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Summary of Research into the Establishment and Early Growth Management of *Eucalyptus nitens*.

B. D. Murphy

NZFRI

Report No. 26 August 1996

PROJECT RECORD NO. 5428

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Executive Summary

Commercial plantations of Eucalyptus nitens *have recently been established in New Zealand for the production of pulpwood. The successful biological control of the major pest,* Paropsis charybdis, *opened the way for the species. The impact of the pest was so severe that few trees were planted and hence successful stands and relevant siting information is limited for most regions, and non-existent for others. The renewed interest in* E. nitens *(illustrated by the current planting rates of 4000-6,000 ha per annum) is hindered in particular by the lack of information on this species' establishment and early management practices. For this reason the local and global literature on* E. nitens *was reviewed to firstly identify areas of concern in siting and establishment, and then identify 'best-practice' processes that are considered necessary to ensure successful establishment and attainment of desirable growth rates.*

Several key areas were identified as vital to the success of the establishment of E. nitens, *including provenance selection, site cultivation, fertilisation and in particular, weed control. Although some information is available, much more is required to ensure the species can reach its full potential. Current practices and research results relating to these aspects are examined. Also considered are other areas where the potential of the species may be enhanced by non-standard practices, such as effluent treatment programs and super-fertiliser regimes.*

TABLE OF CONTENTS

1. INTRODUCTION

1.1 Status of Eucalyptus nitens

New Zealand's forestry related industries are increasing their investment in the establishment and management of local hardwood plantations because of an increase in demand for locally produced short fibre pulpwood for use in domestic pulp and paper mills and for export. Currently the main contenders for a suitable hardwood species for pulp or sawlog production are a range of eucalypts. The main species currently being planted is *Eucalyptus nitens* (Deane et Maiden) Maiden (commonly known as Shining Gum in Australia). Very little *E. nitens* has previously been planted and not on the sites currently being planted. Currently the standing area of exotic hardwood plantations is less than 30,000 ha, which accounts for only 2% of total plantation forests (NZ MOF 1995). This includes a eucalypt resource of approximately 20,000 ha but until recently *E. nitens* only occurred in a few trial plots. The main species of choice was *Eucalyptus regnans*, particularly for pulpwood production, but interest has declined due to inconsistent growth patterns, in particular the variation of growth at the microsite level. Research is continuing in an attempt to determine the factors responsible.

E. nitens is renowned for its juvenile growth vigour and resistance to low temperatures, frosts and even episodic snows. Despite these attributes it was not considered suitable for use in forestry in New Zealand because it was often severely defoliated by the exotic insect pest *Paropsis charybdis* (Miller *et al* 1992). This insect pest has been dramatically reduced in numbers by a biological control agent with the result that *E. nitens* is now planted on a commercial scale of about 4000 ha per year.

There has been variable success in establishment, highlighting the sensitivity of the species to siting and establishment practices. It is well known that eucalypts are sensitive to establishment techniques and in order to assist forest managers it is desirable to summarise all existing information and identify key factors that should be considered in determining management practices and research programmes.

Eucalyptus nitens is capable of outstanding growth under optimal conditions. Mature trees often attain heights of up to 70 m in Australia, while annual height increments of juvenile trees can reach 2 m on good sites (Turnbull & Pryor 1984). Most encouragement for the species comes from the outputs of volume production, where common figures for annual increment are in the order of 35-40 m^3 ha^{-1}, with standing volumes of 300-350 m^3 ha^{-1} attainable in 10 years. This excellent growth vigour translates into short rotations (8-12 years) when planted under pulp regimes.

Recent interest in the species in New Zealand has coincided with reports of successful plantations in Chile, South Africa and Australia. Other countries such as Argentina, Brazil, China, Colombia, Sri Lanka and the United States (California), are also examining the potential of this and other eucalypt species.

The species is being considered for a wide range of other applications. Researcher Garry Waugh, CSIRO, Victoria, Australia has indicated that the species is performing well in processing trials for sawn timber production and is also likely to be suitable for veneer (E. Hay *pers comm*). Many small plantation growers of the species utilise it as a fast rotation firewood crop (Parker 1986). Waste treatment trials have been undertaken and the species is being successfully used in at least one small New Zealand land waste disposal scheme (H. McKenzie *per comm*). *Eucalyptus nitens* can be coppiced which may be an advantage for a second rotation (Oliver 1991).

Eucalyptus nitens has often been associated with a variant, that of trees from the Errinundra provenance, but it has now been recognised that they are separate species (Cook & Ladiges 1991). Note that although Errinundra provenance is now officially referred to as *E. denticulata*, the current practice is to still refer to it as a provenance of *E. nitens* and this convention is maintained in this report. *Eucalyptus nitens* belongs to the group of southern blue gums, but as its timber qualities are so similar to those of the ash species it is often referred to as an ash by the timber industries in Australia (Miller *et al* 1992).

1.2 Scope of this Report

This report is a summary of available literature on *E. nitens* that is relevant to eucalypt establishment in New Zealand. The Management of Eucalypts Cooperative requested a literature survey and review to assist in decision making and also to provide a background document for planning the research programme.

This report is divided into 11 main sections. Following the introduction, section two covers the species natural growth habits highlighting attributes that will affect *E. nitens'* success on different sites.

Section three deals briefly with what is known of the pulp and wood qualities, while section four covers the growth habits and nutritional requirements of *E. nitens*. Section five outlines results of *E. nitens* plantings in countries that have achieved success with the species and intend to expand this resource. This provides some idea of the levels of productivity of *E. nitens* in plantations.

The sixth section deals with the New Zealand planted *E. nitens* stands and plantations, provenance and regime trials. After examining the major influence the insect pest *Paropsis* has had on local *E. nitens* plantations, and the advent of a successful biological control, the next section contains a summary of current plantings by New Zealand forestry companies.

Section eight is a literature review of *E. nitens* research from around the world, and in particular from countries such as Australia, Chile and South Africa, which have significant relevant experience with eucalypt plantations. Results from New Zealand trials are compared where appropriate. Topics examined are those which affect establishment and continued growth of *E. nitens*, such as site cultivation, fertilisation and weed control.

The ninth chapter begins with a discussion and examination of the information contained in the previous sections. Emphasis is placed on the valuable ideas we can gain from overseas experiences, and how these can be turned into 'best practices' that will promote successful establishment of *E. nitens*, and subsequent vigorous growth.

The penultimate section concludes the discussion with points on 'best practices' and highlights possible areas of concern that will need further investigation in order to maximise the potential of *E. nitens*.

2. OCCURRENCE OF *EUCALYPTUS NITENS*

2.1 Natural Distribution

Eucalyptus nitens is found in discontinuous populations from regions of northern New South Wales to the mountain forests of south eastern Victoria, with a latitudinal range of 30-38°S (Turnbull & Pryor 1984). Generally the species exists in small scattered stands, in association with wet sclerophyllous forests, between forests of *E. regnans* and *E. delegatensis* (FAO 1976). The natural altitudinal range is recorded as between 800-1300 m but stands have been found from 1600 m in NSW to 640 m in Victoria (Cook & Ladiges 1991). Miller *et al* (1992) suggest the best stands are found between 1000 and 1300 m on undulating plateaux on either side of the Great Dividing Range in Victoria and along the Victoria - New South Wales border. Presumably the natural occurring range of the species can be extended for plantation purposes, as plantation management practices enhance the range via suppression of plant competition, improved nutrition, etc.

The largest naturally existing stand is located on the Errinundra Plateau in East Gippsland. Specimens from this site regularly reach heights of 70 m and measure over 2 m diameter at breast height (Cook & Ladiges 1991).

Eucalyptus nitens enjoys a cool, mild climate with summers that only rarely achieve very high temperatures. Mean temperatures of the hottest months are 21-24° C, and the mean minimum of the coldest month is -3 to 2° C. Winter temperatures can be as low as -12° C. *Eucalyptus nitens* has outstanding abilities to withstand frost, encountering between 50-150 frosts per year, and in some areas snowfall can also occur. On the other hand, *E. nitens* is sensitive to hot, dry winds and suffers under drought conditions (Turnbull & Pryor 1984).

Desired rainfall is 750-1750 mm per annum, with natural rainfall distribution heaviest in summer for NSW and in winter for Victoria (Miller *et al* 1992). This imposes limitations as to which provenances succeed best in differing locations around their world, as they will grow best where the maximal rainfall period closely resembles that of their natural range.

2.2 Provenances of Eucalyptus nitens.

The *E. nitens* provenances are located in three principal regions, central Victorian highlands, southern New South Wales and northern New South Wales. Six main provenances have been identified (Appendix 1), and within each provenance seedlots are identified by locality (Appendix 2). Breeding programmes identify variation in families (seedlings grown from seed collected from one parent) from each locality as a starting point for identifying heritable traits for breeding. Thus any provenance trial for commercially important species must evaluate performance of not only the individual provenances, but the families within them.

2.3 Soils

The most common soil types where *E. nitens* occurs naturally are moderately fertile moist loams, over a clay subsoil (Turnbull & Pryor 1984). The species also occurs on soils derived from basalt, granite, schist, shale, and sandstone, but best growth is reported on deep, rich loamy soils over clay (Miller *et al* 1992).

3. WOOD AND PULPING PROPERTIES OF *E. NITENS*

3.1 Pulp and Basic Density

Although one of the lighter eucalypt timbers, *E. nitens* has performed well in various pulping trials. Basic densities have been recorded as between 450-610 kg m^{-3} (Turnbull & Pryor 1984). In a sawlog study of 20 year old Australian *E. nitens*, McKimm *et al* (1988) reported that the basic density was 488±7 kg m^{-3}. This was reputedly 6% higher than that reported for 8.5 year old *E. nitens* and 10% lower than in mature trees, as reported in other studies. There exists conflicting evidence within the literature as to whether density is variable between provenances, but it does appear to be influenced by growth rates. There are considerable differences in density between the sapwood and the heartwood (McKimm 1985) and also with increasing height of the tree (Purnell 1988). This suggests that any measurements of density must take into account the part of the tree sampled, and must be consistent between different trees measured.

In South Africa, van Wyk and Gerischer (1994) compared eight eucalypt species for pulp qualities against a known excellent source of pulp, *E. grandis*. *Eucalyptus nitens* performed very well, with excellent strength development during beating, had low percentage of rejected material, and acceptable scores for burst, tear and breaking length.

A density study of 8.5 year old *E. nitens* done by McKimm and Ilic (1987) shows an average basic density of 480 kg m^{-3} with variation between the provenances of up to 48 kg m^{-3} between the densest and lightest averages (Table 1). Analysis of the basic density and growth rates in the range of provenances found that the Western and Errinundra provenances were the fastest and slowest growing respectively, and this growth rate may have a strong negative correlation with density, as the Western provenances (Central Highlands of Victoria & Northern N.S.W.) had the lowest average basic density, while Erinunderra had the highest. Average fibre length does appear to differ between the provenances.

Table 1. Mean growth, basic density and fibre length for 8.5 year old *E. nitens* in Australia.

Provenance		Mean DBH	Mean MTH	Basic Density	Fibre Length
		(cm)	(m)	(kg m^{-3})	(mm)
Western	(VIC)	31.7	26.6	454	0.82
Errinundra		25.4	23.2	502	0.53
South N.S.W.	(NSW)	26.9	24.9	470	0.51
Barrington Tops	(NSW)	29.0	25.2	481	0.58
Mt Ebor	(NSW)	29.2	27.1	491	0.79

Purnell (1988) measured an 11 year old South African provenance trial for basic density and other wood properties (Table 2). It was found that moisture content and density showed strong negative correlations over the length of the tree, and that there exists large between and within-tree variations in many wood properties.

