Silviculture (from the Latin "Silva" meaning wood) is simply the manipulation of forests, and the trees within them, for wood production. The potential to direct tree and forest growth to enhance value makes silviculture the most powerful tool of the farm forester - whatever their interests: For example, a tree that might otherwise only be of value for firewood can be turned into high value veneer or sawlog, or, a regrowth native forest dominated by one tree species can be thinned to promote greater biodiversity in the understorey.

A "silvicultural regime" is a series of management interventions that are imposed on trees, or forests, over time, from establishment through to harvest. The tools used include: the choice of initial spacing, layout and establishment method and the type and timing of thinning, pruning, fire, grazing, harvesting or other interventions. Choosing to "let nature take its course" is, in a way, a silvicultural decision. Unfortunately, leaving a forest to its own devices is rarely the most appropriate means of providing the mix of economic products and environmental services farmers commonly seek. This chapter reviews how trees grow and highlights some of the more universal principles of silviculture that farmers can use to redirect forest growth in order to satisfy their own goals.

Farmers and foresters discuss silvicultural options for a private native forest on a Northern N.S.W. farm.
Tree growth and wood production

Growth of the above ground part of a tree essentially occurs in two ways: the most obvious growth occurs on the leading shoots of the main stem and branches making the tree taller and the branches longer. The second is the cambium growth. The cambium is a thin layer of cells found just below the bark that produces the growth that increases trunk diameter and branch thickness. The wood produced as a result of the elongation of the stems is quite different to that of the cambium. In most species, growth of the leading tips produces a soft corky wood called the "pith" that can be often seen in the centre of a log. In almost all cases the pith is considered a defect in sawn timber.

The cambium growth produces bark cells on the outside and wood cells on the inside. The young bark cells form the conductive "phloem" which carries sugars from the leaves down the stem feeding the cambium and, eventually, the roots. On the inside of the cambium the recently formed wood cells hollow out to allow for the movement of water up the stem. This is called the sapwood.

In the temperate regions cambium growth generally produces one growth ring each year. The ring is evident because the large thinned walled cells produced in spring (called earlywood) are lighter in colour than the small thick walled cells produced later in the growing season (called latewood). As the tree grows new sapwood, part of the inner sapwood is "retired". During this transition of sapwood to heartwood a number of chemicals (mostly lignin) are deposited in the wood cells often giving the wood attractive colours and increased durability.

Four aspects of silviculture

Forest growth is largely determined by how the mix of plants respond to the soil and climate in which they are growing. Silvicultural design and intervention allows us to direct this growth to where it has the most economic, environmental or aesthetic value. There are four aspects of silviculture that farmers need to consider:
I. THE GENETIC COMPOSITION OF THE FOREST

In many situations the farmer has an opportunity to choose the species mix and the genetic origins of any plants that will be added to the site. Active intervention may also be used to reduce, or increase, the prevalence of those species already present. These genetic choices may be based on the known performance of species or varieties, an inclination towards indigenous or introduced genetic material, or a preference for greater or lesser genetic diversity.

Although tree breeding has been able to demonstrate improvements in growth and productivity across a range of forestry and horticultural species, farmers should be cautious about tending towards a very narrow genetic base in their plantings. The extreme example is a clonal forest (such as is common in poplars) where there is no genetic difference between the individual trees. Because of the complexity of the interaction between the genetics and the environment, and the long time periods involved in forestry, maintaining a broad genetic base is often a sensible risk management strategy. Where there are particular selections (either species or varieties) that appear preferable, the farmer could choose to incorporate a number of these into a mixed planting rather than select just one.

These poplars (above) are all clones grown from cuttings from a single tree. Any differences must be the result of the environment or management. Small gap harvesting in this private native forest (top) allows the indigenous species to regenerate by seed from nearby mature trees thereby maintaining the local genetic integrity.
Any decision regarding the genetic composition of a forest needs to be made carefully as the introduction of new genetic material may irrevocably change the genetic composition within the existing vegetation (through hybridisation or interbreeding) or be very difficult to remove in the future (weediness). Another concern is that native genotypes lost from a site may be expensive or impossible to recover.

