An Australian Government Initiative

Joint Venture Agroforestry Program

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Silviculture Research to Assist Large-scale Commercial Farm Forestry in Queensland

A report for the Joint Venture Agroforestry Program and the Natural Heritage Trust

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April 2005

RIRDC Publication No 04/185
RIRDC Project No PN99.2008

ISBN 1 74151 130 5
ISSN 1440-6845

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Published in April 2005
Printed on environmentally friendly paper by Canprint

Foreword

In recent years, large plantings of pulpwood plantations have commenced in proximity to the port of Brisbane in southern Queensland and port of Gladstone in central Queensland. These represent the first large-scale hardwood pulpwood plantations to be established in Queensland and currently there is little long-term information available, which identifies appropriate species to site matching and optimum silvicultural practices to support the large-scale expansion of the hardwood pulpwood plantation industry. To ensure the economic viability of these plantations, it will be essential to have the silvicultural knowledge that will optimise growth and reduce rotation lengths.

The research strategy adopted in this project was to establish trials to test the suitability of pure and hybrid eucalypts and some acacias for pulpwood plantations across a range of sites in the region. On selected, highly representative sites, a series of silvicultural trials was also established to provide silvicultural outcomes to help increase the productivity and profitability of commercial pulpwood plantations.

This publication details the early results from 19 taxa × site evaluation trials and 24 silviculture trials established across southern and central Queensland as part of this project. Trials were planted 1998 to 2001 and the research was completed in March 2002. While early results must be treated with caution, some preliminary recommendations have been made with regard to species to site matching and the identification of the most promising establishment and stand management silvicultural regimes.

This project was funded by the Natural Heritage Trust through the Forest Wood Products Research & Development Corporation (FWPRDC) and the Joint Venture Agroforestry Products (JVAP). The JVAP is supported by three R&D Corporations — Rural Industries Research & Development Corporation (RIRDC), Land & Water Australia (L&W) and FWPRDC together with the Murray-Darling Basin Commission (MDBC). The R&D Corporations are funded principally by the Australian Government. State and Australian Governments contribute funds to the MDBC.

This report is an addition to RIRDC's diverse range of over 1200 research publications and forms part of our Agroforestry and Farm Forestry R&D program, which aims to integrate sustainable and productive agroforestry within Australia's farming systems.

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Acknowledgments

The authors would like to acknowledge the support of Canterwood and the Queensland Government (Private Plantation Initiative and Hardwoods Queensland programs) for the provision of substantial in-kind funding over the project lifetime, to enable the achievement of project objectives. Strong collaborative support from East Coast Tree Farms, Integrated Tree Cropping Ltd., Great Southern Plantations Ltd., Plantations International (Qld operations managers for GSP) and DPI&F-Forestry, is also recognised and thanks are given for the provision of access to their commercial plantations for trial purposes and for regular operational support for trial management activities.

Abbreviations

AFFS	Agency For Food and Fibre Sciences
DPI&F	Department of Primary Industries and Fisheries
DPI&F-F	Department of Primary Industries and Fisheries – Forestry
ECTF	East Coast Tree Farms
GSP	Great Southern Plantations Ltd.
ITC	Integrated Tree Cropping Ltd.
SFNSW	State Forests of New South Wales (now Forests NSW, part of the NSW Department of Primary Industries & Trading)

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Executive summary

This project was conducted with close collaboration from the four main commercial plantation growers in Queensland; East Coast Tree Farms, Great Southern Plantations, Integrated Tree Cropping and DPI&F-Forestry, and through funding support from NHT, JVAP, the Queensland government (Private Plantation Initiative and Hardwoods Queensland) and from Canterwood, the primary woodchip processor operating in Queensland. Through these strong linkages, an extensive experimental program was conducted, which involved the establishment and/or management of 19 taxa evaluation trials and 24 silviculture techniques trials, across a geographic expanse from the Queensland/NSW border to Yeppoon in central Queensland. Trials were planted February 1998 to April 2001 and the research was completed in March 2002.

The 19 taxa evaluation trials were located on a broad range of representative soil and site types and investigated a wide range of hardwood species suitable for both pulpwood and pulpwood/sawlog regimes. Three acacia taxa, 42 eucalypt taxa and 13 eucalypt hybrids were tested in this study. The 19 individual trials varied widely, with different taxa treatments and experimental designs utilised at each location as dictated by site and operational constraints. Early results indicate that *Eucalyptus grandis* and *E. dunnii* are the taxa with the greatest adaptability and reliability for the immediate establishment of productive pulpwood plantations in this region. Promising results were also observed with hybrids including *E. grandis* × *E. camaldulensis*, *E. grandis* × *E. urophylla* and *E. urophylla* × *E. pellita*, however there is a higher risk associated with these until more detailed testing can be made over a longer time period. Early results also indicate *Acacia glaucocarpa* may also have good potential for certain sites. *Corymbia citriodora* subsp. *variegata* (CCV) has high potential in this region for application in integrated regimes, whereby both pulpwood and sawlog products are produced.

In these subtropical and tropical environments, plantation sites need to be carefully chosen as it appears that only the better quality soils and site types have the potential to realise productivities (mean annual increment) of at least 20 m^3/ha/year. Unfortunately, many of the sites available for forestry expansion are generally degraded, have shallow soils, and include sodic, strongly-duplex soil types. These sites are unsuitable for pulpwood plantations, with many examples of productivities <10m^3/ha/year measured for even the best performing species on that site type.

A range of silvicultural techniques (spacing, site preparation, fertiliser and weed control) were investigated for the key hardwood species; primarily *E. grandis*, *E. dunnii*, selected *E. grandis* hybrids and CCV. As many of the results collected in this study are from trials ≤ two years of age, accurate long-term and site-specific silvicultural recommendations are not yet possible, however these results do provide a useful preliminary guide for a range of operational techniques.

Initial tree stockings of 1000–1250 trees/ha appear the most suitable for high productivity sites, but may need to be reduced to levels as low as 625 trees/ha on low productivity sites. Site preparation techniques involving high mounding have consistently proven to increase plantation growth across a wide range of soil types. Deep ripping is generally unnecessary, although is still an important technique on heavily compacted sites. Fertiliser responses are complicated by interactions between species, site and soil type, however there generally appears to be little advantage in applying large quantities of fertiliser on the most productive sites. Growth responses to increased fertiliser application on low productivity sites can be substantial, although may still be uneconomical. For those tree species which develop dense crowns at a young tree age (*E. grandis*), there may be little benefit of extending weed control beyond 9–12 months duration. For species with narrow, open crowns (CCV), it is expected that there will be substantial growth benefits of extending weed control to ≥15 months. Currently, Simazine + Roundup remains the most effective formulation for achieving optimum weed control on most site types, however emerging selective herbicides now offer plantation managers more flexibility. A range of new pre-emergent herbicide products have potential for greatly extending the effectiveness of a single pre-emergent herbicide application, however will need to undergo further testing before they can be more widely used.

Over the duration of this project, the early results from these trials were regularly communicated to the main industry collaborators (ECTF, ITC, GSP, Canterwood) and other interested stakeholders through various means including regular hard copy project milestone reports, short internal reports, experimental summary sheets, a number of conference and journal publications, individual field visits, large industry bus tours (40–60 attendees) and through the addition of research information to the DPI & F Hardwoods Queensland web site (www.dpi.qld.gov.au/hardwoodsqld/).

1. Introduction

The pulpwood industry in Queensland is currently based on the export of approximately 700 000 tonnes/year of pine woodchip from the Brisbane and Gladstone ports in southern Queensland. Most of this product is sourced from a diminishing resource of private pine plantations north of Brisbane, from delayed thinning operations in DPI&F-Forestry pine plantations and from exotic pine sawmill residues (QCE, 1997). It is recognised that to ensure a reliable resource of raw material for the future, it will be necessary for the plantation industry to expand (primarily onto cleared, ex-pastoral farmland), to help meet the shortfall of pulpwood supply from the existing pine plantation estates.

In Queensland, the hardwood plantation industry is undergoing a period of rapid expansion with the area of hardwood plantation planted/year increasing from 1000 hectares in 1995 (National Forest Inventory, 2000) to 8798 hectares in 2001 (National Forest Inventory, 2002). Approximately 3000 ha of this new area is managed purely for pulpwood production. The remainder is managed primarily for solid wood production, however most management plans include a commercial thinning at age 5–10 years, with this product potentially available for the pulpwood market (DPI, 1996). Unfortunately much of this expansion has been initiated with little reliable information available for species selection and appropriate silviculture techniques for hardwood plantations in this region.

Two of the areas with greatest potential for hardwood plantation establishment are south-east Queensland within a 200 km radius of Brisbane and coastal, central Queensland between Maryborough and Yeppoon. While both areas are characterised by relatively low land prices and moderate to high rainfall (>900 mm), climatic conditions differ between both areas, becoming more tropical and harsher with decreasing latitude. In the southern area, Beaudesert (Latitude: 28°01´, Longitude: 153°01´, Rainfall: 915 mm, Altitude: 50 m), receives 66% of annual rainfall over 6 months, averages 82 days/year of maximum temperature >30°C and averages 20 frosts/year. In the northern area, Gladstone (Latitude: 23°52´, Longitude: 151°16´, Rainfall: 918 mm, Altitude: 75 m), receives 72% of annual rainfall over 6 months, averages 108 days/year of maximum temperature >30°C, and averages 0 frosts/year (BOM, 2003). Within regions, the range of site qualities is also highly variable, and is strongly influenced by local climate effects, soil type, soil chemistry, soil physical characteristics, past land use and levels of degradation. Consequently accurate predictions of site productivity based on soil chemistry alone are generally not possible and it is necessary to consider all these factors when estimating site quality in southern Queensland (Baker and Eldershaw, 1993).

In the period 1997–2002, the DPI&F Forestry Research group has established numerous genetics and silviculture trials throughout this region, in order to help fill this knowledge gap. This report details the early results from the trials established and managed by the DPI&F, under the FWPRDC Project PN99.2008, administered by the Joint Venture Agroforestry Program (JVAP) and funded by the Natural Heritage Trust (NHT), the Queensland Government and Canterwood. This report provides preliminary recommendations on the most appropriate silviculture and species combinations for the development of a sustainable pulpwood industry in southern Queensland.

2. Objectives

The objectives of this project were to develop applied silvicultural technology to facilitate and support the establishment of industrial pulpwood plantations in southern Queensland. Specific objectives from this research project were as follows:

1) Evaluate a wide range of native hardwood species, provenances and hybrid taxa and identify a number of high priority species for large-scale operational pulpwood plantations.
2) Investigate a range of establishment silviculture regimes and identify silviculture techniques, which will maximise hardwood plantation pulpwood productivity.
3) Promote these research findings to the plantation pulpwood industry, so that they can be progressively incorporated into future operational plantation management plans.

3. Methodology

3.1 Taxa evaluation research

Species trials assessing the growth and productivity of a range of species with high potential for industrial pulpwood plantations were established and/or managed on 19 sites in the region from Imbil in the south, to Yeppoon in the north. Sixteen of these sites were established and managed in partnership with Canterwood, the primary woodchip (softwood) processor in the region, as part of a pilot study to identify suitable plantation pulpwood species for their existing area of operations between Maryborough and Yeppoon. In 1998, twelve of these trials (experiment series 478/1-3 and 575/1-9) were established within a 80 km radius of Maryborough, one year before the commencement of this JVAP project. A further two trials (Expt. 585a/b) were established in 1999, also in the Maryborough region, followed by two more trials (Expt. 622) in 2000 in the Yeppoon region. The three remaining taxa evaluation trials in this study were established by DPI&F and JVAP funds in 1999/2000 and included a site at Tiaro (Expt. 578), Imbil (Expt. 584) and Miriam Vale (Expt. 605).

The 19 taxa evaluation trials were located on a broad range of representative soil and site types across the region and investigated a wide range of hardwood species suitable for both pulpwood and pulpwood/sawlog regimes, with three acacia taxa, 42 eucalypt taxa and 13 eucalypt hybrids tested. The 19 individual trials were generally established in a number of series, with each series including similar taxa treatments and experimental design. Differences between each series varied widely, with different taxa treatments and experimental designs utilised as dictated by seed availability, site characteristics and operational constraints. Experimental methods utilised in each experiment are detailed further in this report. Trial ages at the last assessment performed vary from between 1.1 to 3.1 years and hence, while they provide some good early indications of taxa performance, these results must be treated with caution. Experiment details are presented below in Table 1.

Table 1: Experiment details for the 19 taxa evaluation experiments

Expt. No.	Location	Area (ha)	Planting date	Australian Soil Classification	Rainfall (mm)	Last measure age (years)
575/1	Wades, 36 km SW of Maryborough	1.0	01/1998	Brown Sodosol	1000	3.1
575/2	Lyons (1), 26 km S of Maryborough	1.0	01/1998	Brown Sodosol	1050	3.1
575/3	Owanyilla, 14 km S of Maryborough	1.0	01/1998	Redoxic Hydrosol	1100	3.1
575/4	Lyons (2), 16 km E of Maryborough	1.0	01/1998	Brown Chromosol	1200	3.1
575/5	Horne, 20 km NE of Maryborough	1.0	01/1998	Brown Sodosol	1200	3.1
575/6	Fluerty, 8 km NW of Maryborough	0.5	01/1998	Redoxic Hydrosol	1150	3.1
575/7	Fazio, 6 km N of Maryborough	0.5	01/1998	Redoxic Hydrosol	1150	3.1
575/8	Powell, 12 km SE of Maryborough	0.5	01/1998	Redoxic Hydrosol	1150	3.1
575/9	Hughes, 54 km W of Maryborough	0.5	01/1998	Red Vertosol	900	3.1
478/1	Hughes, 54 km W of Maryborough	1.0	03/1998	Yellow Sodosol	1100	2.9
478/2	Lyons (2), 16 km E of Maryborough	1.0	03/1998	Brown Chromosol	1200	2.9
478/3	Owanyilla, 14 km S of Maryborough	1.0	03/1998	Red Vertosol	900	2.9
585a	Wades, 36 km SW of Maryborough	1.0	02/1999	Brown Kurosol	1000	2.0
585b	Kingston, 18 km E of Maryborough	0.5	02/1999	Redoxic Hydrosol	1200	2.0
622a	Byfield, 20 km NW of Yeppoon	2.2	05/2000	Yellow Sodosol	1300	1.6
622b	Murphy's, 12 km SW of Yeppoon	1.2	05/2000	Yellow Dermosol	1100	1.6
578	Campbell, 4 km W of Tiaro	2.8	02/1999	Redoxic Hydrosol	1050	2.3
584	Imbil SF, 5 km W of Imbil	1.8	01/1999	Grey Chromosol	1200	2.0
605	Reinke's, 44 km S of Miriam Vale	1.5	03/2000	Brown Chromosol	1050	1.1

3.1.1 Canterwood series

Experiments 575/1-9 were the first of the Canterwood series established and included nine sites, which were representative of local soils and available lands within an 80 km radius of the Owanayilla wood-chip mill near Maryborough. These sites were planted in January 1998 and investigated seven taxa (Table 2) with potential for pulpwood products (two *E. camaldulensis* provenances, two *E. grandis* provenances, *E. urophylla*, *E. grandis* × *E. camaldulensis* hybrid clones and a reputed *E. pellita* × *E. brassiana* hybrid). The *E. grandis* × *E. camaldulensis* hybrid was represented by 10 clones, with data analysed and presented for these individual clones. Taxa and provenance details are illustrated in Table 2. Within this series, sites 1-5 were 1.0ha in size, with trial design involving 40-tree square plots replicated 2 to 3 times. Sites 6-9 were 0.5 ha in size, with trial design involving 30-tree square plots replicated twice. Trees were measured for height, DBH (diameter at 1.3 m) and survival at 6-month intervals, with the last measure performed at age 3.1 years. Using a DPI&F volume equation (Henry 1987), volume figures (total under bark) were then calculated. Although developed specifically for *E. grandis*, it is anticipated that this equation will be broadly applicable to the other sub-tropical eucalypt species and hybrids examined in these trials. Standing volume per hectare was then estimated for each taxa/clone by summing the individual tree volumes and dividing by plot areas. Growth rates of *E. grandis* in four previous DPI&F trials of more than 10 years of age were studied and a technique of forecasting age 10 volume, from age 2-3 volume, was developed. Mean annual increment – MAI (m^3/ha/year) was then calculated for each taxa, by dividing this figure by 10. It must be emphasised that volume projections developed from such early data are only estimates, and should be viewed with some caution. In addition to growth measures, an entomological survey of these trials was performed at age 2 years, with the incidence of attack by boring larvae of the giant wood moth (*Endoxyla* sp.) also assessed.

