# THE EFFECT OF GENETIC IMPROVEMENT, FERTILISATION, WEED CONTROL AND REGENERATION METHOD ON THE ESTABLISHMENT AND PERFORMANCE OF *EUCALYPTUS MACARTHURII* AND *EUCALYPTUS NITENS*

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## DECLARATION

This thesis was supervised by Professor J. Zwolinski and Dr. K. M. Little.

I hereby declare that this thesis, submitted for the degree of Master of Science at the University of KwaZulu-Natal, Pietermaritzburg, is the result of my own investigation, unless acknowledged to the contrary in the text.

**GERHARDUS JOHANNES VAN DEN BERG**
**FEBRUARY, 2005**

We the undersigned certify that the above statement is correct:

Professor J. Zwolinski (Supervisor)

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## CONFERENCES AND FIELD DAYS ATTENDED RELATED TO THESIS

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## ABSTRACT

*Eucalyptus grandis* was introduced into South Africa late in the 19$^{th}$ century, and has since become the most important of the hardwood plantation tree species grown for pulp. Until the late 1980's *E. grandis* was virtually the only eucalypt species grown. In order to meet the increasing demand for pulpwood in South Africa, forestry companies need to increase their timber output from an existing land base (Brown and Hillis, 1984; Kimmins, 1994 and Little and Gardner, 2003), or alternatively extend the planting of favourable alternative tree species into areas previously considered unsuitable for forestry due to unfavourable climatic conditions. From 1984 the major timber companies expanded their plantation forestry into the colder, frost-prone highland areas of western KwaZulu-Natal, the northeastern Cape, and southeastern Mpumalanga Highveld. As *E. grandis* was not tolerant to severe frost, *E. macarthurii* and *E. nitens* were planted in these areas as alternatives (Schonau and Gardner, 1991). As much of the earlier research had been centered around the development of silvicultural standards for *E. grandis,* it became necessary to test these for the different eucalypt species. Two trials were therefore established to *E. macarthurii* and *E. nitens* with the following objectives:

- to extend current recommendations to include different species,
- to determine the degree of interaction between different silvicultural standards (genetic improvement, fertilisation and weed control),
- to determine the effects of weeds, fertilisation, genotype and regeneration method (seedling vs. coppicing) on the initial and long term growth, uniformity, tree straightness and survival of cold tolerant eucalypts,
- cost effectiveness of various methods for re-establishing *E. nitens* and *E. macarthurii.*

Genetic improvement played an important role in the establishment and initial growth of *E. macarthurii* and *E. nitens.* The improved treatments outperformed the unimproved treatments in terms of tree growth until canopy closure. At the

last measured date when the trees were six years of age, the *E. nitens* improved seedlings were still significantly better in terms of basal area when compared to unimproved seedlings. The initial positive effect of genetic improvement of *E. macarthurii* seedling however, was not sustained. Genetic improvement of *E. macarthurii* and *E. nitens* also had a positive effect on tree straightness and survival when the trees were assessed at five years of age. The genetic improvement of both species also showed to be a viable option to produce an optimum timber output at a lower cost when regeneration is carried out by means of replanting with seedlings.

Fertilisation also showed positive effects in terms of the establishment and initial growth of *E. macarthurii* and *E. nitens*. At six years after planting, the basal area of *E. macarthurii* seedlings without fertiliser was still significantly lower than any one of the other treatments. However, the initial positive effect fertiliser had on the growth of *E. nitens* seedlings decreased to a non-significant level at six years after planting. Fertilisation of *E. macarthurii* and *E. nitens* had a positive effect on tree straightness and survival when the trees were assessed at five years of age. The fertilisation of *E. macarthurii* seedlings also produced an adequate amount of timber at a relatively low cost.

The controlling of weeds did not have an impact on tree performance initially or after canopy closure for either *E. macarthurii* or *E. nitens*. This is due to the lack of weed growth at these high altitudes at which the sites were planted. Little and Schumann (1996) found that eucalypts could tolerate an aboveground weed biomass of up to 2000 kg $ha^{-1}$ before there were any severe losses in growth due to competition. At both these trials, the weed load did not reach these levels in order to compete with the trees.

No significant interactions between any of the treatments were detected at both these sites at any stage.

At the last measured date, there were no significant differences in terms of tree growth between the coppice and seedling treatments for either *E. macarthurii* or *E. nitens*. Regeneration by means of *E. macarthurii* and *E. nitens* coppice had a positive effect on tree straightness and survival when the trees were assessed at five years of age. Re-establishment by means of coppice for both *E. macarthurii* and *E. nitens* was also shown to be by far the most cost-effective way at present to produce an adequate amount of timber. Coppicing was shown to be the least costly way to produce a $m^2 ha^{-1}$ of timber provided the right species are coppiced, and optimum density levels are obtained.

# CHAPTER 1

## GENERAL INTRODUCTION AND OVERVIEW

*Eucalyptus* species are important to South African forestry as they contribute 52% of timber grown for pulpwood (Directorate Forest Policy, 2000). In order to meet the increasing demand for pulpwood in South Africa, forestry companies need to increase their timber output from an existing land base (Brown and Hillis, 1984; Kimmins, 1994 and Little and Gardner, 2003), or alternatively extend the planting of trees into areas previously considered unsuitable for forestry due to unfavourable climatic conditions, combined with the lack of suitable species to plant in these areas. During the 1980's and 1990's a series of site-species trials were initiated by the ICFR to find alternatives to *E. grandis*, as well as a breeding program for the improvement of the most favourable alternatives (Schonau and Gardner, 1991; Swain, 2001).

From the early 1980's the major timber companies expanded their planted areas to include the colder, frost-prone highland areas of western KwaZulu-Natal, the north-eastern Cape, and south-eastern Mpumalanga Highveld. As *E. grandis* is not tolerant to severe frost, *E. macarthurii* and *E. nitens* were planted in these areas as alternatives (Schonau and Gardner, 1991). Since then, selective breeding combined with site-species matching has resulted in a significant improvement in tree volume, "stem straightness" and pulping properties (Gardner, 2001). "Stem straightness" is a term used to describe how straight the merchantable portion of the tree is. For pulpwood and mining timber purposes, stem straightness is an important characteristic that is included in all breeding programs.

Past research has also shown that weed control in eucalypt plantations during establishment is likely to bring about an improvement in final yield at harvest (Little *et al.* 2003). Furthermore, it has been shown that fertilisation at planting may also enhance tree performance (Herbert and Schönau, 1990; Herbert, 1996; du Toit, 1998). However, for the full potential of fertilisation to be realised, it needs to be applied at planting, which coincides with the stage at which the trees are most susceptible to competition from weeds. Under weedy conditions, the application of fertiliser may result in poorer tree growth than if the trees were left unfertilised. This has largely been attributed to the stimulation of weed growth by fertiliser (Morris, 1984; 1985). Although this weed-x-fertiliser interaction has been extensively demonstrated in pine studies worldwide (Carlson, 2001), little work has been reported for those eucalypt species grown at the higher altitude sites in Southern Africa.

Although there is extensive literature related to the above aspects in isolation, few studies have been conducted investigating the interaction between different silvicultural treatments and tree improvement as well as the impact these may have on the long-term financial gains.

Eucalypts, unlike other commercially grown species in South Africa (S.A), have the ability to coppice following harvesting. This method of regeneration has been used for the successful re-establishment of existing stands under the right conditions. One of the issues related to Eucalypt regeneration is the decision to coppice or replant following harvesting. Current recommendations suggest that, provided the correct species is matched to a particular site at the correct stand density, similar yields may be obtained through coppicing, as compared to replanting, at greatly reduced establishment costs (Opie *et al.*, 1984). Although much work has been conducted comparing coppicing and re-planting of *E. grandis* in S. A., very little could be found related to that of eucalypts adapted to grow at higher, cooler regions (Cold Tolerant Eucalypts – CTE's) (Little and Gardner, 2003). In these studies the planted material used was mostly genetically unimproved material, and whether coppice will outperform genetically improved material still needs to be investigated.

In order to investigate the interaction between genetic material, fertilisation and weed control as well as the comparison between regeneration methods (seedlings versus coppice), two trials were initiated by the ICFR in 1999. *E. nitens* and *E. macarthurii* were used in these trials as they represent two of the more widely planted commercial species in the cooler areas of SA.

The objectives of these trials were to determine the:

- effects of weeds, fertilisation, genotype and regeneration method on the growth, survival, tree straightness and uniformity of two CTE's;
- interaction between weed control and fertilisation on genetic material;
- cost and growth benefits, if any, that have been made by replanting with genetically improved material instead of coppicing.

# CHAPTER 2

# REVIEW OF LITERATURE

## 2.1 Characteristics of *E. macarthurii* and *E. nitens*

### 2.1.1 *E. macarthurii*

*E. macarthurii* occurs naturally in central and southern New South Wales (Australia) between 500 and 1200 metres above sea level (m a.s.l), with mean maximum and mean minimum temperatures of 25 °C and –1 °C. Rainfall is evenly distributed throughout the year with a mean annual precipitation of 1100 mm. Regular frost and light snowfalls are common in the higher areas. *E. macarthurii* is commonly situated at undulating topography along stream banks or flood plains, on soils derived from shales or basalts. These soils may vary in texture from clay loams to sandy loams, with the best growth occurring on well-drained, but moist sites (Herbert, 1993).

Optimum *E. macarthurii* yields are obtained when it is planted between 1150 and 1500 m a.s.l, with a corresponding mean annual temperature (MAT) between 14 °C and 18 °C (Swain, 2001). Within this temperature range, *E. macarthurii* is the most hardy of the commercial eucalypt species currently planted, producing viable yields, however young trees may still be extensively damaged or killed by severe frost, or be susceptible to stem breakage or bending with heavy snowfalls (Gardner and Swain, 1996). Although *E. macarthurii* can be planted outside of this range, its decline in performance means that it would no longer be a commercial option. *E. macarthurii* requires a minimum mean annual precipitation (MAP) of 780 mm, but in cooler areas this may be even lower.

Optimum performance is obtained on deep apedal soils that are well drained and generally low in clay content. *E. macarthurii* can however, grow in soils with a higher clay content that have drained plinthic or moderately structured subsoils. Soils with an effective rooting depth (ERD) of 0.4 m is sufficient for clay loam soils and for those with a finer texture provided they are not underlain by poorly weathered rock. Coarser textured soils, with low water holding capacity, should have a depth of at least 0.6 m and need higher levels of rainfall (Gardner and Swain, 1996).

In its natural habitat, *E. macarthurii* stem straightness is poor, but selection for improved stem straightness as part of breeding programs has markedly improved in second and third generations (Swain, 2001). The thick fibrous bark of *E. macarthurii* means that manual debarking (the primary means of debarking eucalypts in South Africa) in dry conditions is difficult (Swain, 2001). Wood and pulping properties of *E. macarthurii* are not as desirable as that for other CTE's such as *E. smithii* and *E. nitens* (Swain, 2001). However, this may be a function of the marginal sites on which *E. macarthurii* were originally planted, as well as the use of seed from an unimproved source. Recent studies have shown that when grown on "better sites", second or third generation *E. macarthurii* have wood and pulping properties that are more comparable to *E. smithii* and *E. nitens* (Swain, 2001).

*E. macarthurii* is resistant to damage from many insects and is also considered to be resistant to root damage from termites (Herbert, 1993). *E. macarthurii* is sensitive to fire, especially during its early years.

### 2.1.2 *E. nitens*

In its natural habitat, *E. nitens* occurs in distinct populations in the Victorian Alps, eastern Victoria and southern New South Wales between 600 and 1200 m a.s.l. Two disjunct populations are also found at Barrington Tops and Ebor in northern New South Wales (NSW), at an altitude of approximately 1600 m a.s.l, with mean maximum and mean minimum temperatures of 26 °C and –5 °C. In these regions rainfall is moderate to high (mean annual precipitation of 1000 ml), varying in distribution, with slight summer and winter peaks. Frost is frequent and severe, and snow is common. *E. nitens* can be found on landscapes that vary from flat to mountain slopes, although growth is best on less exposed positions. Soils may be derived from a wide range of parent materials, but growth is best on those giving rise to friable clay subsoils that are deep, well drained and high in organic matter (Swain, 2001).

In South Africa, *E. nitens* grows best in the cooler areas above 1350 m a.s.l, with a MAT between 14 $^{0}$C and 16 $^{0}$C and a minimum MAP of 825 mm. Although *E. nitens* is suited to colder areas, with growth rates increasing with decreasing temperatures (up to 14 °C for optimal growth), it is not as tolerant to frost as is *E. macarthurii* (Darrow, 1994; 1996). For this reason *E. nitens* is not planted in low lying landscape positions, frost pockets or windy and exposed ridges in very cold areas. *E. nitens* has shown to be snow tolerant with less than 1% breakage in heavy snowfalls (Gardner and Swain, 1996).

*E. nitens,* like *E. macarthurii*, is best grown on well-drained apedal soils with an ERD greater than 0.45 m. *E. nitens* grows best in humic topsoils, and any underlying saprolite should be well drained. Where root inhibiting structures occur (like under lying stone lines) they need to be broken up by a sub-soiling operation to allow for root penetration (Herbert, 1993).

On sites with sub-optimal rainfall, *E. nitens* are more prone to stress-related diseases, including *Endothia* spp. and *Botryosphaeria* spp. (Herbert, 1993). The susceptibility of juvenile *E. nitens* leaves (bigger leaves that develop in the initial four years of growth) to leafspot (*Mycosphaerella mulleriana*) has led to the widespread planting of the northern provenances (such as Talaganda), which show greater resistance through the more rapid development of intermediate and adult foliage. *E. nitens* roots are susceptible to wood eating termites, but not to damage by the eucalypt snout beetle (*Gonipterus scutellatus*). *E. nitens* is sensitive to fire, especially during its early years.

## 2.2 Genetic improvement of *E. macarthurii* and *E. nitens*

Both the genetic improvement of important tree species and the correct matching of these species to sites (site-species matching) play a major role in the forestry industry towards yield optimisation. In the cooler areas of S. A., genetic improvement combined with site-species matching of *E. macarthurii* and *E. nitens*, has resulted in a significant improvement in tree volume, stem straightness and pulping properties (Swain, 2001).

### 2.2.1 Selection and breeding of *E. macarthurii*

In 1979, the first in a series of trials was established on three sites in the province KwaZulu-Natal (S. A.) to determine which of 15 CTE's were adapted to grow in the colder regions. Results from these trials when felled at nine years of age showed that *E. macarthurii* is susceptible to timber splitting, and is one of the species with a thicker bark. *E. nitens* on the other hand, exhibited the most variation in timber splitting and had a relatively thin bark (Nixon, 1991).

In 1983, a breeding program was initiated by the Institute for Commercial Forestry Research, S. A. (ICFR) for the improvement of the most promising CTE's (Swain, 2001). The five main cold tolerant species of commercial importance at that time were: *E. elata, E. fastigata, E. fraxinoides, E. macarthurii* and *E. nitens*. Two of these species (*E. macarthurii* and *E. nitens*) still comprise the main component of the present breeding program. *E. macarthurii* trees were selected in local commercial plantations for yield, disease tolerance and stem straightness, the latter of particular importance (Swain *et al.*, 1999). These trees were tested in a series of progeny trials from 1984 to 1988, where it was found that only seven of the 83 seedlots chosen from the first generation were among the top seedlots at all the sites (Swain *et al.*, 1999). They also found that stem straightness had improved markedly relative to series of *E. macarthurii* provenance trials that were implemented in 1984 and 1985. Seed was collected for this series of trials from phenotypically superior trees at different localities in Australia (Stanger, 1991). Results showed that the Pentrose and Paddy's River Provenances, as well as the local South African selections, performed better than the other provenances on good sites. On more marginal sites the Thurat Rivulet Provenance outperformed the other provenances.

In order to detect if any improvement had been made through selection, second-generation progeny trials and genetic gains trials were established by the ICFR in the early 1990's. These experiments confirmed that the selected South African second generation genotypes outperformed the Australian material, and in most cases, the improved families outperformed the commercial seedlots, used by the forestry industry in 1991 Swain *et al.* (1999).

### 2.2.2 Selection and breeding of *E. nitens*

Based on *E. nitens* tree improvement provenance trials conducted in S. A., Swain (2001) was able to conclude that:

- the Ebor and Barren Mountain provenances generally preformed better in the summer rainfall regions of South Africa than the other provenances;
- the Tallaganda provenance appeared to be the most frost tolerant of the *E. nitens* provenances.

From these trials superior trees were selected, cuttings taken and successfully transplanted into grafted gene banks. Regular flowering assessments have been carried out in all breeding seed orchards (BSO's). In order to quantify the gain made by selection, seeds were collected from superior trees in the top performing families in several of the BSO's, and used to establish a series of the second-generation trials at the beginning of 2000. No results from these second generation trials are available yet (Swain, 2001).

Published literature outside South Africa on provenance and family performance, and on the genetic gains of *E. nitens* is sparse. Growth and straightness of most Victorian central highland families was superior to Tallaganda and Barrington Tops families in New Zealand provenance-progeny tests at eight years of age (King and Wilcox, 1988). There was considerable variation among families within central Victorian provenances, while Tallaganda material was consistently poor in straightness. Trials in Victoria showed similar results, from which Pederick (1986) recommended a base population for breeding in that state composed of selections from Rubicon, Macalister and Toorongo provenances. Tibbits and Reid (1987) found seedlings and young trees originating from central Victoria and northern NSW to be notably more resistant to natural and artificial frosting than those from southern NSW.

Johnson (1996) reported on the growth and straightness of *E. nitens* progenies in New South Wales. A single Mt Erica family showed superior performance for several traits, however since sampling at this trial was insufficient, no reliable conclusions could be made. The Tallaganda provenance had particularly bad straightness, but was similar to Barrington Tops in growth performance. The presence of significantly superior individual families for all seed sources tested further implies that all of them could yield valuable selections. To establish a base population for breeding in southern NSW, natural sources should be sampled from northern and southern NSW, central Victoria, as well as improved sources such as seedling seed orchards.

The objectives of a study on *E. nitens* by Gea (1997) was to obtain reliable estimates of genetic parameters for growth, stem characteristics, pilodyn (a hand-held tool used for indirect measure of wood density in standing trees) penetration, basic wood density, and the relative merits of different genetic groups. Rubicon provenance performed the best, whereas northern and southern New South Wales provenances were poorly represented amongst the best. Variance for families in plantations was almost half the size of those for native provenances. Seeds from any Australian seed orchards, or New Zealand progeny trials, showed a standard deviation of approximately 0.6 for growth over the best provenance. The Australian orchards had low pilodyn penetration values while the New Zealand selections showed high values that translated to high-density values.

Hardner and Tibbits (1998) investigated inbreeding depression for growth, wood and fecundity traits in *E. nitens*. Controlled cross-pollinated, self and natural open-pollinated progenies from 12 parents of *E. nitens* were used to estimate inbreeding depression up to 9 years of age. Growth traits exhibited significant inbreeding depression. Inbreeding depression was also present for number of flower buds. However, it was absent for wood density, relative bark thickness, frost damage, and proportion of reproductively mature individuals.

From the above literature, one can conclude that progress has been made on selecting the right provenance for different sites, tree straightness and other morphological characteristics. Similar responses to selection could be expected in South Africa.

## 2.3 Fertilisation

As suitable land for afforestation is limited in South Africa, any increase in the productivity of re-established plantations may compensate for the need for afforestation. In addition to applying proven establishment and regeneration techniques, soil fertilisation may help to achieve this, especially on less productive sites (Schönau, 1983).

Schönau (1983) summarised results from nine fertiliser experiments in South Africa where various quantities and types of fertiliser were applied. In eight out of the nine experiments, there was an increased *E. grandis* timber yield of 39 t $ha^{-1}$ of dry timber due to fertiliser application.

Most fertilisation studies on *E. nitens* and *E. macarthurii* have been performed outside of South Africa. In these studies there is disagreement to the length of time for which fertilisation enhances tree growth. Neilsen (1996) applied various fertiliser combinations to *E. nitens* at establishment and found that nitrogen-phosphorous fertiliser increased growth by 30 $m^3$ $ha^{-1}$ at age seven years. McKimm *et al.* (1979), Bennett *et al.* (1997) and Louzada *et al.* (1991) also found a positive response to fertilisation on the growth of different eucalypt species (including *E. nitens*). Their result indicated that the application of appropriate fertiliser was associated with increased early growth. Whether or not these responses continued until the trees were harvested is unknown. In contrast, Turnbull *et al.* (1997) found that the effect of fertiliser on tree growth is only short-term. In his study, no significant differences between the fertiliser treatments and the control (no fertiliser applied) were detected when the trees were seven years of age.

Aboveground biomass and nutrient content of different eucalypts (including *E. nitens* and *E. macarthurii*) were tested in South Africa by Herbert and Robertson (1991). They found that *E. macarthurii* was one of the species with the highest nitrogen (N) and potassium (K) contents in its aboveground components. It was also the species that contains the largest amount of nutrients in its bark. *E. nitens*, however, consisted of the highest total nutrient mass and had the greatest quantity of nutrients in its litter.

In similar studies by Bennett *et al.* (1997) and Misra *et al.* (1998) on several eucalypt species in Australia, they found that the application of fertiliser increased the concentrations of N and phosphorous (P) in a number of aboveground components when compared with unfertilised trees. They also found that additions of P were important for enhancing early growth. However, ratios of the aboveground biomass relative to P-content indicated an accumulation of P in excess of growth requirements. This resulted in a reduction of efficiency of P addition at the highest rates.

Cromer *et al.* (1991) and Bennett *et al.* (1997) found that the rate of growth in tree seedlings is dependent (amongst other factors) on the rate at which nutrients are applied to and are absorbed by roots. Results from Cromer *et al.* (1991) study showed that benefits with the addition of high rates of fertiliser include:

- a greater ratio of foliage relative to roots;
- an increased leaf area per unit leaf mass (specific leaf area); and
- an enhanced photosynthetic capacity.

Bennett *et al.* (1997), however, found that initial significant effects of N and P additions on tree growth were not sustained on a duplex soil, where the availability of K was to be limiting 45 months after planting.

In contrast Turnbull *et al.* (1997) found no significant differences in the yield of seven-year old *E. nitens* plantations where nitrogen was applied at 300 kg N $ha^{-1}$ or 100 kg N $ha^{-1}$ between planting and three years of age.