2. MODIFICATION OF THE PHYSICAL ENVIRONMENT.

Soil preparation, weed control, fertilisation, fire, irrigation and the provision of shelter are examples of ways in which farmers may be able to change the quality of the site for forest growth. The choice of technique will largely depend on what factors are currently limiting site quality, the costs involved, the availability of appropriate equipment and the anticipated impact. The impact of site modification on growth can be dramatic where treatments are able to address the factors most limiting growth. This is most clearly demonstrated by the effect of controlling weed competition in young plantations or the impact of deep ripping on soils that have pronounced shallow hardpans. However, as the forest develops the factors that limit growth will change. The use of intensive site preparation and fertilisation to promote early growth may simply mean the plantation reaches the growth limits set by other resources more quickly with no real long-term advantage.

Rather than simply follow the recommended "best practice" for site preparation farmers must be clear about their purpose for trying to modify site conditions. In many cases the financial costs of intensive site preparation and its impact on other values - such as the risk of erosion or leaching of nutrients and chemicals - may be unjustified. Farmers may also be able to use their own equipment or methods to achieve a similar outcome at a much lower cost.

These first two aspects of silviculture, genetic selection and site modification, are not dealt with in any more detail in this chapter because of the difficulty of generalising across the country for different sites and scenarios. Farmers are encouraged to explore their options locally and experiment themselves in an attempt to identify the most appropriate genetic material and site modification techniques for their particular circumstances.

3. MANAGEMENT OF THE COMPETITION BETWEEN TREES

Once established, the individual plants on a site will both support and compete with each other. As the trees grow up together what began as welcome shelter from the elements may very soon turn into competition for limited resources. The species composition, spatial arrangement and the impact of natural, accidental or managed interventions will determine how these interactions play out over time. Being able to manage the positive and negative interactions that occur between the individuals within a forest is possibly the most important aspect of silviculture. Much of this chapter examines these interactions highlighting their importance and the potential for farmers to control them.

4. TREATMENT OF INDIVIDUAL TREES

The final aspect of silviculture is the potential to manipulate growth, form and productivity of individual trees by direct treatment. Pruning the canopy or roots, coppicing, the application of chemicals and hormones, and other interventions can, if carefully timed, change the pattern of growth thereby improving the value of a tree for its intended use.
The rest of this chapter will focus on these final two aspects of silviculture.

**Spacing and thinning to manipulate competition**

Competition can have both a positive and a negative effect on tree growth and wood quality. In young plantations a dense forest encourages rapid tree growth by suppressing weeds and providing mutual shelter from strong winds. However, as the trees grow they begin to compete for light and moisture thereby slowing each other's growth. Although tree stocking (stems/ha) is commonly used to describe the level of competition it is limited because it does not take account of the size of the trees. A more useful measure of competition is the basal area. *(See chapter on tree and forest measurement).*

Basal area is the cross-sectional area of all tree stems (at 1.3m) on a hectare and is directly proportional to the volume of timber of the site.

An appreciation of how forest trees behave under varying degrees of competition can be drawn from trials where the same species has been planted at different stocking rates. Figures 2, 3 and 4 illustrate the powerful role that inter-tree competition plays in determining tree diameter and stand volume growth in plantations of eucalypt, poplar and pine. Similar relationships could be presented for many other tall forest species. From these example and others we are able to make some general comments about the effect of competition of tree growth.

**FIG 2a. 11 year old E. pilularis**
**FIG 2b. 4 year old E. grandis**

*Fig 2. The photo above shows a spacing trial of E. grandis where trees are established at 40 stems/ha on the left up to 1111 stems/ha on the right. Fig 2a presents the results of a spacing trial of E. pilularis at age 11 years showing the effect of increasing initial stocking rate on mean diameter, dominant height and total volume (O'Connor 1935). Fig 2b shows the diameter increment of E. grandis trees between age 3 and 4 years against the basal area at age 3 years (Paul Ryan DPI Qld).*
FIG 3.
This photo shows a spacing trial of poplar where trees were established at 40 st/ha on the left up to 1111 st/ha on the right. Fig 3a presents the results at age 9 years showing the effect of increasing initial stocking rate on mean diameter, dominant height and total volume (John Kellas, Vic.). Fig 3b shows the diameter increment between age 8 and 9 years against basal area at age 8 years.

