# Managing insect pests in *Eucalyptus globulus* (Labill.) plantations in Victoria using insecticide tablets at establishment

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## Summary

We studied the effects of fertiliser and insecticide delivered by tablets on defoliation and growth of *Eucalyptus globulus* in plantations near Meredith in west-central Victoria to determine whether improved foliage retention and growth were conferred by the insecticide and/or fertiliser components of the tablet.

Trees at the study site were variably defoliated by three species of insect from March 2004 to September 2005. In the first year of the study, treatments containing imidacloprid insecticide had significantly less defoliation in both the upper and lower crowns than did treatments containing no insecticide. Treatments containing both insecticide and fertiliser showed increased height growth, most likely as a result of a combination of increased levels of available nutrients and protection from defoliating insects provided by the tablets leading to increased overall vigour. The tablets appear to provide adequate protection to trees for about 1 y after planting, although some protection seems to have remained until the 1.7 y assessment. Further observation is required to determine how long this protection lasts.

The implications of the study are significant for eucalypt plantation managers. The application of insecticide and fertiliser in tablets at the time of planting potentially provides a more effective and environmentally safer method of insect control than traditional broadscale insecticide applications during the establishment phase. This could potentially lead to improved growth, yield and general health in the longer term.

*Keywords*: plantations; defoliation; growth; insecticides; fertilizers; application methods; imidacloprid; *Eucalyptus globulus*

## Introduction

Australia had 1.72 million ha of plantations in 2004, consisting of about 716 000 and 1 001 000 ha of hardwood and softwood species respectively. The hardwood estate has expanded rapidly, a 68% increase in area being recorded from 1995 to 2004. New hardwood plantings averaged of 74 000 ha annually from 2000 to 2004. The aim of the Australian government is to expand the plantation estate to over 3 million ha by 2020 (National Forest Inventory 2004; Commonwealth of Australia 2005).

In Australia, hardwood plantations are dominated by *Eucalyptus globulus* Labill. (blue gum) which accounts for 21% of the total plantation area and 60% of the total hardwood plantings, while in Victoria these figures are about 30% and 70% respectively (Commonwealth of Australia 2005). Thus *E. globulus* forms a significant part of the hardwood plantation complex both across Australia and within Victoria (United States Department of Agriculture 2003; National Forest Inventory 2004; Commonwealth of Australia 2005). Most eucalypt plantations throughout Australia (and Victoria) are in private ownership and grown on short rotations (10–25 y) to provide a source of wood fibre for producing pulp and paper (United States Department of Agriculture 2003). About 80% of hardwood chips are exported, with Japan taking over 90% of these (Australian Bureau of Agriculture and Resource Economics 2000).

A major threat to the productivity and economic viability of eucalypt plantations, however, is the risk of severe to total defoliation by insect pests during the first 4 y after planting. The pests involved may be species of leaf-feeding moth (Order Lepidoptera), beetles (Coleoptera), sawfly (Hymenoptera), locust (Orthoptera) or sap-sucking bugs, including psyllids and coreids (Hemiptera) acting either singly or in combination (Stone *et al.* 1998; Collett and Neumann 2002). The causes of sudden insect pest outbreaks in young eucalypt plantings are still not fully understood, although several factors, acting singly or in combination, may be involved. These include:

1. prolonged periods of warm, dry weather accelerating insect life cycles and enhancing survival, and as a consequence increasing population levels
2. susceptibility of the eucalypt species or provenance planted to attack
3. a generally greater susceptibility of monocultures of low genetic diversity to attack
4. the absence of effective biocontrol agents
5. slow initial growth delaying canopy closure and preventing the rapid development of tougher, less susceptible mature foliage.

These factors, either singly or in combination, can lead to the onset of economically damaging outbreaks (Neumann 1993). Studies of the effects of defoliation on *E. globulus* growth have found that single and repeated defoliation events, especially during autumn, adversely affect height, basal area and volume growth (Collett and Neumann 2002). Stone *et al.* (1998) found that the application of pesticides alleviated insect defoliation, enabling the average height and general growth vigour of the *Symphyomyrtus* sub-genera (including *E. globulus*) to significantly exceed that of the *Monocalyptus* sub-genera. Elliott *et al.* (1993) found that 1-y-old *E. regnans* trees repeatedly damaged by chrysomelid leaf beetles lost about 45% and 52% of their potential height and basal area increment respectively, while both Candy *et al.* (1992) and Wills *et al.* (2004) observed, in defoliation trials running for more than 10 y, that repeated defoliation episodes significantly reduced growth and overall economic viability of plantations.

Timely control measures may be required to minimise the threats insect pests pose to plantations; the application of chemical insecticides is one of several techniques available to achieve this control (Neumann 1992). While the application of insecticides during outbreaks can provide effective control, the risks posed by 'traditional' spray applications (including the potential effects on non-target insect populations such as beneficial predator species), concerns relating to the use of chemicals in the environment and risks to human health sometimes limit or preclude their use in plantations (Stone *et al.* 1998; Collett 2001).