Table 2. Mean growth, basic density and moisture content of 11 year old *E. nitens* in South Africa.

Provenance		Mean DBH (cm)	Mean MTH (m)	Basic Density ($kg\ m^{-3}$)	Moisture Content (%)
Barrington Tops	(NSW)	23.6	22.5	534	106
Nimmitabel I	(NSW)	25.1	23.6	480	123
Nimmitabel II	(NSW)	23.1	22.9	499	115
Braidwood	(NSW)	21.8	21.5	553	97
Nelshoogte	(RSA)	23.3	23.3	497	113

Williams *et al* (1995) compared 8 year-old *E. nitens* with *E. globulus* on four sites on an altitudinal transect from 60 to 650 m. Two provenances were included for each species. For *E. nitens* these were Upper Toroongo and Errinundra There were significant differences in pulp yield with the lowest sites being best. Upper Toroongo was significantly better than Errinundra. Pulpwood productivity (a measure of oven dry pulp produced from a unit of wood volume) was highest at lower altitudes and for mechanical pulp, energy requirements decreased with decreasing altitude. Kraft papermaking properties varied considerably between trees. Except at frost-free sites the Toroongo provenance of *E. nitens* was expected to give the best production of pulp.

3.2 Wood Properties

Eucalyptus nitens solidwood timber is non-durable and prone to shrinkage, but will respond to reconditioning. It is typically described as suitable for general building construction, i.e. flooring, panelling and joinery (Hall, Johnston & Marryatt 1963).

4. GROWTH HABITS AND NUTRITION OF *E. NITENS*

4.1 Juvenile Growth and Leaf Area Index

The dramatic early growth rate of *E. nitens* is derived from the juvenile leaves and the high Leaf Area Index (LAI) attained at an early age. In a study of LAI related to stand growth in Tasmania, Beadle and Mummery (1990) found that the Toorongo provenance specimens have a "juvenile-persistent" habit, while the Errinundra trees exhibited an "early-adult" tendency. This suggests that Toorongo provenance typically delay morphological development of their adult form leaves. Consequently the Toorongo plants had a faster rate of development of LAI and correspondingly higher growth rate than the other provenances. The authors believe that the encouragement of the rapid development of leaf area, resulting in early canopy closure should lead to maximum productivity for this early stage of the rotation. This increases the amount of solar radiation intercepted, and should also lead to suppression of understorey weed competition.

Unsure as to whether this difference in growth rates will be maintained and persist over the lifetime of the plants, the authors concluded that the experience of plantations in south-east Australia has shown that the growth rates obtained by "juvenile-persistent" forms still outperform the "early-adult" forms at age 12 years. This fits well with current practices in New Zealand where stands for pulping will be typically harvested at 10-12 years.

Results from the investigation showed that in the four trials used, Tooronga provenance plots had an average standing volume at age 5 years of 91 m^3 ha^{-1} compared to only 51 m^3 ha^{-1} for Errinundra stands. This correlated with LAIs of 5.0-5.9 and 4.0-4.2 and maximum volume increments of 40 and 25 m^3 ha^{-1} at age 4 years for the two respective provenances. Also of note was the decline of both LAI and standing volume with increasing altitude, with the four trials planted at 60, 240, 440 and 650 m above sea level. There is also a suggestion that, in the absence of water stress, the growth of eucalypts is strongly correlated to the mean maximum air temperature. Results from this trial showed that there was a 5° C difference in mean temperature between the lowest and highest elevation.

4.2 Nutrients and Foliar Critical Levels

The addition of fertilisers to a stand of eucalypts, although increasing the growth rates, may also lower the foliar concentrations of nutrients to levels below those of unfertilised trees (Cromer *et al* 1981). It has been suggested that excellent soil nutrition leads to rapid foliage growth, causing a 'dilution effect', where the leaves expand so quickly that nutrient percentages are reduced. Therefore the appearance of low foliar nutrient levels may not necessarily be indicative of nutritional deficiencies, particularly if the site is ex-pasture or has a known fertilised history. Knowledge of the critical foliar levels for nutrients may assist in this diagnosis. Similarly, there is a school of thought which suggests that eucalypts under some form of 'stress' respond by increasing foliar levels of nutrients such as N, which may again give an inaccurate indication as to the health of the tree.

Leaf position, age of leaves, and season of sampling can all influence the levels of foliar nutrients, and so any sampling of leaves must be standardised (time of year, position of leaves on crown) so that less variability is induced into the data. Awareness of the nutritional differences between adult and juvenile foliage is also important when sampling, as a mixture of leaf types will yield results that cannot be interpreted usefully.

The nutrient content of both juvenile and mature foliage from four year old stands of *E. nitens* and *E. fastigata* growing in the Bay of Plenty, NZ (Madgwick *et al* 1981) were determined. Unable to find any literature on the subject they concluded that foliar concentrations of nitrogen and phosphorus are similar to those found in 4 year old *E. globulus*, although lower than levels found in species grown in nutrient cultures. The investigation of copper deficiency in *E. nitens* by Turnbull *et al* (1994a) also documented foliage nutrient levels, albeit for trees less than 2 years old (Table 3).

Table 3. Average foliar nutrient concentrations for *E. nitens*.

Leaf Type	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
Juvenile[a]	1.34	0.08	0.87	1.06	0.22
Mature[a]	2.04	0.13	0.91	0.72	0.19
Juvenile[b]	1.60	0.13	0.55	0.33	0.09

Source: a = Madgwick *et al* (1981) b = Turnbull *et al* (1994a)

The Tasmanian foliage levels show higher levels of N and P than the juvenile foliage of the local study, yet significantly lower levels of K, Ca and Mg. This may be related to the site and treatment that consisted of improved ex-pasture and fertiliser additions, suggesting a lowering of apparent foliar levels as mentioned by Cromer *et al* above.

It can also be seen that at the time of canopy closure, when the juvenile leaves are replaced by the adult form, an increase in uptake of N and P is essential as these levels are higher in the adult leaves. This might suggest that additional increments to the LAI could be gained if N and P were applied around the time when the foliage type transition begins. Foliage testing could be taken at some pre-determined time within a few years of establishment, in order to determine the variation due to soil fertility. This may enable compensatory fertiliser dosages to be administered when foliar nutrient levels are low, possibly indicating a nutrient deficiency, before growth is seriously affected. Unusual colouring of leaves can also be indicative of nutrient deficiencies in Eucalypt species (Appendix 3).

Cromer *et al* (1981) found a relationship between fertiliser response and the ratio of nitrogen to phosphorus in the foliage of *E. globulus*. A comparison of *E. nitens* and *E. globulus* is valid because the two species are closely related taxonomically. On sites that responded best to additions of phosphorus, the unfertilised control trees had a high N:P ratio (17.6 and 19.1). This ratio was reduced by each treatment that included phosphorus.

At the one site where the best growth response was to nitrogen, the N:P ratio was considerably lower for the unfertilised trees (13.6) and this increased when N alone was added. It is possible that a similar optimum ratio could be found for *E. nitens*, where a N:P ratio could be a better indicator of the site fertility than analysing foliage samples for all nutrients. The N:P ratio would need to be determined from unfertilised trees in the stand, and so these randomly placed trees would need to be allocated at planting in order that they received no additional fertiliser. Analysis of these 'nutrient control' trees could identify if stands on individual sites would respond best to addition of either N or P, so that excess fertiliser is not wasted on a stand to stand basis.

Cromer *et al* (1981) also postulate that there may be an optimum N:P ratio for maximal growth of eucalypt species. Their research indicates that for *E. globulus* and *E. sieberi* this ratio is about 15, compared with *P. radiata* that has an optimum ratio of 10. Research to ascertain the optimum N:P ratio for *E. nitens* may allow for development of useful management practices of stands of this species: in combination with the N:P ratios taken from the unfertilised trees mentioned above, forest managers could create stands that are nutritionally at least, operating at maximum potential.

It is interesting to note the study by Turnbull *et al* (1994a) in which copper deficiency was determined to be the major cause of stem deformity in a crop of *E. nitens*. The site was on improved pasture in Tasmania, which had a history of fertiliser applications before its conversion to forestry. In a fertiliser trial with additions of nitrogen and phosphorus, some dosages resulted in severe malformation of the stems and branches within 18 months of planting. Foliar investigation showed that with increasing levels of nitrogen and phosphorus, uptake of copper was reduced, leading to severe copper deficiency. The authors recommended that, "Until the cause of the syndrome is established, eucalypt plantation managers would be well advised to avoid the use of fertilisers on sites with a significant history of fertilisation."

Whether or not these symptoms are likely to occur in New Zealand remains open to speculation, as factors such as soil types, previous history of cultivation and fertilisation of sites chosen are variable. It is however becoming obvious that the 'typical' *E. nitens* site in New Zealand is ex-pasture and at least moderately fertile. Turnbull *et al* (1994a) have noted other occasions where Cu deficiency has occurred with eucalypts, but references in the literature are scarce.

4.3 Frost Resistance

Variation of frost resistance in *E. nitens* associated with seed source and altitude is well documented. Ability to resist frost is seasonal in nature; *Eucalyptus nitens* stands that can resist severe frosts in winter may then be destroyed by mild frosts in summer months. The vital component of development of superior frost resistance is the ability of the species to harden-off (acclimate), a metabolic process where greater resistance is gained by exposures to lower temperatures and or shorter day lengths (Salisbury & Ross 1992). For *E. nitens* this is estimated to occur at about 0.4° C week $^{-1}$, i.e. every week the maximum tolerable frost by a tree increases by 0.4° C, providing night temperatures are low enough to allow this process to occur (Tibbits & Reid 1987a).

Using a range of artificial-frost and field experiments in Tasmania, Tibbits and Reid (1987b) found that there was a consistent separation of two groups of provenances that displayed significantly different levels of frost resistance. The Western provenances (Central Highlands of Victoria & Northern N.S.W.) exhibited frost tolerance higher than those seedlots from Southern N.S.W. and Errinundra provenances. Individual families could be hardened below -10° C, with a range of 2.3° C between the best and the worst families. Examination of the seasonal changes of frost hardiness between summer and winter were from 4.7 to 7.0° C for all the provenances. This would explain the summer mortality rates when even mild frosts occur, as the trees have dehardened and are therefore more susceptible to frost. In New Zealand damage is most likely to occur in late spring or early autumn when trees are not fully hardened (H. McKenzie *pers comm*).

Evaluation of commercial eucalypt species for frost resistance at different elevations in Tasmania confirmed the suitability of *E. nitens* for harsh sites (Hallam *et al* 1989). At altitudes of 60, 240, 440 and 650 m, *E. nitens* and *E. delegatensis* were ranked for their frost hardiness above 5 other species, with *E. regnans* exhibiting the poorest performance. The superiority of *E. nitens* above *E. delegatensis* lay in its greater growth in diameter and height up to the age of two years at least. This difference increased with altitude.

Even though the 60 m site was a frost prone hollow, *E. nitens* exhibited good growth, which is a desirable trait for any plantation species. Hallam *et al* suggested that it may be possible to select provenance or families from frost hollows at low altitude, as these trees could combine excellent growth rates with good frost hardiness. Trees from high altitude may display similar frost resistance qualities, but exhibit poorer growth rates.

