Blackwood (*Acacia melanoxylon* R. Br.) plantation silviculture: a review

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Summary

In Australia, blackwood is logged from native forest stands. The limited size of this resource, and its capacity to meet the demand for blackwood timber in the longer term, has resulted recently in the establishment of plantations in Australia. Plantation silviculture of blackwood has a longer history in New Zealand, South Africa and Brazil. A major problem in plantation establishment is that blackwood has poor apical dominance, producing large numbers of branches and trees of poor stem form when grown in full light.

Blackwood has two types of foliage, bipinnate compound leaves and vertically-oriented phyllodes. A phase change from leaves to phyllodes occurs, though this is reversible. The type foliage present can be a useful indicator of the prevailing light conditions. Apical dominance is associated with conditions of low light; shade also reduces the extent of branch development, encouraging good form. Blackwood is susceptible to frost and defoliation by pests though both are a function of the type of foliage present. Leaves are more efficient than phyllodes at producing photosynthate per unit carbon invested in foliage, though both types of foliage appear reasonably well adapted to a range of light environments.

Application of phosphorus fertiliser at planting is generally associated with improved early growth and this may be allied to increased numbers of root nodules. Addition of nitrogen fertiliser appears unnecessary in the absence of N deficiency. Whether grown in pure or mixed stands, form pruning is necessary to produce good stem form, and lift pruning of live branches to produce clearwood. Various approaches to form pruning have been used but all are designed to prevent the development of large branches. Crown shape, which is variable in blackwood, can determine whether lift pruning reduces subsequent growth. Establishment at high stockings and thinning to a final crop of between 100 and 250 stems ha^{-1} is used commercially. Nurse crops have been used, particularly in Tasmania, to induce good form and to minimise the requirement for form pruning. This practice has met with mixed success as the use of eucalypts or *Pinus radiata* has led to overtopping and suppression of the blackwood. In New Zealand, the use of nurse crops has led to little improvement in stem form.

Key words: silviculture; plantation; blackwood; *Acacia melanoxylon*

Introduction

Blackwood (*Acacia melanoxylon* R. Br.) is one of Australia's native ornamental timber species (Boland *et al.* 1984). It is much sought after by the furniture manufacturing and craft industries (Britton 1996) because of its wood properties, including colour (Harris and Young 1988). Blackwood grows to 6–35 m in height, and occurs naturally throughout the eastern seaboard as far north as southern Queensland in areas with an annual rainfall of greater than 600 mm (Costermans 1981). Small populations also occur further north. Its best development, in terms of superior growth and form, is found in cool temperate environments with deep soils, especially in tall forests in Tasmania and Victoria (Boland *et al.* 1984).

The main source of blackwood is native forest logging in Tasmania and western Victoria, although small quantities come from plantation-based resources in New Zealand, South Africa and Brazil (Nicholas 1981; de Zwaan 1982). Across its natural distribution, there are three forest types — swamp, wet sclerophyll and riverine — that support the production of high quality timber (Jennings 1998; Searle 2000). This is primarily because the structure of the forest encourages apical dominance and height growth, and restricts development of large branches (Allen 1992). Thus each type is characterised by the co-occurrence of blackwood with other species that restrict available sidelight during early growth, while allowing the upper crown to remain well lit. In swamp forests, close-spaced *Leptospermum* and *Melaleuca* species growing at the same rate as the blackwood result in the development of branch-free boles >15 m. In wet sclerophyll forests, the co-occurring species are *Pomaderris apetala* Labill. and eucalypts, mainly *Eucalyptus obliqua* L'Herit. and *E. regnans* F. Muell. The length of the branch-free bole is noticeably shorter (but >5 m) because of the limited height of *P. apetala* which provides most of the sidelight suppression. Some thinning of the eucalypts is required in this forest type to maximise blackwood production (Jennings 1998). In riverine forests, blackwoods emerge through 'light wells' into existing rainforest. These wells provide light conditions for growth and form similar to those found in swamps.

It is unlikely that the limited native forest resource can be managed sustainably to meet the current, as well as potential increases in, demand for blackwood timber (Allen 1992). Hence there is growing interest in Australia in the establishment of blackwood plantations. To date, about 800 ha have been established in Tasmania, the State with most potential for growing blackwood in plantations (Neilsen and Brown 1996). Conditions in plantations differ considerably from natural environments in which blackwood thrives. At planting, there is no suppression of sidelight and no shelter. In addition, intensive silviculture is generally required in order to produce high quality logs (Pinkard and Beadle 2001). The blackwood industry is small, however, and there has been relatively little research into suitable management regimes for plantations.