Experiments 478/1-3 were established shortly after the first Canterwood series, on three of the same sites, in order to test a wider range of genetic material, which had become available. These sites were planted in March 1998 and investigated a total of 12 taxa (*E. globulus* subsp. *globulus*, two *E. grandis* provenances, two *E. tereticornis* provenances, *E. grandis* × *E. camaldulensis* hybrid, *E. grandis* × *E. tereticornis* hybrid, *E. grandis* × *E. urophylla* hybrid, *E. tereticornis* hybrids (unknown father), *Acacia irrorata*, *A. glaucocarpa* and *A. neriifolia*). Due to poor nursery numbers, the three *Acacia* taxa and *E. globulus* were not represented on all three sites. Taxa details are illustrated in Table 2. All sites were 0.9 ha in size with 40-tree plots replicated 3 times. Trees were measured for height and DBH at 6-month intervals, with the last measure performed at age 2.9 years. Using the same methods applied for experiment 575, volume figures (total under bark) were calculated and then projected through to a stand age of 10 years. MAI was then calculated for each taxa, by dividing this figure by 10.

In February 1999, the Canterwood series was extended with the establishment of experiments 585a/b on two new sites in the Maryborough region and included a greater range of taxa including *E. dunnii* and some promising new eucalypt hybrids. The taxa treatments examined in these experiments included a wide range of *E. grandis* provenances, three *E. dunnii* provenances and a range of imported *E. grandis* hybrid bulk seedlots from South Africa. 14 taxa were examined on Expt. 585a with trees established in 36-tree species plots split into two, 18-tree provenance plots and replicated three times. Eleven taxa were examined in Expt. 585b with trees established as 28 tree provenance plots replicated twice. Taxa treatment details are illustrated in Table 2. These experiments were assessed annually with the last measurement of tree growth (height and DBH) performed at age 24 months. The final extension of the Canterwood series was conducted in May 2000, with the establishment of experiments 622a/b on two different soil types at Yeppoon, in an area identified by Canterwood with high potential for future hardwood plantation expansion. The largest site (Expt. 622a) was located at Byfield State Forest, 20 km NW of Yeppoon and examined 19 taxa, with plots established as 40-tree plots replicated three times. The smaller site (Expt. 622b) was located on private property 12 km SW of Yeppoon and examined nine taxa in 40-tree plots replicated three times. On this site, an additional 10 taxa (mostly hybrids) were also established in 40-tree plots without replication. These experiments were assessed annually with the last measurement of tree height growth performed at age 1.6 years.

Table 2: Details of taxa utilised in Experiment series 575, 478, 585, 622, 578, 584 & 605.

Species	Provenance	575/1-9	478/1-3	585a/b	622a/b	578	584	605
Acacia irrorata	Unknown		✓					
A. glaucocarpa	Gayndah		✓		✓			✓
A. neriifolia	Unknown		✓					
Corymbia citriodora subsp. *citriodora* (CCC)	Biloela							✓
C. citriodora subsp. *citriodora* (CCC)	Herberton							✓
C. citriodora subsp. *variegata* (CCV)	Brooyar				✓			
C. citriodora subsp. *variegata* (CCV)	Leyburn					✓	✓	✓
C. citriodora subsp. *variegata* (CCV)	Monto							✓
C. citriodora subsp. *variegata* (CCV)	South Africa Seed Orchard							✓
C. citriodora subsp. *variegata* (CCV)	Woondum				✓		✓	✓
C. henryi	Lockyer							✓
C. henryi	Nerang							✓
E. argophloia	Chinchilla				✓			✓
E. camaldulensis	Katherine, N. Territory	✓				✓		
E. camaldulensis	Petford, N.Qld.	✓			✓	✓	✓	✓
E. camaldulensis	South Africa Seed Orchard							✓
E. cloeziana	Sth Johnstone Seed Orchard							✓
E. cloeziana	Wolvi					✓	✓	
E. dunnii	East Coast Tree Farms			✓				
E. dunnii	South Africa Seed Orchard			✓	✓			
E. dunnii	Teviot, Qld			✓		✓	✓	✓
E. dunnii	Urbenville, NSW			✓		✓	✓	✓
E. globulus subsp. globulus	Victoria		✓					
E. globulus subsp. madenii	Bondai, NSW							✓
E. globulus subsp. madenii	Bolaro Mt, NSW							✓
E. grandis	ACIAR selects, Toolara				✓			
E. grandis	China Seed Orchard				✓			✓
E. grandis	Brazil Seed Orchard				✓			✓
E. grandis	Copperlode, W of Cairns		✓	✓	✓	✓	✓	✓
E. grandis	ECTF			✓				
E. grandis	Mt Windsor, Qld			✓		✓	✓	
E. grandis	Shell selects, Toolara		✓	✓	✓	✓	✓	
E. grandis	South Africa Seed Orchard			✓	✓	✓	✓	✓
E. grandis	W Bells SO, C. Hrbour, NSW	✓		✓	✓	✓	✓	✓
E. grandis	Woondum SF, Qld	✓		✓		✓	✓	✓
E. grandis	Zimbabwe Seed Orchard				✓			
E. longirostrata	Chinchilla (Ballon)					✓		✓
E. longirostrata	Monto				✓			✓
E. pellita	Cardwell Seed Orchard				✓			
E. pellita	Kuranda				✓			
E. pilularis	Deongwar							✓
E. pilularis	Yandina					✓	✓	✓
E. robusta	Noosa							✓
E. robusta	Toolara							✓
E. tereticornis	Blackbutt (Gogga)					✓		
E. tereticornis	Windfirm selects, China		✓					
E. tereticornis	2nd gen. Selects, China		✓			✓	✓	
E. tereticornis	Gladstone				✓			✓
E. tereticornis	Inglewood					✓	✓	
E. tereticornis	Rockhampton					✓	✓	
E. tereticornis	Selection Flats, NSW					✓	✓	
E. tereticornis	Yeppoon				✓			
E. tereticornis	Zimbabwe				✓			✓
E. urophylla	East Timor, Indonesia	✓						
E. grandis x E. camaldulensis (E.G. × E.C.)	Clonal selects, Brazil	✓						
E. grandis x E. camaldulensis (E.G. × E.C.)	CSIR bulk, South Africa		✓	✓	✓		✓	
E. grandis x E. pellita (E.G. × E.P.)	CSIR bulk, South Africa				✓			
E. grandis x E. resinifera (E.G. × E.R.)	CSIR bulk, South Africa				✓			
E. grandis x E. tereticornis (E.G. × E.R.)	CSIR bulk, South Africa		✓	✓	✓	✓	✓	
E. grandis x E. urophylla (E.G. × E.U.)	CSIR bulk, South Africa		✓		✓			
E. pellita x E. brassiana (E.P. × E.B.)	OP, Papua New Guinea	✓						
E. saligna x E. tereticornis (E.S. × E.T.)	Forbio						✓	
E. tereticornis hybrids	OP selects, China		✓					
E. tereticornis x E. urophylla (E.T. × E.U.)	CSIR bulk, South Africa				✓			
E. tereticornis x E. pellita (E.T. × E.P.)	CSIR bulk, South Africa				✓			
E. urophylla x E. grandis (E.U. × E.G.)	CSIR bulk, South Africa				✓			
E. urophylla x E. pellita (E.U. × E.P.)	CSIR bulk, South Africa				✓			

3.1.2 Other trials

Experiments 578 and 584 were established in January-February 1999 on two different soil types at Tiaro and Imbil, both within a 60 km radius of Gympie. Twenty-five taxa were established in this series, although only 22 taxa were represented on each site, hence taxa treatments were not identical for the two sites (Table 2). These taxa represented a wide range of hardwood species, which have been traditionally recognised as suitable for pulpwood, saw-log and integrated pulpwood/sawlog plantation management goals. The taxa and provenance details are illustrated in Table 2. In Expt. 578, plots were 42 trees in size and were replicated three times. In Expt. 584 plots were 40 trees in size and were replicated twice. Both trials were regularly measured at 6–month intervals for height and survival with the last measurements for experiments 578 and 584 performed at ages 24 and 28 months respectively. An entomological survey of experiments 578 and 584 at age 12 months identified a high incidence of beetle defoliation of trees in Expt. 578 only, with the incidence of attack in this trial assessed on new leaves and old leaves across a number of taxa treatments. A follow-up entomological survey at age 2.5 years did not identify any beetle activity, however incidence of attack by boring larvae of the giant wood moth (*Endoxyla* sp.) was observed in Expt. 584 and a damage survey for this attack was conducted for a number of taxa treatments.

Experiment 605 was established on a site 44 km south of Miriam Vale. In this experiment 33 taxa were examined and included a wide range of hardwood species, which have been traditionally recognised as suitable for pulpwood, saw-log and integrated pulpwood/sawlog plantation management goals. The taxa and provenance details are illustrated in Table 2. The experiment was a randomised complete block design, with plots 21 trees in size and replicated twice. This experiment was assessed for height and survival at ages six months and 1.1 years.

3.2 Silviculture research

Silviculture trials assessing the growth and productivity of a range of species with high potential for industrial pulpwood plantations were established on 24 sites from Woodenbong in northern New South Wales to Yeppoon in central Queensland. Trial ages at the last assessment vary from between 1.1 to 4.1 years and hence, while they provide some good early indications of plantation responses to silviculture inputs, these results must be treated with some caution. Silviculture experiment details including site characteristics are presented below in Table 3.

Table 3: Experiment details for the 24 silviculture experiments.

Expt. No.	Description	Location	Planting date	Australian Soil Classification	Rainfall (mm)	Last measure age (years)
581	Cultivation	Campbell’s, 4 km W of Tiaro	02/99	Brown Sodosol	1050	2.3
617	Cultivation	Awoonga, 30 km SW of Gladstone	02/01	Brown Sodosol	940	1.0
579	Spacing	Campbell’s, 4 km W of Tiaro	02/99	Yellow Kurosol	1050	2.3
607a	Spacing	Reid’s, 6 km N of Woodenbong	02/00	Brown Chromosol	1100	2.0
607b	Spacing	Joyce’s, 17 km S of Boonah	02/00	Brown Chromosol	900	2.0
638a	Spacing	Ruhl’s, 22 km S of Miriam Vale	02/01	Brown Dermosol	1050	1.0
638b	Spacing	Ruhl’s, 24 km S of Miriam Vale	02/01	Brown Chromosol	1050	1.0
577	Establishment	Campbell’s, 4 km W of Tiaro	02/99	Grey Kurosol	1050	2.3
583	Establishment	Imbil SF, 5 km W of Imbil	01/99	Black Kandosol / Dermosol	1200	2.0
604	Establishment	Reinke’s, 44 km S of Miriam Vale	03/00	Brown Chromosol	1050	1.1
621	Establish.	Byfield SF, 20 km NW of Yeppoon	05/00	Yellow Sodosol	1300	1.6
559a	Fertiliser	Benson’s, 10 km SW of Caboolture	03/98	Grey Kurosol	1600	4.1
559b	Fertiliser	Ang’s, 15 km SW of Caboolture	03/98	Red Kurosol	1600	4.1
560a	Fertiliser	Basingthwaite’s, 3 km N of Jimna	02/99	Brown Dermosol	1400	2.0
560b	Fertiliser	Joyce’s, 20 km NW of Beaudesert	03/99	Grey Kurosol	925	0.5
582	Fertiliser	Campbell’s, 4 km W of Tiaro	03/00	Grey Kurosol	1050	2.3
608a	Fertiliser	Joyce’s, 17 km S of Boonah	02/00	Red Chromosol	900	2.3
608b	Fertiliser	Logan’s Lane, 10 km NW of Aratula	02/00	Black Vertosol	1000	2.0
608c	Fertiliser	Holloway’s, 10 km NW of Kilcoy	02/00	Grey Sodosol	912	2.0
639a	Fertiliser	Ruhl’s, 22 km S of Miriam Vale	02/01	Brown Dermosol	1050	1.0
639b	Fertiliser	Ruhl’s, 24 km S of Miriam Vale	02/01	Brown Chromosol	1050	1.0
640a	Fertiliser	Noveltie, 21 km S of Miriam Vale	04/01	Black Vertosol	1050	1.0
640b	Fertiliser	Gaythorne, 8 km W of Miriam Vale	04/01	Yellow Kurosol	1050	1.0
580	Herbicide	Campbell’s, 4 km W of Tiaro	04/99	Brown Chromosol	1050	2.3

The methods used in these experiments are detailed in the following sections under the broad silvicultural operations of Site preparation, initial spacing, fertiliser and weed control. Within each section, the techniques currently utilised by industry for each of these operations are also detailed to provide a baseline status of the silviculture technology currently practiced in this region.

3.2.1 Site preparation

At present, all the major hardwood plantation establishment groups operating in coastal Queensland, utilise similar equipment and have adopted an almost generic site preparation regime across all site types for a range of tree species. As a result, the three main site preparation contractors operating in this region operate almost identical machinery. The generic site preparation technique involves a single pass with a D7 bulldozer (or equivalent) with a winged ripper (30 cm wings) ripping to a depth of 60 cm and trailing a Savannah ‘Tomahawk’ 6-disc bedding plough which creates a mound to approximately 40 cm in height. Depending on soil tilth, a secondary cultivation may also be conducted using the “Tomahawk” plough or alternatively tractor mounted offsets discs or a rotary hoe (Dickinson *et al*. 1998).

Site preparation research in this study, has focused on ripping and mounding. Deep ripping adds considerably to the costs of site preparation as it slows machinery speed by as much as 50%. In addition, studies in other states have found that on many soils, ripping has resulted in no improvements in plantation growth or survival (Holtz *et al.*, 1999). Three experiments (577, 581, 583), were established to determine the benefits of ripping, with another experiment (617) also investigating the impacts of variation in ripping depth. In this region, mounding is almost universally conducted on all site types, irrespective of water-logging potential. Experiments 604 and 621 were established to determine the benefits of mounding on different soil types, with two additional experiments (581, 617) also investigating the impacts of mound height

3.2.2 Spacing

In Queensland, the main commercial plantation growers have adopted initial spacing regimes, which target different timber product streams, whether they be solely for pulpwood or for integrated pulpwood and sawlog production. The most widely accepted, initial spacing regime for pulpwood utilises an initial tree stocking of 1250 trees/ha and involves an inter-row spacing of 4 m and an intra-row spacing of 2 m. This is a direct regime, with no tree removal until clear-fall, at a tree age of between 8–12 years.

