

D e s i g n P r i n c i p l e s f o r F a r m F o r e s t r y

A Guide to assist farmers to decide where to place trees and farm plantations on farms



Written collaboratively by Nick Abel, Jenny Baxter, Alex Campbell, Helen Cleugh, John Fargher, Robert Lambeck, Roslyn Prinsley, Miles Prosser, Rowan Reid, Grant Revell, Carmel Schmidt, Richard Stirzaker and Peter Thorburn

RIRDC/LWRRDC/FWPRDC Joint Venture Agroforestry Program

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'Design Principles for Farm Forestry: A Guide to
Assist Farmers to Decide Where to Place Trees and
Farm Plantations on Farms'

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The production of this book was facilitated by two meetings of all authors, many of whom are experts in particular aspects of agroforestry. Each chapter has been edited by most of the authors. Chapters have also been professionally edited by Deborah O'Connell and Alastair Sarre.

What this book is about

Agroforestry – the productive use of trees on farms – is a new concept to most Australian farmers. This book has been written because agroforestry differs from traditional annual forms of production in two main ways.

First, trees are a long-term investment. They deserve extra planning and management to maximise their benefits to the farm. Because of their long-term nature, they can be used for many purposes including financial risk management, retirement planning and transferring wealth between generations. You will need good advice on taxation and investment to optimise these aspects of agroforestry.

Second, trees give indirect benefits to other farm enterprises. Trees can make conditions more favourable for the growth of plants and animals and play a role in keeping farm ecosystems healthy. You may plant trees with one purpose in mind but get other benefits as well. In fact, the indirect benefits of trees can add up to be more important than the original reason for planting them in the first place. Careful design is needed to capture multiple benefits from trees. This is what the book is about.

Trees are deep-rooted and therefore access water-tables and recycle nutrients that are unavailable to most other forms of production. Trees also have an important influence on natural systems and biodiversity which, with good planning, can benefit the farm and region.

Special consideration should be given first to the best places to plant trees in a catchment and second to the best layout of trees in the paddock, in order to improve the productivity of the farm, protect

the soil and water resources and enhance the beauty and conservation value of the land.

It is important to be aware that changes to some environmental aspects, such as rising water-tables, will take as long to reverse as they did to emerge. This is not to say we should not take remedial action, but rather we should give careful consideration to design and planning. In human terms, these effects often span generations!

In compiling this book, it is recognised that Australia has widely differing climatic regions. For this reason, we have concentrated on design principles that hold true across all regions. Some regional examples are given to help demonstrate a point, but you will need to take local advice on regionally specific issues such as establishment techniques and species selection.

It may help most farmers to think of trees as just another crop! The same care in paddock preparation, weed and insect control and species selection will be equally rewarding as for any other crop. Be warned that multiple uses of trees on the farm will increase management demands – but it will be worth the effort.

The contributors to this book are involved in on-going research to further improve our knowledge of tree productivity and their effects on the wider environment. However, they believe the design principles outlined here should enable farmers and their advisers to undertake planning with reasonable confidence to improve the financial and environmental aspects of the farm business.

The principles outlined in this short book will be supported by a second volume which is now being

What this book is about

compiled. It will cover more of the theory and detail used in arriving at the design principles. It is therefore recommended to those readers who want a more in-depth understanding of the issues.

I commend this book to you, and suggest you move straight to the chapter you think is most likely to benefit your farm.

Alex Campbell

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How to use this book

The book identifies seven reasons why you may want to start planting trees. These are:

- to produce timber or other wood products;
- to combat salinity and waterlogging problems;
- to protect or rehabilitate degraded land (soil conservation);
- to provide shade and shelter for plants and animals;
- to provide fodder;
- to conserve and encourage the abundance and diversity of native plants and animals; and
- to improve the scenic beauty of the landscape.

We call the reasons for planting trees 'triggers' and have written a chapter to cover each one. You can start by moving straight to the trigger of most interest. Each trigger chapter gives basic design principles to achieve that particular objective for growing trees. At the end of each of the trigger chapters there is a table which gives you hints as to

how you can alter a design to capture other benefits. Use this table to lead you to the next trigger chapter of most interest to you. Sometimes other benefits can be achieved with relatively little modification, while others will be more difficult to accommodate.

After the seven trigger chapters there is a section called 'Capturing multiple benefits from agroforestry'. This chapter explains how to maximise the positive interactions trees have on the farm and how to minimise the negative ones. The concepts are illustrated with case studies.

The final two chapters give general principles for the establishment of trees and steps you can take to work out the economic viability of the agroforestry design that you have developed for your farm. Depending on the economics, you may need to modify your design.

So pick the trigger chapter that most interests you and start reading!

Trees for wood products

Defining your requirements

If you are seriously interested in timber production for income then you need to do your homework on options, expected yields, opportunity costs, tax implications, market access and risks. Timber production from planting to harvesting involves long rotations so if you are able to achieve other values (such as shade or shelter) by varying your layout and management, why not do so? If you have started with this chapter first you should also read about how revegetation can provide other values before deciding on a final design.

If you have turned to this section as a secondary option you will have already identified the main reason why you want to grow trees. You may also have identified where they need to be planted, what mix of species is required and how the forest as a whole might be structured. You are now interested in whether these same trees might be able to provide a direct commercial product.

Irrespective of the reasons for being interested in timber production there are some clear design principles that can be used to help determine the most appropriate species and management regimes to meet your needs.

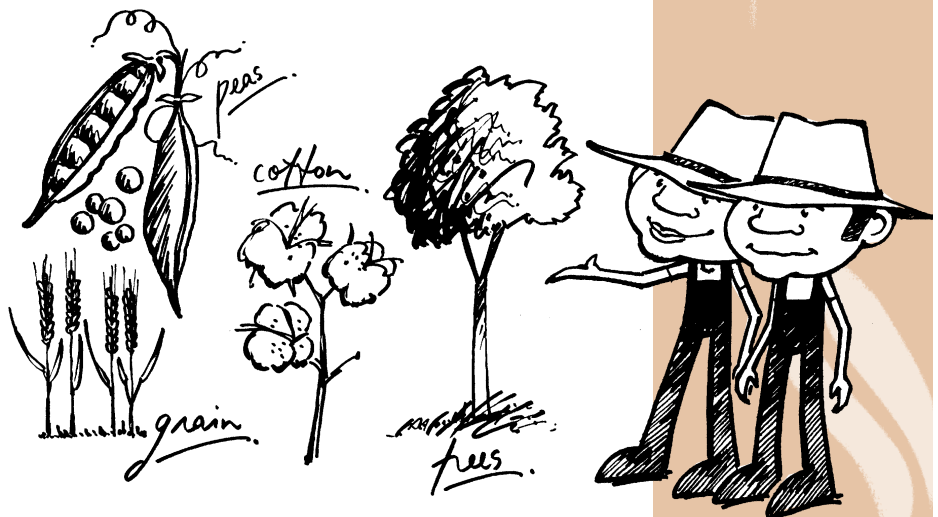
Timber options

There are many different timber product, tree species and timber management options. Financially, the options vary in:

- their costs;
- labour requirements;
- economies of scale;
- risks and uncertainty;
- ease of marketing.

Different options are available in different regions and product options and prices will invariably change over time. What is valuable today may be more or less so in the future.

The uncertainty of future markets can be seen as a positive reason for investing in tree-growing. Many growers look to decreasing supplies of timber from native forests worldwide and an increasing world population as a sign that timber prices will rise. Landowners should be wary of such predictions and first look to ensuring that the product they produce matches the highest quality requirements of their local and regional markets. If prices for timber do rise, only those landowners with access to the market and stands of sufficient size and quality will benefit. What may be profitable in one region may be unsaleable in another.



Growing good wood

The greater the quality of the wood grown the more valuable the trees will be to the processor and therefore the easier to sell for the farmer.

In forestry, quality depends on how well a stand of trees meets the needs of the buyers.

A high quality firewood stand is very different from a high quality sawn timber stand or a pulpwood stand. Whether you intend to sell trees, logs, processed timber or simply use the product yourself, tree and stand quality are critical to success.

Because farmers generally grow trees to sell as logs (which may later be used as sawn timber or chips),

we need to know how species, log dimensions and wood quality influence value. We also need to know what factors will affect harvesting, transportation and marketing costs.

With an understanding of the tree species and stand type we should aim for and a knowledge of management costs, it should be possible to design plantings that meet our immediate needs while remaining commercially viable. It is important to recognise that the most appropriate design for a particular landowner will be determined by the needs and resources of the landowner and the characteristics of the land itself, and may not be the optimum one for maximising wood value or return on investment.

Product options

Wood products can be classified into a number of types:

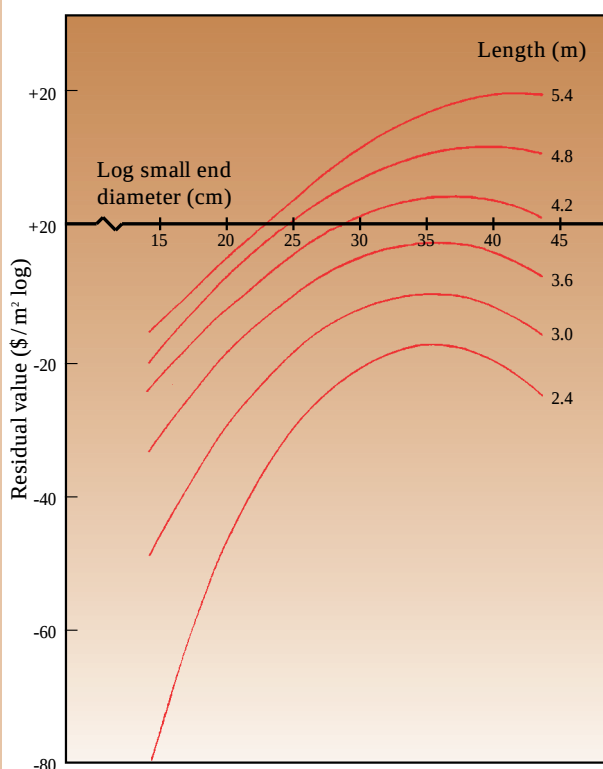
- sawn timber products;
- composite boards;
- paper and cardboard;
- posts and poles; and
- fuelwood.

In each case and for each situation there will be particular log specifications and factors which downgrade the value of the log.

Sawn products

Solid timber products are used for engineering and appearance, as construction timbers, for flooring and lining, and for joinery, furniture and craft purposes. The timber may be used green or dried, it may be seen as a commodity (such as house framing), or as a specialty product (such as kiln dried furniture timbers). Increasingly, mills are specialising in a limited range of species (maybe even only one) and aiming to service particular market sectors.

Figure 1:
The value of a sawlog is greatly influenced by diameter and log length



In this mill the 'optimum' log size is 45 cm in diameter and 5.4 m long.

Trees for wood products

For a given species, factors that affect the value of a log to the mill include:

- diameter;
- straightness;
- log length;
- presence of defects; and
- growth stresses.

These will influence the percentage recovery and grade of the final product. In the hardwood industry, recovery of marketable grades of sawn timber from native logs can be as low as 10% or as high as 50%.

Hence the value of a 'good' log at the mill door is many times that of a 'poor' log and should be reflected in market interest and price.

Composite wood panels

Across Australia timber is used to manufacture a range of veneers, plywoods, particle boards, medium density fibre boards (MDF), chipboards, and other panel products. With the exception of the veneers and plywoods, manufacturing processes involve the reconstitution of wood fibres and generally begin with woodchips.

Many, if not most, of the raw woodchips for use in reconstituted boards are sourced from sawmill waste. More than 30% of a sawlog can end up as woodchips. Mills often prefer mill waste to logs as they are easier to handle and are often of higher quality than woodchips sourced from young, small diameter logs.

Plywood and laminated veneer lumber involve the 'slicing' or 'peeling' of thin veneers directly from the log and can be treated as a 'sawn' product. Veneer mills have very specific requirements for log dimension and quality which are easy to define. However, this is a relatively small market and difficult to predict. Fortunately, in most cases a good veneer log is also a good sawlog.

Woodchips, pulp and paper

Woodchip and pulp processing plants are invariably large scale operations influenced by world prices rather than local demand. There are paper mills and export wood facilities in most states, and within acceptable haulage distances (say 100 km) of these facilities there is interest in the establishment of plantations dedicated to the production of woodchips.