The objective of this paper is to summarise current knowledge of blackwood plantation silviculture. The variables that are known to affect the growth and physiological behaviour of blackwood are first explored, including a consideration of wood properties and environment. Silvicultural practices to improve growth and form in plantations are then discussed.

Growth

As blackwood is considered to be a minor timber species, it is not surprising that existing knowledge about how quickly this species grows, and what drives that growth, is at best basic. On high productivity, sheltered sites in New Zealand, height and diameter growth of about 1 m y^{-1} and 1.5 cm y^{-1}, respectively have been reported for plantations during the first 10–11 y of growth (Nicholas 1988, 2001). On equivalent sites, similar height growth has been reported in Japan and Tasmania (Waki 1984; Neilsen and Brown 1996). This may drop to as little as 0.3 m y^{-1} on exposed or drought-susceptible sites (Neilsen and Brown 1996). More rapid growth has been achieved in South Africa, with height increment of 2 m y^{-1} reported over the first 4 y (de Zwaan 1980).

Heteroblasty, expressed by having foliage of different kinds, and poor apical dominance are characteristics of blackwood that have captured researchers' attentions. In addition, problems associated with unfavourable climatic conditions, particularly frost, and pests have been issues in plantation establishment. The consequences of crown shape and foliage distribution in relation to stem growth also have been investigated. These factors are now considered in more detail.

Light, foliage type and apical dominance

Blackwood has two types of foliage that can be described in broad terms as juvenile and adult. After germination, bipinnate compound leaves are produced. Later, expansion of the petiole results in vertically-oriented phyllodes (Costermans 1981). The leaves are mesomorphic, with thin cuticles and little structural thickening. Virtually all tissues are photosynthetic (Brodribb 1992). In contrast, the phyllodes have a more elaborate structure, with very thick cuticles and substantial lignification; about half the tissue is photosynthetic, the rest serving support and storage functions (Brodribb 1992).

High light conditions lead to an earlier change from leaves to phyllodes. In pot experiments phyllodes appeared within 4–8 mo on seedlings grown in full sunlight, whereas those grown at 20% full sunlight had only leaves until at least 12 mo of age (Milton 1982; Brodribb 1992). Under some conditions this phase change may not occur or is reversed. Thus under prolonged shade, the leaves may persist for several years (E.A. Pinkard, unpublished data) while there may be a reversion to leaves following a change from exposed to shaded conditions. The production of leaves may be associated with environments (e.g. low light conditions) that favour apical growth (Borchert 1965; Carr and Burdon 1975). Factors other than light intensity may also trigger phase change. Brodribb and Hill (1993) hypothesised that photoperiod and temperature may play a role, and Farrell and Ashton (1978) suggested that the age at which conversion from leaves to phyllodes begins was inversely correlated with annual rainfall.

Leaves may be an adaptation to deal with low or variable light conditions, or to maximise height growth in environments where there is competition for light. Farrell (1973) suggested that leaves were shade adapted and phyllodes were sun adapted. This argument was supported by Milton (1982), who found that blackwood grown in shade had greater total foliage area, and greater height growth, than plants grown in sun. In addition, seedlings compensated for low light conditions by retaining leaves for longer and producing larger and more horizontal leaves.

Blackwood has poor apical dominance when grown under high light conditions (Barton 1993; Nicholas and Gifford 1995; Neilsen and Brown 1996). This results in large numbers of branches and relatively short trees. Apical dominance is strengthened by good growing conditions combined with adjacent vegetation that offers sidelight suppression, particularly during the early phase of growth (Brown 1997). Exposure to browsing, strong winds and frost can reduce apical dominance (Neilsen and Brown 1996; Brown 1997).

Thus both apical dominance and height growth increase under low light conditions (Milton 1982). Although height growth increased under shade, shoot dry mass did not differ between plants grown in sun or shade (Milton 1982). The ratio of shoot to root dry mass was also substantially greater in plants grown under shade than those in a high light environment. Blackwood seedlings grown in the shade allocated less biomass to branch development, although total leaf area could be as great as or greater than that of seedlings growing under high light (Milton 1982). These changes in biomass partitioning allow shaded blackwood to maintain height growth and produce trees of good form where suppression of sidelight is adequate.

