

Seedling Quality

Making informed choices

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Including:

- Physical quality of seedlings
- Seedling tray and cell design
- Interactions of cell design with efficient planting technique
- Genetic quality of seedlings



DEPARTMENT OF
Conservation
AND LAND MANAGEMENT
Conserving the nature of WA

Bushcare
THE NATIONAL VEGETATION INITIATIVE

Acknowledgments:

Bushcare (a Natural Heritage Trust program) and the Department of Conservation and Land Management supported compilation of this information.

The technical support of experienced revegetation and nursery practitioners is also gratefully acknowledged. These were:

John Edwards - Field Manager, Blue Gums Forest Products Commission.

Wayne O'Sullivan
Arborescence Consultancy.

David McFall - Regional Manager (Upper Great Southern), Oil Mallee Association.

Bill Hollingworth - Bandicoot Nursery, Mt Barker.

John Brealey - Manjimup Nursery Manager, Forest Products Commission.

Recommended reference for this report:

Mullan, G. D. and White, P. J. 2001. *Seedling Quality: Making informed choices*. Bushcare and the Department of Conservation and Land Management.

Front cover photo's:

Top image shows seed provenance differences between *Eucalyptus loxophleba* subsp. *loxophleba* (York gum) seedlings at 5 months age.

Small images, left to right:

- a) seedling plug grown in a Col-Max® cell showing strong vertical root development.
- b) Col-Max® growing cells.
- c) kwik pot'® (plastic insert type) tray.
- d) seedling plug grown in a fully air root pruned growing cell.
- e) fully air root-pruned growing cells.

All photo's in this report were taken by G. Mullan.

Executive Summary

This report aims to inform nursery customers about the importance of seedling quality.

During the on-ground phase of the 'Dongolocking Pilot Planning Project for Remnant Vegetation', seedling survival and performance were closely monitored. Monitoring and investigation revealed that seedling quality was limiting the ability of revegetation to deliver environmental outcomes.

The main limiting factor was poor seedling root form (architecture). Poor root form is implicated with reduced survival and performance that last the life of the plant. This is a hidden and high cost borne by the customer. It is a truism that the most expensive seedling is one that doesn't survive or performs poorly.

Interestingly, evidence we gathered indicates that seedlings grown for environmental management purposes (landcare) have somehow less need for quality than seedlings grown for commercial tree crops. For example, seedlings grown for environmental management in agricultural landscapes usually escape the rigours of quality control that are common place for commercially oriented seedlings. Nursery management is the central point requiring change in practices, and with this, increased customer awareness of quality and value for money.

A best practice planting technique we developed during the project is illustrated. This technique minimises planting shock and physical damage to the seedling after nursery dispatch and optimises speed and ease of planting.

The genetic quality of seed was also considered. We judged that most environmental management projects in agricultural landscapes underestimate the value of high quality seed and the losses incurred by using undesirable seed. Scarcity of quality seed was a key issue.

Four Key Points

a) **Root form must meet minimum standards**

Nurseries need to pay particular attention to root form. Root pruning in the seedling cell must be consistently effective. We suggest that the cost of ensuring good root form will be minimal compared to the cost of losing informed customers. Indeed, optimal root form could be used as a marketing tool.

b) **Seedlings grown for ‘environmental management’ must improve in quality**

Stakeholders, including funding bodies, nurseries and nursery customers should understand that seedling quality is just as important for environmental management as it is for commercially oriented applications. Customers are encouraged to use a list of quality specifications that must be met in selecting a suitable nursery. Standard quality specifications are now available from the Department of Conservation and Land Management’s NatureBase web site - <http://www.naturebase.net/projects/index.html>. (available Feb 03).

c) **Awareness of ‘value for money’ must increase**

Customers bear the lifelong cost of a poor quality seedling. Awareness raising will help customers make informed choices.

d) **Need for seed production areas and protection and management of remnant bush**

Quality seed in the wheatbelt is scarce. Increasing demand for local seed is already placing excessive pressure on quality remnant bush and forcing collections from undesirable seed sources. Carefully planned and implemented seed production areas for at least some key species will provide local communities with good quality ‘local provenance’ seed.

Additionally, we consider that criteria for all revegetation should include a standard of seed quality. This quality will be such that the revegetation (progeny) will be a suitable seed source for future revegetation (i.e. the progeny seed stock will consist of seed from various population outcrossings).

Action to secure quality seed should also consider the protection and management of all areas of remnant bush.

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Purpose of this report

To improve selection of nursery stock by seedling customers.

Major factors highlighted:

- a) characteristics of a high quality seedling
- b) the impacts of seedling container design and nursery management on seedling quality.
- c) the planting efficiency gains from using particular seedling container designs.
- d) the impacts of the genetic quality of seed.

Who will benefit from this information?

- nursery customers,
- land management personnel involved in revegetation projects and
- nursery operators and staff.

Introduction

Seedlings ranging widely in quality are produced and sold across south west WA annually. Substantial variation also occurs in customer perception of seedling quality issues. Despite this, all customers clearly desire a seedling that will survive and perform to a potential not restricted by seedling quality.

Limitations in seedling quality are, in economic terms, a cost transferred from the nursery to the customer, ie the nursery customer incurs the costs of a sub-optimal quality seedling. Unfortunately for the customer, unlike seedling price, this cost is usually ongoing. The extent of this cost and its relationship with seedling price is demonstrated to be undervalued by nursery customers and nursery operators and staff.

Acknowledgment is given to the economic forces that drive nursery management practices and the bottom line cost of growing each seedling. Acknowledgment is also given to the close links existing between nursery practice, seedling transport, ease of seedling management in the field and seedling quality. In particular, substantial nursery infrastructure is closely tied to the seedling container type(s) used. For

example, a change in container type can mean a change in infrastructure (eg bench type and dimensions, sterilising equipment, container filling equipment, dimensions of transport equipment), watering regime, media usage and fertiliser (type and application), ie a whole new growing system and therefore a decision not to be taken lightly.

In terms of seedling cost, nurseries are inevitably influenced by market forces. Perceptions indicate that where commercial plant production outcomes are not the driving force, eg revegetation for environmental management, a low seedling price tends to take prominence over seedling quality, ie a perceived marginal increase in nursery seedling quality (and price) is apparently not rewarded and so, results in a reluctance to change the nursery growing system. However, requirements of commercial forestry and environmental management are identical, ie maximum growth and survival.

The most revealing indicator of cost to the customer is the success of seedlings in the field. The most expensive seedling is one that fails or performs poorly in the field.

Seedling physical quality

Emphasis is given here to the impact of cell design on the plant root system. As a seedling customer, the root system quality should take at least equal prominence to seedling stem and leaves. Often the only part of a seedling judged is the most visible feature, ie the stem and leaves.

