Overview of the issues affecting fertiliser use in New Zealand's radiata pine forests

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Abstract

Fertiliser application has the capacity to improve the productivity, and potentially the sustainability, of the New Zealand radiata pine estate. While fertiliser is routinely used in locations where critical nutrient deficiencies can be addressed in a cost-effective manner, the uncertainty around the return on investment in fertiliser and concern about negative impacts on wood properties has largely curtailed attempts to transition fertiliser from a deficit management tool to a growth enhancement option. Scion is conducting research to improve the utility of fertiliser by increasing confidence in predictions of fertiliser response and test the effectiveness of new application methods. At the same time, Scion is also addressing potential consequences for wood properties and the wider environmental and regulatory issues associated with nutrient applications.

Introduction

Nutrient availability is a key driver of the ongoing productivity and health of planted forests (Jorgensen et al., 1975). Much research has therefore been devoted to understanding nutrient fluxes within New Zealand's radiata pine forests and examining how site and silvicultural management affects the retention, availability and export of various elements critical to forest growth (e.g. Dyck et al., 1987; Garrett et al., 2015; Smaill et al., 2008a). This research encompasses numerous studies of the impact of nitrogenous fertiliser applications on forest soil nutrient pools and availability in forest soils, and the consequences for forest growth (e.g. Mead et al., 1984; Smaill et al., 2008b; West, 1998). The effects of applications of phosphorus (e.g. Rivaie et al., 2008), magnesium (e.g. Olykan et al., 2001) and boron (e.g. Hunter et al., 1990) have also been explored in some depth.

The results of this research have been recently collated and summarised by Davis et al. (2015) to update the criteria and recommendations for fertiliser use in New Zealand planted forests that have underpinned their application for many years (Will, 1985). However despite this body of work, many issues and uncertainties about both the use and cost-effectiveness of fertiliser are still to be resolved. Due to a recent resurgence in sector interest in modifying site properties to enhance forest productivity (Moore & Clinton, 2015), it has become timely to revisit this work and identify new opportunities to increase the precision of fertiliser use in this country's planted forests. This article briefly reviews some of the issues around the effective application on nitrogen, phosphorus, magnesium and boron in the radiata pine plantations in New Zealand and discusses options to improve confidence in the outcomes of fertiliser use.

Issues limiting effective application of N, P, Mg and B in radiata pine forests

Published reports (e.g. Mead et al., 1984; West, 1998) and various other studies conducted by Scion and industry partners over several decades (summarised by Davis et al., 2015) have identified the potential for nitrogenous fertiliser to enhance forest growth. However there are a number of factors that limit the level of growth response to fertiliser (Davis et al., 2015), including the availability of other nutrients, the age and silvicultural history of the stand, weeds, moisture limitations and diseases. These additional factors, either singly or in combination, make it difficult to predict and extrapolate growth responses, introducing a significant level of risk into calculations of the likely economic returns from investment in nitrogenous fertiliser application. Concerns around reductions in wood density (Beets et al., 2001) and rising fertiliser costs have also further reduced interest in using nitrogenous fertilisers. These considerations have contributed to significant fluctuations in nitrogen additions to the New Zealand planted forest estate and an apparent decline in use since the late 1990s (Table 1). Some of the reduction in nitrogenous fertiliser use has been driven by variations in afforestation rates, but the extent of the decrease in applied mass is disproportionately greater, indicating that less nitrogen is being applied per unit of forest area.

For phosphorus, it has long been considered that radiata pine forests established in the West Coast, Coromandel, Auckland and Northland regions are susceptible to deficiencies in this nutrient and therefore respond positively to phosphorus addition. At a national level, a New Zealand-wide trial series that examined the importance of various soil factors in plantations under enhanced resource stress identified total soil phosphorus as a key driver of radiata pine growth (Watt et al., 2008). However despite the unequivocal need for phosphorus additions in various parts of the country to ensure the value of a given tree crop, and the potential benefits from enhancing phosphorous availability in other areas, recent discussions with sector stakeholders have confirmed there is still a significant need to provide an improved level of precision for where and when this nutrient should be applied. As is the case with nitrogen, this is driven by the unpredictable nature of the extent of the growth response to phosphorus such as: wholly positive effects (e.g. South & Skinner, 1999), positive effects under certain conditions (e.g. Hunter & Graham, 1983), or no effects (e.g. Rivaie et al., 2008). It is likely that this situation is contributing to an apparent decline in rates of use (Table 1).

