Nutrient supply one rotation to the next

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Abstract

There is uncertainty around the ability of many planted forest soils to provide nutrients in the long term and limited suitable data available from long-term rotation length trials to address these concerns. Improved genetic and silvicultural management over the past decades have greatly improved forest productivity in New Zealand and may have the potential to mask reductions in soil nutrient supply. The nutrient balance model NuBalM offers the opportunity for 'precision nutrient management' for planted forests over multiple rotations for long-term nutrient sustainability.

Introduction

The long-term productivity of New Zealand's planted forests will depend on the ongoing supply of nutrients and water from the soil for plant growth. The threat that nutrient removal and other soil disturbances associated with harvesting pose to these resources, and therefore the long-term sustainability of forest productivity, has long been recognised (Dyck et al., 1987; Jorgensen et al., 1975). Consequently, developing an understanding of the soil resources available at a given site, and the stability of those resources, is a key element in both maintaining and sustainably enhancing forest growth and productivity (Powers, 1999). Harvesting and associated soil disturbance on steeplands and possible intensification of silvicultural regimes generally means a very good understanding is required to mitigate impacts.

What we know about inter-rotational nutrient supply

Soil fertility is sensitive to the extent of organic matter removal that occurs during harvesting and may potentially be partially depleted through the removal of timber, harvest residues and the nutrients that they contain from the site (Table 1). This has been demonstrated with the removal of harvest residues depleting nutrient pools compared to harvesting techniques that retain greater masses on organic residue on-site, with the effect persisting for some time (e.g. Smaill et al., 2008b).

Forestry fertiliser management systems have been adopted across at least 80% of New Zealand's planted forests (Payn et al., 2013) and can maintain or increase the fertility of harvested forest soils (Jokela et al., 2010). However, evidence suggests that mineral fertilisers cannot mitigate all of the negative impacts on soil resources associated with increased organic matter removal at harvest (e.g. Smaill et al., 2008a). The impact of harvest activities on soil fertility also depends on the initial soil nutrient pool, vulnerability to soil disturbance, and the number of harvesting events that have occurred over time. Any negatively resulting impact on stand productivity can range from minimal (e.g. Lacey et al., 2000) to substantial (e.g. Murphy et al., 2004).

The sites at greatest risk of nutrient deficiencies are those that have soils already low in nutrients. For example, low in nutrients important for plant growth, nitrogen, phosophours or boron (e.g. Payn et al., 2013). These low nutrient soils make up about a third of New Zealand's total planted forest area. The long-term cropping and removal of nutrients from these soils may result in a decline in the supply of nutrients to future crops, so it is important to understand what the risk of this is and how to mitigate with a nutrient management science (Payn et al., 2013).

It is also apparent that a range of other factors can confound attempts to relate changes in soil properties to site productivity over multiple rotations (Figure 1). For example, improvements in genetics and silvicultural management over the past decades

Table 1: Summary of data on nutrient removals ($kg.ha^{-1}$) for stem only *Pinus radiata* harvest for a range of sites in NZ (from Payn et al., 2005)

Source	Soil type*	Stand age	N	P	K	Ca	Mg
Webber et al. (1983)	–	29	217	31	285	220	63
Berwick Forest	Mottled Fragic Pallic Soil	31	337	38	439	153	107
Canterbury Plains Forest	Pallic Orthic Brown Soil	32	187	28	198	183	69
Kinleith Forest	Immature Orthic Pumice Soil	26	136	22	168	126	97
Tarawera Forest	Buried-Pumice Tephric Recent Soil	27	187	36	302	237	80
Woodhill Forest	Typic Sandy Recent Soil	42	128	38	218	233	73

* (Hewitt, 1998)
Nitrogen (N), phosphorous (P), potassium (K), calcium (Ca) and magnesium (Mg)

have greatly improved the forest productivity in New Zealand (Kimberley et al., in review) and may have the potential to mask reductions in soil nutrient supply (Skinner et al., 1999), while improvement to other aspects of silviculture could produce similar effects (e.g. Turner et al., 1996; Yeo et al., 2001).

In Australia, a recent report concluded that for blue gum plantations between the first and second rotation soil nitrogen supply was reduced, which was directly related to the reduction in productivity for one site (Battaglia et al., 2015a). They concluded that without management of the soil resource the benefits of improved genetics or forest management technologies will not be realised for these forests. Therefore, to adequately understand and maintain the long-term productivity of a given site, active research into soil dynamics is a necessity (O'Hehir et al., 2010).

Many planted forests in New Zealand are now supporting their third rotation of planted forests. Although the uncertainty around the ability of many soils to provide nutrients in these long-term systems has been discussed for more than 30 years in New Zealand (Dyck et al., 1987) and overseas (e.g. Achat et al., 2015; Battaglia et al., 2015b; O'Hehir et al., 2010), suitable data on potential changes to the supply of soil nutrients has not been available from long-term rotation length trials to address these concerns. However, some estimates have been made in the past (see Will, 1968).

