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Short-term effects of clearfelling on soil CO_2, CH_4, and N_2O fluxes in a Sitka spruce plantation

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Abstract

We examined the effects of forest clearfelling on the fluxes of soil CO_2, CH_4, and N_2O in a Sitka spruce (*Picea sitchensis* (Bong.) Carr.) plantation on an organic-rich peaty gley soil, in Northern England. Soil CO_2, CH_4, N_2O as well as environmental factors such as soil temperature, soil water content, and depth to the water table were recorded in two mature stands for one growing season, at the end of which one of the two stands was felled and one was left as control. Monitoring of the same parameters continued thereafter for a second growing season. For the first 10 months after clearfelling, there was a significant decrease in soil CO_2 efflux, with an average efflux rate of 4.0 g m^{-2} d^{-1} in the mature stand (40-year) and 2.7 g m^{-2} d^{-1} in clearfelled site (CF). Clearfelling turned the soil from a sink (-0.37 mg m^{-2} d^{-1}) for CH_4 to a net source (2.01 mg m^{-2} d^{-1}). For the same period, soil N_2O fluxes averaged 0.57 mg m^{-2} d^{-1} in the CF and 0.23 mg m^{-2} d^{-1} in the 40-year stand. Clearfelling affected environmental factors and lead to higher daily soil temperatures during the summer period, while it caused an increase in the soil water content and a rise in the water table depth. Despite clearfelling, CO_2 remained the dominant greenhouse gas in terms of its greenhouse warming potential.

Keywords: Clearfelling; Soil CO_2 efflux; Soil N_2O flux; Soil CH_4 flux; Sitka spruce

1. Introduction

Forest clearfelling is the management practice used most frequently for timber harvesting worldwide. It can have a significant effect on soil CO_2, CH_4, and N_2O fluxes by altering environmental factors (Pyatt et al., 1985; Frazer et al., 1990; Adams et al., 1991) which have an effect on these fluxes, such as soil temperature (Dunfield et al., 1993; Lloyd and Taylor, 1994; Kätterer et al., 1998; Howard and Howard, 1993; Kirschbaum, 1995; Davidson et al., 1998), soil water content (Singh and Gupta, 1977; Goodroad and Keeney, 1984; Schlentner and Van Cleve, 1985; Carlyle and Than, 1988) and depth to the water table (Huttunen et al., 2003; Liblik et al., 1997). Other factors that influence trace gas fluxes include root activities (Bowden et al., 1993; Raich and Tufekgcioglu, 2000), decomposition of organic matter (Binkley, 1986; Hendrickson et al., 1989), availability of substrate (Sahrawat and Keeney, 1986; Skiba and Smith, 2000), soil N dynamics (Vitousek and Matson, 1985; Smolander et al., 1998). These factors can also change after clearfelling (Vitousek and Matson, 1985; Steudler et al., 1991) as tree harvesting results in large amounts of residues, litter and dying tree roots, which are easily decomposed. Furthermore, compaction of the soil by heavy equipment decreases the soil macroporosity and causes reduction in air diffusion and water infiltration rates (Pritchett, 1979), thus, increasing the soil water content and consequently causing the soil environment to become more anaerobic, also influencing fluxes.

A number of studies have compared soil CO_2 efflux under different forest management practices, including clearfelling. The pattern of soil CO_2 efflux reported after clearfelling is not the same in all studies. In some cases it has been reported to increase (Ewel et al., 1987a; Gordon et al., 1987; Hendrickson and Robinson, 1984), in some to decrease (Weber, 1990; Nakane et al., 1986), while non-significant effects have also been reported

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(Fernandez et al., 1993). The magnitude and direction of change in soil CO_2 efflux depends on whether or not litter and organic layers were removed, roots disturbed and mineral soil horizons exposed or mixed (Buchmann, 2000), on the rates of C input to soil from the logging residues and the response of soil microbial biomass to micro-climatic conditions created after the removal of trees. All these responses can differ among ecosystems. Also, the different types of harvesting machines used in each occasion can cause different degrees of disturbance to the soil. Additionally, soil CO_2 efflux has been measured at different times since clearfelling from study to study. For example, Nakane et al. (1986) started measuring soil CO_2 flux in a red pine (*Pinus densiflora*) plantation 3 months after clearfelling, while Gordon et al. (1987) measured soil CO_2 efflux in a white spruce (*Picea glauca*) forest in Alaska 3 and 4 years after clearfelling. Depending on the time since clearfelling, the contributions from decomposing roots and litter, invading grasses on the site or the re-planting of trees will differ and so will the soil CO_2 efflux.