The impacts of a poor root system (especially root spiral), have far reaching penalties and importantly are a cost to the grower. These include:

- a) Increasing the time between out-planting and the reintroduction of agricultural stock, eg returning sheep to a paddock with oil mallee eucalypts. Both sub-optimal seedling performance and the need for infilling increase the number of stock exclusion days.
- b) Reduced plant vigour resulting in increased length of tree harvest rotations.

- c) Reduced water use, and:
- decreased effectiveness of trees planted for salinity control.
 - increased likelihood, and frequency, of moisture and waterlogging stress (including premature death).
- d) Reduced plant vigour, limiting 'habitat value'.
- e) Imposed instability and increases in the incidence of wind-throw.
- f) Imposed greater management and capital outlay requirements in all cases when death occurs and in-filling is necessary.
- g) Increased cost of planting if corrective measures are required in the field, eg cutting or more commonly pulling off excess roots. Seedlings are often damaged, or at best, stressed when this action is taken.
- h) In addition to technical issues, the conditioning of landholder perceptions to sub-optimal seedling performance and survival often leads to reduced interest in revegetation as a land management option.

Published values of the performance differences between a range of physical seedling qualities are not available for the wheatbelt. In their absence, the following indicators are used in support of seedling customers giving increased consideration to seedling quality when placing nursery orders and deciding on value for money:

- a) The wide spread use of a fully air root pruned seedling container type by the forestry industry in Australia, South Africa and New Zealand. This usage is specifically aimed at seedling root quality. The forestry industry is clearly focused on optimising seedling survival and performance.
- b) In one event, 15 % of planted seedlings (mallee eucalypt planting) perished in the first 12 months. A sample of these were excavated. Severe root spiralling was consistently observed with few roots beyond

the spiralled root mass (*E. horistes* and *E. plenissima* - grown in plastic insert trays with poor application of copper based paint). Another planting using seedlings with root spiralling suffered a similar level of losses (*E. polybractea* - grown in plastic insert trays with poor application of copper based paint). In both instances, observations were made by specialist revegetation personnel and were more than casual observations. For example, the possible influence of seasonal conditions, planting technique and seed quality was eliminated by thorough investigations. Additionally, observers were involved with the planting operation and had first hand knowledge of the status of seedling plugs and of the containers.

- c) Excavations of early plantings of mallee eucalypts indicated a clear link between poor growth and root spiralling. Indeed, after a number of excavations, the degree of root spiralling was estimated with reasonable accuracy before excavation. The estimation was based on visual leaf area, plant vigour assessment and the presence of a 'cone' shaped hole around the stem of the seedling. The cone shaped hole indicated a constricted root system that was providing inadequate support, causing the plant to blow around. Contractors planting many of these seedlings confirmed root binding at particular sites. Contractors also indicated that action to minimise the impact of root binding in the field was not taken, as they were not paid to do so. Again in all instances, specialist revegetation personnel made these observations.
- d) The impacts of a restricted root system are demonstrated in revegetation undertaken when Jiffy (compressed peat) cells were in use. Jiffy cells are renowned for restricting roots, in particular, the development of a thick layer of roots in the base of the cell. These roots were not evident, as the peat container was part of the root plug. Evidence at some revegetation sites 10 - 20 years after planting show signs of failing root systems. For example, excessively shallow roots combined with uneven root distribution (the majority of root development occurring on

one side) (figure 1) and a high proportion of leaning trees (in different directions) (figure 2). Three implications are important here: 1. seedlings do not necessarily grow out of a particular root form imposed in the nursery, 2. seedling customers are rarely ever in a position to identify the restricted growth and 3. if growth restrictions were identified by customers, establishing a link with physical seedling quality would be even more difficult. Furthermore, seeking compensation after out-planting would be difficult. Thus, in the absence of an education campaign, consumer demand is unlikely to change to properly reflect known risk factors.



Figure 1. The underside of a 15 year old eucalypt tree. The roots display shallowness and a one sided distribution. The tree was performing poorly and was easily pushed over.



Figure 2. A 15 year old eucalypt tree has lost its grip. The apparent absence of sinker roots combined with an uneven distribution of roots and spiralling of roots immediately beneath the trunk is evidence for nursery imposed poor root form.

Emphasis on particular issues:

- Science, the forestry industry (with clear priorities in producing high quality seedlings), experienced government agency personal and some growers all indicate a common understanding. That is, improvements to seedling quality through reducing known risk factors result in important improvements in the field.
- Proving the exact extent of the costs incurred by degrees of seedling quality would take decades, ie performance and survival characteristics, in some instances, will only become apparent many years after out-planting. Given the amount of empirical evidence already existing however, action to minimise known risk factors as outlined in this information is considered a priority for all nurseries.
- In addition to the above point, some examples of historical events that have stimulated nursery management to improve quality indicate that customer rejection of seedlings is the driving force. Interestingly, of the instances known, all seedlings were for either commercial (Blue gum) or prospectively commercial

(oil mallee eucalypt) applications. Furthermore, in all instances, customers of commercial or prospectively commercial seedling species were aware of the nursery phase risk factors of seedling quality.

The implications of this are reflected in current customer ordering procedures. Customers ordering non-commercial species in particular do not generally have an adequate understanding of seedling quality issues. This particular customer segment rarely, if ever, include specifications of seedling quality when placing seedling orders (this is often Community Landcare Coordinators representing farmer groups).

An added variable of particular note is as follows. Many non-commercial seedlings are essentially free to the landcare customer, by way of NHT funded projects. It is very evident that the value a customer places on quality is proportional to the amount paid. Therefore the notion of 'the customers don't complain' is not a valid reason to postpone the minimisation of risk factors, ie standards are not set by the landcare customer. In contrast, all commercial and prospectively commercial seedlings are grown to quality specifications.

- Customers should be aware that the WA Nursery Industry Association (NIA) does not have a quality assurance accreditation scheme. Nurseries however, can be accredited with the WA NIA hygiene standards scheme.

From a revegetation practitioners viewpoint, the greatest gains on current seedling survival (at least) in the wheatbelt could be achieved through improving revegetation site preparation and matching of species to growing conditions. For example, revegetation projects commonly achieving 85 % survival could realistically be improved to 95 %. This figure is achievable in the wheatbelt, even during seasonal events such as those experienced in 2000 / 2001 (driest period on record). This figure also equals the benchmark set by the Oil Mallee Association.

Seedling genetic quality:

Aside from the physical qualities of seedlings, genetic quality of seed is an issue that rarely rates a mention, in particular, where seedlings are grown for landcare. Ironically, it can impact by producing a tree that forever performs below the potential of the land and climate resource that it occupies. Conversely, investment in quality seedlings will maintain above average growth on the land resource and will continue without further cost.