To eliminate or minimise these risks, a new tablet formulation of an existing insecticide is currently under development. The tablets containing insecticide are placed in holes under the seedlings at planting, wherefrom the insecticide is absorbed systemically into the plant, imparting resistance to insect attack. The advantage of such a targeted delivery system is that risks to human health, non-target insects and the environment in general are greatly reduced. The insecticide formulation being tested is imidacloprid, an active ingredient already used in various horticultural, home-garden and termite-control products.

Imidacloprid belongs to a relatively new class of insecticides called chloronicotinyls that exhibit high levels of insecticidal activity coupled with a high margin of safety — with currently approved use patterns — to mammals and other vertebrates. Imidacloprid is highly systemic in plants, a property very useful when targeting sucking and chewing pests such as defoliating insects in eucalypt plantations.

While initial glasshouse and field trials have demonstrated the efficacy of the buried tablet mode of insecticide delivery, these trials involved simultaneous applications of imidacloprid and fertiliser. There remained some uncertainty as to the apportioning of observed improvements in growth between the insecticide and fertiliser components of the tablets. The aim of the present study was therefore to quantify the effects on defoliation and growth of the insecticide and fertiliser components of the tablets, and so to determine the true magnitude of the effect of the separate components of this tablet formulation on overall growth.

## Materials and methods

### Study site

The selected study site was located about south-east of the township of Meredith in west-central Victoria (37°3'41.94"S, 144°1'08.31"E), or about 40 km south-east of Ballarat and 80 km west of Melbourne. The trial was established on an ex-pasture site used for sheep grazing up to early 2003, after when 46 ha were planted with *Eucalyptus globulus* seedlings in four blocks. The largest of the four blocks was about 28 ha; the trial was established over an area of 1.2 ha in the north-eastern corner of this block at an elevation of 280–300 m on a ridge slope with a westerly aspect. The area around the study site was mainly cleared pasture used for sheep and cattle grazing. Along the northern edge of the study site shelterbelts had been planted using a variety of native eucalypt and acacia species, while to the north-east of the trial site there was a small *E. globulus* plantation about 6 y old. Native vegetation in the area consisted mainly of sparse mixed-species forests in small stands and remnant roadside areas, dominated by eucalypts such as *E. camaldulensis* (Dehnh.) (river red gum), *E. ovata* (Labill.) (swamp gum), *E. leucoxylon* (F.Muell.) (yellow gum), *E. viminalis* (Labill.) (manna gum) and *E. melliodora* (Cunn. ex Schauer) (yellow box) (Costermans 1981; Boland *et al.* 1992). Average annual rainfall is about 670 mm, while the region has average minimum and maximum temperatures of 8° and 18°C respectively (Robinson *et al.* 2003). Soil pH in the study area is generally acid to neutral, while soil structure is generally soft to firm mottled-yellow duplex soils with partial sub-surface bleach and a loamy clay surface texture (Maher and Martin 1987; Robinson *et al.* 2003).

### Trial design and treatment application

A 4 × 4 latin square design was used (four replicates × four treatments) with relatively large plots to take into account any spatial variability across the site in soil properties and other site-related factors. Treatments were:

1. an untreated control (no insecticide or fertiliser added to the seedling-planting hole at establishment)
2. a fertiliser-only treatment of one 2.5 g tablet containing NPKMg at 5.6, 5.4, 4.2 and 1.4% respectively added to each hole at planting
3. an insecticide-only treatment of one 2.5 g tablet containing 500 mg ai of imidacloprid added to each hole at planting
4. an insecticide-plus-fertiliser treatment of one 2.5 g tablet containing both components at the aforementioned rates added to each hole at planting.

Each treatment plot of 32.0 m × 17.6 m contained of 81 *E. globulus* seedlings at a spacing of 4 m × 2.2 m (1100 trees $ha^{-1}$), with an internal measurement/assessment plot of 49 seedlings (24.0 m × 15.4 m). Thus in total 196 *E. globulus* seedlings were assessed for each treatment and 784 seedlings for all four treatments.

The trial site was ripped and mounded in June–July 2003, prior to the trial establishment in August. Trees in the trial were planted using standard establishment techniques with a Potti Putki® seedling planting device whereby a slit is created by the device in the soil and the seedling dropped down a tube into the planting hole to be firmed in place by the heel of the boot. Where the treatment required the addition of a tablet, it was placed in the planting hole prior to the seedling being planted. Follow-up treatments included a post-planting herbicide application to the trial site and surrounding plantation area in May 2004 (G. Ogston, Treecorp, *pers. comm*. 2004). While the surrounding plantation had NPKS fertiliser (14.6 : 6 : 8 : 13.7) applied at a rate of 110 kg $ha^{-1}$ after planting, this was not applied to the trial site so as not to compromise the experimental treatments.