As there are many practical benefits to maintaining a 4 m inter-row, initial spacing research in this study has focused on adjusting the intra-row tree spacing to achieve a range of initial tree stockings. These spacings vary between 1.0–4.0 m, resulting in initial stockings of between 625–2500 trees/ha. As individual site productivity will have a great impact on the optimum tree stocking, three experiments have been established on sites varying from moderate rainfall and high productivity at Woodenbong, NSW (Expt. 607a), to moderate rainfall and moderate productivity at Tiaro, Qld (Expt. 579) to low rainfall and low productivity, Boonah, QLD (Expt. 607b).

3.2.3 Fertiliser

There is much variation in the fertiliser prescriptions utilised by the various hardwood plantation organisations in Queensland. Some have adopted a minimal approach with very low rates of complete fertiliser applied aerially at planting, with future doses dictated by observed nutritional deficiencies, poor growth and some foliar sampling. Most organisations however aim to apply nutrients at final rates of 41–100 kg N/ha and 45–60 kg P/ha, conducted in split applications at planting and at age 9–12 months. At this early stage, there is no fertiliser prescriptions based on site or soil type or tree species planted, with hardwood plantation establishment groups applying their own generic prescription in all cases.

Over the past two years the DPI&F has established many fertiliser trials with a number of commercial and private growers across a range of soil types and including a range of tree species. Results from a number of these experiment are not presented here as either these are still too early (<18 months) to gather useful data on long-term fertiliser effects or they have been terminated due to a range of climatic and operational influences (e.g. fire, drought, deer damage, fertiliser burn and accidental routine fertiliser application). Experimental results discussed in this report compare the effects of nitrogen, phosphorus, potassium and trace element fertiliser application on early tree growth and include seven trials with *E. grandis,* two trials with the *E. grandis x E. tereticornis* hybrid, *E. tereticornis* and *Corymbia citriodora* subsp. *variegata* (CCV) and one trial with *E. dunnii*.

3.2.4 Weed control

Amongst Queensland plantation growers, weed competition is recognised as one of the most important factors influencing early plantation growth and it is generally accepted that a weed free zone should be initially maintained along tree rows to a width of approximately 2 m. Techniques utilised for weed control are almost entirely herbicide based and utilise a range of technologies from hand-held sprayers to booms mounted on tractors and helicopters. Simazine is the primary pre-emergent herbicide utilised, with glyphosate the main knockdown herbicide utilised (Dickinson *et al*. 1998) A range of other herbicide products are also used in specific situations and have application for certain weed species and include some of the selective herbicides which are non-toxic to tree species.

At present there is little knowledge of how long weed control should be maintained to optimise plantation productivity and profitability. Most plantation growers are diligent with their initial pre and post-plant weed control operations, however weed control is often abandoned or poorly maintained after this period. In this study, the DPI&F has established 4 experiments where the effects of extending the period of weed control from 3–5 months to 15–20 months is examined. In addition, a herbicide screening experiment was established to examine a wide range of pre-emergent herbicides: Authority® (sulfentrazone), Balance® (isoxaflutole), Command® (clomazone), Milestone® (azafenedin), Stomp® (pendamethalin) and Simazine® (simazine), and knockdown herbicides Roundup® (glyphosate), Lontrel® (clopyralid), Verdict® (haloxyfop) and Brodal® (diflufenican) to determine their effectiveness of weed control and their phytotoxicity to three commercial tree species. In this experiment, trees were regularly assessed for height, health/phytotoxicity (1–5 scale, where 1 = healthy and 5 = severely damaged), survival and per cent weed cover surrounding each tree.

4. Results

4.1 Taxa evaluation research

4.1.1 Canterwood trials

Regular height, DBH and survival measurements from experiments 478/1-3 and 575/1-9 were used to calculate total-standing (under-bark) volumes for each trial to ages 2.9 and 3.1 years respectively. Utilising the volume forecasting technique described in the methodology section, it was then possible to project these results through to age 10 years (age of clear-fall) to give an early estimation of the potential longer-term volume production for each taxa on each site. MAI was then calculated. These results are presented in Tables 4 and 5 respectively.

Table 4: Projected MAI (m^3/ha/year) for Expt. 575 at age 10 years. (NA denotes the particular clone was not planted at the given site.)

Taxon	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
E. grandis (Woondum)	9.3	6.1	3.2	13.5	9.0	9.8	6.8	3.7	4.4
E. grandis (Wedding Bells)	8.9	7.5	11.1	17.5	16.1	28.6	9.5	7.3	4.5
E. urophylla	2.8	2.2	0.6	3.1	2.7	2.4	1.7	1.2	0.9
E. pellita × E. brassiana	5.4	4.0	2.5	7.4	5.7	5.7	3.4	4.0	2.1
E. camaldulensis (Petford)	3.7	1.9	2.0	3.4	0.6	3.4	0.5	0.9	2.7
E. camaldulensis (Katherine)	1.1	1.0	0.3	2.3	0.4	1.3	0	0.1	0.7
E. grandis × E. camaldulensis									
Clone A	5.9	5.1	0.9	9.8	6.4	NA	2.2	1.9	3.1
Clone B	7.8	7.7	8.8	12.3	13.4	27.0	10.1	10.4	8.2
Clone C	5.9	3.7	4.0	7.6	3.3	12.3	0.1	4.0	5.5
Clone D	3.5	4.9	2.9	2.2	0.6	NA	0.2	0	6.3
Clone E	7.4	5.4	5.8	12.1	1.6	19.3	0.0	6.2	6.1
Clone F	6.7	6.3	4.3	11.3	12.0	17.8	5.1	4.8	4.6
Clone G	6.2	3.7	4.2	14.5	4.0	16.8	5.6	6.4	4.5
Clone H	NA	9.5	NA	NA	NA	NA	NA	NA	NA
Unknown	7.6	3.4	0.5	11.9	0.6	1.7	0	NA	2.3
Mean of all clones	6.6	5.2	4.6	11.5	6.5	15.2	4.0	5.4	4.9

For experiments 575/1-9, the results in Table 4 demonstrate the wide differences in productivity between both sites and taxa. *E. grandis* from a SFNSW seed orchard at Wedding Bells SF, Coff's harbour was the best performer with >10 MAI at four of the nine sites tested and the highest overall MAI figure of 28.6 on the most productive site (site 6). The *E. grandis x E. camaldulensis* hybrid also performed well across a number of sites, attaining a maximum projected MAI of 27.0 on site 6, with strong differences in growth and survival observed between the clones tested. *E. grandis* from the Woondum provenance had intermediate growth, while the remaining four taxa performed very poorly across all sites.

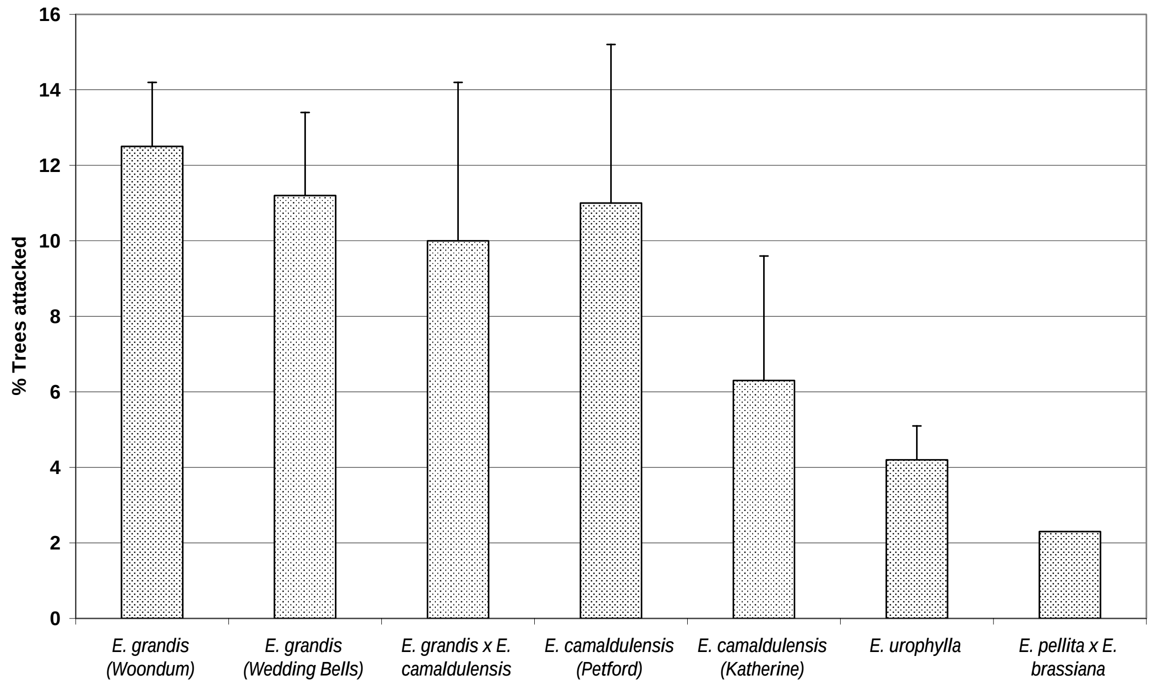
Table 5: Projected MAI (m^3/ha/year) for Expt. 478 at age 10 years. (NA denotes the particular taxa was not planted at the given site.)

Taxon	Site 1	Site 2	Site 3
Eucalyptus grandis (Copperlode)	6.5	14.9	15.6
E. grandis (Toolara selects)	7.4	17.7	16.8
E. tereticornis (wind-firm)	0.8	2.2	0.1
E. tereticornis (2nd Gen.)	1.0	3.2	0.3
E. tereticornis mixed hybrids	3.2	5.7	3.4
E. grandis × *E. camaldulensis*	3.3	6.9	1.8
E. grandis × *E. tereticornis*	2.9	8.5	3.3
E. grandis × *E. urophylla*	6.3	13.8	11.1
E. globulus	NA	57	NA
Acacia irrorata	9.3	7.8	NA
A. glaucocarpa	10.9	NA	21.7
A. neriifolia	NA	8	1.1

For experiment 478/1-3, results at age 2.9 years demonstrated great differences between site and taxa (Table 5), with site 1 (lowest MAR of the three sites) recording very low productivity. *Acacia glaucocarpa* was the best performer on the two sites where it was represented, particularly on site 3 where it recorded an estimated MAI at age 10 years of 21.7. The two provenances of *E. grandis* and the *E. grandis* × *E. urophylla* hybrid, also performed well, with all three taxa achieving >10 MAI at two of the three sites. The remaining eight taxa all performed poorly with <10 MAI at all three sites tested.

In experiments 575/1-9, an additional assessment for the presence of boring larvae of the giant wood moth (*Endoxyla* sp.) was conducted at age two years. Damage was observed in all seven taxa, however was most severe in the two *E. grandis* provenances (Figure 1). Secondary stem damage caused by the yellow-tailed black cockatoo foraging for *Endoxyla* larvae, was minimal at this age.

Figure 1: Expt. 575: Assessment of giant wood moth attack at age two years.



For experiments 585a/b, the last measurement of tree height and DBH taken at age two years is illustrated in Figures 2 and 3. There were very large differences between the two sites, with tree growth much lower on the poorly-drained, duplex soil type of Expt. 585b. On both sites however, the various *E. grandis* and *E. dunnii* provenances were vastly superior to the range of eucalypt hybrids tested. On both sites the *E. grandis* provenances from improved seed sources also performed very well, in particular the South Africa and SFNSW Wedding Bells seed orchards and the Toolara selects.

Figure 2: Expt. 585a: Tree height and DBH at age two years.

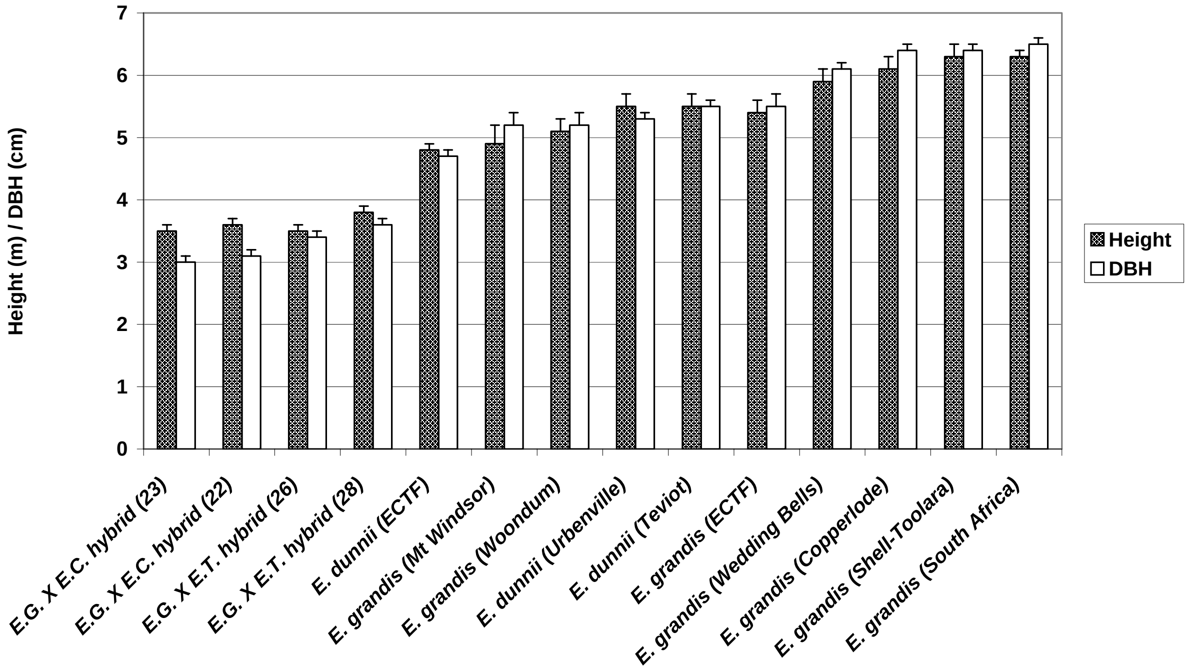
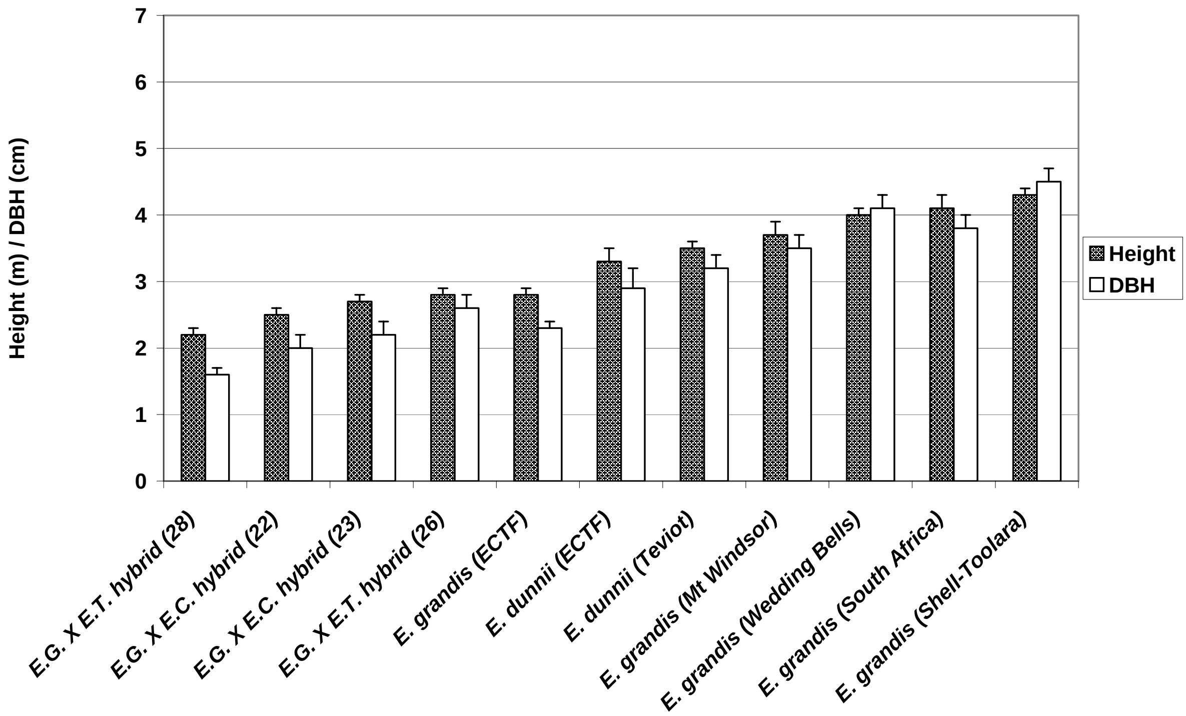
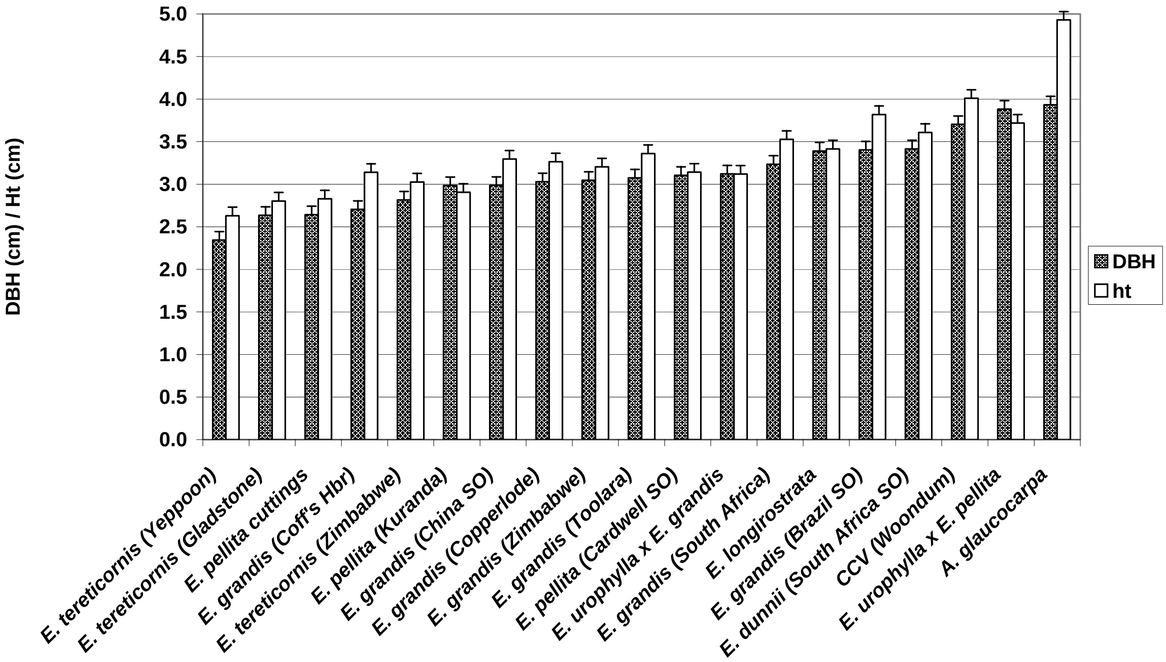


