



RADIATA MANAGEMENT TECHNICAL NOTE

Site Productivity

Number RSPTN-006

Date: July 2010

Impacts of Nitrogen Additions and Harvest Residue Management on Chemical

Summary

Soils are the major pool of terrestrial carbon (C) globally that, if carefully managed, can be used to offset rising atmospheric CO₂. An important consideration for the forestry sector is how forest management practices might affect the New Zealand forest soil C stock.

An experiment has been set up at Berwick 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; major carbohydrates (mannose, glucose, sucrose and trehalose) 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.

Zhiqun Huang (Scion)

Composition of Soil Carbon in a Plantation Forest

Introduction

Soils are the major pool of terrestrial C globally that, if carefully managed, can be used to offset rising atmospheric CO₂ (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 affect 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 carbon 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-year 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, New Zealand and is part of an intensive harvesting long-term soil productivity (LTSP) research program. A second rotation *Pinus radiata* D. Don plantation was planted in 1990. Sixteen 400 m² treatment plots were established with each treatment plot surrounded by a 10-metre buffer zone. Half of the treatment plots received regular nitrogen 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.



RADIATA MANAGEMENT TECHNICAL NOTE

Site Productivity

Number RSPTN-006

Date: July 2010

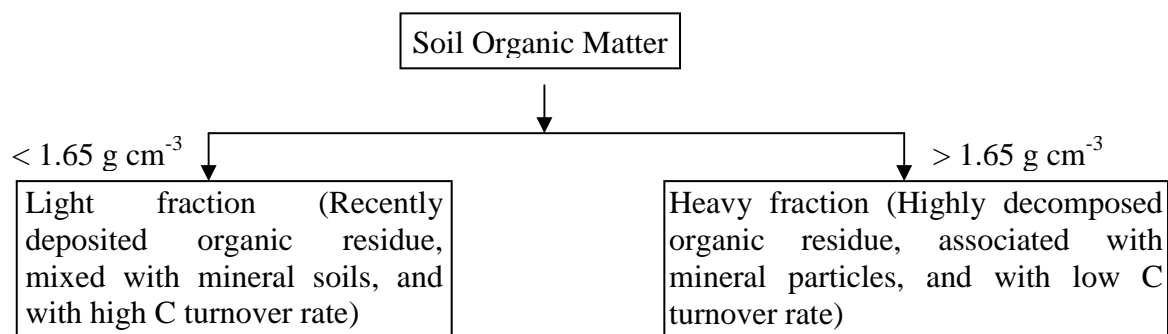


Figure 1. Density fractionation of soil organic matter.

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 analysis. For most analyses, the soils were separated into light and heavy fractions by floating soils in NaI (density < 1.65 g cm⁻³) (Figure 1). 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 ¹³C 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 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 | | | |
|----------|-------------|-------|------|------|-------------|-------|------|------|-----------|-------|-------|-------|
| | NF+SO | NF+WH | F+SO | F+WH | NF+SO | NF+WH | F+SO | F+WH | NF+SO | NF+WH | F+SO | F+WH |
| 0-5 cm | 5.65 | 5.05 | 5.19 | 5.30 | 0.27 | 0.24 | 0.28 | 0.27 | 20.67 | 20.42 | 19.22 | 19.63 |
| 5-15 cm | 2.70 | 2.78 | 2.74 | 2.53 | 0.15 | 0.14 | 0.15 | 0.14 | 18.04 | 19.88 | 17.85 | 17.68 |
| 15-25 cm | 1.83 | 1.70 | 1.84 | 1.97 | 0.11 | 0.10 | 0.11 | 0.13 | 16.63 | 17.00 | 16.22 | 15.53 |



RADIATA MANAGEMENT TECHNICAL NOTE

Site Productivity

Number RSPTN-006

Date: July 2010

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, but 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 affect soil C:N ratios in 0-25 cm mineral soils (Table 1).

