RADIATA MANAGEMENT TECHNICAL NOTE
Site Productivity

Number: RSPTN-023
Date: December 2011

Impacts of Fertiliser on Soil Organic Matter in Production Forestry

Summary

This review summarises our current understanding of the effects of fertiliser addition on soil organic matter dynamics in production forest soils, which is critical to enhancing the value of forestry under the Emissions Trading System scheme. Soil organic matter (SOM) is important to the cycling and long-term storage of carbon and nutrients, and is therefore central to the maintenance of soil function and site productivity. Fertiliser application generally increases SOM content due to enhanced plant growth and greater returns of organic residues to the soil. However, the effects of fertiliser application on the communities of soil microbes that control SOM decomposition rates are complex, and can be influenced by various factors. In order to better manage site productivity and soil carbon sequestration there is a need for further research into the impacts of fertiliser application on SOM dynamics in production forests under different management practices.

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Introduction

Soil organic matter (SOM) is important for the long-term storage and cycling of carbon and nutrients and therefore forest productivity [7]. The SOM pool is also central to environmental quality as it influences soil structure, aeration, water infiltration, and resistance to soil erosion and compaction. The factors controlling the fate of SOM are not well understood, and the study of organic matter dynamics in soil is acknowledged as challenging given the range of complex biological, chemical and physical properties and processes involved [7].

One of the major factors in determining SOM pool size is soil organic carbon (SOC), as carbon is the main component of SOM [7]. The size of the SOC pool varies with soil parent material, climate, land use and soil depth, which has implications for the management of organic matter [5, 20, 22, 26]. Examples of SOC pools to 1 m depth in selected New Zealand *Pinus radiata* forest soils are in Table 1. The effects of variation in first rotation harvesting strategies on mean carbon in the O horizon and upper A horizon (0–2.5 cm depth) across four second rotation *P. radiata* forests (after 10–18 years) are in Table 2.

Table 1: Measured soil organic carbon down to 1 m depth in selected *P. radiata* forest soils.

Forest	SOC (t/ha)	Soil Order[1]	Reference
Kaingaroa	62	Pumice	25
Kinleith	448	Pumice	34
Ngaumu	119	Pallic	25
Tarawera	153	Recent	34
Woodhill	173	Recent	34

[1] New Zealand Soil Classification [10].

Table 2: Variation in soil carbon measurements (second rotation forests) with harvest strategy.

Harvest[1]	O layer C mass (t/ha)	Upper A horizon C concentration (%)
SO	14.9	9.5
WT	10.5	8.7
FF	6.5	5.5

Values taken from Smaill *et al*., 2008a.
[1] SO = stem only harvesting, WT = whole tree harvesting and FF = whole tree harvesting plus forest floor removal.

The soil microbial and, to a lesser extent, faunal communities drive the catabolism of SOM, but also the anabolism of new organic compounds from the components of SOM [8, 9, 27]. Various studies have determined that these communities are sensitive to disturbances associated with forest management [2, 32], which can then alter the processing of SOM by soil microbes and fauna [7, 9].

In order to enhance productivity, global rates of fertiliser application have increased, and many ecosystems are now exposed to substantial inputs of nitrogen and phosphorous from anthropogenic sources [7]. These alterations to the chemical environment could have significant impacts on the size of the SOM pool by altering soil carbon and biotic processes, potentially amplifying a small change into large differences in SOM accumulation and turnover. Recent studies conducted by Scion have focused on the impacts of forest management, including fertiliser application, on organic matter in the upper soil [13, 14, 30] and total soil carbon [17] using our Long Term Site Productivity trials (LTSP 1).

In this review, we summarise our current understanding of the effect of fertiliser additions on SOM in New Zealand production forests,

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predominately based on findings presented in a review by Condron *et al*. (2010) combined with additional relevant literature. As it is probable that soil carbon storage will become a component of the Emissions Trading System (ETS), we will also consider the ramifications of fertiliser application to the sequestration of carbon in the SOM pool of production forest soils.

Soil Organic Matter Definition

Soil organic matter is made up of a combination of carbon, oxygen, hydrogen, nitrogen, phosphorus and sulphur derived either directly or indirectly from plants (e.g. from plant detritus, root exudates, microbes) [7]. There is a range of methods to measure different fractions of SOM, such as separating living (includes various bacteria and fungi) from non-living (includes chemically identifiable plant and microbial constituents, e.g. cellulose, starch and lignin) organic matter components, and then further dividing these fractions into more specific fractions, for example physical size fractions [7]. Soil organic matter contains between 40 and 60% soil organic carbon (SOC), depending on the nature of the carbon inputs to the soil and the decomposition rates of the material [7]. Consequently, in most studies soil organic carbon is measured as a proxy for SOM.

Soil Organic Matter Dynamics

The decomposition of soil organic matter and subsequent release of carbon dioxide and nutrients is predominantly carried out by bacteria and fungi, which represent 95% of the biomass in most soils, with various species of fauna making up the remainder [7]. Carbon sequestration occurs when the inputs of organic carbon are greater than the release of carbon through respiration. Soil microorganisms (bacteria, fungi) and fauna can consume up to half of the organic carbon added to the soil [7], and can be classified into those that respond primarily to the addition of labile carbon and those that mainly use older carbon sources which are more recalcitrant and stable [7]. In most soils, over 90% of the total nitrogen and sulphur, together with over 50% of the total phosphorus, is associated with the microbial biomass and organic matter, therefore nutrient availability for plant growth is primarily controlled by organic matter transformations linked to microbial and faunal activity [7]. The process of organic carbon decomposition can range in time from days to centuries [7, 13] and may act both as a sink and source of carbon during global environment change [7]. Consequently, improving our understanding and management of SOM and SOC has become a key objective of research aimed at protecting the environment [7].