Figure 3: Expt. 585b: Tree height and DBH at age 24 months

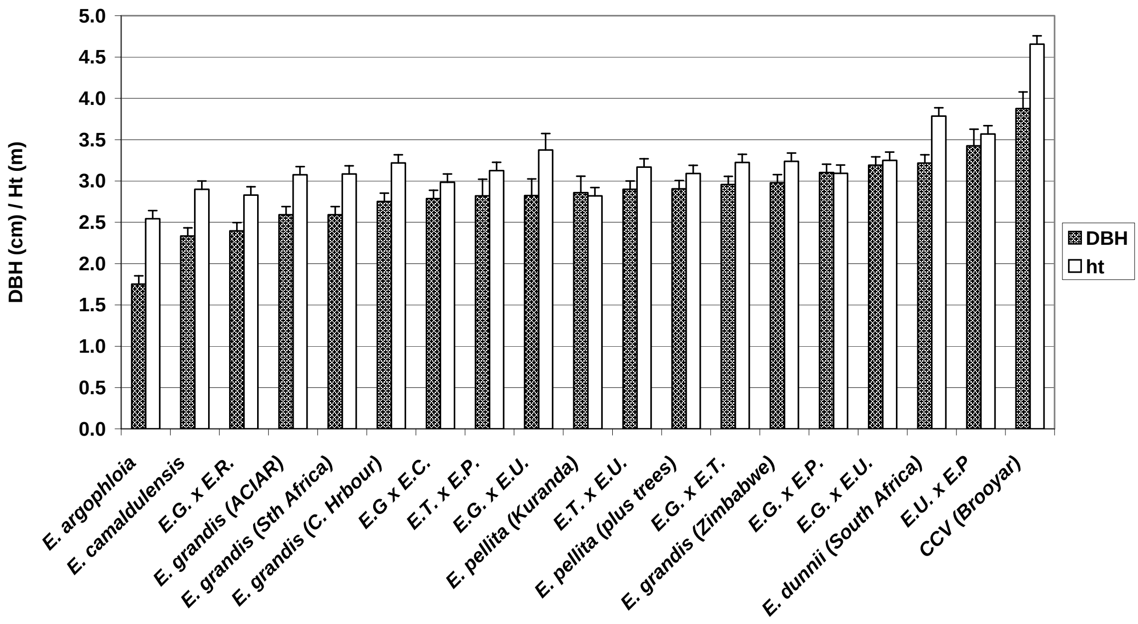


In the two Canterwood experiments established at Yeppoon (Expt. 622a/b), early growth was very good, with the taxa in Expt. 622a (Yellow Sodosol) performing slightly better than those in Expt. 622b (Yellow Dermosol). For Expt. 622a (Figure 4) *A. glaucocarpa* has the best growth at this early age, with the *E. urophylla* × *E. pellita* hybrid, *E. dunnii* and CCV (Woondum) also performing well. In Expt. 622b (Figure 5), CCV (Brooyar) has the best growth of all taxa, with *E. urophylla* and *E. dunnii* again performing well. It is interesting to note that *E. grandis*, which has performed well at an early age on other sites in the Gympie-Gladstone region, have not performed as well on these northern sites.

<u>Figure 4:</u> Expt. 622a: Tree height and DBH at age 20 months.



<u>Figure 5:</u> Expt. 622b: Tree height and DBH at age 20 months



4.1.2 Other trials

Height measurements taken for experiment 578, at age 28 months are illustrated in Figure 6. From these early results it can be seen that the six *E. grandis* provenances and the two *E. dunnii* provenances are performing the best. CCV (Woondum) and *E. cloeziana* are also doing well at this young age. This is quite surprising considering that this is a heavy–textured and often poorly drained site, which does not normally suit these species. The majority of *E. tereticornis* provenances and the two *E. grandis* × *E. tereticornis* (E.G. × E.T.) hybrids are doing quite poorly on this site. Defoliation by insects on this site has also been quite severe and at age 12 months trees were assessed for the severity of defoliation. These results are illustrated in Figures 7 and 8. From these results it can be seen that there are very large differences between taxa in their levels of insect defoliation. *E. tereticornis*, the E.G. × E.T. hybrid, *E. longiroistrata* and *E. camaldulensis* were almost completely defoliated in these attacks. In Figure 8 there are also differences evident between provenances of the *E. grandis*, with the two north Queensland provenances demonstrating the lowest defoliation levels.

<u>Figure 6:</u> Expt. 578: Tree height at ages 18 and 28 months.

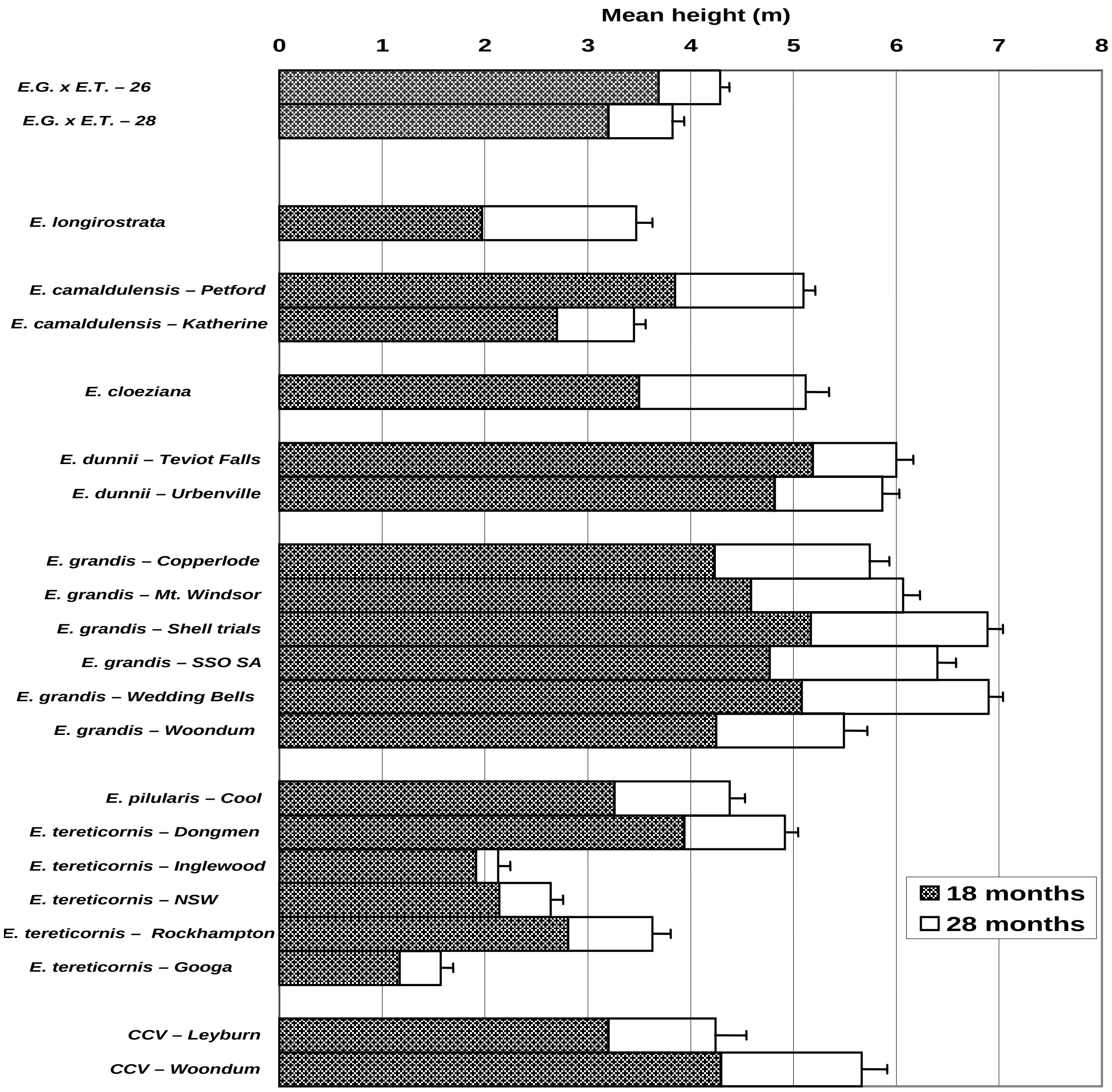


Figure 7: Expt. 578: Leaf beetle defoliation levels for selected taxa at age 12 months.

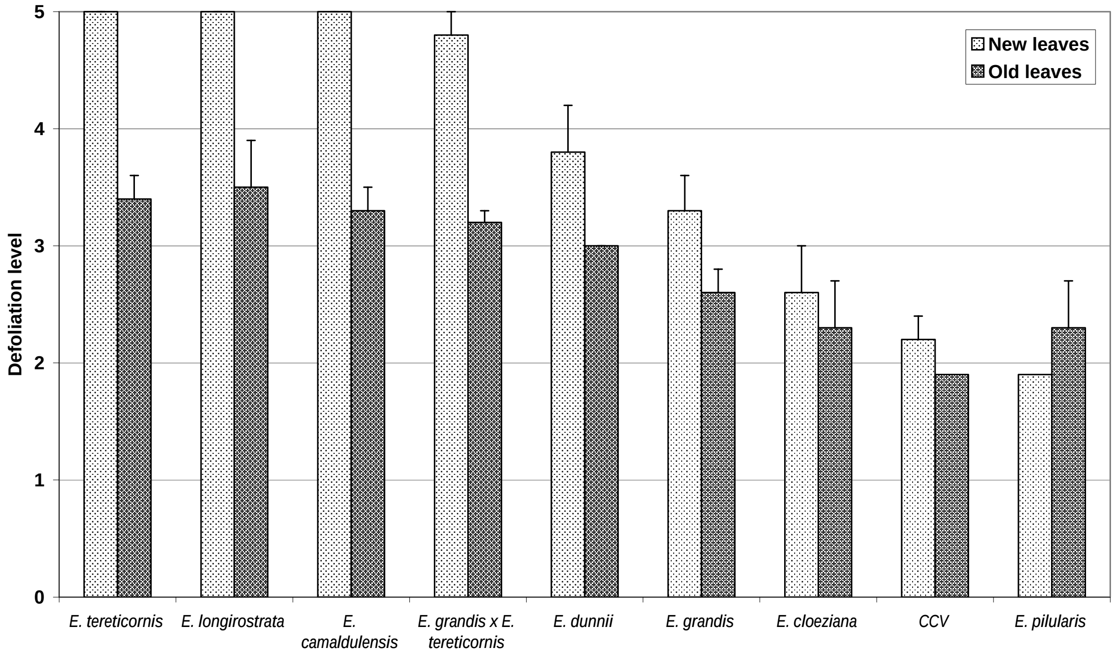
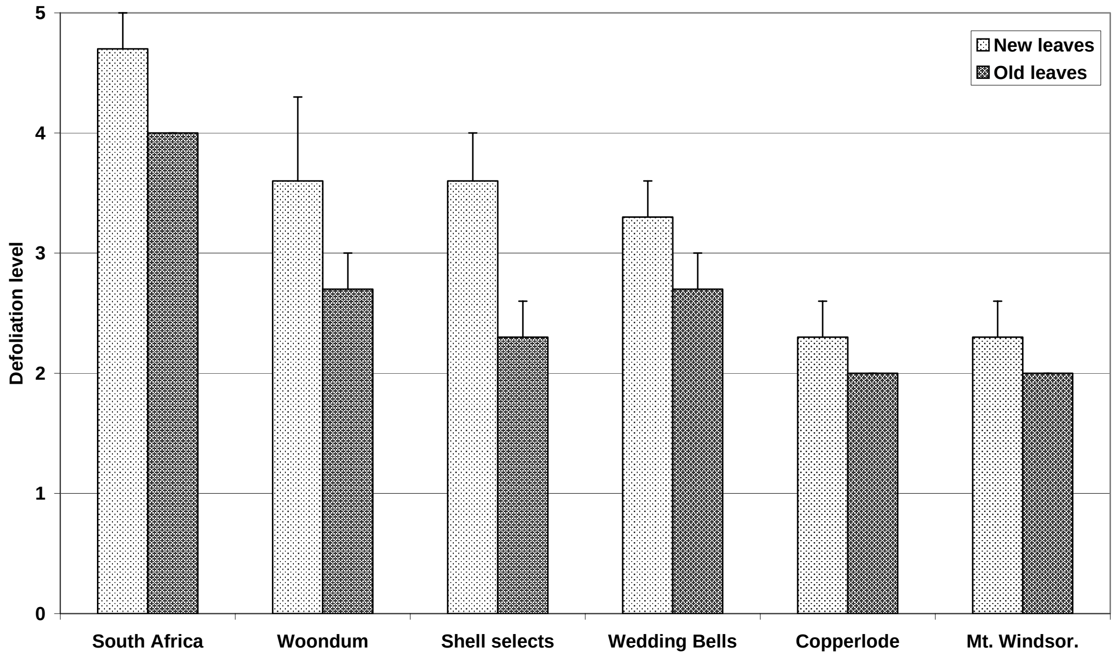


Figure 8: Expt. 578: Leaf beetle defoliation levels for *E. grandis* provenances at age 12 months.