Log quality and stand specifications are as important, if not more so, for pulpwood than for any other timber product. Due to very tight economic margins many factors are critical, including:

- fibre quality;
- tree size;
- harvesting and transport costs;
- plantation area; and
- the uniformity of the stand.

Therefore, the degree to which the layout and management of an 'ideal' pulpwood plantation can be varied to suit other farming concerns (such as shade and shelter) while remaining commercially viable is questionable.

Posts and poles

In some regions there are attractive markets for posts and poles. Unfortunately, the specifications are extremely tight and it is unlikely that a great proportion of trees harvested at any time will meet the specification of the market. The markets themselves may be quite fickle. For example, the current expansion of vineyards has increased the demand for treated pine posts, but because of the automated harvesting systems used now in vineyards the posts must be just under 125 mm in diameter. From any single tree taken from a stand only one short post may meet this market need, while the market for posts of other sizes may be flat.

Fuelwood and extractives

Despite the fact that the greatest use of timber worldwide is as fuel, growing fuelwood for profit remains a specialised business. The major costs are associated with such factors as:

- felling;
- cutting;
- splitting;
- drying;
- stacking; and
- transporting.

Any design or management that can reduce these costs will improve returns.

Wood characteristics such as colour, density, ease of splitting and burning quality will influence acceptance in major markets and affect returns to growers. Some markets simply prefer a particular species.

The use of timber as an industrial fuel or source of extractives (ethanol or tannins) has possibilities although prices will vary depending on the cost of alternatives. Special purpose fuelwood or extractive plantations carry similar risks to pulpwood due to low margins and high processing costs.

What to grow

As small producers looking to take advantage of market opportunities, landowners should carefully consider their product options. Ask yourself “why should industry be interested in my trees?” and look to gain some advantage by good design or management. Some points to consider include:

- look at the trends in the local industry. Is the supply from large scale plantations and native forests increasing or decreasing? What will the industry look like in the future when you come to harvest?
- avoid locking into a product option for which there may be only one buyer, unless you agree on a price at the outset. Examine the trends in the market and aim to produce a product that has a number of market options;
- look to producing products that have a long standing life to avoid having to sell at a particular age or when the market is depressed. Many forest owners who adopted regimes that required commercial thinning to be done at a certain age have been forced to accept a low price or find that the entire program is jeopardised because they cannot secure a market at that time.

Log values

The price paid for a particular tree will depend on the mill door value to the buyer and competition within the industry. In most cases what is good for the processor will improve the value of the standing trees to the grower. Many factors influence price:

- costs of harvesting and delivering the timber to the processing plant are influenced by the scale of the operation, ease of access, site characteristics and transporting costs. Clearly, small areas of forest on steep land at the back of the farm will attract less interest than large uniform plantations on flat land close to roads;
- timber is a heavy product and transport costs can be as high as 10c per km per tonne. This suggests that logs close to the mill may be worth \$10 per m³ more than logs sourced from over 100 km away;
- year-round access for harvesting can greatly increase the value of a stand. In most regions logging slows during the wet season. If your plantation is accessible all year round it will be easier to attract contractors and buyers;
- consistency and security of supply provides processors with long-term stability. Although most small growers will not be able to provide large volumes over long periods, collective marketing or entering into marketing agreements can improve the value of a stand.

As the sawmilling industry becomes more sophisticated and the quality of logs from native forests declines, the price differential between logs of differing quality appears to be increasing. Figure 2 illustrates some examples of the effect of log quality (as determined by log size and the presence of defects) on the value of standing logs in government forests. For small growers the differential might be expected to be greater as they

may be less able to 'encourage' industry to accept lower value timber as part of a parcel of logs.

Where trees are being used to provide other benefits (such as shade and shelter) as well as for timber, financial returns may be compromised by the need to maintain or provide these other benefits. Although the landowner may have to accept a lower return than that being achieved by large scale commercial timber growers in the same area, this may be acceptable in the light of other values such as shade and shelter.

Manipulating a stand of trees to grow good wood

Silviculture is the manipulation of forest stands and the trees within them. Silviculture is the most powerful tool of the farm forester and the means by which 'firewood' might be turned into high value veneer or sawn timber.

Having selected a product, species and site, the silviculture (beginning with planting design and continuing until the time of harvest) will determine:

- the volume of timber in the stand as a whole;
- the volume per tree;
- the distribution of timber within the tree; and
- the quality of timber produced in each part of the tree.

Growing logs to match market specifications requires the determination of the target tree. The most important characteristics of the target tree will often be form, diameter and wood quality. Silvicultural regimes are developed to ensure that these needs are met. But before we can consider silviculture we need to understand how a tree grows.

Trees for wood products

Figure 2:
Effect of log
quality on value

The top part of the table shows log prices in \$ per m³ as quality increases from top to bottom. These values are illustrated in the graph.

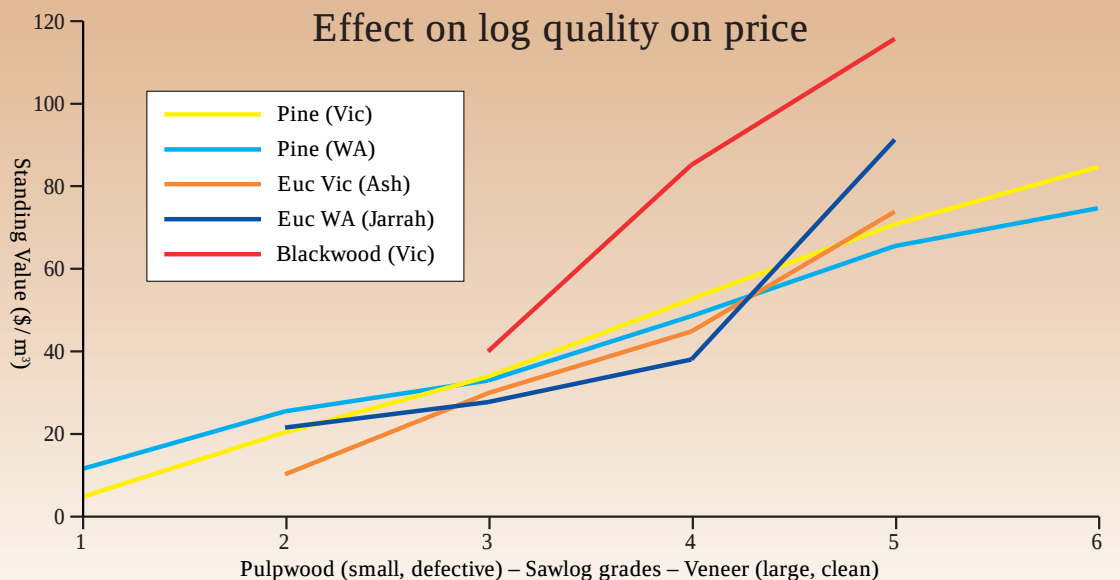
The lower part of the table shows the definition of each quality class for each product.

Information drawn from the average royalty values for a range of log quality grades sold from native forest and government plantations in Victoria and Western Australia in 1995

Comparative prices

Quality rating	Pine (Vic)	Pine (WA)	Euc Vic (Ash)	Euc WA (Jarrah)	Blackwood (Vic)
1	5	12			
2	19	25	12	20	
3	34	33	30	27	40
4	50	47	43	36	80
5	65	69	72	88	110
6	76	84			
Quality Rating	Pine (Vic)	Pine (WA)	Euc Vic (Ash)	Euc WA (Jarrah)	Blackwood (Vic)
1	Pulpwood	Pulpwood			
2	Diam. < 20 cm	Case logs	D grade	Third grade	
3	25 cm	Rough logs	C grade	Second grade	Inferior
4	35 cm	Over 20 cm	B grade	First grade	General
5	45 cm	Over 30 cm	A grade	Premium	Superior
6	Veneer grade	Veneer grade			

Effect on log quality on price



Tree growth and wood production

Trees essentially have two above-ground growing points. The most obvious is the leading shoots of the main stem and branches. At this point cell division leads to elongation and height growth or branch development. The second growing point is the cambium. The cambium is a layer of dividing cells found just below the bark on the main trunk and all branches. The cambium produces two types of growth:

- wood cells on the inside which not only help support the tree but also initially act to conduct water from the roots up to the leaves; and
- bark cells on the outside which initially perform a role in transporting sugars from the leaves down to the roots but then later die to form the protective bark.

When we manipulate the growth of a tree we do so by influencing the growth and development of these two growing points. Through management we are able to suppress or encourage elongation of the main stem and branches and vary the production of wood by the cambium.

Tree form, diameter and wood quality

Arguably the most important criterion of a target tree for timber production is form. For all harvesting and processing procedures, straight single-stemmed trees are easier to process and thus have a higher recovery in milling. Leaning or crooked trees may also induce the development of reaction wood (with a different cell structure) which can affect a log's milling, drying and pulping qualities.

The early management of a timber stand should be focused on the development of well-formed trees

which can be seen as a structure onto which good wood can be grown.

Techniques to induce good form include:

- high initial stocking rates;
- genetic selection;
- nurse crops;
- corrective pruning.

Once a tree is felled and cut into log lengths it is the diameter of the log, not the height of the original tree, that will influence log value.

Log diameter will often determine the harvest age and therefore increasing the rate of diameter growth can reduce rotation lengths.

Wood quality is influenced by many factors:

The type of wood. There are two types of wood in the tree: heartwood and sapwood. In some species only the heartwood is of commercial value. For other purposes, such as chemical treatment, sapwood may be preferred.

Knots or branch stubs. A major defect in plantation timber is the presence of knots or branch stubs. Knots interfere with the grain of the timber and reduce its strength and appearance qualities. They may also become entry points for rot and discolouration that can spread through the tree. Generally the larger the knots the lower the value of the timber although the type of knot is also important. The size, type and location of knots in the log can be influenced by silvicultural regime.

Age. In many timber species wood density increases with age, thereby increasing the strength of sawn timber and the fibre yield of wood chips. For low density species (pines and some eucalypts) this may make young trees less valuable.

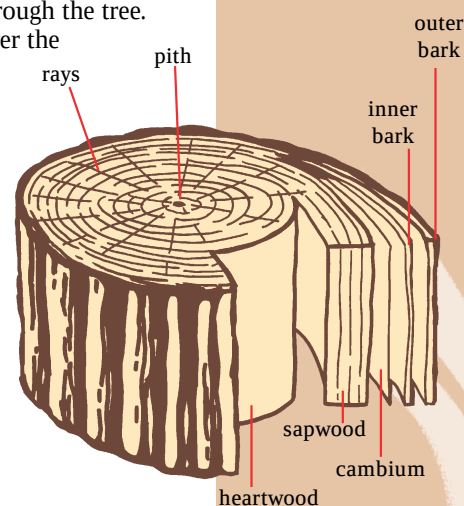


Figure 3:
Tree growth and
wood structure

Site selection

Like all crops, site quality greatly influences tree growth and productivity. For trees we generally consider soil depth, texture and the degree of exposure as the most important criteria. Although irrigation of trees is being trialled, the costs involved are likely to be prohibitive unless the trees are seen as a sink for waste water.

The condition of the existing vegetation on a site (species composition, height, structure and productivity) is often a useful guide to site quality. Problems such as waterlogging, infertility and dry soils can be identified and possibly overcome by appropriate site preparation. Soil fertility can be enhanced by fertilisers and this has been demonstrated as viable on some highly leached infertile soils. Intensive soil preparation may also overcome soil structural problems such as impeding layers or surface waterlogging that may restrict growth.

In many cases you will have already identified where you wish to grow trees. In some cases these areas will also be of low productivity for trees, but this should not be seen as of great concern.

The important point is that in determining the appropriate silvicultural regime the productivity of the site and the likely returns have been considered.

Silvicultural regimes involving intensive tree management, long rotations or high costs are generally only viable on good quality sites. Where growth is likely to be slow or risks of fire, drought or disease are high, less intensive options might be considered to reduce the financial risks.

The silvicultural tools

Landowners can influence the form, diameter and wood quality of their trees by manipulating competition between trees (thinning) and by tree shaping (pruning). For a single species, plantation competition is determined largely by size and spacing of trees on the site.

By understanding how the stocking rate of a plantation affects the growth of individual trees and stand characteristics, managers are able to manipulate the stand and change the outcome. Figure 3 illustrates the powerful influence of inter-tree competition on tree diameter and stand volume. 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 1,100 trees per hectare (3x3 m spacing) and left unthinned until final harvest.