5. PLANTATIONS OF THE WORLD

5.1 Australia

The last few decades have seen upheavals in the management of the eucalypt forestry estate due to conservation and ecological pressures. The result is a movement towards plantation management of eucalypts rather than the harvesting of existing natural stands. Tibbits (1986) found that *E. globulus* spp. *globulus* and *E. nitens* both accounted for 32% of the then 11,400 ha planted in Tasmania. These two species had shown significantly superior early growth response compared to 24 other trialed eucalypt species. Plantations were being established on clearfallen or poorly regenerating land, as well as on former agricultural sites. Planting rates of *E. nitens* relative to *E. globulus* were increasing due to its superior frost resistance, comparable growth rate even at altitudes less than 300 m and good performances in pulping trials.

By 1993 the total area of planted eucalypts was in the order of 125,000 ha, and was increasing by some 14,000 hectares annually (Cromer & Turnbull 1994). Most of the planted area was in NSW, Victoria, Western Australia and Tasmania; Queensland and South Australia only accounted for 5% of this area (Tibbits 1986).

Provenance trials in Tasmania established to assess species suitable for intensive management identified *E. nitens* as the most successful species on all sites covered. At 4 years of age some stands had a standing volume of 47 m^3 ha^{-1} (Turnbull *et al* 1988). Volker and Raymond (1989) found that although *E. nitens* is not native to Tasmania, it has proved to be ideally suited to the colder, higher forest areas and is the most widely planted eucalypt in plantations.

5.2 Chile

The increase in eucalypt plantations in Chile has undertaken a dramatic upturn in the last few decades, with *E. globulus* the main species (75% of eucalypts currently planted), and *E. nitens* planted predominantly in the colder areas. Planting of all eucalypt species rose to 45,000 ha per annum in 1992, leading to an estimated total 170,000 ha of eucalypt plantations (Jayawickrama *et al* 1993).

Eucalyptus nitens has been very successful in trials and operational plantings, growing in areas with frequent snowfalls and temperatures down to -12° C. Recognition of its rapid growth, adaptability to different sites and desirable pulping qualities has led to wide scale plantings. Problems include the high cost of seed imported from Australia (US$5,000/kg of seed) and a suite of pests and pathogens, although none appear as wide spread or lethal as *Paropsis*. Lack or inadequacy of mycorrhiza has been suggested as a reason for the dramatic responses of eucalypts to fertiliser applications. Another problem is that the majority of suitable land is privately owned, so forestry companies are forced to buy pasture or farmland at prices up to US$2,200 per hectare (Jayawickrama *et al* 1993).

Crop sowing and forest harvesting are becoming increasingly automated. The Chilean forestry industry has recognised the value of good site preparation for eucalyptus species, with heavy use of subsoiling, cultivation and weed control. The authors suggest that, as in other parts of the world, the results more than pay for the expense.

Eucalyptus nitens growth rates are estimated at 40 m^3 ha^{-1} per year on the best sites. Rotations of 8 to 10 years will be used for pulpwood production, without thinning, leading to an expected total volume of 300-350 m^3 ha^{-1}. Solidwood rotations are up to 30 years, with fuelwood rotations of 12-20 years for first rotation, and then 8-10 years from the coppiced stumps (Jayawickrama *et al* 1993). Coppicing appears to be a common practice in Chile for second generation eucalypt crops, although the coppice is not always vigorous. Around 80% success rate for coppicing can be achieved for *E. nitens*, and this may be improved if care is taken to ensure that a stump of 20-25 cm height is left after felling (Prado *et al* 1990).

5.3 South Africa

Eucalyptus nitens is desirable for South African sites that experience severe frost and enjoy an ample rainfall, although its distribution has been hampered in the past by lack of available seed. Trees are grown for mining timber and pulpwood. Drying difficulties mean it has not been recommended for sawn timber or poles.

Introduced in 1926, provenance trials and spasmodic plantings since that time, have indicated that NSW provenances suit local conditions better than any others. This is probably related to the summer maximum rainfall that occurs. Plantings have been on a wide variety of soils with very mixed results, from good growth and form to irregular performance, heavy branching and forking (Poynton 1979).

The maximum summer temperature ranged from 27 to 32° C, with a winter maximum of 16 to 32° C at a provenance trial at Jessievale in the Eastern Transvaal Highveld (Purnell & Lunquist 1986). These are above the suggested maximum temperatures of Turnbull and Pryor (1984), and give some indication that *E. nitens* can be planted outside its naturally occurring range of temperatures, providing rainfall is sufficient.

By 1983 there was over 7,200 ha of the species planted in S.A. This was mostly on the eastern Transvaal Highveld (Richardson & McMahon 1992) where it is usually grown on 8-12 year rotations (Purnell 1988).

6. *EUCALYPTUS NITENS* IN NEW ZEALAND

6.1 History in New Zealand

Eucalyptus nitens was first introduced into New Zealand in 1920, but very few plantings were carried out before the 1970s. A series of eucalypt trials were then established by the Forest Research Institute and NZ Forest Products Ltd. involving around 20 species. Measurements of the trials in the first 3-4 years showed that *E. nitens* had the largest mean height, but then subsequent *Paropsis* defoliation of North Island stands as the adult foliage developed severely stunted the growth of the trees. Consequently other species were recommended for eucalypt hardwood forestry plantations ahead of *E. nitens*. Despite the discouragement of the New Zealand Forest Service, NZ Forest Products continued its involvement by planting over 300 ha of *E. nitens* in mixture with *P. radiata* in the Bay of Plenty region between 1976 and 1981 (Miller *et al* 1992).

The potential worth of the species led Forest Health group at FRI to continually investigate the possibility of biological control using natural parasites of *Paropsis*; several insects were trialed before a suitable candidate was found. With the advent of successful biological control for *Paropsis* in the early 90s the way was clear for increased industry planting of the species.

6.2 Siting

In New Zealand *E. nitens* should do well on moist, well drained soils where annual precipitation exceeds 800 mm. However it can not tolerate waterlogging or drought. The rooting system establishes to an effective depth of at least 60 cm, and this is aided by planting on soils with an established 'A' horizon. These types of soils exist over sedimentary rocks in Southland, pumice or volcanic ash in central North Island, or basalt in Northland. Soils that overlie glacial till can be suitable if rainfall is sufficient (Miller *et al* 1992).

Miller *et al* (1992) suggest that *E. nitens* has grown without evidence of reduction of growth due to altitude, at heights of 400-900 m in the North Island, and from sea level to 700 m in the South Island (despite what Australian reports suggest). Environment can play a part in the success of the species, however, with fungi and other pathogens becoming more important on warmer, more humid sites at low altitude. Hollows and areas with poor wind circulation should be avoided when other conditions become extreme (i.e. high altitude), and aspect can also play a role in avoidance of frosts in winter periods. At higher elevations, Miller *et al* suggest planting on the warmer north facing slopes.

In 1975 a trial examining the early growth of *E. nitens*, *E. fastigata*, *E. delegatensis* and *E. regnans* on five different site types was established 2 km to the west of Lake Taupo, at an altitude of 550 m (Moberly & Walter 1977). The trial was an attempt to measure survival and growth on sites defined as rolling terrain, concave, convex, ripped and frost flat. The ripped site was considered very poor, being described as bony; the shallow nature of the soils preventing cultivation to any substantial depth. Trees were planted in groups of 20, with each species contributing a row of 5 trees.

The first assessment two years later showed that on the first four microsites survival was over 90% for all species although some *E. nitens* had suffered severe damage due to deer browsing. On the frost flats however, only *E. nitens* showed satisfactory survival with 90% survival: the other species managed between 48-78%. The frost that caused the damage was reported as between -6 and -6.8° C. The authors noted that *E. nitens* was most tolerant of the wide range of sites and conditions, and that it appeared to be the healthiest species across the 49 plots.

The effect of site on growth can be seen in Table 4. From this table several conclusions can be made. Frost flats, although tolerated by *E. nitens* as far as survival rates are measured, are poor sites for the growth of the species.

Rolling, concave and convex sites appear to be the best sites, with trees on average increasing their heights by 1 m per year.

Table 4. Heights and height increment for *E. nitens* at age 2 years on different microsites

Microsite	Mean Height at Planting (cm)	Mean Height 15.6.76 (cm)	Mean Height 6.10.77 (cm)	Height Increment: Two Years (cm)
Rolling	68	156	278	210
Concave	61	152	276	215
Convex	68	133	267	199
Ripped	66	132	247	181
Frost Flat	69	113	220	151

Seventeen eucalypt species were planted on three different sites, all characterised by pumice soils, in an attempt to provide reliable information on species suitability for the sites (Johnson & Wilcox 1989). The *E. nitens* were severely affected by defoliation as a result of *Mycosphaerella* infection (completely removing juvenile leaves) and subsequent attack by *Paropsis*, which removed the adult leaves. The authors concluded that *E. nitens* began well on all three sites (Rotoehu, Waiotapu and Matea) before the pest attacks, and that it would become one of the favoured species if *Paropsis* could be controlled. They noted several *E. nitens* stands on pumiceland that exhibited good vigour and minimal *Paropsis* infestation.

The increased area being planted in *E. nitens* has already led to stands exhibiting what appears to be site related problems (C. Wilson *pers comm*: Author *pers obs*), and although apparently not considered as severe as exhibited by *E. regnans*, any factors causing a reduction in yield need to be investigated. Variation in growth has occurred on some aspect and slope combinations, although the knowledge and evidence is too preliminary to give useful indications as to which site factors to avoid.

6.3 Shifting Climatic Conditions.

A recent climatic study of growth of *E. regnans* in the Bay of Plenty region alluded to the fact that the region's rainfall was, historically, uniformly distributed throughout the year (Murphy 1996). This suggested that over given periods of time, winter rainfall maxima were occurring, which then shifted to summer maxima for a period. Implications of this are that although Victorian provenances are suited to the winter maxima conditions which are regarded as the norm for that region, any change in rainfall patterns towards summer maxima might mean that the climate would be better suited for the NSW provenances. It might not be entirely unexpected to see in the future that the groups of best/worst provenances may change slightly, according to prevailing climatic conditions. Sites that are located below latitude 45° South (such as the Invercargill region) may also be affected, as this has been suggested as a region of consistent summer maxima (Ashby 1995).

6.4 Health of E. nitens *in New Zealand*

6.4.1 Impact of Paropsis

The announcement of successful biological control of *Paropsis* by the NZ Forestry Research Institute in 1990 led to renewed interest in *E. nitens* as a short fibre hardwood species and re-establishment of plantings, particularly by members of the Management of Eucalypts Cooperative. Miller *et al* (1992) also suggests that interest in the species for farms, shelterbelts and firewood had ensured rapid sales: nursery sales for the South Island alone were 750,000 trees in 1990.

The New Zealand Forest Research Institute has been involved in attempting to find a suitable biological control of *P. charybdis* since the 1960s. Early attempts at introducing a natural parasitic braconid wasp *Aridelus* were aborted when it was found that the specimens were heavily hyperparasitised (i.e. when the parasite itself is parasitised) (Styles 1970), as was another consignment offered to FRI 10 years later (Kay 1990).

Concurrently FRI had received a consignment of several thousand pupae of the tachinid fly *Frogattimyia tillyardi*, known to be an egg parasite of the *Paropsine* family. Exposure of the adult flies to *P. charybdis* larvae resulted in only three first generation tachinid offspring, hardly sufficient to warrant a innundative field release. The second such consignment of *F. tillyardi* in 1974-75 suffered the same failure. Therefore FRI resolved to release the handful of laboratory breed flies and those adults hatched form the egg consignment in a eucalypt stand south of Tokoroa. The flies had not been found to establish when the stand was later monitored.