FIG 4.
Here the photo shows part of the Tikitere agroforestry research site in New Zealand at age 11 years (at 200 st/ha). Fig 4a presents the results at age 19 years showing the effect of increasing stocking rate on mean diameter, dominant height and total volume. Fig 4b shows the diameter increment between age 18 and 19 against basal area at age 18 years.
(Data from Knowles, Hawke and MacLaren (1992). Agroforestry Research at Tikitere, NZ FRI)
SPECIES VARY IN THEIR TOLERANCE TO COMBETITION

There is a great difference in the degree to which competition effects different species. Tolerant trees, such as the native and exotic pines, can form dense narrow canopies that allow forests to reach high levels of competition before individual tree growth is suppressed. Many of the hardwoods, including the eucalypts and teak, are much less tolerant. The lower shaded leaves of the eucalypts die as the competition increases leaving only a small amount of canopy on each tree to sustain growth.

Figure 5 is based on data drawn from over 150 sets of data from eucalypt plantations grown across Australia. The basal area in eucalypt plantations can increase rapidly at first, but appears to reach a natural limit of around 60 m²/ha even on the best sites. On sites with medium to low rainfall, shallow soils or low fertility the maximum basal area for a young eucalypt plantation may closer to 20 m²/ha. At this point any further growth in diameter in the dominant trees must be offset by the death of suppressed trees.

By contrast, unthinned pine plantations grow slower in the early years but can achieve basal areas as high as 100 m²/ha on high quality sites. Because basal area is directly proportional to volume it is not unusual for pine plantations to yield twice the volume of timber at harvest than the native forest they replaced.

As this plantation grows the competition for resources increases yet the stocking remains the same (approximately 1000 stems/ha).

Eucalypts (left) are intolerant of competition and tend to die back in dense plantations whereas unthinned pine plantations can reach very high basal areas.

Another explanation for the low tolerance exhibited by the eucalypts is the fact that they have naked leaf buds that are susceptible to damage during early growth. If the tree crowns rub against each other as they sway in the wind the buds can be lost. This is why it is very uncommon to find the canopies of eucalypts interlocking in the way that is common in pines or
cypress trees. Our other native hardwoods (cabinet timbers) and the introduced deciduous species (oaks, walnuts etc) vary in their tolerance. Some of the rainforest species are able to persist in low light environments, however, to achieve rapid diameter growth they may still need to be widely spaced.

INFLUENCE OF COMPETITION ON HEIGHT GROWTH AND TREE FORM

As shown in Figures 2, 3 and 4 increasing the initial stocking rate (stems/ha) of a plantation can lead to an increase in tree height, although this is only apparent up to stockings of around 400 stems/ha. Above this point height growth remains fairly constant even with a trebling of the stocking rate. Research suggests that the loss of height growth at low stockings is largely the result of excessive exposure.

Dry winds, in particular, can damage the growing tips thereby stunting growth. With adequate mutual shelter the height of the healthy dominant trees within the plantation is surprisingly even. This suggests the elongation of the leading shoot is driven by the small cluster of leaves at the very top of the tree. It also allows height, rather than basal area or volume, to be used as an effective measure of site quality that is largely independent of stocking. The better the site, the taller the plantation will be at a particular age irrespective of spacing. Research suggests that plantation height increases with increasingly soil depth, humidity and rainfall. Farmers may be able to gauge the quality of a site for tree growth from the height of the remnant native forest.

The degree to which competition affects the form of the trees can be critical where is it necessary to grow straight trees or control branch size. Many plantation species, including the eucalypts and softwoods commonly grown for timber, have a strong "apical dominance" which encourages them to grow tall and straight even when relatively open grown. Others, like many of the rainforest species, have low apical dominance and will tend to grow out broad like an apple tree if sidelight is not controlled. In this case maintaining a sufficient level of competition to encourage light branching and straight growth may be essential.

COMPETITION AND TREE DIAMETER GROWTH

Once site resources (particularly light and moisture) become limiting any increase in competition will lead to a direct reduction in the size or efficiency of the individual tree canopies. As a result, the amount of sugars produced by the leaves and fed down the branches and trunk for cambium growth will be reduced. This results in reduced diameter growth. As shown in Figure 2b, increasing the basal area above 5 m²/ha in a young eucalypt plantation can cause a dramatic drop in the annual diameter increment. To maximise diameter growth sufficient trees must be initially established to allow mutual shelter to promote healthy growth. Then, as the trees grow, the forest must be thinned to reduce competition. Repeated thinning to avoid excessive competition while maintaining mutual shelter will allow the trees to maximise height and diameter growth.