Applications of magnesium and boron have predominantly been used to address issues that reduce forest health and quality. Magnesium deficiency leads to a condition known as upper mid-crown yellowing (UMCY), which reduces the effective crown of a radiata stand and diminishes productivity (Beets et al., 1993). Magnesium applications that have been trialled either prevented or treated this condition at various sites, and after limited success initially (Mitchell et al., 1999) successful applications have been made that have reduced UMCY incidence and in some cases restored diminished growth rates (Mitchell et al., 2003; Olykan et al., 2001). Given the extent of the potential negative impact of UMCY, applications of magnesium have become a standard component of forest management in susceptible forested areas. However engagement with forest managers in these areas indicates that operational practices could still be significantly improved through a better understanding of how a tree crop will respond to variations in the timing and amount of magnesium applied, based on soil type and the extent of the deficiency. Boron deficiency can promote stem malformations and reduce growth in juvenile radiata pine (Hunter et al., 1990), and trials have shown that boron applications can alleviate this condition and support better growth under some circumstances (Olykan et al., 2008). Due to the widespread nature of boron deficiency in areas considered suitable for radiata pine plantations (Will, 1990), boron applications are considered a necessity to ensure a satisfactory crop in various regions. However, as with magnesium, more detailed knowledge about the influence of site conditions and the optimisation of application rates would improve the efficiency of boron use.

Another area in which uncertainty has the potential to hinder nutrient management in the forestry sector is in the availability of data describing fertiliser use. It is clear that nitrogen, phosphorus, magnesium and boron are being applied, in some cases routinely, to radiata pine forests. However the lack of clear overall figures makes it difficult to determine the extent to which the sector is reliant on the use of fertiliser, and therefore the scale of any issues that could be precipitated by changes in the availability or regulation of fertilisers. Prudence dictates that forestry companies and associated enterprises capture this information at an individual level to evaluate the success of fertiliser treatments, but there is value in creating a sector-wide repository of fertiliser use data, assuming issues around commercial sensitivity can be resolved. This lack of transparency in the use of fertilisers will also make it difficult to advocate for large-scale fertiliser use in the face of emerging regulatory pressures to control their use in forests (Davis, 2014).

Radiata pine experiencing severe needle yellowing and loss due to a magnesium deficiency

Table 1: Nutrient additions to the NZ radiata pine estate over time (tonnes/yr)

Source	Year	N	P	Mg	B
Ballard & Will, 1978	1975	505 *	479 *	4.4 *	28 *
Will, 1981	1980	1,905	1,140	18	10
Will, 1987	1986	780	1,350	not available	17
Payn et al., 1998	1997	2,300	350	not available	>100
Fertiliser Association (estimate)	2011	<1,000	not available	not available	not available
Fertiliser Association (estimate)	2016	~700	not available	not available	not available

* Calculated from sector-wide figures and estimates of proportional allocations to seed orchards, nurseries and planted forests

Table 2: Projected annual nutrient additions (tonnes/yr) to meet specific scenario targets for 2025 (from Payn et al., 1998)

Scenario	N	P	Mg	B
Nutrient additions needed to remove nutrient limitations from a 2.5 Mha national planted forest estate	65,145	3,658	9,667	966
Nutrient additions needed to replace nutrient exports from a 2.5 Mha national planted forest estate using stem only removal harvesting	12,399	1,598	3,306	220
Nutrient additions needed for the successfully afforestation of land to maintain a 2.5 Mha national planted forest estate	625	972	207	43

Whatever the current figures are, it is certain they are not on a trajectory to meet projected values for the annual fertiliser use to required support maximum forest productivity by 2025, nor do they approach the figure for the maintenance of nutrient pools in response to harvesting (Table 2). While some of this shortfall will clearly be related to the difference between projected and actual planted forest area, it is evident that sustained enhancements to forest productivity will require greater fertiliser use than is currently taking place within the sector.

Emerging pressures on nutrient management in NZ's planted forests

The New Zealand Forest Owners Association has established a target of becoming this country's leading export industry and a top five global supplier by 2025 (NZFOA, 2016). Moore and Clinton (2015) recently discussed some of the drivers of this industry ambition and described a new research programme – Growing Confidence in Forestry's Future (https://gcff.nz/) – funded by the Ministry for Business, Innovation and Employment and the Forest Growers Trust that will help achieve this ambition. While numerous factors are involved in attaining this target, the increases in productivity required will not be met solely by genetic gain and increased temperatures. The sector will need an improved capability to understand and manipulate site nutrition, as indicated in Payn et al. (1998).

