Long-term site productivity research – 30 plus years in the making

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Abstract

Research that spans the full cycle of a stand of trees is rare. This paper summaries a series of recently published articles that provide detailed assessments of the impacts of intensive forest harvesting residue management over the life of several trials located around New Zealand. Key findings were that the impact of increasing harvest residue and forest floor removal on tree productivity was significant only on the poorer site where soil nitrogen pools were initially low, and the intensive residue removal further reduced nutrient pools. However, wood quality at the end of the rotation at the poorer site was not affected. The importance of the forest floor to nutrient storage and supply was demonstrated at the low nutrient sites. These findings demonstrate a need for site-specific management strategies if harvest residues are to be removed for use as feedstocks. The conclusions generated from this long-term research will be of benefit to the New Zealand forestry sector for many years to come. Future research needs are also described, with specific attention to the increasing proportion of planted forests that are entering their second or third or fourth rotation.

Introduction

Research findings from both a national and internationally significant long-term trial series located in New Zealand have recently been published in a series of seven papers. Several of these papers were part of a special issue focusing on long-term planted forest sustainability in the international journal *Forest Ecology and Management* (Hatten et al., 2021). These seven papers add to a legacy of more than 30 research articles from this trial series. Given that the first paper reporting on this long-term trial series was published in the *New Zealand Journal of Forestry* in 1987, it is appropriate to use this journal as a vehicle for reporting the cumulation of nearly 40 years of research at these sites, spanning three generations of researchers and forest managers (Dyck & Beets, 1987).

Sustainability of forest soil nutrient supply

The harvest of planted forests removes biomass and the nutrients they contain from the site. Early in the development of New Zealand's planted forestry estate, research questions were asked about the sustainability of biomass removal and the potential impact on the long-term ability of a site to supply the nutrients required for sustainable forest production. Initial nutrition research on New Zealand's planted forests demonstrated that reduced nutrient supply, occurring as a result of harvesting over multiple rotations (Will & Knight, 1968; Webber, 1978; Dyck & Beets, 1987), or large-scale disturbance of the forest floor and surface soils during harvesting (Ballard, 1978; Ballard & Will, 1981), did have consequences for future forest productivity. This research was subsequently identified as being relevant to assessments of the use of harvesting residues as feedstocks for bioenergy (Dyck et al., 1991).

To address questions around the sustainability of removing forest residues for bioenergy feedstocks the Long-Term Site Productivity (LTSP) trial series was initiated in the 1980s. From 1986 to 1992 six sites were installed (Woodhill, Tarawera and Kinleith in the North Island; Golden Downs, Burnham and Berwick in the South Island), providing a soil fertility gradient spanning recent volcanic soils to highly weathered greywacke gravels. The trials were designed to examine the long-term consequences of increasing levels of biomass removal at harvest, typical of a range of management practices. The intensity of the harvesting treatments varied from removing the tree stem only (SO), removing the whole tree (WT) through to removing the whole tree and the forest floor (FF) (Figure 1). This effort was part of a global initiative to install LTSP harvest removal trials. These treatments have now been repeated in many locations throughout the world (Achat et al., 2015) and represent possible biomass removal through conventional harvesting.

Findings from the New Zealand LTSP trial series indicated that the impact of increasing harvest residue and forest floor removal on tree productivity was significant only at Woodhill Forest (Table 1), where soil nitrogen pools were initially low and the intensive residue removal further reduced nutrient pools (Garrett et al., 2021b). However, this did not impact on end of rotation wood quality at Woodhill Forest (Moore et al., 2021). The end of rotation findings also showed there was limited negative long-term impact on soil nutrient supply with SO and WT removal, but at sites with low initial soil fertility the FF treatment negatively impacted soil fertility (Garrett et al., 2021b). The importance of the forest floor to nutrient storage and supply has been demonstrated for these low nutrient sites where, for example, the forest floor can make up 21% of the forest ecosystem nitrogen pool (Woodhill) compared to just 2% of the forest ecosystem nitrogen pool at more fertile sites (Berwick).