For experiment 584, the most recent measurement of tree height was taken at age 24 months and is illustrated in Figure 9. Compared with Expt. 578, tree growth is better on this site, which is characterised by higher rainfall and a more fertile, well-drained soil type. Taxa rankings however are very similar with *E. grandis, E. dunnii* and CCV all performing well. Potentially as a result of the larger tree size on this site, attack by the giant wood moth and longicorn beetles has been more severe with a survey of this attack illustrated in Figure 10. A serious outcome from this attack has been the subsequent damage by the yellow-tailed black cockatoo in its endeavours to extract the wood moth larvae as a food source. These trees are subsequently weakened and become prone to stem breakage in strong winds (Figure 11a/b).

Figure 9: Expt. 584: Tree height and DBH at ages 12 and 24 months.

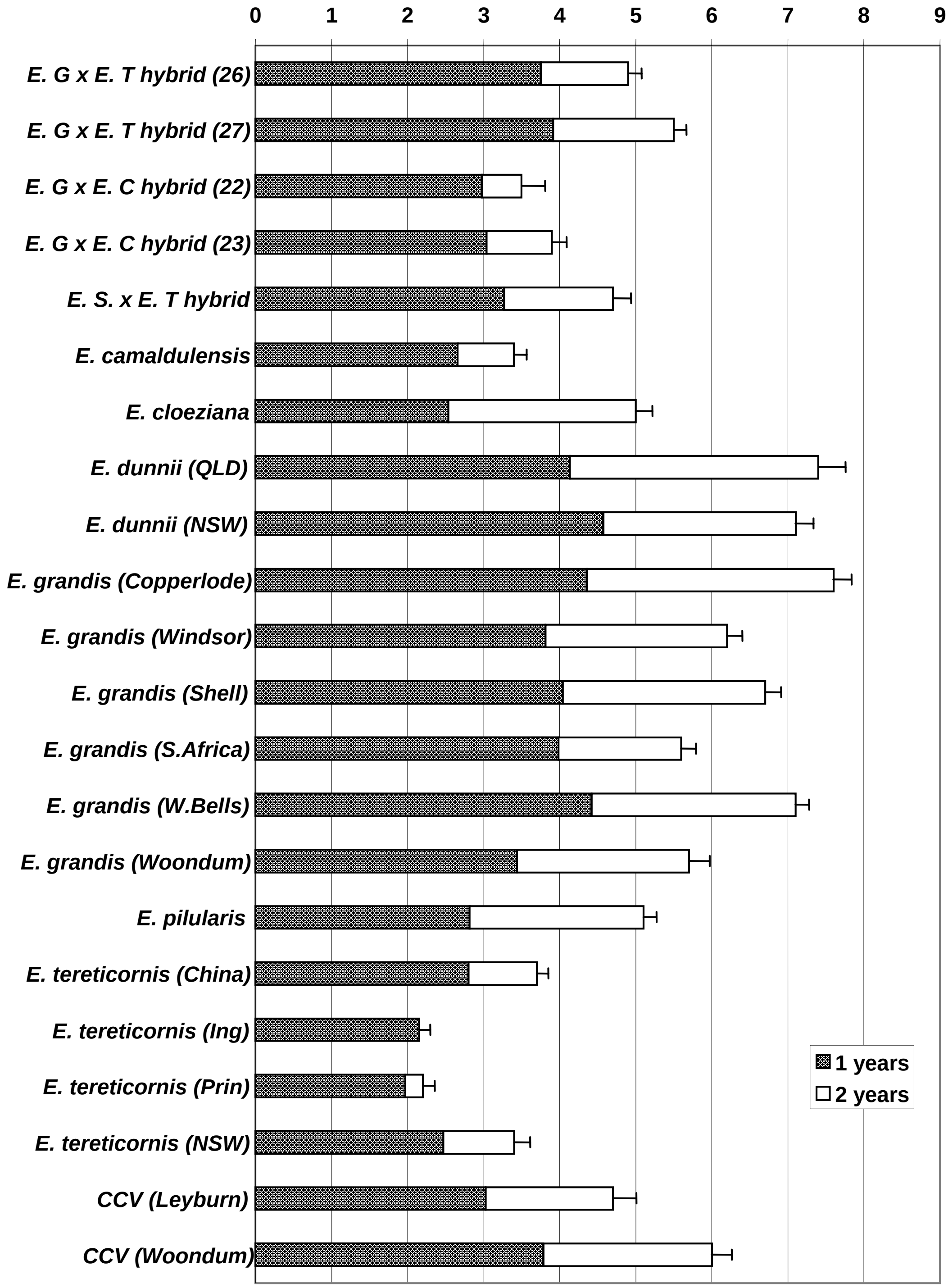


Figure 10: Expt. 584: Incidence of giant wood moth and longicorn attack at age 2.5 years.

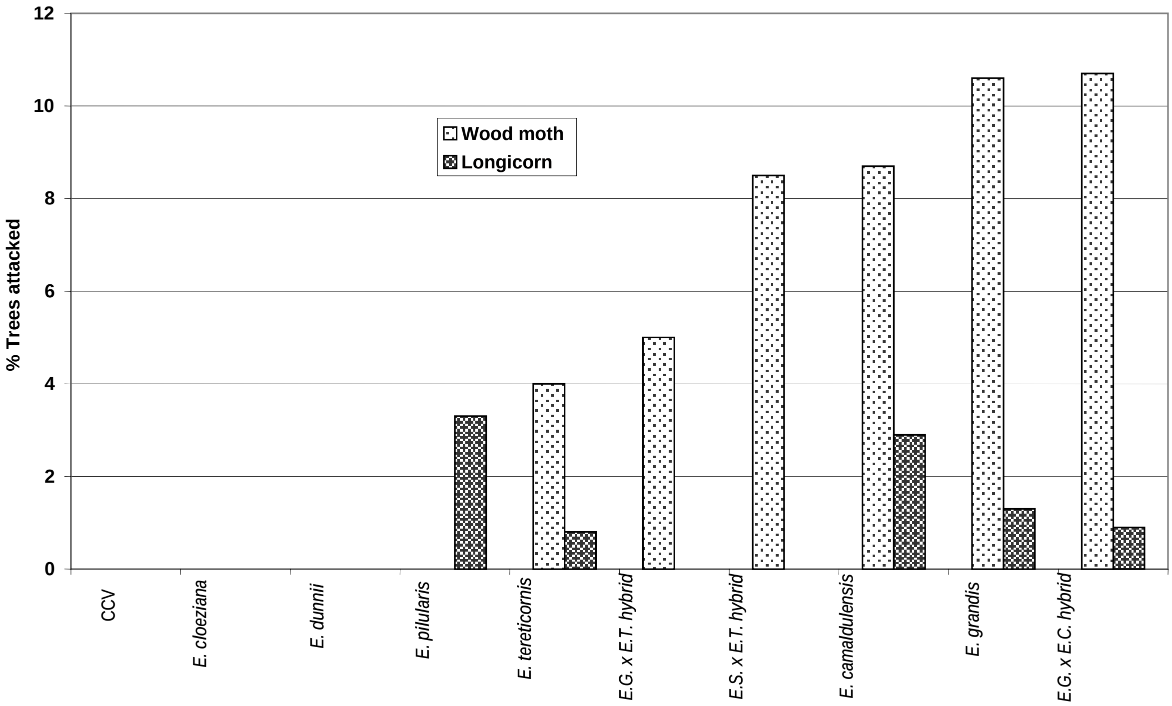
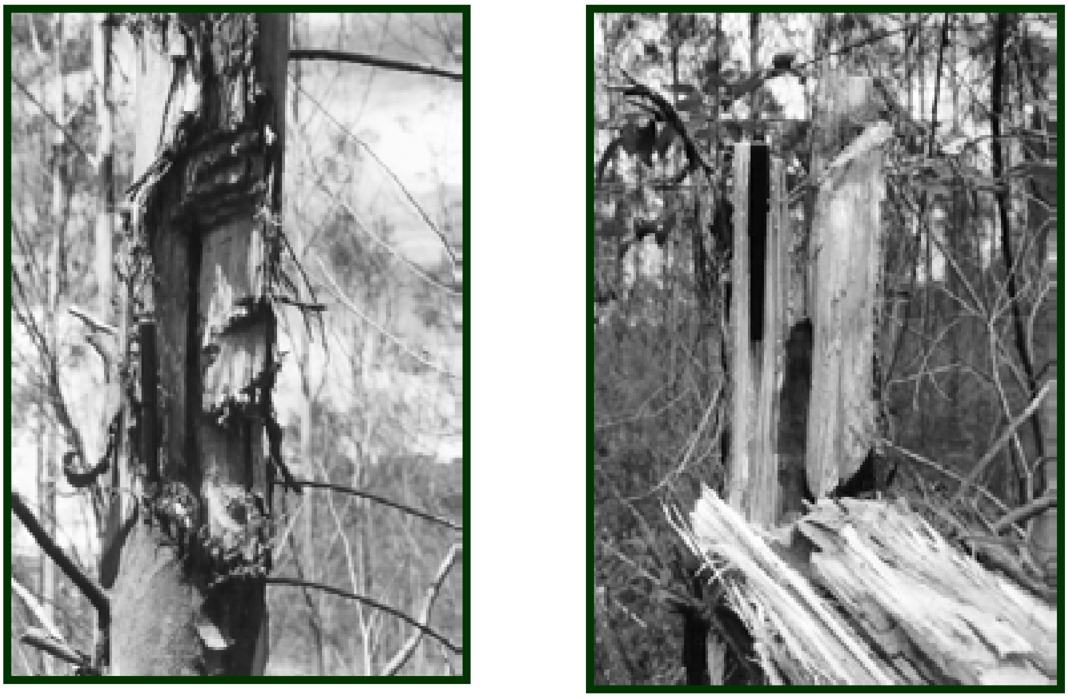


Figure 11: (A) Cockatoo damage caused during extraction of giant wood moth larvae. (B) Wind damage following stem weakening.



(A) **(B)**

For experiment 605, early growth on this site at age 1.1 years was very good with *Corymbia citriodora* subsp. *citriodora* or CCC (Herberton) the tallest, closely followed by the two *E. dunnii* provenances (Figure 12). Most of the *E. grandis* provenances, *E. longirostrata, E. globulus* subsp. *madenii, E. camaldulensis* and CCV (Woondum and Coominglah) are also doing well. An assessment of the disease *Quambalaria pitereka* (Ramularia shoot blight or RSB) which is a major cause of growth reduction and form damage in *Corymbia* trees was made on the three highly susceptible *Corymbia* species in this experiment (Figure 13). It is interesting to note that the taxa with lowest RSB scores were also the tallest *Corymbia* taxa. Further results are in Dickinson *et al.* (2004).

Figure 12: Expt. 605: Tree height at ages 6 and 14 months.

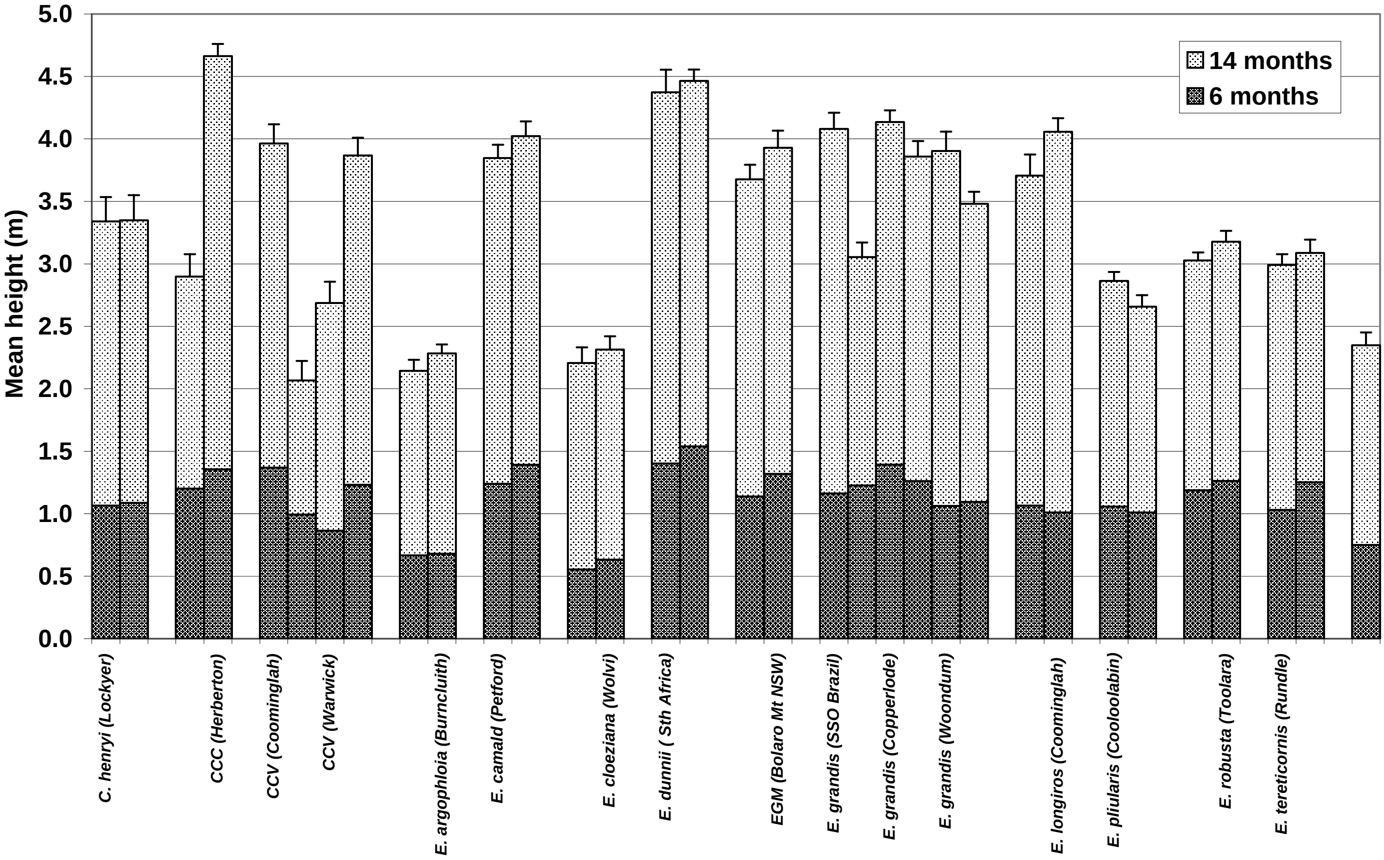
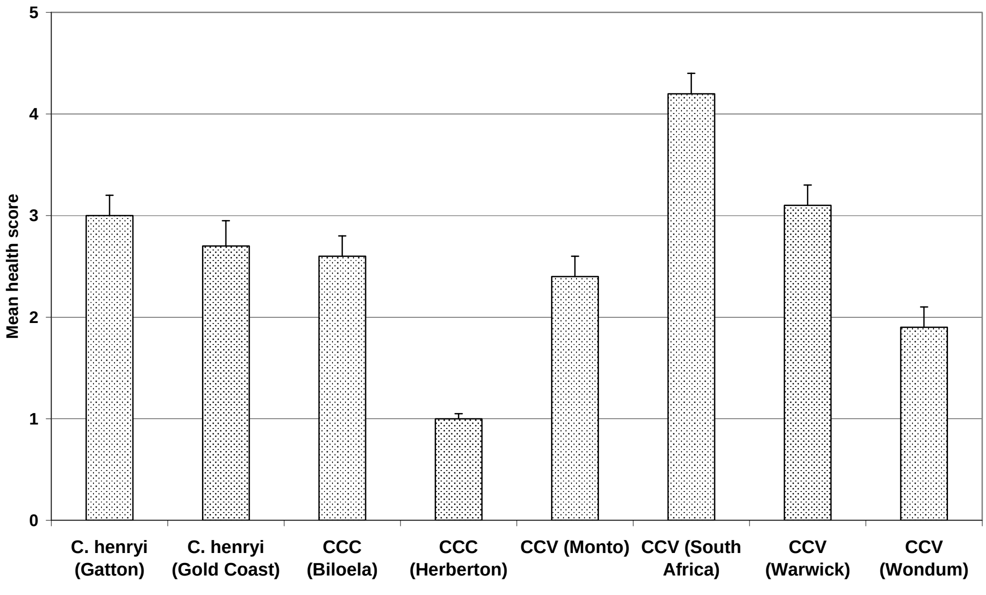


Figure 13: Expt. 605: Mean tree health of *Corymbia* trees at age 14 months (where 1= healthy and 5 = severely damaged).