### Assessment

Tree height was measured using a telescopic height pole, and defoliation due to insect herbivory in the upper and lower 50% of the total tree crown was scored using a scale with increments of 5%. The primary and, if present, any secondary causes of defoliation were identified and recorded. Trees were also assessed for a variety of other factors that, if present, might affect tree health and overall growth including any physical damage caused by animal browsing (i.e. rabbits and wallabies), any discolouration potentially caused by disease or nutritional factors, and foliage loss due to a range of abiotic factors including frost and hail. The type of foliage present (juvenile, transitional, adult) was also recorded as this can directly relate to the susceptibility of *E. globulus* to various insect pests and pathogens. The tree crown was divided into upper and lower portions for scoring defoliation because insect defoliators sometimes display a preference for particular sections of a tree's crown (Collett and Neumann 2002).

The trial was assessed using the above criteria on four occasions throughout the study: in March and July 2004, and March and September 2005. These assessments were scheduled to coincide with the periods of likely peak emergence of potential insect pests when damage to trees would be most evident but before the trees had started to recover.

### Analysis

Percentage defoliation data were transformed using the arcsine transformation. Different treatments within the study were compared using analyses of variance (ANOVA with Fisher's PLSD for variables) to assess the effects of the various fertiliser and insecticide applications against the untreated control treatment on the extent of defoliation and tree height growth. The Kruskal–Wallis H test (Fowler *et al.* 1998, Zar 1999) was used to assess the significance of differences in defoliation between treatments.

## Results

### Major defoliating insect pest species identified during the study

From August 2003 to September 2005, three insect pest species were identified as causing defoliation within the trial. These were the lightbrown apple moth (*Epiphyas postvittana* Walker) in March 2004, autumn gum moth (*Mnesampela privata* Guenee) in August 2004 and September 2005, and the eucalypt leaf beetle (*Chrysophtharta m-fuscum* Boheman) in March 2005. *E. postvittana* is a common leaf- and shoot-feeding caterpillar found throughout south-eastern Australia where it has caused significant damage to a range of plantation and orchard tree species, while *M. privata* is a major pest of juvenile *E. globulus* foliage and has caused significant damage in eucalypt plantations across south-eastern Australia in recent years (Elliott *et al.* 1998). While little information is specifically available on *C. m-fuscum,* this species is a member of a genus that has an extensive history of causing significant defoliation to a variety of eucalypt species throughout Australia (Elliott *et al.* 1998).

While the three defoliators caused various levels of defoliation, the attacks were generally considered to be of low to moderate intensity, and trees substantially recovered lost foliage prior to the next attack. Although the three insect species varied in their mode of attack, due to the relative uniformity of site conditions — including climate, planting stock used, establishment method and foliage type on trial trees available for attack — all trees within the trial had the same probability of being attacked at various stages of their growth, apart from any influence of the experimental treatments.

During the assessment period from March 2004 to September 2005, apart from defoliation caused by the three major defoliating insect pest species identified, no physical damage caused by animal browsing (i.e. rabbits, wallabies, livestock, etc.) or abiotic factors such as frost and hail was observed. No foliage discoloration due to disease or nutritional factors was observed throughout the study. All trees assessed had juvenile foliage only present during the March and July 2004 assessments. During the March 2005 assessment, transitional foliage had appeared in the upper crowns which developed into adult foliage by September 2005, although the lower crowns and a significant proportion of the upper crown still carried juvenile foliage.

### Dimensions and growth of the trial plantings

Table 1 summarises the growth of the *E. globulus* for each of the four treatments from the commencement of the trial in August 2003 to September 2005. The height of all experimental trees at the start of the trial (August 2003) averaged 14.0 cm (range: 13.8–14.2 cm), while in March 2004 it averaged 85.8 cm (76.9–97.7 cm). In August 2004 and March 2005 it averaged 127 cm (120–142 cm) and 354 cm (339–379 cm) respectively, while at the end of the experiment in September 2005 (aged 2.1 y) the trees averaged 422 cm (408–443 cm) (Table 1). Growth was greatest between spring and summer, and least during autumn and winter.

### Effects of treatments on tree height

The patterns of growth of *E. globulus* in all treatments, expressed as mean height from August 2003 to September 2005, were generally sigmoid, thus conforming to generalised growth patterns for young forest trees. At the establishment of the trial in August 2003, height of none of the four treatments was significantly different from that of any other (Table 1). Thereafter, the fertiliser-only treatment displayed growth generally consistent with that of the untreated control, apart from the March 2004 assessment where the height of the fertiliser-only treatment was significantly greater than that of the untreated control. From then on, up to and including September 2005, there was no significant difference in height between these two treatments. Height of the insecticide-only treatment was generally consistent with that of the fertiliser-only treatment up to and including August 2004, after when height of the insecticide-only treatment was significantly greater than that of the fertiliser-only treatment. The insecticide-only treatment

