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RESEARCH ARTICLE

Multi-rotation impacts of increased organic matter removal in planted forests

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Abstract

Organic matter cycling is critical to nutrient supply in forested ecosystems. Harvesting influences future nutrient supply by removing organic matter, but the extent of removal varies with harvesting methods. In New Zealand plantations there is little long-term data to help evaluate the relative impact of these methods on the sustainability of site productivity. To explore this issue a modelling study was initiated using the NuBalM platform to simulate the response of forest nitrogen (N) pools and the productivity of *Pinus radiata* D. Don to the consisten removal of different amounts of organic matter at harvest over multiple 30 year rotations across a range of growth trajectories. The harvesting method involving the greatest amount of organic matter removal (OMR) induced significant reductions in N pools and productivity by the end of the second rotation, while moderate OMR induced reductions by the end of the third rotation. Minimal OMR reduced N pools but not productivity by the end of the fourth rotation. This exploratory work suggests that management practices which influence the amount of organic matter on site can play an important role in long-term productivity and should be considered in further risk based management decision making.
Keywords: Planted forest, nitrogen, organic matter, sustainability,ong-term

1. Introduction

Organic matter is an important and dynamic component of soil. In most soils, over 90% of the total nitrogen (N) and sulphur, together with over 50% of the total phosphorus, is associated with the organic matter and microbial biomass (Condron *et al*., 2010). In forest ecosystems the layer of organic litter and other plant matter that accumulates is critical to soil function, in terms of both the nutrient pools it stores and via the regulatory effect it exerts on various properties of the mineral soil below (Currie, 1999; Sayer, 2006). Given that OMR and some level of soil disturbance is an inherent outcome in the management of planted forests (Kimmins, 1994), various concerns related to the long-term sustainability of productivity have been raised (e.g. Jorgensen *et al*., 1975; Goodland, 1995; Fox, 2000).

Organic matter removal during harvest in New Zealand planted forests is variable. Harvesting methods used include stem only harvesting (SO), in which only stems are removed, and whole tree harvesting (WT), in which all above ground material is removed, but site preparation treatments can also result in the removal or disruption of the forest floor (FF), leaving bare mineral soil (Smaill *et al*., 2008). There is limited data available from long-term rotation length trials to assess the relative sustainability of these practices in New Zealand planted forests (Garrett *et al*., 2015).

NuBalM (Nutrient Balance Model) is a nutrient cycling model that projects productivity and nutrient pools in *Pinus radiata* D. Don forests, and enables the impact of different management scenarios to be assessed (Smaill *et al*., 2011). Briefly, initial predictions of *P. radiata* growth are made by a routine that utilises 300 Index (Kimberley *et al*., 2005) and Site Index values (Goulding, 2005) to forecast annual stem wood growth and mortality under various silvicultural regimes. From these simulated data total biomass growth and mortality masses are predicted using allometric biomass relationships (e.g. Madgwick *et al*., 1977; Madgwick, 1994). The annual nutrient demand required to support predicted growth in a given year is then calculated from nutrient concentration data (e.g. Smith *et al*., 1994). The supply of nutrients to the forest stand is determined from multiple pathways, including inputs from the forest, and losses that may have occurred due to management or environmental factors. From comparisons of nutrient demand and supply, NuBalM utilises a preferential allocation system to revise the initial productivity predictions based on nutrient availability. Specific detail on all model processes is given in Smaill *et al*. (2011).

To explore the potential effects of increased OMR on nutrient availability and productivity over multiple rotations, NuBalM was implemented with data representing *P. radiata* growth trajectories in six different regions of New Zealand under different OMR regimes that were maintained over four rotations. The results of this exploratory analysis are presented here.