The next attempt to find a control agent was a ladybird, *Cleobora mellyi*, the first batch arriving form Tasmania in 1977. Hatching larvae were feed eggs and small larvae of *P. charybdis*, and 20 adult beetles were raised. This raised hopes for the species as a potential control, and following several more importations of batches, and improvements in rearing techniques, over 3000 adult *C. mellyi* were released in Tokoroa near eucalypt plantations. Subsequent releases were made in Rotoehu and Whakarewarewa Forests, and in the Christchurch and Marlborough Sound regions. Although known to have established in some areas, its impact on populations of *P. charybdis* is unknown.

Pteromalid wasps comprised the next attempt, and two species, *Neopolycystus insectifurax and Enoggera nassaui*, were imported in 1987 from Perth in Australia. Both species parasitise the eggs of *P. charybdis*, and were so suitable that field releases of both species were made in Nelson, Canterbury, Southland, Waikato and the Bay of Plenty in the summer of 1987/88. Unfortunately *N. insectifurax* could not be located after release and was deemed unsuccessful. However *E. nassaui* was apparently established the following year, and had been observed ovipositing in *P. charybdis* eggs in a number of localities, so it appeared finally the search for a biological control of the tortoise beetle was over (Kay 1990).

Reasons for the success of *Enoggera* as a biological control agent include, its short life cycle (produces more generations per season than *Paropsis*), hatching of both species synchronised by similar temperature thresholds, and a high female to male ratio that ensures the females are always in abundance to lay eggs (Kay 1990).

6.4.2 Other Pathogens of Eucalyptus nitens

Although biological control of *Paropsis* has reduced its effect under most circumstances, considerable damage may still occur to *E. nitens* due to infection by a range of leaf spot organisms. In particular the fungi *Mycosphaerella cryptica* and *M. nubilosa* can cause damage to *E. nitens* and other eucalypt species, leading to loss of form, dieback of shoots and multi-leadered trees (Dick & Gadgil 1983). Moist sites seem to be most favourable for infection, especially when combined with temperatures of 18-24° C (Dick 1982). Miller *et al* (1992) suggest that generally the older or suppressed leaves are most commonly affected by these fungi, and are thus not contributing seriously to tree health problems, but that in warmer parts of New Zealand these fungi pose considerable risk in years of high summer rainfall.

A South African provenance study first suspected that the inferior growth of some Victorian seedlots could be attributed to high susceptibility to leaf spots caused by *Mycosphaerella* (Darrow 1984). This was followed by more research into the resistance of different *E. nitens* provenances, and determined that NSW provenances were superior in resistance to the pathogen than provenances from Victoria (Lundquist & Purnell 1987). When the 11 provenances were ranked on their defoliation scores and percentage of leaf spot, the 7 NSW provenances were all above those from Victoria. Of importance was the fact that when over 20-25% of the crown was defoliated, growth rates were negatively affected.

One hypothesis from the study was that the *Mycosphaerella* may be affecting the Victorian varieties more severely because of their tendency to maintain their juvenile leaves longer. Purnell and Lundquist (1986) believe that the only practical method of control is to select and breed for disease resistance. Dungey *et al* (1995) have examined the genetic component of *Mycosphaerella* resistance in *E. nitens*, *E. globulus* and their F_1 hybrid. The hybrid showed an increased susceptibility to the fungi, suggesting that with the correct breeding program, expression of resistance factors can be increased.

One conclusion from these two sites suggests that NSW provenances have performed superior to the Victorian provenances due to the fact that although the annual rainfall is within the normal range for *E. nitens* (830 mm for Elandshoogte, 905 mm for Jessievale), both sites received the bulk of precipitation in summer. This has already been shown to be a typical climatic trait of the NSW area (Miller *et al* 1992), and we could therefore expect these conditions to suit NSW provenances more than those from Victoria.

Also of concern in New Zealand is the leaf spot fungi, *Septoria pulcherrima*, which has been seen to cause severe defoliation to *E. nitens* in some areas. There appears to be no control for this problem (Dick & Gadgil 1983).

Among the other defoliators of *E. nitens* are the leaf rolling caterpillars of the moths *Strepsicrates macropetana* and *Ctenopseustis obliquana*, which cause localised damage, and several *psyllids* and scales that can appear prominent without causing significant damage to the species (Miller *et al* 1992). As is noted on several occasions in this document, browsing animals such as deer, possums, wallabies and rabbits find *E. nitens* especially palatable, and may pose considerable risk to newly established stands. One method attempted to deter possums was to plant an 'unpalatable' species, *E. fastigata*, between the possum source of infestation and an *E. nitens* stand (B. Poole *pers comm*), unfortunately this did not work and both species were rapidly chewed to a standstill.

6.5 E. nitens *in FRI trials*

6.5.1 Nelder Trial

Results from a Nelder trial established in 1979 in Kaingaroa Forest were first analysed by McKenzie and Kimberley (1990) at age 11 years, and then again at age 16 (McKenzie & Kimberley 1995). Complete measurements of the stand were not undertaken due to the expected effect of *Paropsis.* However alternating arcs of the nelder were measured each year.

Mean top heights for most of the arcs in the stand were about 26 m by age 11 years. The average height growth tapered off at age 8, possibly the effect of a *Paropsis* attack. Measurements over the next few years have shown an increase in height growth, which may be related to reduced defoliation by *Paropsis* because of *Enoggera* presence. Heights, when measured 5 years after the first analysis, had improved to between 28.8-32 m across the stocking range. The basal area at 1111 spha was 25.5 m^2 ha^{-1} in the first analysis, and had risen to 31.9 m^2 ha^{-1} at age 16.

At age 11 years, the volumes had reached between 56 and 295 m^3 ha^{-1} for initial stockings of 93 to 3383 spha. At 16 years these volumes ranged from 117 to 362 m^3 ha^{-1}, and the mean annual increment (MAI) at this age was from 7.3 to 22.6 m^3 ha^{-1} $year^{-1}$.

At the same time that the mean heights tapered off due to a suspected *Paropsis* attack, the current annual increment (CAI) levels dropped dramatically from age 11 to 12. For example at stockings of 1111 spha, CAI dropped from 23.9 to 7.8 m^3 ha^{-1} in that one year period. Fortunately they began to rise again and by age 16 the CAI was up to 20 m^3 ha^{-1} (McKenzie & Kimberley 1995). The reason(s) for the drop in CAI could not be determined (H. McKenzie *pers comm*).

There are 30 Permanent Sample Plots (PSP) mainly established in provenance trials in the South Island. Growth in the Nelder was similar to that in the PSPs, indicating that the Nelder represented typical growth for *E. nitens* in New Zealand (H. McKenzie *pers comm*).

6.6 Provenance Trials in New Zealand

The first provenance trial in New Zealand was carried out in the mid 1970s at three sites located near Westport in the South Island. Seedlots from 18 families representing the 6 major provenances were established. The first trial at Fletchers creek established that the central Victorian provenances, Macalister, Toorongo and Rubicon were superior to NSW provenances and that Errinundra seedlots were the slowest performing, as shown in Table 5 (Franklin 1980). Central Victorian provenances increased their height growth in 1978-79; in contrast, that of the Errinundra seedlots decreased. It was noted that at age 2 years, the trees from the Errinundra provenances had complete adult foliage coverage.

Table 5. Results from *E. nitens* provenance trial at Fletchers Creek at age 3 years.

Provenance	Seedlot	DBH (cm)	Height (m)
Macalister	Mt Useful	6.2	4.9
Toorongo	Mt Toorongo	5.9	5.0
Toorongo	Mt Erica	5.3	5.0
Rubicon	Cathedral Range	5.8	4.9
Toorongo	Mt Horsfall	5.7	5.0
Macalister	Conners Plain	5.0	4.4
South NSW	Nimmitabel	5.1	4.5
North NSW	Barrington Tops	4.8	4.3
South NSW	Tallaganda	4.3	3.9
South NSW	Anembo	4.2	4.0
South NSW	Nimmitabel	4.3	4.1
North NSW	Ebor	4.3	3.8
South NSW	Badja	4.3	4.1
Errinundra	Hammonds Track	3.7	4.0
Errinundra	Errinundra Plateau	3.9	4.2

The second trial site at Slab Hut Creek confirmed the previous sites result, in that the central Victorian provenances were generally superior to those from NSW or Errinundra, although Barrington Tops displayed the best height growth in the third year. Errinundra seedlots slowed down their height growth in 1979, despite the fact that all other seedlots maintained or increased growth rates. The Toorongo and Macalister provenances displayed diameters significantly bigger than the average, with Rubicon and Barrington Tops close in stature (Table 6).

Table 6. Results from *E. nitens* provenance trial at Slab Creek Hut at age 3 years.

Provenance	Seedlot	DBH (cm)	Height (m)
Toorongo	Mt Horsfall	7.9	7.3
Macalister	Conners Plain	7.4	6.5
Macalister	Mt Useful	7.7	6.9
Toorongo	Mt Toorongo	7.3	6.7
Rubicon	Cathedral Range	6.9	6.1
North NSW	Barrington Tops	7.0	6.5
South NSW	Nimmitabel	6.1	5.6
South NSW	Anembo	5.6	5.4
South NSW	Tallaganda	5.6	5.3
Errinundra	Hammonds Track	5.3	5.6
South NSW	Badja	5.4	5.5
Errinundra	Errinundra Plateau	5.6	6.0

A very different set of results was found in the third trial site at Callaghans Ridge (Table 7). By age three, Errinundra and Nimmitabel seedlots had the greatest diameters and heights, but it had already been noted that Errinundra growth rates had begun to decline dramatically in comparison to the other seedlots. It was therefore expected that central Victorian seedlots would surpass them within several years.

Table 7. Results from *E. nitens* provenance trial at Callaghans Ridge at age 3 years.

Provenance	Seedlot	DBH(cm)	Height(m)
Errinundra	Hammonds Track	4.7	4.5
Errinundra	Errinundra Plateau	4.2	4.5
South NSW	Nimmitabel	2.8	3.1
Rubicon	Cathedral Range	3.2	3.5
Macalister	Conners Plain	2.7	3.1
Toorongo	Mt Toorongo	2.5	3.0
South NSW	Anembo	2.5	3.1
Toorongo	Mt Horsfall	2.7	3.2
South NSW	Tallaganda	2.7	3.0
Macalister	Mt Useful	1.7	2.5
South NSW	Badja	2.0	2.7
North NSW	Barrington Tops	0.8	1.7

After 3 years growth at two of the trial sites, central Victorian provenances were superior to those from NSW, which was reversed on the third site. It was later suggested that this site was hampered by low nutrition and poor soils (Miller *et al* 1992).

Similar evidence comes from the results of a provenance study of 6-8 year old *E. nitens* at three different locations: Rotoaira and Kaingaroa Forests in the Central North Island and Longwood Forest in Southland (King & Wilcox 1988). The trees displayed vigorous growth (mean heights of around 16 m), with central Victorian family trees 10-15% greater in diameter growth and 35-59% better in tree form scores than trees from eastern Victoria (Errinundra) and southern New South Wales seedlots.

At the Rotoaira site, the heights and volumes of *E. nitens* were better than a similarly aged plantation of *P. radiata* D. Don located adjacent, prompting the authors to state that, "*Eucalyptus nitens* thus shows impressive volume growth in cool temperate conditions." Miller *et al* (1992) support this when they state that evidence from trials suggest growth rates in *Paropsis* free *E. nitens* stands could give a standing volume of 250-300 m^3 ha^{-1} at age 11 years, which would take *P. radiata* 15 years to achieve on a site index 30 location.

Provenances from the central Victorian highlands (Rubicon, Toorongo, and Macalister) were considered as the most desirable, due to their better growth rates, straightness, branch habits and retention of juvenile foliage. It has been noted that Toorongo provenance can either perform extremely well or similar to the slower Errinundra provenance, depending on the seed source obtained. Generally there was no clear indication as to which of the central Victorian provenances was overall superior to the others, although the best performing family was #114 Mt Erica, with the Mt Erica, Mt St Gwinear and Mt Horsfall families also doing well overall.