If, however, the aim is to produce large diameter logs suited to milling for solid timber, the trees are planted at a lower initial stocking rate or thinned to maximise diameter growth. Although the total volume of production may be lower, the shorter time needed for the trees to reach the appropriate size and the higher value per tree can offset the loss of volume.

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 of trees are of high quality. Genetic variation is very pronounced within trees grown from unselected seed lots, particularly in our native species. Genetic improvement of tree species may reduce this genetic variation although some allowance should be made for poor growth or form due to planting technique or damage from wind, snow, browsing or disease.

To increase diameter growth on selected trees the competition from adjacent trees must be reduced as the tree grows.

The difficulty for landowners is in determining how many trees to thin and when to begin. Thinning too few trees means that tree growth is not increased sufficiently, while thinning too heavily may encourage excessive branch growth and will reduce total yields.

Experience suggests that for plantations on well watered sites, if trees are to grow freely without competition they should be spaced at an average distance greater than 25 times the diameter of the largest trees.

For example, trees planted at 3 m spacings (1,100 trees per hectare) will begin to compete, and their diameter growth will be restricted, once the trees reach 12 cm diameter.

Where branches are controlled by pruning, thinning to 25 times the diameter can reduce the time taken to reach target log diameters without compromising log quality. Where competition is required to reduce knot size, thinning to 20 times the diameter may be advisable depending on the degree of self-pruning.

The temptation to postpone thinning until the trees are large enough to allow for a commercial thinning for posts or even small sawlogs is common but will slow the growth of the best trees, therefore postponing the lucrative final harvest.

This may be acceptable for landowners who are happy to wait or are unable to fund the costs of pruning or thinning to waste, but in most areas where the return for small wood is very low it is advisable to thin to waste.

Pruning for high quality timber

Branches on the trunk of the tree reduce the timber strength, pulping quality and appearance values of the tree. High value timber contains either

very small knots or no knots at all. Knots larger than 5 or 6 cm in diameter result in timber being unsuitable for many structural grades and for most appearance grade timber. Trees need to be artificially pruned if knots are likely to become large or if clearwood is specified.

Large knots occur if the branches become large. Branches of many species grow large at low stocking rates, especially if the site is fertile.

In order to benefit from the increased diameters achieved at low stocking rates pruning is often essential.

A well pruned tree produces a log with a core of knotty timber containing the pruned stubs surrounded by a sheath of knot-free wood or clearwood. The production of a clearwood log requires careful management over a number of years.

Harvesting and marketing

The nature of the logs and their value dictate the type of harvesting equipment and the scale of operation required to make the sale of timber profitable. For a product like pulpwood, which has a low value to weight ratio (about \$20/tonne) and is sold to large industrial wood processors, the minimum volume required for a sale may be over 2000 m³ or about 10 hectares of plantation. Because of the small size of the logs from young pulpwood plantations, automated harvesting equipment is required and clearfelling is recommended to keep logging costs down.

For high value sawlogs (over \$50/tonne) the minimum lot size might be just one truckload delivered to the sawmill. Farm equipment (chainsaws and adapted tractors) is often adequate and the landowner can learn the skills or pay experienced fallers. Landowners interested in maintaining non-timber benefits may choose not to

clearfell large areas and accept the higher costs of selective or small scale logging.

Joint ventures and lease arrangements

Governments and plantation developers are offering joint ventures or land lease options to landowners for the development of commercial plantations. These should be seen simply as another option for landowners and can be assessed against the farmer's own design criteria for other values and his or her own financial needs.

In most cases the silvicultural regimes on offer will largely be fixed. The joint venture partner will have determined what species, planting pattern, management and products they are interested in. The landowner should be aware of the degree to which the design is flexible and can be varied either financially, legally or physically to better meet specific needs. Understanding the principles of silviculture and the needs of the industry partner will help in the negotiations.

The most appropriate silvicultural regime for your farm

For sites where you need to plant trees for other benefits or for those sites you have identified as available for timber production, a silvicultural regime needs to be developed. The regime will specify:

- the expected target tree;
- stand characteristics;
- the species mix;
- initial stocking rates;
- thinning and pruning prescriptions; and
- other management requirements.

Questions will arise regarding markets, management options or simply species selection. In some cases the answers may be available from local research or experience but quite often you will need to make a judgement yourself. Where there is uncertainty you might choose to test a number of options, be they establishment methods, species or management.

Unfortunately, the long rotations make it impossible to fully test the options on a small scale before you decide to go ahead, but you will learn from your own experience very quickly and be able to see what seems to work.

There is no best bet option suited to all landowners but by understanding the principles involved in timber production and by gaining direct experience you may be able to determine what is best for you.

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Capturing benefits in addition to wood products

The economic return from timber or wood products may offer the opportunity to achieve the scale of plantings needed to capture other major benefits such as water-table control and soil conservation. Shelter and, with careful planning, some nature conservation and scenic beauty objectives can also be captured.

Other benefits to capture	Opportunity	Things to look out for
Salinity and waterlogging	Belts of timber trees can be planted to intercept laterally moving groundwater and prevent waterlogging or salinity problems downslope Plantations in recharge areas will reduce additions of water to the water-table	Optimum location of trees for timber may not coincide with locations required for salinity management Upland recharge sites often have poor soils
Soil conservation	Belts of timber trees reduce effective slope length and drop litter which can reduce sheet and rill erosion Timber trees reduce wind erosion Trees can cycle nutrients from subsoils Trees can improve compacted subsoils by making root biopores	Some species can make erosion worse by suppressing ground cover or reducing infiltration Harvesting trees can cause erosion and remove nutrients
Shade and shelter	Plantations make effective windbreaks for surrounding paddocks, and this can be improved with appropriate choice of plantation shape and location Access to plantation for stock gives excellent shelter	Square-shaped plantations give a small area of protection to pasture/crops relative to the number of trees planted
Fodder	Pasture in young plantation paddocks can be grazed once trees are large enough to withstand possible damage Some commercial tree species may yield livestock fodder	Browsing can have adverse effects on tree growth rates and form Moderate to high tree densities will inhibit pasture production
Nature conservation	Plantation trees can potentially provide useful food and nesting resources for some wildlife Plantations adjacent to remnant vegetation may buffer the remnant against extreme environmental conditions Plantations linking existing remnants may increase the chance of animals moving through the landscape	Requirements for uniform timber quality reduces structural diversity and hence reduces the habitat potential of plantations Large block plantings reduce patchiness in the landscape and hence reduce habitat diversity Tree harvesting may cause resource shortages and hence population declines for some species
Scenic quality	The need to manage scenic quality may require alternative and creative silvicultural and harvesting practices but these need not affect economic output	Visual impacts of standard silvicultural prescriptions and harvest operations usually lower scenic quality

Trees for controlling dryland salinity and waterlogging

Introduction

Saline and waterlogged soils, saline creeks and rising water-tables often trigger interest in tree planting. This raises questions such as: *What area of trees do I need to plant? Where in a catchment should I put them? Which species are best?*

This chapter will describe the factors that need to be considered when planting trees for controlling salinity or waterlogging and give some principles that can be used to answer these questions. Only generalities can be given here because many of the factors are site-specific.

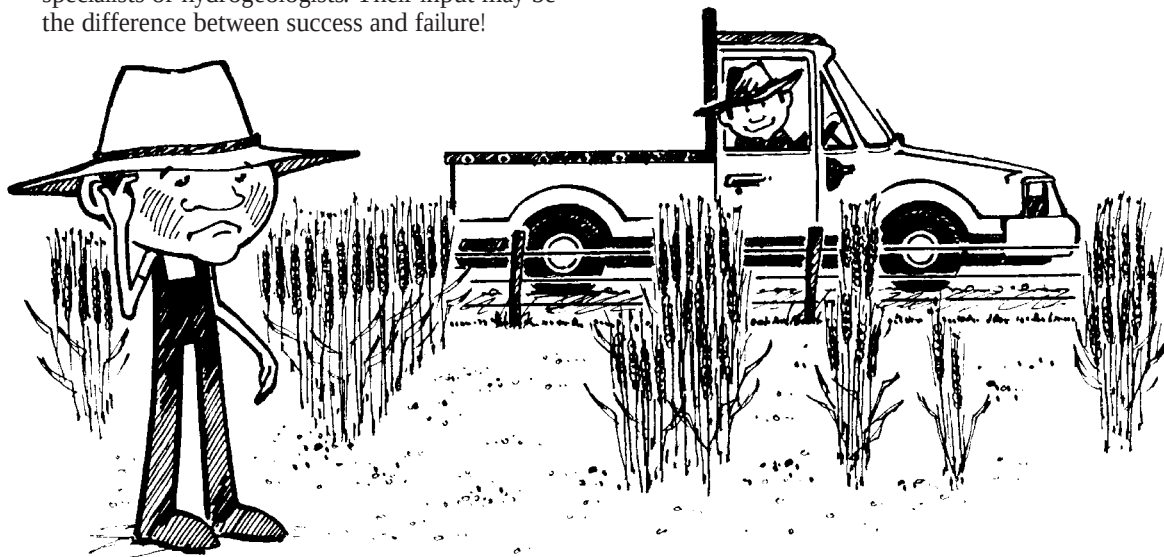
Since effective salinity control will generally require a large financial and labour investment, it is important to understand your local conditions as well as possible. You should consult local salinity specialists or hydrogeologists. Their input may be the difference between success and failure!

What is the cause of dryland salinity?

Dryland salinity is a groundwater problem – salinity is only a symptom. Salinity occurs when there is an imbalance between inputs of water into groundwater within a catchment and the amount of groundwater leaving the catchment (Figure 4). This imbalance may occur, for example, when native trees are cleared for cropping.

When more water goes into a catchment than comes out, the water-table rises, bringing salt to the surface.

Salts are carried in water moving through soils and the landscape. Salts can then accumulate at the soil surface when groundwater evaporates from shallow water-tables.



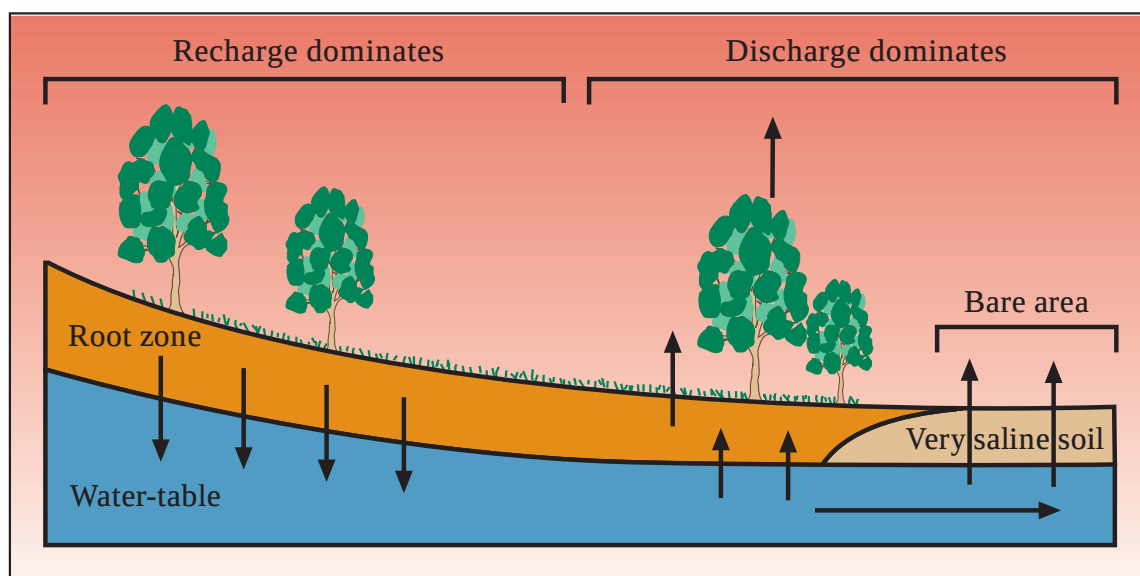


Figure 4: Water movement to (recharge) and from (discharge) the water-table in a catchment

Inputs to groundwater are known as recharge. Recharge can come either from the small amount of rainfall that percolates below the root zone of plants, or from water seeping into the groundwater from streams, rivers, lakes and dams. The amount of water that percolates below the root zone of crops and pastures can be 10–100 times that percolating below trees. While all sources of recharge can contribute to dryland salinity, increased groundwater recharge under crops and pastures is the major cause of dryland salinity. Losses of water from groundwater are known as discharge. Discharge can occur by subsurface lateral flow (when the groundwater flows directly into a stream or river or when it evaporates from soils or transpires from plants. As the groundwater level comes closer to the soil surface, discharge into streams and from soils and plants increases, resulting in increased stream and soil salinity (particularly if the groundwater is saline). If

water-table levels are regularly less than about 2 m deep, salts can build up at the soil surface, eventually killing plants and leaving the soil bare and salt-crusted.