2. Material and Methods

The OMR regimes investigated in this study were SO, WT and FF within a *P. radiata* planted forest. Implementation of NuBalM was based solely on (N) dynamics, as only this nutrient has been tested sufficiently to date (Smaill *et al*. 2011). Productivity was measured as stem wood biomass development. Genetic gain, representing the estimated increase in stem wood volume derived from improved genetic material from rotation to rotation, was set at 11% (Kimberley *et al*., 2015). Mean values describing the growth trajectories of *P. radiata* in the three most afforested regions in both the North Island and the South Island of New Zealand were taken from Palmer *et al*. (2010) (Table 1) and were considered to provide a realistic range of growth rates within New Zealand. Site variables describing the condition of the site prior to rotation one were held constant, describing a forest established on a site subjected to SO harvesting with moderate N availability, and established at 1000 *P. radiata* per ha, thinned to 450 *P. radiata* per ha at age eight. The harvest of this forest using either the SO, WT or FF method provided the data necessary to initiate the simulation of rotation one; initialisation data for rotations two, three and four were provided by the end points of the previous rotation. This use of common starting conditions enabled unbiased comparisons of the impact of the various growth trajectories on N availability under variable levels of OMR. For simplicity it was assumed that no erosion driven N losses or inputs from the growth of N-fixing plant species occurred between rotations or during the early growth of the next rotation. Given the projections were for indicative purposes only and no real data were available for comparison, no statistical analysis was performed on the model outputs.

Table 1. Planted areas and mean growth trajectory values (300 Index and Site Index) for *P. radiata* forest in six regions of New Zealand

Region	Area (ha 000's)	300 Index	Site Index
Northland	148 (9.4 %)[a]	26.8	31.7
Waikato	347 (22.0 %)	27.5	32.6
Bay of Plenty	208 (13.2)	27.2	31.9
Tasman	77 (4.9 %)	25.8	31.3
Canterbury	82 (5.2 %)	22.2	24.1
Otago	87 (5.5 %)	23.6	24.7

[a]Values in parentheses are the percentage of the national *P. radiata* estate held in the region.

3. Results and Discussion

The simulated trajectories of N pool size were very similar across the range of growth trajectories, which was anticipated given that site properties were held constant. Projected reductions in the N pool after four rotations of either the FF, WT or SO regimes varied from 81 – 84%, 59 – 63% and 29 – 33%, respectively. This agreed with various reports of reduced nutrient pools following the increased removal of organic matter at harvest (e.g. Bååth, 1980; Richter *et al*., 2000; Smaill *et al*., 2008). The projected effect of OMR regime selection on stem wood biomass production was minimal for the first two rotations (varying from a 0 – 7% reduction) but beyond this point the effect of OMR was substantial. For all six growth trajectories, productivity losses with the FF regime ranged from 58 – 59% by the end of the third rotation and from 75 – 77% by the end of the fourth rotation; losses associated with WT treatment were 2 – 7% and 24 – 28% by the ends of the third and fourth rotations, respectively. No loss of productivity was projected under the SO regime for any rotation. The mean values for N pool reductions and productivity loss across the range of growth trajectories are presented in Figures 1 and 2. Examination of these figures indicates that the dramatic productivity reductions for FF regimes in rotations three and four occurred after N pools had been reduced by more than 50% at the end of rotation two, while for the WT regimes the decrease in productivity during the fourth rotation aligned with a 50% reductions in N pool size by the end of the third rotation. No reduction in productivity was associated with the SO regime over the simulated time period, during which time the reduction in N pool size did not approach 50%.

However, due to the associated uncertainties and lack of specificity in the simulations, these outputs cannot be construed as solid evidence that a 50% reduction in N pools is a threshold for rapid productivity decline. While it is likely that thresholds exist, the simulations presented here did not integrate the potential impacts of other soil properties that are both sensitive to variations in OMR and important to nutrient availability, such as pH and moisture content (e.g. Johnson, 1994; Ballard, 2000; Smaill *et al*., 2008), or soil microbial community biomass and activity (Smaill *et al*., 2010; Achat *et al*., 2015). Integration of this additional data would likely also see more variations arise between the different growth trajectories based on other regional differences. Consequently, only the general trends identified here should be considered further.

The consistency in productivity decline with increased OMR over a range of growth trajectories (as indicated by the 300 and Site Index values for the different regions, see Table 1) indicates that the retention of organic matter during harvest is important to the maintenance of the long-term productivity capacity of the New Zealand *P. radiata* forests. Approximately a third of New Zealand's total planted forests have been established on sites with low soil nutrient stocks (*Garrett et al*., 2015). The threshold where productivity is markedly negatively impacted by increased OMR from these low nutrient sites may be reached sooner rather than later. Understanding and managing the risks will ensure New Zealand planted forests are productive into the future.

