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Short communication

Soil CH_4 oxidation: response to forest clearcutting and thinning

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We measured CH_4 flux rates for temperate forest soils, with adjacent intact and recently felled areas, to test the hypothesis that net soil CH_4 consumption would be reduced after felling. The results showed that while clearcutting reduced net CH_4 consumption, thinning actually increased the rate of net soil CH_4 consumption. The effects on CH_4 consumption appeared to be linked to changes in soil N cycling or pH following felling. In well-drained soils, such as the ones studied, the soil CH_4 flux will be the resultant of CH_4 oxidation and CH_4 production within the soil profile. As the soils were net CH_4 consumers over the course of this experiment, CH_4 oxidation dominated production and this is typical for such well-drained forest soils (Conrad, 1995).

Temperate forest soils are a major sink for atmospheric CH_4 and conversion to other land-use (e.g. pasture) has been associated with reductions in net soil CH_4 consumption (Dobbie and Smith, 1996). However, the immediate effects of forest clearcutting on CH_4 flux have been largely ignored, despite the increases in soil mineral N concentrations frequently observed in recently clearcut areas (Martikainen, 1996; Smolander et al., 1998) and the widely reported inhibition of CH_4 oxidation by elevated soil inorganic N, e.g. Steudler et al. (1989). Indeed, the few studies on the effects of clearcutting on CH_4 uptake, conducted in tropical systems (Keller et al., 1986; Steudler et al., 1991) and in drained spruce mires (Nieminen et al., 1996), have noted a reduction in net CH_4 uptake and suggested a link to disturbance effects in the N cycle. Steudler et al. (1991) reported that the generality of the reduction in soil CH_4 uptake following tropical forest cutting could not be evaluated because there had been too few studies; this is even more applicable to temperate systems.

The investigation was carried out at Grizedale Forest, UK (NGR SD 340930). Six sites were used, located in pairs adjacent to each other and forested with the same single species, planted in the same year and on the same soil type but with different recent cutting (Table 1). The soils were freely draining brown earths, classified as Manod series and within the Denbigh 1 (oak) or Manod (larch and beech) Associations (Jarvis et al., 1984).

Three intact soil cores (15 cm diameter) were collected on 21 May 1998 in PVC piping (25 cm deep) from each site; three additional soil samples from the H and mineral horizon were taken to determine soil pH (following Grimshaw, 1989) and gravimetric weight. The cores were returned to the laboratory where soil CH_4, N_2O and CO_2 fluxes were determined using an open chamber technique. Chambers consisted of the PVC soil core cylinders sealed at the base and capped with a Perspex lid. External ambient air, supplied via a single mixing-chamber to ensure all cores received input air with the same trace gas concentrations, was drawn through the chamber headspaces at 50 cm^3 min^{-1}. The gas stream was automatically monitored for trace gas concentrations by gas chromatography; for a full description of the gas analysis and data storage, see Ineson et al. (1998). Soil cores from the same tree species were always monitored simultaneously and, because soil water status is an important determinant of soil CH_4

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Table 1
Tree species and management at Grizedale Forest

Tree species	Year planted	Adjacent management comparisons
Beech (*Fagus sylvatica* L.)	1939	Undisturbed and clearcut November 1997
Japanese larch (*Larix kaempferi* Carrière)	1957	Undisturbed and clearcut October 1997
Oak (*Quercus robur* L.)	na[a]	No thinning for 40 years and thinned May 1997

[a] Not applicable: site is ancient semi-natural woodland.

uptake rates (Gulledge and Schimel, 1998), cores were re-monitored after soil water was standardised. To standardise soil water status, cores were brought to field capacity using deionised water additions and equilibrated for four days.

All data analyses and statistical comparisons were performed using SAS (SAS Institute, 1988). Repeated measures ANOVA were used to analyse for felling effects on trace gas fluxes, while *t*-tests were used to compare soil pH (as μeq H^+ l^{-1}) and gravimetric water content. Flux data were pooled to determine the effects of wetting soil cores (paired *t*-test) and for correlation and multiple-regression analysis to assess relationships between trace gas fluxes. Non-parametric data (N_2O fluxes) were $\log_{10}$-transformed (for paired *t*-test) or ranked (for ANOVA).

All soils displayed net CH_4 oxidation and this was significantly reduced ($P < 0.05$) in the clearcut plots but significantly increased ($P < 0.05$) by thinning (Fig. 1a). The decrease in CH_4 uptake for clearcut sites is consistent with the observations by Keller et al. (1986) and Steudler et al. (1991) for tropical forests and by Nieminen et al. (1996) for drained spruce mires. The effects were maintained after soil water status was standardised, suggesting that factors other than varying soil water content were responsible. As expected, wetting significantly decreased ($P < 0.001$) net soil CH_4 oxidation (Fig. 1a). Values for CH_4 consumption at the sites were comparable to reported values for other temperate forest soils (Crill, 1991; Priemé and Christensen, 1997).

