RADIATA MANAGEMENT TECHNICAL NOTE

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N Fertiliser Effects on Soil C in a Radiata Pine Plantation

Summary

Forests cover one-third of the Earth's land surface and account for 30 to 40 % of soil carbon (C). Present understanding of the global C cycle is limited by considerable uncertainty over the potential response of soil C dynamics to rapid nitrogen (N) enrichment of ecosystems, mainly from fuel combustion and fertiliser application. Here, we show an average increase of 14.6% in soil C concentration in the 0-5 cm mineral soil layer in N fertilised (defined as N+ hereafter) sub-plots of a second-rotation *Pinus radiata* plantation in Kinleith Forest compared to control sub-plots. ^{14}C and lignin analyses of soil C indicate that N additions significantly ($p<0.05$) accelerated decomposition of soil C. In the N+ sub-plots, soil C in the light (density < 1.70 g cm^{-3}) and heavy fractions had mean residence times of 23 and 67 yr, respectively, which are lower than those in the control sub-plots (36 and 133 yr in the light and heavy fractions respectively). The commonly used lignin oxidation indices (vanillic acid to vanillin and syringic acid to syringaldehyde ratios) were significantly ($P<0.05$) greater in the N+ sub-plots than in the control sub-plots, suggesting increased lignin decomposition due to fertiliser application. The estimation of C inputs to forest floor and $\delta^{13}C$ (stable carbon isotope ratio ($^{13}C/^{12}C$)) analysis of soil C fractions indicates that the observed build-up of surface soil C concentrations in the N+ sub-plots can be attributed to increased inputs of C mass from forest debris. We conclude that long-term N additions in productive forests may increase C storage in both living tree biomass and soils despite elevated decomposition of soil organic matter.

This work is being undertaken by a Post-Doc Fellow as part of the Foundation for Research, Science and Technology funded program ‘Protecting and Enhancing the Environment through Forestry’. The work aims to improve our understanding of the impact of forest management practices on soil carbon, and underpins work on soil carbon being undertaken by Scion for MfE and MAF. Under the Kyoto Protocol New Zealand is required to account for changes in soil carbon associated with activities such as afforestation and deforestation, though not for practices such as fertilisation. Accounting for soil carbon change is not yet included in the Emissions Trading Scheme.

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Introduction

Forest ecosystems contain more carbon (C) per unit area than other vegetation types, and account for more than 50% of total C in terrestrial ecosystems. Human activities have increased nitrogen (N) input into forest ecosystems through intensive N fertiliser application and atmospheric deposition in the past two centuries, and will likely continue to increase these inputs in the future. Elevated levels of soil N availability can have positive effects on above-ground C sequestration in forest ecosystems. However, because soils contain approximately two-thirds of the terrestrial C pool, even small alterations in soil C turnover resulting from N additions may change net C accumulation in vegetation and soils. Soil C turnover mainly depends on the balance between inputs from plant debris and decomposition of soil organic matter (SOM). The response of SOM decomposition to N additions has been reported to be positive, neutral, or even negative depending on the chemical composition of SOM and the availability of easily decomposed C substrates in soil.

Fig. 1. Nitrogen fertiliser may increase forest productivity on deficient sites, but what are the effects on soil carbon?

A literature review of N enrichment effects on CO_2 sinks indicated that N additions increased ecosystem C concentration of forests by an average of 6%, but further studies are needed to better characterise the relationship between N additions and forest soil C

storage (Liu and Greaver 2009) [4]. The most precise understanding of how N additions affect soil C storage and turnover and ecosystem C in forests comes from decades-long and well-replicated field experiments under controlled fertiliser application regimes. The Scion Long Term Site Productivity trial series provides such a resource. The objective of this study was to assess the long-term effects of N additions on C concentration and decomposition of SOM in the upper soil layer in one of these trials. We hypothesized that, as the forest was N limited, N additions would increase long-term organic matter inputs from litter and that this would overcome any fertiliser-induced increase in SOM decomposition. The results of this study are to be published in the journal Soil Biology and Biochemistry.

