Impacts of nitrogen additions and harvest residue management on chemical composition of soil carbon in a plantation forest

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Abstract
Soils are the major pool of terrestrial C globally that, if carefully managed, can be used to offset rising atmospheric CO_2. An important consideration for the forestry sector is how forest management practices might impact on the forest soil C stock. An experiment has been set up to determine how long-term fertilisation and harvest residue management will affect soil C stocks and the relative abundance of biochemically resistant compounds in soil organic C. The early results suggested that soil C concentration has not been affected by fertilisation and harvesting methods. The following results were achieved in the light fraction of soil organic matter (SOM): long-term fertilisation increased alkyl C and alkyl-to-O-alkyl ratio; the abundance of cutin-derived compounds was greater in fertilised soil C than in non-fertilised soil C; major carbohydrates (mannose, glucose and sucrose) decreased in the fertilised plot despite greater forest litter inputs. Also, in the light fraction of SOM, the stem only harvesting treatment had a greater amount of cutin-derived compounds and carbohydrates, compared with whole tree harvest treatment. The project will eventually lead to a better understanding of forest management impacts on both quantity and quality of soil C in New Zealand forests.

Key Words
Soil organic matter, carbon chemical composition, NMR, forest plantation.

Introduction
Soils are the major pool of terrestrial C globally that, if carefully managed, can be used to offset rising atmospheric CO_2 (Lal 2005). Forest soils make up about 30 % of soil organic C in terrestrial ecosystems (Jandl *et al.* 2007). In New Zealand, an important consideration for the forestry sector is how forest management practices might impact on forest soil C stock to meet Kyoto Protocol requirements. An increase in nitrogen (N) due to long-term fertilisation is predicted to increase forest productivity (Smith *et al.* 1994; Smith *et al.* 2000), whereas whole tree harvesting can generally reduce second rotation forest productivity (Walmsley *et al.* 2009). However, on average, soils contain three times as much C as terrestrial vegetation. Thus if changes in N availability or forest harvesting methods alter soil C turnover, net C sinks or sources from increased or decreased forest growth could be significantly enhanced or reduced, depending on the direction of the soil responses. Soil organic compounds are made up of different pools which vary in their turnover time or rate of decomposition. The labile soil organic compounds, such as proteins and carbohydrates, turn over relatively rapidly (< five years), whereas biochemically resistant compounds, such as lipids from leaf cuticles and roots and lignin from woody tissues, are expected to remain stable throughout 10- to 100-yearl timescales. Unfortunately, considerable uncertainty remains concerning which soil organic matter (SOM) structures are likely to be accumulated or degraded in forest ecosystems under the increased N availability or from the changed inputs of harvesting slash and litter. The sensitivities of SOM decomposition to soil N availability or change in litter input in forest ecosystems are critical for modelling changes in soil C stock.

Methods
The trial site is located in Berwick forest, Dunedin of New Zealand and is part of an intensive harvesting long-term soil productivity research program. A second rotation *Pinus radiata* D. Don plantation was planted in 1990. Sixteen 400 m^2 plots were established with each treatment plot surrounded by a 10-metre buffer zone. Half of the treatment plots received regular N applications (urea) between 1990 and 1999 with total N addition of 95 g/m^2. Two different organic matter removal treatments were also established by using different harvesting techniques (stem only and whole tree harvesting) during the first rotation harvest. These two treatments, combined with the presence or absence of fertiliser, produced four different treatment combinations, replicated four times. All treatment plots were weeded manually at establishment, and herbicide was applied to suppress weed growth until canopy closure.

Soils were sampled at 15 random points within each plot in March 2009 using a 25 mm diameter corer at three depth intervals (0-5, 5-15 and 15-25 cm). The 15 soil cores collected from each treatment plot were thoroughly mixed, air-dried and sieved (2 mm mesh) to remove stones, roots and other extraneous material. Soil moisture content was determined from a sub-sample dried at 100 °C. Another sub-sample was ground thoroughly into a fine powder before chemical analyses. For most analyses, the soils were separated into light and heavy fractions by floating soils in NaI (density < 1. 65 g/cm^3). The concentrations of C and N were determined with a Leco Corporation CNS-2000 Elemental Analyser. The chemical composition of SOC was analysed by CPMAS ^{13}C NMR. Carbohydrates, cutin and suberin compounds and lignin monomers were extracted by solvent extraction, base hydrolysis and copper oxidation, respectively, and analysed by gas chromatography/mass spectrometry.