Smethurst and Wang (1998) investigated the effectiveness of P-application on the establishment of *E. nitens.* The objectives of his study were to determine the effects of fertiliser on:

- concentrations of P in soil solution around the micro sites where P was applied at 2, 6, 18 and 42 months after application and on
- fine root distribution at 18 months.

Results indicated that P could leach to 300 mm below the point of application. Concentrations of P close to the point of application remained high for at least 42 months after treatment, which means that there is enough phosphorous available to some root surfaces for this period of time.

## 2.4 Weed control

A weed may be defined as "any plant growing where it is not wanted" (Anderson, 1996). Weeds are familiar plants that are seen encroaching lawns, sidewalks, roadsides, fencerows, ditches and ditch banks, ponds and waterways, gardens, croplands, rangelands, and forests. In general, weeds affect the use, economic value, and aesthetic aspect of the land and waters they encroach. To the forester, the infestation of weeds in a plantation can lead to competition for resources, such as light, water and nutrients, which could lead to a decline in yields. It is therefore essential to keep the plantations free from these "unwanted" plants in order to gain optimal yields.

In the South African forestry industry, weed management research has received much attention. The aim is to develop appropriate cost-effective vegetation management recommendations for commercial forest species to match a range of sites and management requirements (Schumann, 1992). Schumann (1992) reviewed some competition experiments performed in South Africa. Data from these experiments indicate the importance of concentrating weed control efforts on the tree row, regardless of the tree species. The dry weed biomass in this zone should not be allowed to exceed

1200 kg $ha^{-1}$ for the first two years after plantation establishment, or until canopy closure has occurred. For any particular tree espacement, a 50% or greater reduction in weed cover from the tree row outwards should minimise the impact of weeds on tree performance while reducing weed control costs and soil erosion.

In another study, Schumann (1991) found that 120 days after planting (dap), a complete manual and chemical weeding produced the best tree growth, compared to other weeding treatments. When compared to weed free plots, trees that were row weeded showed a reduction of 32% in leaf surface index (LSI), those that had a ring weeding a reduction of 61%, and those on the weedy control a reduction of 68%. However, there were indications that the trees were beginning to dominate the weeds since accelerating growth rates in most weedy treatments were observed.

Results from a series of trials by Little and Schumann (1996), indicated that row weeding was found to be preferable to inter-row weeding at various sites, but the onset of weed-induced tree suppression differed according to the development of competitive weed levels. At these sites acceptable row weeding widths varied between 2 m and 2,4 m. The maximum tolerable dry aboveground weed biomass for eucalypt trees in these trials was between 1500 and 2000 kg $ha^{-1}$, similar to that found by Schumann (1992).

Male and Havenga (1998) found that different weeding treatments had a significant influence on the growth rate of trees. Trees from the manual weeding plots produced 64% more wood than the trees from the weedy control plots, while the row weeding produced about 13% more wood.

Very little research has been done in S. A. on weed control in *E. nitens* and *E. macarthurii* plantations. This is probably because these species are generally grown under cold conditions where the occurrence of weeds is less extensive. However, a limited number of studies have been carried out in countries other than S. A. on the controlling of weeds in CTE plantations.

In Australia trees were established to test the effect of herbicide application on woody weed development, and the growth of some eucalypt species, including *E. nitens* (Neilsen and Ringrose, 2001). At 12 years of age, there was less total under-storey weed biomass in the herbicide-treated plots. Despite under-storey weed biomass being substantially greater in the no-herbicide plots, this weed competition had a minor impact on the growth of trees. Those site preparation treatments that provided weed-free conditions at the time of planting resulted in woody weed control adequate to establish seedlings without the use of herbicides. Although pre-planting herbicide treatment was not necessary for optimum growth of *E. nitens* grown from bare-root transplants, it did improve growth of the slower-growing planting stock.

Fagg (1988) found that at 21 months after planting *E. regnans*, several herbicide treatments gave significantly greater height growth than the manually weeded or untreated controls, without increased tree mortality.

Barron *et al.* (1998) investigated the effect of second-year weed control on the direct seeding of *E. porosa* in a low rainfall environment. There was a significant growth benefit from using second-year weed control; however, none of the seedlings treated with residual herbicides grew significantly better than those with the glyphosate shielded spray alone. Despite being difficult to apply, glyphosate shielded sprays are attractive because, if correctly applied, they do not have a negative effect on the seedlings and can allow for follow-up control of newly germinating tree and shrubs.

Ellis *et al.* (1985) investigated the effect of weed competition and N nutrition on the growth of *E. delegatensis* seedlings in a Highland area of Tasmania, Australia. The elimination of competing vegetation resulted in faster growth of the seedlings, higher foliar concentrations of N, and higher levels soil mineral N in treated plots than in control plots. A pot trial also done by Ellis *et al.* (1985) showed similar responses. During the six months following the elimination of grass by manual weeding or herbicide treatment, soil incubation studies showed similar net rates of N-mineralization in treated and control soils. The resultant slow rate of mineralization of soil nitrogen and the competition from grass combined to cause a deficiency of N in eucalypt seedlings that was a factor contributing to a reduction in growth.

Kropff (1988) modelled the effects of weeds on crop production, and concluded that the period between crop and weed emergence was the main factor causing differences in yield loss. Sensitivity analysis also showed a strong interaction between the effects of the weed density and the period between crop and weed emergence on yield reduction.

From past weed research it is clear that a proper weeding management regime can play a very important role in achieving the crop yield. Generally, the removal of weeds around the trees is essential in order to reduce competition for limiting resources, which in turn will lead to higher yields. Aldrich (1987), however, found that the prediction of crop growth responses relative to weed control is difficult for the following reasons:

- there is a shift in crop yield from a weed density-dependent to a weed density-independent relationship;
- the effect of weed density on essential growth factor competed for;
- differences among weed species in relative competitiveness for essential growth factors;
- the differential effects of environmental conditions on the competitiveness of weed species;
- the effect of time of weed emergence on competition.

## 2.5 Interactions between genetic improvement, fertilisation and weed control

Gains from tree improvement can only be achieved and sustained to the fullest extent in practice, by establishing, tending and protecting planted trees in an optimal manner (Davidson, 1996). This section will focus on research that has been performed on the interaction between genetic improvement of trees and/or fertilisation and/or weed control.

Literature regarding this subject is very sparse, especially for eucalypts. In South Africa (KwaZulu-Natal Province), a study was established to investigate the effect of different silviculture levels on the growth of *E. grandis* (Boden and Herbert, 1986). It was concluded that complete preparation (complete soil cultivation and weed control) with fertiliser outperformed all the other treatments. The complete preparation without fertiliser was the second best, whereas the treatments without weeding and/or fertiliser performed worst. In other countries, McNabb *et al.* (1994) and Davidson (1996) also found that high levels of productivity are related to intensive management particularly that of site preparation, planting stock quality, genetic improvement, fertilisation and weed control. McNabb *et al.* (1994) found that weed control and fertilisation made the greatest contribution by the end of the first year, but by age three, tree improvement was the dominant factor. Tree improvement became even more dominant by age six years, but fertiliser and weed control applied in the first two years still had a significant impact on wood volume growth.

Turnbull *et al.* (1994) however, found no significant interactions between weed control and fertiliser treatments at any time for mean height, diameter, mean relative height growth rates or survival of *E. nitens*. However, results showed that the application of fertiliser increased tree height from 16 months onwards and diameter from 23 months onwards. The addition of fertiliser also increased weed cover from 41% to 68%. Post-planting weed control following pre-planting weed control however, had no advantageous effect on the growth of *E. nitens* plantations.

Studies in pine plantations showed similar results to that of eucalypt studies. Morris *et al.* (1985) investigated the effect seedling age, weed control and fertiliser has on survival and growth of two *Pinus* species. Intensive weed control (removal of all weeds) and fertiliser application improved early growth. Fertiliser application also improved height and weed control improved ground level diameter. In combination with intensive weeding, the application of fertiliser resulted in a significant increase in survival (from 91% to 97%). However, with minimal weeding (removal of only the woody weeds) the application of fertiliser reduced survival (from 94% to 92%). Smethurst *et al.* (1993) found similar results in their investigation of the effect weeds have on early K and P nutrition and growth of slash pine. During the initial 187 days, trees in the weedy treatment lost half their initial K content, yet P content remained unchanged. However, trees in the weed-free treatment accumulated significant amounts of K and P and increased four-fold in biomass by day 187. Concentrations of K and P in shoot biomass of weeds increased significantly by day 69 and thereafter remained unchanged. Colbert *et al.* (1990) also found a positive growth relation to the combination of fertilisation and weed control in pine plantations. They concluded that management activities that influence soil-plant nutrient availability (i.e. fertiliser addition and competition management) could have a significant impact on tree performance.

In contrast, Mikola (1987) found that although fertiliser and herbicide applications slightly improved diameter growth of pine seedlings, no significant growth differences were found for the different treatments.

From the above, it is clear that there needs to be integration between silviculture and tree breeding to better understand any results obtained and allow for sound recommendations. How weeding and fertilisation effect the performance of improved *E. nitens* and *E. macarthurii* in South Africa, still remains unanswered. One of the main objectives of this study is to investigate this, and to determine whether there is any interaction between weed control, fertilisation and genetic improvement.

## 2.6 Coppice

Coppice growth arises from buds that lie dormant beneath the bark and can be a very cost-effective way for the re-establishment of eucalypt plantations and it plays a very important role in forestry. One of the concerns regarding coppicing is the loss in genetic gain that could have been made by replanting with genetically improved stock. This section focuses on the comparison between coppice and planting stock (genetically similar and improved material).

In South Africa, Schönau (1991) looked at growth, yield and timber density of short rotation coppice stands of *E. grandis*. One of the aspects he investigated was the relationship between the yield and timber density of the parent seedling crops and those of the coppice crops. Results from this trial showed the following:

- under average conditions, tree straightness of coppiced stands was poorer than that of their parent crops;
- stump wastage of the coppice crop was about double that of its parent crop, and it was increased by retention of more than one shoot per stump;
- there was no decline in productivity as expressed by MAI when the coppice crop was compared to its parent crop;
- timber density of the coppice crop was closely related to the parent crop.

Harrington and Fownes (1993) compared allometry and growth between planted and coppice stands. This study was carried out using four fast-growing tropical tree species of which one was a eucalypt species. Results showed that allometry of woody biomass and leaf area differed between planted and coppice treatments. Coppice stands had higher stand population density than the original planted stands, due to the production of multiple stems per stump following cutting. Competition began earlier in coppice stands, resulting in thinner shoots than in planted stands of the same age. Mean monthly increment peaked earlier in coppice stands than in planted stands, but maximum mean monthly increment and leaf area index were not consistently higher in either treatment. Schönau (1991) however, recommended that one should reduce these multiple stems in coppice stands to the original density in order to limit intraspecific competition between the multiple stems.

Blake (1980) investigated the effect of coppicing on growth rates, stomatal characteristics and water relations in *E. camaldulensis*. When compared to planted material of the same age, coppice stems had a more vigorous rate of height growth. Elongation of the main coppice stem was three times than that of intact seedlings after ten weeks. Transpiration rate of coppice stems increased to 8,4 times more than that of the seedlings after five weeks, but declined to 5,4 times after eleven weeks. There was a non-significant difference in the water potential values in the upper leaves of coppice shoots and seedlings although there were almost twice as many stomata per square millimetre on the lower surface of coppice leaves as there were on either surface of leaves on the seedlings.

Research on the gain that has been made by replanting with genetic improved stock, relative to that of coppicing, still needs to be undertaken and forms part of this study.

## 2.7 Economics associated with the re-establishment of *E. macarthurii* and *E. nitens*

Forestry is a long-term investment. In South Africa, the rotation of growing eucalypts normally varies from eight years to twelve years (Schönau and Stubbings, 1987). In the coastal Zululand region however, eucalypts can be harvest as early as six years for pulp production. Overlooking the masked cost of the time value of money may result in serious losses in such long-term investments (de Laborde, 1991). If a profit is to be made from forestry, it is important to ensure that the expected returns from capital expenditure, particularly those incurred during establishment, will result in sufficient timber yields with an estimated revenue equal to the costs incurred. Below is a summary of some work that has been carried out.

A spreadsheet network, FINAL (FINancial AnaLysis), is being developed to facilitate the production and cost analysis of all forest operations and provide a detailed financial analysis of the entire investment. De Laborde (1991) provides a detailed description on the operation of this spreadsheet network.

Studies on the economics of the interaction between fertilisation, weed control and genetic improvement are very limited. In the KwaZulu-Natal Province, a study was conducted to investigate the effect of different silviculture levels on the growth of *E. grandis* and the associated profitability of each treatment (Boden and Herbert 1986). Results showed that complete preparation (complete soil cultivation and weed control) with fertiliser was the most profitable (13,67 % internal rate of return). The complete preparation without fertiliser was the second most profitable treatment (12,13 % internal rate of return), whereas the treatments without weeding and/or fertiliser performed worst.

Davidson (1996) discussed levels of management and financial inputs required to produce high yields in eucalypt plantations. Financial results were examined in relation to investment costs. Tree improvement and cultural activities were observed to have only a low to moderate effect on internal rates of return. It was concluded that it is profitable to pay almost any price for good seedlings. It pays also to do site preparation well, control weeds totally and add fertiliser at optimal rates to promote maximum growth. Increases in yield give a very high return on investment, even if investment in seedling genetic and physiological quality, land preparation, planting, tending and fertilizing are high. This means always adopting a "high input – high output investment strategy".

South *et al.* (1995) investigated the economic returns from enhancing loblolly pine establishment. Effects of seedling grade, fertilisation, hexazinone, and intensive soil cultivation were investigated. Results showed that combining intensive mechanical site preparation with fertilisation and herbicides were attractive in terms of 12-year volume production but these practices increased the unit per cost of wood production and decreased the benefit/cost ratio. Therefore, a significant biological response does not necessarily translate into an economical choice. It seems likely that volume differences among treatments will decline after the periodic annual increment begins to decline.

George and Brennan (2002) determined the costs involved with herbicide weed control, in comparison with other weed control methods. They concluded that herbicides were significantly more cost-effective than any of the other treatments used when the eucalypt trees were two years of age.

Little *et al.* (2002) found that the planting of cowpeas in eucalypt plantations, as a cover crop together with a pre-germination herbicide realised the greatest profit. This was due to the lower cost associated with fewer weeding operations required as a result of the combined effect of the cowpeas and herbicides on suppressing weed growth.

Nwonwu and Obiaga (1988) found similar results in a pine plantation, where planting a cover crop was more cost-effective than manual weeding.

Rusk *et al.* (1991) investigated the economics of growing eucalypts in South Africa in comparison with other competing farming enterprises. Factors taken into account to determine profitability were total sales, harvesting costs, transport costs, establishment costs, tending costs, protection costs and overhead costs. Conclusions from this study were that the growing of eucalypts can be profitable and that it compares favourably with other competing farming enterprises.

Smethurst *et al.* (2001) looked at the economics of N fertilisation of eucalypts and found that it is profitable when applied to plantations expected to have a medium-to-high response in wood yield.

In order to address the above-mentioned issues, this study was design to define growth responses to an interaction, if any, of weed control, fertilisation and genetic improvement. Several factors such as the competition for nutrients and water, and the effectiveness of photosynthesis, that might be responsible for these growth responses, were also investigated.

# CHAPTER 3

# GENERAL MATERIALS AND METHODS

## 3.1 Description of trials

### 3.1.1 Trial locations and description of sites

Both sites were chosen for their suitability for the optimal growth of *E. macarthurii* and *E. nitens* as discussed in chapter two. *E. macarthurii* was planted at the NCT-managed Tweefontein plantation (lat. S29°15'48"; long. E30°13'06"). Draycott trial was planted at the Masonite-managed Draycott plantation (lat. 29° 04' 31" S; long.0 29° 36' 53" E).

Site characteristics for both these sites are summarised in **Table 3.1**.

**Table 3.1 Site characteristics for the Draycott trial and the Tweefontein trial**

| | Tweefontein | Draycott |
|---|---|---|
| **Latitude** | S 29° 15' 48" | S 29° 04' 31" |
| **Longitude** | E 30° 13' 06' | E 29° 36' 53" |
| **Altitude (m a.s.l.)** | 1520 | 1496 |
| **MAP (mm)** | 816 | 799 |
| **MAT (°C)** | 13.6 | 15.2 |
| **Soil type** | Clovelly (2200) | Hutton (2200) |
| **ERD (mm)** | 579.8 | 786.3 |
| **Previous site history** | Grassland | Grassland |
| **Previous crop** | *E. macarthurii* | *E. nitens* |
| **Site preparation** | Pitted | Pitted |
| **Date planted** | January 1999 | January 1999 |
| **Spacing** | 3 m x 1.8 m | 3 m x 2 m |
| **Species planted** | *E. macarthurii* | *E. nitens* |

### 3.1.2 Trial Designs

Both trials are 2 x 2 x 2 factorials arranged in a Randomised Complete Block design (RCB) with coppice regeneration as an additional treatment. The nine treatments were imposed and replicated four times, resulting in a total of 36 plots. Each plot consists of 6 x 6 trees of which the inner 4 x 4 trees were measured. The tree espacement is 3 m x 1.8 m (1852 stems per hectare) for the Tweefontein trial, resulting in a plot size of 194 $m^2$, and a total area of 0,70 ha. For the Draycott trial the espacement is 3 m x 2 m (1667 stems per hectare), resulting in a plot size of 216 $m^2$, with a total area of 0,78 ha.

### 3.1.3 Treatments

**Factor A : Weed Control**

1) Weedy - no further weed control after planting
2) Weedfree - total chemical (glyphosate at 4*l* $ha^{-1}$) weed control until canopy closure

**Factor B : Fertilisation**

1) Fertilized - 125 g 2:3:2(22) of NPK placed in a buried ring around the seedling at planting
2) Unfertilised - no fertiliser applied

**Factor C : Genetic improvement**

1) Improved - second generation seed
2) Unimproved - first generation seed (seed direct from Australia without any improvement)

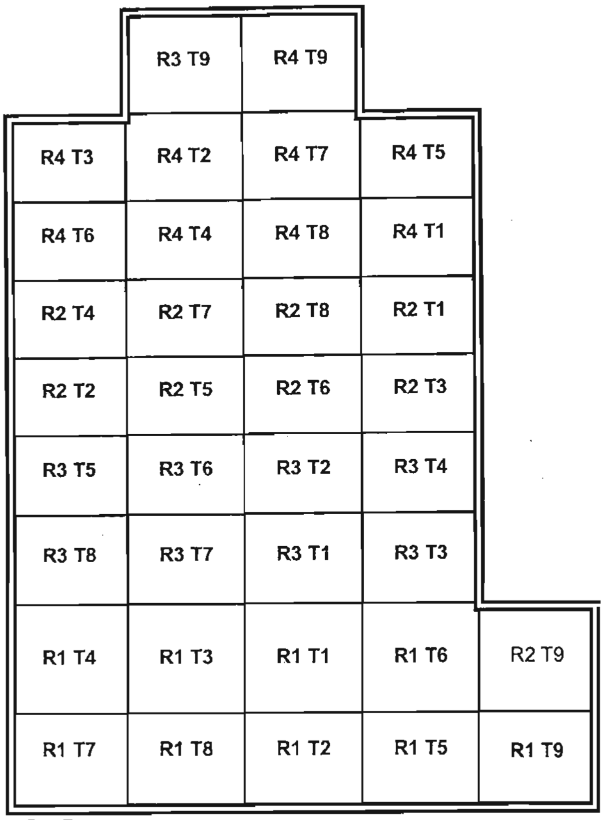
**Additional treatment:**

1) Regeneration by means of coppicing

#### 3.1.3.1 Treatment Layout in the field

The field layout of the treatments for both these trials was the same and is illustrated in **Figure 3.1** and **Table 3.2**.

**Figure 3.1 Layout of treatments in the field for both trials**




R = Rep
T = Treatment

**Table 3.2 List of the different treatments for both trials**

| Treatment | Fertiliser | Level of genetic improvement | Weed control | Regeneration method |
|---|---|---|---|---|
| 1 | Yes | High | No | Seedlings |
| 2 | No | High | No | Seedlings |
| 3 | Yes | High | Yes | Seedlings |
| 4 | No | High | Yes | Seedlings |
| 5 | Yes | Low | No | Seedlings |
| 6 | No | Low | No | Seedlings |
| 7 | Yes | Low | Yes | Seedlings |
| 8 | No | Low | Yes | Seedlings |
| 9 | No | Low | Yes | Coppice |

## 3.2 Selection of seed for use in trials

Since the breeding programme of *E. nitens* and *E. macarthurii* are probably the most advanced of all the CTE breeding programs at the ICFR, these two species were chosen for this study. They also provided extremes in terms of their ability to coppice. Unlike *E. macarthurii, E. nitens* does not coppice well (Little and Gardner, 2003). As each provenance is site-specific (Swain, 2001), it would be difficult to match a single best provenance to any one site. Results could be biased if one provenance were to be used as improved genetic material. When deciding on ways to overcome this problem, two possible solutions considered were:

- The inclusion of more treatments to cater for an increase in the number of "best provenances." This was not a viable option, as the trial area would become unmanageable (with 6 x 6 tree plots) from a weed control perspective if the total number of plots were to be increased.
- The use of a bulked sample of the three best performing seedlots of *E. nitens* and *E. macarthurii* from three sites, which are most similar to that of where the trials are situated.

The latter of these two options was chosen as the most suitable for these trials with the following seed sources being used:

1) Improved genetic material:
    - Bulked sample of the 3 best performing families of *E. nitens* from the Jessievale breeding seed orchard (BSO).
    - Bulked sample of the 3 best performing families of *E. macarthurii* from Jessievale BSO.

2) Unimproved genetic material:

    The Tweefontein site was originally planted with unimproved *E. macarthurii* material from the NSW provenance and the Draycott site with unimproved *E. nitens* material from the Talaganda provenance in Australia. These were then commercially grown, harvested and coppiced. The same seed source that was used for these original crops, was used to generate the new seedlings that were planted as unimproved material at these trials.

### 3.3 Selection of coppice plots adjacent to the Tweefontein and Draycott trials

Four coppice plots in the immediate surroundings of each trial were selected for measurements. The plot sizes chosen were the same as that of the seedlings (6 x 6 stumps, of which the inner 4 x 4 are measured). The espacement between the stumps were the same as of the planted seedlings. For the purpose of this trial coppice shoots were reduced to original density (two stems are left on a stump adjacent to a dead stump to compensate for the dead stump) at canopy closure.