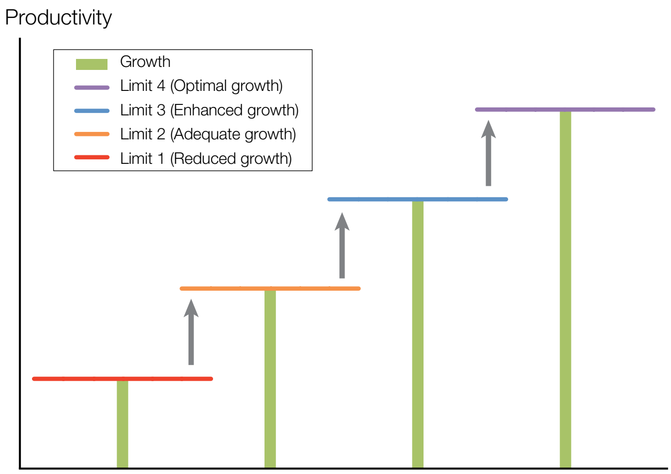

Figure 1: Hypothetical example of fertiliser application (blue arrows) lifting the limitations on site productivity by eliminating one limitation to growth until the next is reached, then taking the action required to eliminate that limitation and raise growth rates to the following limit

Any increases in the uptake of site resources will also need to be sustainable to maximise benefits from future conditions and avoid degrading soil capital (Garrett et al., 2015). The ability to transition fertiliser use from a predominantly deficit avoidance strategy to a growth enhancement strategy (Figure 1), while remaining within future environmental limits, will also be needed. This presents a number of significant issues around current confidence in return on investment from traditional fertiliser products and their use, both from an economic and environmental perspective, as well as alleviating concerns around potential consequences for wood properties. Increased nutrient application will also trigger various regulatory concerns, particularly in relation to the loss of nitrogen and phosphorus into waterways, which is a significant issue in New Zealand (PCE, 2015).

Options to improve confidence in outcomes from fertiliser use

Overseas research has demonstrated it is possible to use fertiliser effectively at a wide scale. The successful intensification of productivity in the pine forest estate in the south-eastern United States has been driven to a significant extent by improved efficiency in fertiliser use, which was supported by efforts to better understand variations in nutrient availability (Jokela et al., 2010). Foliage sampling and analysis is the principal tool available to managers to assess the nutritional status of their forests, and Scion supports nutritional evaluations through a monitoring system maintained with industry partners (Payn et al., 2013). This provides a useful yardstick of relative nutrient supply and demand that can help drive improved fertiliser use, but sample collection is not extensive, and this approach does not fully account for the effect of climatic fluctuations on the ability of soil to supply nutrients (Payn & Clinton, 2005), thus reducing the precision of this data. A renewed emphasis on investigating the soil itself as a long-term indicator of fertiliser response has also developed (Smethurst, 2010). Recent Scion research has indicated that a combination of soil and climatic data appears to provide more accurate prediction of growth response to nitrogenous fertiliser use, for both deficit removal and growth enhancement, than traditional foliar parameters. Due in part to these outcomes, stakeholders within the New Zealand forestry sector are now beginning to invest in new soil sampling campaigns.

Other systems to improve confidence in fertiliser response have also been under development. A recent research outcome is the completion of a national productivity gap surface, which provides new capability to identify forest stands where productivity is below biological potential due to temperature and other climatic factors. This, in turn, helps identify where fertiliser use should have the greatest impact on growth. New remote sensing technologies are also being investigated, focusing on the potential to use spectral imaging and analysis to rapidly and precisely identify nutrient deficiencies based on foliar properties.

Concerns around the sustainability of nutrient removals over multiple rotations are also being extensively studied by Scion (Garrett et al., 2015). This work revolves around end-of-rotation analysis at a number of long-term trial sites established to determine the impacts of variations in site and nutrient management (Smaill et al., 2008a, 2008b). These trials have recently yielded significant new data around the factors that influence the nutritional sustainability of forest management, and the effectiveness of fertiliser use as an option to alleviate any negative impacts. This data is also being used to improve the nutrient balance model NuBalM (Smaill et al., 2011), which is currently being redeveloped as a stakeholder tool to help improve the precision of nutrient applications in radiata pine plantations for both individual nutrients and the relative ratios of multiple nutrients. These long-term studies have also provided an opportunity to explore how fertiliser use affects the soil microbial processes that influence radiata pine growth and health, adding a new dimension to the evaluation of fertiliser response (e.g. Smaill et al., 2010).