**Table 1.** Tree heights (H), and levels of upper (U) and lower (L) crown defoliation of young *Eucalyptus globulus* following application of fertiliser and/or insecticide in tablets, and an untreated control

| Treatment and variable | | Mean height (cm), upper and lower-crown defoliation[1] (%) ± s.e.[2] (*n* = 180, 187) | | | | |
|---|---|---|---|---|---|---|
| | | Aug 2003 Establishment | Mar 2004 Assessment | Aug 2004 Assessment | Mar 2005 Assessment | Sep 2005 Assessment |
| 1. Untreated control | H[3] | 14.0 ± 0.2a | 76.9 ± 2.0a | 119.6 ± 2.9a | 338.8 ±6.5a | 410.1± 7.3a |
| | U[3] | 0.0 ± 0.0a | 6.2 ± 0.6a | 14.7 ± 0.8a | 2.7 ± 0.2a | 2.0 ±0.5a |
| | L[3] | 0.0 ± 0.0a | 7.8 ± 0.5a | 16.3 ± 0.8a | 4.9 ± 0.3ab | 2.8 ±0.5a |
| 2. Fertiliser only | H | 13.8 ± 0.2a | 83.6 ± 2.1b | 122.4 ± 2.6a | 340.2 ± 5.3a | 407.8 ± 6.4a |
| | U | 0.0 ± 0.0a | 5.9 ± 0.7a | 14.7 ± 0.7a | 2.7 ± 0.2a | 1.8 ± 0.2a |
| | L | 0.0 ± 0.0a | 8.8 ± 0.7a | 17.0 ± 1.0a | 5.0 ± 0.3a | 2.3 ± 0.2a |
| 3. Insecticide only | H | 14.0 ± 0.2a | 84.9 ± 1.7b | 124.3 ± 2.5a | 356.9 ± 5.3b | 428.7 ± 6.0b |
| | U | 0.0 ± 0.0a | 1.7 ± 0.3b | 9.1 ± 0.5b | 2.2 ± 0.2ab | 1.4 ± 0.2a |
| | L | 0.0 ± 0.0a | 2.9 ± 0.3b | 9.7 ± 0.6b | 4.2 ± 0.3bc | 2.5 ± 0.2a |
| 4. Fertiliser and insecticide | H | 14.2 ± 0.2a | 97.7 ± 1.7c | 141.8 ± 2.4b | 379.3 ± 5.1c | 442.6 ± 6.1b |
| | U | 0.0 ± 0.0a | 0.8 ± 0.2b | 8.0 ± 0.4b | 1.8 ± 0.2b | 1.4 ± 0.2a |
| | L | 0.0 ± 0.0a | 1.8 ± 0.2b | 9.0 ± 0.5b | 3.9 ± 0.2c | 2.2 ± 0.2a |

[1] Within columns and for each variable, the means designated by different letters are significantly different ($P < 0.05$)
[2] s.e. = standard error
[3] H = height, U = upper crown, L = lower crown

was significantly taller than the untreated control apart from August 2004, when no significant difference was observed. The combined fertiliser-plus-insecticide treatment, however, displayed significantly greater height than the other three treatments from March 2004 to March 2005, while recording no significant difference to the insecticide-only treatment in September 2005.

## Effects of treatments on upper-crown defoliation

At the establishment of the trial in August 2003, seedlings were generally uniformly covered in healthy foliage and no insect browsing damage was observed. No treatment was therefore significantly different from others in observed upper-crown defoliation (Table 1). Throughout the study, no significant difference was observed between the untreated control and fertiliser-only treatments, with mean upper-crown defoliation levels of 6% and 6% respectively for the March 2004 assessment, 15% and 3% respectively for both treatments for the August 2004 and March 2005 assessments, and 2% and 2% for the September 2005 assessment. The insecticide-only and insecticide-plus-fertiliser treatments did not significantly differ throughout the study, with similar levels of defoliation being observed over all four assessment periods from March 2004 to September 2005. When the untreated control and fertiliser-only 'pair' of treatments are compared to the insecticide-only and fertiliser-plus-insecticide pair of treatments, however, treatments containing the insecticide component displayed significantly less defoliation due to insect herbivory than the untreated control or fertiliser-only based treatments for the March and August 2004 assessments. During the March 2005 assessment, however, the insecticide-only treatment did not differ significantly from any of the other three treatments in mean levels of upper-crown defoliation, while in September 2005, no treatment differed significantly.

## Effects of treatments on lower-crown defoliation

At the establishment of the trial in August 2003, seedlings were generally uniformly covered in healthy foliage with no insect browsing observed: no treatment was significantly different from others in lower-crown defoliation (Table 1). As with the upper-crown observations, no significant difference in levels of lower-crown defoliation was observed between the untreated control and fertiliser-only treatments throughout the study assessment period (March 2004 – September 2005). The insecticide-only and fertiliser-plus-insecticide treatments also did not differ significantly throughout the study, with similar levels of defoliation being observed over all four assessment periods (March 2004 – September 2005). These observations confirm a general trend observed in the upper crown that when the untreated control and fertiliser-only 'pair' of treatments are compared to the insecticide-only and fertiliser-plus-insecticide treatment pairs, treatments containing the insecticide component displayed significantly less defoliation due to assorted insect herbivory than the untreated control or fertiliser-only treatments. This trend was consistent for the March and August 2004 assessments. In the March 2005 assessment, however, the untreated control, while having a higher mean level of defoliation than the insecticide-only treatment, did not differ significantly from it, while no treatment differed significantly in the September 2005 assessment.