The area of sapwood in a tree is related to the volume and health of its canopy and is therefore related to the level of competition. Basal area is a measure of the total cross sectional area of the forest and therefore includes both the heartwood and sapwood. Because of this, it is not correct to assume that a basal area of say 10 m²/ha implies the same level of competition in plantations of different age.
For example, to maximise diameter growth in a eucalypt plantation the first thinning may reduce basal area to less than 5m²/ha, the second thinning to 10m²/ha and the third to 15m²/ha. The difference would be the result of the increasing area of heartwood in the larger trees. A useful guide is to thin to a third of the basal area of a fully stocked forest of the same age and species on that site. If some level of competition is required to control form or branch development then thin to half the maximum basal area.

Farmers can use unthinned eucalypt or pine plantations growing on similar soil types in their area as an indication of the basal areas of fully stocked stands. Better still, farmers can establish measurement plots in their own forests and monitor diameter growth over time. When they notice the diameter growth falling they can determine the corresponding basal area and make a judgement of the extent of thinning required. Examples of this were provided in Chapters 4 and 6.
COMPETITION AND VOLUME PRODUCTION

Although individual tree diameter declines with increasing competition the total volume of wood on the site increases. If the object is to maximise the volume of timber (as for pulpwood or fuelwood) then the higher the stocking rate the greater the yield. This is why pulpwood plantations are established at over 1000 trees per hectare (<3x3m spacing) and left un-thinned until they are harvested. The rate of volume production is greatest when canopy of the young plantation first reaches its full potential. As the trees grow on competition increases and the rate of volume production may decline. Eventually, the plantation reaches a maximum volume for the site. At this point any further growth of individual trees can only be possible if other trees die or are removed. Many unmanaged native forests are at this point as demonstrated by repeated measurements of total volume that show no change over time.

Stand stability is a common problem in dense stands. Because the trees are tall and skinny they are susceptible to toppling, (particularly if the soils are prone to waterlogging), or bending in strong winds. Even where the trees do not fall over the swaying in the wind has been shown to increase the formation of tension wood in the butt log of eucalyptus affecting both sawn timber and pulpwood quality. Other problems common in dense plantations include increased difficulty of harvesting, lack of light to support understorey plants and an increased susceptibility to drought, insects and disease.

COMPETITION AND BRANCH DEVELOPMENT

Depending on the product specifications and the species involved, shading of the lower branches may be sufficient to control branch size or even encourage self-pruning. However, because competition reduces the size of the canopy it will also lead to a reduction in diameter growth.

If the tree does not naturally eject the branches soon after they die the dead branches may remain in the new wood forming loose black knots and providing an access point for rot. In this case the branches would still need to be manually pruned to produce clearwood. Even where the trees are to be manually pruned encouraging smaller branch size by allowing some competition may make pruning easier.

Epicormic shoots (new branches that form on the main stem) can be initiated by heavy thinning in forests where the competition has previously been high. Epicormic shoots come from dormant buds held in the cambium.
Under normal growth these buds are held in a dormant state by hormones produced in the canopy. If there is insufficient capacity in the existing canopy to grow more canopy in response to thinning then epicormic shoots may be initiated.

**Intervening to manipulate growth and function**

**PRUNING FOR WOOD QUALITY**

Branches on the trunk leave knots in the log that can reduce the timber strength, pulping quality and appearance values. Timber clear of knots and other defects is called "clearwood" and is commonly prized for appearance uses including furniture, flooring and joinery work. Knots larger than 5 or 6cm in diameter can result in timber being unsuitable for many structural grades due to weakness around the knot.

Pruning does not reduce the number of knots in the tree, only their size and location. The woody stem of live branches, other than those formed from epicormic buds, runs back inside the trunk of the tree to the pith. Pruning simply confines the branch knot to the core of the tree allowing the trunk wood to grow over it. If all the branches on part of the trunk are pruned early, when the trunk diameter is small, then a clearwood sheath can develop over a core of branch stubs. On milling, clearwood timber is sawn...
from the sheath and the core discarded or sawn for lower grade timber.