However, it should be remembered that groundwater also discharges through transpiration from vegetation on the perimeter of the bare areas, where water-tables are deeper (eg within 4 m of the surface) and surface soil salinity is less obvious. Groundwaters are often saline in discharge areas, with an electrical conductivity ranging from 6 to over 60 dS/m.

Dryland salinity will be controlled by restoring the balance in a catchment (Figure 5). This can be achieved in two ways:

- reducing groundwater recharge; or
- increasing groundwater discharge.

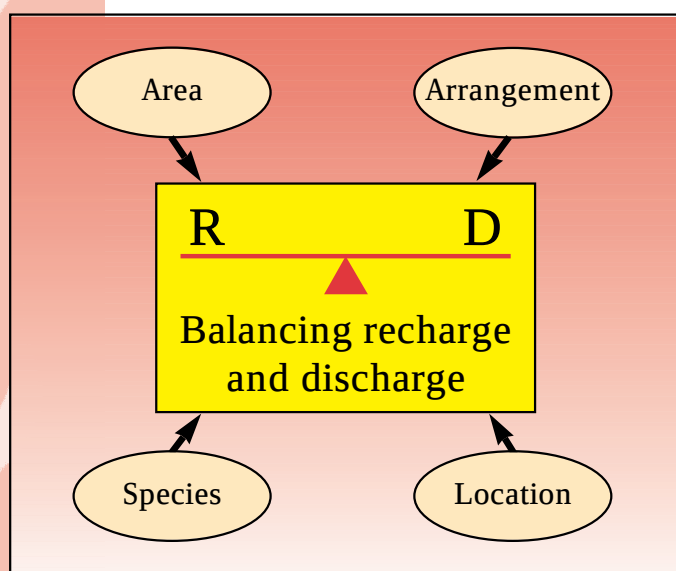
Planting trees can help in both these processes.

H I N T

How salty is it? A quick guide to water salinity and units

Water salinity is measured by either the weight of salts in water or, more commonly, the ability of water to conduct electric current – known as electrical conductivity (EC). There are different units for these measures, especially for EC. This table provides a rough guide to a range of common water salinities.

Units	Rain water	Tap water	Sea water
EC units (the same as $\mu\text{S}/\text{cm}$ – micro Siemens per centimetre)	20 to 50	less than 1 500	50 000 to 60 000
EC dS/m (deci Siemens per metre; the same as milli mhos per centimetre)	0.02 to 0.05	less than 1.5	50 to 60
EC mS/m (milli Siemens per metre)	2 to 5	less than 150	5 000 to 6 000
Milligrams per litre (mg/l – the same as parts per million)	10 to 30	less than 1 000	33 000 to 40 000



There is no set size of a catchment in the context of dryland salinity. Catchments will vary from a few hectares to large drainage basins (eg the Murray-Darling basin) and large catchments can contain many small catchments. Management options for controlling dryland salinity will depend on catchment size and what part of the catchment is being treated (eg areas of dominant recharge or discharge). In general, the relief of the land will determine the catchment size that is relevant to dryland salinity problems – the steeper the relief and more hilly the area, the smaller the catchment. It is important to remember that property boundaries are usually different from catchment boundaries.

Figure 5: Restoring the balance between groundwater recharge and discharge for dryland salinity control – the four factors that can be managed when planting trees

Waterlogging

Waterlogging is caused by the same processes as dryland salinity. The difference is that salts do not accumulate at the soil surface, either because groundwater is of very low salinity (less than 6 dS/m) or it flows out of the soil (ie from a small spring), flushing the salts away. Waterlogging problems can also be ephemeral, such as when a perched water table develops on an impermeable subsoil in a wet season. Most of the information given in this chapter is also directly relevant to management of waterlogging, except the references to salt accumulation and its effects. Thus waterlogging will generally not be discussed separately.

Design principles

There are four factors that can be manipulated when designing agroforestry systems for controlling dryland salinity (Figure 5). These are:

- area planted;
- the arrangement of the trees;
- their location within a catchment; and
- the tree species selected.

All of these can impact on recharge and/or discharge of groundwater and all need to be considered when undertaking tree planting for dryland salinity control. The principles associated with these factors are described in general below. The optimum design will always be dictated by specific landscape and climatic conditions, as well as by the overall land management objectives and restrictions relevant to the site. Also, the design may be varied to capture some of the other positive benefits of agroforestry (see table at the end of this chapter). Thus, the final design will most likely be a compromise between salinity control and other factors.

To help in determining the final design, the rationale behind each of the principles will be explained briefly. Local input from salinity specialists, hydrogeologists and foresters will be invaluable in the design process and will increase the chance that the exercise will be a success.

What area of trees should be planted?

This is an important but, unfortunately, difficult question to answer, because the answer depends on knowing what changes in recharge and discharge rates are required in a catchment to reduce water-table levels. Answers will be region or even site specific. A wide range of areas has been planted with trees in successful attempts at dryland salinity control – ranging from about 30–70% of catchments in parts of southern WA, to the establishment of a few hectares of trees near discharge areas in southeast Queensland.

One overriding principle is that the impact of trees on the groundwater balance will depend on the area planted – the greater the area, the greater the impact (Figure 6).

The arrangement, location and species of trees can also influence their impact, as described in the following section. The greater your knowledge about the groundwater hydrology of your catchment, the better you can target tree plantings for salinity control.

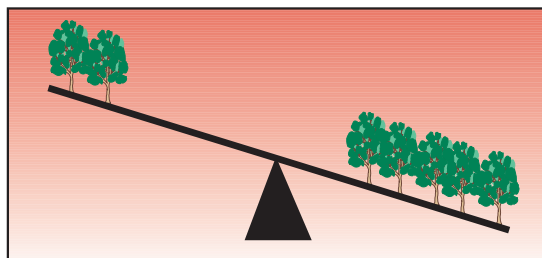


Figure 6: What area of trees should be planted? The greater the area the greater the impact

Arrangement of trees

Trees reduce recharge by using water stored in the soil faster than crops and pastures. The rate at which water can be taken up from the soil by plants is influenced by their leaf area – the more leaves the better! Tree canopies may develop more quickly (and so leaf area increases more quickly) if trees are spaced closely.

Select a tree density that will give a full canopy as quickly as possible.

However, the final leaf area achieved is mainly governed by soil, climate and species performance rather than tree spacing, so the leaf area of wider spacings will 'catch up' to those of closer spacings after a few years. Therefore, other factors such as access, weed management, species selection, other possible benefits of the trees, etc should also be considered when selecting a tree spacing.

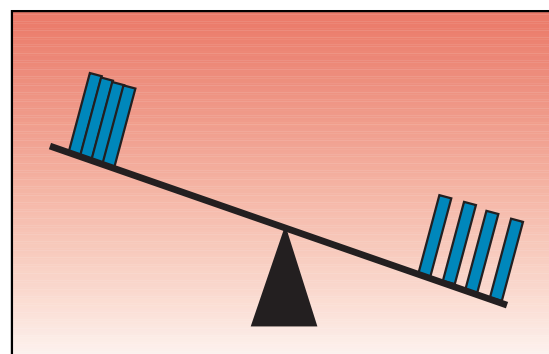
H I N T

Managing trees for fodder

It is important to avoid overgrazing trees that have been planted for salinity control, as their leaf area determines the amount of water they can use. Apart from careful management, keeping watering points away from the trees can help reduce the pressure of stock on trees.

Maximise 'edge effects'. Tree roots can extend considerable distances beyond the edge of the plot. A common distance used is $1\frac{1}{2}$ times the tree's height, although it could be up to 3 times in some situations. Also, transpiration rates from trees on the edge of plots are often greater than from those in the middle, because trees on the plot edge are 'dried' more by winds. Thus, trees will be more effective if they are planted in strips or small clumps rather than larger groups (Figure 7).

Figure 7: Increase the impact of trees by planting in strips or small groups (note: the total tree area is the same in both arrangements)



Location of trees in the catchment

Recharge areas

Groundwaters will be recharged in virtually all parts of a catchment. However, there may be areas where recharge occurs at preferentially higher rates. Examples would be areas of permeable (lighter textured) soil or areas of exposed, fractured rock – that is, places where water infiltrates into soil quickly and can move downwards rapidly. These areas often occur in higher parts of the catchment. If recharge areas can be identified they should be targeted for tree planting for the greatest impact on recharge and salinity.

Caution is needed, however, as it may not be possible to accurately identify preferential recharge areas. Also, it is possible for several separate groundwater systems to exist in a single catchment. Thus, you need to be confident the recharge area identified is linked to the saline area being controlled. Local knowledge of hydrogeology is vital in this exercise.

Trees for controlling dryland salinity and waterlogging

Discharge areas

Trees (and other deep-rooted plants) can increase discharge rates because roots take up water close to the water-table. However, the high soil salinity levels common in discharge areas cause difficulty with tree establishment and restrict water uptake by trees.

Trees should be planted around the perimeter of salt-scalded soils (the green area in Figure 8, for example), where water tables are slightly deeper and often less saline and surface soils are not obviously salt-crusted or highly saline.

Trees (and shrubs and pastures) can be planted in the saline soils to stabilise the soil and reduce run-off and salt washing away. However, these trees will be much less effective for water-table control than trees on the perimeter of the saline area.

Trees will have the greatest impact on water-table levels if water-tables have a salinity less than 10 dS/m and are at least 3–4 m deep. Also, any factor that prevents tree roots from being active close to the water-table (such as hard pans in the soil) will reduce discharge from plants. It is worth digging a hole to check on soil conditions and collecting information on water-table depth and salinity before putting a large effort into establishing trees in these areas.

Other important benefits come from establishing trees and other plants in the bare scalded/waterlogged soils of discharge areas. These include stabilising the soil and preventing soil and salts from being washed off the site (see chapter on soil conservation).

Interception of lateral groundwater flow

In hilly country, groundwater may flow laterally within the soil down the hill.

If trees can access and use laterally flowing groundwater there will be less water recharging areas further downslope (Figure 9).

H I N T

How to measure water-table depths

Attach something fairly heavy onto a tape measure and lower it down the bore or well pipe until a noise is heard as the weight hits the water surface. A small diameter metal bath plug attached so that it hangs horizontally off the end of the tape is a good weight, as the hollow underneath it will make a distinct 'plop' as the plug hits the water surface. A fox whistle bronzed to a copper pipe can also be used. Jiggle the tape up and down listening for the noise until you have a good idea of the water-table depth.

Figure 8: Plant trees on the perimeter of bare, salt-scalded soils in discharge areas to control water-table levels

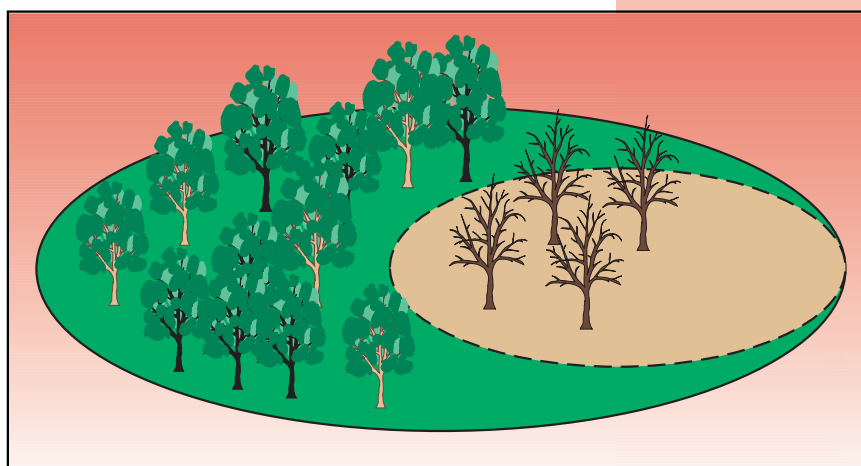


Figure 9:
Trees intercept
groundwater
flowing down a
slope. Water used by
the trees will reduce
recharge of water
tables further down
the slope.