Scion is also driving efforts to identify new fertiliser products, and new methods to deliver those products that will increase the cost-effectiveness of nutrient applications. This includes detailed examinations of growth response to the foliar application of nutrients, and the impacts of adding nutrients in complex molecules as opposed to simple elemental forms. This research is partnered with investigations of the fundamental processes driving wood formation, providing new information that can be used to better understand the impact of nitrogen and other nutrients on wood quality over time. Results to date suggest some of these new products and application techniques also have lower environmental impacts, and should enable fertiliser use to continue under future regulatory constraints.

The redevelopment of NuBalM by Scion is also driven by the emerging need to provide a reliable system to address regulatory concerns around the use of fertiliser in the New Zealand planted forest estate. A plan to address these concerns has been generated with input from forest growers and regulators, although the depth of data required indicates that a fully operational model will not be available for some time. Some components of the model will, however, be available in the near future and will still offer valuable information to stakeholders seeking to optimise productivity enhancement and reductions in negative environmental impacts.

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References

Beets, P.N., Gilchrist, K. and Jeffreys, M.P. 2001. Wood Density of Radiata Pine: Effect of Nitrogen Supply. *Forest Ecology and Management*, 145: 173–180.

Beets, P.N., Payn, T.W. and Jokela, E.J. 1993. Upper Mid-Crown Yellowing (UMCY) in *Pinus radiata* Forests. *New Zealand Journal of Forestry*, 38: 24–28.

Davis, M. 2014. Nitrogen Leaching Losses from Forests in New Zealand. *New Zealand Journal of Forestry Science*, 44: 1–14.

Davis, M., Xue, J. and Clinton, P. 2015. *Planted-Forest Nutrition*. Rotorua, NZ: Scion.

Dyck, W.J. and Beets, P.N. 1987. Managing for Long-Term Site Productivity. *New Zealand Forestry*, Nov: 23–26.

Garrett, L.G., Smaill, S.J. and Clinton, P.W. 2015. Nutrient Supply One Rotation to the Next. *New Zealand Journal of Forestry*, 60: 16–20.

Hunter, I.R. and Graham, J.D. 1983. Three-Year Response of *Pinus radiata* to Several Types and Rates of Phosphorus Fertiliser on Soils of Contrasting Phosphorus Retention. *New Zealand Journal of Forestry Science*, 13: 229–238.

Hunter, I.R., Will, G.M. and Skinner, M.F. 1990. A Strategy for the Correction of Boron Deficiency in Radiata Pine Plantations in New Zealand. *Forest Ecology and Management*, 37: 77–82.

Jokela, E.J., Martin, T.A. and Vogel, J.G. 2010. Twenty-Five Years of Intensive Forest Management With Southern Pines: Important Lessons Learned. *Journal of Forestry*, 108: 338–347.

Jorgensen, J., Wells, C. and Metz, L. 1975. The Nutrient Cycle: Key to Continuous Forest Production. *Journal of Forestry*, 73: 400–403.

Mead, D.J., Draper, D. and Madgwick, H.A.I. 1984. Dry Matter Production of a Young Stand of *Pinus radiata*: Some Effects of Nitrogen Fertiliser and Thinning. *New Zealand Journal of Forestry Science*, 14: 97–108.

Mitchell, A.D., Loganathan, P., Payn, T.W. and Olykan, S.T. 2003. Magnesium and Potassium Fertiliser Effects on Foliar Magnesium and Potassium Concentrations and Upper Mid-Crown Yellowing in *Pinus radiata*. *New Zealand Journal of Forestry Science*, 33: 225–243.

Mitchell, A.D., Loganathan, P., Payn, T.W. and Tillman, R.W. 1999. Effect of Calcined Magnesite on Soil and *Pinus radiata* Foliage Magnesium in Pumice Soils of New Zealand. *Australian Journal of Soil Research*, 37: 545–560.

Moore, J. and Clinton, P.W. 2015. Enhancing the Productivity of Radiata Pine Forestry With Environmental Limits. *New Zealand Journal of Forestry*, 60: 35–41.

New Zealand Forest Owners Association. 2016. Available at: www.nzfoa.org.nz/plantation-forestry.