A 20cm core in a log with an underbark diameter of 60cm means that about 85% of the log volume is clearwood. The central knotty core will also contain the pith and juvenile wood that is often discarded anyway due to poor wood characteristics. Farmers are advised to aim for underbark log diameter at least three times the size of the knotty core diameter to allow large dimension clearwood timber to be easily sawn from the log. In some cases the knotty core of specialty timber species may produce sawn timber with interesting character if branches are pruned when small and live.

How to prune for clearwood production

The production of a clearwood log requires careful management over a number of years to ensure an even knotty core and thick clearwood sheath. The most effective means of achieving an even knotty core is to prune regularly (every year for most species) to a predetermined stem diameter. For example, annual pruning to a stem diameter of 8 to 10 cm will ensure that sufficient green crown remains for growth while containing the knots within a core of less than 20cm. A useful rule or thumb is to annually prune any branch that is over 2cm in size anywhere up to the anticipated log length and then lop all remaining branches below the point where the main trunk is 10cm in diameter. In most cases this means pruning will be done over 3 or 4 years beginning when the trees are about 5m tall. The removal of large branches early reduces the workload in later years and the likelihood of disease entering through the stubs. Any trees that are clearly malformed due to a twisted stem, kinks or large branches are usually culled.
Prior to doing any stem pruning it is common practice to "form prune" young trees. The aim is to achieve a single straight stem to at least the pruned height. Removal of large branches or double leaders early can avoid kinks in the stem. As a guide, simply remove any branch from within the pruned height that is over 2cm in diameter.

Each branch should be pruned such that the cut is approximately at right angles to the branch and close to, but not into, the collar. The collar is the swollen area around the base of the branch and is made up of trunk wood rather than branch wood. Once the branch is removed the undamaged collar will be able to rapidly grow over the stub. Any small dead branches should be knocked off, rather than cut, to remove any unattached stub.

Some species, such as Queensland Kauri Pine (*Agathis robusta*), have an unusual response to pruning whereby if a live branch is cut the tree responds by naturally ejecting the branch stub entirely. This greatly increases the clearwood volume and allows farmers to prune the trees by simply cutting the branches back to short stubs rather than right back to the stem.

Pruning should be done to a height required to produce a high value log. Some veneer mills only require a log of 2.5 or 3m whereas many sawmills would prefer large diameter logs to be 5 or 6m long. Accounting for a stump of around 0.5m, pruning to 6.5 or 7m would allow for two veneer logs or one long sawlog. Other factors to consider are the costs and returns of pruning, the ultimate height of the tree and volume of timber in the unpruned crown. It is clear that the costs, and the risks, associated with pruning increase with height and that the clearwood yield diminishes up the tree because of the smaller stem diameter. Unless the trees are expected to grow more than 30m tall there may be little opportunity to recover two 6m sawlogs from a single tree. In any event the proportion of total volume in the first 6m log may be as much as 70% of the total stem volume. Some high value cabinet timbers are difficult to grow tall and straight in which case a pruned height of 3 or 4m may be acceptable. In pines and eucalypts pruning to 6.5 or 7.0m allows for the production of a long clean sawlog or two veneer logs. In very tall species, like Californian Redwood, it may worth pruning to 8m or more depending on the availability of a safe and effective pruning method.
Whatever technique is used for pruning, safety should be the first consideration. We prefer to use hand tools (loppers and saw) and to climb the tree with ladders so that each cut can be made carefully. One simple technique requires a specially designed tree climbing ladder and a pole harness. The ladder is set up vertically against the trunk and the harness looped around the tree while still on the ground. The operator can then climb straight up, tying the ladder onto the tree as they go, and lean back in the harness while they prune. The risk of a serious fall is largely eliminated and the operator is free to concentrate on pruning rather than hanging on. Some farmers prefer to stay on the ground and use pole pruners. Pole saws and loppers are quite effective when the branches are small and perpendicular to the trunk. Large, steep angled branches are difficult to accurately cut from the ground. Pruning contractors in large plantations often use platforms, like the type used in horticulture.

Whatever technique used, pruning is always labour intensive and it is critical to get the best return from the time involved. This can only be achieved by thinning your plantations so that diameter growth of pruned trees is not slowed by competition. In fact, because the farmer doesn’t need to rely on competition to control the branch size they are able to space pruned trees further apart than generally accepted and thereby greatly reduce the time it takes to grow a big sawlog. For intolerant species, like eucalypts, this may mean thinning down to around 100 pruned trees per hectare whereas 200 may be appropriate for the more tolerant softwoods.
This allows for grazing amongst the trees or the incorporation of understorey species for productive or environmental purposes. If understorey growth is not controlled, access, weeds and the risk of fire may present management problems. Where this is of concern more trees may be required to suppress the understorey growth.