This is the philosophy behind 'break-of-slope' tree planting, although trees can be located anywhere on the slope where water-tables are shallow for this strategy to apply. This interception of groundwater is an attractive option for enhancing discharge because salt build-up in the root zone is limited. However, there are several factors that may limit the effectiveness of these plantings. If groundwater salinity is greater than 10–15 dS/m and/or water-tables are deep, the amount of water that can be extracted by trees will be small. The amount of groundwater removed by the trees will also be small if only a few rows of trees are planted. Finally, it is possible that the groundwater system being recharged by the lateral flow is not the one responsible for dryland salinity, so there will be no impact on the salinity problem.

Species selection

Plant deep-rooted species

Trees will reduce recharge by using more of the rainfall that is stored in the soil than crops and pastures. This increased use is due primarily to the

ability of trees to take up water deep in the soil profile – very little water escapes the root zone if it is 6 m deep. Additionally, trees will enhance discharge more if their roots can reach deep water-tables.

For salinity control, tree species should be selected that have the potential to grow deep root systems (such as many eucalypts).

Local nurseries or forestry departments should be able to give advice on the species suitable for specific areas.

It should be noted that soil conditions (rock, hardpans, acidity, etc) may limit the depth to which roots can develop, limiting the benefits of trees. It is worth augering a hole to at least 3 m to see if there are any impediments to root growth before planting trees in either recharge or discharge areas.

Plant salt tolerant and/or waterlogging tolerant trees in discharge areas

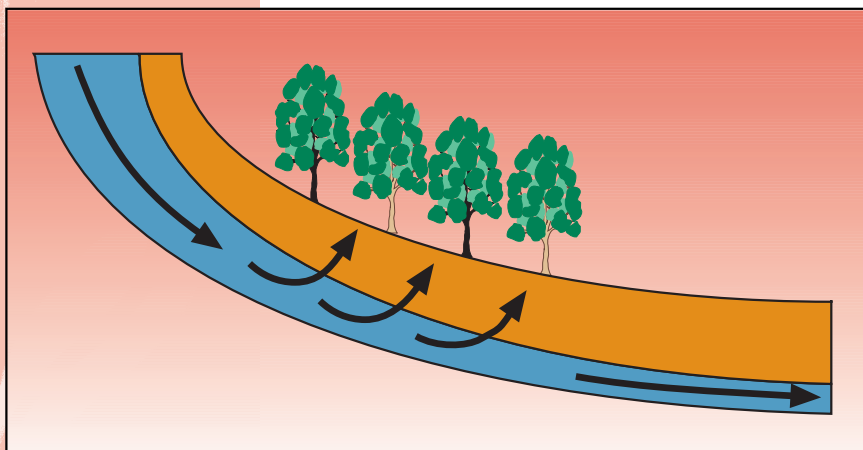
Salt tolerant trees will establish more successfully and grow better in the saline soils that commonly occur in and near discharge areas. Similarly, if waterlogging is a problem, waterlogging tolerant species should be selected.

Salt tolerant trees will also contribute more to groundwater discharge than will salt-sensitive species.

Marcar *et al.* (1995) have provided a comprehensive guide for selecting native species for saltland planting.

Plant species that perform well locally

There is little point in investing time and money in establishing tree species that will not grow well in your district. Local nurseries or forestry departments will give advice on the species that are both suitable for specific areas and exhibit the characteristics described above.



Other factors

Before finalising any design for planting trees to control salinity, there are additional factors that should be considered.

Where does your farm fit into the catchment?

Dryland salinity is a catchment-wide problem. If you have obvious salting on your property you are at the discharge 'end' of the catchment (Figure 10, location A) or subcatchment (Figure 10, location B). But do you control the recharge areas too? If not, as is the case in location A of Figure 10, some of the options described above may not be available to you. You should also remember that both surface water and groundwater may flow from your discharge area into another property or catchment (as at location B in Figure 10).

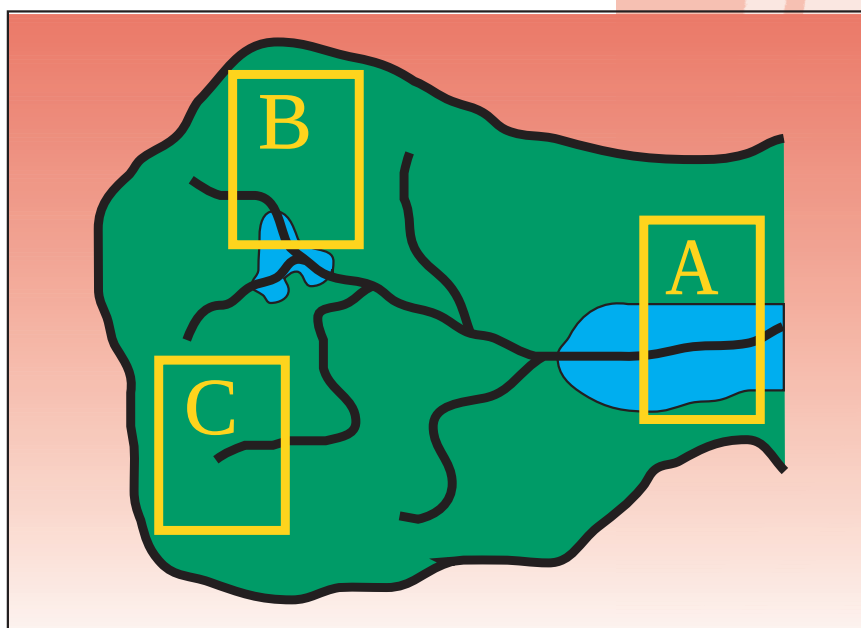
Alternatively, if you do not have any signs of salinity on your property you may be in the recharge zone of the catchment (location C in Figure 10) and your management choices may impact on others lower in the catchment.

Because salinity does not respect property boundaries, a 'whole of catchment' approach will be most successful in managing the problem.

You should become involved in a catchment management committee or landcare group if one exists in your area, or consider starting one if not. Also, consult your neighbours to develop a coordinated approach to salinity control.

Time-scales

There are time lags involved in the cause and effect of dryland salinity. It commonly takes several decades (and possibly centuries) after clearing trees before dryland salinity problems appear. The reverse is also true – it may take equally long after re-planting trees to 'fix' the problem. Unfortunately, it may take even longer because fewer trees will generally be replanted than were cleared.



Strategies for controlling dryland salinity need to be integrated into long-term farm and catchment management plans.

Consider all sources of recharge

Any input of water to the groundwater will exacerbate dryland salinity problems. Such inputs can come from farm dams (especially if poorly sealed), irrigation or poorly controlled run-off.

All possible sources of recharge should be considered when devising management plans to control dryland salinity.

Dams should be checked for leaks, irrigation should not be applied in recharge areas, and banks should be built to keep run-off away from recharge areas.

Consider the role of other plants

Trees are not the only means of managing dryland salinity. Perennial pastures have a role in reducing

Figure 10: Where does your farm fit into the catchment? Two of the locations, A and B, have some salinity evident (blue areas)

recharge and managing discharge areas. Fodder shrubs may also be useful. The principles given in this chapter can be applied to any type of plant to judge its role in managing salinity.

H I N T

Can you use the water from your shallow water-table?

One way to lower water-tables is to pump water from them. The cost of this can be offset if the water is used for some productive purpose. It may be possible to use it for stock or supplementary irrigation (even to water salt tolerant trees), depending on its salinity. Advances are being made with low-flow irrigation systems and the management of saline irrigation water which make these options increasingly feasible. These options are worth considering – water is too valuable a resource to waste!

Engineering options for enhancing discharge

There are also 'engineering' options for balancing recharge and discharge, such as draining water tables and pumping groundwater from bores. They have some drawbacks that limit their use, such as cost, disposal of the water (see the hints box), and the suitability of hydrological conditions (this will affect drain spacing, flow rates from bores and other design criteria). Nevertheless, engineering options may have a role in controlling dryland salinity, especially in conjunction with other measures such as planting trees, so should be considered when devising management plans.

How do you know if you are being successful?

There are a number of attributes of a catchment that can be monitored to assess the effect of your actions to manage salinity. These include water-table depth and salinity, stream salinity (if there is a stream there), the size of the salted area, tree growth and survival and the mixture of species growing in paddocks. Some of these, such as the area of salted soil or the rate of tree growth, are fairly obvious and so it is easy to think there is little need for formal (ie written) record keeping.

Changes can be deceptive and may be related to other factors (such as weather), so more formal records are useful.

Some details of monitoring these are given below.

Water-table depth and salinity in discharge areas

The depth of water-tables can be easily measured in wells or bores in discharge areas to check if they are getting deeper (or shallower) with time. If there are no wells present, they can be installed quite easily (see the hints box next page). Small EC meters can be purchased for measuring the salinity of water samples. Alternatively, water samples can be taken to local departments of agriculture or conservation where salinity measurements can usually be arranged.

You should check with your local hydrogeologist before monitoring existing wells or bores. If there is more than one groundwater system in a catchment, existing bores may not be in the systems that are responsible for your salinity problem. This is particularly likely with deep bores. In that case it would be best to put in a shallow well solely for measuring water-table heights.

Water-table levels will be affected by short and long term weather patterns, as well as by changes in land

Trees for controlling dryland salinity and waterlogging

management. For example, water-tables will be deeper after a run of dry years than after a run of wet years. Also, water-table salinity may change after a season (or drought) breaks. Thus, the impact of tree planting cannot be judged from only a few measurements.

Measurements need to be made regularly (every 1–3 months is best) over a few years to a decade to establish any trends.

Records of the weather are needed, too, for establishing patterns. Another factor that will influence bore or well water levels is the amount of water pumped out of the bore or well if they are used to provide water for stock, etc. It may be best to put in a shallow well solely for measuring water-table heights if the existing ones are used for water supply.

Stream salinity

Water can be sampled from streams flowing through salted paddocks and its salinity measured. As with measuring water-table levels, records need to be kept for a number of years to establish trends. In addition, the depth of the stream needs to be measured or estimated when salinity is measured. Rain makes streams run but dilutes the salinity of the stream water.

Lower stream salinity after rain or during wet years is not a reliable sign of an improvement in the salinity problem.

Area of scalded soil

Changes in the area of bare scalded soil are directly related to improvements or worsening of the salinity conditions in a paddock or catchment. Often, the area will change relatively slowly, more over decades than years. It may also be influenced by weather conditions over a few years. For example, soil will look better after a run of dry years than after a run of wet years because of the effect of weather on water-table depths.

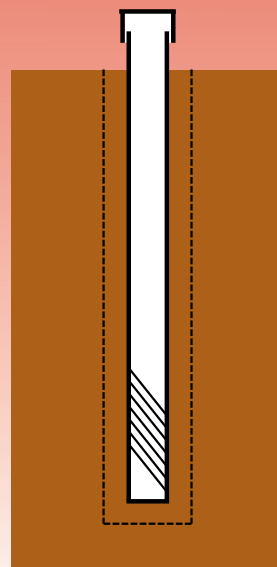
H I N T

Installing a well to measure the depth of shallow water-tables

A suitable bore for measuring water-table levels can be made fairly easily. A hole needs to be dug with a hand auger, post-hole digger or drill to a depth of 2–3 m. PVC stormwater pipe can be used as the casing.

Fix a cap to the bottom end of the PVC pipe. Cut slots around the bottom half to one metre of the pipe with a hacksaw or angle grinder, to let the water in. Backfill the hole around the pipe with gravel (1–2 cm diameter), up to 30–60 cm from the soil surface, to keep soil out of the pipe. Then backfill the rest with clay or cement to prevent water from running down the outside of the well.

Put a cap on the top, but make a small hole or cut in the side of the pipe below the top cap to allow air to move in and out. Keep the pipe fairly short above the ground if cattle are around, as they will knock it over.



A series of measurements every year or two is necessary to establish trends.

Changes will need to be considered with respect to the weather, so rainfall records are useful too.

A good way of assessing bare areas is from aerial photographs. Aerial photographs are taken of many parts of the country every few years and held in a library within the state government department responsible for mapping and surveying. Copies of these photographs can often be purchased or borrowed. It is valuable to obtain a series of these photographs (say, one or two per decade) to follow the development of the salted area through time.

Another way to monitor the change in area of salted soil is to use electromagnetic induction

(EMI) meters. These sense soil salinity through the soil's ability to conduct magnetic fields and are a rapid way of surveying soil salinity. Measurements could be made every year or two. These instruments are costly and generally require calibration or experience at interpreting the results, so their use should be arranged through local departments of agriculture or conservation.

