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Interactive effects of simultaneously applied thinning, pruning and fertiliser application treatments on growth, biomass production and crown architecture in a young *Eucalyptus nitens* plantation

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ABSTRACT

Thinning, pruning and fertiliser are often applied simultaneously but interactions between these treatments are rarely examined. This may inhibit managers from making the most of these silvicultural investments. This study examined whether thinning, pruning and nitrogen fertiliser application at age 3.2 years, interact with each other to influence the growth and crown architecture of *Eucalyptus nitens* trees to age 8.1 years. Two levels of each treatment were applied in a factorial design replicated three times in a plantation near Carrajung, Victoria, Australia. Treatments included: unthinned, or thinned from ca. 900 to 300 trees ha^{-1}; unpruned, or 50% of the live crown length pruned of the largest 300 potential sawlog crop trees ha^{-1}; and nil, or 300 kg ha^{-1} N fertiliser. All treatments interacted, such that by age 6 years the relative pruning effects were greater in thinned and fertiliser application treatments. The treatment interactions observed were consistent with ecological theory relating to the influence of resource availability on defoliation. Increases in crown size after thinning and fertiliser application were associated with increases in branch sizes and longevities. Leaf area density (m^2 leaf area per m^3 volume of a given crown section) increased with height in the crown and treatments had only a minor influence on this trend. Thinning and fertiliser also increased the ratio of leaf to wood mass, while pruning had the opposite effect, and all were independent of differences in tree size. Due to these treatment effects on biomass partitioning, treatment interactions in terms of stand above-ground biomass of the largest 200 potential sawlog crop trees ha^{-1} were not significant. Despite significant variability across treatments, stand level biomass growth across all treatments was closely related to leaf area index, with deviations occurring for about one year after thinning and pruning due to increases in the growth efficiency expressed as volume growth per unit leaf area. This study illustrates the crown plasticity with which foresters can work to achieve specific management goals relating to growth rates and log quality. It also shows that responses to thinning, pruning and fertiliser application may not be independent of each other, with both thinning and fertiliser application increasing the effects of pruning.

1. Introduction

Thinning, pruning and fertiliser application are used to accelerate the growth of crop trees and to improve wood quality and value in plantation forests. Many studies have examined the growth responses to each of these silvicultural treatments as well as some of the mechanisms behind them (e.g. for eucalypts see Forrester et al., 2010). However, despite the fact that treatments are often applied simultaneously, less is known about how these treatments interact (Forrester and Baker, in press). For example, to make the most of pruning, thinning and/or fertiliser application is used to increase growth rates of the retained trees and hence the production of knot-free or clear wood. Thus knowledge of how silvicultural treatments interact can assist with optimising financial investment and returns.

Nitrogen (N) fertiliser application can increase growth by increasing leaf area, branch size and branch longevity (Wiseman et al., 2006), as well as reducing the proportion of biomass partitioned below ground (Litton et al., 2007). Thinning can lead to similar responses (Medhurst and Beadle, 2001). However thinning also provides trees with more space to expand their root and crown

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zones, which in turn increases their supplies of light, water and nutrients. Not only can thinning result in larger crowns, it can also shift the vertical distribution of foliage so that it is less skewed towards the top of the crown (Brix, 1981; Medhurst and Beadle, 2001). Since stand growth is closely related to the development of tree crowns, the differing response mechanisms to thinning and fertiliser application could result in interactions between these treatments on crown sizes, architectures and hence tree and stand growth.

Ecological theory concerning modes of competition also dictates that an interaction between thinning and fertiliser application (or site quality) is possible. Competition for light will be size-asymmetric if tall trees can shade shorter trees but not vice versa. In contrast competition for water and nutrients will be more size-symmetric because the roots of smaller trees can generally take up similar amounts of these resources per unit root area (Weiner, 1985, 1986; Kikuzawa and Umeki, 1996). Thus where light is the primary factor limiting growth, such as on a high quality site or because of fertiliser inputs, competition is likely to be size-asymmetric and tall trees may be relatively less responsive to thinning compared to lower quality sites or in unfertilised stands; in these, competition is likely to be more size-symmetric, and tall trees may benefit more from the removal of smaller trees. Nevertheless, although the relative growth response to thinning may be greater on lower quality/unfertilised sites, the absolute responses may still be greater on higher quality/fertilised sites simply because of much faster growth rates.

Thinning studies in forestry that consider the effects of site quality, or that incorporate different fertiliser treatments are uncommon; even fewer studies focus on a given dominance class, such as the largest-diameter crop trees that have potential for sawlogs. Dominance class is a crucial variable that allows definition of different responses by different size classes. However, even in studies that meet these criteria, their findings vary between increases in relative thinning responses with increasing site quality or fertiliser application (Stoneman et al., 1996), to inconsistent trends or no interactions (Messina, 1992; Mäkinen and Isomäki, 2004b; Omule et al., 2011).