Table 1. Mean C and N concentrations and C:N ratio in mineral soil (< 2 mm) under different treatments in a second-rotation *Pinus radiata* plantation, Berwick, New Zealand. Means were based on four replicate values per treatment. F: long-term N-fertilised; NF: not fertilised; SO: stem only harvesting plots and WH: whole tree harvesting plots.

	Total C (%)			Total N (%)			C:N ratio		
	0-5 cm	5-15 cm	15-25 m	0-5 cm	5-15 cm	15-25 cm	0-5 cm	5-15 cm	15-25 cm
NF+SO	5.65	2.70	1.83	0.27	0.15	0.11	20.67	18.04	16.63
NF+WH	5.05	2.78	1.70	0.24	0.14	0.10	20.42	19.88	17.00
F+SO	5.19	2.74	1.84	0.28	0.15	0.11	19.22	17.85	16.22
F+WH	5.30	2.53	1.97	0.27	0.14	0.13	19.63	17.68	15.53

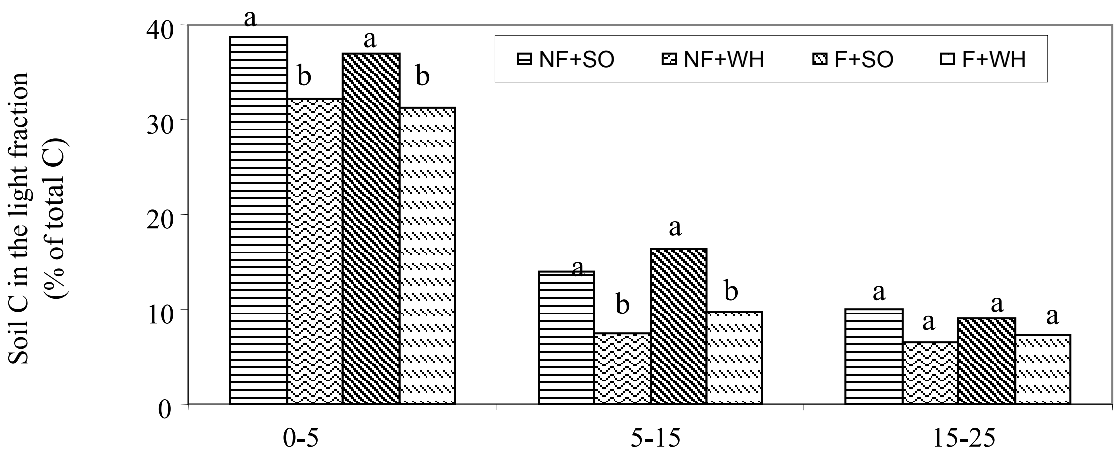

Figure 1. Soil C in the light fraction (density < 1.65 g/cm^3) in mineral soil (< 2 mm) under different treatments in second-rotation *Pinus radiata* plantation forest, Berwick, New Zealand. For the same soil depth, means followed by the same letter are not significantly different (P < 0.05).

Results and discussion

Early results suggested that fertilisation and harvest residue management had no significant effect on the C and N concentrations in 0-25 cm mineral soils. It is evident that addition of N to soils had a tendency to decrease soil C:N ratio, however, the difference in soil C:N ratio between fertilisation and non-fertilisation treatments was only marginally significant at $P < 0.1$. Harvest residue management did not significantly impact soil C:N ratios in 0-25 cm mineral soils (Table 1).

