 cm thick and the eluvial layer 6 cm. The site is described in detail by Nohrstedt (1988a).

Fertilization with urea was performed during the summer of 1968. Several doses were included. Those examined in this study were 120, 240 and 600 kg N $ha^{-1}$. The experiment comprised two replicates (blocks) and treatment plots were 40 m × 40 m.

Soil samples were taken during three consecutive days in the middle of June 1995. On each study plot, 25 systematically distributed subsamples were taken from the humus layer and from 0–7.5 cm of mineral soil using a steel corer, 7 cm diameter for humus layer and 2.7 cm for mineral soil. All subsamples from one layer within an individual plot were pooled into a composite sample. The soil samples were stored cooled from sampling to incubation: in the field in a hole dug in the ground, during transportation in an insulated box, and finally in the laboratory in a room with a constant temperature of 2–3 °C. The humus layer samples were passed through a 5.6-mm sieve and the mineral soil samples through a 4-mm sieve.

The incubation was initiated within one week after the start of the soil sampling in the field. Between five and seven g fresh weight of soil were put into glass flasks (Duran, 134 ml), one per plot and horizon. After aeration for 15–30 minutes, the flasks were closed by gastight butyl stoppers. An extra volume of 30 ml air was inserted into the flasks to facilitate gas sampling and to check for gas leakage. The incubation was done at 15 °C for 12 hours. Respiration was measured as production of carbon dioxide, which was analyzed on a gas chromatograph (Carlo Erba model 2350; Chrompack micro-TCD) (Börjesson and Svensson 1997). Every second hour, a 1-ml gas sample was removed and immediately injected on the gas chromatograph. Carbon dioxide accumulated linearly ($r > 0.99$)

and the respiration rates were calculated as the slope obtained from the regression analysis.

The respiration was expressed on the basis of the dry weight of the soil and also in relation to soil C. Dry weight was determined gravimetrically after drying over-night at 80 °C for humus layer and 105 °C for mineral soil. Soil total C and N were examined on an elemental analyzer (Carlo Erba, elemental analyzer NA 1500) by quantitative analyses of gaseous C- and N-oxides formed during dry combustion. Nitrogen was only determined in the humus layer.

Using SAS, the resulting data were statistically analyzed with a conventional ANOVA including treatment (fertilizer dose) and block as independent, classified variables. The possible differences between individual treatments were tested according to Tukey.

# 3 Results

The fertilization with N had no statistically significant effect on soil respiration, either on a d. w. basis, or on a C basis ($p = 0.08–0.9$). In the humus layer, the average respiration over all plots was 1.1 moles $CO_2$ (g d. w.)$^{-1}$ h$^{-1}$ or 3.0 moles $CO_2$ (g C)$^{-1}$ h$^{-1}$ (Fig. 1). On a C basis, five out of six N-fertilized plots had a higher respiration than the control plots.

In the mineral soil, the respiration was, on average, 0.10 moles $CO_2$ (g d. w.)$^{-1}$ h$^{-1}$ or 5.6 moles $CO_2$ (g C)$^{-1}$ h$^{-1}$ (Fig. 2). This means that the respiration on a C basis was higher in the mineral soil than in the humus layer.

The moisture of the soil samples did not differ between treatments, either in humus layer ($p = 0.76$), or in mineral soil ($p = 0.27$). The water