### 3.4 Tree growth and characteristic assessments

Height (ht) and ground line diameter (gld) of the seedlings (16 trees per plot) were measured at trial initiation and then at every second month after that until the seedlings reached canopy closure (*E. macarthurii* at 419 days after planting (dap), *E. nitens* at 398 dap). After canopy closure, trees were measured on an annual basis after each growing season (in April). All the diameters at breast height (dbh) were measured for all the treatment plots. The ht of the first four trees in each treatment plot was measured by means of a vertex III and transponder T3.

Trees were scored for stem straightness when they were 5 years of age using a simple four-point scoring system (Gardner, 2001) as follows:

1 = Best. Entire bole is straight in all planes. Only one or two very slight defects allowed.

2 = Good. Some defect is present, e.g. very slight waviness or kinking in the stem. The bole is otherwise straight.

3 = Bad. Some straight portion/s exist in the bole, but the degree of waviness, kinking or spiraling in the stem makes the tree unsatisfactory in the whole

4 = Worst. Less than 25% of bole is straight. The remainder of the bole is wavy or spiraling.

In general, trees were not downgraded for forking. However, a tree which had the best tree straightness and which would normally be scored as category 4 was demoted to category 3 if any forking was present above breast height.

### 3.5 Derived tree variates

The volume index was used to illustrate tree performance over time from when the trees were planted until the trees reached canopy closure. The volume index ($V$ in $cm^3$ $ha^{-1}$) was calculated, based on the volume of a cylinder as follows:

$$V = \pi[\frac{gld}{2}]^2 \; x \; ht \; x \; density$$

Where: gld = ground line diameter in cm

ht = height in cm

After canopy closure, the stem cross sectional area per tree ($cm^2$) was calculated by converting the diameter at breast height measurements as shown below:

$$Stem\ area = \Pi \; x \; (\frac{dbh_{ob}}{2})^2$$

where $dbh_{ob}$ is the over bark diameter at breast height.

From this the basal area per hectare ($m^2$ $ha^{-1}$) was calculated with the use of the density obtained for the respective treatments. From the tree variates of ht, dbh and stem area, the growth rates were determined. The growth rate for ht ($GR_{ht}$ in m $day^{-1}$) is calculated as shown below:

$$GR_{ht} = \frac{ht_2 - ht_1}{t_2 - t_1}$$

where $ht_2 - ht_1$ is the difference in tree height over the time period $t_2 - t_1$.

In a similar way the growth rate for diameter at breast height ($GR_{dbh}$ in cm day$^{-1}$) and stem area ($GR_{stem}$ in cm$^2$ day$^{-1}$) were calculated.

Each category of tree straightness (best, good, bad, worst) was presented as a percentage of the total number of trees assessed for each of the treatments

In order to explain the reasons for growth differences between any of the treatments, various measurements and samples were taken and analysed at the two eucalypt stands.

### 3.6 Weed assessments in the weedy treatments

The following weed measurements and samples were taken in order to describe the type and abundance of weeds that occurred at these sites:

- The percentage cover of three functional categories of vegetation (woody vegetation, herbaceous broadleaf plants and grasses) was assessed in three 1m$^2$ quadrants per weedy treatment plot. Cover is defined as the area of ground within a quadrant, which is occupied by the aboveground parts of each species when viewed from above (Kent and Coker, 1998). The weed cover is a subjective measurement and is estimated visually as a percentage. A number of recording scales are available, but in this case the Domin scale was used, where the range 0 – 100 percent is partitioned into 10 classes with smaller graduations nearer to the bottom of the scale.
- Aboveground weed biomass samples were taken at each of the three 1m$^2$ quadrants for each of the weedy treatment plots. The biomass was obtained by clipping the aboveground weeds using shears and then the dry mass was obtained by drying the samples for 48 hours at 80 °C and weighing. The biomass is expressed in kg ha$^{-1}$.

Both these assessments were carried out every time the trees were measured in the first growing season until the stands canopy closed at 14 months of age.

## 3.7 Nutrient assessments

Foliar and soil samples were taken in order to determine the nutrient uptake by trees. This was also used to determine which nutrient enhanced tree growth. The weed biomass was also analysed for nutrients in order to quantify competition for nutrients, if any, between the weeds and trees. The nutrient sampling event took place 14 months after planting when the weeds were at their most competitive level and the trees were rapidly growing. The method of sampling was as follows:

- Two sets of soil samples (one when the trees were 8 months of age, and the other at 14 months of age) were taken at a depth of 0 -15 cm. At each survey, four samples were taken per treatment plot, which were then bulked for analysis. These were used to determine any change in soil nutrient levels, for the different treatments, from 8 months to 14 months.
- Tree foliar samples were taken as a bulk sample from the first eight trees per treatment plot. The youngest, fully developed foliage closest to the top of the tree were sampled (Boardman *et al.*, 1997).
- Aboveground weed biomass samples were taken as described in section **3.6** and was submitted for nutrient analyses.

### 3.7.1 Soil preparation and analysis

Soil sample analyses were performed on soil samples that were sieved through a 2 mm screen and air-dried for at least 48 hours. Analytical determinations were expressed on an oven-dry mass basis.

The oxidisable organic carbon fraction in the soil was determined using the wet oxidation technique according to Walkley (1947), commonly referred to as the Walkley-Black method. Air-dried soil was ground to pass a 0,5 mm screen. Soil was then digested in a potassium dichromate/sulphuric acid mix in which the organic matter was oxidised. Soil organic matter content was determined by back-titration of the excess dichromate, using a 0,5N ferrous ammonium sulphate solution.

Soil pH was determined in equilibrated soil: electrolyte solutions. The value obtained in a 1M KCL solution was reported.

The pipette method was used to determine soil texture. Air-dried soil samples (10 g) were pre-treated with 30% $H_2O_2$ if the soil samples had an organic carbon content greater than about 5% to remove organic matter by oxidation. Dispersion of the soil samples was achieved by the addition of Calgon, and the soil slurries were then subjected to ultrasound for approximately 3 minutes using a probe sonicator. Clay (< 2$\mu$m settling diameter) and silt (2-20$\mu$m) fractions were determined by sedimentation and pipette sampling. These were expressed as a percentage of oven-dried soil (Day, 1965). The sand fraction (0,02 - 2 mm) was determined by difference from 100%.

Soil organic nitrogen was determined through the sulphuric acid digestion of organic nitrogen to ammonium sulphate, with a subsequent determination of ammonium ions, using Potassium/Sodium Sulphate based catalyst. Under alkaline conditions, ammonia was distilled into a hydrochloric acid solution and was then back - titrated with a previously standardised solution of HCl. The soil organic nitrogen content is expressed in terms of percentage of the oven-dried soil sample.

A mixed extractant of 0,03*M* $NH_4F$ in 0,1*M* HCl (known as Bray-2 extractant) has been found to be an effective extractant of available phosphorus, particularly for acid soils. The reference methodology used follows that of Bray and Kurtz (1945). Soil samples were equilibrated with Bray-2 extractant. The resulting slurry was then centrifuged and filtered. Extractable phosphorus was determined colorimetrically at 880 nm on an automated segmented flow analyser using the molybdenum blue complex method.

Extractable basic cations (Ca, Mg, K, Na) were defined after soil samples were equilibrated with 1*M* ammonium acetate. The resulting slurry was centrifuged and then filtered. The filtrate was suitably diluted and appropriate ionisation suppressants were added. The basic cations in the solution (calcium, magnesium, potassium and sodium) were determined using atomic absorption and flame emission spectroscopy, and expressed in $cmol_c$ $kg^{-1}$ soil.

Soil samples were equilibrated with unbuffered 1*M* KCl, centrifuged and then filtered to define exchangeable acidity. An aliquot of filtrate was titrated against a previously standardised solution of NaOH solution using phenolphthalein indicator.

### 3.7.2 Tree and weed foliar preparation and analysis

Foliage material was air-dried in a drying room (30-40°C) until the material was sufficiently brittle for grinding. The material was then ground and passed through a 0,5 mm screen. The ground sample was then submitted for analysis.

Plant material (2.5 g) was dry ashed and taken up in a solution of approximately 0.6N HCL, filtered and made up to volume 50 ml (40 times dilution).

Total Kjeldahl Nitrogen was determined through the sulphuric acid digestion of organic nitrogen to ammonium sulphate, with a subsequent determination of ammonium ions, using selenium as a catalyst (FRI Bulletin no.70, p.13). Under alkaline conditions, ammonia was distilled into a hydrochloric acid solution and is then back - titrated with a standardised solution of HCl. The nitrogen content was expressed in terms of percentage of the oven-dried soil sample.

Total Phosphate was defined in a procedure in which ammonium molybdate and antimony potassium tartrate react in an acid medium with dilute solutions of phosphorus to form an antimony - phosphomolybdate complex. This complex was reduced to an intensely blue coloured complex by ascorbic acid. The colour was proportional to the phosphorus concentration and was measured at 880 nm.

For Ca, Mg, Cu, Fe, Zn, Mn, K and Na an air-acetylene flame was used. Ca, Mg, Cu, Fe, Zn and Mn were determined using atomic absorbtion spectroscopy, and K and Na were determined by flame emission spectroscopy.

## 3.8 Soil moisture measurements and water potentials of trees

Soil moisture and water potential measurements were carried out at 14 months after the trees were planted when competition from weeds was prone to be at its highest level and when the trees were growing rapidly. These measurements were carried out after one week of dry weather in order to highlight competition for water, if present.

- Soil moisture measurements of the topsoil (0-7.5 cm) were taken with a ThetaProbe in order to determine the soil moisture content for the treatments. According to ThetaProbe moisture sensor Type ML1 : User manual [ML1 – UM - 1] (1995), the ThetaProbe relies on Frequency Domain Reflectometry (FDR) for soil water content determination. To do this, the ThetaProbe uses capacitance measurements at radio frequencies to determine the soil dielectric content and thus the water content. A linear correlation between the square root of the dielectric constant and volumetric water content has been documented by the manufacturer. Volumetric soil water content is thus the ratio between the volume of water present and the total volume of the sample and is expressed by the ThetaProbe in $m^3 m^{-3}$ (Little *et al.*, 1997). One reading was taken next to each of the measured trees and the mean was used to determine any treatment effects.
- Osmotic potentials of the trees were measured by means of a "pressure chamber" in order to detect any competition for water between the different treatments. To measure the osmotic potential, a leaf is removed from the sample tree and placed in the pressure chamber with the cut end protruding. Pressure is applied into the chamber to higher positive values than osmotic potentials are negative, so water diffuses out of the cells (Salisbury and Ross, 1992). As soon as sap began to exude from the cut end, a pressure reading was taken. The more stressed the plant is for water, the more pressure needs to be applied in order to diffuse water

from the cells. Due to time constraints, only two sample leaves were taken per treatment plot for only one replicate of each trial. These measurements were taken at midday when transpiration rates were high and when water stress, if any, should be on the highest level.

### 3.9 Chlorophyll fluorescence measurements

Chlorophyll fluorescence measurements were taken at the same time as that nutrient, soil moisture and water potential readings. Chlorophyll fluorescence is a physiologically based measurement that measures the efficiency of the light harvesting mechanism associated with photosystem II (Peterson, 1999). Fluorescence has been shown to be sensitive to water uptake (Lenman 1994, Oogren 1990), mineral nutrition, chilling (Mohammed *et al.*, 1995) and light intensity (Groninger *et al.*, 1996). The photochemical efficiency of photosystem II is an ideal measurement of the impact of environmental stresses on the health of the photosynthetic mechanism. The photochemical efficiency of photosystem II is estimated by Fv/Fm, which is the ratio of variable fluorescence (Fv) to maximum fluorescence (Fm). Most forest trees usually exhibit Fv/Fm values of 0.6 to 0.8. Further, Fv/Fm was found to provide the most consistent results with regards to fertility and other environmental stresses (Peterson, 1999). For these reasons, Fv/Fm will be the primary fluorescence parameter discussed in the results. All fluorescence measurements were taken with a portable fluorimeter (Plant Efficiency Analyser, PEA) on the uppermost fully expanded attached leaves of the trees. Four trees from each of the treatment plots were used for measurements. Due to time constraints, only one replicate in each trial was used for these measurements. The fluorescence signals were recorded within a time span of 10 $\mu$s to 1 s with a data acquisition rate of 10 $\mu$s for the first 2 ms and 1 ms thereafter. All samples were dark adapted for 30 minutes prior to fluorescence measurements (Rolando *et al.*, 2003).

## 3.10 Statistical analysis

Analysis of variance (ANOVA), appropriate for a RCBD, was used to test for treatment effects. Analysis was carried out by means of Genstat version 5.1. Only if the *F*-value was significant ($p < 0,05$) were treatment differences further investigated using the least significant differences test (*lsd's*). Bartlett's Test was used to test for the homogeneity of variances within the different treatments. This test was based on the mean tree diameter at breast height for each plot. In this thesis, everything that has been indicated as significant in the text had a *P*-value of less than 0.05.

Note: for the purpose of this study, where ever "seedlings" were compared to coppice, the "seedlings" refers to the mean of all the planted material for all the different treatments.

# CHAPTER 4

# ECO-PHYSIOLOGICAL AND GROWTH RESPONSES TO GENETIC IMPROVEMENT, FERTILISATION AND WEED CONTROL DURING THE ESTABLISHMENT OF *E. macarthurii* AND *E. nitens*

## 4.1 Introduction

Past research indicates that selective breeding combined with site-species matching has resulted in a significant improvement in tree volume, stem straightness and pulping properties (Gardner, 2001). Weed control in eucalypt plantations during establishment is also likely to bring about an improvement in final yield at harvest (Little, 1998). Furthermore, it has been shown that fertilisation at planting will also enhance tree performance (Herbert and Schönau, 1990; Herbert, 1996; du Toit, 1998). However, for the full potential of fertilisation to be realised, it needs to be applied at planting, which coincides with the stage at which the trees are most susceptible to competition from weeds. Under weedy conditions, the application of fertiliser may result in poorer tree growth than if the trees were left unfertilised. This has largely been attributed to the stimulation of weed growth by fertiliser (Morris, 1984; 1985). Although this weed x fertiliser interaction has been extensively demonstrated in pine studies worldwide (Carlson, 2001), little work has been reported for those eucalypt species grown at higher altitude sites in Southern Africa. Although there is extensive literature related to the above aspects in isolation, few studies have been conducted investigating the interaction between different silvicultural treatments and tree improvement.

In order to address the above-mentioned issues, this study was designed to define growth responses in terms of an interaction between weed control, fertilisation and genetic improvement. In this chapter the growth responses to the above mentioned factors during establishment are investigated.

## 4.2 Results and discussion

Several factors, such as weed abundance and competition for nutrients and water that might have been responsible for some of the differences in tree growth (as described later), are discussed below:

### 4.2.1 Weed biomass and abundance for the weedy treatments at both trials

Little and Schumann (1996) found that during the establishment of CTE's an aboveground weed biomass of up to 2000 kg $ha^{-1}$ was necessary before there were any severe losses in growth due to competition. At both these trials, the weed load did not reach high enough levels in order to compete with the trees. A possible explanation for this might be the high altitudes (above 1500 m a.s.l.) at which these trials were planted. The colder climate at these altitudes results in the lack of adequate weed development for competition (Jarvel and Pallet, 2002; Little and Rolando, 2001 and Masson, 1993).

No significant differences in the aboveground biomass or the percentage ground cover by the weeds were detected between any of the weedy treatments at each trial site. At both sites however, the aboveground weed biomass (**Figure 4.1** and **Figure 4.2**) and the percentage cover (**Figure 4.3** and **Figure 4.4**) of the weeds were less in the plots with improved seedlings, than the ones with unimproved seedlings. This difference in weed growth could be due to the faster growing improved seedlings, which suppressed weed growth more than the unimproved seedlings. At the Draycott trial, the weed cover (**Figure 4.4**) and biomass (**Figure 4.2**) were more in the plots where fertiliser were applied when compared to the unfertilised treatments. This is similar to what Turnbull *et al.* (1994) and Morris (1984; 1985) found in their studies, where the application of fertiliser increased the weed cover. In contrast the unfertilised treatments at the *E. macarthurii* stand had higher aboveground weed biomass (**Figure 4.1**) and percentage weed cover (**Figure 4.3**) when compared to the fertilised plots. Weed growth at both sites were very low and variable, which could be a possible explanation for the different weed growth patterns at these sites.

The aboveground weed biomass in the weedy control at the Tweefontein trial, reached a maximum of 1721 kg $ha^{-1}$ at the end of the second growing season (383 dap). After 383 dap the trees started to close canopy and shaded out some of the weeds. At 419 dap the aboveground weed biomass decreased to 1082 kg $ha^{-1}$ (**Figure 4.5**). In the Draycott trial the aboveground weed biomass reached a maximum at 369 dap (923 kg $ha^{-1}$) before the trees started to shade out some of the weeds. At 398 dap the aboveground weed biomass dropped to 573 kg $ha^{-1}$ (**Figure 4.6**).

At both trial sites, grass (mainly tufted grasses) made up the highest percentage cover by weeds (**Figure 4.7** and **Figure 4.8**). At the *E. macarthurii* trial at Tweefontein, grass reached a maximum cover of 26,2% at 383 dap, followed by herbaceous broadleaves (20,5%) and then woody weeds (3,2%). At 419 dap, the percentage cover by all the weeds categories started to decrease due to the shading effect caused by the trees. Similar trends were found in the Draycott trial where grass reached a maximum percentage cover of 19,8% at 369 dap, followed by woody weeds (8,9%) and herbaceous broadleaves (7,1%). At 398 dap, the percentage cover by weeds also started to decrease due to the shading effect by the trees.

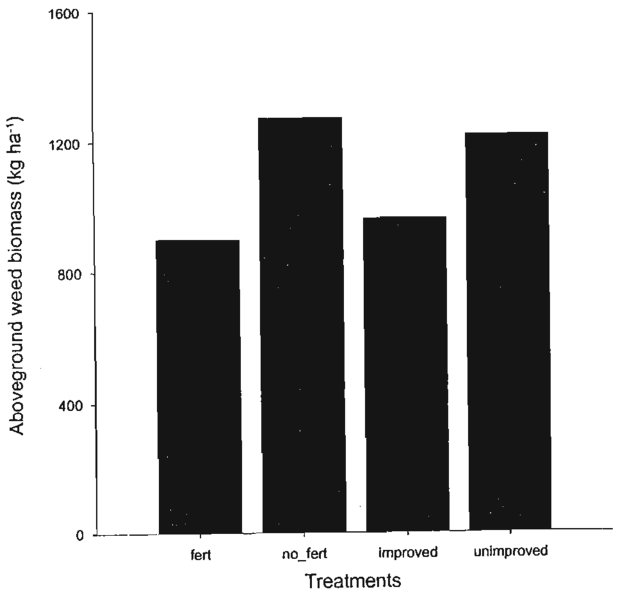



**Figure 4.1** **Aboveground biomass of the weeds in the weedy treatment plots at the Tweefontein trial when assessed at 419 dap**

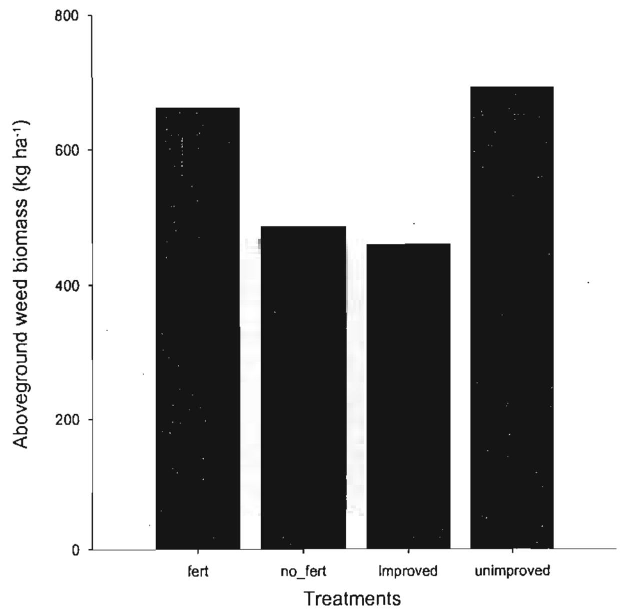



**Figure 4.2** **Aboveground biomass of the weeds in the weedy treatment plots at the Draycott trial when assessed at 398 dap**

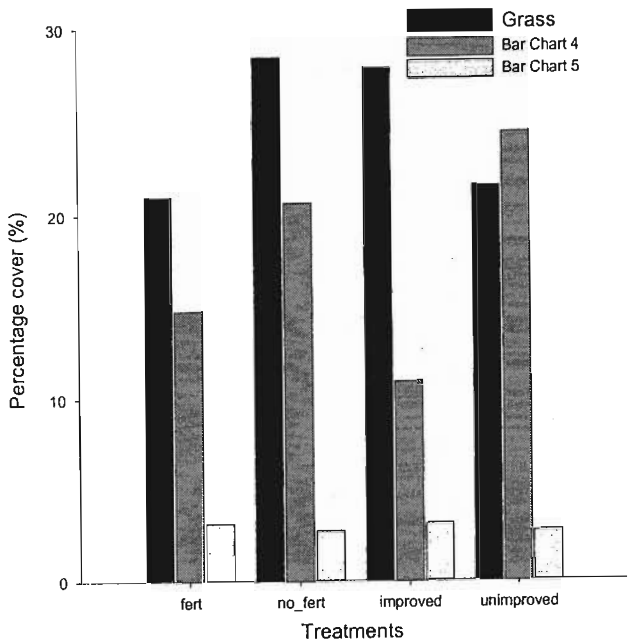



**Figure 4.3** **Percentage ground cover by different groups of weeds in the weedy treatment plots at the Tweefontein trial when assessed at 419 dap**