Frost

Phyllodes have greater frost resistance than leaves, probably as a result of the thicker cuticle and greater cell wall thickening (Brodribb and Hill 1993). In a comparative study of several *Acacia* species, including blackwood, Pollock *et al.* (1986) observed seasonal increases in frost tolerance of up to 4°C in winter. Blackwood was one of the more frost-resistant species. Provenance trials, however, have demonstrated inter- and intra-provenance variation in frost susceptibility (Franklin 1987; Brodribb 1992; Neilsen and Brown 1996). Neilsen and Brown (1996) found that high-altitude provenances were less affected by frost than low-altitude or coastal provenances, but were also slower growing. Within these generalisations, it is important to recognise that microenvironment and ambient conditions during hardening and dehardening are important determinants of the ability of any species to survive a frost (Greer and Stanley 1985; Hallam *et al.* 1989). A study of blackwood in China found that frost injury was most related to cold air pooling associated with topography and terrain rather than to altitude (Yang *et al.* 1992).

Pests

Blackwood foliage contains up to 16% protein, and is a desirable food for many browsing animals (de Zwaan 1982; Neilsen and Brown 1996). Neilsen and Brown (1996) found that mammal browsing significantly reduced height growth over the three years following planting, with little height increment if seedlings were left unprotected from browsing. As pointed out above, browsing can lead to poor apical dominance. Another study using insecticides concluded that insect defoliation was not the major cause of poor apical dominance at one site in New Zealand (Nicholas and Hay 1990).

As phyllodes are less palatable than leaves to browsing animals and phosphorus (P) increases the proportion of phyllodes to leaves in the nursery, sound P nutrition may contribute to the survival of outplanted stock (Knight 1986).

Crown characteristics and stem growth

Stem growth rate may vary with crown shape and hence with patterns of foliage distribution through the crown. de Zwaan (1981a) found that trees with conical (largest branches in lower crown) or diamond-shaped (largest branches in mid-crown) crowns grew faster than those with poplar-shaped (long and narrow) crowns. Differences in crown shape appeared to be related to foliage area. The proportion of phyllodes present in the crown also may affect height growth. de Zwaan (1982) determined that growth rate decreased as the proportion of phyllodes increased, and Brodribb and Hill (1993) observed that slower-growing provenances of blackwood generally produced phyllodes earlier than did faster-growing provenances. This may also be an adaptation to deal with prolonged frost susceptibility associated with slower growth.

Physiological characteristics

Brodribb (1992) demonstrated that, while photosynthetic rates per unit leaf area were similar between leaves and phyllodes, leaves had greater photosynthetic rates per unit dry weight at most light intensities than did phyllodes. This means that a leaf is more efficient than a similar-size phyllode at producing photosynthate per unit of carbon invested in foliage. The reduced investment of carbon required for leaf production results in a greater potential for rapid development of shoots and roots early in the life cycle (Brodribb 1992). This author also found that, under conditions favourable for plant growth and as the level of light increased, increases in photosynthetic rates of leaves and phyllodes were similar. A high degree of between-leaf/phyllode variability in these response curves suggests that foliage of either type has the capacity to adapt to a range of light environments (Brodribb 1992).

Brodribb (1992) observed that under water-stressed conditions, phyllodes had higher water-use efficiency (g CO_2 g^{-1} H_2O) than leaves. At soil water potentials below –2.8 MPa, leaves had lower water-use efficiency than phyllodes, irrespective of relative humidity. Leaves were damaged beyond recovery at these water potentials, whereas phyllodes recovered fully from water potentials as low as –5.5 MPa. These findings support the belief that phyllodes are an adaptation to drought (Givnish 1978).

Like many legumes, blackwood forms a symbiotic relationship with a nitrogen-fixing bacterium that induces nodule formation on blackwood roots. The bacteria provide nitrogen (N) to the plant in return for carbohydrate (Fogg 1966). Little is known, however, of the physiology of blackwood root nodules, although light environment, nutrition and water availability all may affect nodulation (Davey and Wollum 1984). Milton (1982) found that, while number and size of nodules on 15-mo-old seedlings were reduced under low compared to high light conditions, nodule dry mass per unit root dry mass was greater for the shaded than for the exposed plants. Nodule dry mass per unit whole plant dry mass was the same for sun and shade plants.

The effect of water stress on blackwood root nodules is unknown. However, water stress has been reported to reduce both N fixation and nodule development in a number of species (Mrema *et al.* 1997; Gonzalez *et al.* 1998). In *Leucaena leucocephala* seedlings inoculated with *Rhizobium* bacteria the combined effect of water stress and N addition resulted in cessation of N fixation, although the presence of root nodules in plants not receiving N increased tolerance to water stress (Mrema *et al.* 1997).