Olykan, S., Payn, T., Beets, P. and Kimberley, M. 2001. Magnesium Fertilisers Affected Growth, Upper Mid-Crown Yellowing, and Foliar Nutrients of *Pinus radiata*, and Soil Magnesium Concentration. *New Zealand Journal of Forestry Science*, 31: 34–50.

Olykan, S.T., Xue, J., Clinton, P.W., Skinner, M.F., Graham, D.J. and Leckie, A.C. 2008. Effect of Boron Fertiliser, Weed Control and Genotype on Foliar Nutrients and Tree Growth of Juvenile *Pinus radiata* at Two Contrasting Sites in New Zealand. *Forest Ecology and Management*, 255: 1196–1209.

Parliamentary Commissioner for the Environment (PCE). 2015. *Update Report On Water Quality in New Zealand: Land Use and Nutrient Pollution*. Wellington, NZ: PCE. 27 p.

Payn, T.W., Beare, M.H., Shepherd, M.J., Bayne, K.M., Botha, N., Collins, A., Curtin, D., Davis, M.R., Fraser, P., Hedley, C.D., Hoogendoorn, C., Johnstone, P., Lucci, G., Parfitt, R.L. and Xue, J. 2013. *Nutrient Management Science – State of Knowledge, Use and Uptake in New Zealand*. Prepared for the Ministry for Primary Industries. pp. 439.

Payn, T.W. and Clinton, P.W. 2005. The Environmental Footprint of New Zealand's Plantation Forests: Nutrient Fluxes and Balances. *New Zealand Journal of Forestry*, 50: 17–22.

Payn, T.W., Skinner, M.F. and Clinton, P.W. 1998. Future Nutrient Requirements of New Zealand Plantation Forests. In L.D. Currie and P. Loganathan (Eds), *Long-Term Nutrient Needs for New Zealand's Primary Industries: Global Supply, Production Requirements and Environmental Constraints – Occasional Report No. 11*. Palmerston North, NZ: Fertilizer and Lime Research Centre. pp. 97–106.

Rivaie, A.A., Loganathan, P., Graham, J.D., Tillman, R.W. and Payn, T.W. 2008. Effect of Phosphate Rock and Triple Superphosphate on Soil Phosphorus Fractions and Their Plant-Availability and Downward Movement in Two Volcanic Ash Soils Under *Pinus radiata* Plantations in New Zealand. *Nutrient Cycling in Agroecosystems*, 82: 75–88.

Smaill, S.J., Clinton, P.W. and Greenfield, L.G. 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.J., Clinton, P.W. and Greenfield, L.G. 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.

Smaill, S.J., Clinton, P.W. and Höck, B. 2011. A Nutrient Balance Model (NuBalM) to Predict Biomass and Nitrogen Pools in *Pinus radiata* Forests. *Forest Ecology and Management*, 262: 270–277.

Smaill, S.J., Leckie, A.C., Clinton, P.W. and Hickson, A.C. 2010. Plantation Management Induces Long-Term Alterations to Bacterial Phytohormone Production and Activity in Bulk Soil. *Applied Soil Ecology*, 45: 310–314.

Smethurst, P.J. 2010. Forest Fertilization: Trends in Knowledge and Practice Compared to Agriculture. *Plant and Soil*, 335: 83–100.

South, D.B. and Skinner, M.F. 1999. Nursery Stock and Field Fertiliser Application Affect Early Performance of *Pinus radiata* on a Phosphorus-Deficient Site in Northland. *New Zealand Journal of Forestry Science*, 28: 361–372.

Watt, M.S., Davis, M.R., Clinton, P.W., Coker, G., Ross, C., Dando, J., Parfitt, R.L. and Simcock, R. 2008. Identification of Key Soil Indicators Influencing Plantation Productivity and Sustainability Across a National Trial Series in New Zealand. *Forest Ecology and Management*, 256: 180–190.

West, G.G. 1998. *Pinus radiata* Growth Responses to Pruning, Thinning and Nitrogen Fertiliser in Kaingaroa Forest. *New Zealand Journal of Forestry Science*, 28, 165–181.

Will, G.M. 1985. Nutrient Deficiencies and Fertiliser Use in New Zealand Exotic Forests. *Forest Research Institute Bulletin No. 97*. Rotorua, NZ: FRI.

Will, G.M. 1987. *Fertiliser Use in New Zealand Forestry*. Unpublished report to the New Zealand Forest Site Management Cooperative.

Will, G.M. 1990. Influence of Trace-Element Deficiencies on Plantation Forestry in New Zealand. *Forest Ecology and Management*, 37: 1–6.

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