In one of the most recently surveyed species/provenance trials at Knudsen Road, south of Kaikohe, Northland, 11 provenances of *E. nitens* were planted in 1991, and measured in 1995 by the MEC (unpublished data). The results are summarised in Table 8. Three blocks of each provenance were planted, but in the cases of Mt. Erica and Barrington Tops, only two of the blocks were used for the data collection because the other blocks displayed very poor growth. Similarly for Toorongo, case data from only one block was useable.

Table 8. Knudsen Road *E. nitens* trial growth summary.

Provenance		Stocking (stems ha^{-1})	DBH (cm)	MTH (m)	VOL ($m^3 ha^{-1}$)	MAI ($m^3 ha^{-1} yr^{-1}$)
Toorongo	(VIC)	1932	15.0	14.7	168.2	42.0
Rubicon	(VIC)	2841	13.4	14.2	182.6	45.7
Macalister	(VIC)	2159	12.1	11.6	79.4	19.9
Errinundra	(VIC)	2728	10.8	11.6	82.7	20.7
Brown M	(NSW)	3069	12.3	13.3	144.1	36.0
Tallaganda	(NSW)	3182	11.0	10.6	95.8	24.0
Badja	(NSW)	2614	12.3	13.8	139.7	34.9
Barrington Tops	(NSW)	-	-	-	79.9	20.0
Rotoaira	(NZ)	2728	14.1	14.7	180.9	45.2
Mt Erica	(VIC)	-	-	-	146.5	36.6
Conners Plain	(VIC)	2273	13.8	14.9	140.8	35.2

The provenances of Toorongo, Rubicon, Brown Mt, Badja, Rotoaira, Mt Erica and Conners Plain all show MAIs of about 35 and over which would be a very acceptable baseline for defining a successful plantation. This is under Northland conditions and may not be representative of other sites, with stocking levels higher than are found in 'typical' pulp regimes.

Three provenances of 7 year old *E. nitens* were measured at the Karaka Road site, north-west of Whangarei (Table 9). There does not appear to be any significant differences in growth performance between the Victorian and New South Wales provenances.

Table 9. Karaka Road growth summary.

Provenance	Stocking (stems ha^{-1})	DBH (cm)	MTH (m)	VOL ($m^3 ha^{-1}$)	MAI ($m^3 ha^{-1} yr^{-1}$)
New South Wales	1090	19.8	20.3	231.9	32.2
Mt. Erica	974	20.2	20.6	222.4	30.9
Mt. Erica	959	20.7	20.7	234.4	32.6

6.7 Foreign Provenance Trials

Provenance trials in Tasmania have shown provenances from central highlands origin are superior to the others in all desired traits (Volker & Raymond 1989). In a species trial at Mt Gambier (South Australia) Mt Erica was the best of four provenances at age 4 years (Cotterill, Moran & Grigg 1985). A Bago State Forest (NSW) species/provenance trial showed Victorian provenances performed better than those from NSW, even in NSW itself (Johnson & Stanton 1993).

Provenance trials in Chile are in their infancy, but *E. nitens* plantings at three sites in one region have shown the best sources for their conditions are Barrington Tops (NSW) and Snob's Creek (Victoria). These trials were only 18 months old at the time of measurement. Five more provenance-progeny trials are under way, examining 16 provenances and 187 families (Jayawickrama *et al* 1993).

South African experience with provenance trials offers results that differ from other countries; after 5 years the most vigorous growth was exhibited by the NSW provenances (Purnell & Lundquist 1986). In 1979 another trial in Natal included 12 provenances, where southern NSW provenances proved more resistant to *Mycosphaerella* and northern NSW provenances more resistant to frost.

6.8 Research on Waste Treatment with Eucalyptus nitens

There exists a great potential for *E. nitens* as a species suitable for effluent and waste treatment. Research in Australia and New Zealand is limited but already the available results confirm the suitability of the species.

The requirements of species to be suitable for waste treatment schemes are: good survival, high growth rates, development of a large leaf area, as well as resistance to frost, salinity and water-logging. The species must also be resistant to damaging pests and disease. At the end of a rotation there must be a product that can be harvested and is marketable on local markets (Myers *et al* 1995). *Eucalyptus nitens* fulfils most of these requirements, and is now gaining recognition for this potential new role, particularly as a N sink. The Wagga Wagga (NSW) effluent plantation project is a large investigation into the suitability of 60 species and provenances. *Eucalyptus nitens* performed well, with the largest DBH of all species at 34 months after planting, and overall rated the third best of the species trialed.

The most comprehensive New Zealand experience concerns the effluent treatment trial at Whakarewarewa Forest, south of Rotorua (Nicholas *et al* 1994). This trial measures the growth of 10 special purpose species, to determine their potential relative to that of *P. radiata*. The trial design incorporates growth plots (30 m^2 blocks of each species) and row plots (2 m spacing) with treatments of 0, 50 and 80 mm of effluent per week. The results at 3 years can be seen in Table 10.

Table 10. Growth data for 3 year old *E. nitens* in the Whakarewarewa effluent treatment scheme.

Trial Type	Mean Top Height (m)			Mean Top Diameter (cm)		
Effluent rate (mm/week)	0 mm	50 mm	80 mm	0 mm	50 mm	80 mm
Growth Plots	8.5	8.6	9.3	11.8	11.2	11.8
Row plots	5.9	7.6	6.5	8.7	13.7	10.5

The addition of effluent increased growth of *E. nitens* above that of the control (0 mm effluent). The effect is more noticeable for the row plots than for the growth plots. The net volume MAI increased significantly with effluent applications above the control. The control had a MAI of 13 m^3 ha^{-1}, that was increased to 20 and 21 m^3 ha^{-1} with the 50 mm and 80 mm treatments respectively. Generally it can be concluded that *E. nitens* displays better growth on sites where it receives some form of effluent treatment. No other species in the trial performed satisfactorily.

7. CURRENT NEW ZEALAND PLANTINGS AND PRACTICES

7.1 New Zealand Forestry Companies

7.1.1 South Wood Export Ltd

Currently South Wood are planting *E. nitens* in the Invercargill region, at rates between 800 and 1200 ha annually. Their present planted area for various commercial groups is approximately 5600 ha (R. Washborn *pers comm*). Selected sites are on moderately rolling hill-country, at 400-450 m altitude. Some of this area is ex-farmland, most soils characterised as free draining and moderately fertile.

Seed sources were selected from the Waiouru seed orchard (via Proseed NZ Ltd.) and Glentunnel, which is located near inland Canterbury. The Waiouru source (60% of plantings) was chosen as it is recommended as the best local seed source, and Glentunnel as the parent stand displays excellent growth and form characteristics.

Site preparation involves a deep rip to 1 m depth, that is then cultivated by a bedding plough to give a raised bed over the rip. This is achieved on all sites where tractor access is possible. Weed control is spraying of Gallant and Gardoprim from a tractor boom, or by hand with a knapsack (1.5 m diameter around seedling) where the site is inaccessible to a tractor. Trial work is suggesting that it could be very advantageous to administer some form of weed control in the second year after planting, before canopy closure, possibly by aerial spraying. Fertiliser application consists of 50-60 g of DAP per tree applied into a spade slit 1 month after planting. Some ex-pasture sites may have a sufficient nutrient base to not warrant additional fertiliser applications, and trials are investigating this approach.

Trees are spaced at 3 x 3 m giving approximately 1100 spha, although trials are looking at the effect of stocking levels from 800 to 1600 spha.

7.1.2 Tasman Forest Industries Ltd

Tasman Forest Industries Ltd. is also involved in an *E. nitens* planting program, with a current stand area of approximately 2000 ha, of which the oldest trees are 2 years old (S. Kincheff *pers comm*). Plantings are 70% *E. nitens* and 30% *E. fastigata*, and in the future supplementary plantings of *E. regnans*, *E. saligna* and *E. globulus* may proceed. Projected target planting rates are up to 2000 ha per annum for the next 10 years. The sites are all ex-farmland, and are located in a hypothetical triangle that stretches from Tauranga to Taupo to Opotiki, in an attempt to keep plantations within 100 km of Kawerau mill. Altitudes of sites range from sea level to about 600 m, although most sites are at around 350-400 m (B. Poole *pers comm*).

Provenance sources are from the Toorongo plateau, Mt Gwinear and other Victorian and NSW families. The stands are planted as a pulpwood regime with the stocking usually at 1200 spha.

Cultivation is practiced where possible, and includes ripping to 40-80 cm depth, mounding, and rotary hoeing where compacting of pumice and soils has occurred.

Sites planted are ex-pasture and farmland, so the biggest problems encountered are with large areas of established gorse and blackberry, and the usual method to destroy this is by applications of Escort by hand or from the air. Line spraying or 2 m square spots around each seedling with Roundup/Gardoprim is used for pre-plant weed control. This is followed by Gardoprim/Gallant/Versatill spraying in the second year. Extremely wet seasons, as have occurred in recent years, can break down residual chemical herbicides, necessitating applications of these sprays in summer despite the potential damaging effects to the foliage. If this occurs regularly, Gardoprim may be left out of the mixture for applications outside the winter period.

Even on these fertile sites 60 g of urea is applied at planting, followed by 90 g of NPK at the start of the second year. Borated super is applied on those sites that exhibit B deficiency. Rotation times are expected to be in the order of 10 years, and productivity of sites is aimed at an average of 25 MAI.

Trials using sheep-grazing on blocks will study the beneficial effects of grass reduction, lowering of the fire potential, and dispersal of nutrients. Some work with oversowing crops has also taken place, but will feature little in the future due to costs of establishment and competitive vigour of the grasses. This practice may be suitable for sites with extreme problems of gorse and blackberry.

After weed control the second largest problem facing the establishment of *E. nitens* plantations is the continual defoliation by rabbits, possums, deer (and wallabies in some areas). This has necessitated the dropping of large quantities of 1080 poison to control these pests, adding to the costs of establishment as well as creating ecological concerns.

7.1.3 Fletcher Challenge Forests

Company policy did not allow any information to be provided.

7.1.4 P.F. Olsen & Co./Caxton Forests Ltd.

P.F. Olsen and Company Ltd. are involved with the planting of *E. nitens* plantations for Caxton Forests. Areas planted include the Kawerau region (logging cutover after one rotation of *P. radiata*) and the central North Island on ex-pasture sites at high altitude i.e. 550-750 m.a.s.l. (P. Keach *pers comm*).

Kawerau sector land preparation involves desiccation spraying to release weeds in February and March. This is a combined Escort/Roundup/Pulse treatment. *Eucalyptus nitens* seedlings are then planted in July to August at a stocking of 1100 spha, and receive 60 g DAP as fertiliser within a month of planting. Gardoprim is used as the herbicide for spot weed releasing in November to December, and the second year weed release is also a spot spray with a mixture of Gardoprim/Gallant in September/October.

Central N.I sites receive slightly different preparation due to the nature of the sites. Because altitude is relatively high, slopes are ripped and mounded, and frost flats V-bladed in April/May. Stocking is again at 1100 spha and planted in July to August, followed by aerial blanket release of weeds with Gardoprim in the following September to October. A second weed release the next season is an aerial strip spray of a Gardoprim/Gallant

Mixture again in September to October. Previously these sites have been supplied with 60g DAP or Urea at establishment, but this policy is under revision.

The most favoured provenance is that of Snobs Creek (Victoria) followed by lesser areas of Mt Erica and Mt Horsfall (Victoria). Several stands have been planted with Badja Mt and Tallaganda provenances from NSW.