The effects of clearfelling on soil CH_4 fluxes have not been extensively studied. It has generally been reported that clearfelling of temperate forests causes a reduction in CH_4 uptake (Steudler et al., 1989; Bradford et al., 2000). A shift of the soil from a sink to a source has been reported by Castro et al. (2000) who measured CH_4 fluxes in two slash pine plantations in Florida before and after clearfelling. They found that, although the soils were CH_4 sinks before clearfelling, they became a CH_4 source after clearfelling.

Clearfelling affects soil N_2O fluxes by altering the rates of nitrification and denitrification. Dutch and Ineson (1990) measured increased denitrification during the first 2 years after clearfelling of a Sitka spruce forest on peaty gley soil, in Northern England. On the other hand, Smolander et al. (1998) found increased nitrification after clearfelling of unfertilised plots of a Norway spruce stand in Finland, while before clearfelling, nitrification occurred only in the plots that had been fertilised. Paavolainen and Smolander (1998) confirmed the same trend as Smolander et al. (1998) for the third summer after clearfelling.

Commercial forestry represents a large land use category in Britain and during the period 1950–1980s about 315,000 ha of peaty gley soils were drained, ploughed and planted with coniferous forests, mostly Sitka spruce (*Picea sitchensis* (Bong. Carr.) (Hargreaves et al., 2003). As soils have a vital role to play as a sink or source for C at the global scale and in offsetting atmospheric trace gas concentrations, it is important to evaluate accurately the effects of forest management on soil C storage and trace gas emissions to the atmosphere. This is particularly the case for forestry activities carried out on organic-rich soils, which can be more sensitive to clearfelling than mineral soils. Organic-rich soils are expected to have particularly high rates of nitrogen mineralisation and nitrification, leading to denitrification process as well, after clearfelling. Despite this interest, they have seldom been studied (e.g. Huttunen et al., 2003). Here, we report on the short-term effects of clearfelling on soil CO_2, CH_4, and N_2O fluxes and related environmental factors (soil temperature, soil water content and depth to the water table) in a Sitka spruce plantation on peaty gley soil, in N.E. England.

2. Materials and methods

2.1. Site description

The study area is located in Harwood Forest, Northumberland, N.E. England (55° 10′ N, 2° 3′ W), 30 km inland from the North Sea coast. The size of the forest is approximately 4000 ha and its elevation varies from 200 to 400 m a.s.l. The average annual rainfall is about 950 mm. The establishment of the forest started in the 1930s and now Sitka spruce stands of several different ages dominate the area. The previous land cover was grassland (upland rough pasture). The forest is managed with rotations of about 40 years, the cycle being determined by the age at which risk of windthrow becomes unacceptably high (mean annual increment peaks at about 60 years of age). At this age, a whole stand is clearfelled and re-planting takes place after 2–3 years. The dominant soil type is peaty gley, i.e. a seasonally waterlogged soil with a black-coloured, organic-rich O_L layer of depth variable between about 15 and 40 cm. The experimental sites were identified from stock and soil maps. There was no understorey vegetation in the forest stands after canopy closure. After clearfelling, grasses, sedges and rushes (*Juncus* sp., *Deschampsia* sp., *Molinia caerulea*, *Holcus mollis*) started invading the site towards the end of the summer and when grasses grew within the collars or chambers, they were clipped.

Two mature stands, both 40-year-old (in 2001), of Sitka spruce on peaty gley soil were chosen. In each stand, a 30× 30 m plot was established. Measurements took place from June 2001 till December 2002. One of the stands was kept intact throughout the study period, as the control (from now on 40-year), whereas the other was clearfelled in February 2002 (from now on CF_{before} and CF, before and after clearfelling, respectively). The stands were about 1000 m apart. The most important features of the two stands are given in Table 1. Additional data with regard to soil properties can be found in Zerva and Mencuccini (2005).

In January 2002, just prior to clearfelling, a strong windstorm blew down many of the trees within the CF_{before}. The remaining trees were felled with mechanised harvesters soon after. These machines have a mechanically operated harvesting head that fells a tree, de-limbs it, and transfers the logs to a specially extended rear frame. The machine then carries them out of the forest. After felling a tree, the harvester places all the limbs directly in front of it, so when the machine moves forward, it rides on these limbs, to reduce soil compaction. The brash resulting from felling large branches is finally bulked into large heaps to make