## Effects of treatments expressed as a function of defoliation category

The defoliation scores across the four treatments show that most trees defoliated in both the upper and lower crowns in March 2004 by *E. postvittana* were generally subjected to nil (0%) or trace (≤10%) levels of defoliation, with only a small number experiencing more than 10% defoliation. This is indicative of low populations of this defoliator. In contrast, in the August 2004 assessment for *M. privata* larvae, substantially more trees across the four treatments recorded defoliation levels of >10% (Figs 1 and 2), reflecting a more sustained attack by a larger population. In the March 2005 assessment for the defoliator *C. m-fuscum,* most trees across the four treatments recorded 10% or less defoliation, with >50% (upper crown) and 20% (lower crown) of trees in each treatment recording nil (0%) defoliation. Thus *C. m-fuscum* was at very low levels and causing only traces of damage. This pattern of defoliation was also observed in September 2005 when *M. privata* caused little defoliation (<10%) in most trees across all four treatments.

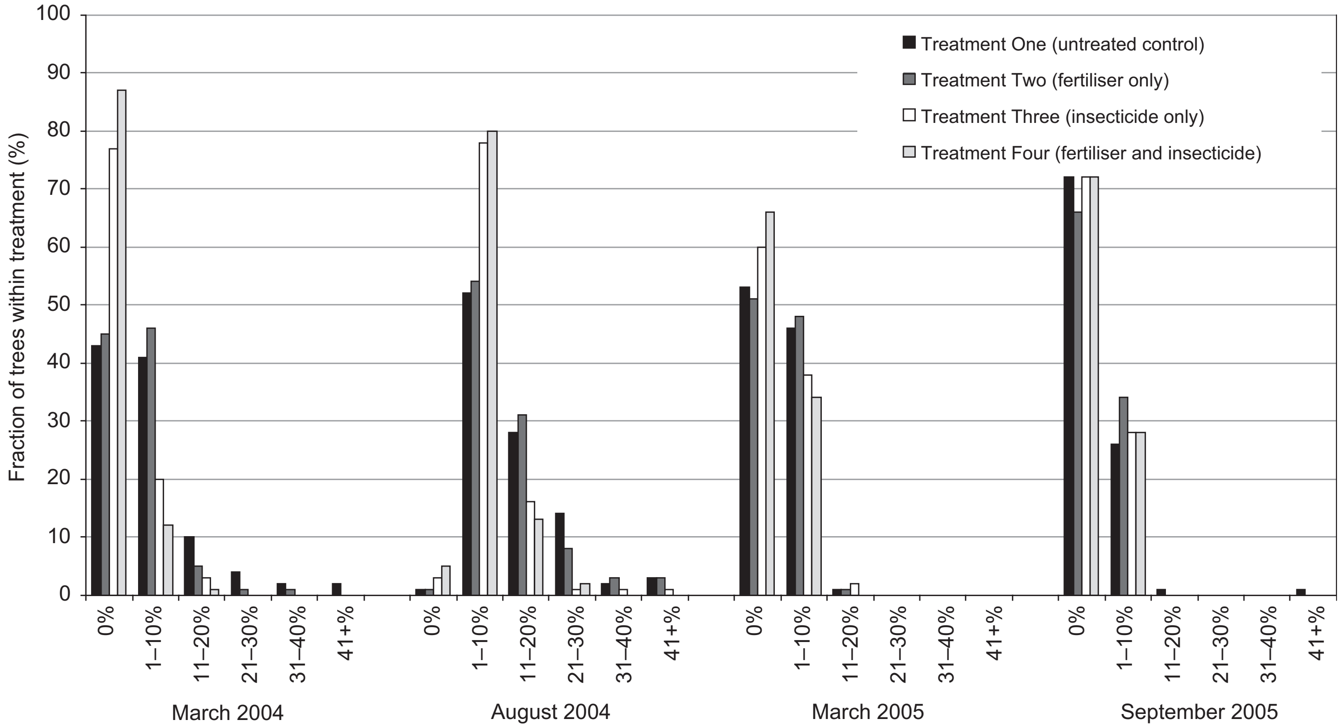


**Figure 1.** Frequency of *Eucalyptus globulus* trees within the four treatments examined in various categories of defoliation based on percentage of defoliation to the upper crowns