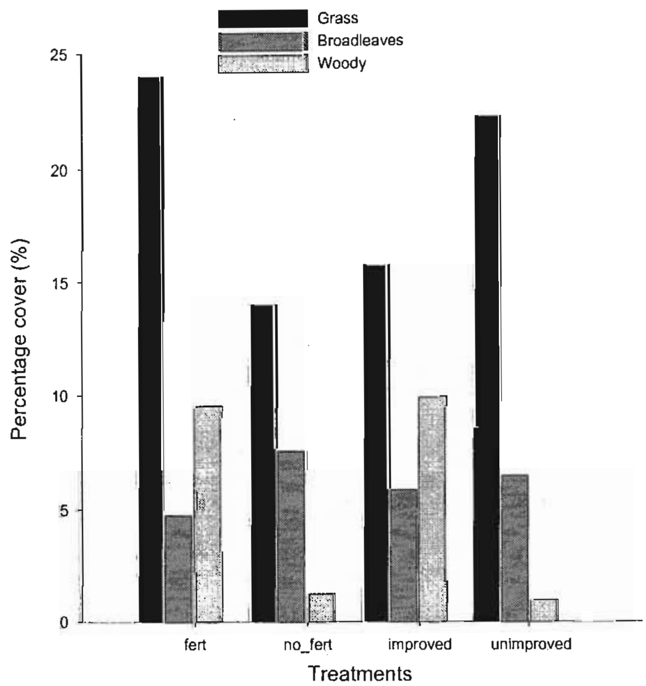



**Figure 4.4** **Percentage ground cover by different groups of weeds in the weedy treatment plots at the Draycott trial when assessed at 398 dap**

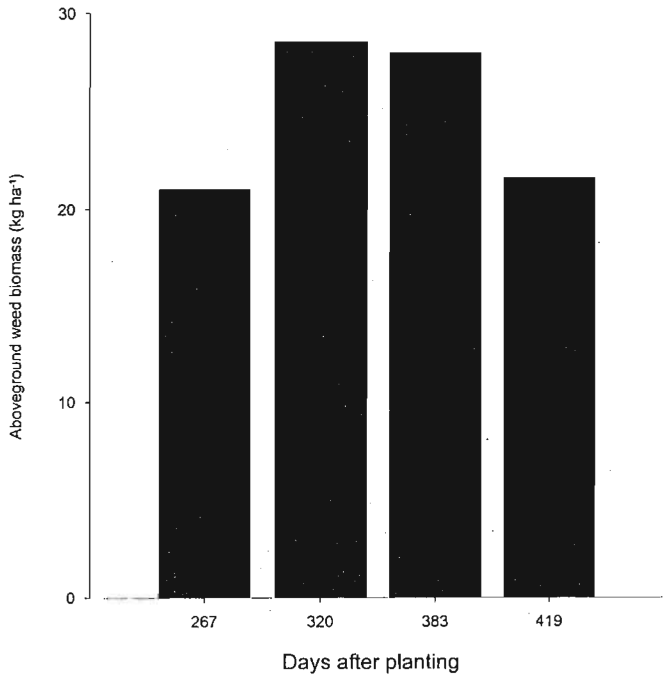



**Figure 4.5 Changes in the aboveground weed biomass with time in all the weedy treatment plots at the Tweefontein trial**

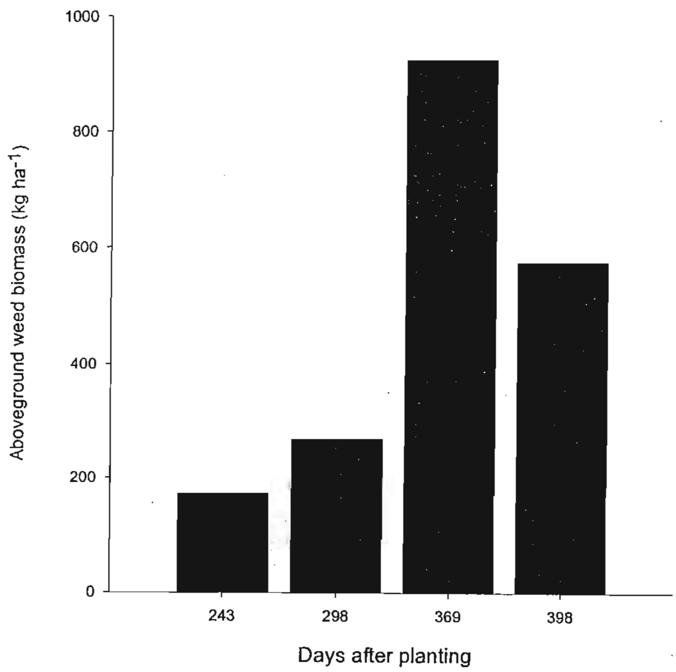



**Figure 4.6 Changes in the aboveground weed biomass with time in all the weedy treatment plots at the Draycott trial**

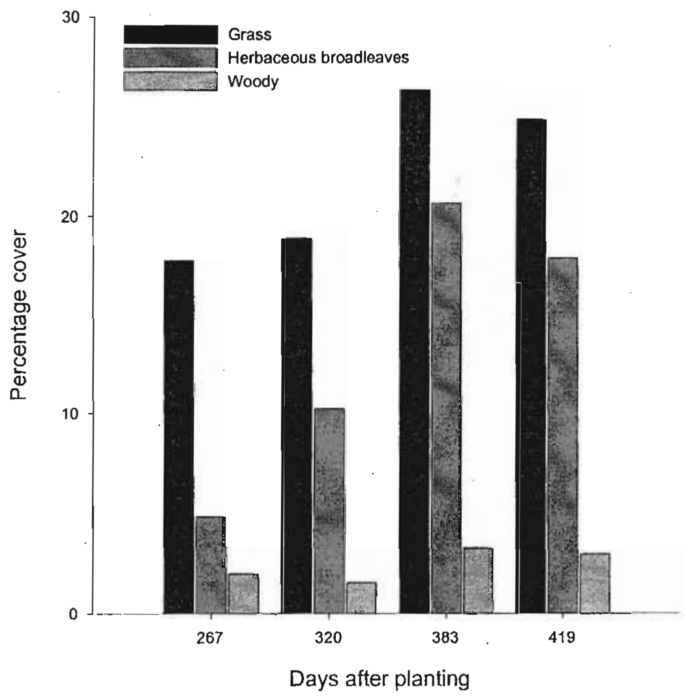



**Figure 4.7** **Changes in the percentage weed cover for the different groups of weeds over time at the Tweefontein trial**

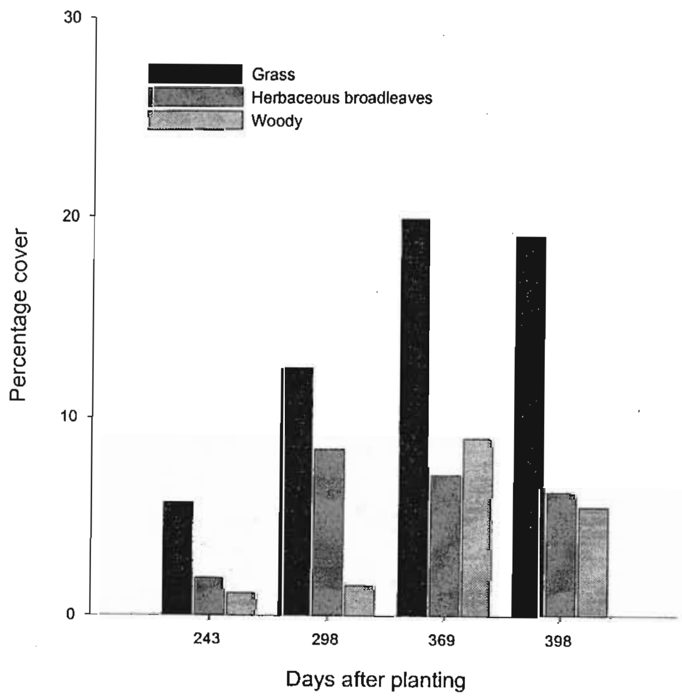



**Figure 4.8** **Changes in the percentage weed cover for the different groups of weeds over time at the Draycott trial**

### 4.2.2 Nutrients

#### 4.2.2.1 Initial soil nutrient levels and the change in soil nutrient over time for the different treatment plots

The Tweefontein trial is situated on a Clovelly (2200) soil type with an ERD of 579.8 cm, while the Draycott trial is situated on a Hutton (2200) soil type with a deeper ERD of 786.3 cm. From **Tables 4.1** and **4.2** it is clear that the Hutton soil at the Draycott trial generally has higher nutrient levels than the Clovelly soil at the Tweefontein trial at the beginning of the second growing season (250 dap). However, no significant differences in terms of soil nutrients between the different treatments were detected at this stage. The lower nutrient levels and ERD of the Clovelly soil at the Tweefontein trial might be the reason why the trees at this trial responded better to fertilisation than the trees at the Draycott trial as will be discussed in chapter five.

The mean change in soil nutrients from 250 dap to 400 dap were calculated and presented in **Table 4.3** and **Table 4.4** for both trials. At the Tweefontein trial there were no significant increases or decreases in soil nutrients for any of the treatments or their interactions. In the case of *E. nitens,* however, there was a significantly higher increase in N and a significantly lower decrease in the S–value (sum of the exchangeable basic cations, Ca + Mg + Na + K) in the unfertilised treatment when compared to the fertilised treatment. A reason for this could be the more rapid growth of the fertilised trees, which utilised the soil nutrients in a more effective way than the unfertilised trees. There was also a significantly bigger decrease in the S-value for the weedy treatment, when compared with the weed-free treatment. This might be an indication that some of the soil nutrients got utilised by the weeds. However, the tree foliar nutrient values (**Tables 4.5** and **4.6**) for the weedy treatments were well within the optimum limits. This is an indication that there were sufficient nutrients available for tree growth, even though some got utilised by the weeds.

## Table 4.1 Different soil nutrient levels at 267 dap for the Tweefontein trial

| Nutrient | Units | Treatment means (+ = increase; - = decrease) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Fert | No fert | Weed free | Weedy | Fert + weed-free | Fert + weedy | No_fert + weed-free | No_fert + weedy |
| N | % | 0.23 | 0.21 | 0.22 | 0.22 | 0.23 | 0.22 | 0.22 | 0.21 |
| P | % | 4.75 | 5.19 | 4.87 | 5.06 | 4.75 | 4.75 | 5.00 | 5.37 |
| K | % | 0.38 | 0.33 | 0.36 | 0.35 | 0.39 | 0.36 | 0.32 | 0.33 |
| Ca | % | 0.31 | 0.25 | 0.25 | 0.31 | 0.24 | 0.37 | 0.26 | 0.24 |
| Mg | % | 0.50 | 0.47 | 0.46 | 0.51 | 0.46 | 0.53 | 0.45 | 0.49 |
| O_C_WB | | 3.64 | 3.51 | 3.68 | 3.47 | 3.78 | 3.51 | 3.58 | 3.44 |
| ph_KCL | | 3.96 | 3.95 | 3.95 | 3.96 | 3.95 | 3.97 | 3.96 | 3.95 |
| S_value | | 1.24 | 1.12 | 1.12 | 1.23 | 1.14 | 1.34 | 1.10 | 1.13 |
| Clay | % | 42.88 | 43.06 | 43.50 | 52.44 | 44.00 | 41.75 | 43.00 | 43.13 |
| Sand | % | 31.56 | 30.81 | 30.56 | 31.81 | 30.50 | 32.63 | 30.62 | 31.00 |
| Silt | % | 25.81 | 26.12 | 26 | 25.94 | 25.62 | 26.00 | 26.37 | 25.87 |

Note: ☐ One-way interaction.

▨ Two-way interaction.

## Table 4.2 Different soil nutrient levels at 245 dap for the Draycott trial

| Nutrient | Units | Treatment means (+ = increase; - = decrease) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Fert | No fert | Weed Free | Weedy | Fert + weed-free | Fert + weedy | No_fert + weed-free | No_fert + weedy |
| N | % | 0.37 | 0.37 | 0.37 | 0.37 | 0.37 | 0.38 | 0.37 | 0.37 |
| P | % | 5.30 | 7.40 | 4.60 | 8.10 | 4.60 | 6.00 | 4.60 | 0.30 |
| K | % | 0.18 | 0.20 | 0.18 | 0.20 | 0.18 | 0.17 | 0.18 | 0.22 |
| Ca | % | 0.31 | 0.22 | 0.25 | 0.27 | 0.29 | 0.34 | 0.22 | 0.21 |
| Mg | % | 0.40 | 0.31 | 0.36 | 0.36 | 0.39 | 0.42 | 0.33 | 0.30 |
| O_C_WB | % | 6.43 | 6.41 | 6.52 | 6.32 | 6.61 | 6.25 | 6.44 | 6.39 |
| ph_KCL | | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 |
| S_value | | 0.94 | 0.78 | 0.84 | 0.88 | 0.90 | 0.98 | 0.78 | 0.78 |
| Clay | % | 59.63 | 57.19 | 57.69 | 59.13 | 58.13 | 61.13 | 57.25 | 57.13 |
| Sand | % | 11.25 | 12.56 | 12.63 | 11.19 | 12.13 | 10.38 | 13.13 | 12.00 |
| Silt | % | 29.25 | 30.31 | 29.75 | 29.81 | 29.87 | 28.62 | 29.62 | 31.00 |

Note: ☐ One-way interaction.

▨ Two-way interaction.

## Table 4.3 Increase or decrease in soil nutrients from 267 dap to 419 dap at the Tweefontein trial for the different treatment plots

| Nutrient | Units | Treatment means (+ = increase; - = decrease) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Fert | No fert | Weed free | Weedy | Fert + weed-free | Fert + weedy | No_fert + weed-free | No_fert + weedy |
| N | % | -0.0075 | 0.0087 | -0.0088 | 0.01 | -0.0188 | 0.0037 | 0.0012 | 0.0163 |
| P | % | | | | | | | | |
| K | % | -0.002 | -0.038 | -0.001 | -0.039 | 0.008 | -0.011 | -0.009 | -0.066 |
| Ca | % | -0.021 | 0.091 | 0.047 | 0.023 | -0.011 | -0.03 | 0.105 | 0.076 |
| Mg | % | -0.139 | -0.051 | -0.096 | -0.094 | -0.142 | -0.135 | -0.049 | -0.052 |
| O_C_WB | | 0.13 | 0.24 | 0.05 | 0.33 | 0.01 | 0.26 | 0.09 | 0.4 |
| ph_KCL | | 0.005 | 0.0219 | 0.0256 | 0.0012 | 0.01 | 0.00 | 0.0413 | 0.0025 |
| S_value | | -0.167 | -0.002 | -0.049 | -0.121 | -0.145 | -0.19 | 0.046 | -0.051 |

Note: [white box] One-way interaction.

[grey box] Two-way interaction.

## Table 4.4 Increase or decrease in soil nutrients from 243 dap to 398 dap at the Draycott trial for the different treatment plots

| Nutrient | Units | Treatment means (+ = increase; - = decrease) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Fert | No fert | Weed free | Weedy | Fert + weed-free | Fert + weedy | No_fert + weed-free | No_fert + weedy |
| N | % | 0.0275[b] | 0.0494[a] | 0.0406[ab] | 0.0363[ab] | 0.0313 | 0.0238 | 0.05 | 0.0488 |
| P | % | 0.13 | -0.69 | -0.25 | -0.31 | -0.13 | 0.38 | -0.38 | -1.00 |
| K | % | -0.089 | 0.008 | -0.002 | -0.079 | -0.03 | -0.149 | 0.026 | -0.01 |
| Ca | % | -0.089 | 0.019 | 0.015 | -0.085 | -0.018 | -0.161 | 0.048 | -0.009 |
| Mg | % | -0.235 | -0.186 | -0.167 | -0.254 | -0.179 | -0.291 | -0.155 | -0.216 |
| O_C_WB | | -0.086 | 0.109 | -0.001 | 0.023 | -0.07 | -0.103 | 0.069 | 0.149 |
| ph_KCL | | -0.0144 | -0.0181 | -0.0188 | -0.0138 | -0.0125 | -0.0163 | -0.025 | -0.0113 |
| S_value | | -0.443[b] | -0.186[a] | -0.178[a] | -0.451[b] | -0.244 | -0.641 | -0.111 | -0.26 |

Note: [white box] One-way interaction.

[grey box] Two-way interaction.

Values followed by the same letter are not significantly different: $p < 0.05$.

#### 4.2.2.2 Foliar nutrients for the different treatment plots at both trials

At both the trials, some significant differences in foliar nutrient levels were detected for the main treatments effects but not for the interaction between any of the main effects (**Table 4.5** and **Table 4.6**).

At the Tweefontein trial, the fertiliser treatments had a significantly higher foliar concentration of potassium (K), calcium (Ca), manganese (Mn), zinc (Zn) and copper (Cu) than the unfertilised treatments. In studies carried out by Bennet *et al.* (1997) and Misra *et al.* (1998), N and P concentrations in foliar samples were higher in the fertiliser treatments. The weed-free treatments also showed significantly higher foliar concentrations of nitrogen (N), K and Cu. This could mean that the weeds might have utilised some of the nutrients that otherwise could have been available to the trees. However, if one compares the lowest foliar nutrient values with the optimal values given by Hebert (1992), Dell *et al.* (1995), Boardman *et al.* (1997) and Linder (1995), it is clear that these values are still well above the adequate levels for tree growth.In the case of *E. nitens,* however, the trees without fertiliser had significantly higher foliar concentrations of Zn and Cu, than those with fertiliser. No other significant differences were detected in *E. nitens* foliar nutrient concentrations.

For both trials there were no significant differences in terms of foliar nutrient levels between genetically improved and unimproved seedlings. When any of the foliar nutrient concentrations were compared to optimum foliar nutrient values, all were well within the optimal ranges (**Table 4.5**).

**Table 4.5 Foliar nutrient contents for *E. macarthurii* on different treatment plots**

| Nu - trient | Units | Treatment means | | | | Comparative values | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Fert | No fert | Weed-free | Weedy | Optimum values (Herbert, 1992) | Adequate ranges (Dell *et al.*, 1995) | Adequate ranges (Boardman *et al.*, 1997) | Target ratios relative to N (% of N) (Linder, 1995) |
| N | % | 3.51[ab] | 3.57[ab] | 3.75[a] | 3.33[b] | 2.8 | 1.8 – 3.4 | 2.0 – 3.5 | [28] |
| P | % | 0.22 | 0.21 | 0.22 | 0.21 | 0.15 | 0.1 – 0.22 | 0.1 – 0.2 | 10 |
| K | % | 1.00[a] | 0.88[b] | 1.00[a] | 0.88[b] | 0.75 | 0.9 – 1.8 | 0.8 | 35 |
| Ca | % | 0.61[a] | 0.50[b] | 0.53[b] | 0.57[ab] | > 1.0 | 0.3 – 0.6 | 0.3 – 0.5 | 2.5 |
| Mg | % | 0.20 | 0.21 | 0.20 | 0.21 | 0.35 | 0.11 – 0.21 | 0.09 – 0.15 | 4 |
| Mn | ppm | 1309[a] | 1123[b] | 1219[ab] | 1212[ab] | 600 | 193 – 547 | 960 – 1400 | 0.05 |
| Fe | ppm | 89.80 | 94.20 | 94.00 | 90.00 | 110 | 63 - 128 | 23 – 75 | 0.2 |
| Zn | ppm | 22.75[a] | 20.75[b] | 22.12[ab] | 21.37[ab] | 18 | 17 – 42 | 9 – 19 | 0.05 |
| Cu | ppm | 8.44[a] | 7.56[b] | 8.44[a] | 7.56[b] | 12 | 1.7 – 7.4 | 4.9 | 0.02 |

Note: Values followed by the same letter are not significantly different: $p < 0.05$.

**Table 4.6 Foliar nutrient content for *E. nitens* on different treatment plots**

| Nu - trient | Units | Treatment means | | | | Comparative values | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Fert | No Fert | Weed-free | Weedy | Optimum values (Herbert, 1992) | Adequate ranges (Dell *et al.*, 1995) | Adequate ranges (Boardman *et al.*, 1997) | Target ratios relative to N (% of N) (Linder, 1995) |
| N | % | 2.68 | 2.76 | 2.75 | 2.69 | 2.8 | 1.8 – 3.4 | 2.0 – 3.5 | [28] |
| P | % | 0.15 | 0.16 | 0.16 | 0.15 | 0.15 | 0.1 – 0.22 | 0.1 – 0.2 | 10 |
| K | % | 0.92 | 1.00 | 0.99 | 0.92 | 0.75 | 0.9 – 1.8 | 0.8 | 35 |
| Ca | % | 0.44 | 0.40 | 0.42 | 0.43 | > 1.0 | 0.3 – 0.6 | 0.3 – 0.5 | 2.5 |
| Mg | % | 0.14 | 0.15 | 0.14 | 0.14 | 0.35 | 0.11 – 0.21 | 0.09 – 0.15 | 4 |
| Mn | ppm | 633 | 617 | 641 | 609 | 600 | 193 – 547 | 960 – 1400 | 0.05 |
| Fe | ppm | 42.20 | 40.90 | 43.20 | 39.90 | 110 | 63 - 128 | 23 – 75 | 0.2 |
| Zn | ppm | 19.75[b] | 22.19[a] | 21.12[ab] | 20.81[ab] | 18 | 17 – 42 | 9 – 19 | 0.05 |
| Cu | ppm | 5.94[c] | 6.81[a] | 6.62[ab] | 6.12[bc] | 12 | 1.7 – 7.4 | 4.9 | 0.02 |

Note: Values followed by the same letter are not significantly different: $p < 0.05$.

#### 4.2.2.3 Aboveground weed nutrient content for both trials

In order to detect if the weeds were competing for nutrients with the trees, aboveground weed biomass samples were taken and analysed to determine the nutrient contents. For the purpose of this study, only the weed nutrient levels for the fertilised and unfertilised plots were analysed to determine if the weeds benefited from the applied fertiliser. At both trials, no significant differences in the aboveground weed nutrient levels for the fertilised and unfertilised treatments were detected. A summary of the mean weed nutrient levels for the different trial treatments of both these trials are presented in **Table 4.7** and **Table 4.8**.