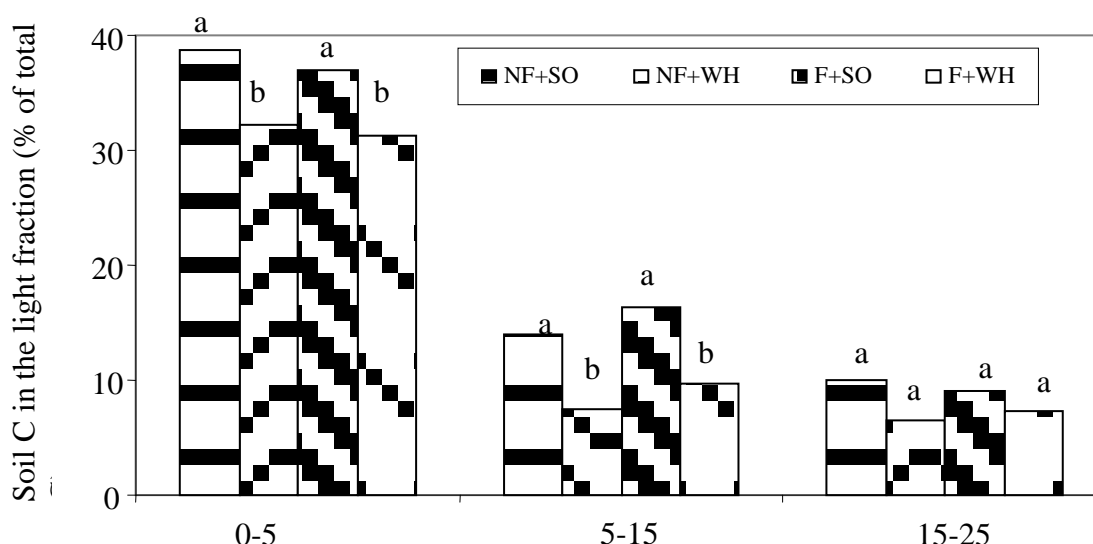
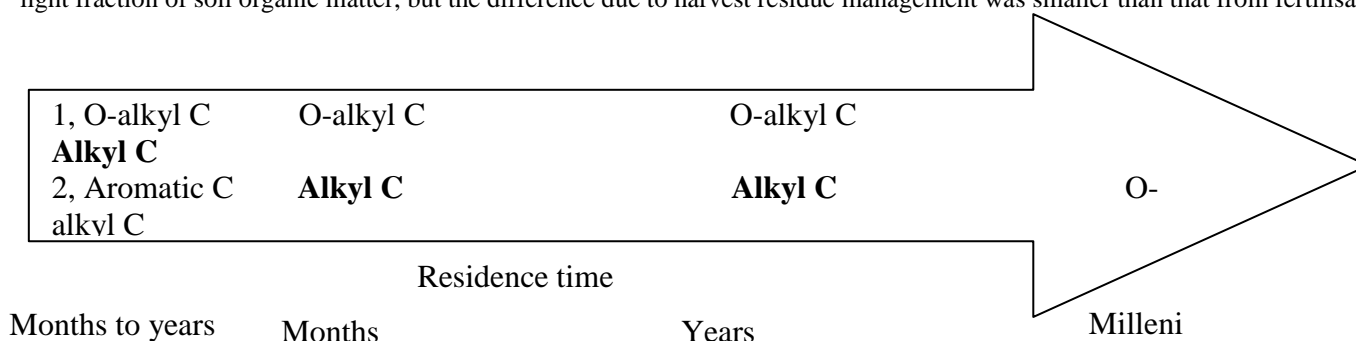


Figure 2. Soil C in the light fraction (density $< 1.65 \text{ g cm}^{-3}$) in mineral soil ($< 2 \text{ mm}$) under different treatments in second-rotation *Pinus radiata* plantation forest, Berwick, New Zealand. For the same soil depth, means followed by the same letter are not significantly different.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

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, but not by fertilisation (Figure 2).

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%. Alkyls or 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 (Figure 3). 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, but the difference due to harvest residue management was smaller than that from fertilisation.





RADIATA MANAGEMENT TECHNICAL NOTE

Site Productivity

Number RSPTN-006

Date: July 2010

Figure 3. Relative enrichment of alkyl C during biodegradation of soil organic matter and approximate residence times of C in soil pools (Cited from Lorenz *et al.*, 2007).

Table 2. ¹³C-NMR spectral assignment of C functional groups

| C functional groups | Compounds included |
|---------------------|--|
| Alkyl C | Terminal methyl (CH ₃), long-chain aliphatics, fatty acids, waxes, cutins, suberin , lipids |
| O-alkyl C | Carbohydrates , cellulose, hemicelluloses, amino sugars |
| Aromatic C | Lignin and tannin components, C- and H- substituted aromatic C, olefinic C, phenolics |
| Carboxyl C | Amide and ester C, organic acids, carboxylic acid |

The abundance of cutin-derived compounds was greater in the light fraction of fertilised soil C than in that of non-fertilised soil, 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 ¹³C-NMR (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, sucrose and trehalose) 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 4).