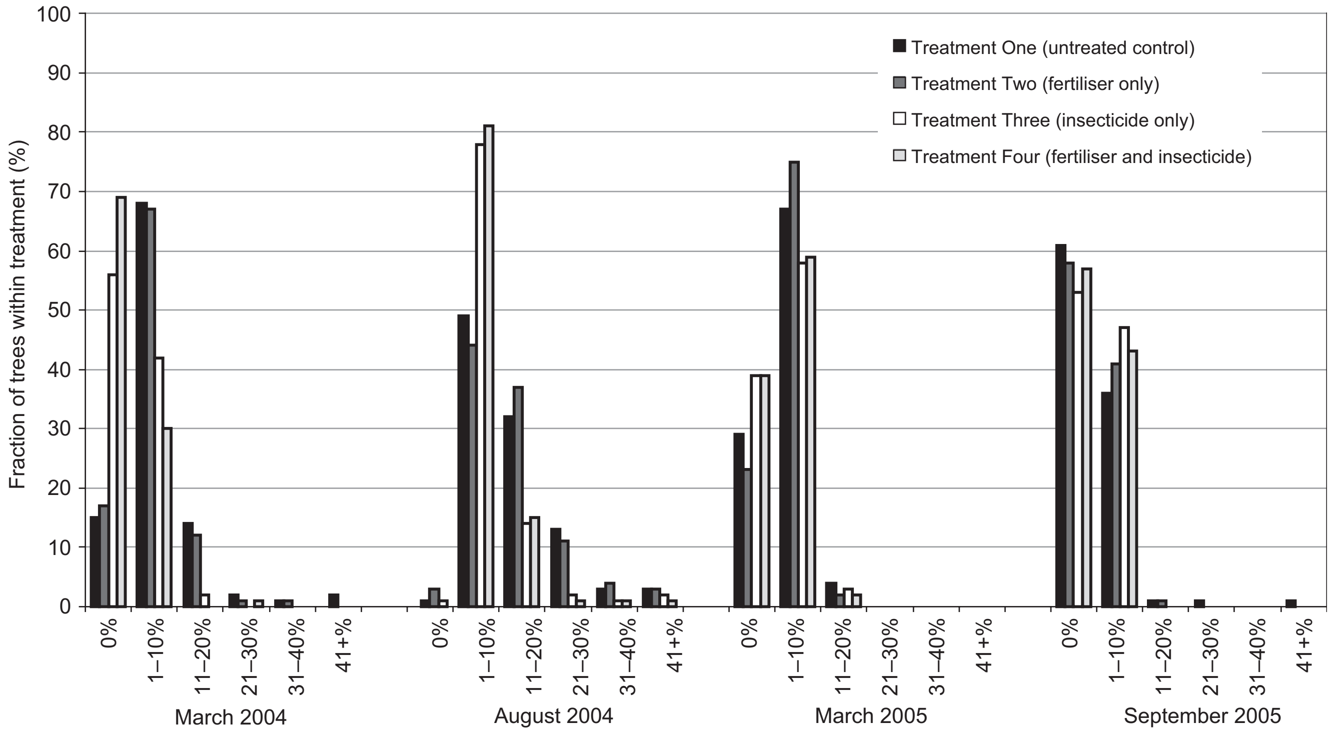


**Figure 2.** Frequency of *Eucalyptus globulus* trees within the four treatments examined in various categories of defoliation based on percentage of defoliation to the lower crowns

For the March 2004 assessment, 44, 45, 77 and 87% of trees in the untreated control, fertiliser-only, insecticide-only and fertiliser-plus-insecticide treatments respectively recorded 0% (nil) defoliation for the upper crown. The corresponding levels of upper-crown defoliation for the same treatments in August 2004 and March 2005 were 1, 1, 3, 5%, and 53, 51, 60, 66% respectively, while for the final assessment in September 2005 nil defoliation was recorded in 73, 66, 72 and 72% of trees in the above respective treatments (Table 2, Fig. 1). For lower-crown defoliation in March 2004, 16, 17, 56 and 69% of trees in the untreated control, fertiliser-only, insecticide-only and fertiliser-plus-insecticide treatments recorded 0% (nil) defoliation, while the corresponding fractions of trees with 0% defoliation in the lower crown for the same treatments in August 2004 were 0.0, 0.5, 3 and 2% (Table 2, Fig. 2). In March 2005, 29, 22, 39 and 38% levels of 0% defoliation occurred respectively in the aforementioned treatments, while in September 2005 corresponding levels of 62, 58, 53 and 57% were recorded.

When the number of trees with 0% (nil) defoliation was compared to the number with defoliation levels of >1% in the four different treatments at the March 2004 assessment, significantly more trees within treatments containing insecticide (insecticide-only and fertiliser-plus-insecticide) had 0% (nil) defoliation when compared to those in treatments not containing insecticide (the untreated control and fertiliser-only treatments). However, at the August 2004 assessment, no significant difference was observed (Table 3), indicating greater insect defoliating pressure on trees across all treatments for this period. For the March 2005 assessment, while no significant difference was observed between treatments for upper-crown defoliation, a significant difference was observed in levels of lower-crown defoliation. No significant difference between the number of trees with 0% (nil) defoliation and those with >1% defoliation was observed in September 2005.