These findings demonstrate a need for site-specific management strategies if residues and forest floor are to be removed for bioenergy feedstocks (Garrett et al., 2021a). This consideration is particularly important in New Zealand, where planted forests are supported by soils with a wide range of soil fertility due to variations in soil types and legacy effects from previous land uses (e.g. fertiliser use for pastoral grazing) (Watt et al., 2008; Ross et al., 2009; Beets et al., 2019). Therefore, some sites are inherently more capable of buffering the impact of intensive harvest residue removal compared to others. Overall, the body of work published in the seven papers demonstrates the sustainability of planted forestry in New Zealand, which is essential for public acceptance of these forests and also for meeting the requirements of external agencies such as the Forest Stewardship Council.

The importance of maintaining the forest floor can been seen in Figure 1 where the Nutrient Balance Model (NuBalM) has been used to illustrate the impact of removing the forest floor at Woodhill Forest.

Assessments of soil biodiversity demonstrated the degree to which the soil microbial communities varied between sites, but regardless of these inherent differences the diversity of the soil fungal communities was consistently reduced by the FF treatment compared to the SO treatment (Addison et al., 2019). Interestingly, in contrast, the response of the soil bacterial communities showed no evidence of long-term effects indicating that soil bacteria were less sensitive to different environmental pressures created by variations in harvest removal management.

Table 1: Main treatment – forest floor removal (FF), whole tree (WT), stem only (SO) – effects on tree stocking, mean top height, stand basal area and volume 27 years after establishment at Woodhill Forest

	FF	WT	SO
Stocking (stems ha^{-1})	583	575	542
Mean top height (m)	33.4	32.2	32.1
Basal area adjusted for stocking (m^2 ha^{-1})	48.9a	55.3b	55.9b
Stem volume adjusted for stocking (m^3 ha^{-1})	540	591	601
Age when DBH=35 cm (years)	28.6a	25.6ab	25.5b

Note: Basal area and volume are shown for a standardised mean stocking of 549 stems ha^{-1} (using analysis of covariance). Also shown is the estimated age when trees achieved a quadratic mean DBH of 35 cm. Significant differences between harvesting treatments are identified by letters. Source: From Garrett et al. (2021b)

The lessons learnt from the research are globally relevant, not only for other radiata pine growing countries but for other forest plantation species. This global reach has been supported by the fact that the research has been reported in several very highly ranked international peer reviewed journals, for example, in *Soil Biology and Biochemistry* (Huang et al., 2011), which is ranked second in the field of soil science, and in *Biology and Fertility of Soils* (Smaill et al., 2010) ranked number three (top 1%) of 334 agronomy and crop science journals.