Although C concentrations in the mineral soils were not significantly affected by fertilisation and harvest residue management, the percentage of light fraction in soil C of the 0-15 cm depth was significantly altered by harvest residue management, however not by fertilisation (Figure 1). The chemical composition of light fraction C in different soils as revealed by CPMAS ^{13}C NMR was generally similar. The largest compound class in the light fraction soils was O-alkyls, ranging between 33.3% and 36.6%. Aromatics represented the next largest group. Long-term fertilisation increased the relative enrichment of alkyl C and alkyl-to-O-alkyl ratio in the light fraction of soil organic matter, which may suggest an increased decomposition of light fraction (Mendham *et al.* 2002; Mathers *et al.* 2003; Huang *et al.* 2008) and, as a result, an increased relative resistance of soil C due to fertilisation (Table 2). Compared with whole tree harvest plots, stem only harvest plots also showed a greater alkyl-to- O-alkyl ratio in the light fraction of soil organic matter, however the difference due to harvest residue management was smaller than that from fertilisation.

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Table 2. Relative signal distributions (%) in the solid-state CPMAS ^{13}CNMR spectra of light fraction of mineral soils (0-5 cm) under different treatments in a second-rotation *Pinus radiate* plantation forest. Values are single determinations of composite samples from four replicate plots, each of 12 replicate cores.

	Alkyls	N-alkyls	O-alkyls	Aromatics	Phenolic	Carboxyl C	A/O ratio
NF+SO	16.9	9.1	35.6	26.4	5.8	6.3	0.47
NF+WH	14.6	8.2	36.6	26.7	6.5	7.4	0.40
F+SO	19.5	10.1	34.6	24.8	5.3	5.8	0.57
F+WH	17.8	9.8	33.3	25.1	6.0	8.2	0.53

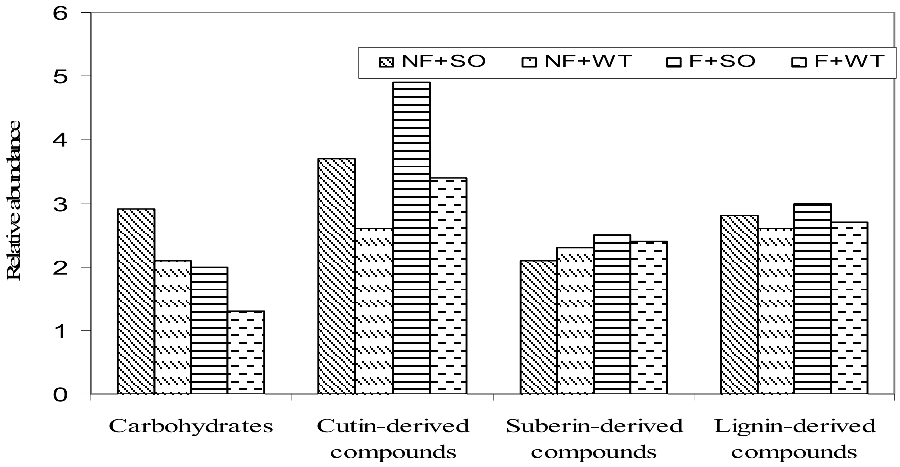

Figure 2. Relative abundance (mg/100mg OC) of major SOM components in 0-5 cm mineral soils subjected to different treatments.

The abundance of cutin-derived compounds was greater in the light fraction of fertilised soil C than in that of non-fertilised which may indicate the reduced decomposition of cutin-derived compounds after fertilisation. Alternatively, increased growth of trees due to N fertilisation may increase leaf litter production that contributes to increased cutin inputs into the light fraction of soil (Smaill *et al.* 2008b). Cutin-derived compounds originate from the waxy coating of leaves and are believed to be recalcitrant. The result from GC/MS is consistent with that from ^{13}C-NMR (Figure and Table 2). The stem only treatment had a greater amount of cutin-derived compounds in the light fraction of soil, compared with whole tree harvest treatment. This may also be attributable to the increased leaf litter. Major carbohydrates (mannose, glucose and sucrose) in the light fraction of soil decreased in the fertilised plot despite greater inputs from forest litter. This observation is consistent with the studies of Neff *et al.* (2002), in which carbohydrates are considered to be among the most labile constituents of the light fraction of SOM and their decomposition is accelerated by fertilisation. The carbohydrate abundance in the light fraction of SOM was lower in whole tree harvest plots than in the log only plots. This may be due to the decreased input from plant litter (Figure 2).

Conclusion

In the first step of the research, the chemical compositions of soil C in light fraction were identified. The results suggest long-term fertilisation may lead to an increased decomposition of light fraction and an increase in percentage of aliphatic C.

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