4.2 Silviculture research

4.2.1 Site preparation

On the four soil types where the effects of deep ripping (to 60 cm) were examined (experiments 577, 583, 581, 617), positive benefits were only observed on the one site (Expt. 617) with a Brown Sodosol soil type (See Graphs 14 and 15). This result is not unexpected as this soil type is characteristically hard-setting, prone to compaction and the heavy clay B horizon can impede water drainage and root penetration. On this site, deep ripping increased height growth of CCV trees by 18% and the E.G. × E.C. hybrid by 33% at age 24 months. For the E.G. × E.C. hybrid, tree survival was also marginally improved in the deep ripped treatments. Shallow ripping (to 30cm) was also conducted on this site, but gave only intermediate results with no increase in height of CCV trees and only a 15% height increase for the E.G. × E.C. hybrid. For the E.G. × E.C. hybrid, growth responses to ripping were most obvious in the treatments with no mounding. Potentially, mounding techniques are producing some soil disturbance and fracturing benefits similar to ripping.

Mounding techniques produced positive benefits to tree survival and growth for a range of tree species on all four trial sites (Expts. 581, 604, 617, 621). However, the most pronounced responses were observed on the three poorly drained sites with either a Brown Sodosol (Expt. 581, 617) or Yellow Sodosol (Expt. 621) soil types. For CCV, large mounds resulted in substantial early height growth increases of up to 19% (Figure 14) and DBH increases of up to 55% (Figure 17). For the E.G. × E.C. hybrid, height growth increases of up to 27% were identified between un-mounded and large mounded treatments (Figure 15). For the E.G. × E.T. hybrid, height and DBH growth increases of up to 30 and 40% respectively were recorded between un-mounded and mounded treatments (Figure 16). For *E. grandis*, mounding resulted in DBH increases of up to 46% (Figure 17). Where small mounds (15–25 cm) were also examined, height growth responses were intermediate between the nil and high mounded treatments (Figures 14 and 16). On the better drained, but shallow Brown Chromosol soil type (Expt. 604), high mounds were not examined, however small mounds (25 cm) resulted in good DBH growth increases of 11% and 20% respectively for CCV and *E. grandis* (Figure 18). It is likely that in addition to some improved drainage, mounding has given some early benefits on this site, by increasing the depth of fertile top-soil in close proximity to the young tree.

<u>Figure 14:</u> Expt. 617: The effects of ripping and mounding on height of CCV to age 24 months.

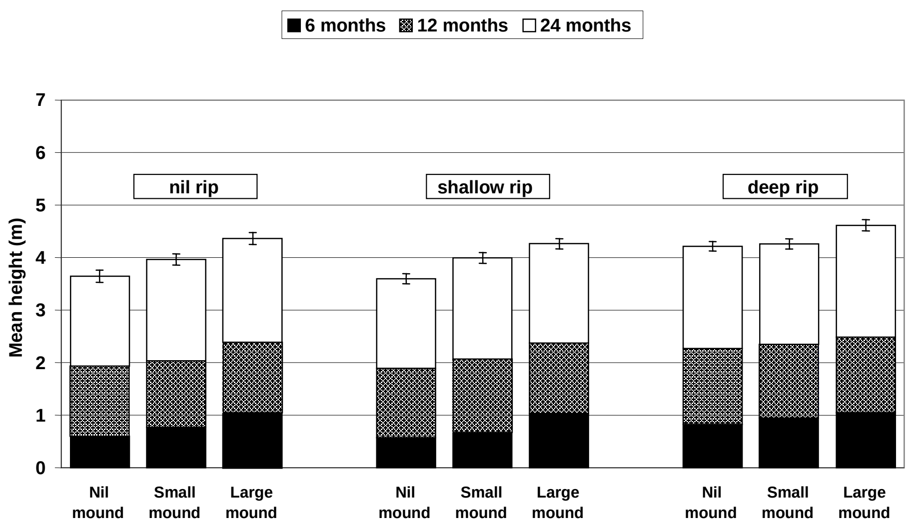


Figure 15: Expt. 617: The effects of ripping and mounding on height of E.G. × E.C. hybrids to age 24 months.

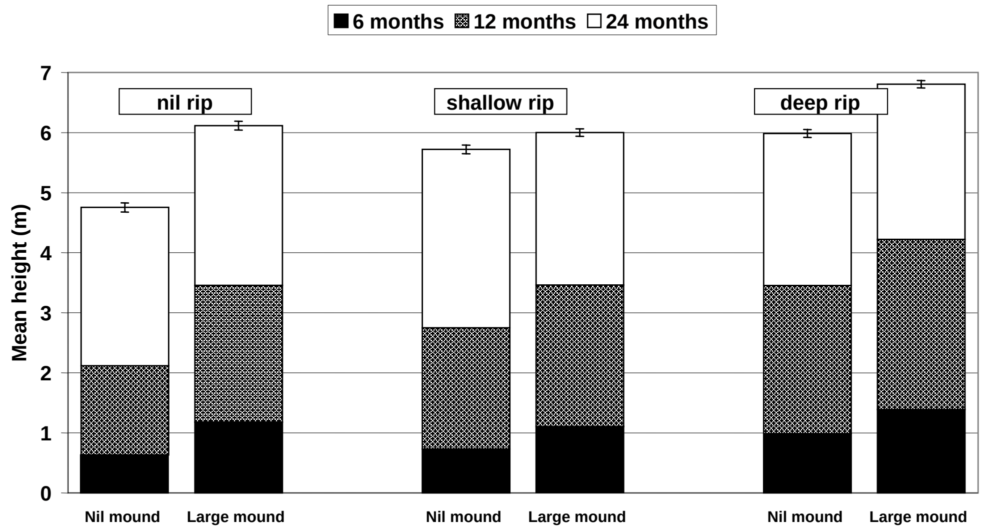


Figure 16: Expt. 581: The effects of ripping and mounding on height and DBH of E.G. × E.T. hybrids to age 3.2 years.

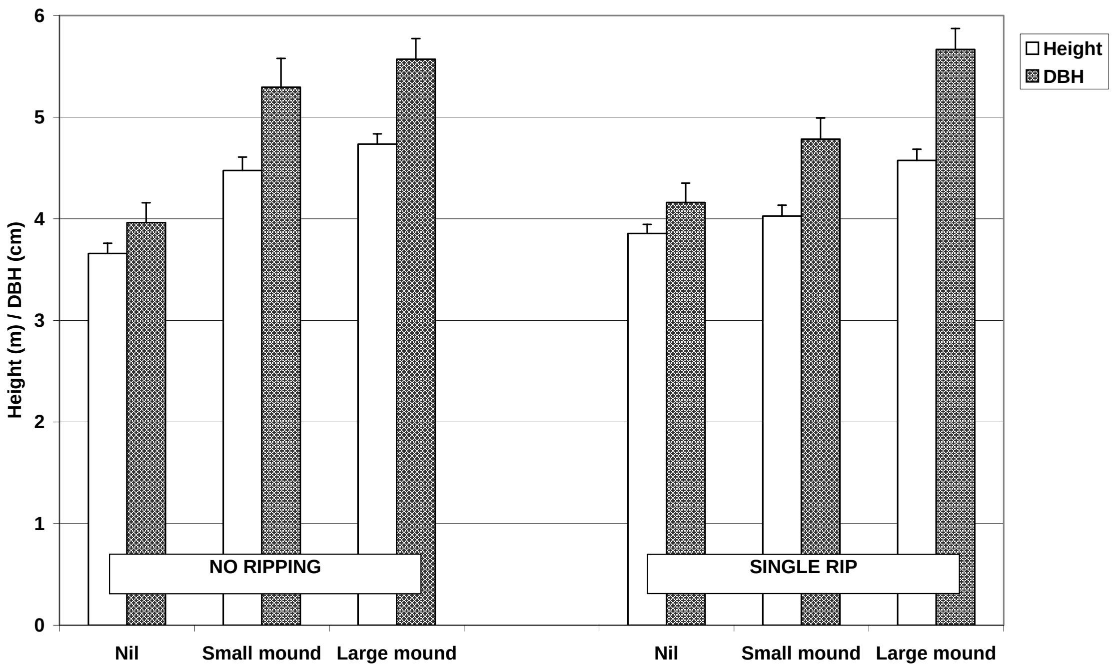


Figure 17: Expt. 621: Effects of various silviculture treatments on CCV and *E. grandis* DBH growth to age 1.6 years. (C= cultivation, W = weed control, F = fertiliser).

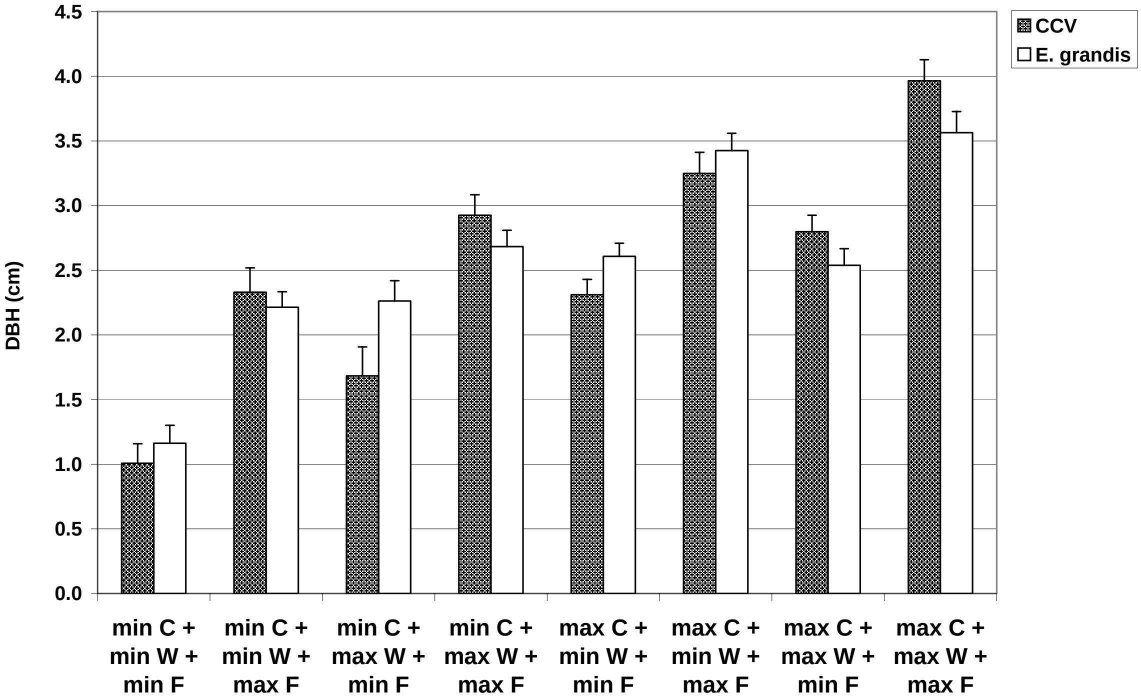
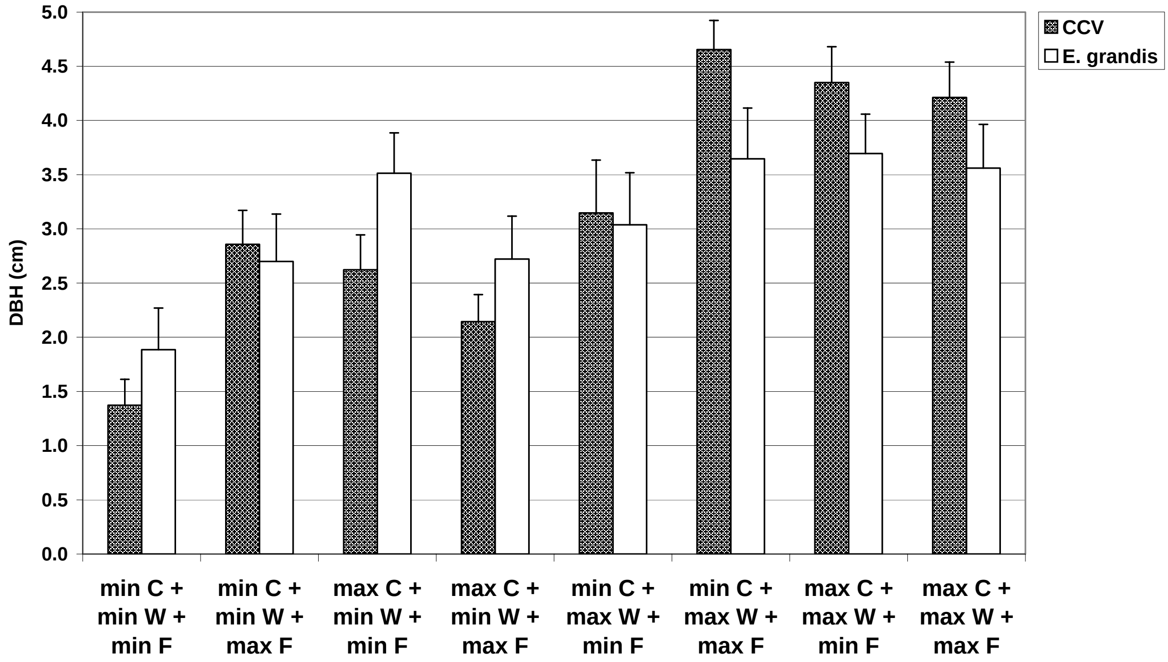


Figure 18: Expt. 604: Effects of various silviculture treatments on CCV and *E. grandis* DBH growth to age 2 years. (C= cultivation, W = weed control, F = fertiliser).