**Plantation regimes for timber production**

**HIGH VOLUME PRODUCTION REGIMES: PULPWOOD, FIREWOOD & BIOMASS**

To maximise volume production intensive site preparation and higher stocking rates are used to encourage early canopy closure and generate high basal areas. The high level of competition has the advantage of minimising the canopy area on each tree therefore reducing the size of the branches and ensuring that the majority of the wood produced is concentrated in the stems. Knowing the mean tree diameter required for economical harvesting and processing and the likely basal area at the time of harvest can help determine the most appropriate initial spacing. For example, if the basal area of a eucalypt plantation at age ten is expected to be 20m²/ha and the farmer would like the mean tree diameter to be 20cm the final stocking would need to be about 640 stems/ha. Allowing for some losses, they may choose to plant around 700 stems/ha at a spacing of say 3.5 x 4.0m. On a better quality site, where the final basal area might be expected to reach 30m²/ha, the same mean DBH would require 955 stems per hectare. In this case an initial stocking of 1111 stems/ha (3x3m) might be used.

Because dominant height and the maximum possible basal area are largely a function of site quality only the best quality sites are able to achieve very high volume yields. Sites with cool climates, rainfall of over 1000mm/year and deep fertile soils are ideal and fantastic production levels are possible. However, with many more marginal sites being planted to pulpwood plantations it is common to find that although early growth is excellent the plantations soon "hit the wall" as basal area and height reach their limit. At this point the growth of any tree in the stand must be compensated for by the death of others. Unfortunately, many of plantations are reaching their limit at an early age with no prospects for commercial pulpwood production.
SAWLOGS WITHOUT PRUNING

Conventional pine plantation management across most of Australia has focused on the production of sawlogs with small branches that are suitable for structural timber. Instead of manual pruning, competition is used to control the size of the branches. To prevent competition slowing growth to a halt, or threatening the stability or health of the forest, a number of thinning operations are undertaken to reduce the basal area. Where possible pulp or other small diameter products are produced from the thinning operation to help cover costs.

The great risk inherent in adopting these regimes is that without a viable market for the thinnings, at the time required to control competition, the whole investment may be at risk. Overstocked plantations under excessive

FIG 9.
The Current and Mean Annual Increment curves for *E. globulus* adapted and predicted from data and observations of plantations on a very high quality site in Western Australia (rainfall over 1100mm) and average sites in Victoria (rainfall 850mm). Where the MAI and CAI curves cross is the point at which MAI is maximised. Note that the initial growth on both sites is similar until the limitations of the poorer site begin to affect productivity.

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competition are susceptible to drought, diseases, insects and wind. Diameter growth on the best trees can slow to a halt as the plantation becomes "locked up". Thinning in dense stands can also lead to severe epicormic shoot development (shoots sprouting up the stem) as the trees try to rebuild a canopy after a period of intense competition.

The temptation to postpone the first thinning until the trees are large enough to allow for a commercial return is common. However experience suggests that farmers with small plantations should be cautious about assuming they will be able to negotiate a commercial thinning. To be viable the plantation must be large, easy to access and close to markets. The machinery required to harvest, delimb, debark, and load small diameter logs efficiently is expensive. Few farmers have access to such equipment and many find themselves unable to attract contractors due to the small areas involved. A possible compromise for those who still wish to use competition to control branch development in their plantations or native forest is to look for cheap methods of culling such as stem injection or ring barking. Where this is possible the farmer can maintain competition at a level required to encourage self-pruning and then thin repeatedly to maintain diameter growth.

SAWLOGS WITH PRUNING IN HALF THE TIME

In addition to increasing the log quality pruning can reduce the time taken to grow large logs. Because it is not necessary to maintain competition to control branch development the farmer is able to space their trees further apart thereby ensuring each tree can maintain a large canopy to drive diameter growth.

Figure 10 suggests that pruned plantations of eucalypt may be able to reach 50cm in average diameter in half the time of conventional plantations. Because they are under less stress the trees in these plantations may also be less susceptible to drought or disease.