Wood properties

Blackwood is a medium-density hardwood. Its basic density ranges between 465 and 671 kg m^{-3} (Harris and Young 1988; Clark *et al.* 1992). Basic density generally increases with age, although there is a large between-tree variation (Harris and Young 1988). A strong negative relationship has been found between basic density and rainfall in *Eucalyptus globulus* Labill. (Raymond and Muneri 2000): the effects of environment on basic density of blackwood have not been investigated. Streaks of tension wood are common in blackwood, and tend to become very gummy in the heartwood. This gives rise to dark-coloured wood (Harris and Young 1988). Blackwood with poor form (i.e. poor apical dominance) tends to have severe cross-grain which makes processing difficult (Haslett 1986).

Heartwood development is greatest on moist but well-drained deep organic soils. Wetter, more organic soils seem to produce finer grain, and high rainfall may promote heartwood darkness (Harrison 1975b). The number of rain days may be more important than total annual rainfall in determining darkness, and a dormant growth season may maximise the brown pigment that is important in determining heartwood darkness (Harrison 1975b). In a study of genetic and environmental effects on timber quality, Harrison (1975a) found no correlation between timber and foliage characteristics.

Silvicultural practices to improve growth and form

Silviculture in blackwood plantations aims to improve growth rates and apical dominance, thereby producing tall, straight stems with small branches. The most valued products are logs of veneer quality and timber suitable for furniture manufacturing and craft (Britton 1996). In most instances intensive silvicultural management is required in order to produce high quality blackwood in plantations over rotations of around 45 y (Searle 1996). To date only limited research has been undertaken, and this is summarised below.

Fertiliser application

As nitrogen-fixing bacteria provide N to the plant, it is commonly considered that N fertilisation is unnecessary in blackwood plantations. Waki (1984) found that large applications of N to established *Acacia mearnsii* did not improve growth, while growth was improved through P application. Similar results were observed in a field study of blackwood (E.A. Pinkard, unpublished data). Large growth responses of blackwood to P but not to N or potassium (K) in South Africa (de Zwaan 1982) support this finding. In a study using potted seedlings, Knight (1986) showed a substantial and similar requirement for sulphur (S) and P to maximise seedling height and dry mass. Vigorous growth was associated with foliar N:P:S of 2.7%:0.23%:0.16% and he concluded that superphosphate (10% P:11% S) was a suitable source of both nutrients.

Applications of N are important to early growth of *A. mearnsii* (Waki 1984). In blackwood, Brodribb (1992) found that N deficiency significantly depressed rates of photosynthesis of leaves, although phyllodes with similar levels of N were unaffected, suggesting that N nutrition may be an important determinant of growth during the juvenile phase.

Fertilising 4-y-old trees with P doubled the number of root nodules, but applications of N had no significant effect on nodulation at a site in Tasmania (E.A. Pinkard, unpublished data). Waki (1984) also found that applications of P improved root nodulation in *A. mearnsii*, while N application had no effect. Large positive responses of blackwood to P addition have been reported in a number of studies (e.g. de Zwaan 1982; Nicholas 1988). This has led to the general recommendation that P fertiliser be applied routinely at establishment of blackwood plantations (Nicholas 1988; Neilsen and Brown 1996). At one New Zealand site with poor soils and summer drought, however, a negative linear relationship between diameter increment and rate of application of superphosphate was observed. This was partly related to increased weed competition following the fertiliser application (Fairweather and McNeil 1997). Fertiliser responses will depend on soil type, water availability, competition from surrounding vegetation, and the presence and activity of root nodules.

Pruning

The primary objective of growing blackwood in plantations is the production of clearwood (knot-free timber). The characteristic lack of apical dominance exhibited by blackwood growing in high light environments, and its propensity to produce large branches, means that pruning may be necessary to produce clearwood. Two types of pruning are used: form pruning where selected branches are removed from throughout the crown; and clearwood pruning where all branches are removed from the lower crown to a predetermined height above ground.

Form pruning has been found to improve stem form and increase the number of trees that can be selected for clearwood pruning (Nicholas and Gifford 1995). Form pruning removes large (>3 cm diameter) branches and/or competing leaders. In New Zealand an experiment investigated annual and triennial form pruning, and annual form pruning to remove all branches >3 cm diameter. The treatments improved tree form by 15–18%, where form is judged on stem straightness, presence or absence of multiple leaders and number of large or competing limbs. The annual pruning that only removed branches >3 cm diameter removed the least number of branches over a 4-y period (6.9 $tree^{-1}$), while the annual form pruning removed 11.3 branches $tree^{-1}$. Diameter and height increments were not affected by these treatments 4 y after pruning (Nicholas and Gifford 1995). Both treatments improved the ease of clearwood pruning because they reduced the number and size of branches to be removed in that operation.