**Table 4.7 Nutrient content of the aboveground weed biomass at the Tweefontein trial**

| Nutrient | Units | Treatments means | |
|---|---|---|---|
| | | Fert | No_fert |
| N | % | 1.54 | 1.41 |
| P | % | 0.11 | 0.11 |
| K | % | 0.89 | 0.93 |
| Ca | % | 0.25 | 0.35 |
| Mg | % | 0.18 | 0.18 |

**Table 4.8 Nutrient content of the aboveground weed biomass at the Draycott trial**

| Nutrient | Units | Treatments means | |
|---|---|---|---|
| | | Fert | No_fert |
| N | % | 1.27 | 1.26 |
| P | % | 0.12 | 0.07 |
| K | % | 1.38 | 1.08 |
| Ca | % | 0.18 | 0.15 |
| Mg | % | 0.23 | 0.14 |

### 4.2.3 Results on soil moisture and water potentials of trees

#### 4.2.3.1 Soil moisture readings for all the different treatments at both trials

Significant differences in terms of soil moisture readings between some of the treatments were detected. At the Tweefontein trial there was a significant difference between weedy and weed-free in terms of soil moisture content (**Table 4.9**). The weedy treatments showed lower soil moisture readings than the weed-free treatments. No significant differences in soil moisture for the rest of the treatments, or their interactions were detected.

In contrast with the Tweefontein trial, the Draycott trial showed that the interaction between fertiliser and weeding had a significant impact on soil moisture content (**Table 4.10**). The weedy treatments with fertiliser had much higher soil moisture content than any of the other treatments. A possible explanation for this is that this site is located on a slightly steeper slope than the Tweefontein trial. Better- developed root systems of the fertilised trees, as well as the presence of weeds in these plots could have formed a protective layer to prevent runoff of water at this site. However, tree roots and water runoff was not assessed at these trials and no sound conclusions can be made. No significant differences in the soil moisture content were found when the rest of the treatments were compared.

#### 4.2.3.2 Water potentials of the trees for the different treatments at both trials

When the tree water potentials were compared, no significant differences between any of the main effects at both trials were detected (**Table 4.9** and **Table 4.10**). This is an indication that even though their were differences between some of the treatments in terms of soil moisture, no intraspecific competition for water between the trees, or interspecific competition for water between the weeds and the trees occurred.

### 4.2.4 Chlorophyll fluorescence readings of the trees at both sites

The mean Fv/Fm values for the main effects of fertilisation and weeding and for the interaction between the two are presented in **Table 4.9** and **Table 4.10** for both trials. At the Tweefontein trial, there was a significant difference in the Fv/Fm values between fertilised and unfertilised treatments, as well as between weed-free and weedy treatments. In a study carried out by Peterson *et al.* (1999), the fertilised treatments also showed higher Fv/Fm values than the unfertilised treatments. This is possibly an indication that the light harvesting mechanism associated with photosystem II, is more efficient in the fertilised trees, than in the unfertilised trees. This could lead to better growth due to the better utilisation of light energy, and the conversion of that to carbohydrates and other essential nutrients for growth. Contradicting with the soil moisture values, the Fv/Fm values for the weedy treatments were significantly higher than that of the weed-free treatments. When the Fv/Fm values for the interaction between fertiliser and weeding were compared, the weedy treatments with fertiliser were significantly higher than the weed-free treatments without any fertiliser. No further significant differences between any of the main effects or their interactions were found.

At the Draycott trial, no significant differences in Fv/Fm values were detected for any of the treatments.

**Table 4.9 Soil moisture, water potential and chlorophyll fluorescence readings for the different treatments at the Tweefontein trial**

| Treatment | Measurement | | |
|---|---|---|---|
| | Water potential | Soil moisture | PEA (Fv/Fm) |
| Fertilise | 1650 | 0.2664[ab] | 0.8217[a] |
| No_fertilise | 1744 | 0.2672[ab] | 0.7999[b] |
| Weed-free | 1669 | 0.2985[a] | 0.8019[b] |
| Weedy | 1725 | 0.2350[b] | 0.8198[a] |
| Fert + weed-free | 1663 | 0.3003 | 0.8119[ab] |
| Fert + weedy | 1638 | 0.2324 | 0.8315[a] |
| No_fert + weed-free | 1675 | 0.2967 | 0.7919[b] |
| No_fert + weedy | 1813 | 0.2376 | 0.8080[ab] |

Note: Values followed by the same letter are not significantly different: $p < 0.05$.

One-way interaction.

Two-way interaction.

**Table 4.10 Soil moisture, water potential and chlorophyll fluorescence readings for the different treatments at the Tweefontein trial**

| Treatment | Measurement | | |
|---|---|---|---|
| | Water potential | Soil moisture | PEA (Fv/Fm) |
| Fertilise | 1406 | 0.3104 | 0.804 |
| No_fertilise | 1500 | 0.3007 | 0.821 |
| Weed-free | 1513 | 0.3058 | 0.821 |
| Weedy | 1394 | 0.3053 | 0.805 |
| Fert + weed-free | 1525 | 0.3037[bc] | 0.821 |
| Fert + weedy | 1288 | 0.3171[a] | 0.787 |
| No_fert + weed-free | 1500 | 0.3078[b] | 0.820 |
| No_fert + weedy | 1500 | 0.2936[c] | 0.823 |

Note: Values followed by the same letter are not significantly different: $p < 0.05$.

One-way interaction.

Two-way interaction.

### 4.2.5 Growth responses of *E. macarthurii* and *E. nitens* to the different treatments at canopy closure (14 months of age)

There was a significant difference for the main effects of fertilisation and genetic improvement for ht, and volume index at both trial sites when canopy closure occurred (**Figures 4.9 - 4.13**). The fertilised treatments significantly outperformed the unfertilised treatments, and the genetic improved material outperformed the unimproved material. Gld however, was not significant between improved and unimproved *E. macarthurii* material. The controlling of weeds, however, did not have a significant effect on tree performance during establishment. No significant differences were detected for any interactions between the main effects when the ht's and gld's for the different treatments were compared. However, there was a significant interaction between fertiliser and genetic material when the volume index for the different treatments at the Tweefontein trial was compared. Fertiliser x improved material showed to be the best treatment, and unfertilised x unimproved the worst treatment.

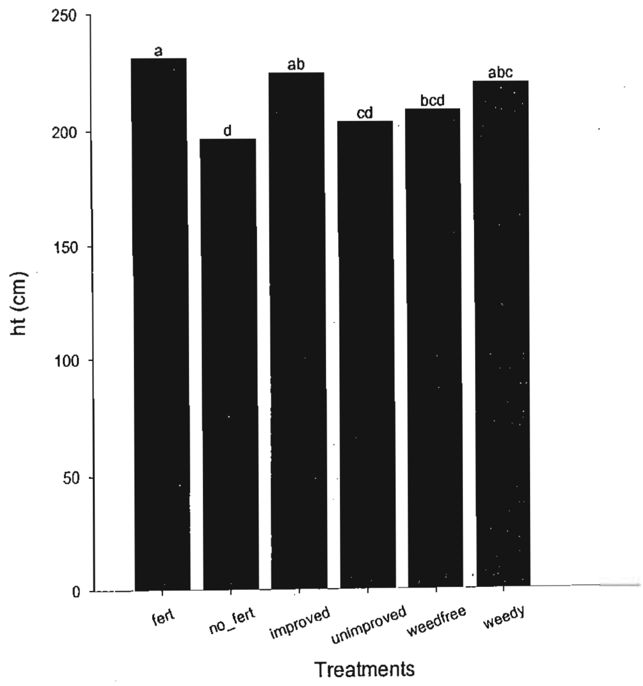



**Figure 4.9** **Height for the main effects at the Tweefontein trial at canopy closure (419 dap)**

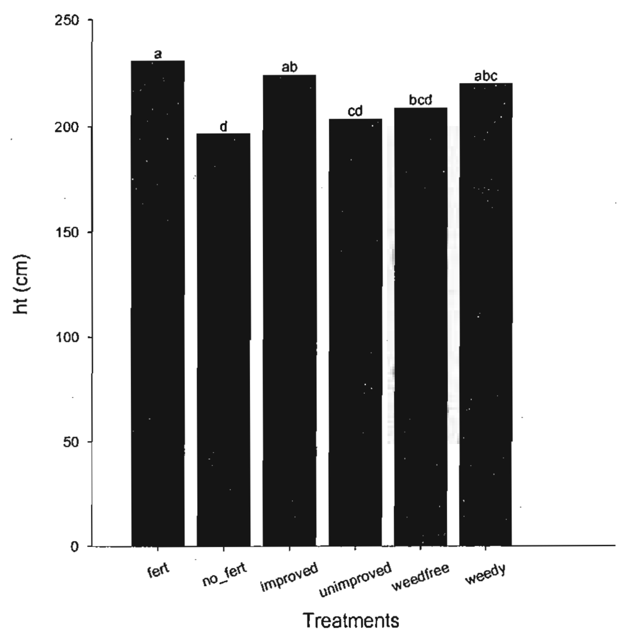



**Figure 4.10** **Height for the main effects at the Draycott trial at canopy closure (398 dap)**

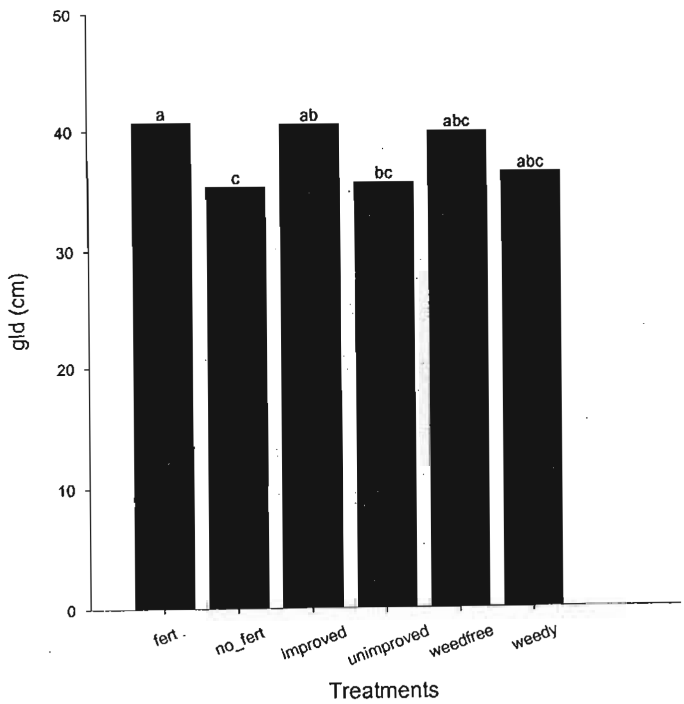



**Figure 4.11 Gld for the main effects at the Tweefontein trial at canopy closure (419 dap)**

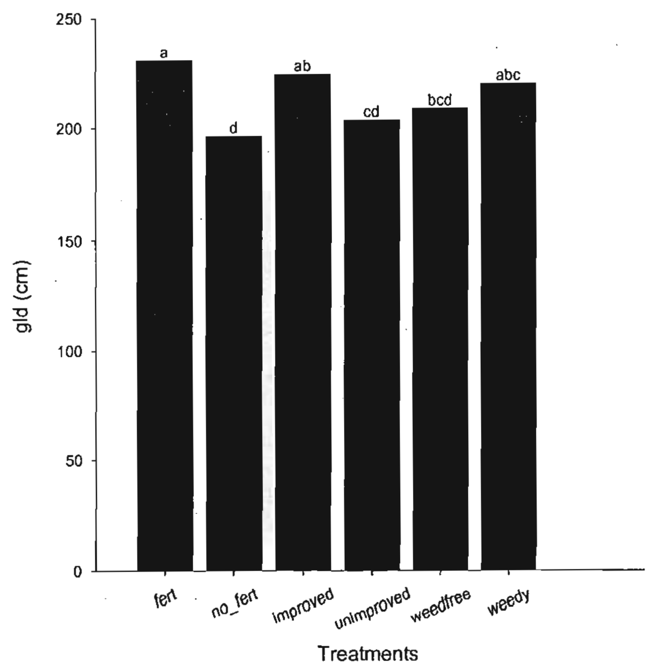



**Figure 4.12 Gld for the main effects at the Draycott trial at canopy closure (398 dap)**

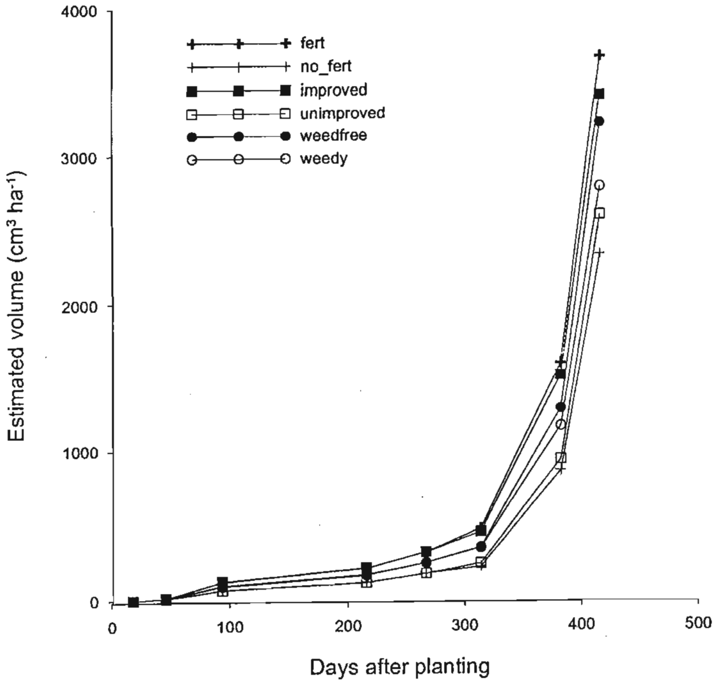



**Figure 4.13 Volume index for *E. macarthurii* over time up to canopy closure (419 dap)**

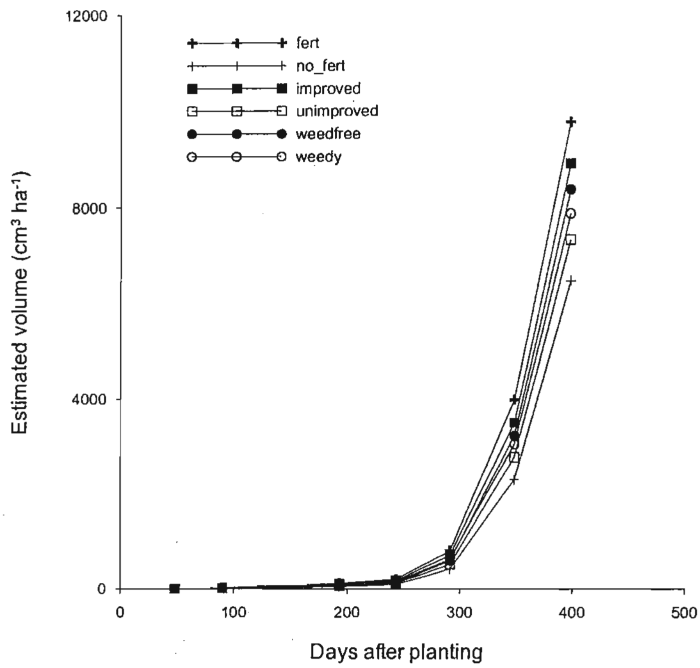



**Figure 4.14 Volume index for *E. nitens* over time up to canopy closure (398 dap)**

### 4.2.6 Discussion of growth responses to the different treatments until canopy closure occurred

The early positive responses to fertiliser, were similar to those obtained by Bennet *et al.* (1997), Louzada *et al.* (1991), McKimm *et al.* (1979) and Misra *et al.* (1998). They found that eucalypts respond positively to fertilisation, but whether these benefits were carried through to harvesting, is unknown. This positive growth response could be supported by the higher concentrations of K when the N, P and K concentrations for the foliar samples of the two treatments were compared at the Tweefontein trial. However, there were no significant differences in foliar N, P and K concentrations when these two treatments were compared at the Draycott trial. A possible explanation for the different response of foliar nutrients to fertilisation between the two sites could be the fact that the soil at the Tweefontein trial was lower in nutrients (**Tables 4.1** and **4.2**). When the increase, or decrease in soil N, P and K levels was compared, there was a significantly higher increase in N for the unfertilised plots at the Draycott trial. Chlorophyll fluorescence readings indicated that the fertilised *E. macarthurii* trees were more efficient in terms of photosynthesis than the unfertilised trees. However, no differences were detected in chlorophyll fluorescence readings at the Draycott trial.

Similar to Swain's *et al.* (1999) study on these CTE's, the genetic improvement of trees had a positive effect on tree growth. Even though there was a significant difference in growth between improved and unimproved treatments, no significant differences were detected for soil and foliar nutrient levels, soil moisture, water potentials or chlorophyll fluorescence readings between these two treatments. This could be an indication that no intraspecific competition occurred between trees at this stage, and that the growth differences that occur are purely due to the genetic improvement of the trees.

In contrast with studies done by Barron *et al.* (1998), Ellis *et al.* (1985), Fagg (1988), Little *et al.* (1996), Male *et al.* (1998) and Schumann (1992), there was no response to weed control at both these sites. The lack of response to the controlling of weeds could be due to the poor weed growth at these high altitude (1500m a.s.l.) sites (Jarvel and Pallet, 2002; Little and Rolando, 2001 and Masson, 1993). Little and Schumann (1996) found that eucalypts could tolerate aboveground weed biomass levels of up to 2000 kg $ha^{-1}$. In this case a maximum of only 1720 kg $ha^{-1}$ aboveground weed biomass was reached at the Tweefontein trial, and even less at the Draycott trial. Foliar samples of *E. macarthurii* showed higher concentrations of N and K for the weed-free treatment when N, P, and K foliar concentrations were compared. However, the foliar concentrations in the weedy plots were still above the optimal level given by Herbert (1992), Dell *et al.* (1995), Boardman *et al.* (1997) and Linder (1995). This is an indication that the weeds at the *E. macarthurii* trial did compete for nutrients, but not at a level that effected tree growth. At the Tweefontein trial, there were also a sign of competition for water by the weeds when the soil moisture readings were compared. However, when the water potential readings were compared, there were no significant differences. This is an indication that the trees in the weed-free and weedy treatments absorbed equal amounts of water, and that the competition from weeds for water were not at a level to effect tree growth. The chlorophyll fluorescence readings for the weedy treatments at the *E. macarthurri* site were higher than that of the weed-free treatments. This is just another indication that the trees in the weedy treatments were not stressed, and were just as efficient in terms of photosynthesis as the trees in the weed-free treatment. No significant differences in terms of nutrients, moisture or chlorophyll fluorescence readings were detected at the Draycott trial when the weed-free and weedy treatments were compared. This is an indication that there was no competition from weeds for any of these factors at this site.

### 4.2.7 The impact of the different treatments on standing density at both trials

In order to detect if any of the treatments (in isolation or interacting) had an impact on tree mortality, the stand density at canopy closure was calculated. No significant differences in terms of stand density were detected when the main effects or their interactions were compared at both sites. The stand density at the Tweefontein trial was slightly lower than at the Draycott trial. This was due to some damage caused by bacterial wilt at about 216 dap.

### 4.2.8 Tree variability in terms of diameter

To quantify the effect of treatment-related variability, the coefficient of variation was calculated by using the ground line diameter measurements at canopy closure (Turner and Rabinowitz, 1983). The coefficient of variation for both trials is presented in **Table 4.11** for each of the main effects. At both sites, fertilisation and genetic improvement had a positive effect on tree uniformity. Although not significant, the fertilised and the improved trees were less variable than their controls. Weed control did not have an effect on tree uniformity.

**Table 4.11 Coefficient of variation (%) for the main effects at canopy closure**

| Treatments | Variances | |
|---|---|---|
| | *E. macarthurii* | *E. nitens* |
| Fertilise | 22.5 | 17.1 |
| No_fertilise | 25.9 | 21.7 |
| Improved | 21.0 | 17.6 |
| Unimproved | 27.4 | 21.2 |
| Weed-free | 24.4 | 18.2 |
| Weedy | 24.0 | 20.6 |

### 4.3 Conclusions

Fertilisation and genetic improvement played an important role in the establishment and growth of *E. macarthurii* and *E. nitens* until canopy closure. The fertilised and improved treatments outperformed the unfertilised and unimproved treatments. The controlling of weeds did not have an impact on tree performance. This could be due to the lack of weed growth at these high altitudes at which the sites were planted. No significant interactions between any of the treatments were detected at both these sites at canopy closure. However, at a site with a high weed load, the interaction between weeds and fertilisation could play a major role in the establishment of eucalypts.

Whether or not these positive growth responses will be carried through to harvesting, still needs to be investigated.

# CHAPTER 5

# GROWTH RESPONSES TO GENETIC MATERIAL, FERTILISATION, WEED CONTROL AND REGENERATION METHOD AFTER THE ESTABLISHMENT OF *E. macarthurii* AND *E. nitens.*

## 5.1 Introduction

Fertilisation and genetic improvement, but not weed control, had a significant positive effect on the initial growth of *E. macarthurii* and *E. nitens*. Similar responses to both fertilisation and genetic improvement have been found for eucalypts in S.A. and other regions of the world (Swain, 2001; Neilsen, 1996; McKimm *et al.*, 1979; Bennett *et al.*, 1997 and Louzada *et al.*, 1991). Whether these initial growth responses to small amounts of fertiliser applied at planting will be maintained through to felling in these trials still needs to be determined. Turnbull *et al.* (1997) for instance, detected that the effect of fertiliser on eucalypt tree growth is only short-term and that there were no significant differences between the fertiliser and control treatments at seven years of age. If the initial aim of fertilisation is to get the trees to canopy close as soon as possible in order to reduce weeding costs, then it might be worth while to fertilise. However, at high altitude sites in S.A. like these, where the weed biomass does not develop to competitive levels (Little and Schumann, 1996), it might not be cost effective.

In the case of genetic improvement, initial growth may not be as great as the fertilised trees, but the interaction between site and genotype becomes more important over time McNabb *et al.* (1994). In the cooler regions of South Africa, selective breeding combined with site-species matching of *E. macarthurii* and *E. nitens*, has showed to have a significant improvement in tree volume, stem straightness and pulping properties over a longer period of time (Swain, 2001).

In order to investigate the long-term effect of fertilisation and genetic improvement, as well as to determine if there was any interaction between these silvicultural treatments after canopy closure, the trees were measured until six years of age. Results will be discussed in this chapter. The effects of initial weed control after canopy closure is also reported.