Tree growth

Where trees are planted, their survival and growth can be recorded. This is particularly handy if different species are planted to provide a good record of which preformed best. Growth rates can be deceptive – if trees are growing 1 m per year, for example, the growth of small trees only 1 or 2 m high may be more noticeable than the growth of larger trees.

It is worth making measurements of tree growth about once a year.

Evidence of insect attack, other pests, susceptibility to frosts or waterlogging, etc should also be noted.

Species mixtures in paddocks – look for indicator species

Certain plants tolerate salinity better than others and thus are more common in saline soils. Examples are naturally occurring salt bush species and some common pasture grasses (such as sea barley grass in southern Australia and Rhodes grass in northern Australia). These species are often called indicator species, as their presence indicates the onset of salinity.

It is useful to determine the indicator species in your district and check if they are present in a paddock.

If they are spreading over time, salinity levels may be rising! Local departments of agriculture or conservation will have information on indicator species.

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Capturing benefits in addition to salinity and waterlogging

When planting trees for the management of salinity and waterlogging, the investment is being made primarily to ensure the long-term viability of the farm rather than for the direct value of the trees. Native species may be used which offer a good opportunity to capture nature conservation and scenic beauty objectives. Designs to manage salinity are also compatible with shelter and fodder objectives, depending on layout and species choice. Soil conservation and timber product objectives can also be realised.

Other benefits to capture	Opportunity	Thing to look out for
Wood	Recharge areas, which are planted to reduce additions of water to the water-table, can also be favourable locations for the production of wood products Trees planted on slopes to intercept laterally moving groundwater before the water mixes with saline ground water can have fast growth rates (break-of-slope plantings)	Tree species and planting locations required to address issues of salinity may not coincide with those giving the best productivity or returns Trees planted in saline discharge areas will often have poor wood quality and slow growth and may die before maturity
Soil conservation	Trees planted for salinity management could coincide with sites requiring erosion control Revegetation of saline areas may prevent salt-scalded areas from being eroded Nutrient cycling by trees can ameliorate saline soils	Tree species and planting locations required to address issues of salinity may not coincide with those required for soil conservation management
Shade and shelter	Strips or belts of trees are favourable designs both for salinity management and shelter effects Large areas of trees planted for salinity control can achieve a shelter effect at the 'regional' scale	Sites requiring trees for dryland salinity control may not match those sites requiring shelter Trees planted on saline soils may not be effective windbreaks
Fodder	Trees established for salinity control can provide an important source of fodder on either a regular basis or in times of feed shortages	Leaf area is important in determining tree water use (and salinity impact), so over-grazing should be avoided. If fodder species are shallow-rooted, they will not have the same impact on salinity as deep-rooted trees
Nature conservation	Strategic planting in recharge and discharge areas provides opportunities to simultaneously provide wildlife habitat, especially if native species are planted Break-of-slope tree plantings can serve as wildlife corridors if the plantings are sufficiently dense and link existing remnant vegetation	Spreading trees out for the purpose of using more water over a wider area conflicts directly with a nature conservation guideline to minimise edge effects
Scenic quality	Revegetation for salinity control will generally increase scenic quality depending on species type and planting layout	Poor tree growth and potential death will reduce scenic quality

Trees for soil conservation

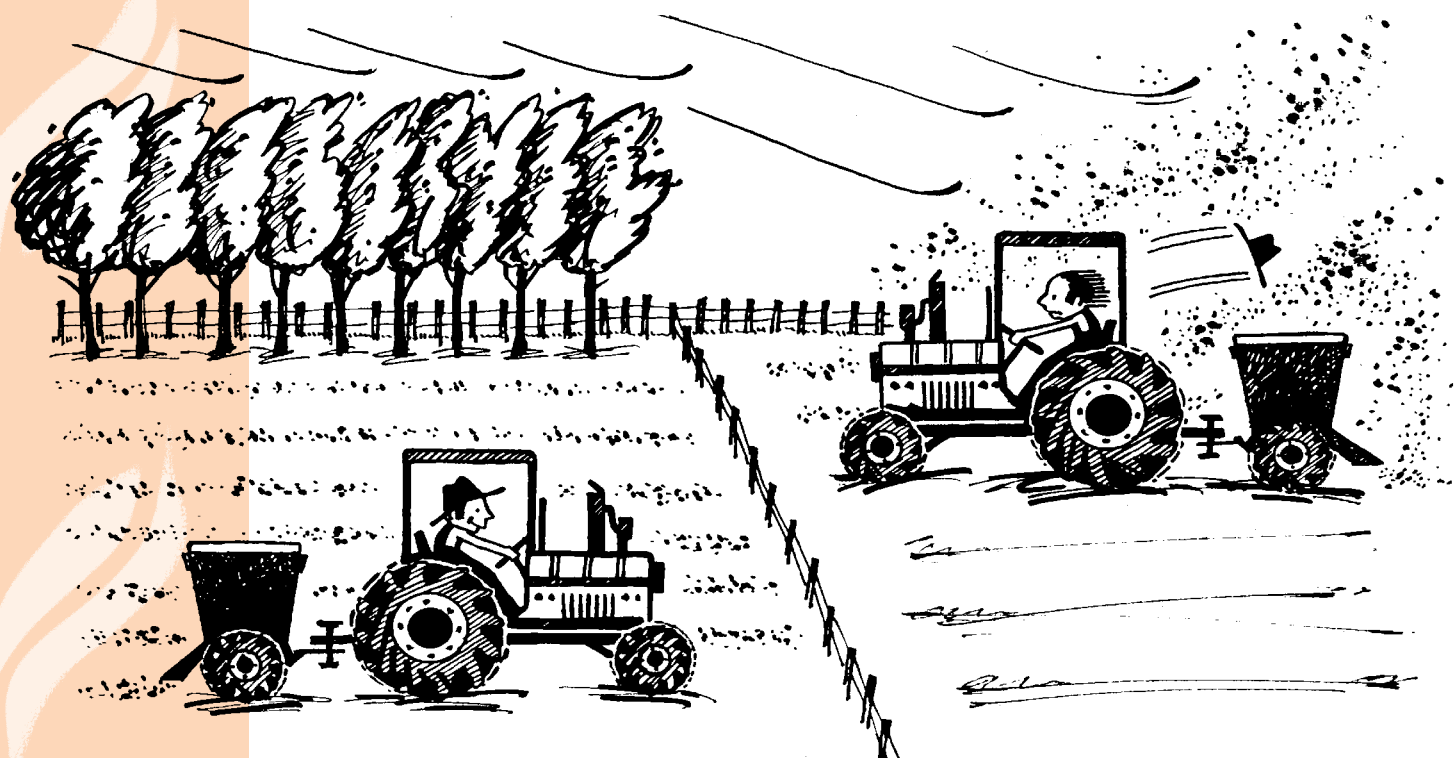
Introduction

Has your interest in planting trees been triggered by a soil problem? Trees can help conserve soil on your land by:

- reducing soil erosion;
- increasing soil organic matter;
- improving soil structure; and
- assisting in nutrient cycling.

Soil salinity and waterlogging can also be ameliorated by trees and are covered in greater detail in the salinity section of this manual.

The purpose of using trees for soil conservation is to assist in retaining fertile soil on the farm where you need it most by regulating flows of wind and water.



Soil erosion – what happens when soil goes?

The top few centimetres of soil are critical to crop and pasture growth. This is because topsoil is usually the most fertile portion of the soil profile, and any loss of it will therefore result in a loss of soil fertility. While the loss of a few millimetres of soil may not seem critical in any one year, over several years these losses will cause decreased crop and pasture growth and lead to an increase in fertiliser requirements.

Soil erosion can take many forms, including gully, rill, wind, sheet and water erosion. In general, soil erosion occurs because of:

- over-clearing of the land;
- over-grazing;
- strong winds; and
- rain.

Where do I start?

It is often wise to begin soil conservation work at the head of the catchment because your gains here will benefit land lower in the catchment. A catchment is any area of land that catches and drains all the rain which falls on it. Therefore, a slope which supplies water to an erosion gully is a catchment, as is the Murray-Darling basin (Figure 11).

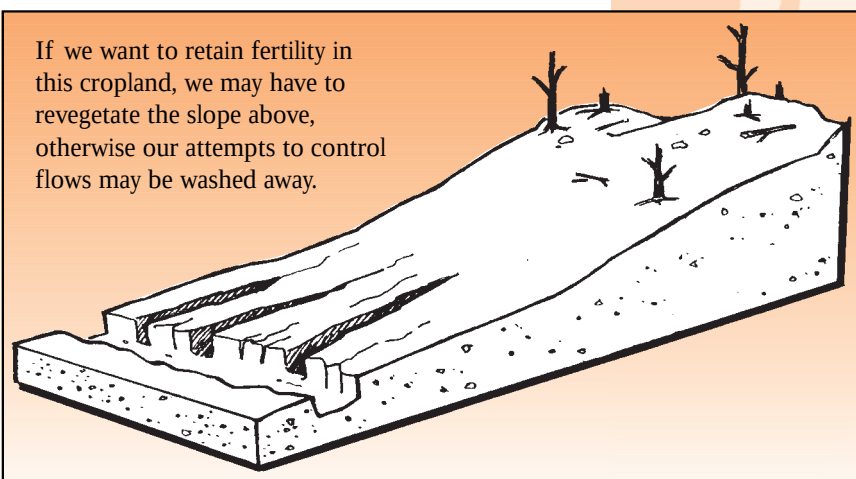
Your property may have several catchments on it and you can manage their water flows. However, your property will also lie within a larger catchment and it will be most effective if you manage this in cooperation with other landholders.

By managing water flow you are able to slow the rate at which top soil moves out of the catchment and thus you can retain the most fertile part of your soil.

Using trees to conserve soil

Trees can help reduce erosion by:

If we want to retain fertility in this cropland, we may have to revegetate the slope above, otherwise our attempts to control flows may be washed away.



- slowing wind and water flows;
- providing protection from wind and water;
- holding soil together; and
- increasing infiltration.

The first step in combating erosion is to identify the type of erosion that occurs on your property. Having done this, by choosing the right type and placement of trees you will be able to take steps to overcome the problem.

Gully erosion

Gully erosion occurs when:

- the shape of the terrain concentrates water flow over or through the land; and
- the soil is not cohesive enough to prevent soil loss.

Gully erosion is best controlled by reducing water flow to it rather than by trying to stop erosion in the gully. However, you can have a significant impact by taking steps on your own farm even if you are unable to convince everyone in the catchment to become involved in fixing the problem.

Figure 11:
Where does the problem start?

HINT

Stock can greatly increase gully erosion, particularly if the gully is the only source of water. Wherever possible fence gully areas and provide alternative water sources.

Slow down the rate of water flow. This can be done by planting trees on higher ground around the gully area. Wherever possible, trees should be planted in conjunction with deep-rooted and fast-growing grasses which will also use water, increase infiltration and control flow. While slowing of water flow may not prevent gully erosion completely, it can dramatically reduce the rate of erosion. Diversion banks can take water elsewhere, but quite often this just shifts the problem to a new site. Building a dam is an effective but expensive solution.

Trees can help hold the soil together. Although not as important as reducing flow, trees planted in and around the gully may help hold the soil together. The closer you are to the gully, the wetter the soil will be, and you may want to plant different tree species.

To avoid scouring, plant small shrubs with flexible stems within the gully rather than trees.

Sheet and rill erosion

Sheet and rill erosion are caused by:

- slope length and steepness;
- poor ground cover and surface roughness;

- poor tree and shrub cover;
- poor soil structure;
- poor infiltration; and
- intensity of rainfall.

If your property suffers from sheet or rill erosion you will again need to slow down the rate of water flow, increase infiltration, and keep as much ground cover on the soil surface as possible.

Slow down the rate of water flow. Both the length and steepness of the slope have an impact on the rate of water flow. The rate of soil loss increases with the length of the slope.

Slope length can be decreased by planting trees across the slope.