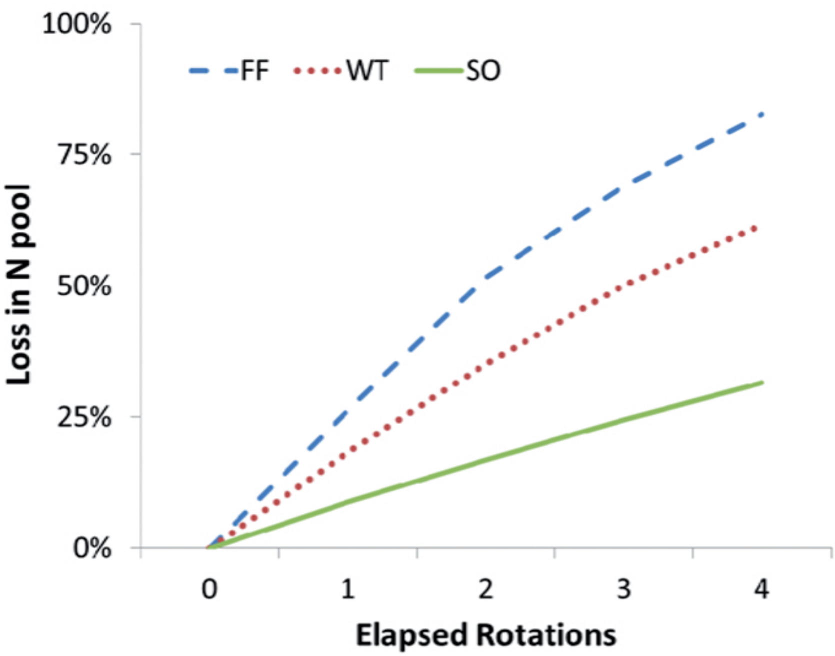

Figure 1. Mean reductions in N pool size over multiple rotations with consistent FF, WT or SO harvesting methods.

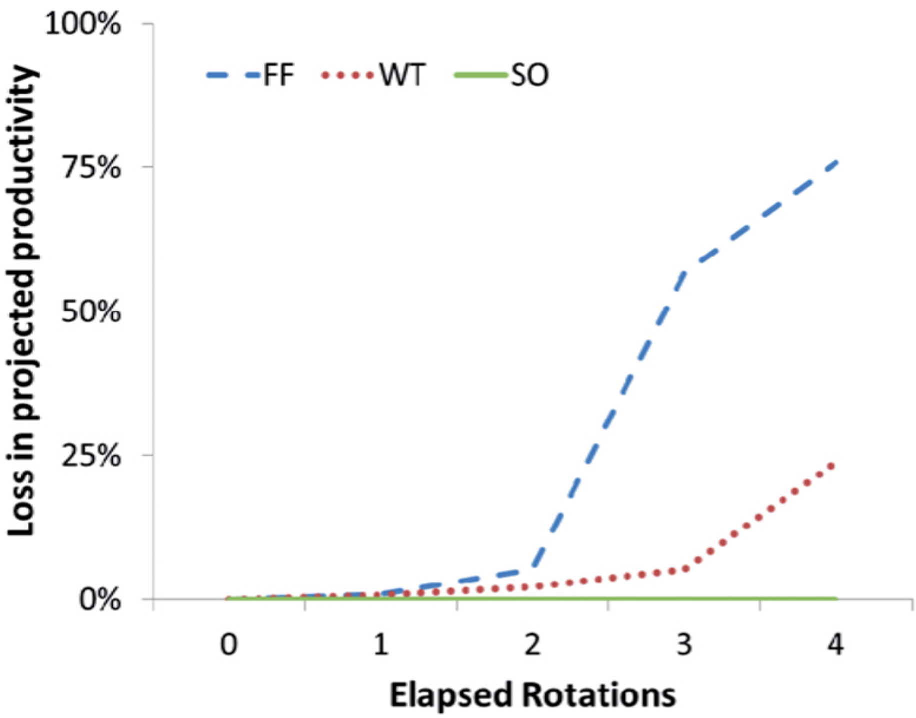

Figure 2. Mean reduction in productivity from projected values over multiple rotations with consistent FF, WT or SO harvesting methods.

4. Conclusions

In summary, planted forest management practices that maximise the retention of organic matter during harvest operations are important for sustained long-term productivity. The negative impacts of OMR on the N pool and productivity may not manifest for one or more rotations at any given site, however, the impacts of continued removal will only remain hidden for so long. Therefore, there is a need for forest management systems that recognise this risk. Further improvements to NuBalM, such as addressing the limitations identified in this paper, provide the opportunity to develop NuBalM as a precision nutrient management tool for long-term sustainable production.

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