Another aspect concerns the decision to coppice or replant following harvesting. Current recommendations suggest that, provided the correct species is matched to a particular site, at the correct stand density, similar yields may be obtained through coppicing, as opposed to replanting, at greatly reduced establishment costs (Opie *et al.*,1984). In order to address this issue, four coppice plots were selected adjacent to each trial site. These plots were measured from canopy closure until six years of age.

## 5.2 Results and discussion

### 5.2.1 Growth responses to the different treatments after canopy closure at the Tweefontein and Draycott trial

At the Tweefontein trial, coppice significantly outperformed seedlings in terms of height, diameter and basal area after canopy closure (**Table 5.1, 5.3 and 5.5**). The better performance by coppice initially was presumed to be due to the already established root system of the stumps they grow from. These established root systems provide sufficient nutrients and water to the plant for optimum growth. However, at the last measurement when the trees were six years old, there were no significant difference in terms of dbh and basal area between the *E. macarthurii* coppice and seedlings. These differences could be explained by looking at the different growth rates for coppice and seedlings (**Tables 5.1, 5.3**). When the height growth rates (**Table 5.1**) between coppice and seedlings were compared, the coppiced trees significantly outperformed the planted trees at the last measurement. However, when the diameter growth rates (**Table 5.3**) were compared, coppice showed a significantly lower growth rate than that of the seedlings. This could be due to the fact that the coppice reached a stage of intra-specific competition earlier than the seedlings. This would mean that the coppice started to compete against each other for water, nutrients and light at an earlier stage than the seedlings. This caused the reduced growth rates in diameters, which gave the *E. macarthurii* seedlings a change to catch up in terms of diameter. However, nutrient and water competition assessments were not done after canopy closure and no sound conclusion on why the above mentioned growth patterns occurred can be made. In the case of *E. nitens*, the coppice and seedlings performed equally well and no significant differences were detected for any of the measured variables (**Tables 5.2, 5.4** and **5.5**). These are similar results to that of a study done by Schönau (1991) where no differences in terms of growth were found between coppice and seedlings.

The fertilised *E. macarthurii* trees significantly outperformed the unfertilised trees in terms of height (14.62 m versus. 13.65 m), diameter (12.5 cm versus. 11.6 cm) and basal area (20.56 $m^2 ha^{-1}$ versus 16.78 $m^2 ha^{-1}$) until the trees were six years old (**Table 5.1, 5.3** and **5.5**). These are similar results to those that were found by Neilsen, 1996; McKimm *et al.*, 1979; Bennett *et al.*, 1997 and Louzada *et al.*, 1991. However, in these studies only early results were reported, and the long-term effect of fertilisation at planting is unknown. Although not significant, the growth rates for the treatments with fertiliser declined more than that of the treatments without fertiliser from canopy closure to the last measurement. This could mean that even though the fertilised trees are significantly better than the unfertilised trees at this stage, it might not be the case later on at the end of the rotation. It is therefore important that the trees should be assessed until harvesting before sound conclusions can be made. In the case of *E. nitens* however, there were no significant differences in terms of height, diameter and basal area between the fertilised and unfertilised trees (**Tables 5.2, 5.4** and **5.5**) at the last measurement, even though it has been significant before. A possible explanation for the different response to fertilisation between the two sites could be the fact that the soil at the Tweefontein trial was initially lower in nutrients than the soil at the Draycott trial as described in **Chapter 4**. The unfertilised *E. nitens* trees at the Draycott trial therefore had enough soil nutrients available to sustain a sufficient growth rate (**Tables 5.2, 5.4**). Turnbull *et al.* (1997) also found that the positive effect of fertilisation at planting is not sustained until harvesting.

No significant difference in terms of height and diameter between the improved and unimproved *E. macarthurii* seedlings were detected at the last measurement (**Tables 5.1** and **5.3**). When the basal areas however, were compared, the improved material (19.93 $m^2$ $ha^{-1}$) outperformed the unimproved material (17.41 $m^2$ $ha^{-1}$). At the Draycott trial, there was a significant difference between improved and unimproved material in terms of height (17.11 m versus 15.68 m), diameter (13.3 cm versus 12.3 cm) and basal area (22.93 $m^2$ $ha^{-1}$ versus 18.94 $m^2$ $ha^{-1}$), with the improved *E. nitens* material outperforming the unimproved material at the last measurement (**Tables 5.2, 5.4** and **5.5**). Swain *et al.* (1999, 2001) found similar results for genetic improvement trials that have been done on *E. macarthurii* and *E. nitens* in S.A.

The initial controlling of weeds did not have any effect on tree performance after canopy closure for *E. macarthurii* and *E. nitens*. Reasons for the lack of growth response to early weed control have been discussed in **Chapter 4**.

No significant interactions between any of the treatments were detected. This contradicts a study done by Boden and Herbert (1986) in S.A. on the establishment of *E. grandis*. They concluded that complete preparation (complete soil cultivation and weed control) with fertiliser outperformed all the other treatments. However, their study was carried out on virgin sites where grass was the dominant species. McNabb *et al.* (1994) and Davidson (1996) also found that high levels of productivity are related to intensive management particularly that of site preparation, planting stock quality, genetic improvement, fertilisation and weed control. The lack of interaction between the different silvicultural treatments at both sites could be due to the low level of weeds that occurred at these sites as described in **Chapter 4**.

The combination of diameter and diameter increment for *E. macarthurii* is illustrated in **Figure 5.1**. The reduction in growth rates for all the treatments after canopy closure was probably due to intra-specific competition. Initially (631dap) the treatments with bigger diameters showed a larger diameter increment. In **Figure 5.2** the relationship between diameter and diameter increment for *E. nitens* is illustrated. Up to 1211 dap it is clear that all the treatments still showed an increase in diameter increments. After that, the trees probably started to compete with each other and the diameter increment started to decrease for all of the treatments. Initially (579 dap) the treatments with bigger diameters showed a slightly higher diameter increment than those with a smaller diameter. However, with time the bigger trees started to compete with each other which caused a reduction in diameter increments. As a result the treatments with a smaller diameter showed a slightly higher diameter increment than those with a bigger diameter at the last measured date.

The change in basal area for the different treatments is presented in **Figures 5.3** and **5.4**.

## Table 5.1 ANOVA table for *E. macarthurii* height, and height growth rate performance after canopy closure

| Source of variation | Degrees of freedom | *F*-probability for height (m) | | | | | *F*-probability for height growth rate (m day$^{-1}$) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Days after planting | | | | | Days after planting | | | |
| | | 631 | 826 | 1204 | 1587 | 1952 | 826 | 1204 | 1587 | 1952 |
| Reps | 3 | 0.693 | 0.401 | 0.456 | 0.196 | 0.294 | 0.339 | 0.493 | 0.927 | 0.756 |
| Coppice x seedlings | 1 | 0.001*** | 0.001*** | 0.001*** | 0.039* | 0.001*** | 0.007** | 0.001*** | 0.024* | 0.004** |
| Coppice x fertilisation | 1 | 0.027* | 0.001*** | 0.011* | 0.014* | 0.027* | 0.183 | 0.424 | 0.657 | 0.728 |
| Coppice x genetic improvement | 1 | 0.618 | 0.296 | 0.712 | 0.766 | 0.260 | 0.779 | 0.947 | 0.571 | 0.013* |
| Coppice x weed control | 1 | 0.585 | 0.416 | 0.265 | 0.733 | 0.553 | 0.867 | 0.238 | 0.064 | 0.624 |
| Coppice x fertilisation x genetic improvement | 1 | 0.777 | 0.931 | 0.295 | 0.252 | 0.093 | 0.366 | 0.074 | 0.966 | 0.263 |
| Coppice x fertilisation x weed control | 1 | 0.902 | 0.802 | 0.395 | 0.467 | 0.379 | 0.502 | 0.089 | 0.981 | 0.738 |
| Coppice x weed control x genetic improvement | 1 | 0.842 | 0.957 | 0.282 | 0.824 | 0.498 | 0.412 | 0.071 | 0.063 | 0.107 |
| Coppice x fertilisation x genetic improvement x weed control | 1 | 0.723 | 0.508 | 0.923 | 0.839 | 0.759 | 0.326 | 0.267 | 0.945 | 0.837 |
| Residual | 24 | | | | | | | | | |
| Total | 35 | | | | | | | | | |
| Summary of means (values shown only for those where there was significance) | | | | | | | | | | |
| **Coppice** | **Coppice** | **6.30** | **10.01** | **12.53** | **13.84** | **16.49** | **0.01924** | **0.00655** | **0.00341** | **0.00728** |
| | Seedlings | 3.35 | 6.25 | 10.25 | 12.55 | 14.15 | 0.01457 | 0.01071 | 0.00607 | 0.00438 |
| Coppice x fertilisation | Fert | 3.62 | 6.72 | 10.77 | 13.06 | 14.62 | | | | |
| | No fert | 3.07 | 5.76 | 9.69 | 12.01 | 13.65 | | | | |
| Coppice x genetic improvement | Improved | | | | | | | | | 0.00517 |
| | Unimproved | | | | | | | | | 0.00354 |
| Coppice x weed control | Weed-free | | | | | | | | | |
| | Weedy | | | | | | | | | |
| Grand mean | | 3.69 | 6.69 | 10.51 | 12.70 | 14.42 | 0.01511 | 0.01024 | 0.00577 | 0.00471 |
| S.e.d (Coppice x fert x gen x weeds) | | 0.3624 | 0.4099 | 0.609 | 0.617 | 0.638 | 0.0017 | 0.00120 | 0.0115 | 0.0009 |
| Cv % (Rep. Plot) | | 17.6 | 11.0 | 10.4 | 8.7 | 7.9 | 19.8 | 21.0 | 35.8 | 35.8 |

* = significant at the 5% level

** = significant at the 1 % level

*** = significant at the 0.1 % level.

## Table 5.2 ANOVA table for *E. nitens* height, and height growth rate performance after canopy closure

| Source of variation | Degrees of freedom | *F*-probability for height (m) | | | | | | *F*-probability height growth rate (m day$^{-1}$) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Days after planting | | | | | | Days after planting | | | |
| | | 466 | 579 | 803 | 1211 | 1571 | 1952 | 803 | 1211 | 1571 | 1952 |
| Reps | 3 | | | | | | | | | | |
| Coppice x seedlings | 1 | | 0.034* | 0.127 | 0.331 | 0.680 | 0.742 | 0.001*** | 0.981 | 0.296 | 0.415 |
| Coppice x fertilisation | 1 | 0.002** | 0.033* | 0.100 | 0.123 | 0.261 | 0.858 | 0.575 | 0.409 | 0.413 | 0.037* |
| Coppice x genetic improvement | 1 | 0.113 | 0.097 | 0.014* | 0.045* | 0.049* | 0.022* | 0.032* | 0.462 | 0.934 | 0.047* |
| Coppice x weed control | 1 | 0.175 | 0.256 | 0.111 | 0.197 | 0.094 | 0.093 | 0.187 | 0.638 | 0.450 | 0.828 |
| Coppice x fertilisation x genetic improvement | 1 | 0.497 | 0.492 | 0.901 | 0.535 | 0.682 | 0.523 | 0.708 | 0.284 | 0.065 | 0.055 |
| Coppice x fertilisation x weed control | 1 | 0.983 | 0.712 | 0.813 | 0.813 | 0.793 | 0.627 | 0.974 | 0.554 | 0.359 | 0.616 |
| Coppice x weed control x genetic improvement | 1 | 0.336 | 0.458 | 0.433 | 0.250 | 0.206 | 0.132 | 0.621 | 0.298 | 0.826 | 0.457 |
| Coppice x fertilisation x genetic improvement x weed control | 1 | 0.131 | 0.418 | 0.857 | 0.874 | 0.744 | 0.811 | 0.692 | 0.677 | 0.756 | 0.138 |
| Residual | 24 | | | | | | | | | | |
| Total | 35 | | | | | | | | | | |
| Summary of means (values shown only for those where there was significance) | | | | | | | | | | | |
| **Coppice** | **Coppice** | **#** | **6.03** | **8.89** | **12.34** | **15.57** | **16.40** | **0.01278** | | | **0.00258** |
| | Seedlings | | 5.28 | | | | | 0.02021 | | | |
| Coppice x fertilisation | Fert | 4.74 | 5.53 | | | | | | | | 0.00251 |
| | No fert | 4.21 | 5.03 | | | | | | | | 0.00145 |
| Coppice x genetic improvement | Improved | | | 10.32 | 13.93 | 16.21 | 17.11 | 0.01878 | | | 0.00148 |
| | Unimproved | | | 9.30 | 12.61 | 14.92 | 15.68 | 0.02164 | | | 0.00248 |
| Coppice x weed control | Weed-free | | | | | | | | | | |
| | Weedy | | | | | | | | | | |
| Grand mean | | 4.48 | 5.37 | 9.71 | 13.17 | 15.52 | 16.36 | 0.01930 | 0.00847 | 0.00655 | 0.00205 |
| S.e.d (Coppice x fert x gen x weeds) | | 0.2981 | 0.4435 | 0.7730 | 1.2520 | 1.2490 | 1.1660 | 0.0025 | 0.0020 | 0.0019 | 0.0010 |
| Cv % (Rep. Plot) | | 9.4 | 11.7 | 11.3 | 13.5 | 11.4 | 10.1 | 18.3 | 33.0 | 40.5 | 66.2 |

* = significant at the 5% level

** = significant at the 1 % level

*** = significant at the 0.1 % level.

# = No data

**Table 5.3 ANOVA table for *E. macarthurii* diameter, and diameter growth rate performance after canopy closure**

| Source of variation | Degrees of freedom | F-probability for diameter (cm) | | | | | F-probability for diameter growth rate (cm $day^{-1}$) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Days after planting | | | | | Days after planting | | | |
| | | 631 | 826 | 1204 | 1587 | 1952 | 826 | 1204 | 1587 | 1952 |
| Reps | 3 | | | | | | | | | |
| Coppice x seedlings | 1 | 0.001*** | 0.019* | 0.424 | 0.575 | 0.286 | 0.001*** | 0.273 | 0.023* | 0.019* |
| Coppice x fertilisation | 1 | 0.001*** | 0.001*** | 0.001*** | 0.010** | 0.030* | 0.045* | 0.350 | 0.352 | 0.773 |
| Coppice x genetic improvement | 1 | 0.005** | 0.011* | 0.006** | 0.058 | 0.079 | 0.271 | 0.614 | 0.398 | 0.572 |
| Coppice x weed control | 1 | 0.969 | 0.324 | 0.158 | 0.127 | 0.098 | 0.055 | 0.489 | 0.906 | 0.131 |
| Coppice x fertilisation x genetic improvement | 1 | 0.161 | 0.231 | 0.376 | 0.874 | 0.706 | 0.804 | 0.574 | 0.289 | 0.061 |
| Coppice x fertilisation x weed control | 1 | 0.912 | 0.807 | 0.860 | 0.839 | 0.933 | 0.618 | 0.900 | 0.846 | 0.709 |
| Coppice x weed control x genetic improvement | 1 | 0.843 | 0.323 | 0.788 | 0.700 | 0.900 | 0.144 | 0.332 | 0.287 | 0.404 |
| Coppice x fertilisation x genetic improvement x weed control | 1 | 0.771 | 0.896 | 0.890 | 0.871 | 0.631 | 0.878 | 0.836 | 0.641 | 0.164 |
| Residual | 24 | | | | | | | | | |
| Total | 35 | | | | | | | | | |
| Summary of means (values shown only for those where there was significance) | | | | | | | | | | |
| Coppice | Coppice | 4.9 | 6.9 | 9.6 | 10.7 | 11.4 | 0.00901 | | 0.00263 | 0.00210 |
| | Seedlings | 2.4 | 6.0 | | | | 0.01847 | | 0.00398 | 0.00302 |
| Coppice x fertilisation | Fert | 2.7 | 6.5 | 9.8 | 11.4 | 12.5 | 0.01909 | | | |
| | No fert | 2.0 | 5.5 | 8.8 | 10.5 | 11.6 | 0.01785 | | | |
| Coppice x genetic improvement | Improved | 2.6 | 6.3 | 9.7 | | | | | | |
| | Unimproved | 2.1 | 5.7 | 8.9 | | | | | | |
| Coppice x weed control | Weed-free | | | | | | | | | |
| | Weedy | | | | | | | | | |
| Grand mean | | 2.6 | 6.1 | 9.3 | 10.9 | 11.9 | 0.01700 | 0.00860 | 0.00383 | 0.00292 |
| S.e.d (Coppice x fert x gen x weeds) | | 0.3666 | 0.4785 | 0.500 | 0.627 | 0.736 | 0.0012 | 0.0010 | 0.0007 | 0.0005 |
| Cv % (Rep. Plot) | | 19.6 | 11.1 | 7.6 | 8.1 | 8.7 | 9.5 | 15.8 | 27.3 | 23,6 |

* = significant at the 5% level

** = significant at the 1 % level

*** = significant at the 0.1 % level.

## Table 5.4 ANOVA table for *E. nitens* diameter, and diameter growth rate performance after canopy closure

| Source of variation | Degrees of freedom | *F*-probability for diameter (cm) | | | | | | *F*-probability for diameter growth rate (cm day$^{-1}$) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Days after planting | | | | | | Days after planting | | | | |
| | | 466 | 579 | 803 | 1211 | 1571 | 1952 | 579 | 803 | 1211 | 1571 | 1952 |
| Reps | 3 | | | | | | | | | | | |
| Coppice x seedlings | 1 | | 0.882 | 0.835 | 0.894 | 0.936 | 0.502 | | 0.973 | 0.215 | 0.386 | 0.140 |
| Coppice x fertilisation | 1 | 0.001*** | 0.001*** | 0.001*** | 0.012* | 0.060 | 0.092 | 0.832 | 0.815 | 0.376 | 0.707 | 0.850 |
| Coppice x genetic improvement | 1 | 0.001*** | 0.001*** | 0.001*** | 0.003** | 0.002** | 0.005** | 0.221 | 0.716 | 0.019* | 0.165 | 0.386 |
| Coppice x weed control | 1 | 0.941 | 0.808 | 0.452 | 0.757 | 0.612 | 0.210 | 0.730 | 0.194 | 0.821 | 0.340 | 0.091 |
| Coppice x fertilisation x genetic improvement | 1 | 0.959 | 0.695 | 0.764 | 0.794 | 0.701 | 0.924 | 0.591 | 0.829 | 0.658 | 0.359 | 0.950 |
| Coppice x fertilisation x weed control | 1 | 0.243 | 0.474 | 0.678 | 0.619 | 0.668 | 0.967 | 0.861 | 0.111 | 0.131 | 0.889 | 0.500 |
| Coppice x weed control x genetic improvement | 1 | 0.710 | 0.266 | 0.297 | 0.306 | 0.202 | 0.214 | 0.141 | 0.923 | 0.392 | 0.590 | 0.882 |
| Coppice x fertilisation x genetic improvement x weed control | 1 | 0.808 | 0.394 | 0.424 | 0.430 | 0.300 | 0.165 | 0.242 | 0.944 | 0.338 | 0.512 | 0.261 |
| Residual | 24 | | | | | | | | | | | |
| Total | 35 | | | | | | | | | | | |
| Summary of means (values shown only for those where there was significance) | | | | | | | | | | | | |
| Coppice | Coppice | # | 4.9 | 7.3 | 10.7 | 12.0 | 12.5 | | | 0.00909 | | |
| | Seedlings | | | | | | | | | | | |
| Coppice x fertilisation | Fert | 4.2 | 5.3 | 7.6 | 11.1 | | | | | | | |
| | No fert | 3.5 | 4.6 | 6.9 | 10.4 | | | | | | | |
| Coppice x genetic improvement | Improved | 4.1 | 5.3 | 7.6 | 11.2 | 12.5 | 13.3 | | | 0.00794 | | |
| | Unimproved | 3.6 | 4.6 | 6.9 | 10.3 | 11.5 | 12.3 | | | 0.00885 | | |
| Coppice x weed control | Weed-free | | | | | | | | | | | |
| | Weedy | | | | | | | | | | | |
| Grand mean | | 3.8 | 4.9 | 7.2 | 10.7 | 12.0 | 12.8 | 0.01000 | 0.01000 | 0.00800 | 0.00300 | 0.00200 |
| S.e.d (Coppice x fert x gen x weeds) | | 0.2230 | 0.3281 | 0.3138 | 0.568 | 0.6010 | 0.6220 | 0.0017 | 0.0011 | 0.0007 | 0.0004 | 0.0004 |
| Cv % (Rep. Plot) | | 8.3 | 9.4 | 6.1 | 7.5 | 7.1 | 6.9 | 23.6 | 15.5 | 12.0 | 18.0 | 27.2 |