8. RESEARCH ON SITE PREPARATION AND CULTIVATION

8.1 The Role of Fertiliser and Weed Control

Eucalypts have evolved on soils in which nutrients, in particular phosphorus, are characteristically low, and are therefore very efficient at recycling nutrients such as N and P. Nonetheless, the addition of nutrients to sites can result in substantial growth increases (Cromer *et al* 1981). It must also be realised that the addition of fertilisers, without a partnership with effective weed control, will result in fertiliser-boosted weed growth and increased competition (for light, water and nutrients) for site occupancy. This usually occurs at the expense of the growth rates of the plantation species. Effective weed control needs to be maintained until canopy closure, which takes about 3-4 years in *E. nitens* (Beadle & Mummery 1990). For this reason, the contribution of fertilisers and weed control are considered in the same context.

Weed control has been identified as possibly the most serious concern facing any planting program for *E. nitens* (S. Kincheff *pers comm*), and as such may need to be the focus of intense investment and research.

It has been noted that eucalypts are more sensitive to herbicides than *Pinus radiata*, especially to Australian created herbicides, as these were designed to kill eucalypts that were viewed as a woody weed in *P. radiata* plantations. The role of weed killers will be increased as New Zealand eucalypt plantations are established on ex-pasture sites, due to the high residual nutrient levels and established weed seed banks.

It is suggested that at the site level any growth response to a herbicide treatment is a function of three inter-related factors (Wilkinson & Neilson 1990):

- reduced competition due to weed control,
- direct effects of herbicides on the eucalypt seedlings,
- interaction between herbicide treatments, seedling stocking type and soil factors.

8.1.1 Australian Research

In a combined application of fertiliser and *atrazine* (a post planting weed control commercially registered as *Gesaprim* 500 FW) on young *E. nitens* sites, Turnbull *et al* (1994b) found that the addition of fertiliser increased tree height and stem growth over the control treatments. Nitrogen was applied as urea at 200 kg ha^{-1}, and phosphorus as triple superphosphate at 120 kg ha^{-1}. Averaged over the treatments, the addition of fertilisers raised the LAI from 1.2 (control) to 1.9 (treatment) at 29 months of age.

Atrazine was applied at three levels to examine its effect as a weed control agent, against a control with no weeding and hand weeded sites. The applications of atrazine slightly reduced height and diameter growth, significantly so at the highest application rate. This was despite the fact that atrazine did have a significant effect on weed control and therefore reduced competition for nutrients. Overall the post-planting weed control by atrazine did not appear to benefit the tree crop over the trial period, and although effective on weeds, there also appear to be phytotoxic effects on the growth of *E. nitens*. This species is more tolerant to the chemical than *E. regnans* which can experience heavy mortality (Wilkinson & Neilson 1990).

In a similar trial using atrazine as a pre-plant and post-plant herbicide, Wilkinson and Neilson (1990) found that levels of 4 kg ha^{-1} for atrazine as a pre-plant application were effective and safe for use on *E. nitens*. They also suggested that lower residual levels of atrazine gave better growth than expected which may be due to direct growth stimulation, as well as the effect of reducing weed competition. Their main concern was that all post-plant applications of atrazine reduced significantly the survival of paper-pot seedlings: open-rooted seedlings are unaffected by the treatment.

By the time the residual effect on weed control disappears (less than 2 years), the canopy should be sufficiently dense and enclosed to reduce the light levels reaching the under-canopy. This should prevent significant levels of weed growth and result in continued beneficial growth response (Wilkinson & Neilson 1990).

On a severely harsh site in Toorongo Plateau in central Victoria, McKimm and Flinn (1979) designed a trial to determine the best combination of eucalypt species, site preparation and fertiliser treatments for reforestation. There was no apparent response in height to P alone, which they conclude is a typical response by eucalypts due to the genus evolving on low P sites. There was also no response to K or trace elements, which is in agreement with results from other plantation eucalypt forests in Australia. They do suggest that on sites in other countries there is usually a requirement for trace elements, in particular B, at time of establishment.

Response to N was large, but also dependant on the form supplied. Urea gave the largest increase in growth response, with nitrate-N the least rewarding. There is a suggestion that the high rainfall of the area was responsible for the leaching of the applied nitrate-N below the root zone, hindering its effectiveness.

8.1.2 New Zealand Research

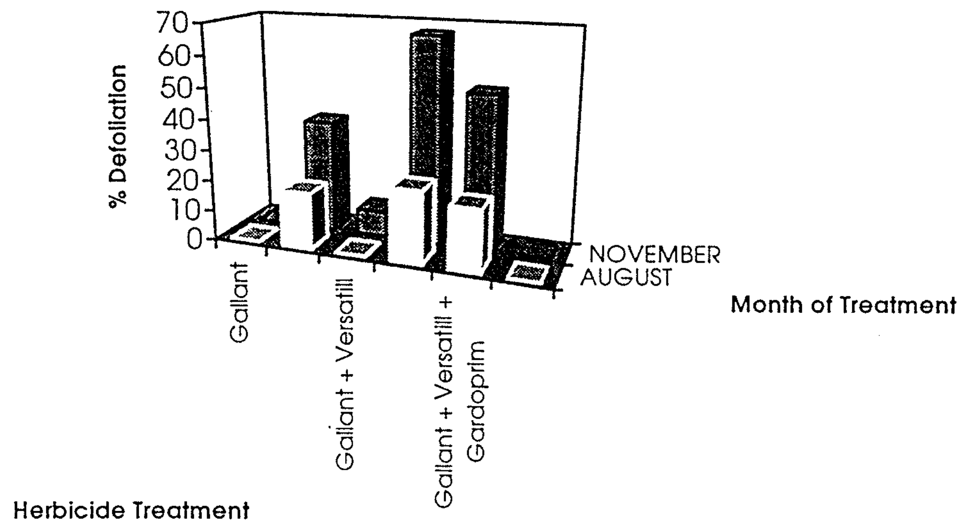
The susceptibility of eucalypt species to many herbicides prompted FRI (1982) to warn that eucalypt should not be planted close to farmland or young pine plantations where spray programs are likely to occur.

A local study on a range of herbicides for use at establishment suggests that of four eucalypt species studied, *E. nitens* was the most tolerant (Buchanan, Lobb & Smith 1994). The report discusses the effects of a combination of three herbicides: *Gallant* to control grasses, *Versatill* to control broadleaf weeds and *Gardoprim* as a pre-emergent herbicide to prevent emergence and germination of weed seedlings. All seedlings were bare-rooted.

Utilisation of Gardoprim can cause significant foliar damage depending on time of application, but the authors state that these effects are transitory and that seedlings recover quickly. They also believe that the reduction in growth caused by lack of weed control was greater than that of chemical damage due to the herbicide. From Figure 1 it can be seen that the damaging effects of Gardoprim occur both alone and in combination with the other herbicides (where its damaging effect on foliage is potentiated), and that the two other herbicides (Gallant and Versatill) give minimal damage to the plants. The effect of Gardoprim is even more significant when applied in the active growing season.

This does not necessarily mean that Gardoprim is an unsafe herbicide for use around eucalypts, but that its use requires skilled management as to time of application and careful spraying to minimise contact with *E. nitens* foliage.

FIGURE 1. Defoliation of Eucalyptus nitens by Combinations of Herbicides.



The recommended practices (Buchanan *et al* 1994) were to:

- Treat seedlings when dormant, as they are more tolerant of herbicides at this time
- Treat with Gallant and Versatill because these cause minimal damage to the foliage and are safe even during active growing periods
- Use Gardoprim in combination with the other herbicides, applied to the base of eucalypts in the second season after planting.

A study on weed control by Balneaves and Clinton (1992) also suggests that for weed control around eucalypts, Gardoprim 500 FW should be sprayed at 15 litres ha^{-1} post-planting to control grasses and broadleaved weeds before spring growth in September.

One feature of the growth habit of *E. nitens* that has not been noted in any literature, and may not have been realised by forestry concerns due to the young nature of the majority of stands, is that during the transition from juvenile to adult foliage, LAI is lost, the previously closed canopy opens and the weed problem re-emerges (C. Wilson *pers comm*). Although at this early stage the exact effects of this occurrence are not quantified, if the problem becomes more obvious in the future, weed control programmes may need to be re-examined.

8.2 Fertiliser Applications

Applications of fertilisers to *E. nitens* in New Zealand usually involves a 60 g dosage of urea or similar product within 4 weeks of planting, and a second dosage at 1 year after establishment, usually about 90 g of some form of NPK. The first dose should be placed in a spade slit 15-20 cm to the side of the seedling, along the contour of a slope, and caution must be exercised as the urea can easily burn the roots and destroy the seedling (FRI 1982). Trials testing the timing of fertiliser application with species including *E. nitens* have shown that application 1-3 months after planting produces more growth than 6-9 months after planting (Nicholas *et al* 1991).

8.2.1 Multiple Applications of Fertilisers

Typically the extent of fertiliser applications for eucalypt species has consisted of a dosage of N-supplying fertiliser at planting, and an NPK type application twelve months later. This has proved to give a substantial boost to the initial growth rate and this growth advantage is maintained over the crop rotation (i.e. the big get bigger). There are suggestions that multiple applications of fertiliser until the time canopy closure can increase this growth enhancement even more (Cromer & Turnbull 1994).

The reason behind this response is that in Stage I of a forest nutrition cycle, before canopy closure occurs, nutrients are taken up directly from the soil. In later stages effective recycling through translocation and re-absorption of nutrients made available via decomposition of litterfall will occur, but until these processes are established, addition of accessible nutrients in the soil will assist growth rates. This boost correlates with increased foliage and LAI, allowing greater interception of radiation, thus improving photosynthetic activity and production of carbohydrates.

Experiments by Cromer *et al* (1991) have tested the applications of heavy fertiliser loads to *E. globulus* and *E. grandis*. In one *E. grandis* trial on infertile yellow soils, 1600 kg ha^{-1} N and 500 kg ha^{-1} P were applied over the first three years after planting. In the best stand, the response to this boost was a standing volume of 105 m^3 ha^{-1} at age 3, towering over the unfertilised control of 19 m^3 ha^{-1}.

Response of this magnitude should not be expected on relatively fertile ex-pasture sites, but there should always be a significant gain in growth rates with a suitable application of fertiliser at planting. Establishment of second rotation crops could also be affected by the limited nutrient capital on the site, due to nutrient storage in litter.

Even on sites that were considered fertile for the first rotation, nutrient applications may be necessary because of the inaccessibility of nutrients stored in biomass and litterfall (Cremer *et al* 1978).

8.3 Site Cultivation

Even as early as the 1960s and 70s it was recognised that eucalypts are more sensitive to the effects of site cultivation than other plantation species. George Fry in an interview with Lembke (1977) suggested that, 'you just plant radiata and walk away... on the other hand we have now found that eucalypts needed the development of intensive site preparation techniques to achieve the successful establishment of vigorous growing crops.' Although it is unlikely that Fry was thinking about *E. nitens* at the time, his conclusions are especially applicable.

McKimm and Flynn (1979) examined the effect of different types of soil cultivation and fertiliser applications on an extremely desolate site on the Toorongo Plateau (central Victoria). The site was defined as harsh, with long cold winters, frequent snowfall and severe frosts occurring regularly, at an altitudinal range of 950 to 1250 m. The experiment compared the effects of complete cultivation (ploughing), ripping, furrowing and a control (no site preparation) on the establishment of *E. nitens*, *E delegatensis*, *E. regnans* and *E. globulus*.