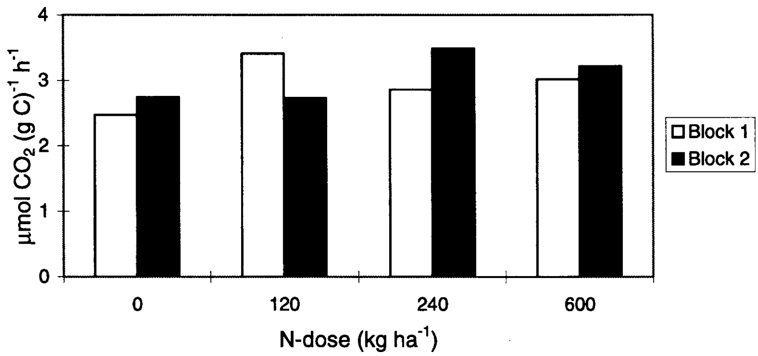


**Fig. 1.** Respiration in samples from the humus layer, expressed on C basis.

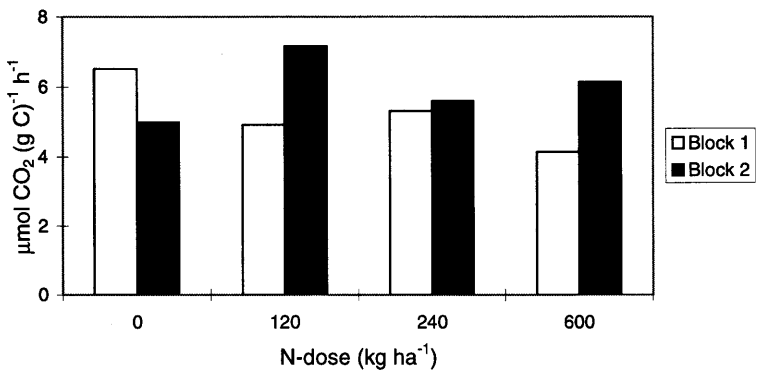


**Fig. 2.** Respiration in the mineral soil 0–7.5 cm, expressed on C basis.

**Table 1.** Water content, C- and N-concentration, and C/N-ratio in soil.

| Variable | Soil layer | Block | 0N | 120N | 240N | 600N |
|---|---|---|---|---|---|---|
| Water (% FW) | Humus | 1 | 67.1 | 55.8 | 64.8 | 64.3 |
| | | 2 | 67.3 | 69.6 | 66.7 | 68.1 |
| | Mineral soil | 1 | 17.8 | 19.9 | 15.2 | 19.1 |
| | 0–7.5 cm | 2 | 17.0 | 17.7 | 17.3 | 19.2 |
| C-conc. (% DW) | Humus | 1 | 35.8 | 24.7 | 40.9 | 33.8 |
| | | 2 | 45.2 | 42.5 | 38.1 | 41.9 |
| | Mineral soil | 1 | 1.78 | 1.79 | 1.29 | 2.06 |
| | 0–7.5 cm | 2 | 1.54 | 1.62 | 1.57 | 2.28 |
| N-conc. (% DW) | Humus | 1 | 0.88 | 0.57 | 0.90 | 1.01 |
| | | 2 | 0.90 | 1.10 | 0.85 | 1.18 |
| C/N-ratio | Humus | 1 | 40.9 | 43.0 | 45.4 | 33.5 |
| | | 2 | 50.2 | 38.6 | 45.0 | 35.5 |

content was, on average, 65 % of fresh weight in humus and 18 % in mineral soil (Table 1).

The fertilization had no statistically significant effect on the C concentration in the humus layer ($p = 0.70$). It was 38 % d. w. on average for all plots (Table 1). One plot, 120N in block 1, deviated substantially from the other with a C concentration of 25 %. In the mineral soil, both plots receiving the highest N dose (600N) tended to have a higher C concentration than the control, although not significantly different ($p = 0.10$). The C concentration was 2.1–2.3 % d. w. on the 600N plots and 1.3–1.8 % d. w. on the other plots.

The treatment effect as regards N the concentration in the humus layer was far from being statistically significant ($p = 0.56$). Both plots given the highest fertilizer dose tended to have a higher N concentration than most of the remaining plots (Table 1). On average for both blocks, the plots with the highest N dose had a N concentration of 1.1% d. w., which may be compared with 0.8–0.9 for the other N doses. However, the two 120N plots differed substantially. As also found for the C concentration, the 120N-plot in block 1 had a remarkably low N concentration, 0.57 % d. w.

There was also a tendency ($p = 0.18$) that the plots with the highest N dose had a lower C/N-ratio than the other plots, 33.5–35.5 compared with, on average, 44.