While thinning and fertiliser can increase growth rates, they can reduce wood quality by encouraging the development of larger branches and more wood defect resulting from knotty wood (Montagu et al., 2003; Pinkard and Neilsen, 2003). Pruning is often used to improve wood quality by removing lower branches so that clear, knot-free wood is grown. Pruning immediately reduces the leaf area and alters the diameter distribution of branches. It can also increase leaf-level rates of photosynthesis in the remaining foliage (see review by Forrester et al., 2010). Pruning is often done around the time of thinning and fertiliser application to counter the effects those treatments might have on wood quality.

The Limiting Resource Model (Wise and Abrahamson, 2007) suggests that growth responses to pruning and defoliation depend on the resources that are currently limiting growth and how their capture is changed by loss of leaf area. Experiments have shown that the influence of fertiliser application or site quality on growth responses to pruning and defoliation is variable with greater effects under higher resource supply (e.g. see review by Wise and Abrahamson, 2007), lower resource supply (Pinkard and Beadle, 1998; Anttonen et al., 2002; Pinkard, 2002) or no interaction (Pinkard et al., 2006; Wiseman et al., 2009). Interactions between thinning and pruning are also possible. In unthinned stands where the lower canopy foliage is poorly lit, pruning may have little influence on growth; in thinned stands where the lower canopy is well lit, its removal may have a substantial influence on growth (Forrester and Baker, in press).

Few studies in forestry have included each of thinning, pruning and fertiliser, or explored their interactions (Messina, 1992; Velazquez-Martinez et al., 1992; Forrester and Baker, in press). Similarly, few have specifically examined the response of different dominance classes to these treatments, which often vary in both absolute and relative terms (Moore et al., 1994; Pukkala et al., 1998; Mäkinen and Isomäki, 2004a), but instead have focused on total stand responses, which can hide or confound treatment effects on crop trees. In the study reported here, we focus on the potential sawlog crop trees (SCT), which are usually the most valuable in thinned and pruned stands; they are defined as the largest-diameter 200 trees ha^{-1} (SCT_{200}).

Our objective was to examine interactions by implementing thinning, pruning and fertiliser treatments simultaneously in an *Eucalyptus nitens* (Deane and Maiden) plantation near Carrajung in Victoria, Australia. We hypothesised that thinning, pruning and fertiliser application would interact with each other as follows: (1) that by reducing tree leaf area pruning reduces the ability of a tree to respond to thinning, and that thinning increases the pruning effect because in thinned stands the lower crown is well lit and contributes more to carbon (C) fixation than that of unthinned stands where the lower crown is shaded; (2) that any loss in growth after pruning may be lower without nitrogen fertiliser application because trees do not have the nutrients required to maintain their lower crowns which are naturally shed, whereas the lower crowns of fertilised trees are more efficient, retained for longer, and their loss via pruning will have a greater effect on growth; and (3) that nitrogen fertiliser application would increase absolute, but reduce relative thinning responses. These hypotheses were tested by comparing stand level above-ground biomass, volume and leaf areas and tree-level measures of crown sizes and crown architectures.

2. Methodology

2.1. Site and plantation establishment

The study was conducted in an *E. nitens* (Deane and Maiden) plantation located 1.5 km south-west of Carrajung, Victoria, Australia (38°23′ S, 146°41′ E). The site elevation is about 610 m ASL and with a north-easterly aspect. Mean annual pan evaporation is 1039 mm, and precipitation 1124 mm with a spring maximum. Mean daily maximum temperature is 22.3 °C in January and mean daily minimum temperature is 3.9 °C in July. The soils have a gradational texture profile, with silty loam to clay loam A horizons and light clay to medium clay B horizons. They are classified humose-acidic, dystrophic, red or brown dermosols (Isbell, 1998), Gn4.11 or Gn4.71 Primary Profile Form (Northcote, 1979). The profile is mildly acidic with pH (1:5 soil:water) about 4.8. The immediately previous land-use was *Eucalyptus regnans* plantation. *E. nitens* seedlings were planted in June 2003 at a spacing of 4 × 2.5 m (1000 trees ha^{-1}) and the canopies had closed about 6 months before the study began at age 3.2 years. Weeds were controlled with pre-planting application of knock-down and pre-emergent herbicides. Fertiliser was applied to individual trees 2 and 12 months after planting, a total equivalent of 170 N, 110 P and 50 K kg ha^{-1}.

2.2. Experimental treatments, design and layout

The trial design was a 2 × 2 × 2 factorial design with two levels each of thinning, pruning and nitrogen fertiliser application, in a randomised block design with three replicates. Treatment plots were 10 rows wide (about 40 m) × 30 m in length (10–12 trees) with an inner tree-measurement plot with eight rows (about 32 m) × 8–10 trees (about 0.07 ha). Measured individual plot