4.2.2 Spacing

Early results at age two years, suggest that initial tree stocking is having an effect on tree growth, survival and productivity rates on all three sites examined (Figures 19, 20, 21). On the two poorer sites (experiments 579 and 607b), there is an early trend of decreasing DBH and tree height with increasing tree stocking/ha (Figures 19 and 20). On the poorest site (Expt. 607b), there also appears to be a decrease in survival % with increasing tree stocking/ha (Figure 20). By entering height and DBH measurements into a volume equation, an estimation of early plantation productivity (m^3/ha) was also calculated. (Note. These volume calculations are quite sensitive to minimal variations in height and DBH at an early age (2–4 years) and need to treated with some caution). In these results, it is appears that the poorer height and DBH (and survival % for Expt. 607b) of the higher initial stockings is negating the benefits of planting a higher tree number/ha. Consequently volumes are not very different between initial spacing treatments up to a stocking of about 1250 trees/ha. At 1666–2500 trees/ha the high tree numbers/ha are still resulting in an increased volume/ha at age two years. These results at such a young age may be an early indication that on the poorer quality sites, lower tree stockings can achieve equivalent volume/ha as compared to very high initial tree stockings. This offers many economic advantages at establishment and particularly when harvesting and processing whereby volume is contained within a lower number of larger trees.

Figure 19: Expt. 579: The effects of initial spacing on *E. grandis* height, DBH, volume and survival % at age two years.

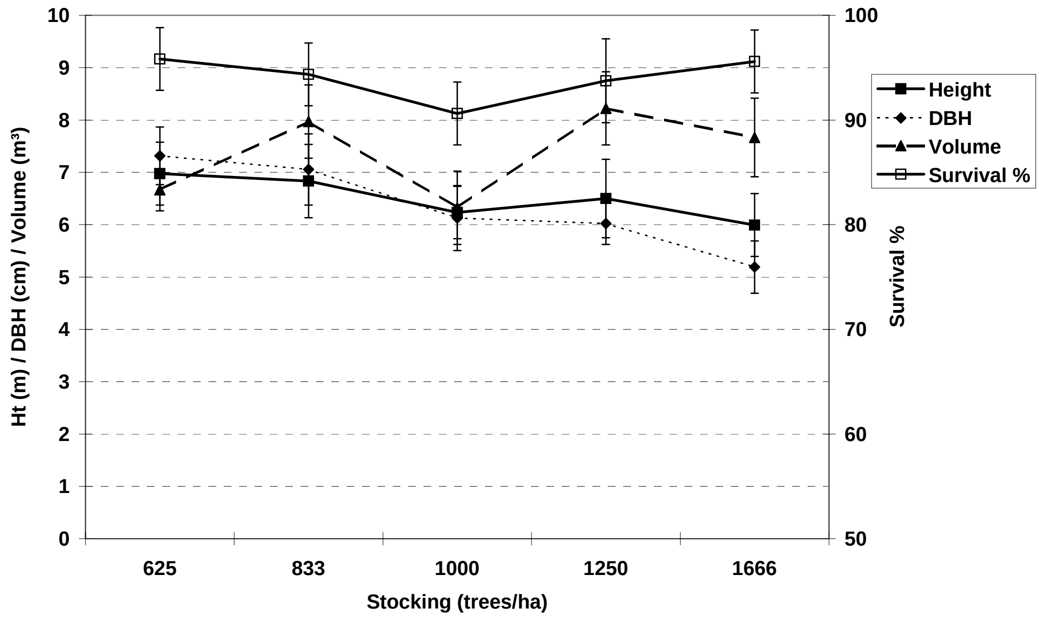
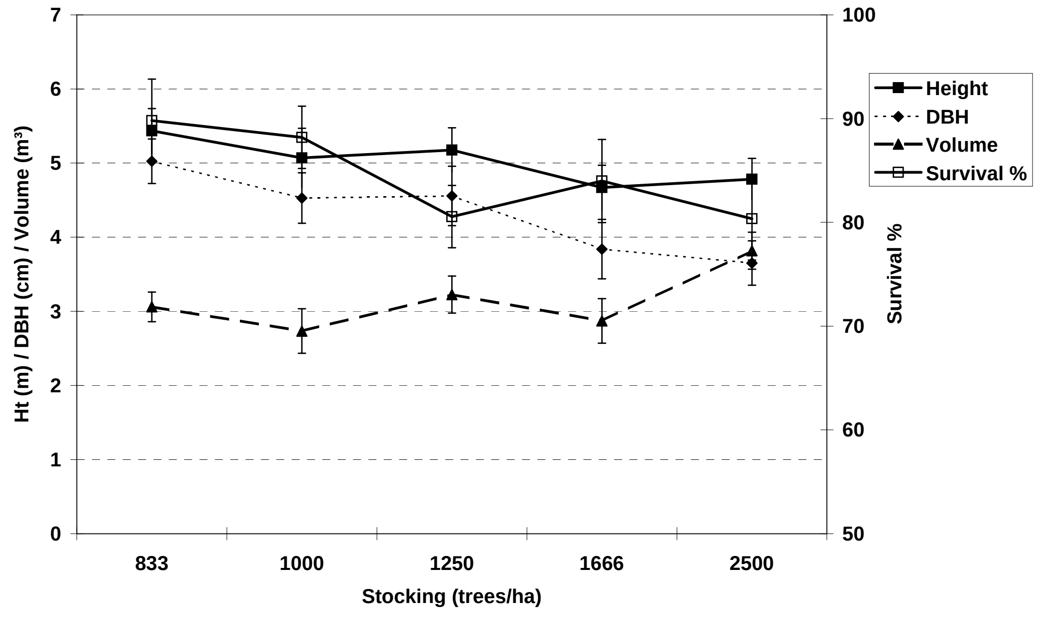
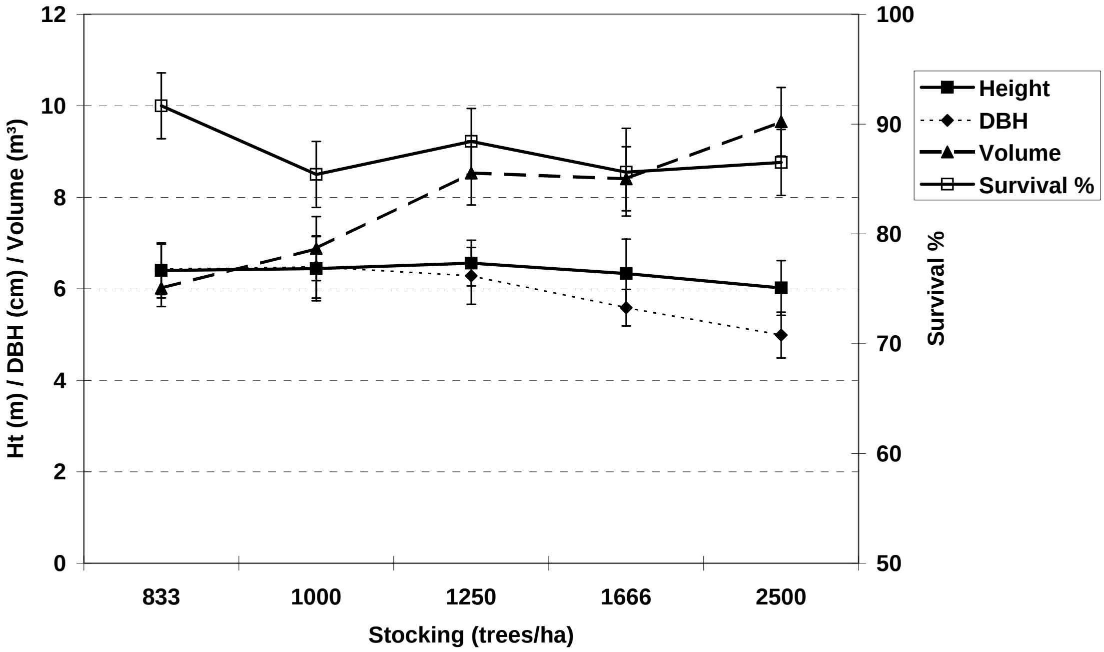


Figure 20: Expt. 607b: The effects of initial spacing on *E. grandis* height, DBH, volume and survival % at age two years.



On the higher productivity site (Expt. 607a), the effects of inter-tree competition on tree height and DBH are only obvious on tree stockings >1250 trees/ha at age two years (Figure 21). On this site, survival appears unaffected by tree stocking rate. As compared to the two poorer sites, height, DBH and volume are considerably higher on this site and there is obviously a greater supply of site resources available to trees, which is minimising early inter-tree competition at the higher tree stockings. As a result, there is a trend of increasing volume/ha with increasing tree stocking/ha.

Figure 21: Expt. 607a: The effects of initial spacing on *E. grandis* height, DBH, volume and survival % at age two years.



4.2.3 Fertiliser

E. grandis is a species with a reputation for exhibiting good growth responses to increased fertiliser application. On the seven sites where it was tested in this study, growth responses to increased fertilisation have been variable, and often difficult to link with a single parameter such as soil type or soil chemical analysis. As described by Baker and Eldershaw (1993), inherent site quality in this region is best determined by knowledge of the site soil chemical and physical characteristics and the crop species adaptability to these characters.

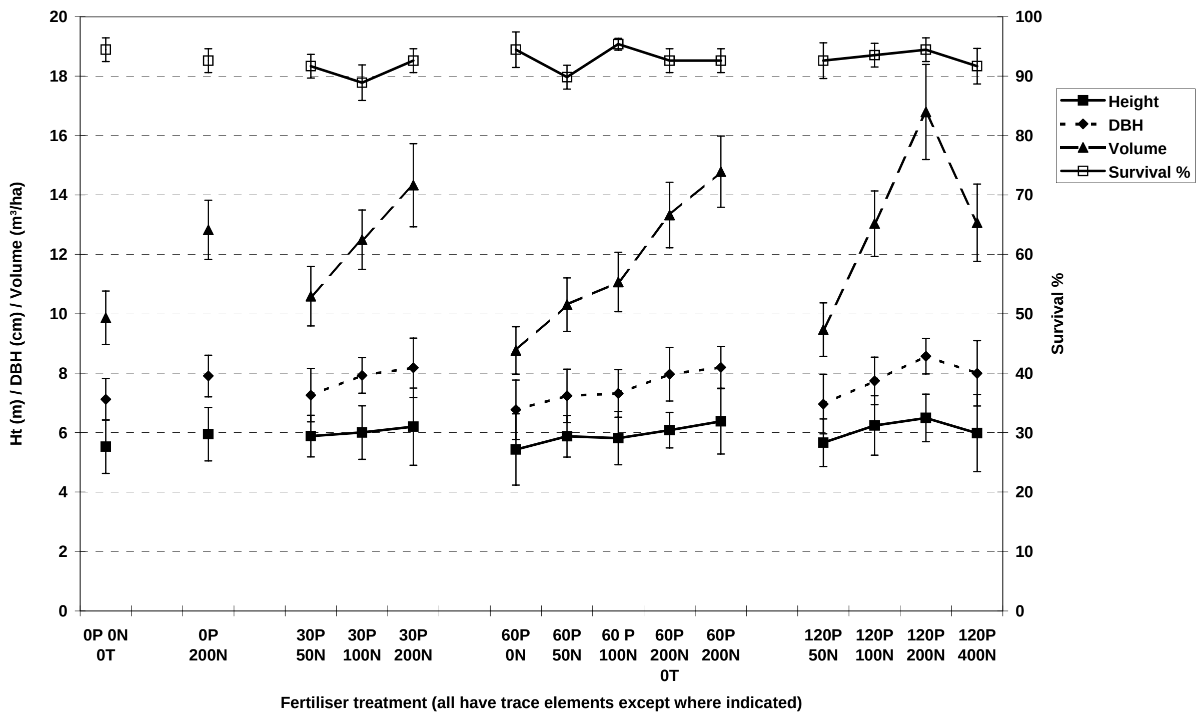
On the three most productive sites (Expts 583, 604, 559a) there appears to be little benefit to the application of nitrogen and phosphorus fertilisers above the initial minimum starter dose of 14–41 kg N/ha and 30–45 kg P/ha (Expt. 604, Figure 18). On one site (Expt. 559a) there was a small increase in growth with the application of potassium and trace element fertilisers, however this is unlikely to justify the additional costs of this application. On the four poorer sites, there has been a substantial growth increase with increased fertiliser application, although these responses appear site and soil type specific, with different elements required to achieve these growth improvements. On one of the poorest sites (Expt. 559b) with a very shallow Red Kurosol, *E. grandis* responded well to nitrogen application at rates >122 kg/ha, with an increase in plantation volumes of 51% by age four years as compared to base rates. On sites with a Grey Kurosol soil type (Expt. 577) and a Yellow Sodosol soil type (Expt. 621, Figure 17), the application of complete fertiliser above base rates did improve growth rates by 18% and 39% respectively. On a site with a Grey/Yellow Kurosol soil type (Expt. 582), *E. grandis* has responded well to phosphorus application at rates >30 kg/ha with an increase in plantation volumes of 60% by age two years, as compared to base rates. On this site, there also appears to be a good response to the application of potassium and trace element fertilisers with plantation volumes increased by 32% by age two years, as compared to control treatments. On these poorer quality sites, it will however be necessary to carefully determine if the additional costs of fertiliser application, can be justified, by sufficient improvement in overall plantation productivity to meet accepted profitability targets.

On the two sites where the E.G. × E.T. hybrid and *E. tereticornis* were trialed (Expts 577, 583) insect attack was very severe on these species and consequently tree growth rates were quite poor. Results were relative to those also measured on the *E. grandis* trees within these trials, with greatest growth responses to increased fertiliser application recorded on the poorer site type (Expt. 577) and minimal growth response on the high quality site type (Expt. 583).

CCV was examined on two sites, one with a moderately productive, Brown Chromosol soil type (Expt. 604, Figure 18) and a degraded Yellow Sodosol soil type (Expt. 621, Figure 17). Growth responses to increased fertiliser application were closely matched to expected site quality, with increases in tree height and DBH of only 7% and 13% respectively for the higher quality site and 31% and 60% for the low quality site.

E. dunnii was only examined on the one site (Expt. 608b), which with a deep Black Vertosol soil type would be considered to be of moderate to good productivity. On this site, there was a substantial growth increase as a result of increasing the rate of nitrogen fertiliser application from 0 to 200 kg/ha, with plantation volumes increased by 69% at age two years (Figure 22). Responses to phosphorus, potassium and trace element fertiliser application were less obvious on this site type.

<u>Figure 22:</u> Expt. 608b: The effects of nitrogen, phosphorus, potassium and trace element fertilisers on *E. dunnii* height, DBH, volume and survival % at age two years.



4.2.4 Weed control

In all four trials where the effects of extending the period of weed control from 3–5 months to 15–20 months was examined (Expts 577, 583, 604, 621), moderate to good growth increases were observed in all the maximum weed control treatments. Individual trial results have been influenced by both the weed spectrum and species growth characteristics. Species with sparse and narrow crowns such as

CCV and *E. tereticornis* appear to benefit most from increased weed control, which is understandable as these species produce very little canopy shading which can help suppress weed growth. On the two sites where it was represented, DBH growth of CCV was increased by 28% (Expt. 621, Figure 17) and 72% (Expt. 604, Figure 18). It is interesting to note that in Expt. 604 (Figure 18), there also appears to be an interaction between the fertiliser, cultivation and weed control treatments. Where maximum fertiliser and cultivation treatments have been applied but with only minimal weed control, tree growth may have been reduced through greater weed vigour and competition.