Methods

The study site is located in Kinleith Forest, in a second-rotation *Pinus radiata* plantation. The trial was set up to examine the effects of harvest intensity on stand productivity. Three harvest residue treatments were installed before harvest in 1991. Each of twelve plots was split in to fertilised (N+) or not fertilised (control) sub-plots. In the N+ sub-plots, N fertiliser (urea) was broadcast quarterly at an average rate of 250 kg/ha/yr from 1993 to 1999. The three treatments (each replicated four times) included (in increasing order of severity of harvest removal) stem-only harvest, whole tree harvest, and whole-tree harvest plus forest floor carefully removed. For the present study, the soils were sampled in the plots with the whole-tree harvest plus forest floor removal treatment only. The soil samples were separated into two fractions based on density; the light fraction (density less than 1.7 g/cm^3) and heavy fraction. Analyses were made of the whole soil as well as the constituent fractions. Soil sampling, laboratory analytical techniques and estimation of carbon inputs are described in Huang *et al*. (in press) [3].

Results

The long-term N additions significantly increased soil C concentration in the whole soil (P = 0.01) and its light (P = 0.05) and heavy (P = 0.01) fractions in the 0-5 cm layer (Fig. 2).

There are two possible explanations for the increase in soil C concentration arising from the N additions. First, N enrichment may reduce the decomposition of soil organic C (SOC). Some previous studies have suggested that increased N inputs would reduce the mineralisation of the recalcitrant (decay resistant) C pool by suppressing microbial mining of N – they would preferentially use the N from the nitrogen fertiliser. Second, the increase in soil C concentration may be explained by N-induced increases in forest productivity, and subsequent inputs of organic matter to the forest floor and ultimately to the mineral soil.

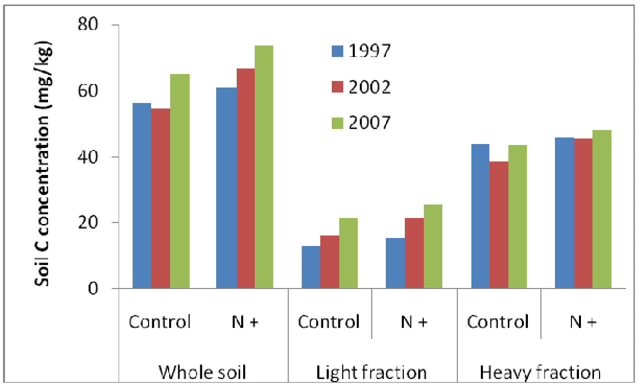

Fig. 2. Soil carbon concentration in the 0-5 cm layer, in whole soil and light and heavy fractions, with and without nitrogen fertiliser.

Above-ground nuclear bomb testing in the 1950s and 1960s greatly increased the $^{14}CO_2$ in the atmosphere. Therefore new soil C derived after the 1950s has a distinctive isotopic composition. The N additions caused significant differences in soil $\Delta^{14}C$ contents in both light (P = 0.05) and heavy (P < 0.01) fractions. Using an annual-time step model, we estimated the soil C turnover time, yielding mean residence times of 23 and 67 yr for the light and heavy fractions of SOC, respectively, in the N+ sub-plots, and 36 and 133 yr for the light and heavy fractions of SOC, respectively, in the control sub-plots. The results of radiocarbon analysis suggest acceleration of SOC turnover in both light and heavy fractions in the N+ sub-plots compared to the control sub-plots.

To further examine how the decomposition of recalcitrant C components in SOM was affected by long-term N additions, we analysed the relative abundances of lignin-derived phenols which are important indicators of lignin composition, source and decomposition. Lignin contributes substantially to the stable C pool in soils due to its chemical recalcitrance, and high N availability inhibits lignin degradation by suppressing the activity of lignin-degrading enzymes. The relative abundance of lignin-derived compounds was unaffected by the N additions in this study. However, the commonly used lignin oxidation indices (vanillic acid to vanillin and syringic acid to syringaldehyde ratios) were significantly greater in the N+ sub-plots than in the

control sub-plots (P < 0.05), suggesting increased lignin oxidation due to N additions. The results indicate that N additions increased the decomposition of lignin-derived compounds of SOM, which is inconsistent with reports from Berg and Matzner (1997) [1] and Carreiro *et al.* (2000) [2], who generally found long-term N additions would reduce decomposition rates of these components.