Tip pruning has been suggested as an alternative to form pruning for open-grown trees (Barton 1993; Brown 1997). It involves removing about a third of the length of all competing shoots, and has been found to improve stem form. A similar method, known as segmental pruning, reduces stem malformation and development of large branches. Segmental pruning removes competing shoots, and reduces any remaining vertical shoots to half their original length (Brown 1997). Both tip and segmental pruning start about 6 mo after planting, and must be carried out at the beginning and end of each summer in order to be successful. Hence they are expensive options for large-scale plantations.

Clearwood pruning removes live branches and is usually done in a number of stages known as lifts. In studies with species other than blackwood (e.g. Helms 1964; Heichel and Turner 1983; Pinkard and Beadle 1998), the effects of pruning on growth were related to the amount of leaf area removed and physiological characteristics such as foliage distribution throughout the crown, photosynthetic responses and rates of leaf development following pruning. Little such information is known for blackwood, but in South Africa it was demonstrated that crown shape (i.e. foliage distribution) affects responses to first-lift pruning. Trees with poplar- or diamond-shaped crowns showed little change in stem growth following pruning, because little foliage was removed by the removal of 40% of the length of the green crown. There was a significant reduction in stem diameter of trees with cone- and bullet-shaped crowns following pruning, although growth rates recovered in the longer term (de Zwaan 1981a). Nicholas and Gifford (1995) recommended removing a maximum of 50% of crown length to minimise growth losses following pruning. In Tasmania the recommended pruning regime involves removal of 40% of crown length (Neilsen and Brown 1996).

Pruning creates a cut surface that is a potential portal for the entry of pathogens causing disease and decay. Pruning wounds heal fastest when small (1–2 cm diameter) and when cuts are vertical (Nicholas *et al.* 1994). Large wounds (>4 cm diameter) may take more than four years to occlude, increasing the risk of decay entry. There has been little study of microbial infection of pruning wounds in blackwood (Nicholas and Hay 1990; Swanson 2001), although serious problems may be encountered in eucalypts

(Wardlaw 1996; Mohammed *et al.* 1998). Nicholas and Gifford (1995) recommended that form pruning should commence before 4 y of age to reduce the incidence of large pruning wounds.

Thinning

Thinning is required in blackwood plantations to ensure good diameter growth of pruned stems (Nicholas 1988). In New Zealand crown diameter ratios were used to determine that a final stocking of 100 stems ha^{-1}, while not maximising volume production of the stand, would allow maximum diameter growth of crop trees during a rotation of 40 y (Nicholas 1988). The recommended regime involves three thinning operations, from an initial stocking of 1500 stems ha^{-1} to 1000 stems ha^{-1} at age 3, then to 150 stems ha^{-1} at age 10, and to the final stocking of 100 stems ha^{-1} at age 13 y (Nicholas 1988).

A progressive thinning to a final stocking of between 300 and 400 stems ha^{-1} at age 17 y maximised the volume of utilisable timber at age 34 y in South Africa (de Zwaan 1982). Thinning to 173 stems ha^{-1} was too severe, and to 445 stems ha^{-1} may have been too light in terms of maximising both stand and individual tree volume.

The optimum stocking in natural stands in swamp forest in Tasmania is about 200 stems ha^{-1} (Allen 1992). The Tasmanian blackwood plantation regime recommends thinning to a final stocking of 250 stems ha^{-1} in one operation (Neilsen and Brown 1996).

Using nurse crops to improve stem form and early growth

In native forests that include a blackwood component, the surrounding vegetation suppresses sidelight and offers buffering from high and low temperatures and wind, thereby promoting apical dominance (Jennings 1998). Nurse crops are used in plantations to induce these effects. The main species that have been used to date are *Pinus radiata*, *Eucalyptus nitens* (Deane and Maiden) Maiden or *E. globulus* (Neilsen and Brown 1996), although rainforest species such as *Pomaderris apetala* and *Melaleuca ericifolia* Sm. have been used on a small scale in experimental trials (S. Jennings, Forestry Tasmania, *pers. comm.*). Inter-planting blackwood with a nurse crop species can improve blackwood form in some instances (Neilsen and Brown 1996). In New Zealand, however, there was little improvement in form when mixed blackwood/*P. radiata* plantings were compared with pure blackwood stands, and this led to the recommendation that pure blackwood stands be established. The success of the nurse crop species in suppressing sidelight and providing protection from wind and temperature extremes will depend on the density at which the nurse crop is planted, the species used and the relative growth rates of the blackwood and the nurse crop. In Tasmania, alternate rows of blackwood and the nurse crop are spaced at intervals of 2.5 m to 4.0 m. This system results in little early ‘nursing’ of the blackwood and means that pruning must be combined with the nurse crop system.