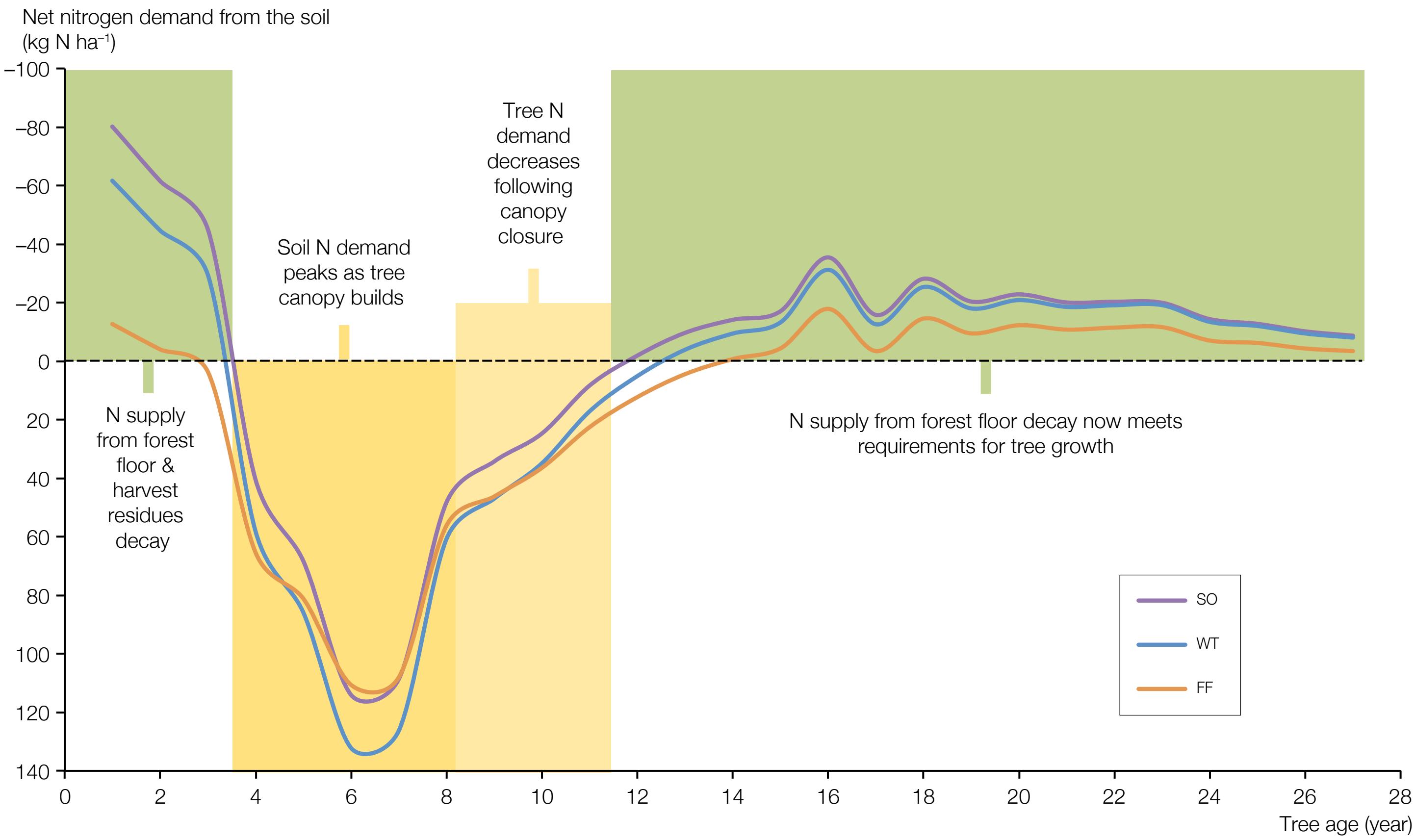

Figure 1: Tree crop nitrogen demand over a rotation for the stem only (SO), whole tree (WT) and whole tree plus forest floor removal (FF) treatments at Woodhill Forest estimated using NuBalM with thinning occurring at age seven and 15 years

Legacy of research infrastructure

The LTSP harvest residue removal trials have provided the framework in which the original objectives of the trials have been addressed, cumulating in a final assessment of tree productivity and soil and biomass nutrient stocks at the time of tree harvest (Garrett et al., 2021b). In addition, intensive timeseries measurements of forest biomass and where in the forest ecosystem nutrients are held (e.g. in the soil, forest floor and live tree) have been made.

Many new additional research projects have emerged as a result of the trial infrastructure. Examples of how this infrastructure supported new research directions is provided by the emergence of the NuBalM (Smaill et al., 2011) and the study of the forest floor and soil microbiome (Smaill et al., 2010). This work has been further built on in recent years and unearthed a greater understanding of the impacts of intensive residue management practices on soil biodiversity (Addison et al., 2019, 2021).

A variety of research findings have been reported in the numerous publications based on the research infrastructure provided by the six trials. There is not sufficient space in this paper to fairly summarise the 30 or more papers so the focus of this summary will be directed to a few key points raised in the most recent papers. Garrett et al. (2021a) provides an excellent summary of the key lessons learnt over the years and we suggest this is the best place to start any assessment of the value this trial series has provided.

Considerable effort was expended at the establishment of each of the trials to describe the preharvest tree and soil nutrient pools (Figure 2). This data now represents an important source of information describing the variation in planted forest ecosystem carbon storage, nutrient storage and site quality (Garrett et al., 2019).