Species which develop a dense, broad crown at a young age such as *E. grandis*, *E. grandis* hybrids and *E. dunnii* are more likely to suppress weed growth at an earlier tree age and would benefit less from increased levels of weed control. The results obtained for *E. grandis* confirm this theory, with a positive growth effect observed in the increased weed control treatments, although at much lower levels than those observed for CCV. On the four sites where it was represented, DBH growth of *E. grandis* was increased by 17% (Expt. 621, Figure 17), 28% (Expt. 604, Figure 18), 11% (Expt. 583) and 6% (Expt. 577).

Eight pre-emergent herbicide formulations were tested for their effectiveness of weed control and phytotoxicity on CCV, *E. grandis* and *E. dunnii* (Expt. 580). The eight pre-emergent treatments were applied once after planting only. The three pre-emergent + knockdown applications were applied at regular four month intervals to age 12 months. Of the herbicide treatments tested, Milestone and Simazine + Stomp provided weed control for periods considerably greater than the Simazine controls (Figure 23). Unfortunately Milestone was moderately phytotoxic to the trees, with poor tree health recorded for all three species at age 10 weeks (Table 6). For CCV and *E. grandis*, survival % at age 18 months was also lowest in the high rate Milestone treatment (Table 6). As all the pre-emergent herbicide treatments was applied immediately after planting, alternative application strategies such as application pre-establishment may need to be investigated in future. Of the three knockdown/pre-emergent herbicide combinations investigated, glyphosate + simazine still provided the most effective weed control and caused little tree damage when applied carefully. The selective herbicides Lontrel, Verdict and Brodal gave slightly poorer weed control, however as they are non-damaging to eucalypts, they can be applied over the top and offer many practical advantages.

<u>Figure 23:</u> Expt. 580: Per cent weed cover at a tree age of nine months.

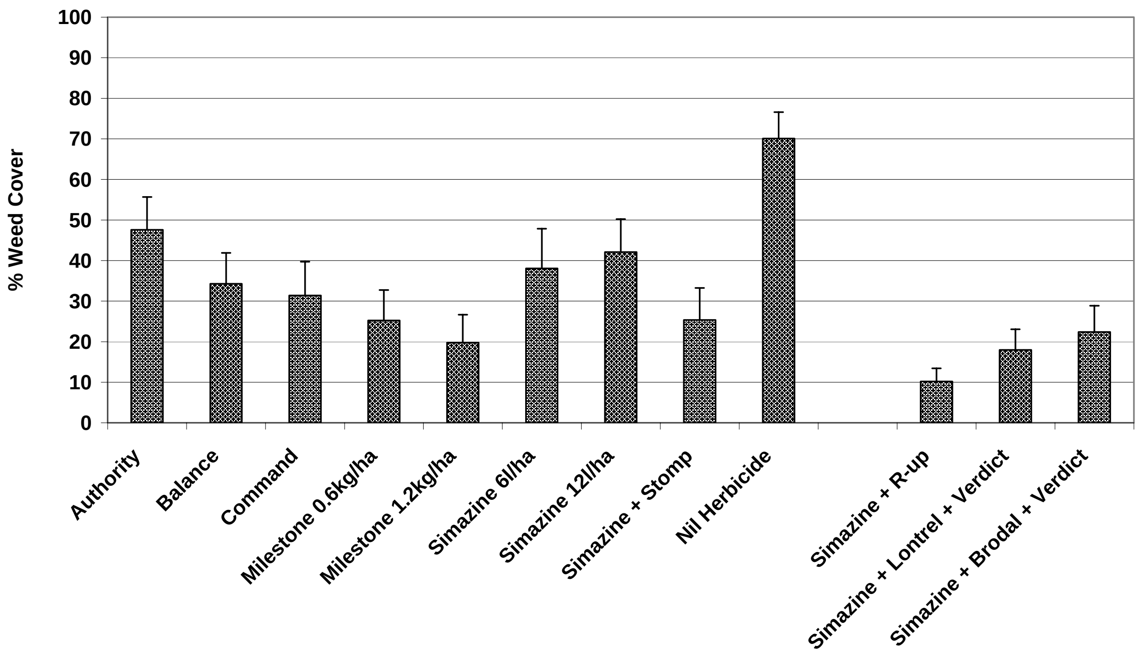


Table 6: Expt. 580: Tree health (tree age 10 weeks), height and survival % (tree age 18 months) for CCV, *E. dunnii* and *E. grandis* trees.

Herbicide	**CCV**			***E. dunnii***			***E. grandis***		
	Health	Height (m)	Surv. (%)	Health	Height (m)	Surv. (%)	Health (m)	Height	Surv. (%)
Authority (0.7 kg/ha)	1.6	2.4	84	-	-	-	-	-	-
Balance (0.7 kg/ha)	1.4	2.7	97	-	-	-	-	-	-
Command (3.2 L/ha)	1.0	3.3	97	-	-	-	-	-	-
Milestone (0.6 kg/ha)	1.7	2.9	84	1.9	3.4	97	2.4	2.2	97
Milestone (1.2 kg/ha)	3.1	3.1	71	3.3	3.3	100	3.5	2.2	81
Simazine (6L/ha)	1.2	3.0	97	-	-	-	-	-	-
Simazine (12 L/ha)	1.2	2.8	96	-	-	-	-	-	-
Simazine (6 L/ha) + Stomp (6 L/ha)	1.2	3.1	96	1.1	3.3	96	1.3	2.7	93
				-	-	-	-	-	-
Simazine (6 L/ha) + Roundup (4 L/ha)	1.2	3.1	99	1.1	3.5	99	1.2	2.7	94
Simazine (6 L/ha) + Lontrel (0.8 L/ha) + Verdict (0.6 L/ha)	1	3.3	100	1.4	3.5	98	1.2	2.4	91
Simazine (6 L/ha) + Brodal (0.8 L/ha) + Verdict (0.6 L/ha)	1	3.0	100	-	-	-	-	-	-
Nil herbicide	1	2.8	97	1.0	2.7	97	1	2.3	90

5. Discussion

5.1 Taxa evaluation research

In most experiments and on most sites examined, *E. grandis* provenances and in particular seedlots representing improved genetic material from seed orchards (e.g. Wedding Bells SF, SFNSW) or plus trees from provenance trials (e.g. Shell-Toolara) have demonstrated the best and most consistent growth rates at an early age. In the oldest experiments (Expts 478 and 575) productivities of between 4.5–28.6 m^3/ha/year were predicted for the improved *E. grandis* seed sources, which also demonstrates the high variability in site productivity present in these regions. It is only on the three northern sites where the performance of *E. grandis* has generally been surpassed by other taxa. Attack by defoliating insects and stem boring longicorn beetles was moderate within *E. grandis*, however this species has proven to be highly susceptible to attack by the giant wood moth, with attack levels increasing as trees obtained diameters of >6 cm (Lawson *et al*. 2002). While this attack may not be a large cause for concern, the resulting predation of the larvae by the yellow-tailed black cockatoo can cause severe stem damage (Figure 11a). In the worst cases, these trees become weakened and are highly susceptible to stem breakage in strong winds (Figure 11b). At this point, most of the cockatoo damage has been observed in the Gympie–Beaudesert area and it is yet to be seen how great an impact this phenomenon will have on the long-term productivity of *E. grandis* pulpwood plantations throughout the region.

Another consistent performer on the sites where it was tested was *E. dunnii*. This species performed particularly well in the northern part of this region on the three sites at Miriam Vale and Yeppoon. The climate of these areas is however, considerably different from the climate characteristic of the natural distribution of *E. dunnii*, where it occurs in high altitude regions (>300 m) along the Qld/NSW border. It will be necessary to observe the performance of this species over a longer term, to confirm its early promise for these regions.

Corymbia citriodora subsp. *variegata* is the primary sawlog species planted in southern Queensland for sawlog production, however a number of recent studies (Hicks and Clark, 2001) have recognised this taxa as possessing high potential for pulpwood purposes when harvested at a young age (<15 years). Growth across all sites where it was tested in this study was very good, including some of the heavy-textured sites with poor drainage (Expts 578 and 622a) where it may not have been expected to be well adapted. Insect attack from both defoliators and wood borers was very low and disease problems associated with *Ramularia* shoot blight, appear to be greatly reduced by selecting resistant provenances such as Woondum. The highly desirable sawlog and pole characteristics of this species combined with an emerging reputation as a high-yielding pulpwood species, make CCV a prime candidate for the use in integrated sawlog/pulpwood regimes in this region.

On three of the four sites where *Acacia glaucocarpa* (Gayndah provenance) was tested, it had the greatest growth of all taxa tested. (Accidental herbicide damage from the use of Lontrel caused severe damage to this taxa in Expt. 605). *A. glaucocarpa* is reputed to have good pulp-making properties and combined with its very good early growth rates appears to have some good potential for pulpwood plantations in this region. These trials however do represent some of the few locations where this taxa has been tested in Queensland and it would be recommended to conduct further research over greater areas before this species is more extensively planted.

Of the diverse range of imported *Eucalyptus* hybrids tested in these experiments, *E. urophylla* × *E. pellita* (Expt. 622a/b), *E. grandis* × *E. urophylla* (Expt. 478/1-3) and selected clones of *E. grandis* × *E. camaldulensis* (Expt. 575/1-9) appear to have the most potential for pulpwood plantations in this region. The performance of the remaining hybrids was generally average to very poor across the range of sites tested where they appeared to be particularly susceptible to insect and disease attack. There are considerable risks associated with importing improved seedlots and hybrids from overseas environments and the poor performance of these taxa in Australian conditions confirms that careful field assessment of these seedlots is of great importance.

5.2 Silviculture research

5.2.1 Site preparation

Early results indicate that on most soil types deep ripping (to 60 cm) provides little obvious benefit to tree growth and survival for a number of tree species. This is particularly the case if high mounding (to 40 cm) is to be routinely conducted on these soil types. It is only on the heavily compacted and poorly drained soil types that deep ripping has produced measurable growth responses and it would be recommended to deep rip on these sites.

Mounding has proved highly beneficial to early tree growth and survival on all soil types where it has been tested. The most substantial growth increases were recorded on the sites with poorest drainage, however good growth increases were also recorded on a better drained site where topsoil depth was shallow. Mounding appears to provide multiple benefits with good soil disturbance, improved drainage and some accumulation of topsoil in shallow soil types. It is strongly recommended that on the soil types examined in this study, high mounding be conducted as part of routine site preparation operations.

5.2.2 Spacing

While the early results from the three spacing trials are showing good early trends, these should still be treated with caution as inter-tree competition effects are expected to increase with increasing tree size and volume/ha. It does appear however, that on the poorer quality sites, lower tree stockings may be the best option for maintaining plantation productivity, while concentrating plantation volume on a lower number of larger trees. Early indications are that this stocking rate could be in the range of 625 –1000 trees/ha. On the higher quality sites, it will be possible to maintain higher tree stockings, which will result in greater plantation productivity in terms of volume/ha. Early indications are that this stocking rate could be in the range of 1000–1250 trees/ha.

5.2.3 Fertiliser

The development of specific fertiliser prescriptions for the wide range of species, site and soil types utilised in these regions will be an extremely difficult and expensive task. On the most productive sites, there appears to be little advantage in applying large quantities of fertiliser, however on the poorest and most economically marginal sites, growth responses to fertiliser application can be substantial. It would appear that the application of fertiliser at moderate rates of between 41–100 kg N/ha and 45–60 kg P/ha in two applications at planting and at age 9–12 months will continue to be the most economic and practical method of ensuring adequate site nutrition for the greatest range of site types. It is anticipated that further developments in the identification of macro and trace element deficiencies through foliar sampling will provide the most economic technique for ameliorating site-specific nutritional problems in the future.

5.2.4 Weed control

For tree species such as *E. grandis*, which develop thick crowns at a young tree age, there may be little benefit of extending weed control beyond 9–12 months duration. For species with a narrow, open crown such as CCV, the effects of weed competition are expected to last longer and it is expected that there will be substantial growth benefits of extending weed control to a period of 15 months or greater.

Simazine + glyphosate remains the most effective formulation for achieving complete weed control on most site types. However, selective herbicides such as Lontrel, Verdict and Brodal will offer plantation managers more flexibility particularly where weed control has slipped and there are some dangers of applying Roundup in windy or excessively weedy conditions. New products such as Milestone and Stomp have potential for greatly extending the effectiveness of a single pre-emergent herbicide application, however will need to undergo further testing before they can be more widely used.

6. Conclusions

6.1 Species selection

- In southern areas, *E. grandis* sourced from seed orchards and plus trees, has consistently demonstrated very good early growth rates across the majority of sites tested. On the three most northern sites (Miriam Vale and Yeppoon) however, its performance although satisfactory, has been surpassed by other taxa.
- *E. grandis* has been proven to be highly susceptible to attack by the giant wood moth, with subsequent predation by the yellow-tailed black cockatoo causing stem breakage in damaged stems. If attack rates increase, this may have serious impacts on the financial viability of affected plantations.
- *E. dunnii* has demonstrated good early growth rates, particularly in the northern areas and appears less susceptible to giant wood moth attack. It is however, considerably distant from its natural climatic range and its longer-term growth potential is yet to be determined.
- Most eucalypt hybrids have generally performed very poorly in this region, although *E. urophylla* × *E. pellita, E. grandis* × *E. urophylla* and some clones of *E. grandis* × *E. camaldulensis* have demonstrated good early growth rates on certain sites.
- *A. glaucocarpa* has performed very well on the limited sites where it was tested and its potential for pulpwood plantations in this region should be further tested.
- *C. citriodora* subsp. *variegata* has performed well on all sites where it was included and appears to be adaptable to the widest range of environments and soil types of any taxa examined in this study. Its wood characteristics make it highly suitable for both sawlog and pulpwood products, thus making this taxa the most suitable choice for use in integrated plantations in this region.

6.2 Silviculture techniques

- Site preparation techniques involving high mounding have consistently proven to increase plantation growth across a wide range of soil types. Deep ripping is generally unnecessary, although is still an important technique on heavily compacted sites.
- Initial tree stockings of 1000–1250 trees/ha appear the most suitable for high productivity sites, but may need to be reduced to levels as low as 625 trees/ha on low productivity suites, where site resources are more limited.
- Fertiliser responses are complicated by interactions between species, site and soil type factors, however there generally appears to be little advantage in applying large quantities of fertiliser on the higher quality sites. Growth responses to increased fertiliser application on low productivity sites can be substantial, although may be uneconomical. It would appear that the application of fertiliser at moderate rates (41–100 kg N/ha and 45–60 kg P/ha) in split applications, will ensure adequate site nutrition for the greatest range of site types.
- For tree species such as *E. grandis*, which develop thick crowns at a young tree age, there may be little benefit of extending weed control beyond 9–12 months duration. For species with a narrow, open crown such as CCV, the effects of weed competition are expected to last longer and it will be expected that there will be substantial growth benefits of extending weed control to a period of 15 months or greater.
- Simazine + Roundup remains the most effective formulation for achieving complete weed control on most site types. Selective herbicides such as Lontrel, Verdict and Brodal do offer plantation managers more flexibility, particularly where weed problems exist and there are some dangers of applying Roundup in windy or excessively weedy conditions. A range of new pre-emergent herbicide products (Milestone, Stomp) have also shown promise and offer potential for greatly extending the effectiveness of a single pre-emergent herbicide application.

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- A number of short summaries of experimental results detailed in this report, have been formatted for inclusion in the DPI&F, Hardwood Plantations Information web site: www.dpi.qld.gov.au/hardwoodsqld/.

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