# 4 Discussion

We were unable to show an effect on soil respiration of N fertilization performed 27 years ago. Thus, the reduction shown to occur for at least 11–14 years after fertilization in previous studies does not seem to be persistent. The prevailing reduction in respiration may be caused by changes in both substrate and environmental factors. N-fertilized needles have a lower weight loss than unfertilized needles in the long run (Berg et al. 1982). At the study site in question, the last needles that were influenced by the fertilization probably fell to the ground in the early 1980's. The annual weight loss of needles in Sweden is 20–30 % (Berg 1991). Thus, at the soil sampling in 1995, only a small part of the N-influenced litterfall ought to have been remaining in the forest floor. However, a reduction in soil respiration is most probably also an effect of an external environmental factor (cf. Nohrstedt et al. 1992). A reduction has been induced in the laboratory in the absence of plants, and in field studies occurs in deeper soil layers soon after fertilization. The external factor may be a change in soil chemistry and/or a related change in microbial populations. Obvious immediate chemical changes in the forest floor after a single N fertilization are not especially longlasting. The concentration of inorganic N has normally reached background levels within a year (Melin

1986, Nohrstedt 1988b). However, a change in species composition has been shown for both mycorrhizae and saprophytic microfungi several years after a single N dose of 600 kg ha$^{-1}$ (Arnebrant et al. 1990, Arnebrant 1991). Since we did not find an effect on soil respiration 27 years after fertilizer application, it is possible that changes in species composition of the microbial community have also levelled off.

The concentration of C is an important predictor for respiration per unit weight of soil (Nohrstedt 1985). When the influence of other environmental factors is examined it is therefore often suitable to express soil respiration on a C basis. In the study presented here, we were unable to prove an influence of the fertilization on the C concentration in soil. In a previous study after repeated N fertilization, an increase was shown for C concentration in humus layer, but not in mineral soil (Nohrstedt 1992).

Repeated N fertilization often causes a clear increase in the N concentration of the humus layer (Nohrstedt 1990, 1992). A large part of a fertilizer dose is retained in the upper part of the soil profile without being assimilated by plants (Melin 1986, Mälkönen et al. 1990). The result is an increased N concentration and decreased C/N-ratio (cf. Popovic 1985). The reduction in respiration that often follows a fertilization with N acts in the opposite direction, i.e. to increase the C/N-ratio, but the effect is too small to counteract the overall reduction in C/N-ratio. In the present study, we were unable to demonstrate a change in N concentration and C/N-ratio. In contrast to other studies, N fertilization had been done only once, several years earlier. For the highest N dose, there were however some clear tendencies in the expected direction.

## Acknowledgements

The study was partially financed by the Foundation of Swedish Plant Nutrition Research. The soil samples were taken by Eva Ring and Sten Nordlund at the Forestry Research Institute of Sweden.

## References

Amador, J.A. & Jones, R.D. 1993. Nutrient limitations on microbial respiration in peat soils with different total phosphorus content. Soil Biology and Biochemistry 25: 793–801.

Arnebrant, K. 1991. Effects of forest fertilization on soil microorganisms. University of Lund, Department of Ecology. Dissertation. ISBN 91-7105-016-7.

— , Bååth, E. & Söderström, B. 1990. Changes in microfungal community structure after fertilization of Scots pine forest soil with ammonium nitrate or urea. Soil Biology and Biochemistry 22: 309–312.

— , Bååth, E., Söderström, B. & Nohrstedt, H.-Ö. 1996. Soil microbial activity in eleven Swedish coniferous forests in relation to site fertility and nitrogen fertilization. Scandinavian Journal of Forest Research 11: 1–6.

Bååth, E., Lundgren, B. & Söderström, B. 1981. Effects of nitrogen fertilization on the activity and biomass of fungi and bacteria in podzolic soil. Zentralblatt für Bakteriologie und Hygiene, I. Abt. Orig. C2: 90–98.

Berg, B. 1991. Klimatförändringar kan ge större humusmängd i skogsmark. Swedish University of Agricultural Sciences, Skogsfakta No. 10. Uppsala. 4 p. (In Swedish.)

— , Wessén, B. & Ekbohm, G. 1982. Nitrogen level and decomposition in Scots pine needle litter. Oikos 38: 291–296.

Börjesson, G. & Svensson, B.H. 1997. Seasonal and diurnal methane emissions from a landfill and their regulation by methane oxidation. Waste Management & Research 15: 33–54.