Nitrous oxide release increased after clearcutting, as has been commonly observed (e.g. Paavolainen and Smolander, 1998), and decreased after thinning (Fig. 1b). As N_2O production rates are commonly correlated with soil solution NO_3^- concentrations (e.g. Melillo et al., 1983), the changes in N_2O production after felling were taken to indicate similar changes in soil NO_3^- concentrations (see Steudler et al., 1991). Given the observed inhibition of CH_4 oxidation by elevated NO_3^- in similar soils (Bradford, unpublished Ph.D. Thesis, Exeter University, 1999), it is hypothesised that changes in soil NO_3^- concentrations after felling caused the observed changes in soil CH_4 uptake. In support of this, there was a significant negative correlation between N_2O release and CH_4 uptake across all sites ($P < 0.001$; $r^2 = -0.60$).

Soil moisture and pH did not significantly differ ($P > 0.05$) between cut and uncut sites, except pH for the beech sites (Table 2). The drop in pH might have contributed to the inhibition of net CH_4 consumption in the clearcut beech soils because the pH dropped below the pH optima for CH_4 oxidation in acidic soils (Dunfield et al., 1993; Bender and Conrad, 1995; Dedysh et al., 1998). Changes in other factors, such as increased soil bulk density through soil compaction during cutting, may also have contributed to the observed decrease in net CH_4 consumption, as shown by Han-

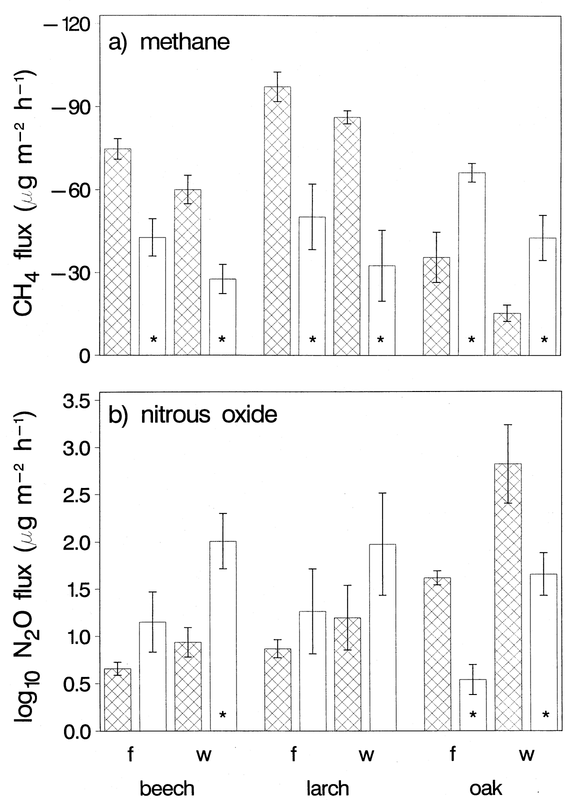

Fig. 1. CH_4 (a) and N_2O (b) fluxes for soils from uncut (cross-hatched bars) and cut (empty bars) woodlands of beech, larch and oak. Harvested soil cores were monitored fresh (f) and after wetting (w) to field capacity. The oak "cut" site was thinned and the beech and larch "cut" sites were clearcut. Rates are means ± 1 SEM (n = 3). $*$ denotes significant differences within pairs ($P < 0.05$).

Table 2
Acidity (pH) and moisture content (% moisture) of fresh collected soil from uncut and cut[a] forest sites ($n = 3$)

Tree species	Beech				Larch				Oak			
Horizon (H: Organic; M: Mineral)	H		M		H		M		H		M	
Uncut (U)/cut (C)	U	C	U	C	U	C	U	C	U	C	U	C
pH	4.2	3.7[b]	4.1	3.9[b]	4.0	3.8	3.8	3.4	3.8	3.8	3.6	4.1
Soil moisture ± SEM (%)	54 ± 3	55 ± 3	39 ± 1	39 ± 2	47 ± 4	67 ± 8	33 ± 3	44 ± 7	65 ± 5	61 ± 5	37 ± 3	33 ± 1

[a] Oak "cut" was thinning of the woodland but was clearcutting for the beech and larch.
[b] Significant difference between uncut and cut site variable ($P < 0.05$).

sen et al. (1993) after soil compaction by tractor traffic.

Changes in CH_4 production were assumed to have contributed little to the observed changes in net soil CH_4 oxidation after felling, due to the low methanogenic potential of similar forest soils (Bradford, loc. cit.). The lack of consistent effects of felling on net CO_2 production suggested that the activity of the overall soil microbial community was not affected.

This study showed that two clearcut sites had reduced net CH_4 consumption in laboratory incubated soils but that thinning at a third site increased net CH_4 consumption. Thus, felling can have marked effects on forest soil CH_4 flux and these effects appear to be directly or indirectly mediated through changes in soil N cycling or pH. The effects of felling on greenhouse gas fluxes should be considered when planning forest management and developing greenhouse gas budgets for specific land-uses.

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