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Impact of defoliation by *Essigella californica* on the growth of mature *Pinus radiata* and response to N, P and S fertilizer

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ABSTRACT

A study of responses of radiata pine (*Pinus radiata* D. Don) to fertilizer applied after thinning and the impact of repeated infestations of the Monterey pine aphid (*Essigella californica* Essig.) over 12 years showed that the defoliation of upper crowns was exacerbated by nutrient deficiencies of P and S. Remedial treatment with NPS fertilizers in 1997 and 2003 improved average retention of foliage especially during the second 6-year period of the study when damage from annual infestations of aphids was relatively consistent. In 2003 treatment with N, NP and NPS raised N and P in foliage to satisfactory levels while the sulfur status of trees ranged from severe deficiency to satisfactory. This increased average foliage retention by 6%, 12% and 20% compared with unfertilized trees. Corresponding volume responses to N, NP and NPS over 6 years were estimated at 12, 45, and 88 m^3 ha^{-1} at Warrenbayne and 19, 31 and 48 m^3 ha^{-1} at Stanley indicating a significant response to the remedial treatment of sulfur deficiency.

There was considerable variation in aphid damage between trees irrespective of fertilizer treatment reflecting strong genetic variation in susceptibility of radiata pine to defoliation by aphids. This had a substantial impact on tree growth showing a three to fourfold difference in basal area increment over 6 years across a wide range of aphid damage classes. The reduction in basal area increment was strongly correlated with average retention of upper crown foliage. Although remedial treatment with NPS increased average foliage retention from 50% to 70% therefore reducing aphid damage by 20%, a significant proportion of trees (around 25%) continued to be severely defoliated by aphids and did not respond to fertilizer. The reduction in basal area growth due to defoliation of trees treated with NPS fertilizer was estimated at approximately 30% over 6 years. Selective removal of susceptible trees at thinning was shown to be a feasible management strategy without any unacceptable changes in stand structure and reduced potential defoliation by aphids by 15%. This together with remedial fertilizer treatment provides a viable option for the management of radiata pine plantations to reduce aphid damage and improve stand productivity.

1. Introduction

Incursions of the Monterey pine aphid (*Essigella californica*) were first observed in Australia in radiata pine (*Pinus radiata* D. Don) plantations near Canberra in 1998. Subsequent surveys showed that within a few years aphids had spread through all the major pine growing regions of Australia (Carver and Kent, 2000; May and Carlyle, 2003; Wharton and Kriticos, 2004; Smith et al., 2008). This together with studies of damage associated with infestations of the Monterey pine aphid demonstrated that within a relatively short period the aphid has become a major pest species in softwood plantations with the potential to significantly reduce the productivity of plantations in south-eastern Australia (May and Carlyle, 2003; Wharton and Kriticos, 2004).

Symptoms of damage include mottled chlorosis of the older needles followed by premature shedding of needles mostly from the upper crown between early-autumn and late winter when temperatures are most favorable for aphid breeding (May and Carlyle, 2003; Wharton et al., 2004). Aphid damage and loss of foliage varies considerably from tree to tree (May and Carlyle, 2003; Sasse et al., 2009) and while defoliation is observed most frequently in radiata pine stands older than 15 years, aphids are present in plantations of all ages (Wharton and Kriticos, 2004; Smith et al., 2008). Surveys have shown that the aphid is most active in plantations in the upland areas of south-eastern Australia where significant levels of defoliation occur on a yearly basis. Loss of upper-crown foliage was strongly correlated with loss of growth over a 3 year period and represented a significant reduction in the productivity of plantations (May and Carlyle, 2003). However the specific impact of infestations of aphids on defoliation and growth can be difficult to identify in radiata pine plantations

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simultaneously affected by other environmental stresses such as drought (Eyles et al., 2011). This is partly due to the considerable variation in susceptibility to aphid damage between individual trees. Resistance to defoliation by aphids was shown to be highly heritable and therefore provides an opportunity for the selection and future deployment of aphid-resistant breeds of radiata pine (Sasse et al., 2009). However this does not provide a solution for the management of existing plantations affected by aphids and removal of defoliated trees at thinning may be a viable option to reduce the impact of infestations on growth and productivity of radiata pine (May and Carlyle, 2003).

Thinning of radiata pine plantations changes stand dynamics, it reduces inter-tree competition for water and nutrients and opens up the canopy for crown expansion of the remaining trees generally improving tree growth. Application of fertilizers such as nitrogen immediately after thinning stimulates production of foliage biomass and promotes stem growth provided availability of water and other nutrients are not limiting. This provides an opportunity to increase growth and enhance the productivity of plantations (Turner et al., 1992; Carlyle, 1995).

The widespread presence of the Monterey pine aphid in radiata pine plantations has raised the issue of the interaction between aphid associated defoliation and changes in the nutrient status of plantations in response to fertilizer (May and Carlyle, 2003; Hopmans et al., 2008). Fertilization in general raises the nutrient content of foliage and can make it more palatable to folivorous insects especially where nitrogen is applied (Kyto et al., 1996; Kainulainen et al., 1996; Day et al., 2004; Edenius et al., 2012). This has the potential to exacerbate defoliation by insects and therefore could reduce the gains in growth, reduce the merchantable yield and financial returns expected from fertilizer treatment of plantations.