Hägglund, B. & Lundmark, J.-E. 1981. Handledning i bonitering med Skogshögskolans boniteringssystem. National Board of Forestry, Jönköping, Sweden. 124 p. ISBN 91-857448-14-5. (In Swedish.)

Jacobson, S. & Nohrstedt, H.-Ö. 1993. Effects of repeated nitrogen supply on stem growth and nutrients in needles and soil. The Foresty Research Institute of Sweden, Report 1, Uppsala. 36 p.

Mälkönen, E., Derome, J. & Kukkola, M. 1990. Effects of nitrogen inputs on forest ecosystems – estimation based on long-term fertilization experiments. In: Kauppi, P., Anttila, P. & Kenttämies, K. (eds.). Acidification in Finland. Springer Verlag, Berlin–Heidelberg. p. 325–347. ISBN 3-540-52213-1.

Martikainen, P.J., Aarnio, T., Taavitsainen, V.-M., Päivinen, L. & Salonen, K. 1989. Mineralization of carbon and nitrogen in soil samples taken from three fertilized pine stands: long term effects. Plant and Soil 114: 99–106.

Melin, J. 1986. Turnover and distribution of fertilizer nitrogen in three coniferous ecosystems in central Sweden. Swedish University of Agricultural Sciences, Department of Forest Soils, Reports in Forest Ecology and Forest Soils 55. Uppsala. 122 p. ISBN 91-576-2800-9.

Nohrstedt, H.-Ö. 1985. Biological activity in soil from forest stands in central Sweden, as related to site properties. Microbial Ecology 11: 259–266.

— 1988a. The forest fertilization experiment D164 Billingsjön – a description. The Institute for Forest Improvement, Report 7. Uppsala. 13 p.

— 1988b. Effect of liming and N-fertilization on denitrification and $N_2$-fixation in an acid coniferous forest floor. Forest Ecology and Management 24: 1–13.

— 1990. Effects of repeated nitrogen fertilization with different doses on soil properties in a Pinus sylvestris stand. Scandinavian Journal of Forest Research 5: 3–15.

— 1992. Soil chemistry in a Pinus sylvestris stand after repeated treatment with two types of ammonium nitrate fertilizer. Scandinavian Journal of Forest Research 7: 457–462.

— , Arnebrant, K., Bååth, E. & Söderström, B. 1989. Changes in carbon content, respiration rate, ATP content, and microbial biomass in nitrogen-fertilized pine forest soils in Sweden. Canadian Journal of Forest Research 19: 323–328.

— , Arnebrant, K. & Palmér, C.H. 1992. Skogsgödsling påverkar markens biologiska aktivitet. The Institute for Forest Improvement, Information Växtnäring – skogsproduktion No. 2 1991/92. Uppsala. 4 p. (In Swedish.)

Nömmik, H. & Möller, G. 1981. Nitrogen recovery in soil and needle biomass after fertilization of a Scots pine stand, and growth responses obtained. Studia Forestalia Suecica 159: 1–37.

Persson, T. & Wirén, A. 1989. Microbial activity in forest soils in relation to acid/base and carbon/nitrogen status. In: Brække, F.H., Bjor, K. & Halvorsen, B. (eds.). Air pollution asstress factors in the Nordic forests. Meddelelser fra Norsk Institutt for Skogforskning 42: 83–94.

Popovic, B. 1985. The effect of nitrogenous fertilizers on the nitrification of forest soils. Fertilizer Research 6: 139–147.

Salonius, P.O. & Mahendrappa, M.K. 1975. Microbial respiration and exchangeable ammonium in podzol organic horizon materials treated with urea. Canadian Journal of Forest Research 5: 731–734.

Söderström, B., Bååth, E. & Lundgren, B. 1983. Decrease in soil microbial activity and biomasses owing to nitrogen amendments. Canadian Journal of Microbiology 29: 1500–1506.

Troedsson, T. & Nykvist, N. 1974. Marklära och markvård. Almqvist & Wiksell, Uppsala. 403 p. ISBN 91-20-05544-7. (In Swedish.)

*Total of 26 references*