When defoliation was assessed in March 2004 for the untreated control, fertiliser-only, insecticide-only and fertiliser-plus-insecticide treatments, the fractions of trees within treatments recording <10% defoliation in the upper crown were 71, 74, 91 and 97% respectively (Table 2). The corresponding levels of upper-crown defoliation for August 2004 and March 2005 were 30, 20, 52, 57% and 93, 96, 97, 98% respectively, while for the final assessment in September 2005 proportions of 97, 97, 99 and 100% were recorded. For lower-crown defoliation in March 2004, 64, 64, 90 and 97% of trees in the untreated control, fertiliser-only, insecticide-only and, fertiliser-plus-insecticide treatments recorded <10% defoliation. In August 2004 and March 2005 the corresponding levels of lower-crown defoliation for the same treatments were 17, 16, 50, 50%, and 78, 81, 82, 85% respectively, while for the final assessment in September 2005 proportions of 93, 97, 97 and 99% were recorded (Table 2).

When the number of trees with <10% defoliation was compared to the number with 10% or more in the four different treatments for the March and August 2004 assessments, significantly more trees in treatments containing insecticide (insecticide-only and fertiliser-plus-insecticide) had <10% defoliation compared with treatments with no insecticide (the untreated control and fertiliser-only treatments) (Table 3). However, for the March and September 2005 assessments, no significant difference was observed, indicating that most trees across all treatments experienced very little insect defoliation. No differentiation between treatments was observed over the four observation periods regardless of whether defoliation occurred in the upper or lower crown.

## Discussion

This study is one of the first in Australia to evaluate the effects of applying insecticide in a tablet form at planting to eucalypts in plantations as an alternative to more traditional broadscale spray applications with their potential adverse environmental effects and effects on non-target organisms. Previous studies by

**Table 2.** Fraction of *Eucalyptus globulus* trees recording a nil (0%)[1] or low (<10%)[2] defoliation score over from March 2004 to September 2005 after defoliation by three different insect pest species

| Treatment | Fraction of trees defoliated (%) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LBAM[3] (*E. postvittana*) March 2004 | | | | AGM[3] (*M. privata*) August 2004 | | | | ELB[3] (*C. m-fuscum*) March 2005 | | | | AGM[3] (*M. privata*) September 2005 | | | |
| | UC[4] | | LC[4] | | UC | | LC | | UC | | LC | | UC | | LC | |
| | 0% | <10% | 0% | <10% | 0% | <10% | 0% | <10% | 0% | <10% | 0% | <10% | 0% | <10% | 0% | <10% |
| Untreated control | 44 | 71 | 16 | 64 | 1 | 30 | 0.0 | 17 | 53 | 93 | 29 | 78 | 73 | 97 | 62 | 93 |
| Fertiliser only | 45 | 74 | 17 | 64 | 1 | 20 | 0.5 | 16 | 51 | 96 | 22 | 81 | 66 | 97 | 58 | 97 |
| Insecticide only | 77 | 91 | 56 | 90 | 3 | 52 | 2.7 | 50 | 60 | 97 | 39 | 82 | 72 | 99 | 53 | 97 |
| Fertiliser + insecticide | 87 | 97 | 69 | 97 | 5 | 57 | 1.6 | 50 | 66 | 98 | 38 | 85 | 72 | 100 | 57 | 99 |

[1] Per cent of trees within treatment with nil (0%) defoliation compared to trees with 1% or more defoliation
[2] Per cent of trees within treatment with 9% or less defoliation compared to trees with 10% or more defoliation
[3] LBAM = light brown apple moth, AGM = autumn gum moth, ELB = eucalypt leaf beetle
[4] UC = upper crown, LC = lower crown

Neumann and Collett (1997a,b) examined the effects of different insecticides at varying rates using spray application methods in a controlled testing environment, while work by Candy *et al.* (1992) and Collett and Neumann (2002) examined the effects of artificial defoliation on tree growth. However, such studies have been conducted in isolation to the extent of examining insecticide application independently of tree growth, or examining the effects of defoliation on tree growth in the absence of both defoliating insects and insecticide application. The current study addresses this gap in our knowledge by examining a new environmentally-friendlier method of insecticide application in eucalypt plantations, coupled with assessments of tree defoliation by various defoliating agents and of height growth. Studies involving insecticides and associated defoliation in the field are subject to the uncertainty that defoliating insect species may not appear at the right time and place and in sufficient numbers to inflict measurable levels of damage. This study was fortunate, however, in experiencing defoliation episodes of sufficient intensity at different times across the entire study area and its surrounds to enable the various treatments to be thoroughly assessed.

We have shown that in an *E. globulus* plantation from initial establishment up to 2.1 y of age and prior to canopy closure, trees treated at planting with tablets containing imidacloprid (with and without accompanying fertiliser) generally displayed significantly better height growth and had more unbrowsed foliage than treatments containing no imidacloprid (the untreated control and fertiliser-only treatments). This trend was particularly evident in the first year of the study, when insect-related defoliation in both the upper and lower crowns was significantly less in treatments with an imidacloprid component than in those with no imidacloprid. By the completion of the study, however, levels of both upper and lower-crown defoliation were approaching uniformity across all treatments, indicating that the protective effects of the tablets containing imidacloprid were diminishing. This could be due either to the eventual breakdown and disappearance of the tablets by the second year, and/or the growth of the trees to such a size that the amount of imidacloprid available to them no longer provided adequate and uniform protection from herbivorous predators.