Nurse crops may be ineffective in protecting blackwood from wind and frost damage. Franklin (1987) found that an *E. nitens* nurse crop established with blackwood had little effect on frost-induced damage of blackwood, even when the eucalypts were 4–5 m tall. Most of the frost damage appeared to be caused by ponding of air and freezing fogs rather than radiation frosts. Where blackwood was planted under an existing cover of eucalypts, however, frost damage was negligible. Neilsen and Brown (1996) similarly found that there was greater frost damage and reduced height growth of blackwood grown near a windbreak than in the open, which they attributed to poor cold air drainage. This suggests that row orientation may be important in determining the effectiveness of a nurse crop if ponding of cold air is likely to be a problem. In frost-prone areas establishing the nurse crop before the blackwood may offer greater protection from frost damage.

Eucalypt species and *P. radiata* remain the favoured nurse crop species (de Zwaan 1981b; Nicholas 1988; Neilsen and Brown 1996) and, as they generally have a much faster growth rate than does blackwood, it is possible to get effective early nursing if the *P. radiata* is spaced appropriately. However, overtopping and eventual suppression of the blackwood can then be a problem (de Zwaan 1981b). For example at age 5 y, the average heights of the blackwood and *P. radiata* nurse crop were 5.4 and 7.2 m, respectively (Medhurst and Worledge 2001). Thinning of the nurse crop is therefore required. Removal of 66% of the *P. radiata* nurse crop at age 5 y resulted in a significant increase in diameter growth of the blackwood (Medhurst and Worledge 2001) although this was accompanied by some deterioration of stem form of the blackwood (J.L. Medhurst, unpublished data).

There is little information comparing direct versus progressive thinning regimes for blackwood/nurse crop systems. Direct regimes are favoured in large-scale plantations in Tasmania except where the aim is to produce clearwood from selected nurse-crop trees as well as the blackwood (Neilsen and Brown 1996). Windthrow can occur if the nurse crop is thinned too late or too severely as blackwood growing in low-light environments has a greater shoot:root ratio than do open-grown trees (Milton 1982). However, factors influencing windthrow, including timing and severity of thinning, have not been examined in detail. When the nurse crop is much taller than the blackwood, the potential for damaging the blackwood stems during thinning also requires consideration.

An alternative to thinning was tried in South Africa. It involved lopping the tops of the nurse crop trees. However, it was done once the nurse crop was too large for thinning, and it proved impractical (de Zwaan 1981b).

Conclusions and implications for management

Blackwood has proven to be a species that is not easy to grow in plantations without a substantial amount of intervention. This must include some level of form pruning and lift pruning to produce clearwood (Barr 1987; Barton 1993). Thinning schedules have also been developed. However, there may be opportunities to use nurse crops more effectively than at present. While nurse crops like eucalypts and *P. radiata* may improve form and reduce branch size (Neilsen and Brown 1996), there is little evidence that they provide much ‘nursing’ of the blackwood early in the rotation. Later, if managed inappropriately, nurse crops can result in suppression of the blackwood and damage to blackwood stems during thinning operations. As nurse crops remain an attractive option for inducing form in industrial plantations, more effective management of the species used at present or the possible use of alternative nurse crops requires some attention.

The response of blackwood to fertiliser and the role of root nodules in its nutrition remain poorly understood. There is a positive response to phosphorus application (de Zwaan 1982; Nicholas 1988) and apparently no response to nitrogen application. Fertiliser responses, however, are anticipated to vary with site conditions such as soil fertility, moisture availability and level of weed competition, a level of detail that still requires more insight.

As blackwood has considerable within- and between-provenance and between-tree variation in growth, timing of phyllode initiation, crown shape and wood properties of blackwood (Harrison 1975a; de Zwaan 1982; Brodribb 1992), there may be potential for tree improvement through provenance selection and genetic manipulation (Searle 2000).

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