* = significant at the 5% level

** = significant at the 1 % level

*** = significant at the 0.1 % level.

# = No data

**Table 5.5 ANOVA table for *E. macarthurii* and *E. nitens* basal area performance after canopy closure**

| Source of variation | Degrees of freedom | Basal area F-probabilities for *E. macarthurii* | | | | | Basal area F-probabilities for *E. nitens* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Days after planting | | | | | Days after planting | | | | | |
| | | 631 | 826 | 1204 | 1587 | 1952 | 466 | 579 | 803 | 1211 | 1571 | 1932 |
| Reps | 3 | | | | | | | | | | | |
| Coppice x seedlings | 1 | 0.001*** | 0.001*** | 0.014* | 0.086 | 0.250 | # | # | # | 0.428 | 0.581 | 0.578 |
| Coppice x fertilisation | 1 | 0.046* | 0.003** | 0.001*** | 0.001*** | 0.002** | 0.001*** | 0.002** | 0.002** | 0.040* | 0.015* | 0.051 |
| Coppice x genetic improvement | 1 | 0.199 | 0.033* | 0.020* | 0.020* | 0.028* | 0.001*** | 0.004** | 0.001*** | 0.001*** | 0.001*** | 0.001*** |
| Coppice x weed control | 1 | 0.936 | 0.635 | 0.494 | 0.263 | 0.166 | 0.844 | 0.789 | 0.099 | 0.069 | 0.067 | 0.087 |
| Coppice x fertilisation x genetic improvement | 1 | 0.254 | 0.069 | 0.053 | 0.112 | 0.286 | 0.396 | 0.786 | 0.836 | 0.950 | 0.673 | 0.911 |
| Coppice x fertilisation x weed control | 1 | 0.878 | 0.788 | 0.775 | 0.922 | 0.925 | 0.434 | 0.684 | 0.326 | 0.911 | 0.843 | 0.924 |
| Coppice x weed control x genetic improvement | 1 | 0.832 | 0.300 | 0.438 | 0.972 | 0.788 | 0.801 | 0.374 | 0.645 | 0.622 | 0.585 | 0.782 |
| Coppice x fertilisation x genetic improvement x weed control | 1 | 0.936 | 0.880 | 0.964 | 0.453 | 0.257 | 0.698 | 0.475 | 0.495 | 0.129 | 0.166 | 0.967 |
| Residual | 24 | | | | | | | | | | | |
| Total | 35 | | | | | | | | | | | |
| Summary of means (values shown only for those where there was significance) | | | | | | | | | | | | |
| Coppice | Coppice | 6.90 | 11.54 | 14.62 | 17.78 | 20.57 | | | | 15.98 | 19.91 | 21.96 |
| | Seedlings | 0.90 | 4.94 | 11.41 | | | | | | | | |
| Coppice x fertilisation | Fert | 1.18 | 5.82 | 13.08 | 17.11 | 20.56 | 2.28 | 3.68 | 7.57 | 16.15 | 19.72 | |
| | No fert | 0.62 | 4.06 | 9.73 | 13.66 | 16.78 | 1.67 | 2.87 | 6.42 | 14.13 | 17.66 | |
| Coppice x genetic improvement | Improved | | 5.53 | 12.41 | 16.50 | 19.93 | 2.20 | 3.65 | 7.61 | 16.57 | 20.40 | 22.93 |
| | Unimproved | | 4.35 | 10.41 | 14.28 | 17.41 | 1.75 | 2.91 | 6.38 | 13.71 | 16.98 | 18.94 |
| Coppice x weed control | Weed-free | | | | | | | | | | | |
| | Weedy | | | | | | | | | | | |
| Grand mean | | 1.57 | 5.67 | 11.76 | 15.65 | 18.88 | 1.97 | 3.28 | 7.00 | 18.83 | 15.22 | 21.05 |
| S.e.d (Coppice x fert x gen x weeds) | | 0.528 | 1.044 | 1.606 | 1.785 | 2.153 | 0.232 | 0.460 | 0.658 | 1.848 | 1.493 | 2.074 |
| Cv % (Rep. Plot) | | 47.6 | 26.0 | 19.3 | 16.1 | 16.1 | 16.6 | 19.9 | 13.3 | 13.7 | 13.7 | 13.7 |

* = significant at the 5% level

** = significant at the 1 % level

*** = significant at the 0.1 % level.

# = No data

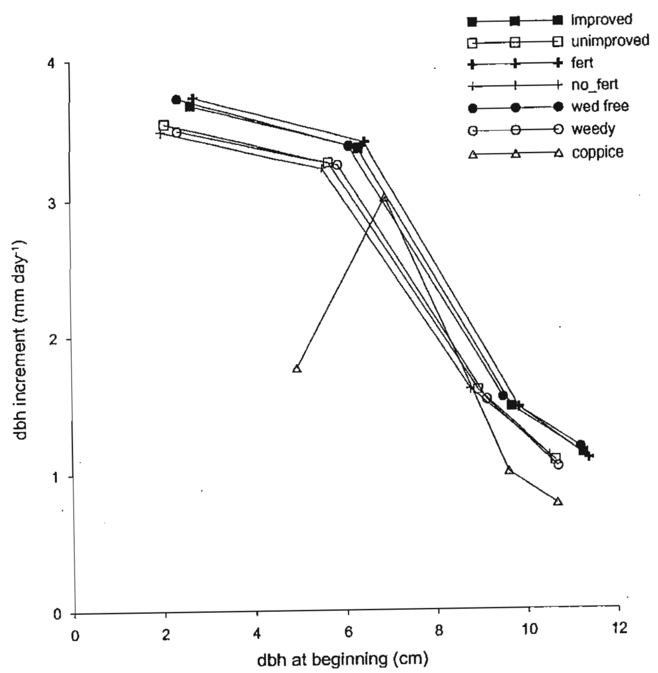



**Figure 5.1** **Relationship between diameter at breast height (dbh) and dbh daily increment for *E. macarthurii* trees under different silvicultural treatments**

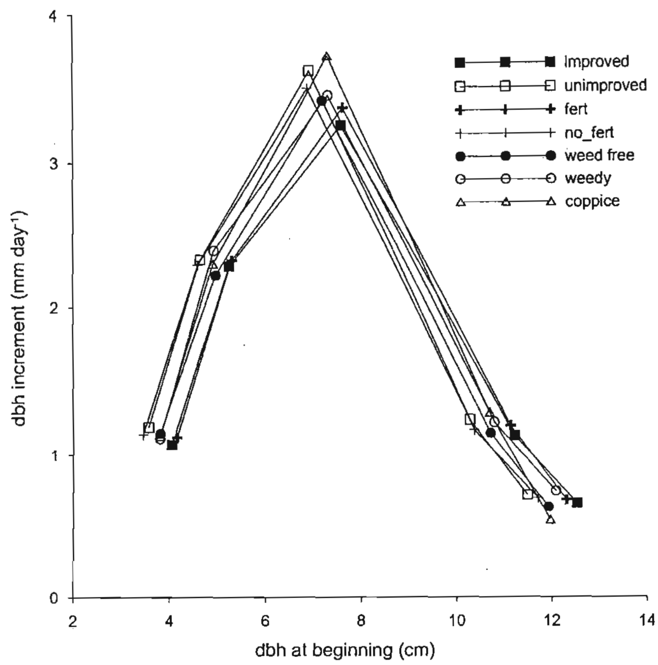



**Figure 5.2** **Relationship between diameter at breast height (dbh) and dbh daily increment for *E. nitens* trees under different silvicultural treatments**

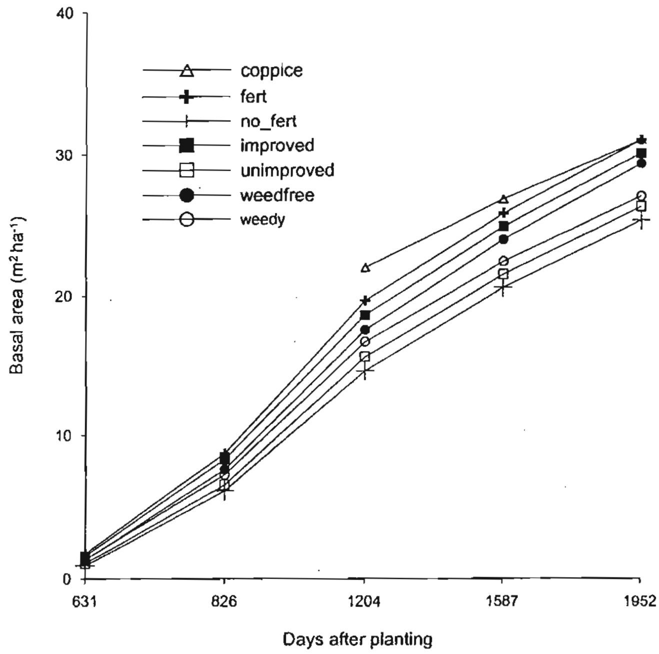



**Figure 5.3 Change in basal area for *E. macarthurii* from canopy closure until the trees were six years of age**

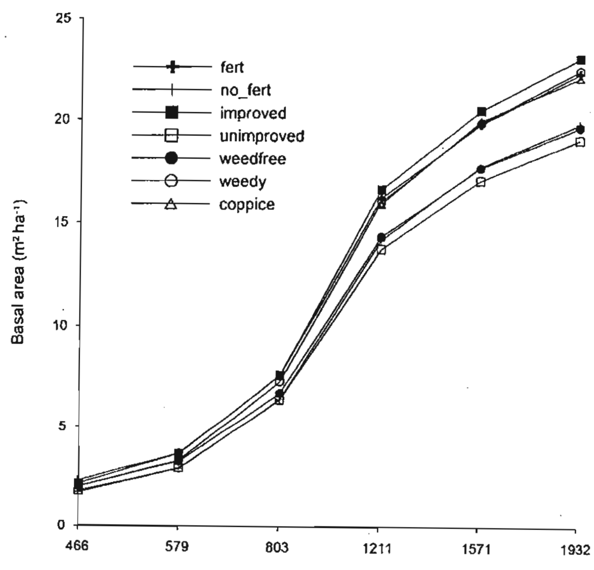



**Figure 5.4 Change in basal area for *E. nitens* from canopy closure until the trees were six years of age**

### 5.2.2 Differences in tree straightness for the different treatments at five years of age

Tree straightness plays a very important role in the forestry industry. Poor tree straightness can result in higher harvesting, transport and milling costs. All the measured trees were scored for straightness (as described in **Chapter 3**) when they were five years of age. The percentage of each category was then calculated for each treatment and presented in **Figures 5.5** and **5.6**. The effect of weed control on tree straightness was excluded from this presentation since no differences were detected.

Fertilisation, genetic improvement and regeneration by means of coppice all had a positive effect on tree straightness for the *E. macarthurii* and *E. nitens*. In both cases, the total percentage for the "best" and the "good" scores together were higher for fertilised, improved and coppice treatments respectively. However, the difference in tree straightness between *E, macarthurii* improved and unimproved material were minimal. In all three cases, better tree straightness is probably due to the initial faster growth of all these treatments. The faster growth would mean that the trees get away from any competition that might have occurred at a younger stage, which could have had a negative effect on tree straightness. Faster growth also means that the trees harden off at an earlier stage, which makes it less susceptible to deformations like but-sweep, caused by wind. In the case of coppice, the better tree straightness is also a result from selective reduction. With the coppice reduction operation, only the best-formed and attached stems are selected to be left on the stump, which will eventually lead to better tree straightness. In the case of improved material, better tree straightness is also a result of the selection of plus trees as parent material. Existing plantations form a source from which parent trees are selected for a breeding population of above average trees. Selection crews comb plantations in search of vigorous, healthy trees with straight stems, with relatively thin and wide-angled branches. A wood sample is extracted from the selected tree to determine its wood density, fibre length and grain spirality. For eucalypts, especially when grown for solid wood products, splitting of log-ends are a very important selection criterion. Stem taper and rootability and root quality of cuttings taken for vegetative propagation are other criteria. After passing all these tests, the tree is classified as a PLUS TREE and included in the breeding programme (van Wyk *et al.* 2000).

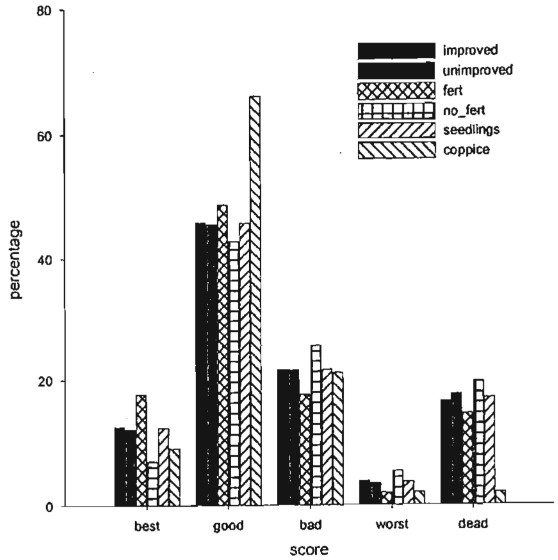



**Figure 5.5 Number of *E. macarthurii* trees (%) per straightness class for the main effects**

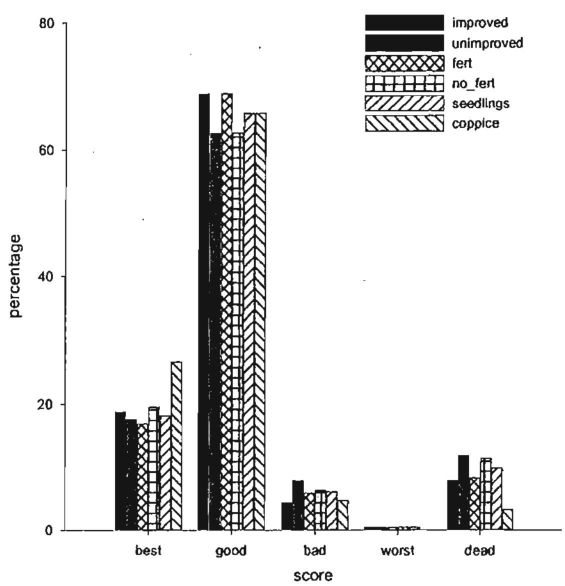



**Figure 5.6 Number of *E. nitens* trees (%) per straightness class for the main effects**

## 5.3 Conclusions

Fertilisation, genetic improvement and regeneration by means of coppice all had a positive effect on initial tree performance respectively. Most of these positive effects however, seemed to decline with age. The reduction in growth rates of these best performing treatments is probably caused by intra-specific competition. Due to the limited resources available to trees for their growth, the bigger trees start to compete with each other. This results in the reduction of growth rates. The slower-growing treatments, like the unfertilised and unimproved treatments, only reach this level of intra-specific competition at a later stage that gives them the opportunity to catch up with the better performing trees. At the last measurement, there were no significant differences in terms of tree growth between the coppice and seedling treatments for either *E. macarthurii* or *E. nitens*. The basal area of *E. macarthurii* seedlings without fertiliser was still significantly lower than any one of the other treatments. However, this difference in growth seems to decrease over time, and the positive effect of fertiliser might not be visible at the time of harvesting. At the last measured date, the *E. nitens* improved seedlings were still significantly better in terms of basal area when compared to unimproved seedlings. However, again these differences in basal area seem to decrease over time and final conclusions can only be made at harvesting.

Fertilisation, genetic improvement and regeneration by means of coppice also seem to have a positive effect on tree straightness and survival. In each case tree straightness and survival was good. This could be a very important factor when harvesting, transport and milling costs are calculated.

The control of weeds did not have a significant impact on tree performance after canopy closure. The weed load at both these sites was too low to have a significant effect on tree growth. However, at sites with a different weed spectrum the impact of weed control cannot be ignored, and adequate weed control is essential for optimum tree survival and growth.

No significant interaction between any of the treatments was detected after canopy closure. However, interactions for different species or under different circumstances should not be ignored, for instance at a site with a more competitive weed load the interaction between weeds and fertiliser could be severe. Fertilisation could encourage weeds to grow, which will result in higher weed control costs.

# CHAPTER 6

# COST ANALYSIS OF SILVICULTURAL PRACTICES IN GROWING *E. macarthurii* AND *E. nitens*

## 6.1 Introduction

Forestry is a long-term investment with high expenses incurred during establishment and thereafter little or no revenue until the trees are felled (de Laborde, 1991). In South Africa, the rotation length of growing eucalypts normally varies from 8 to 12 years (Schönau and Stubbings, 1987). In the coastal Zululand region however, eucalypts can be harvest as early as six years for pulp production. If profits are to be made from forestry, expected returns must be considerably greater than total capital expenditure. As a result of the initial costs incurred early in the rotation, one must include a loss on returns of capital spent had the capital been invested elsewhere (de Laborde, 1991). Thus financial analysis must be used to assess the profitability of intended silvicultural practices to determine whether such practices will provide suitable returns.

Although forestry in South Africa is viewed as a permanent enterprise that maintains an ongoing series of cycles which generate annual income, by harvesting a portion of the plantation each year, followed by re-establishment of that area (Rusk *et. al.* 1991), it is still important to understand how improved growth from research will impact on long-term profitability.

The approach that has been adopted in this chapter includes the cost-analysis of the early silvicultural practices tested in these trials. More appropriate financial analysis, like discounted cash flow analysis (*Net Present Value* and *Equivalent Annual Income*), will be used once the trees are harvested and final timber volumes are available for the different treatments.

## 6.2 Description of costs

### 6.2.1 Layout of costs

All the costs shown in this chapter were obtained from the Forestry Economics Services of South Africa (1999). The costs for the various silvicultural activities are direct costs for 1999, the period over which the trials were established. The various silvicultural activities undertaken at each trial are illustrated in **Table 6.1**, and include labour costs, land preparation, planting, fertilisation, blanking, weed control and coppice reductions. The item cost per hectare in each activity is the total value of that item divided by the total hectares for the activity. The total cost per hectare is the summation of the per hectare components for that activity. These costs are all based on the total area planted to eucalypts in South Africa. A description of what each activity entails, and what was carried out in each trial is discussed in more detail below.

- Labour costs:
  Labour costs include wages and the earnings of salaried workers and the wages of casuals.

- Land preparation:
  Land preparation costs includes the clearing of bush, scrub, the remains of the previous crops, all methods of mechanical cultivation, full cover spray with herbicide, marking planting spots and pitting, i.e. preparing planting holes. Land preparation is complete when planting holes are ready to be planted. Preparation costs are influenced by factors such as topography, methods of harvesting previous crops, the interval between harvesting and re-establishment, fire damage to previous crop and whether re-afforastation is to the same crop or another species. At both trial sites, the residue from the previous crop was burned, and the sites were then pitted to be planted.

- Planting:

  Planting costs includes seedling costs, seedling transport, watering, applying insecticides or moisture absorbing gels, and the planting of the seedlings. The number of plants per hectare is the weighted average for all the areas planted to eucalypts in Kwazulu-Natal, South Africa (1628 stems per hectare). This average is slightly lower than the actual planting density at these sites (Tweefontein = 1852 stems per hectare, and Draycott = 1666 stems per hectare). Improved and unimproved seedlings are sold at the same price in South African nurseries. Therefore, no differences in planting costs between the improved and unimproved treatments are shown. This is surprising as improved material is developed at a large cost and it would therefore pay to plant improved material regardless.

- Fertilising:

  Fertilising costs includes both the transport of the fertiliser and the application. Costs and application rates refer to total compartments areas for those eucalypt compartments that were fertilised in KwaZulu-Natal, South Africa. Repeated fertiliser applications will increase the costs but not the total areas fertilised. In this case however, fertiliser was only applied at planting, namely 125 g 2:3:2(22) of NPK placed in a buried ring around the seedling at planting

- Blanking:

  Blanking costs includes seedling costs, seedling transport, watering and replanting gaps. Costs and mortality rates (16 %) refer to total compartment area for those compartments that were blanked in eucalypt plantations in Kwazulu-Natal, South Africa. Repeated blanking will increases the costs but not the total areas blanked. Only one blanking operation was carried out at these trials. Mortality rates for both trials were at 10 % only and the cost was based on that.

- Weed control:

  Costs of weed control refer to hoeing, slashing and post planting herbicide spraying with the object of enhancing growth. These operations normally cease once the trees have canopied or when the weeds are no longer competitive. The weeding costs in **Table 6.1** are per single operation up to canopy closure. The total cost of weeding to canopy closure is therefore the cost per single operation multiplied by the number of weedings. Only two weeding operations were carried out between planting and canopy closure at both these trials. The weeding costs used for these trials are the cost of a single weeding operation multiplied by two (**Table 6.2**). At sites with higher weed loads the number of weeding operations would increase. The average number of weed control operations until canopy closure in KwaZulu-Natal (South Africa) was between five and seven in 1999 when the trials were planted.

- Coppice reduction (thinning):

  Costs for re-establishment by coppice thinning consist of reducing the number of coppice shoots to a final required stem population per hectare through a series of thinning operations. The coppice reduction costs in **Table 6.1** are the cumulative costs of these thinnings.

A breakdown of costs from 1999 for each of the different operations used in these trials is shown in **Table 6.1.** The total costs for the different treatments initiated in these trials are shown in **Table 6.2.**

**Table 6.1** **Costs (R ha$^{-1}$) used for the different silvicultural operations for the establishment of *E. macarthurii* and *E. nitens* at Tweefintein and Draycott in the KwaZulu-Natal midlands (S.A.)**

| | Land preparation | Planting | Fertilising | Blanking | Weed control (per ha per single operation) | Coppice reduction |
|---|---|---|---|---|---|---|
| Labour | 171.17 | 81.58 | 26.29 | 31.15 | 34.49 | 156.92 |
| Machinery | 49.42 | 70.47 | 3.47 | 12.93 | 5.89 | 8.27 |
| Herbicides | 94.82 | 0 | 0 | 0 | 21.82 | 0 |
| Insecticides | 0 | 39.86 | 0 | 0 | 0 | 0 |
| Plants | 0 | 563.24 | 0 | 90.28 | 0 | 0 |
| Fertiliser | 0 | 0 | 253.16 | 0 | 0 | 0 |
| Contractors | 683.31 | 233.54 | 87.10 | 81.99 | 147.74 | 356.33 |
| **Total costs** | 998.72 | 988.69 | 370.02 | 216.35 | 209.94 | 524.60 |

**Table 6.2** **Total costs (R ha$^{-1}$) used for the establishment of *E. macarthurii* and *E. nitens* at Tweefontein and Draycott in the KwaZulu-Natal midlands (S.A.)**

| Treatments | Land preparation | Planting | Fertilising | Blanking | Weed control | Coppice reduction | Total costs |
|---|---|---|---|---|---|---|---|
| Improved + fert + weed-free | 998.72 | 988.69 | 370.02 | 216.35 | 419.88 | 0 | 2993.66 |
| Improved + fert + weedy | 998.72 | 988.69 | 370.02 | 216.35 | 0 | 0 | 2573.78 |
| Improved + no_fert + weed-free | 998.72 | 988.69 | 0 | 216.35 | 419.88 | 0 | 2623.64 |
| Improved + no_fert + weedy | 998.72 | 988.69 | 0 | 216.35 | 0 | 0 | 2203.76 |
| Unimproved + fert + weed-free | 998.72 | 988.69 | 370.02 | 216.35 | 419.88 | 0 | 2993.66 |
| Unimproved + fert + weedy | 998.72 | 988.69 | 370.02 | 216.35 | 0 | 0 | 2573.78 |
| Unimproved + no_fert + weed-free | 998.72 | 988.69 | 0 | 216.35 | 419.88 | 0 | 2623.64 |
| Unimproved + no_fert + weedy | 998.72 | 988.69 | 0 | 216.35 | 0 | 0 | 2203.76 |
| Coppice | 0 | 0 | 0 | 0 | 0 | 524.60 | 524.60 |

### 6.2.2 Inflation

In order to compare differences in costs for the different treatments, an average of the annual inflation from the initiation of the trials until present was taken into account. Three inflation scenarios were investigated, namely:

- a static inflation rate of five percent per annum from 1999 until 2004,
- the actual inflation rates from 1999 until 2004 (7.5 % in 1999, 9.0 % in 2000, 7.8 % in 2001, 8.5 % in 2002, 8.5 % in 2003 and 8.1 % in 2004) (Myer *pers. comm.*, 2004),
- a static inflation rate of ten percent per annum from 1999 until 2004 was used **(Table 6.3)**.