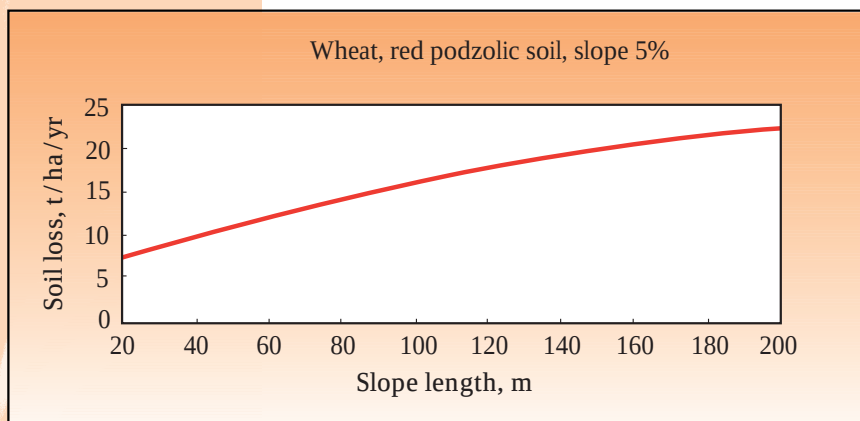
The distance between the rows of trees planted across the slope affects slope length which in turn affects the rate of soil loss. Trees and shrubs can also be planted in strips along contours to check run-off.

Banks can be used to decrease slope length, but trees are much less susceptible to damage by floods than conventional banks and have the added bonus of increasing the rate of water infiltration. Where banks are being used, trees can also be planted on them to provide bank stabilisation.

The effect of slope angle on soil loss is shown in Figure 13. The steeper the slope the faster water flows and the greater the chances of soil erosion. While trees obviously cannot change slope steepness, they will slow down the rate of water flow when planted across the slope.

Trees are most effective on steep slopes when used in conjunction with dams and contour and diversion banks for changing slope angles and increasing infiltration.

Figure 12: Slope length and soil loss from sheet and rill erosion



Trees for soil conservation

Increases in soil organic matter and litter from trees and other vegetation help improve soil structure and increase infiltration. The better the soil structure the more spaces there are for soil infiltration and storage. Similarly, the more soil organic matter the greater the activity of soil organisms and the more channels they make for water entry and storage. All vegetation forms root channels which promote the entry of water. The more water that enters the land the less there is to run-off and carry soil away.

H I N T

The rougher the ground the slower water will flow

Leaving tree stumps and stones in place will slow water flow. The occurrence of tree trunks, grass tussocks, logs or other obstructions and the lying of branches on the contour are also ways of decreasing water flow.

Because tree roots are able to penetrate compact soils they can be particularly effective in increasing water infiltration in areas of high soil compaction. Although it may take many years before you get to see the benefit of the 'biopores' (continuous pores left behind after roots have decayed) made by tree roots, these pores are very important. Even our annual crops today often get through compacted subsoils by using biopores made by trees many years ago before the land was cleared.

When planting trees to overcome soil compaction/water infiltration problems, choose species carefully as not all trees are suitable for planting on compact soils.

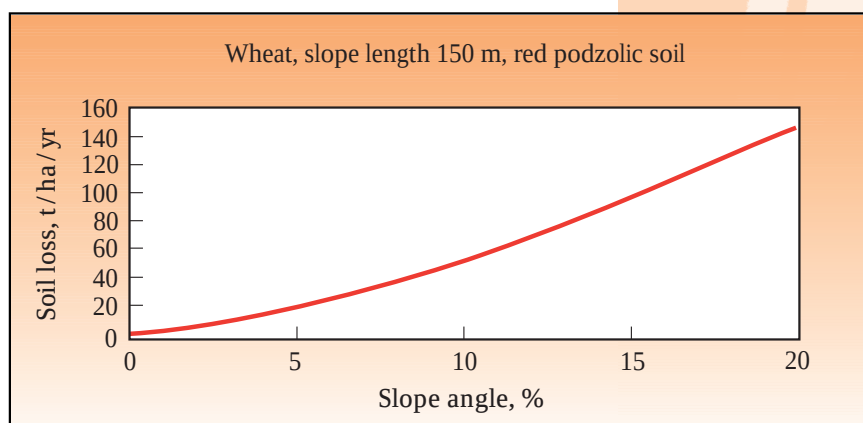


Figure 13: Slope angle and soil loss from sheet and rill erosion

Increase surface roughness. The rougher the soil surface the slower the rate of flow, the greater the infiltration and the less the soil loss. Roughness is enhanced by vegetation (live and dead), including stumps, fallen branches and litter. To rehabilitate land you can cut and arrange branches along the contour where they trap litter and seeds. As the seeds germinate and grow, these areas become little fertile strips which increase their control over water and wind flow and nutrient cycling over time.

Protect the soil from heavy rainfall. Choosing trees which allow grasses to grow under them so that water infiltration is increased and the soil is not left bare will help protect the soil from rain (Figure 14).

Ground cover varies during the life of an agroforestry crop. It is lowest at times of establishment, when bare land is highly vulnerable to erosion.

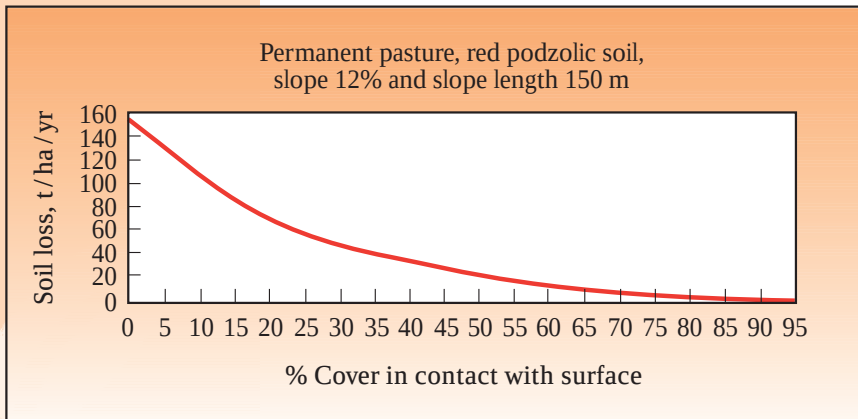
Mulching or planting cover crops can help overcome bare soil at tree establishment.

Plantations are vulnerable to erosion again at harvesting. Even a single storm can wipe out years of benefits which accumulated while the trees were growing.

H I N T

Trees are only part of the solution. Ground covers such as pastures, crops and crop residues also play an important part in decreasing soil erosion. Aim for 30–40% ground cover at all times (70% in gully areas).

Figure 14:
Ground cover and
soil loss from
sheet and rill
erosion



Slumping

Slumping of hillsides occurs when:

- slopes are steep;
- rainfall is heavy;
- soils are deep;
- infiltration is good until the land is saturated;
- evapotranspiration is slow;
- the underlying rock is parallel to the slope; or
- the rock has a low-friction surface (eg shale).

Trees are often the most effective option on land prone to slumping. Because slumps are generally high on the slope dams may not be feasible. Because infiltration is generally good on

slump-prone areas, trees which bind and dry the soil reduce the risk of slumping. Diversion banks might also be of assistance.

If you are in an area of high rainfall and have soils prone to slumping choose tree species which are deep-rooted and which have high water use.

Wind erosion

Wind erosion occurs when the force of wind is sufficient to detach and carry soil particles. The factors that affect the rate of erosion by wind are:

- soil type;
- ground cover;
- shelter; and
- windspeed.

The higher the proportion of fine sands and the drier the soil, the greater the susceptibility to wind erosion because these particles are small enough to be carried and are not cohesive. Soils with the least ground cover are obviously the most prone to erosion, while the more elevated parts of the landscape tend to receive the highest wind speeds and so are also very susceptible.

Trees can provide shelter against prevailing winds and thus decrease wind speed. The role of trees in providing shelter is covered extensively in the chapter on trees for shelter and shade, so only the basics as they relate to soil loss will be covered here.

If wind erosion is already a serious problem on your farm, choose fast-growing tree species when planting windbreaks.

Trees are most effective at decreasing soil erosion when planted at 90 degrees to the prevailing wind. Figures 15 and 16 show the effect of planting windbreaks at 45 degrees and 90 degrees to the prevailing winds.

Trees for soil conservation

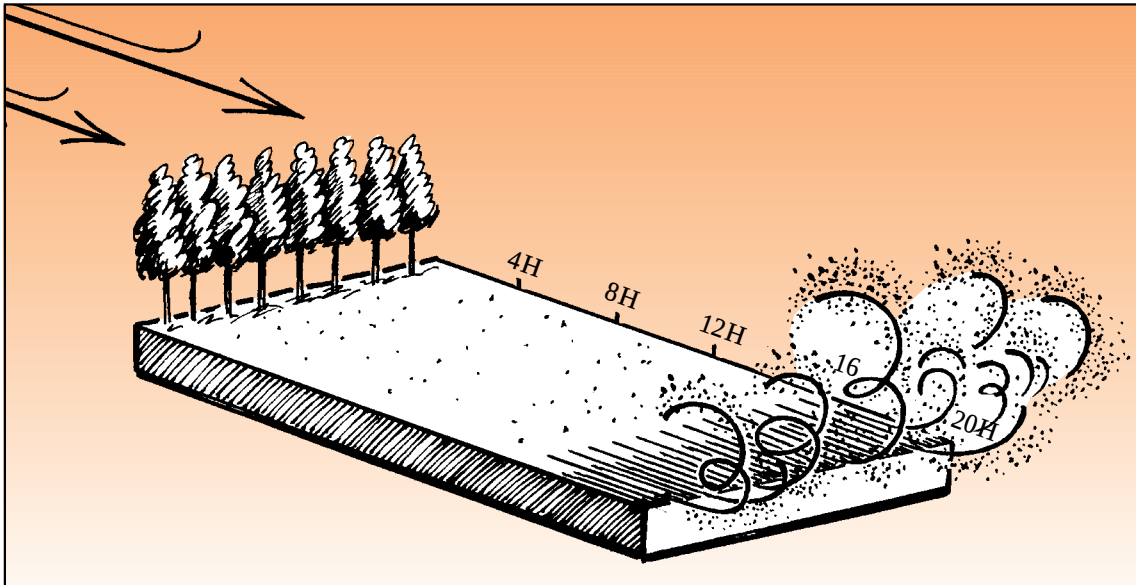


Figure 15: Wind blowing 90° to windbreak (distance from the windbreak in multiples of windbreak height(H))

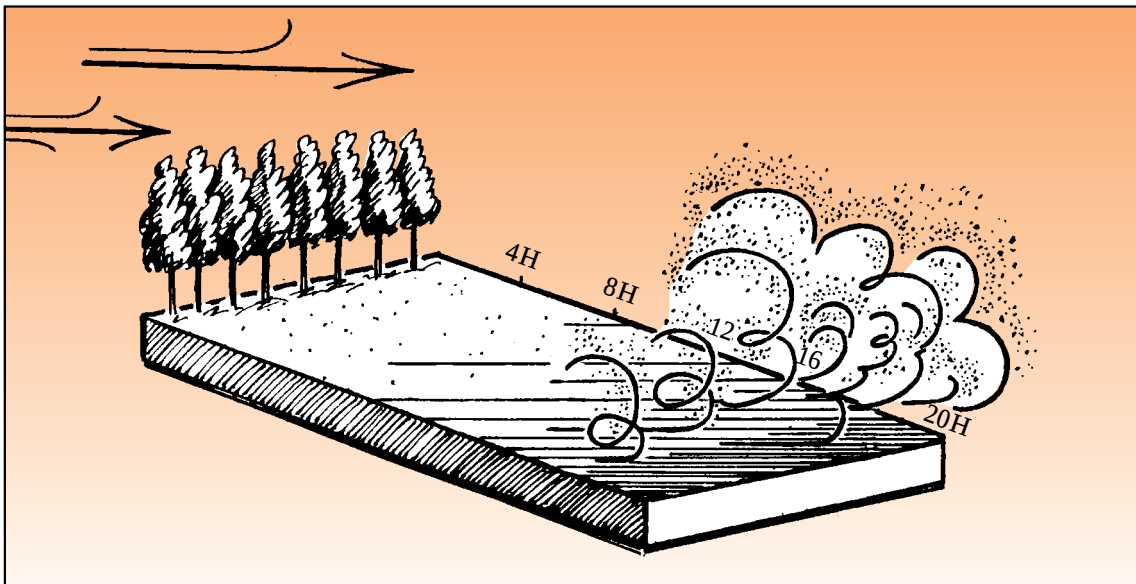


Figure 16: Wind blowing 45° to windbreak (distance from the windbreak in multiples of windbreak height(H))

Both figures adapted from Leys (1991)

Areas prone to wind erosion are coastal sand dunes and inland rainfed farming areas where soils are sandy and mean annual rainfall is less than 400 mm per year. Much of Australia's wheat is grown on such land. Alley farming, which involves planting rows of trees to form 'alleys' between rows of crops or pastures, may be suitable in these conditions. Often the trees are planted at approximately 90° to the prevailing wind to form a permeable barrier. The spacing and height of the rows of trees help determine the amount of shelter which they provide for the crop or pasture in between.