Importantly, the results of poor genetic seed quality are hardly ever identified. Even in acute cases, if seedlings succumb to an early death or seeds fail to germinate, without comparisons with seedlings grown from good quality seed, recognition of the problem is difficult.

In terms of acquiring appropriate seed, customer timing of seedling orders often limits access to high quality seed stock by nurseries. Orders in the wheatbelt generally allow time only for off the shelf seed purchases from seed merchants before seeding.

Issues raised in the preparation of this information

a) **Defining successful establishment.** The role of seedling quality in the concept of successful plant establishment was interpreted differently by nursery personnel, farmers and revegetation practitioners. Specific to seedling quality, this guide identifies successful seedling establishment as:

- High survival (greater than or equal to 95 percent),
- Early and longer term (eg 10 - 20 years) growth rates that are only restricted by the land and climate resource, ie not restricted by an imposed (in the nursery) root form.
- Use of a seed source that minimises the impact of inbreeding depression.

Even though point 2 may be difficult to assess, empirical evidence indicates benefits from employing a fully air-root pruned cell (container) type. Forestry companies involved with optimising production routinely demand, or use themselves, this type of cell.

b) **High quality seedlings – Low quality revegetation site preparation!** Can we postpone further advancement of seedling quality until the majority of revegetation sites are prepared to a matching level of quality? Whether nursery best practice is applied or not is unrelated to how customers prepare sites for revegetation. However, background information is given to this issue.

Revegetation site preparation standards in the WA wheatbelt are generally improving, albeit slowly. Without a short rotation commercial tree crop for much of the wheatbelt, the urgency to improve site preparation for landcare plantings alone appears to be a low priority to land managers. However, with a number of revegetation focused projects, the commercially prospective mallee eucalypt and likely others, eg *Melaleuca* spp., *Acacia* spp. in the wheatbelt, site preparation is predicted to improve at a faster rate than previous. Therefore, it is contended that the current standard of site preparation provides little reason for delaying

further improvements in seedling quality. Even if site preparation standards remained unchanged, improved seedling quality allows for greater tolerance of site preparation limitations.

c) **Making the nursery growing system work.** Determining the reasons for a sub-optimal quality seedling can often be difficult to pin point. For example, a particular cell or tray type may be identified as being responsible for root spiralling. However, as is outlined further on, it may indeed be a nursery management issue rather than a product limitation. Likewise, seedlings may be difficult to extract from some cell types. This could be a result of the media used or the length of time spent in the nursery.

d) **Impact of seed quality.** Identification of the increasing demand for seed will no doubt result in increased pressure on the seed resource. Already, seed collectors are resorting to roadside collections to fill orders. This practice increases the percentage of 'bad' seed resulting from self-pollination or closely related matings. Indications are that good quality seed is increasing in scarcity and therefore predicted to increase in cost proportional to scarcity.

Indeed, with increasing demand for quality seed, there is good reason to recommend the establishment of localised seed production sites.

Definitions:

Seedling cell - The container that each individual seedling occupies.

Seedling plug - The root mass and the rooting media that is contained within each cell.

Seedling tray - One unit containing multiples of cells. A tray can be rigid and free standing or a flexible insert arrangement. Trays in common use contain 64 seedlings.

Plug popping (seedlings) - seedlings are pushed upwards from their base by about 30 mm. This process loosens seedlings sufficiently to allow unassisted removal from each cell.

Plug popping pad - this is a flat section of rigid material incorporating one solid cylindrical pin per seedling cell. There are two types:

- a) Automatic plug popper (foot operated). The pins sit about 30 mm in height from the base plate when fully extended (by the action of the foot pedal). The pins fit snugly into the opening at the bottom of each seedling tray cell (figure 20). This type is usually nursery based.
- b) Manual plug popper (operator pushes the tray onto the pins). The pins sit about 30 mm in height from the base plate and are fixed in this position. The pins fit snugly into the opening at the bottom of each seedling tray cell. This type is a single flat plate without any attachments and is highly portable. It is most suited to on-site field based operation.

Both types require the cylindrical pin material to be very durable and maintain its rigidity, eg steel, aluminium, etc.

Types of seedling cells / trays

A vast array of cell / tray types exist. These include, injection moulded rigid plastic trays, vacuum moulded disposable tray inserts, individual plastic cells, paper and compressed peat. The selection criteria that a nursery uses to choose a cell type may be different to that desired by the purchaser of seedlings - the tree grower (investor) and / or those in the field planting the seedlings.

The key issues that are relevant to the seedling customer include:

- a) Root pruning ability
- b) Root training ability
- c) Seedling cell shape
- d) Seedling cell volume
- e) Packing density
- f) Cell diameter
- g) Cell depth
- h) Ease of seedling extraction
- i) Ability to retain moisture
- j) Total seedling number per tray

1. Root pruning ability

Once germinated, the seedling root will grow towards the base of the container. Without effective root pruning the dominant vertical root will bend at the bottom of the pot and grow in circles following the internal wall of the cell. As the root tip is still actively growing, there is little tendency for lateral roots to develop (figure 3).

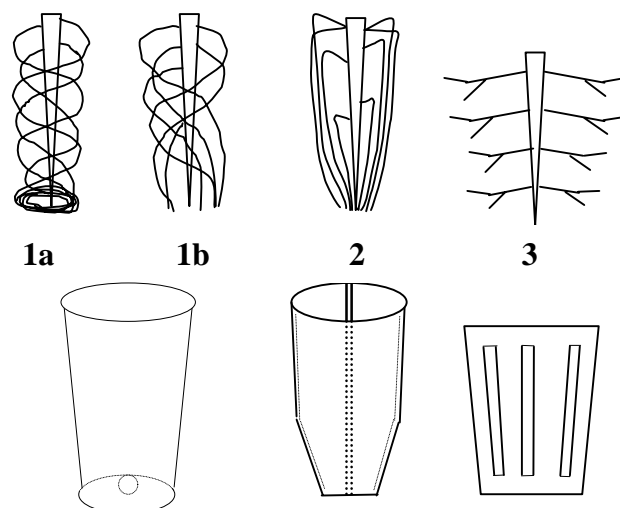


Figure 3. Important developments in container design were the addition of basal air root-pruning (1b) and addition of vertical root-training ribs (2). Recent designs incorporate side wall slots for lateral air root-pruning (3).

There are two methods of root pruning employed - air pruning (figure 4 and 5) and chemical pruning (figure 6 and 7).