What we are doing

To address the uncertainties of harvest and fertiliser impacts on New Zealand planted forest productivity and soil resources, six nationally unique long-term sustainable productivity trials were established between 1986 and 1994 on sites across a range in climate, soil and physiography (Smaill et al., 2008a; Smith et al., 2000). The remaining trials are now nearing harvest and offer a unique opportunity to investigate the performance of *Pinus radiata* growth and productivity during the second rotation and consequences of organic matter removal during the harvest of the initial tree crop on the soil nutrient and biological resources. Part of the Scion MBIE research programme, Growing Confidence in Forestry's Future (GCFF – see http://gcff.nz/), is to measure the remaining long-term sustainable productivity trials at end of rotation. In addition, data on biomass production, nitrogen content and soil and forest floor nitrogen resources will be used to improve the prediction capabilities of the nutrient balance model NuBalM for nitrogen (Smaill et al., 2011).

NuBalM can be utilised to provide projections of productivity and nitrogen pools in *P. radiata* plantations, and enables the effects of various management practices to be predicted with a reasonable degree of confidence (Smaill et al., 2011). The GCFF programme is further developing NuBalM by improving the nitrogen pool allocation and through collecting end of rotation data from remaining long-term sustainable productivity trials to test the model. Further improvements to NuBalM will also be made through the integration of a drainage model, enhancing the ability of the model to identify situations where management (e.g. fertiliser addition) may increase the risk of nitrogen leaching. The outcome will give the forestry sector confidence in the forest ecosystem nitrogen cycling and where nitrogen sits over a rotation or multiple rotations for different harvest methods and sites. The applications of NuBalM include predicting future sustainable supply of nutrients and if fertilisers are required for maintained forest growth under different harvest removal methods.

What still needs to be known

While the potential for the effect of improved genetics and silvicultural management to mask losses in nutrients is understood (as described above), the extent to which this may be occurring across New Zealand planted forests is not well understood (Figure 1).

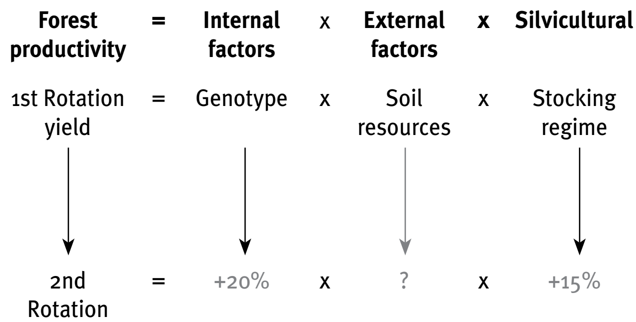

Figure 1: Hypothetical example of second rotation gain through genotype and management and uncertainties of the sustainability of the soil resources

Improvements in forest productivity through genetics and silvicultural management increase biomass on-site (e.g. more trees per hectare or larger trees), and could result in the greater removal of nutrients from a site at harvest. While the retention of harvest residues on-site can help mitigate the extent of this removal (for both current forests and in more intense future plantation systems), on steepland sites this may not always be achievable due to the hauler harvesting method (see photo). This method often results in the concentration to woody debris in a number of locations, precipitating reduced cycling of nutrients across most of the site during the next rotation.

More rapid changes in soil nutrient supply can occur on steepland forests through erosion and loss of top soil negatively impacting the soil's ability to support planted forest productivity. For example, sediment generation has been shown to increase during the harvesting of a steepland site at Pakuratahi experimental catchment site in Napier (Fahey et al., 2003). However, very limited data exists of the impact of erosion on planted forest soil nutrient pools and impact on forest productivity. One example, also at Pakuratahi, shows the loss of soil through shallow landslide erosion to result in a reduced timber volume of 10% for trees planted within the erosion scars (Heaphy et al., 2014). There is no research on the time