This observation is further strengthened when defoliation assessment scores were grouped in a 0% (nil) category or in categories of 1–10%, 11–20% etc., and examined in more detail. In the first year of observation, regardless of grouping, treatments containing imidacloprid retained more foliage and were subject to less insect defoliation than were treatments without imidacloprid. Although the large populations of the defoliating insect *M. privata* present in August 2004 damaged most trees in all treatments, the treatments containing imidacloprid still experienced significantly less defoliation (<10%) than treatments with no imidacloprid. That the effects of the imidacloprid appeared to be diminishing in the second year of the study is indicated by the observation that levels of defoliation across all treatments were trending towards statistically-similar levels.

Treatment effects on tree heights require particular examination in that while it appears that increased height growth in

**Table 3.** Significance of differences between three different fertiliser/insecticide treatment datasets and an untreated control expressed by their mean rankings for the Kruskal-Wallis H-test, for three defoliation periods split into upper and lower crown assessments for a) trees with 0 % defoliation and b) trees with <10% defoliation

| Defoliation category, date and crown position | | Treatment/mean rank ($n$ = 180–188)[1] | | | | $H$ statistic[2] and significance |
|---|---|---|---|---|---|---|
| | | 1. Untreated control | 2. Fertiliser only | 3. Insecticide only | 4. Fertiliser + insecticide | |
| a) 0% (nil) defoliation[3] | | | | | | |
| March 2004 | Upper crown | 444 | 441 | 319 | 284 | 82.9*** |
| | Lower crown | 461 | 456 | 311 | 261 | 125.3*** |
| August 2004 | Upper crown | 380 | 375 | 367 | 365 | 0.6NS |
| | Lower crown | 381 | 369 | 363 | 373 | 0.7NS |
| March 2005 | Upper crown | 385 | 395 | 360 | 339 | 7.8NS |
| | Lower crown | 381 | 406 | 346 | 346 | 10.3* |
| September 2005 | Upper crown | 361 | 386 | 364 | 363 | 1.6NS |
| | Lower crown | 357 | 370 | 388 | 359 | 2.5NS |
| b) <10% (low) defoliation[4] | | | | | | |
| March 2004 | Upper crown | 419 | 409 | 340 | 320 | 29.6*** |
| | Lower crown | 423 | 442 | 325 | 297 | 61.8*** |
| August 2004 | Upper crown | 406 | 443 | 328 | 310 | 48.9*** |
| | Lower crown | 433 | 440 | 308 | 308 | 66.7*** |
| March 2005 | Upper crown | 380 | 369 | 367 | 361 | 0.7NS |
| | Lower crown | 383 | 370 | 369 | 359 | 1.2NS |
| September 2005 | Upper crown | 375 | 372 | 365 | 362 | 0.4NS |
| | Lower crown | 381 | 366 | 369 | 360 | 0.9NS |

[1] $n$ = range of the number of observations across the four treatments
[2] Levels of significance are * = $P$<0.05, *** = $P$<0.001 and NS = not significant (Kruskal–Wallis $H$-test)
[3] Ranking based on numbers of trees within each treatment with 0% (nil) defoliation
[4] Ranking based on numbers of trees within each treatment with <10% defoliation

imidacloprid-only treated trees is a function of them experiencing less defoliation and consequently growing more vigorously than untreated trees, trees treated with fertiliser would also benefit in terms of their potential to grow more vigorously. This trend is confirmed early in the trial with the fertiliser and insecticide-only treatments displaying similar height growth patterns compared to the untreated trees which recorded inferior height growth. Of particular interest however, were the apparent positive synergies developed when fertiliser and imidacloprid were combined in one treatment and subsequent height growth was superior to that in all other treatments. This trend remained constant throughout the two-year study, indicating that not only would trees treated with imidacloprid but those also containing a fertiliser component would substantially increase in height growth. Despite indications that the initial direct effects of the insecticide and the fertiliser tablets wear off after one year post planting, height growth in both treatments containing imidacloprid was still superior to that in the other treatments at the conclusion of the study. This indicates that the treatments may have assisted in establishing healthier and vigorously growing trees with better root systems and access to water and nutrients. Similar recent studies undertaken by Forests New South Wales indicate that height growth responses in treatments using the tablets were maintained for up to 5 y (C. Stone, Forests NSW, *pers. comm.*, 2007). Re-assessment of the current study is therefore desirable at a later date to determine whether this height growth trend also subsequently continues.

When the aforementioned observations are considered in light of the practical relevance for commercial eucalypt plantations, the cost-benefit over time from the use at planting of the combined fertiliser/imidacloprid tablet could potentially be considerable. The requirement for other insecticide and fertiliser application in the first one to two years could potentially be eliminated, saving the application costs in both instances and using the synergies of the one-step tablet application at planting. Furthermore, the growth benefits imparted by the tablet may result in greater yields over shorter rotation periods. Further study, however, is required to accurately quantify these potential benefits.

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