Both types can be equally effective at producing suitable root systems. The effective application of chemical to seedling cells however, (in SW Western Australia at least) has proven to be problematic in some instances (figure 8). For example, various moulded insert containers employ a copper-based paint on the inside walls of the cell. The major limitations that have, and continue to occur with these include:

- a) Paint is often not effectively applied to stop root tip growth, eg too thin or missed painting - causing roots to spiral.
- b) A deficient copper concentration is only discovered when seedlings are well advanced, ie damage is already done (figures 9, 10 and 11).
- c) The apparent unsuitability of this particular root pruning method for *Banksia* (Proteaceae family) and *Acacia* spp. (Mimosaceae family). The chemical severely limits proteoid root development in the former. Two limitations occur with the latter. Firstly, nitrogen fixing root nodules appear to be less

abundant and second, the vigour of some *Acacia* species roots override the effectiveness of the chemical at stopping root growth at the surface of the root plug. Empirical evidence indicates that the effectiveness of this method is also less for mallee eucalypts than for *Eucalyptus globulus* (Blue Gum).

Excavated trees and shrubs (2 to 4 years old) suggest that early root spiralling (initiated in the nursery) is largely maintained and is responsible for reduced growth rates and depending on severity, early tree death from 'droughting out'.

In contrast, with effective nursery management, full (side wall and base) air root-pruning cells consistently produce better quality root systems (figures 12 and 13). These are characterised by an abundance of lateral roots and numerous root ends (lateral and vertical growing) on the outer surface area of the root plug. This characteristic enables active seedling root ends (lateral and vertical) to explore new soil immediately after out-planting. Other advantages include:

- a) Allows greater flexibility of planting out dates by reducing the impact of root crowding on root quality. This is important in a climate where planting dates can vary by up to 3 months, ie nursery dispatch can range from early June in some years to late August in others (when winter rainfall is late).
- b) Less risk of desiccation after removal from cell. Cells with root pruning on all surfaces have a large proportion of root tips at the plug surface and these tend to be within the protection of the growing medium.
- c) Seedling performance is strongly correlated to the number and distribution of lateral roots. In addition, local empirical evidence suggests improvement to early growth of out-planted seedlings grown in cells with full air root pruning (J. Brealey, pers comm).
- d) Easier and more efficient plug extraction when using appropriate equipment, eg a 'plug popper'.

Some cell designs use air root pruning at their base only with solid side walls (figure 14). This design produces a root mass having a strong vertical orientation and often with an abundance of side wall, vertically oriented, exposed lateral roots (root cage effect) (figure 15). Risk factors arising from this design as compared to a fully air root pruned cell or a properly functioning chemical root pruning system include:

- a) Given the bunching of vertical root tips at the cell base and that most new growth will develop radially from these dominant roots, a very small cross section of attachment between the root system and the trunk will develop. Plant instability may result from this cell design.
- b) Reduced flexibility of planting out dates, ie many species display root crowding in late dispatch years. The detrimental effects of root crowding on root quality are increased when the base only is air root pruned.
- c) Desiccation after removal from the cell. An increased proportion of vertically orientated lateral roots are at the root plug surface as opposed to within the protection of the growing medium.
- d) High risk of physical damage at planting. The exposed vertically growing lateral roots are vulnerable to damage.
- e) A degree of performance loss through root 'shaping' by the solid side walls of the cell.

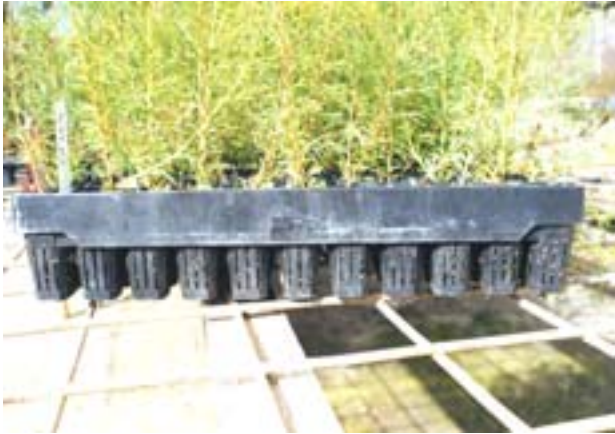


Figure 4. Cells with full (sidewall and base) air root-pruning, ie physical root pruning.



Figure 6. A chemically treated (copper oxide based paint) plastic insert 'kwik pot'®, ie chemical root pruning.



Figure 5. The underside of cells with full air root-pruning.



Figure 7. The underside of a chemically treated plastic insert 'kwik pot'®. The single slot in the base of each cell is for drainage.



Figure 8. Areas of uneven application of copper based paint indicated by the arrows. This inevitably results in a few dominant roots with a reduced fibrous root system.



Figure 9. Above: the underside of cells with an incorrectly applied copper based root pruning system and below: an edge cell showing excessive and dominant root growth. This growth must be removed before planting. Increases in out-planting shock and time result, equalling loss of performance and higher planting costs. Note that the poor root form is not a product of the root pruning system. The application and effectiveness of the paint is the limiting factor.



Figure 10. The underside of a root plug taken from a central cell of the tray as illustrated in figure 6. Note the bunching and bending of roots at the base of the plug and the lack of lateral root ends on the side walls of the root plug, despite a sizeable above ground seedling.



Figure 11. The extremely poor form of an extracted root plug from the edge row of the tray as illustrated in figure 8.



Figure 12. A cell design with full (side wall and base) air root pruning.



Figure 14. A cell design with enclosed side walls with an air root-pruning base.



Figure 13. A root plug from a full air root-pruned seedling cell. This cell design limits the 'shaping' of lateral roots and is associated with improved fibrous root development and seedling performance.



Figure 15. Strong vertical root orientation resulting from 'shaping' of the lateral roots by an enclosed side wall seedling cell ('root cage' effect).

2. Root training ability

Pots classified as root trainers are those incorporating a structure that encourages roots to grow straight and vertical, eg internal (cell) vertical ribs (figure 16). This is important to eliminate any early spiralling root development patterns that may persist and cause future growth limitations and / or premature death.

Note that some cell / tray types listed as root trainers perform poorly at training roots vertically, ie the root trainer 'label' is no guarantee of effective root training. For example, the vertical ribs are undersized or too smooth (figure 17). Extracted seedlings should always be inspected to ensure effective root training prior to taking delivery from the nursery.

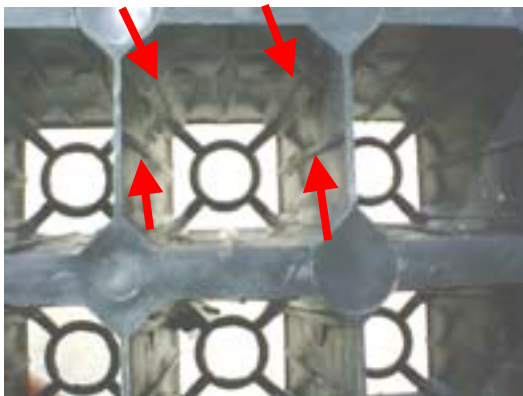


Figure 16. Plan view of a Col-Max® tray. Arrows identify vertical root training ribs employed to minimise root spiralling.