The duration of the trials themselves highlight the many issues and challenges that confront long-term research projects of this nature. For example, changes in personnel, funding arrangements and pressures from land use change and the climate itself all played a part in determining outcomes across the six trial sites. These factors all came into play at one point or another for the trials, threatening both the quality of the data that could be collected and the return on the investment made in the establishment and maintenance of the sites. Some events were effectively out of context problems, with two sites being lost due to conversions of land use from forestry to pasture and the Golden Downs site (Nelson) being subjected to a catastrophic windthrow event.

Bioenergy

As was the case when the trials were established, the use of harvest residues for bioenergy feedstocks is still currently under active consideration in New Zealand (Suckling et al., 2018), as well as on the international

Figure 2: Removal of the forest floor in a trial plot at Woodhill Forest prior to harvest. Source: Photo courtesy of Bill Dyck

stage. Around the world there is much debate about the sustainability of this practice and the climate effects of bioenergy (Cowie et al., 2021). Even though these local trials examined the impact of harvesting residue removal intensity after one rotation, the question still remains as to what might happen in subsequent rotations. This issue will gain more attention in the coming years as an increasing proportion of the current planted forest estate enters into its third or fourth rotation and reductions in the use of fossil fuels increases the attractiveness of bioenergy production from forest residues. The findings generated by the LTSP trials over 30 years can be used to address issues arising around the sustainability of biomass harvesting (e.g. Vance et al., 2014) and could prove very useful in underpinning any development of local guidelines (e.g. Titus et al., 2021) to support the use of forest residues for bioenergy or feedstocks for tree-based biorefineries.

The results provide confidence that not only is the productive capacity of most sites unlikely to be impacted upon by one rotation, but wider encouragement that the future security of forest carbon pools and sequestration capacity is also maintained. This confidence also extends to issues of:

- Energy security, should local forest biomass use become important to the economy
- Regional economic growth and the supply of timber for onshore processing, to ensure it is not impacted upon
- Future exports of timber products, to ensure they are maintained
- Reducing the carbon footprint of exporters through the sustainable production of bioenergy.

Future demands on forest soils

It is important to continue this line of research because there will be an increasing area of third and fourth rotations arising in the not too distant future (Garrett et al., 2021). Consequently, it will be important to understand not just the consequences of crop and/or residue removal after one rotation, but also after two or three or four rotations (Smaill & Garrett, 2016). Increasing global demand for timber products is creating more pressure on forests and new management practices will need to be developed to buffer the soil resources against any pressures resulting from intensification (e.g. shorter rotations, higher stocked stands, more disturbance and residue removal) (Clinton, 2018) However, new technologies promise the potential to avoid some negative impacts, such as robotic harvesting systems that protect the soil surface from disturbance while improving worker safety (Parker et al., 2016). Strategies to ameliorate nutrient removals, particularly nitrogen, may include the use of nitrogen-fixing plants during periods of increased nutrient demand up until canopy closure (e.g. West et al., 1991). It is even more important to maintain and enhance productivity of our planted forests here in New Zealand given the reliance on forestry to meet the country's zero carbon emissions aspirations. Overall, the research described in this review shows that it is better to keep what you have in terms of site resources, such as those contained in the forest floor, than to rely on the use of mineral fertilisers.

What's next?

It was not anticipated at the time of the trial establishment that they would be re-established to study a subsequent third rotation. However, an evaluation of the pros and cons of continuing the trials at the existing sites following harvest, and significant issues related to the size of the plots, the pressures of prior sampling and the use of large amounts of fertiliser were identified. Consequently, no attempt was made to re-establish any of the trials for another rotation.

The new Accelerator trial series that was established to study and monitor the impacts of intensification are now providing research infrastructure to explore a number of research questions, for example, the use of drones to identify individual trees at a young age and monitor their growth (Hartley et al., 2020). The trials are examining a range of management options, including novel plant biostimulants, greater stockings, new genetics and site preparation techniques, all while capturing sufficient data to assess the sustainability of these treatments.

Although the scenario of increasing rotation numbers has been modelled, the impact of intensification of management practices through greater stocking rates, the deployment of faster-growing genotypes and shorter rotations still needs further examination across a range of soil types. These questions are likely to become the focus of new research projects in the near future.

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