However the interactions between insect populations, environmental conditions and host tree nutrient status are complex and findings from studies often appear to be contradictory. For example Straw and Green (2001) and Williams et al. (2005) showed that green spruce aphid (*Elatobium abietinum*) populations developed more rapidly and reached higher densities on Sitka spruce (*Picea sitchensis*) with higher nitrogen levels in foliage. Reductions in height growth were related to aphid population densities when nutrients were in limited supply but were not correlated with aphid densities when nutrient availability was high (Straw and Green, 2001). In contrast, defoliation of 11 year-old Sitka spruce associated with an infestation of green spruce aphid showed little difference between treatments of N fertilizers applied monthly at low rates but fertilized trees recovered more rapidly (Thomas and Miller, 1994).

Likewise, May and Carlyle (2003) found little difference in defoliation of radiata pine by the Monterey pine aphid between N and P fertilizer treatments applied 3 to 4 years earlier. In contrast, treatment with NPS fertilizers applied in 1997 to correct deficiencies of these nutrients was shown to reduce defoliation and increase growth in mature radiata pine stands subject to repeated infestations of aphids over 6 years (Hopmans et al., 2008). A second application of NPS fertilizers in 2003 did not prevent aphid damage but improved the average retention of foliage compared with unfertilized trees and increased growth. However aphid damage and short-term (2 year) responses to fertilizer after the second treatment were highly variable indicating little improvement of trees most susceptible to defoliation by aphids. Therefore remedial treatment with fertilizer to reduce aphid damage and improve growth of radiata pine plantations may be ineffective in the long term. To evaluate this hypothesis the original study was extended by a further 4 years to 2009 in two plantations deficient in phosphorus and sulfur to determine the long-term effects of remedial treatment with fertilizer on defoliation by aphids and growth of individual trees varying in susceptibility to aphid damage. Tree data was also used to evaluate the feasibility of removing the most vulnerable trees at the start of the second treatment in 2003 as a silvicultural management option to improve the productivity of radiata pine plantations affected by aphids.

2. Materials and methods

2.1. Study areas

Experimental sites were located at Warrenbayne (36°49′S and 145°54′E) and Stanley (36°20′S and 146°54′E), and elevation of 620 and 830 m. Soils were classified as mesotropic red dermosols (Isbell, 1996) or chromic acrisols (IUSS Working Group WRB, 2006) derived from granite at Warrenbayne and from shale at Stanley. Climatic conditions at these sites are similar with long-term median annual rainfall at Warrenbayne and Stanley of 1025 mm and 992 mm and mean minimum and maximum temperatures of 1.6 °C and 2.6 °C (July) and 27.1 °C and 27.3 °C (February) respectively. Rainfall during the study period (1997–2009) was well below average at each location and included a year with the lowest rainfall on record *viz.* 390 mm and 416 mm in 2006 (Fig. 1).

In 1997 two experiments were installed in radiata pine stands age 21 (Warrenbayne) and 22 years (Stanley) within 1 year of completion of a somewhat delayed routine first thinning from below (removing outrows for access and smaller trees within retained bays) to reduce stocking of live trees by approximately 70% from 1200 to 360 stems ha^{-1}. Stand characteristics following thinning at Warrenbayne and Stanley were stocking at 330 and 390 stems ha^{-1}; average tree height of 27 m and 26 m, and basal area at 19

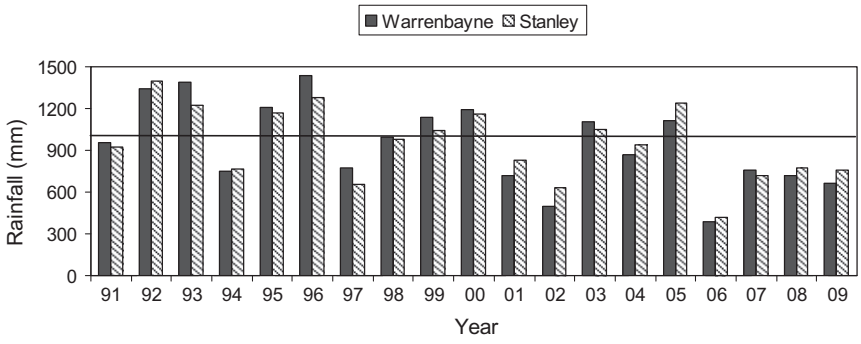

Fig. 1. Annual rainfall for period 1991–2009 (labeled as 91 to 09) at Warrenbayne (median rainfall 1025 mm shown) and Stanley (median rainfall 992 mm). Plantations were thinned in 1996 and fertilizer treatments were applied in 1997 (period 1: 1997–2003) and 2003 (period 2: 2003–2009).