Figure 17. Plan view of an individual root training cell. This design allows a substantial proportion of roots to spiral, regardless of the root training label.

3. Cell shape

Extensive research has determined that the cell architecture must not shape the roots per se, however it must necessarily shape the root plug. Some form of root pruning or breaking of root (apical) dominance is required to achieve this. Optimal shape features (when physical root pruning is employed, ie air) include:

- Root training ribs on the internal walls of the cell.
- Lateral-root pruning slots (vertical side wall slots in cell).
- Maximum possible openness of the cell base to allow air pruning and
- Slight tapering with depth.

The ultimate aim is to prevent the development of a few dominant roots, and so, produce a fibrous root system that:

- Promotes the formation of a large number of active root tips on all sides.
- Holds the root ball together enabling easy handling without damage.
- Once out-planted, will re-establish root apical dominance and lose the appearance of a planted root plug and develop a natural root form.
- Allows easy extraction to minimise damage in the field during planting.

4. Seedling cell volume and weight

Cell volume interacts with tray packing density and cell depth (see points 5 and 7). The acceptable volume range is 40 - 90 cc (cubic centimetres), (standard set by the Department of Conservation and Land Management for the Oil Mallee Association). Volume is important to allow the roots to develop sufficiently without becoming crowded in the cell. Root crowding is often exacerbated when seedlings are forced with excessive fertiliser, in an effort to produce a tall lush looking seedling (a disadvantage to survival in the field).

Research has shown that large volume cells (> 90 cc) are beneficial to plant growth. The root pruning cell design (chemical or physical) however, has allowed for a decrease in cell size without impacting on performance. Gains in

ease of handling and reducing cost per unit seedling have accompanied this change also.

Volume also impacts on the weight of a tray of seedlings. This is of concern when hand planting (using a tube type planter, eg a Pottiputki). Although the type of potting mix used and the number of plugs per tray contribute to the weight, cell volume should allow for at least 64 seedlings to be carried comfortably on the waist with a seedling carrier. If planting seedlings by machine, the total weight of a full tray is of less concern.

Examples of volumes (per cell) include:

- Col-Max® (64 cell) - **49 cc**,
- Lannen Plantek (121 cell) - **50 cc**
- Premium Plastics (64 cell) - **51 cc**
- Kwik pot® (64 cell) - **52.5 cc**
- Lannen Plantek (81 cell) - **85 cc**,

5. Cell packing density

A packing density within the range of 16 - 26 square centimetres per seedling is considered acceptable (standard set by the Department of Conservation and Land Management for the Oil Mallee Association). Generally the minimum packing density is used (to maximise seedlings per tray area) whilst maintaining sufficient air circulation between seedlings. Insufficient air circulation is a key factor in the build up of detrimental fungal activity. This typically occurs as the seedlings develop branches and add leaf growth. Packing densities of less than 16 cm² per seedling can be employed when the species grown have few branches and small leaves, eg some *(Allo)casuarina* spp., *Melaleuca* spp. . These species are upright and slender as seedlings and therefore allow sufficient air circulation.

Examples of packing density per seedling include:

- Lannen Plantek (121 cell) - **12 cm²**
- Kwik pot® (64 cell) - **16 cm²**
- Col-Max® (64 cell) - **16 cm²**
- Premium Plastics (64 cell) - **16 cm²**
- Lannen Plantek (81 cell) - **18 cm²**

6. Cell diameter

Is closely related to packing density and is usually of minor concern to the nursery customer. If using tube type tools for hand planting, eg pottiputki's, then seedling root plugs need to comfortably fit down the tube. Hand planting tubes vary in tube diameter. The size of Pottiputki most commonly used in WA is a No.5. This size accommodates seedling root plugs of up to 45 mm in diameter.

7. Cell depth

Trends in cell depth indicate a move towards less depth without compromising basic requirements for successful establishment in the field. Even a marginal reduction in depth of cells provides benefits in reducing weight. A generally accepted maximum cell depth is stated as 90 mm (Nelson, 1997). The minimum cell depth will primarily be determined by the volume requirements of the roots over a given time (in the nursery). For example, roots should not be overcrowded in the cell (figure 18). This will also vary between species grown.

Examples of cell depths include:

- Kwik pot® (64 cell) - **40 mm**
- Col-Max® (64 cell) - **53 mm**
- Premium Plastics (64 cell) - **70 mm**
- Lannen Plantek (81 cell) - **73 mm**
- Lannen Plantek (121 cell) - **73 mm**

Historical expectations (of some nursery industry personnel and customers) of seedling quality have influenced nursery practice. For example, perceptions indicate that deep cells are required for tap rooted species. This influence has often led nurseries to use cells of increasing depth. As this increases volume, packing density has also often increased in an effort to minimise volume (and thus cost of potting mix).

Limitations of using long, thin cells include increasing the likelihood of damage during seedling extraction and planting, eg bending the base of a long thin root plug during planting. This increases the risk of root development problems and associated poor growth and / or limited longevity.

Limitations of using long, thin cells in association with increased cell packing density include:

- a) Resulting tall spindly plants have increased susceptibility to foliar disease in the nursery.
- b) Tall spindly plants are less able to withstand exposed paddock conditions.



Figure 18. A jam wattle (*Acacia acuminata*) root plug taken from a nursery on the 20th March. Overcrowding (and root deformity) of the roots in this root plug will be severe at the time of dispatch, ie May - July.

8. Ease of seedling extraction

Dramatic improvements occur in planting efficiency when seedlings are easy to extract. To gain employment as a contract Blue gum tree planter in southwest WA, a minimum of 6000 seedlings per day must be planted by hand. A number of Blue gum contractors prefer the use of disposable plastic insert-type trays. The reasons given for this include, their flexibility (can use fingers to push out from base of tray), they can be ripped apart when seedlings are difficult to extract and the tray used to hold the insert can be used to stack extracted seedlings into. Comments on solid walled rigid plastic trays, include being very difficult to extract and were considered less desirable than the flexible insert type.

Recent advances in hand planting efficiency show that 'popped' seedling plugs (see definitions), can be moved directly from the cell to the hand planting tube. Traditional practice in the field is characterised by (1) extracting

seedlings from cells and storing loosely into a 'bucket type' seedling carrier (figures 19 and 20) and (2) transfer of seedlings from the carrier to the planting tube. This technique involves handling the seedling twice. The initial step can be eliminated if using tray types incorporating cells with an opening (figure 21) at their base. The opening will allow the use of a plug-popping device (either in the nursery or in the field). This in turn allows the whole tray to be loaded onto a carrying frame (figure 22).