The effects of different site cultivation techniques were first measured at 9 months after planting. The mean survival was the mode of measurement for each species, and even at this stage *E. regnans* and *E. globulus* were almost completely destroyed by frosts and snow (10% and 6% survival respectively). The survival % of *E. nitens* across three sites and four cultivation methods is shown in Table 11.

Table 11. Mean survival for *E. nitens* at 9 months on 3 Toorongo Plateau sites, relating to site preparation technique.

Site Preparation	Site Number			
	1	2	3	Mean
	Survival (%)	Survival (%)	Survival (%)	Survival (%)
Control	62	48	80	63.3
Ripped	84	76	88	82.7
Furrowed	90	76	94	86.7
Ploughed	82	94	99	91.7

It can be seen that as the intensity of site-preparation increases, so does the initial survival rate of the trees planted. Obviously any form of site cultivation is better than the control, so where physically possible, site preparation should take place. The benefits would become more obvious on less than optimum sites.

At age 5 years the sites were measured for height and diameter. These were significantly affected by method of site preparation and planting site. All three preparation techniques significantly increased the mean heights and diameters over the control (Table 12).

Table 12. Heights and diameters for 5 year old *E. nitens* on Toorongo Plateau, related to site preparation technique.

Site Preparation	Site 1		Site 2		Site 3		Mean	Mean
	Height (m)	Diam. (cm)	Height (m)	Diam. (cm)	Height (m)	Diam. (cm)	Height (m)	Diam (cm)
Control	5.60	9.0	4.03	5.2	4.68	5.7	4.77	6.6
Ripped	7.28	11.4	5.83	9.4	6.69	8.6	6.60	9.8
Furrowed	6.73	10.0	5.74	6.9	7.16	9.4	6.54	8.8
Ploughed	6.95	10.5	7.04	9.0	7.41	9.9	7.13	9.8

Despite the harsh conditions, trees with heights in excess of 8 m and diameters over 15 cm were common. Overall, ploughing on these harsh Victorian sites was the most successful method tested for survival and growth, but furrowing and ripping were also acceptable. This suggests that in similar New Zealand localities, some form of site preparation would have a similar beneficial effect.

FRI (1982) advice concurs, noting that the rapid development of young eucalypts is dependant upon their ability to extend roots into the surrounding soil. Compacted soils are liable to prevent root formation and movement through the soil strata, and areas similar to these need to be ripped. FRI recommended discing, because it improves the soil properties, removes the competing vegetation and can reduce the frost levels on harsh sites. However these cultivation techniques may also expose dormant weed seeds.

9. DISCUSSION

9.1 Coordination and Planning of Eucalyptus nitens *Planting*

Any project involving the planting of *E. nitens* must be thoroughly planned and thought through before the first seedlings are put into the ground. There must be consideration of the seed source (provenance or seed stand) to be planted to suit the site, which nursery will supply the seedlings (based on costs and quality of stock), fertiliser and herbicides to suit the background levels of nutrition and weed bases respectively, and applications of site cultivation to maximise the success of establishment and early growth.

9.1.1 Siting

Various factors must be taken into consideration when considering the suitability of a piece of land for growing *E. nitens*. Among the factors covered below are the effects of site fertiliser history, typical weed cover and established weed seed bank, the landform and aspect as related to solar radiation and frosts, and the stand size as related to possible *Paropsis* problems. But other areas also need to be considered:

9.1.1.1 Possum Threat

The proximity of bush and forest areas may be of considerable concern, as these areas often contain large populations of possums that frequently migrate from bush to farmland under cover of darkness. This migration effect is increased if palatable grass species such as clover are present on ex-pasture sites. Once the *E. nitens* stands are discovered by migrating possums, and if no effective protection is maintained, those stands will be devastated.

If planting on sites located close to such stands of existing vegetation, some pro-active form of possum control must be considered, and then acted upon. Currently the *modus operandi* is dropping of 1080 poison baits, which may be effective for a time, but must be backed up with other methods such as manual hunting at night, in order to contain population levels. Any hunting or trapping operation should maintain records of dates and volumes of kills, as this information can help examine the effectiveness of any eradication program, as well as enabling estimation of pest population levels. This facilitates the management of future programs, as the amount of time and effort to maintain reasonable animal population levels can be determined.

9.1.1.2 Maku Lotus

E. nitens planted close to radiata pine plantations that have been oversown with Maku lotus may be browsed by *Heliothis* spp caterpillars that have consumed the undersown species and moved on to other vegetation (Author *pers obs*). It is not known to what extent they are defoliators of *E. nitens*, but when high numbers are present some damage must be expected, and if it occurs on apical shoots, loss in form of the trees may be experienced. Therefore consideration of the location of eucalypt stands near oversown pine stands must be thought through, and perhaps *E. nitens* stands should be considered as part of any spray programme. These eucalypt stands may act as refuge sites for the caterpillars, which then migrate back into the radiata stands at a later time.

9.1.2 Provenances

From reports of overseas provenance trials and the few that have been carried out locally, it seems obvious that the central Victorian provenances are superior in most growth properties desired for *E. nitens*. These seedlots have displayed better growth, form and frost tolerance on a number of different sites, soils, climes and altitudes.

In principle at least, companies interested in planting *E. nitens* should concentrate their plantings with these Victorian provenances. However there may be a significant amount of variation between families and seedlots on different sites - determination of which family is most advantageous in separate New Zealand geographic regions will yield better results in the long term, and enable a more focused approach to genetic improvement. It is obvious that some companies have varied the seedlots used in plantings, but whether this is a conscious and integrated effort to increase their information, or is a result of what can be supplied by seed suppliers was not determined.

Selection of provenances, although with the superiority of the central Victorian provenances in mind, should also consider details at the microsite level. If gullies or sites likely to experience frosts are to be planted, care should be taken to choose provenances or families that will exhibit the least loss of growth from these harsh conditions. Seedlings raised in South Island nurseries may have undergone superior hardening conditions, and appear more tolerant of harsh sites (S. Kincheff *pers comm*).

The otherwise less attractive NSW provenances may be more suitable under harsh conditions, such as climatic conditions likely to lead to outbreak of *Mycosphaerella* or similar pathogens. Likewise, these provenances may be well suited to those regions that normally experience summer maxima rainfall conditions or where they may occur periodically. Therefore it is recommended that companies invest some time researching historical climate patterns for the regions that constitute the bulk of their plantings, and in particular rainfall patterns over the last decade. Companies may feel inclined to neglect NSW provenance stands due to their slow growth rates, but if some trials are maintained to collect long term growth data. Any change in their performance would be noticed, and they could be used as indicators of a change in rainfall distribution.

Therefore a compromise on provenance selection may have to occur, the extent of which is determined by climate and sites chosen. It may become a hazardous practice to blanket-plant in only one seedlot or provenance; with plantings of mixed genetic stock, the trade off between loss of some productivity due to slower growing trees may be countered by the increased survival of the plantation due to biodiversity and suitability of some trees to the site conditions, especially fluctuating climatic conditions. In order to benefit from this knowledge in the long run, it is essential that accurate records are kept on the sourcing of all seed.

9.1.3 Fertiliser and Weed Control Options

When establishing *E. nitens* on different plantation sites, a clear plan of cultivation, herbicide and fertiliser treatments must be decided upon. In the 3-4 years until canopy closure it is vital that weed regeneration and growth is suppressed, in order to avoid competition of resources and wastage of fertilisers applied to the site. This is particularly so on ex-pasture sites or areas with a history of fertiliser applications, where high residual levels of nutrients mean that weed establishment will be rapid and compete with seedlings soon after planting.

If *E. nitens* plantings were defined into geographic regions, based on soil types, climate and average soil nutritional levels, e.g. Bay of Plenty region., trials could be set up in each region that utilise different herbicide treatments on the same provenance seedlings. The companies should already have some idea of what seed sources are best for their plantation areas, and this will avoid complicating the experimental results due to variation in provenance response.

There appears to be a need to establish separate fertiliser trials for separate geographic regions, due to the interaction of plants, soils and fertiliser. In a study of eucalypt responses to addition of fertilisers soon after planting, Cromer *et al* (1981) found for *E. globulus* that there were clear differences in response to fertiliser by plants from the same seed origin when grown in different environments. For two sites investigated, the trees responded most to added nitrogen, and at the third site, the addition of phosphorus had significant effects.

As a control there should be untreated plots, and it may be worthwhile to investigate oversown nitrogen-fixing species such as Maku lotus (*Lotus uliginosus*) as a form of weed suppression. This has been found to establish on a wide range of unfertile sites, tolerates acidic soils and has good resistance to insects and other pests or diseases. As lotus is relatively slow to establish, it is useful to mix it with other grasses that rapidly assume control of the site. The optimum mix varies with soil type, rainfall, fertiliser applications, season of sowing and weed type that usually dominates the site. If canopy closure is lost in the transition to adult foliage, the seeds from oversown crops can still remain and germinate before weed species, so their effectiveness is doubled.

Also of importance is the standardisation of pre-planting cultivation and herbicide treatments. As was suggested by McKimm and Flinn (1979), some form of site preparation is essential for satisfactory establishment. If a thorough cultivation of the site precedes the planting of seedlings, this may reduce the need for contact herbicides to be applied. Once the seedlings are established, then a post-planting herbicide can be administered to control weed regeneration, and this should be sufficient to counter this problem until a stage where the *E. nitens* canopy is sufficiently developed to deter rampant weed growth.

This is another area where the utilisation of a desired understorey crop could be useful, as it would suppress weeds, and prevent the loss of valuable topsoils on plantation sites where a previous crop has just been removed and cultivation administered.

9.1.4 Problems with Paropsis *for Small Stands*

Although there is little current interest by industry on the assessment of *Paropsis* populations on *E. nitens*, evidence suggests that there may be some problems with infestations on small stands of susceptible eucalypt species (M. Kay *pers comm*).

It has been found that in some small blocks of stands of *E. nitens* and *E. fraxinoides*, *Paropsis* arrives in stands after pupating underground through winter, and the adults begin eating the spring flush. These leaves are also the food source for the young larvae, so the eggs are oviposited on this foliage type. Because few *Enoggera* arrive due to the small nature of the stand, only about 2% of the eggs may be parasitised. Subsequently there is a population explosion of *Paropsis* in the second generation, which consume most of the flush foliage available. *Enoggera* populations by now have increased in size due to rapid proliferation of numbers, and parasitise 99-100% of the eggs laid. However, *Paropsis* instars and adults have no significant predators, so the canopies of the trees are destroyed, and adults appear to disperse to other sites in search of edible foliage. Consequently no *Paropsis* enter the ground at the original site to pupate and the population crashes. As a consequence *Enoggera* have no *Paropsis* eggs to consume or parasitise, and presumably disperse from the site also.

This example of population peaks and crashes is disastrous for *E. nitens*, as the trees are defoliated in consecutive years as the populations never achieve a sustainable equilibrium. For effective biological control, the host and parasite species must maintain similar levels, and avoid the huge oscillations found in small stands. In suitably sized blocks, the control of *Paropsis* is excellent, as enough eggs are laid to sustain *Enoggera* and yet allow some *Paropsis* to reach the adult stage. This dynamic means that no population explosions of *Paropsis* occur, and very little foliage is consumed.

This suggests that management practices of *E. nitens* stands should include careful consideration of the size and spacing of individual stands. It will not always be possible to blanket plant the species due to constraints of available land and selection criteria for suitable sites, but some problems must be expected if stands are going to be isolated some distance from others. There is no data that could suggest the minimum stand size required to create its own stable population dynamics with host and parasite, nor is there any information on what distance constitutes an "isolated" stand.