Importance of Microorganisms and Nutrient Additions

Although microbial biomass is generally accepted to comprise less than 5% of the soil carbon, the activity of this biomass controls the decomposition of soil organic matter [7]. Therefore it is critical to understand the impacts of nutrient additions on the microbial soil community. A review of the responses of microbial biomass to nitrogen additions in various studies determined that addition of nitrogen fertiliser decreased microbial biomass on average by 15%, dependent on the duration and loads of the applied nitrogen and the characteristics of the ecosystem itself [7]. Nitrogen fertiliser additions have also been found to alter the community structure of the soil bacteria and shift the microbial community composition from fungal to bacterial dominance as a result of a decreased carbon-to-nitrogen ratio [7, 29]. Furthermore, anthropogenic nitrogen inputs have been associated with increases in the respiration rates of soil microbes [6], and can also produce long term effects on other aspects of microbial activity such enzyme activity and the formation of mycorrhizal associations, which may have detrimental long-term effects for forest productivity [1, 33].

The effect of applying phosphorous, sulphur or other elements either by themselves or in combination on microbial communities in forest soils has been less extensively studied, although it is suggested that phosphorus additions could increase soil microbial biomass [7]. Overall, it is apparent that any increase in nutrient availability can change the activity of soil microbes, thereby altering the decomposition rate of soil organic matter.

Impacts of Fertiliser Inputs on Soil Organic Matter

Fertiliser inputs to the soil alter ecosystem functions and processes, such as the quantity or quality of organic matter inputs [7]. Fertiliser inputs increase crop growth [34, 37] and therefore organic matter additions to the forest floor [13, 21]. With the incorporation of the organic matter in the mineral soil [14] it is expected that soil organic carbon would also increase. However, the addition of fertiliser on the overall decomposition of SOM depends on the chemical composition and stage of decomposition (early, late, and final stages) of the SOM. For example, nitrogen addition can reduce respiration by

retarding lignin degradation at later stages of decomposition [3], but this effect may not hold in earlier stages. The decomposition rates of the various fractions present in SOM may also react differently to nutrient addition [35].

Long-term fertiliser additions to the 15-year LTSP 1 *P. radiata* trial in Kinleith forest have been calculated to increase SOC inputs to the 0–5 cm soil depth by up to 9%, outweighing the increased loss of carbon via elevated decomposition rates [13]. However this effect did not extend to lower soil depths (0–30 cm) [17], and long-term nitrogen fertiliser additions at another LTSP 1 trial site showed no effect at depths of 0–25 cm [15]. The effect of long term nitrogen fertiliser additions on a wider range of New Zealand *P. radiata* forests showed no significant changes in soil carbon concentrations (0–2.5 cm mineral soil depth) despite greater litter inputs, but did identify significant increases in the nitrogen concentration and decreases to the mineral soil carbon:nitrogen ratio [30]. The change in the soil organic matter after fertiliser addition can persist for some time after fertilisation has ceased [30].

International studies have produced conflicting results, with some demonstrating increased mineral soil carbon pools following fertiliser application [12, 16, 23, 24, 28], while others have shown no change [4, 11, 19, 36]. The inconsistencies in the results of these studies are most likely a product of the complexity of soils, and the potential for various factors related to site characteristics and history to influence results significantly. For example, harvest residue management [17, 31], past land use, soil carbon protection [22] and soil depth [5, 25] are all known to have an impact on SOM in managed forest landscapes.

A further issue is the variation in techniques used to measure SOM. Most studies have measured SOC and used factors to then estimate SOM. Direct measurements of SOM will produce more accurate assessments of the impact of fertiliser applications on SOM and the correlations to associated biotic and abiotic soil processes.

The likely inclusion of production forest soil carbon stocks into the ETS scheme crystallises the need for better understanding of the potential for fertilisation to increase SOM accumulation. Independent projections indicate that fertiliser use could increase the value of the carbon sequestered in forest soils by approximately $90 million per annum if better fertiliser use strategies are developed [18]. Consequently, more targeted, long-term research is needed to better understand the mechanisms by which fertiliser inputs increase soil organic matter accumulation, especially across sites with diverse characteristics and management practices [24].

Conclusions

The addition of nitrogenous fertiliser to forest soils alters soil microbial community structure and function, typically decreasing microbial biomass while increasing rates of organic matter decomposition and respiration. The increased decomposition of soil organic matter is offset by increased organic matter inputs to the soil, and therefore most studies conclude that fertiliser application will increase soil organic matter accumulation, although turnover may be greater. It is also evident that any increases in SOM accumulation can persist for some years after fertiliser application has stopped, although the magnitude of the change is substantially influenced by site-based factors. Fundamental issues still remain unresolved. Few studies have examined the effects of the application of other elements commonly used to fertilise soil, such as phosphorous, while the majority of the studies discussed here have relied on SOC as a proxy for SOM. With the establishment of the ETS, it is now imperative to better understand SOM so it can be managed appropriately. This can be achieved by the establishment of fertilisation studies that:

- utilise direct measurements of SOM;
- examine how variation in response to fertiliser is influenced by climate and site conditions;
- identify correlations between response and soil microbial community properties;
- determine the effects of past and current forest management strategies; and
- relate the above findings to site productivity.

The results of these studies will confirm the effects of fertiliser application on SOM dynamics in New Zealand production forests and define the implications for forest sustainability, productivity and soil carbon sequestration.

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