Key factors in making this system work include (1) the use of injection moulded trays (opening at base of cell is accurate and sturdy), (2) an operational popping pad located in the nursery or at the planting site and (3) the use of a carrier that is complementary to the tray design (this will allow for one tray to fit comfortably onto the carrier) (figure 22).

Deciding on when to pop the seedling plugs depends on the circumstances. The two alternatives are discussed below.

- a) At nursery dispatch: - the use of an automatic (foot operated) plug popping device (see definitions) is the quickest method (figures 23 and 24). Experience in 2000 and 2001 indicated that most seedlings extracted from their cells without assistance after transport to the revegetation site. The maximum time from plug popping to planting was two days. Seedlings popped during nursery dispatch are at increased risk of drying out and are reputedly vulnerable to ejecting from their cells during transport, especially when driving over rough terrain. Careful handling and transport however, poses no risk to nursery popped seedlings.
- b) On-site: - Only when seedlings are exposed to the least ideal conditions or when the nursery doesn't provide a popping service should popping be implemented in the field (figures 25 and 26). For example, when seedlings are held for a considerable time out of the nursery before planting and / or access to the revegetation site is extremely rough.



Figure 19. Seedling carrier with waist and shoulder straps. This carrier was designed specifically for open root plugs, ie seedlings are transferred from their cells to the carrier before planting.



Figure 21. The open circles at the base of each cell allow easy extraction and increased planting efficiency through the use of a 'plug popper'.



Figure 20. Seedling carrier with waist and shoulder straps. This carrier was designed specifically for open root plugs, ie seedlings are transferred from their cells to the carrier before planting.



Figure 22. A seedling carrier designed specifically to accommodate a tray. Seedling are transferred directly from their cells to the planting tube.



Figure 23. Automatic (foot operated) 'plug popping' device used in the nursery. Each tray takes about 4 seconds to be 'popped'.



Figure 25. A manual 'plug popping' pad. This will allow 'plug popping' on-site if popping was missed during nursery dispatch or if circumstances necessitate on-site 'plug popping'.



Figure 24. A tray being slid into position on the automatic (foot operated) 'plug popping' device.



Figure 26. A manual 'plug popping' pad with seedling tray fitted part way down 'plug popping' position.

9. Ability to retain moisture

Acknowledgment is made here that the enclosed cell design used by, for example, a Kwik pot®, will reduce the rate of cell media drying as compared to slotted cells or cells with relatively open bases. This particular feature is sometimes considered an advantage to the farmer. For example, seedlings are occasionally held for a number of days, on-farm, without watering before planting. Undoubtedly this scenario does occur in the field and the seedlings in the enclosed cell design last longer without water than those in slotted cells.

The mistreatment of seedlings after nursery dispatch should not be part of nursery management planning, ie nurseries should use containers that optimise seedling quality and not be supportive of seedling mistreatment.

10. Total seedling number per tray

The most commonly used moulded tray holds 64 seedlings. The importance of the total number per tray is relevant to how seedlings are handled in the field at planting. For example, if using the 'plug popping' method (whereby seedlings are extracted direct from their cells and planted).

Ideally the seedling number per tray carried while planting will optimise efficiency, ie facilitate speed of planting and minimise stress on planting personnel. When planting seedlings direct from their cells, efficiency is determined mostly by the accuracy of full tray placement in front of planting personnel, ie one planting crew member delivers 'plug popped' trays to a location where planting personnel will finish their current tray. Calculating this distance is determined by plant spacing. Efficiency is a primary concern of contract tree planting crews in particular, as planting is usually paid on a per seedling planted basis.

An adult easily carries a commonly used 64 cell (seedling) tray. The dimensions of this tray size also allows the seedlings to be located relatively close to the planters' waist, an important aspect in minimising lower back strain. Trays containing 81 cells (seedlings) may pose difficulties for some people. For example, the tray dimensions extend further away (than 64s) from the waist of the person planting and may cause strain to some people.

Other standards to observe

Central placement of seedling in cell

This is a basic requirement and allows for balanced development of lateral roots. Central placement also reduces extraction difficulties and reduces the likelihood of seedling damage.

Seedling height

Recommended seedling height is between 15 and 25 cm (OMA and Blue gum industry specifications). Importantly, seedlings destined for sandy soil types need to be around the maximum height to allow for deep planting. For example, planting Blue gums (*Eucalyptus globulus*) on a Bassendean soil association (deep grey sand) on the Swan Coastal Plain showed improved growth responses with increasing depth of planting. Planting depths were from 9 to 15 cm. Greatly improved survival in these conditions is a major reason to use seedlings around 25 cm in height.

Fully hardened healthy seedlings less than 15 cm in height can still perform well in most sites (excluding deep sands), where deep planting is not necessary. Difficulty planting these seedlings however, will arise if planting with a machine.

Seedlings above 25 cm provide no advantage (there may be some minor exceptions) to survival or performance. In most cases seedlings above 25 cm would indicate excessive growth and possible 'softness'. Disadvantages include:

- Difficulty of planting when using a hand operated planter, eg Pottiputki. The increased number of leaves on the seedling slows or prevents it sliding down the tube. The tube also has to be lifted higher and the seedling is often caught when closing the beak of the Pottiputki.
- Increased risk of mortality through increased leaf area exposure and thus, greater requirement for moisture. This will be especially relevant in years with dry seasonal conditions.

Properly hardened seedlings

Seedlings should be 'toughened up' a few weeks before nursery dispatch, ie reduced application of water and fertiliser to seedlings and removal of overhead shade cloth. This will slow growth, reduce the lushness of the foliage, encourage 'woodiness', increase frost tolerance and produce a seedling more able to withstand planting shock (figure 27). This practice may even be required much earlier in the nursery phase if seedlings are too 'soft'. Additionally soft seedlings are considerably harder to plant.



Figure 27. A hardened (left) and soft (right) one-sided bottlebrush (*Calothamnus quadrifidus*) seedling. The soft seedling is bigger and more lush, however has limp foliage and a soft stem.

Transplanted seedlings

This process occurs in the plant nursery during the thinning stage when cells without seedlings are in-filled with bare rooted seedlings thinned from other cells. In ideal conditions this process works well. However, a poorly transplanted seedling can result in bending at the junction of the root and stem (figure 28). This will limit the potential of the transplant. For example, once planted in the field the plant will be sensitive to wind throw and possible premature death.

Two nurseries in the wheatbelt have successfully employed a system of 'nipping off' excess roots when transplanting, cutting roots back to 1 - 2 cm to avoid 'j' rooting.