As the results do not indicate that N additions have reduced SOM decomposition, the observed build-up of soil C concentration in the N+ sub-plots appears likely to be due to increased inputs of C mass from forest litter and debris. More negative $\delta^{13}C$ (stable carbon isotope ratio ($^{13}C/^{12}C$)) of SOM in both the light and heavy fractions (P < 0.01) in the N+ sub-plots than in the control sub-plot provided support for this (Fig. 2). In forests, surface litter and below-ground root inputs have lower $\delta^{13}C$ relative to existing SOM in mineral soil. The significantly more negative $\delta^{13}C$ values may therefore reflect the increased flush of new plant material into both light and heavy fractions of fertilised soil. The lower $\delta^{13}C$ values measured in the light fraction of SOM support the argument that this fraction of SOM was of more recent origin and less decomposed than the heavy fraction of SOM (i.e., having isotopic ratios closer to litter inputs). The soil $\delta^{13}C$ in both the light and heavy fractions were different between the N+ and control sub-plots from 1997, which indicates that the increased C inputs due to N additions occurred before 1997. As the C inputs from above-ground litter to mineral soil up to age 5 are likely to be quite small, we believe that the fertilization caused increase of C input before 1997 may mainly come from below-ground roots.

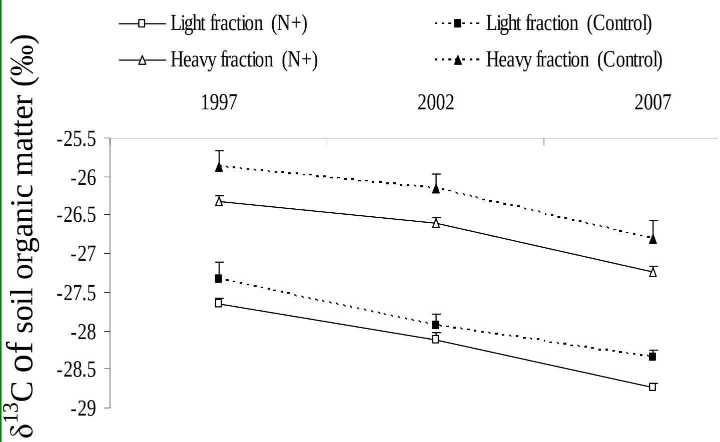

Fig.2 $\delta^{13}C$ values of soil organic matter in the 0-5 cm mineral soil layer between 1997 and 2007 in the N+ (N additions) and control sub-plots.

An increased flush of new plant material into the soil can be attributed to the significantly elevated plantation productivity in the N+ sub-plots (P < 0.01). On average in 2007, we estimated there was 4.5 Mg ha^{-1} more C mass accumulated in the living trees in the N+ sub-plots than the control sub-plots. We estimated the inputs of C to the forest floor over the 15 years derived from canopy litter-fall and plantation thinning (Table 1). These totalled 105.3 and 95.2 tonne ha^{-1} in the N+ and control sub-plots, respectively.

Table 1. Carbon inputs (tonnes ha^{-1}) from canopy litterfall and thinning to the forest floor (1992-2007) and C mass remaining in the forest floor in 2007.

	Canopy litter-fall	Thinning	Sum of inputs	Forest Floor C mass
Control	19.0	76.2	95.2	10.6
N +	22.6	82.7	105.3	11.0

Using the Roth-C model, it has been estimated that 10% of litter-fall C over a 26-year rotation would enter the mineral soil in *Pinus radiata* plantations (Scott *et al.* 2006) [5]. Based on measurement of tree heights and diameters, modelling and associated assumptions, we estimated an increase in inputs of 10.1 Mg C ha^{-1} from litter-fall and plantation thinnings in the N+ sub-plots, compared to the control plots, which might increase soil mineral C by 1.0 Mg ha^{-1}. The estimation of C mass on the forest floor in 2007 demonstrated that there was no significant difference between N+ and control sub-plots regardless of increased total inputs from canopy litter-fall and thinnings (Table 1).

We did not estimate the belowground biomass at this site, but data from another site (part of this long-term trial) suggests an increase of 0.46 t ha^{-1} in the 0-10 cm soil depth by N additions in the whole-tree harvest plus forest floor removal treatment. Assuming a 3-year mean residence time for live fine roots in pine forests, we estimate that the increased fine roots in the N+ subplot may increase soil mineral C by 0.08 t ha^{-1} annually in the 0-5 cm soil layer compared to control sub-plots.

Although changes in soil C storage and decomposition of SOM in forest ecosystems subjected to long-term N additions are not easy to estimate, the Kinleith trial provides an approach that allows such estimates to be made. The well-replicated permanent plots, extensive within-plot composite sampling over time, and soil archiving

have been especially useful. From an ecosystem perspective, this study clearly suggests that long-term N additions in this forest can increase C storage in both living tree biomass and surface mineral soils despite the elevated decomposition of SOM. The build-up in C concentrations in surface soil due to N additions was associated with the increased productivity and therefore inputs from forest debris.

References

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