It is common in plantation forestry to plant more trees than are expected to be harvested. This not only provides mutual shelter for the young trees and helps control tree form and branch growth but also allows for a degree of selection so that all the final crop trees are all of high quality. For example,
if the aim is to grow a plantation of at least 100 perfectly straight high pruned eucalypts per hectare the farmer may start with more than 600 stems/ha. As the plantation grows, the better performing trees are selected for the first pruning (say 400 stems/ha of the most vigorous straight trees) and the remaining are culled. The following season the best 200 may be selected for a second prune and the others culled. Finally the best 150 stems/ha may be high pruned to the final height and the others culled. The trees are then left to grow on with 50 trees in reserve in case of disease or wind damage.

If the same farmer was growing a more tolerant species like the exotic or native pines they may choose to aim for around 200 stems/ha in which case they may start with 800 or 1000 stems/ha. If they are confident that the trees do not require early shelter and growth will be very uniform they may be able to plant less trees initially.

**FIG 10.**
The majority of the eucalypt plantations grown in Australia over the last 60 years have engaged competition as a means of controlling branch growth and maximising timber volume. The few pruned plantations show how pruning allows the trees to be widely spaced and therefore grow large diameter logs in half the time.
MANAGING INDIVIDUAL TREES IN MIXED SPECIES PLANTATIONS

Many farmers are managing mixed species or mixed age forests for a range of products and services of which timber production is only one. In this case it may be viable for the farmers to manage individual trees within their forest rather than the plantation as a whole. The emphasis, again, must be on high quality to ensure that the trees are viable to harvest. Promising trees, located in areas with easy access for harvesting, could be pruned. At the time of each pruning it is important to release the tree from any competition. The aim is to ensure that the canopy of the selected tree is able to develop freely.

Firstly, any tree that is overtopping the selected tree, or affecting its canopy shape, should be culled. Then the farmer can make a judgement as to whether any other trees need to be removed in order to reduce competition. A relatively simple method for assessing competition is the use of the spacing factor described in the measurement chapter. If, for example, the farmer wanted to reduce the competition in their forest down to 10 m²/ha the spacing between trees of a similar diameter would need to be about 30 times the diameter. For example, if the trees were all around 15cm in diameter then culling any tree within 4.5m (15cm x 30 = 4.5m) would reduce the basal area to less than 10m²/ha. As the tree grows it will require more space.

In a mixed forest where the trees are of differing size the same technique can be used to determine if a large tree adjacent to the selected tree should be culled. If it is located within 30 times its own diameter then it might be assumed to be competing with the selected tree. For those farmers comfortable with the use of the MTG Tape they could stand beside the selected tree, estimate the basal area (including the selected tree in the count), and thereby assess the level of competition affecting that tree. If it is over 10m²/ha (or the desired level of competition for the species on that site) they might repeat the sweep and determine which trees would need to be culled to reduce the competition to the appropriate level.

Silviculture for multiple values

Balancing timber production with other values is possible, such as land degradation control, agricultural production or biodiversity, especially where the emphasis is on the production on high value pruned trees. Understorey native species can be grown between the widely spaced pruned trees thereby improving the provision of environmental services.

Alternatively farmers might choose to graze pastures between widely spaced trees or use the area for stock shade and shelter. This has the added advantage of reducing the fire hazard and stock may also benefit from access to fresh fodder from the prunings and thinnings. There is a risk of stock damaging the trees when they are young by rubbing or chewing on the bark.

Harvesting

If timber is the only product and the aim is to maximise profit then clearfelling large areas will reduce the costs of harvesting and probably maximise the return. However, where trees also provide salinity control, wildlife, shelter or other values harvesting small volumes over a long period may be preferred. If the logs are large, pruned and well spaced, a trained operator using a chainsaws in combination with a farm tractor, loader and log trailer can be cost competitive against specialised mechanical log harvesting machines. However, if the logs are small, branchy and in a dense...
plantation the costs associated with the use of farm equipment can be higher than the value of the trees. (See Chapter 10).

The choice of harvesting method will also depend on the requirements for regeneration. Light demanding species, such as eucalypts, may need to be a full tree height away from any mature trees if they are to grow well. This means that a gap or 30 or 50 metres may be required. More shade tolerant species, such as the rainforest trees or the softwoods, may grow well in the gap left after the harvesting of a single tree. In some cases the second generation can be grown amongst well-spaced older trees prior to harvest.