Undesirable root bending has been observed within nurseries where transplanting has not

occurred. The media composition is thought to be the causal agent. Regardless of the cause, it is a quality defect (risk factor) and should be corrected.

Recent developments in nursery practice and equipment show that the use of 'mini plugs' (figure 29) as a transplanting source greatly minimises the risk of damage to roots and also improves nursery efficiency.



Figure 28. The likely result of a poorly transplanted seedling from the nursery thinning process. The bent ('j') root creates a weak area at the base of the plant stem. Susceptibility to wind-throw can result from this root condition.



Figure 29. A 'mini-plug' tray with seedlings ready for transplanting. Mini-plug extraction is undertaken with a 'plug popper'.

Disease free

The Nursery Industry Association of WA (NIAWA) offer a nursery hygiene accreditation scheme. This scheme accredits those nurseries that apply and conform to nursery layout and management practices consistent with minimising disease entry and spread.

Originally hygiene guidelines were designed to address the soil borne fungal disease commonly referred to as dieback (*Phytophthora* spp., in particular the most widespread and destructive species *Phytophthora cinnamomi*). As many as 2000 of the estimated 9000 native plant species in the south-west of Western Australia are susceptible to *P. cinnamomi* root rot disease. In field studies of south western plant communities the families with the highest proportion of susceptible species were Proteaceae (92%), Epacridaceae (80%), Papilionaceae (57%) and Myrtaceae (16%).

In general, *P. cinnamomi* is restricted to areas in the south-west of the State receiving at least 400 mm of average annual rainfall although in water-gaining sites it is possible for the pathogen to exist in slightly drier areas.

Aside from the NIAWA accreditation mechanism that gives the customer some degree of surety of disease free status, the only other practical measure is to observe the seedlings. Fungi, many of which are microscopic, are the predominant cause of disease in nurseries. Fungi are both soil and air borne. Visual indicators of plant disease include discolouration of leaves; stem lesions; fuzzy areas on the plant; spots on leaves; and twisted and / or distorted leaves. These indicators however, may not always be the result of disease. For example, leaf discolouration is often a nutrient related issue, or can be induced by chemical drift.

When contracting a nursery, it is recommended that the customer supply a list of seedling specifications to be met by the nursery. The nursery should address each specification and if satisfactory, both parties sign. Just as many nurseries have 'conditions of sale', so to the customer should have an agreement of 'conditions of purchase'. A general list of seedling specifications can be obtained from the Bushcare network or from the Department's

NatureBase web site -
<http://www.naturebase.net/projects/index.html>.

Stem diameter

The recommended stem diameter at nursery dispatch is sometimes listed as 3 mm. However, this is hard to achieve in a well managed nursery and will vary between species. A 2.5 mm diameter is probably a more realistic value.

Stem diameter in this context is a measure of the robustness of the seedling and so stem hardness and rigidity are also important. For example, pressure and tensile force is applied to the lower stem in the seedling extraction process. The stem must be sturdy enough to easily withstand this action. As well as conferring sturdiness to the seedling, a strong stem facilitates efficient planting by contributing to ease of extraction.

Greater than 95 % plantable seedlings per tray

Some nurseries allow for a small percentage of non-plantable or missing seedlings, eg charge for 60 seedlings per 64 cell tray. If charged for the total number of cells per tray, then the actual plantable seedling numbers per tray should be closely scrutinised over the whole order. Negotiation should occur if discrepancies arise between invoiced seedling numbers and actual plantable numbers.

Disposable or reusable trays / cells?

Mention is given here of a couple of concerns regarding disposable trays, though point two is not a seedling quality issue. 1. Some seedling growers (for their own use) choose to reuse the plastic insert type trays. As these trays are chemically treated to last one year and for the purpose of root pruning, their ability to perform this critical role for a second season is potentially limited. Additionally, sterilising these trays is problematic. 2. Plastic waste is created on an annual basis and eventually ends up in land fill.

In contrast, after the useful life of a plastic reusable tray, it can be recycled, ie granulated and made into other products of lesser value.

Genetic quality

In many plants, a variety of mechanisms including form (morphological) and functioning (physiological) encourage cross-pollination and prevent self pollination. However, in many cases these mechanisms fail to prevent inbreeding. For example, in the bush, mating among close relatives such as parents and their offspring, siblings and cousins, results in inbreeding depression. This is characterised by fewer offspring or offspring that are weak or sterile. The reason for this is that the plants are not generally mobile and cross pollination tends to be concentrated in the local neighbourhood. Thus seed collected from the bush, given the 'neighbourhood effect' will be composed of a mixture of 'good and bad' seed (figure 30). The bad or poorest quality seed will be produced by self pollination. The degree of inbreeding will progressively decrease, the less related the parents are until you reach the ultimate of unrelated crosses which produce the so-called hybrid vigour.

Inbreeding depression is a common phenomenon in eucalypts. Eucalypts however, can tolerate a fair degree of related mating. Despite this tolerance, self pollinated eucalypt seedlings show reduced growth and survival as compared to seedlings from outcrossed parentage (unrelated trees). One study reported a 37 % reduction in volume in self pollinated seedlings as compared to outcrossed stock. Simply by breaking the 'neighbourhood effect', a substantial increase in growth can be expected, eg around 10 - 15 % volume increase. Similar effects have been observed in other species also.

To take advantage of breaking the 'neighbourhood effect', seed must be collected from a stand with 20 or preferably 30 unrelated parents in close proximity, ie a seed production area. Those considering establishing such an area as a source of first generation seed for future revegetation should also ensure the layout optimises the benefits derived from out crossing.

One of the problems with inbreeding depression is that it is often difficult to detect at the nursery stage unless the seedling is so defective it dies or simply doesn't grow. In general, inbreeding depression is expressed relatively slowly and

may not be obvious for a year or even longer after planting. In any case, detection probably only ever occurs when trials are conducted to compare different seedlots.

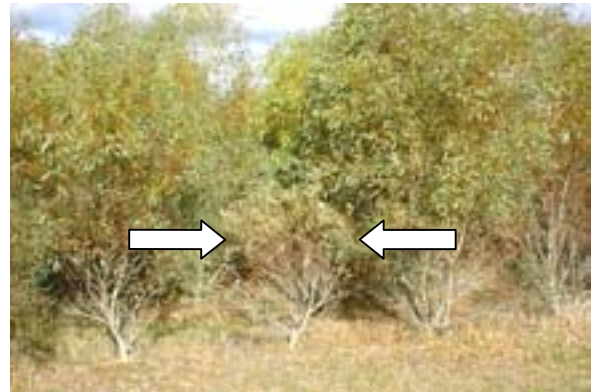


Figure 30. A likely scenario of inbreeding depression. This site was planted with mallee eucalypts in 1996. Seed genetic quality has major impacts on plant productivity.