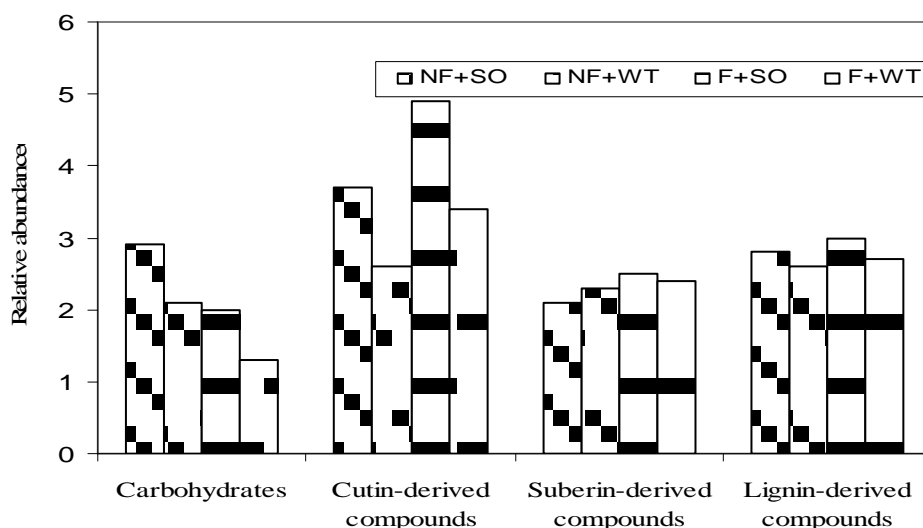


Figure 4. Relative abundance (mg/100mg organic carbon) of major SOM components in 0-5 cm mineral soils subjected to different treatments.

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 (Figure 2 and Table 2).

Acknowledgements

This project is funded by Scion post-doctoral program. I am grateful to Dr Peter Clinton and Mr Murray Davis for discussion on this project. I would like to thank Alan Leckie for assistance in soil sampling, and Stefan Hill and Hank Kroese for help in NMR and GC/MS analyses.

References



RADIATA MANAGEMENT TECHNICAL NOTE

Site Productivity

Number RSPTN-006

Date: July 2010

Huang, Z., Xu, Z., Chen, C. & Boyd, S., (2008). Changes in soil carbon during the establishment of a hardwood plantation in subtropical Australia. *Forest Ecology and Management* 254, 46-55.

Jandl, R., Lindner, M., Vesterdal, L., Bauwens, B., Baritz, R., Hagedorn, F., Johnson, D.W., Minkinen, K. & Byrne, K.A., (2007). How strongly can forest management influence soil carbon sequestration? *Geoderma* 137, 253-268.

Lal, R., (2005). Forest soils and carbon sequestration. *Forest Ecology and Management* 220, 242-258.

Lorenz, K., Lal, R., Preston, C.M. & Nierop, K.G.J., (2007). Strengthening the soil organic carbon pool by increasing contributions from recalcitrant aliphatic bio(macro)molecules. *Geoderma* 142, 1-10.

Mathers, N.J. & Xu, Z.H., (2003). Solid-state C-13 NMR spectroscopy: characterisation of soil organic matter under two contrasting residue management regimes in a 2-year-old pine plantation of subtropical Australia. *Geoderma* 114, 19-31.

Mendham, D.S., Mathers, N.J., O'Connell, A.M., Grove, T.S. & Saffigna, P.G., (2002). Impact of land-use on soil organic matter quality in south-western Australia - characterisation with C-13 CP/MAS NMR spectroscopy. *Soil Biology & Biochemistry* 34, 1669-1673.

Neff, J., Townsend, A., Gleixner, G., Lehman, S., Turnbull, J. & Bowman, W., (2002). Variable effects of nitrogen additions on the stability and turnover of soil carbon. *Nature* 419, 915-917.

Smaill, S., Clinton, P. & Greenfield, L., (2008a). Postharvest organic matter removal effects on FH layer and mineral soil characteristics in four New Zealand *Pinus radiata* plantations. *Forest Ecology and Management* 256, 558-563.

Smaill, S., Clinton, P. & Greenfield, L., (2008b). Nitrogen fertiliser effects on litter fall, FH layer and mineral soil characteristics in New Zealand *Pinus radiata* plantations. *Forest Ecology and Management* 256, 564-569.

Smith, C.T., Dyck, W.J., Beets, P.N., Hodgkiss, P.D. & Lowe, A.T., (1994). Nutrition and productivity of *Pinus Radiata* following harvest disturbance and fertilisation of Coastal Sand Dunes. *Forest Ecology and Management* 66, 5-38.

Smith, C.T., Lowe, A.T., Skinner, M.F., Beets, P.N., Schoenholtz, S.H. & Fang, S.Z., (2000). Response of radiata

pine forests to residue management and fertilisation across a fertility gradient in New Zealand. *Forest Ecology and Management* 138, 203-223.

Walmsley, J.D., Jones, D.L., Reynolds, B., Price, M.H. & Healey, J.R., (2009). Whole tree harvesting can reduce second rotation forest productivity. *Forest Ecology and Management* 257, 1104-1111.