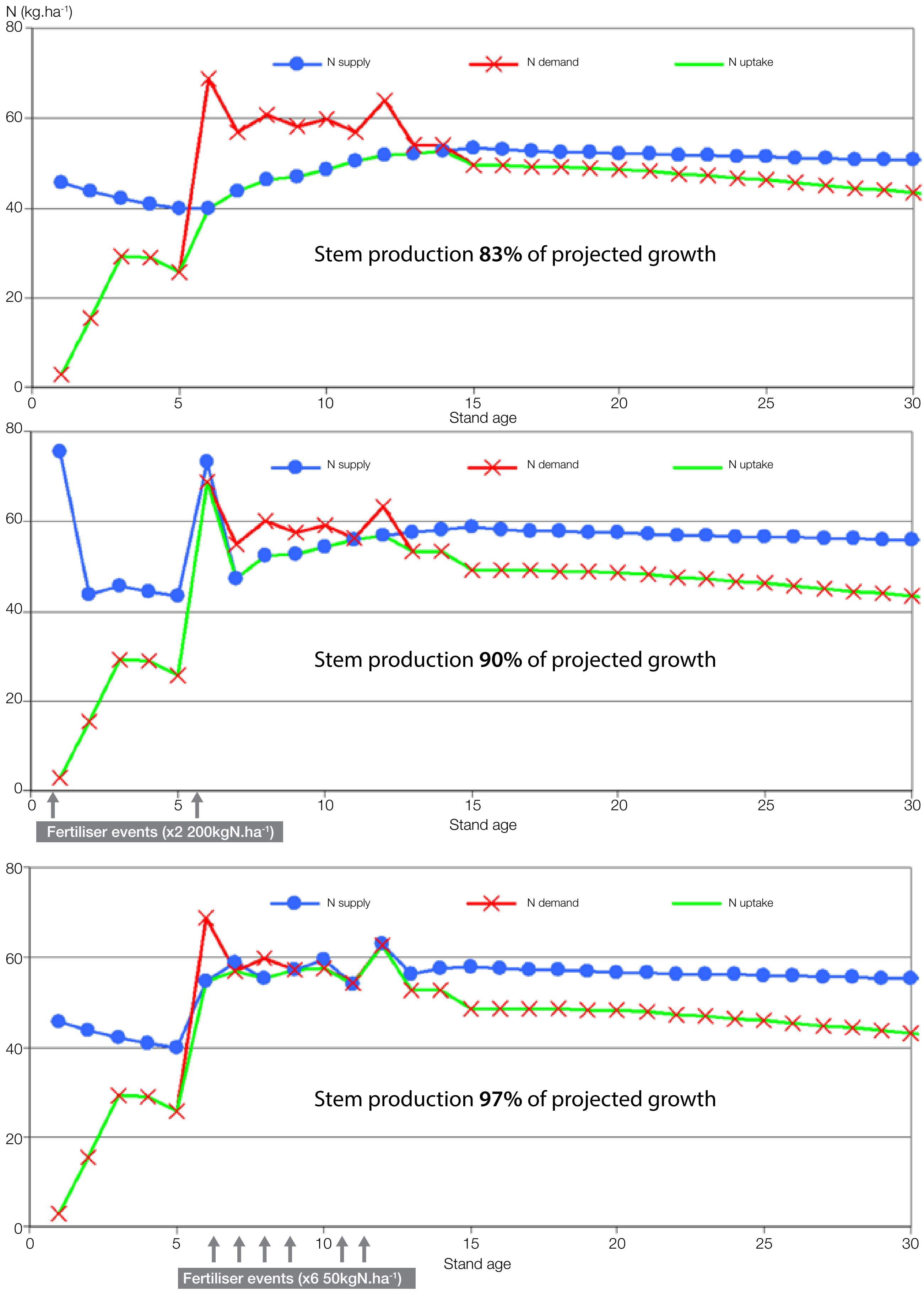

Figure 2: Hypothetical example of precision nitrogen (N) fertiliser management for targeting percent of projected stem production using NuBalM: a) with no intervention and 83% of projected growth, b) with two doses of 200kgN.ha^{-1} and 90% of projected growth, c) six doses of 50kgN.ha^{-1} and 97% of projected growth

required for planted forest soil to recover from erosion. Research in pasture soils has shown that post-erosion time required for soil to recover just a percentage of the original fertility is significant, reinforcing the impact of this disturbance (Rosser et al., 2011).

With a long rotation cycle in planted forestry, measuring the change in the soil resource over multiple rotations requires commitment to long-term permanent sample plots. Data from this type of trial across New Zealand planted forests, with time, will start to reveal the trends in the state of soil nutrient resource in flat and steepland forests. Moreover, the data can be used to estimate future nitrogen supply scenarios using NuBalM and add to its ability to predict other nutrients. To further improve NuBalM's ability to define initial site conditions at harvest, making the model spatial and linking to erosion and/or sediment generation predictions are essential steps that will make it more applicable to steepland environments.

Implications for inter-rotation planning

NuBalM offers the opportunity for 'precision nutrient management' for planted forests, predicting the nitrogen balance for the planted forest ecosystem and providing that ability to simulate the effects of interventions when nitrogen becomes a limiting factor to productivity (Figure 2). This will enable forest managers to establish silvicultural systems that are sustainable over multiple rotations, while also optimising the timing and extent of any nutrient applications that are necessary to overcome a projected deficiency. The predictions from NuBalM will be improved with on-site data on the forest stand and soil. Nutrient supply from the soil is the most difficult pool to model and collection of pre-harvest soil samples for nutrient analysis (Davis et al., 2015) will greatly improve NuBalM outputs.

The ability to predict changes in soil nutrients is important for the sustainable productivity of planted forests under current and intensified management practices. Mitigation management in steepland forestry to retain soil on-site and, where possible, retain the harvest residue within the forest ecosystem nutrient cycle will help in the supply of nutrients from one rotation to the next. Intervention with precision nutrient management may further improve the long-term production ability of sites sustainably.

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Example of hauler logging harvest residue distribution with most of the debris located around skid sites

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