An added variable, in the growth stakes at least, is seed provenance (origin of seed). Substantial performance differences can occur between different provenances. In some cases, outstanding growth differences can be observed at the nursery stage (figure 31 and 32).



Figure 31. Provenance differences of *Eucalyptus loxophleba* subsp. *loxophleba* (York gum).

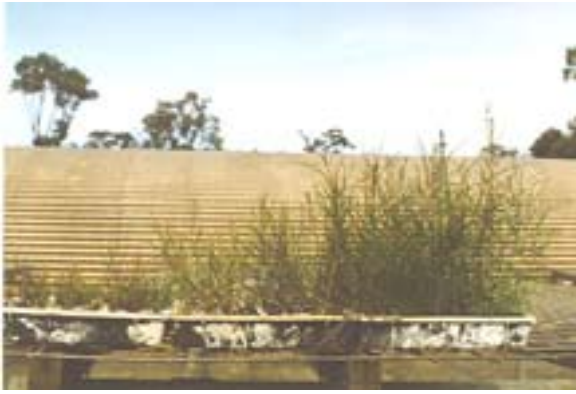


Figure 32. Provenance differences of *Melaleuca uncinata* (Broombush). This species is currently under review and is likely to be split into a number of different species and subspecies (this may indeed explain the above differences).

In addition to seed provenance, seed age appears to impose a substantial influence on seedling germination and early performance. For example, some wheatbelt species (particularly *Hakea* spp.) thought to be difficult to germinate have shown the converse in the last two years at Narrogin's Department of Conservation and Land Management nursery. This has coincided with new revegetation projects supplying this nursery with fresh seed and the use of fresh seed from the Department's Manjimup seed store. Increased seed demand from this seed store has, in part, driven the requirement to pursue new stocks of seed and thus make possible the availability of fresh seed.

The use of fresh seed however, does not have the same relevance to all species. Some of those that are known to lose viability relatively quickly are from the Proteaceae family, and at genus level *Allocasuarina*, *Atriplex* and *Santalum* species. Conversely, Eucalypts and *Melaleuca*'s are known to have a long shelf life (10 - 15 years) if stored under controlled cool room conditions.

A further influencing factor is the ripeness of seed. Green seed will reduce both viability and shelf life.

The desirability of a range of seed sources are outlined in Table 1. The table highlights the need to avoid 1. isolated trees with seed, 2. single trees with seed within a stand lacking any other nearby seed and 3. purchased seed of unknown origin(s). Importantly, if you are aiming to establish a seed production area, then at least 20, preferably 30 unrelated seed lots (genotypes) are required to escape the influence of the 'neighbourhood effect'.

Table 2 shows the gains made in plantation tree breeding work conducted by the Department of Conservation and Land Management. Although this level of intervention is not necessarily representative of trees grown for landcare purposes, it gives a perspective of the opportunities that exist with native bush seed.

Table 1. Desirability of different seed sources. Source: Mazanec, (1997).

Desirability	Seed Source	Why?
0	Single isolated tree in backyard or paddock.	Low viability and a high level of inbreeding depression.
0	Only tree in a stand that has fruit (seed).	As above
0	Buy seed of unknown origin(s).	Unknown number of parents. Could include the above problems.
1	Bush seed of known origins.	Often is only choice. Likely to include a range of outcrossed and inbred seed and seed from good and undesirable crosses. Use best provenances for the area.
2	Seed production area.	Good if adjacent trees are unrelated - minimises related mating. To eliminate the 'neighbourhood effect', at least 20 and preferably 30 unrelated seed lots (genotypes) are required for establishing a seed production area.
3	Seed orchard.	Best. Unrelated parents of known pedigree yield highest probability of vigorous outcrossed offspring.

Table 2. Examples of gains achieved from tree breeding work. Source: Mazanec, (1997).

Species	Bred for:	Gains
<i>Pinus pinaster</i> (Maritime Pine)	Sawlogs	40 % gain in volume achieved in the first generation of selection and breeding. A further 20 % gain in volume achieved in the second generation of improved stock. Total of 60 % increase in volume productivity over unimproved planting stock.
<i>Pinus radiata</i> (Monterey Pine)	Sawlogs	Plantations from first generation seed orchards yielded an increase of 10 % volume over unimproved stock. Plantations from second generation orchards yielded a further 10 - 30 % volume increase. Total of 20 - 40 % increase in volume productivity over unimproved planting stock.
<i>Eucalyptus globulus</i> (Tasmanian Bluegum)	Pulp	First generation clonal seed orchards yielded trees of 40 % improvement in volume. First generation seedling seed orchards are currently yielding trees of between 13 - 17 % improvement in volume.

References cited

- Dalton, M. (2001). Personal Communication.
- Day, R. J., Duncanson, T. T. and Hyde, C. E. (1989). *Effects of Container Type and Volume on the Survival and Growth of Eucalyptus globulus Labill. Nursery Stock Six Months after Out planting*. CALM internal report. Western Australian Department of Conservation and Land Management. Perth.
- Griffin, A. R. and Cotterill, P. P. (1988). Genetic Variation in Growth of Outcrossed, Selfed and Open-Pollinated Progenies of Eucalyptus regnans and some Implications for Breeding Strategy. *Silvae Genetica*. 37: 124 - 131.
- Kietzka, J. (1991). *Tangled tree Roots*. In: Seedling News. Institute for Commercial Forestry Research, South Africa.
- Mazanec, R. (1997). *CALM'S Tree Breeding Programme*. Paper presented at Farm Forestry Field Day. Western Australian Department of Conservation and Land Management, Perth.
- Mexal, J. and Burton, S. (1978). *Root development of planted loblolly pine seedlings*. Symposium on root form of planted trees, Canada. 85 - 90.
- Molloy, S. (2001). Personal Communication.
- Nelson, W. (1989). A Review of the Role of Root Pruning for Containerised Forest Seedlings. *South African Forestry Journal*. 151: 90 - 92.
- Nelson, W. (1996). Container Types and Containerised Stock for New Zealand Afforestation. *New Zealand Journal of Forestry Science*. 26: 184 - 190.
- Nelson, W. (1997). *How deep should containers be for tree seedlings?* Corangamite Farm Forestry Project. Ballarat University. Transplant Systems Limited, New Zealand.
- Nelson, W. (2000). *Nursery Containers for Eucalypt Seedling Propagation*. Paper presented at the TimberCorp Nursery Seminar, New Zealand.
- Oil Mallee Association of WA (Inc) (1999). *Call for expressions of interest and work specifications for supply of oil mallee seedlings for winter 1999*. OMA, Perth.
- Sprigg, P. (2001). Personal Communication.