Until accurate data is collected on the minimum stand size that enables stable population dynamics, minimum distances between stands for effective parasite interactions, or which environmental factors are causing the system to break down, stands of *E. nitens* should be as large as possible to avoid possible later defoliation by uncontrolled infestations of *Paropsis*.

The following areas are major issues for *E. nitens* and require further research:

- Effect of microsite on different provenances and families i.e. which seedlots should be planted in a gully bottom as opposed to a ridge or a frost flat? Pooling of information and cooperation between forestry concerns may provide a sufficient database to develop suitable protocols for site conditions.
- Do high fertility ex-pasture sites require any fertiliser additions at planting - do the benefits over a crop rotation outweigh the compounded cost? - is there a significant boost to growth?
- Are NSW provenances, apparently superior in resistance to *Mycosphaerella* although slower in growth than Victorian provenances, a better bet in warm, humid areas that are likely to suffer continued *Mycosphaerella* attacks every summer?
- Can more beneficial combinations of 'friendly' weeds that are not as competitive to *E. nitens* as Maku Lotus be found, to act as an oversown crop? This could be especially important on fertile sites with high weed bank levels, and at the time of foliage transition from juvenile to adult forms.
- Will higher initial stockings of *E. nitens* at planting enable suppression of weeds and encourage height growth so that the trees rapidly outgrow the effects of the weeds?
- Can super-applications of fertilisers boost growth of *E. nitens* over the crop rotation, and if so, is this a similar effect as to what may be achieved by effluent and waste treatment.
- Can coppicing for second crop rotations increase immediate productivity, whilst reducing establishment costs and physical damage to site?
- After canopy closure, and the subsequent change to adult foliage, the canopy opens up again; what effects does this have in relation to the understorey competition and does this act to reduce growth?
- Weed control: until canopy closure, is total weed control on the site superior to line weed control or spot weed control around each tree? Weed control to what age gives best tree protection? Would it be cost effective to develop chemicals that are specially designed to avoid damage to eucalypts?

10. RECOMMENDATIONS

On the basis of available literature and experience of eucalypts, the following practices make the most sense and should give the best results at establishment for *Eucalyptus nitens*:

- Provenance selection should be made for individual sites, taking into account the ability of Victorian strains to maintain higher LAIs and juvenile foliage, leading to faster canopy closure and suppression of weed competition. This must be balanced against the superior frost/fungal resistance of NSW provenances. Increase in altitude can be an influencing factor (due to decreased annual temperature, increased frequency and severity of frosts) as well as locations that enjoy warm and humid temperatures, increasing the likelihood of *Mycosphaerella* to cause damage. Although it has been suggested that no decline in growth has been displayed with increasing altitude, it is likely that this will not improve growth.

- Best site characteristics include rolling, concave or convex terrain. Although the excellent frost-resistance of *E. nitens* allows it to survive in frost flats, this comes at the expense of reduction in growth. On harsh sites, north facing slopes are recommended due to better temperatures.

- Sites *must* undergo some form of preparation where possible, with best practices including ploughing, furrowing and ripping, to a depth of 1m where possible. Ploughing appears to give best protection against frosts and encourages best early growth rates. Bedding to raise the seedlings above the surface would also be beneficial on sites that experience frequent/harsh frosts. The removal of weeds and opening up of soils facilitates root penetration - if the root system does not properly establish in time then the seedlings will suffer in the summer period.

- Seedlings planted at 1100 - 1200 spha, following cultivation procedures listed below.

- Weed control is *essential* on all sites, even more so where fertilisers are applied. Should involve both pre- and post-planting programs. Where possible, if site is ex-pasture, it would be useful to allow areas to be grazed in order that grasses and weeds are kept to manageable levels. Any program must endeavour to determine the likely weed species or seeds present, in order to define a thorough weed elimination program. Heavy gorse and blackberry problems should be treated with Escort or Roundup. Cultivation will destroy existing weeds, but exposes dormant seeds, therefore residual sprays are needed to effect continual knockdown against the weed threat. Gallant and Versatill are safe and effective in the first year of growth, Gardoprim should only be applied in winter when the seedlings are dormant, or in the second year of growth. There is no evidence to suggest if spot or strip spraying is best, so whatever is achievable for a site is recommended. If weed problems follow into the third or later years, weed control should still be implemented - any growth lost to competition for resources is not recoverable. Severe sites that are likely to experience continued weed problems may benefit from oversown protection, as long as the 'desirable' weed species is not allowed to compete directly with the trees for resources.

- Sites need to be protected against browsing mammals. This can take the form of hunting, trapping, poisoning, taste/smell deterrents or fencing. This is especially so with stands located close to existing bush stands, and in all cases records should be maintained on kill rates in order to quantify the effect of any control program. Blanking of any trees that are killed is not usually successful, as the other trees have grown too fast for blanks to catch up or stay competitive.

Fertiliser application within one month of planting is essential, even on fertile farmland (until any information is available that suggests otherwise). This is usually 60g of DAP or Urea based product. At commencement of the second year, this is augmented by 90g NPK, and trace elements where visible signs of deficiencies occur. If available moisture is low, this may affect nutrient uptake, leading to nutrient deficiencies even when the soil nutritional status is ample.

There are also several management practices that, although not of immediate priority at establishment, will enable valuable knowledge to be gained and increase productivity of subsequent plantations:

- Obtain foliar nutrient levels where possible to gain better understanding of critical levels and to allow estimation of the optimum N:P ratio for the species

- Consider involvement with waste treatment by *E. nitens*: with stand rights, the trees are guaranteed water and nutrients in even the driest climate conditions, and display excellent potential for fast rotation pulp regimes

- Consider distances to possible mills, pulping plants or ports when establishing stands, as lowering of production costs should increase the popularity/acceptability of the species - everyone benefits

- Plant alternative species (*P. radiata* etc.) in those microsites where *E. nitens* is likely to be less effective than other species - it is better to get good growing radiata than poor *E. nitens* on microsites likely to be detrimental to the eucalypt, e.g. very steep slopes, waterlogged gully bottoms

- Assess stands for trees whose growth and form is superior, and that may be suitable for either genetic improvement programs or growing on to sawlog status

11. SUMMARY

- use experienced people to check nursery stock to determine if any nutrient or pathogen problems are present
- examine histories of any nearby plantations to planting site, in order to quantify any history of nutritional problems
- mechanically cultivate all sites where possible, as deep as possible
- avoid planting *E. nitens* on compacted soils i.e. skid tracks
- apply recommended dosages of fertiliser at establishment, and if possible at commencement of second year
- apply contact herbicide after cultivation and residual weed control before planting
- apply weed control where possible at second year, and if feasible until canopy closure
- avoid frost hollows: *E. nitens* is resistant but growth will suffer as a consequence
- practice animal pest control at planting such as trapping, hunting and poisoning, repelling
- plant as large stands, or small stands close together, to minimise any possible *Paropsis* effects
- plant on rolling or concave sites
- plant on moderate slopes to give good air drainage and exposure to solar radiation
- avoid hollows with no air drainage at very high or very low altitudes
- consider risks of *Mycosphaerella* when choosing location of sites, especially low altitude, warm and humid areas
- plant *E. nitens* on warmer, north facing slopes when climatic conditions will be cold and harsh
- consider suitability of provenances to different environmental conditions/hazards
- invest in planting different provenances and families to gain maximum genetic insurance
- plant where rainfall exceeds 800 mm *per annum*
- assess climatic history of a site in order to determine likelihood of a change in rainfall distribution in the near future
- avoid planting in areas that may receive summer maximum rainfalls - unless the provenances are matched to these conditions
- avoid sites likely to experience droughts, and hot dry winds
- attempt to use seedlings from areas that are likely to have undergone some form of hardening, and are therefore more likely to survive harsh winters

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14. APPENDICES

Appendix One. Eucalyptus nitens *Provenances.*

1. ***Rubicon*:** Located in the area immediately south and east of Taggerty, but mainly to the north of the Great Dividing Range.

2. *Toorongo*: South and East of the Rubicon provenance and mainly south of the Great Dividing Range.

3. *Macalister*: Mainly on the coastal side of the Great Dividing Range, to the east of Rubicon and Toorongo provenances.

4. *Errinundra*: Occurring on the Errinundra plateau in East Gippsland, Victoria, with a few outlying stands just north of the New South Wales border. Now recognised as *E. denticulata*, a separate species.

5. *Southern New South Wales*: A predominantly southern New South Wales provenance that occurs in scattered stands along the great divide and includes a small stand at Mt. Kaye just over the border in eastern Victoria.

6. *Northern New South Wales*: Two very small outlying areas at Barrington Tops and Ebor, separated from southern New South Wales provenances by 400 km.

Source: Miller *et al* (1992).

Appendix Two. *Provences of* Eucalyptus nitens *known to have been Trialed in New Zealand.*

This is a list of provenances that are known to have been trialed in New Zealand at some stage. Seedlots marked with an asterisk have shown to be well suited to at least some of the sites they have been trialed on, and are tentatively recommended, bearing in mind that no one provenance or seedlot will succeed on every site.

Rubicon	**Toorongo**	**Macalister**
Barnewall Plain	Link Road	Conners Plain*
Blue Range Road	Mississippi	Heyfield
Bullfight Creek	Mt Erica*	Mt Skene
Cathedral Range*	Mt Horsfall*	Mt Useful*
Federation Range	Mt St Gwinear*	Mt Wellington
Mt Torbeck	Mt Toorongo Plateau*	
Mt Victoria	Penny's Saddle	
Roystan Range	Starling Hill	
Roystan Road	Upper Thomson	
Snob's Creek		
Toolangi		
Tweed Spur		

Errinundra	**South NSW**	**North NSW**
Bendoc	Anembo	Barrington Tops
Errinundra Plateau	Badja Mt*	Ebor
Hammonds Track	Nimmitabel	
	Tallaganda	

Note: * = *possible suitable seedlot for New Zealand conditions.*

Appendix Three. *Symptoms of Nutrient Deficiencies in Eucalypts*

These are nutrient deficiencies as recorded in Will (1985) for eucalypts in general, and should also be applicable to *E. nitens* (the full paper should also be consulted for remedies if any symptoms do occur). Additional information on nutrition and likely symptoms is from Salisbury and Ross (1992).

Care should be taken to examine all nursery stock before it is a) purchased and b) planted, not only for any possible nutrient problems but also for any insect pests or pathogens. Several psyllids are very small, and pathogens may be attached to the roots, so plants may require close expert scrutiny to determine their presence. Often new leaves and shoots contain bright colourations, which may be confused with nutrient deficiencies.

Until sufficient data on *E. nitens* foliar nutrition levels at different ages is collected, it may not be useful to conduct foliar analysis at an early age in an attempt to detect any potential problems

Nitrogen: Greenish yellow, yellow orange or red foliage depending on species and extent of deficiency. Similar colouration may occur on petioles or twigs. Older leaves will display the most severe symptoms, as N is translocatable and is transported to new leaves where the demand is greater. Some degree of deficiency exists in all New Zealand forests, but may not be as severe in pasture sites.

Phosphorus: Purple discolouration of foliage, probably due to accumulation of anthocyanin pigments. Phosphorus is also readily translocatable, so mature leaves will display deficiency symptoms first. Likely to occur in forests and areas where *P. radiata* requires extra P supplements.

Boron: Dieback of the new growing shoots in the crown, and may result in failure of root tips to elongate, although this will not be obvious. So far only recorded in stands in Nelson.

Iron: Interveinal chlorosis (loss of chlorophyll content and turns yellow). Similar to symptoms of magnesium deficiency found in other plants, but occurs first in the younger leaves, as it is relatively immobile and will not leave older leaves easily. Can be common in nursery or potted stock.