The values in 2004 are used in order to compare the costs per unit wood (basal area, $m^2 ha^{-1}$) that was produced at the last measured date.

**Table 6.3 Accumulative costs (R $ha^{-1}$) for the different treatments at the actual inflation rate and at a static inflation rate of five or ten percent**

| Treatments | Total establishment costs | Inflation rate | | |
|---|---|---|---|---|
| | | 5.0% | actual | 10.0% |
| Improved + fert + weed-free | 2993.66 | 4011.79 | 4812.18 | 5303.45 |
| Improved + fert + weedy | 2573.78 | 3449.11 | 4137.24 | 4559.60 |
| Improved + no_fert + weed-free | 2623.64 | 3515.92 | 4217.38 | 4647.93 |
| Improved + no_fert + weedy | 2203.76 | 2953.24 | 3542.45 | 3904.09 |
| Unimproved + fert + weed-free | 2993.66 | 4011.79 | 4812.18 | 5303.45 |
| Unimproved + fert + weedy | 2573.78 | 3449.11 | 4137.24 | 4559.60 |
| Unimproved + no_fert + weed-free | 2623.64 | 3515.92 | 4217.38 | 4647.93 |
| Unimproved + no_fert + weedy | 2203.76 | 2953.24 | 3542.45 | 3904.09 |
| Coppice | 524.6 | 703.01 | 843.27 | 929.36 |

### 6.2.3 The relationship between establishment costs and timber output

The relationship between establishment costs and timber output in terms of basal area at the last measured date ($m^2 ha^{-1}$) are shown in **Tables 6.4** and **6.5**. The costs used were the sum of the establishment costs for each treatment and the actual inflation rates over the last six years. The basal areas used in the analysis were the ones calculated at the last measured date when the trees were six years of age. The ranking of basal area into the three classes (high, medium and low) in **Tables 6.4** and **6.5** was obtained by subtracting the smallest basal area value from the biggest basal area value. The difference was then divided by three to obtain the intervals for the tree basal area classes.

The cost to produce a $m^2 ha^{-1}$ of timber over the last six years for the different treatments were also calculated and presented in **Tables 6.6**, **6.7** and **6.8**, and **Figures 6.1** and **6.2**. This was done by dividing the total costs (including actual inflation after six years) by the last calculated basal area for each treatment.

Profits made, if any, will only be calculated once the trees are felled at the end of the rotation and more accurate height and under bark diameter measurements can be taken to calculate the tree volumes. At this moment of time some divergence in growth is still occurring between some of the treatments, and using profits to make conclusions would be misleading.

## 6.3 Results and discussion

### 6.3.1 Comparison between timber output and costs for both trials when the trees were six years of age

The relationship between timber output (basal area, $m^2 ha^{-1}$) and costs for *E. macarthurii* and *E. nitens* as well as the various treatments are presented in **Tables 6.6** and **6.7**.

*E. macarthurii* and *E. nitens* coppice showed promising results in terms of establishment costs versus timber output. In both cases, the coppice produced a relatively high timber output (*E. macarthurii* = 20.57 $m^2 ha^{-1}$; *E. nitens* = 21.96 $m^2 ha^{-1}$) at a low establishment cost (R843.27 $ha^{-1}$ including inflation), which only consisted of a coppice reduction operation. This coincides with current recommendations that state that, provided the correct species is matched to a particular site, at the correct stand density, similar yields may be obtained through coppicing, as opposed to replanting, at greatly reduced establishment costs (Opie *et al.*,1984). It must however, be kept in mind that at a site with inadequate survival or where the wrong species was planted, this might not be the case. For the purpose of these trials, coppice plots with adequate survival were selected. This might not be the case in commercial plantations, especially in the case where a species was planted with poor coppicing ability such as *E. nitens* (Little and Gardner, 2001).

At both the Tweefontein and Draycott trials weed control did not have an impact on tree performance in terms of basal area. However, the weed free treatments cost more to establish, which makes the weedy treatment a more cost-effective option at these high altitudes with low weed abundance. However, at a site with a different weed spectrum, this may not be the case, and severe losses in terms of timber output could result due to the lack of adequate weed control. For instance, weed control in the coastal Zululand region of South Africa is more critical due to the sub-tropical climate which favours an extended period over which the weeds are able to grow and the susceptibility of the tree species grown to competition from these weeds

(Little, 1999).The fertilised improved material without any weed control was the most promising treatment when the planted trees were compared, due to the low establishment costs (no weed control) and high timber output.

Another very important point that needs to be highlighted is that the improved material outperformed the unimproved material in all instances when timber production was compared. This could be to a great benefit to the forestry industry in South Africa since improved and unimproved material are currently sold at the same price in South African nurseries. However, the fact that the tree breeding costs to produce improved material are not factored into sales could be misleading. Companies will need to add the real cost to the production of improved material in order to quantify the true benefit of improved material in terms of cost.

The cost to produce a $m^2$ $ha^{-1}$ of timber over the last six years for the different treatments is presented in **Tables 6.6**, **6.7** and **6.8**, and **Figures 6.1** and **6.2**. The costs for all three inflation scenarios are presented, but only the cost where the actual inflation was taken into account will be discussed.

*E. macarthurri* and *E. nitens* coppice was far more profitable than the planting stock option. The *E. macarthurrii* coppice produced a $m^2$ $ha^{-1}$ of timber at a cost of R40.99 and *E. nitens* at a cost of R38.40. The average costs to produce a $m^2$ $ha^{-1}$ of timber for *E. macarthurrii* seedlings were R225.45 and R205.60 for *E. nitens* seedlings. The reason for these big differences in profitability between seedlings and coppice is due to the very low establishment costs of coppice. This would only be the case however, if the species have good coppicing ability and are at the right density as discussed earlier.

When the profitability between the different treatments for the seedlings was compared, the fertilised, improved material without any weed control was relatively profitable in both cases (*E. macarthurii* and *E. nitens*). In the case of *E. macarthurii* a $m^2$ $ha^{-1}$ of timber was produced at R184.2 and for *E. nitens* at R166.22. At the Draycott trial, genetic improvement showed to be the dominant factor, and the improved material without any fertiliser produced a $m^2$ $ha^{-1}$ of timber at R147.60. In the case of *E. macarthurii* however, fertilisation seems to play a more important role and the improved material without fertiliser produced a $m^2$ $ha^{-1}$ of timber at a higher cost (R219.34) than that with fertiliser. These differences in response to fertiliser between *E. macarthurii* and *E. nitens* are also reflected if the least profitable treatments are compared. In the case of *E. macarthurii* it was the treatment with unfertilised unimproved material, which was kept weed-free (R256.53 per $1m^2$ $ha^{-1}$ timber produced). In the case of *E. nitens* it was the fertilised unimproved material, which was kept weed-free (R 269.14 per $1m^2$ $ha^{-1}$ timber produced). The extra timber production due to the application of fertiliser in the latter did not make up for the costs to fertilise. The different reactions to fertilisation between *E. macarthurrii* and *E. nitens* were discussed in **Chapter 5**.

In all the above-mentioned cases, any extra timber produced due to weed control did not make up for the costs of weed control. The lack of response to weed control at both these sites was discussed in **Chapter 4**.

**Table 6.4** **Treatment costs (using actual inflation rates) and timber output for *E. macarthurii* at six years**

| Treatments | Costs at 6 years (R $ha^{-1}$) | Ranking of basal area at 6 years ($m^2$ $ha^{-1}$) | | |
|---|---|---|---|---|
| | | High | Medium | Low |
| Improved + weed-free + fert | Highest (4812.18) | 22.35 | | |
| Unimproved + weed-free + fert | 4812.18 | | 20.20 | |
| Improved + weed-free + no_fert | 4217.38 | | 18.75 | |
| Unimproved + weed-free + no_fert | 4217.38 | | | 16.44 |
| Improved + weedy + fert | 4137.24 | 22.46 | | |
| Unimproved + weedy + fert | 4137.24 | | | 17.22 |
| Improved + weedy + no_fert | 3542.45 | | | 16.15 |
| Unimproved + weedy + no_fert | 3542.45 | | | 15.76 |
| Coppice | Lowest (843.27) | 20.57 | | |

**Table 6.5** **Treatment costs (using actual inflation rates) and timber output for *E. nitens* at six years**

| Treatments | Costs at 6 years (R $ha^{-1}$) | Ranking of basal area at 6 years ($m^2$ $ha^{-1}$) | | |
|---|---|---|---|---|
| | | High | Medium | Low |
| Improved + weed-free + fert | Highest (4812.18) | 23.61 | | |
| Unimproved + weed-free + fert | 4812.18 | | | 17.88 |
| Improved + weed-free + no_fert | 4217.38 | | | 17.88 |
| Unimproved + weed-free + no_fert | 4217.38 | | | 17.52 |
| Improved + weedy + fert | 4137.24 | 24.89 | | |
| Unimproved + weedy + fert | 4137.24 | | 22.31 | |
| Improved + weedy + no_fert | 3542.45 | 24.00 | | |
| Unimproved + weedy + no_fert | 3542.45 | | | 18.07 |
| Coppice | Lowest (843.27) | | 21.96 | |

**Table 6.6 Cost per timber output(R per $m^2$ $ha^{-1}$) for the different treatments at a five percent inflation rate for both trials**

| Treatments | *E. macarthurii* Basal area ($m^2$ $ha^{-1}$) | *E. nitens* Basal area ($m^2$ $ha^{-1}$) | Total costs (R $ha^{-1}$) | Cost to produce a $m^2$ of timber (R per $m^2$ $ha^{-1}$) | |
|---|---|---|---|---|---|
| | | | | *E. macarthurii* | *E. nitens* |
| Improved + fert + weed-free | 22.35 | 23.61 | 4011.79 | 179.49 | 169.91 |
| Improved + fert + weedy | 22.46 | 24.89 | 3449.11 | 153.56 | 138.57 |
| Improved + no_fert + weed-free | 18.75 | 17.88 | 3515.92 | 187.51 | 196.64 |
| Improved + no_fert + weedy | 16.15 | 24.00 | 2953.24 | 182.86 | 123.05 |
| Unimproved + fert + weed-free | 20.2 | 17.88 | 4011.79 | 198.60 | 224.37 |
| Unimproved + fert + weedy | 17.22 | 22.31 | 3449.11 | 200.29 | 154.59 |
| Unimproved + no_fert + weed-free | 16.44 | 17.52 | 3515.92 | 213.86 | 200.68 |
| Unimproved + no_fert + weedy | 15.76 | 18.07 | 2953.24 | 187.38 | 163.43 |
| Coppice | 20.57 | 21.96 | 703.014 | 34.176 | 32.01 |

**Table 6.7 Cost per timber output (R per $m^2$ $ha^{-1}$) for the different treatments at the actual inflation rates for both trials**

| Treatments | *E. macarthurii* Basal area ($m^2$ $ha^{-1}$) | *E. nitens* Basal area ($m^2$ $ha^{-1}$) | Total costs (R $ha^{-1}$) | Cost to produce a $m^2$ of timber (R per $m^2$ $ha^{-1}$) | |
|---|---|---|---|---|---|
| | | | | *E. macarthurii* | *E. nitens* |
| Improved + fert + weed-free | 22.35 | 23.61 | 4812.18 | 215.31 | 203.82 |
| Improved + fert + weedy | 22.46 | 24.89 | 4137.24 | 184.20 | 166.22 |
| Improved + no_fert + weed-free | 18.75 | 17.88 | 4217.38 | 224.92 | 235.87 |
| Improved + no_fert + weedy | 16.15 | 24.00 | 3542.45 | 219.34 | 147.60 |
| Unimproved + fert + weed-free | 20.2 | 17.88 | 4812.18 | 238.23 | 269.14 |
| Unimproved + fert + weedy | 17.22 | 22.31 | 4137.24 | 240.26 | 185.44 |
| Unimproved + no_fert + weed-free | 16.44 | 17.52 | 4217.38 | 256.53 | 240.72 |
| Unimproved + no_fert + weedy | 15.76 | 18.07 | 3542.45 | 224.77 | 196.04 |
| Coppice | 20.57 | 21.96 | 843.27 | 40.99 | 38.40 |

**Table 6.8 Cost per timber output (R per $m^2$ $ha^{-1}$) for the different treatments at a ten percent inflation rate for both trials**

| Treatments | *E. macarthurii* Basal area ($m^2$ $ha^{-1}$) | *E. nitens* Basal area ($m^2$ $ha^{-1}$) | Total costs (R $ha^{-1}$) | Cost to produce a $m^2$ of timber (R per $m^2$ $ha^{-1}$) | |
|---|---|---|---|---|---|
| | | | | *E. macarthurii* | *E. nitens* |
| Improved + fert + weed-free | 22.35 | 23.61 | 5303.45 | 237.29 | 224.62 |
| Improved + fert + weedy | 22.46 | 24.89 | 4559.60 | 203.01 | 183.19 |
| Improved + no_fert + weed-free | 18.75 | 17.88 | 4647.93 | 247.89 | 259.95 |
| Improved + no_fert + weedy | 16.15 | 24.00 | 3904.09 | 241.73 | 162.67 |
| Unimproved + fert + weed-free | 20.2 | 17.88 | 5303.45 | 262.54 | 296.61 |
| Unimproved + fert + weedy | 17.22 | 22.31 | 4559.60 | 264.78 | 204.37 |
| Unimproved + no_fert + weed-free | 16.44 | 17.52 | 4647.93 | 282.72 | 265.29 |
| Unimproved + no_fert + weedy | 15.76 | 18.07 | 3904.09 | 247.72 | 216.05 |
| Coppice | 20.57 | 21.96 | 929.36 | 45.18 | 42.32 |

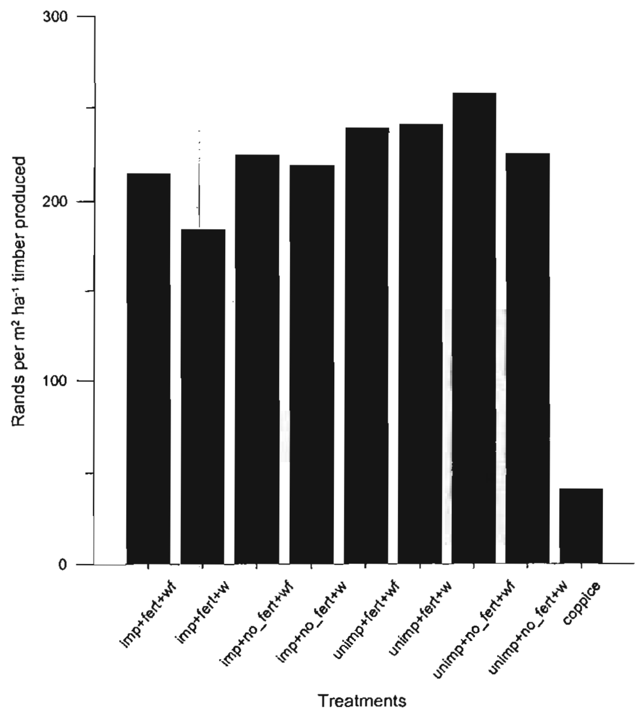



**Figure 6.1 Cost per timber output (R per $m^2$ $ha^{-1}$) for *E. macarthurii* at the actual inflation rates**

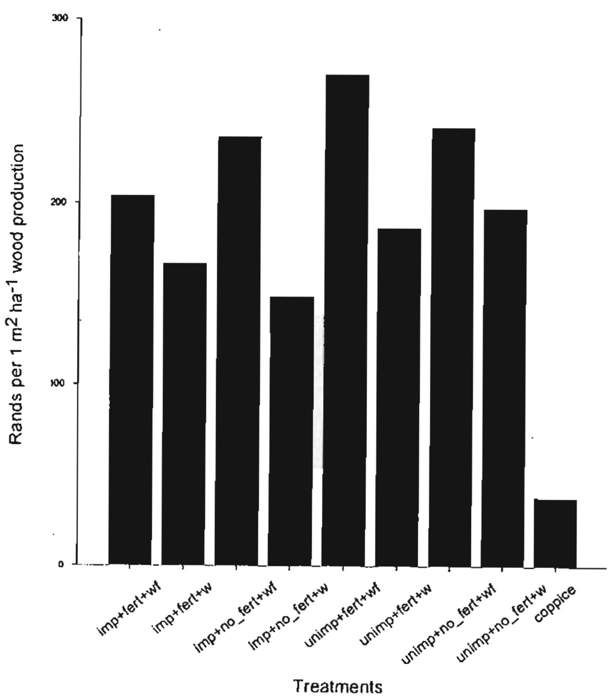



**Figure 6.2 Cost per timber output (R per $m^2$ $ha^{-1}$) for *E. nitens* at the actual inflation rates**

## 6.4 Conclusions

Re-establishment by means of coppice for both *E. macarthurii* and *E. nitens* has been the most cost-effective way at present to produce an adequate amount of timber. Coppicing was shown to be the least costly way to produce $1m^2\ ha^{-1}$ of timber provided the right species are coppiced, and optimum density levels are obtained.

Genetically improved *E. macarthurii* and *E. nitens* material was also shown to be a viable option to produce an optimum timber output at a lower cost in the case of replanting with seedlings. The fertilisation of *E. macarthurii* seedlings produced an adequate amount of timber to cover the fertilisation costs. In the case of *E. nitens* however, the impact of fertilisation on tree growth was not sustainable, and at six years of age was shown to be not cost-effective.

The impact of weed control on *E. macarthurii* and *E. nitens* tree growth was inadequate to produce timber at a cost-effective level. This is due to the lack of initial response to weed control as described in **Chapter 4.**

# CHAPTER 7

## OVERALL CONCLUSIONS

Genetic improvement played an important role in the establishment and initial growth of *E. macarthurii* and *E. nitens*. The improved trees outperformed the unimproved material in terms of tree growth until canopy closure. At the last measured date when the trees were six years of age, the *E. nitens* improved seedlings were still significantly better in terms of basal area when compared to unimproved trees. However, these differences in basal area are decreasing over time and final conclusions can only be made at harvesting. The initial positive effect of genetic improvement of *E. macarthurii* seedlings however, was not sustained. No significant differences between *E. macarthurii* improved and unimproved seedlings were detected at six years after planting. Genetic improvement of *E. macarthurii* and *E. nitens* had a positive effect on tree straightness and survival when the trees were assessed at five years of age. The genetic improvement of both species also showed to be a viable option to produce an optimum timber output at a lower cost when regeneration is done by means of replanting with seedlings.

Fertilisation also showed positive effects in terms of the establishment and initial growth of *E. macarthurii* and *E. nitens*. The fertilised treatments outperformed the unfertilised treatments until canopy closure. At six years after planting, the basal area of *E. macarthurii* seedlings without fertiliser was still significantly lower than any one of the other treatments. However, again this difference in growth is decreasing over time, and the positive effect of fertiliser might not be visible at the time of harvesting. The initial positive effect fertiliser had on the growth of *E. nitens* seedlings decreased to a non-significant level at six years after planting, even though the fertilised trees were still bigger. Fertilisation of *E. macarthurii* and *E. nitens* had a positive effect on tree straightness and survival when the trees were assessed at five years of age. The fertilised trees had a higher percentage of straight trees, and a lower mortality rate. The fertilisation of *E. macarthurii* seedlings also produced an adequate amount of timber at a relatively low cost. In the case of

*E. nitens* however, the impact of fertilisation on tree growth was not sustainable, and at six years of age was shown to be a relatively expensive operation for the amount of timber produced.

The unsustainability of the initial positive effects of genetic improvement and fertilisation on tree growth could possibly be due to intra-specific competition. Due to limited resources, such as water and nutrients, available to trees for tree growth, the bigger, faster growing trees start to compete with each other. This results in the reduction of growth rates. The slower-growing trees, like the unfertilised and unimproved trees, only reach this level of intra-specific competition at a later stage, which give them the opportunity to catch up with the better performing trees.

The controlling of weeds did not have an impact on tree performance initially or after canopy closure. This is due to the lack of weed growth at these high altitudes at which the sites were planted. Little and Schumann (1996) found that eucalypts could tolerate a aboveground weed biomass of up to 2000 kg $ha^{-1}$ before there were any severe losses in growth due to competition. At both these trial sites, the weed load did not reach these levels in order to compete with the trees. However, at sites with a different weed spectrum the impact of weed control cannot be ignored, and adequate weed control is essential for optimum tree survival and growth. The impact of weed control on *E. macarthurii* and *E. nitens* tree growth was inadequate to produce timber at a relatively low cost.

No significant interactions between any of the treatments were detected at both these sites at any stage. However, interactions could occur under different circumstances, for instance at a site with a more competitive weed load the interaction between weeds and fertiliser could be severe. Fertilisation could encourage weeds to grow, which will result in higher weed control costs.

Adjacent to each one of these trials, four coppice plots were selected and measured from canopy closure until six years of age. These were assessed and measured to investigate the differences, if any, between coppice and seedling in terms of growth, tree straightness and survival. At the last measured date, there were no significant differences in terms of tree growth between the coppice and seedling treatments for either *E. macarthurii* or *E. nitens*. Regeneration by means of *E. macarthurii* and *E. nitens* coppice had a positive effect on tree straightness and survival when the trees were assessed at five years of age. Re-establishment by means of coppice for both *E. macarthurii* and *E. nitens* shown to be by far the most cost-effective way at present to produce an adequate amount of timber. Coppicing was shown to be the least costly way to produce $1 m^2 ha^{-1}$ of timber provided the right species are coppiced, and optimum density levels are obtained.

These trials have been invaluable in terms of providing an understanding about the impacts of different silvicultural practices on the establishment and growth of *E. macarthurii* and *E. nitens.* These trials have also highlighted future research requirements, such as the sustainability of various silvicultural practices on CTE growth, and the determination of wood property differences between CTE seedling and coppice. These trials will be continued by the ICFR and future research for these trials should include: the determination of the impact of different silvicutural practices on the final volume of *E. macarthurii* and *E. nitens*, differences in wood properties at harvesting for the different treatments, and the cost-effectiveness of the different treatments at harvesting when final volumes are available.

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