As a rough guide, if windbreaks are 2 metres high, row spacing should be 25 m.

This spacing can of course be adjusted to fit your machinery and particular wind conditions. Usually, alley farming trees are used for grazing (see chapter on trees and shrubs for fodder), although prunings from the trees can also be used to supplement ground cover.

Soil organic matter and nutrient recycling

Trees recycle nutrients by taking them up from depth and depositing them on the soil surface as litter, which then decomposes to form soil organic matter.

Because they are deposited under the trees, the challenge is how to make these nutrients available to crops and animals. Options are to:

- alternate tree and annual crops or pasture on the same land in a long rotation;
- grow fodder trees and let animals transport the nutrients;
- grow fodder trees and transport the fodder to the animals; and
- grow crop or pasture alongside the trees, and place prunings on the crop (eg alley farming).

The design of layouts to enhance the benefits of trees on crops and pastures is discussed in the chapter 'Capturing multiple benefits'.

Organic matter

Organic matter improves soil nutrient content and structure. The amount of organic matter contributed by trees is affected by:

- the volume of foliage dropped;
- the quality of foliage dropped;
- additions from the roots; and
- tree species.

The rate at which litter decomposes to organic matter is affected by the ratio of carbon to nitrogen in the soil. Usually, the higher the level of nitrogen in the leaves the greater the contribution of litter to organic matter. Digging the litter in increases the rate of decomposition. Tree litter low in nitrogen may immobilise fertiliser. Nitrogen from foliage is much less prone to leaching than that from commercial fertilisers.

Trees vary greatly in the type, volume and effectiveness of nutrients they recycle.

Nutrient cycling

Leguminous trees usually add more nitrogen to your soil than other tree types, while other tree leaves are low in nitrogen and may immobilise fertiliser. Some native acacias seem to produce litter which decomposes very slowly. The actual amount of nitrogen added depends on tree species and local conditions.

Some trees (eg *Banksia* species, *Eucalyptus gummifera*), increase the availability of phosphorus by secreting root exudates. Others grow in association with mycorrhizae, which also increase the availability of nutrients (eg *Pinus radiata*, *Eucalyptus marginata*). Establishment of such plants can be a step in the rehabilitation of degraded land.

Trees for soil conservation

Vegetation type	Nitrogen yield, kg/ha/yr	Phosphorus yield kg/ha/yr	Place
<i>Pinus radiata</i> plantation	14–24	0.97–2.30	Gippsland
<i>Eucalyptus</i> forest	21–46	0.94–2.00	Gippsland

Table 1:
Nutrient additions
from trees

Nutrient recycling of trees on crop and pasture growth can be most effective when trees are planted in alley farming systems. Tree canopies can trap significant amounts of nutrients, a source of free fertilizer which is washed from the leaves to your soil by rain.

Examples of nutrient additions and recycling from trees are in the Table 1.

Thinning and harvesting

If trees are thinned or harvested as timber, nutrients will be exported, though usually less than are lost through cereal cropping.

Nutrient losses are reduced by leaving roots, foliage and bark on site, and minimising soil disturbance.

In the majority of cases, commercial tree harvesting leaves trees residue on site, thus reducing fertiliser requirements for the next tree crop. As with all other crops, soil testing will help determine fertility losses.

Time-scale

We have seen that trees can control landscape processes, but they do this on a longer time-scale than pastures and crops. For example, trees can improve soil fertility at a site, but the improved patch remains under the tree until it dies or is removed. If it suits your farming objectives, you could alternate trees and crops on a long cycle (10 years or more) as a way of using the improved fertility.

Reference / Further reading

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Capturing benefits in addition to soil conservation

When planting trees for the purpose of soil conservation, the investment is being made primarily to ensure the long term viability of the farm rather than for the direct value of the trees. Native species may be used which will offer a good opportunity to capture nature conservation and scenic beauty objectives. With appropriate design, shelter, fodder and timber benefits could also be realised. Planting would need to be on a large scale to capture salinity benefits.

Other benefits to capture	Opportunity	Thing to look out for
Wood	Trees planted to reduce erosion, stabilise gullies, cycle nutrients or rehabilitate unproductive soils could be harvested for timber if appropriate species are selected	Establishment costs may be high and growth slow on degraded sites Some soil conservation benefits may be lost through the harvesting process – manage it carefully!
Salinity and waterlogging	Strips of trees planted to reduce slope length may access laterally moving groundwater and thus have some benefit on water-tables downslope If enough trees are planted for soil conservation purposes they could reduce or reverse a trend of rising water-tables	
Shade and shelter	Scattered trees, pockets of trees or belts will give shelter to crops, pastures and animals	Planting locations required to address issues of soil degradation may not coincide with those required for maximum shelter effect
Fodder	The use of fodder species for soil conservation is a good way to get some economic return from land which is being degraded under conventional management	Grazing pressure will need to be strictly managed
Nature conservation	The opportunity to use native vegetation for soil conservation purposes will potentially enhance wildlife habitat diversity	
Scenic quality	Planting degraded areas will have a positive impact on scenic beauty	

Trees for shade and shelter

Introduction

Trees arranged either as windbreaks, woodlots or scattered individually through paddocks can improve productivity by protecting stock, crops and pasture from extremes of weather and climate. The value of providing shade and shelter depends on how important these extremes are in limiting your current productivity.

This chapter addresses the following questions:

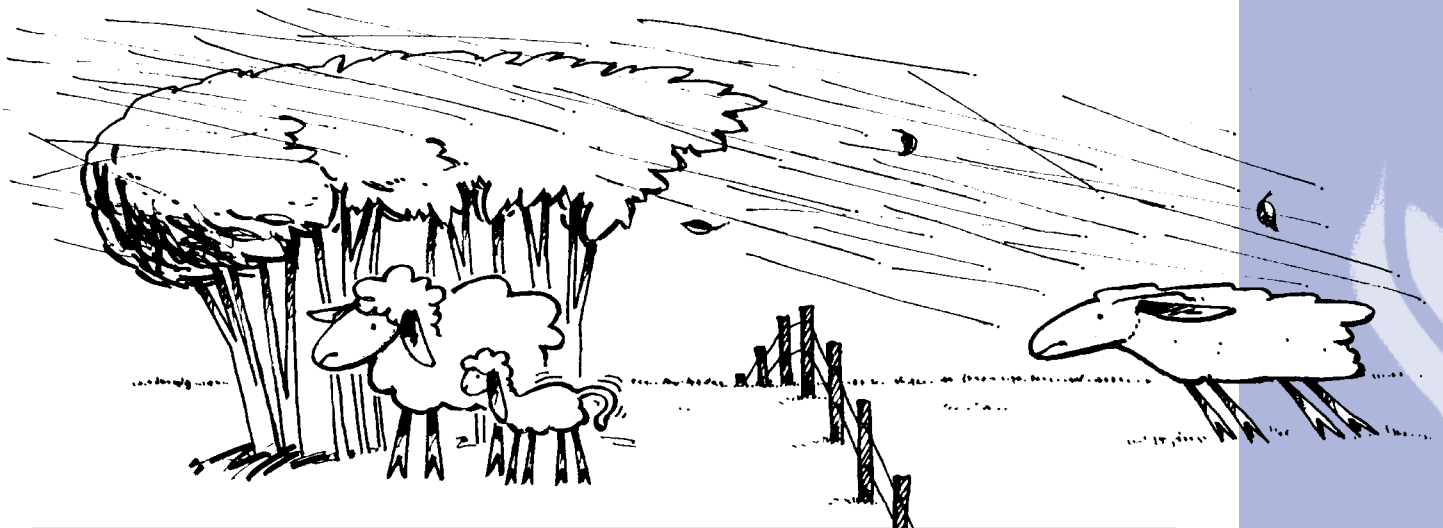
- what are the effects of shade and shelter upon animal and plant productivity?
- how do tree windbreaks affect shade and shelter?
- what things do I need to know before I design and plant a windbreak?
- how can I design tree windbreaks to maximise shade and shelter benefits?

- what other tree arrangements will also provide shade and shelter?
- what can I monitor to test whether I am benefiting from shade and shelter?

What are the effects of shade and shelter on productivity?

There are five main ways that shade and shelter influence productivity. These are:

- the protection of plants;
- the protection of livestock;
- the alteration of microclimate;
- competition; and
- reduction in soil losses.



Trees for shade and shelter

These are discussed in more detail below.

Protection of plants from direct wind damage

Trees can provide protection from wind damage, especially for high value products such as fruit and crops.

Strong winds directly damage plants through abrasion and sandblasting; stripping and tearing of leaves; and lodging of whole plants at either the root or stem. Abrasion will make crops susceptible to disease infestations. Such damage can then limit growth rates and final yields in pastures and crops. Blowing sand and soil particles also bury young seedlings during wind erosion events. Thus horticultural products can be reduced in quality and quantity as a result of direct wind damage. For example, kiwi fruit are easily damaged by rubbing and abrasion even from moderately strong winds.

Protection of livestock from heat and cold stress

Providing shade is important in tropical to subtropical climates, not only for improving feed conversion efficiencies but to prevent cattle deaths

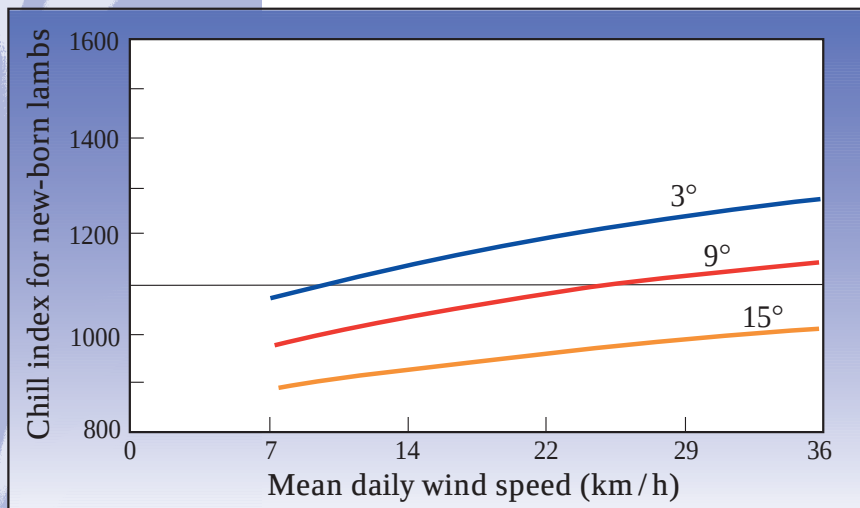
due to heat stress. Heat stress has also been found to reduce fertility in sheep and affects the well-being and size of calves.

Energy requirements by livestock are reduced by shelter from cold winds, especially during rain and snow. This translates into improved growth rates, livestock yields and productivity.

Figure 17 shows the way that heat losses (plotted as a chill index) in new-born lambs depend on mean daily air temperature (3°, 9° and 15°C) and wind speeds. If the chill index exceeds 1100, new-born lambs will lose so much heat that they will die.

Using this figure, we can see that even at 9°C, the heat losses exceed the critical value of 1100 in moderately strong winds (around 30 km/h). Reducing the wind speed to about 15 km/h reduces heat losses to safer levels. At air temperatures of 3°, wind speeds need to be reduced to less than 10 km/h to prevent dangerously large heat losses. This graph does not include the effects of rain, which will further increase heat losses.

Figure 17: The effect of wind and temperature on heat losses from new born lambs



H I N T

Combining pre-lamb shearing and windbreaks is one way of reducing lambing losses. New-born lambs are greatly affected by cold conditions. If ewes have been shorn, they too will feel the cold and are more likely to seek shelter, taking their lambs with them to the protection of the trees.

Mortality rates in newborns can therefore be reduced as a result of shelter from the wet and cold. Similarly, shelter can reduce losses of shorn sheep which occur in cold, wet and windy conditions – losses as high as 100,000 have been reported in Victoria for a single extreme event. Trees can provide a protected environment for grazing and breeding livestock.

Trees for shade and shelter

Changed microclimate and water use

Shade and shelter affect productivity indirectly because of changes in the microclimate and water use. Planting trees can improve crop yields and pasture growth because a more favourable microclimate is created by shelter – warmer daytime temperatures, increased humidity and, in many cases, better growing conditions.

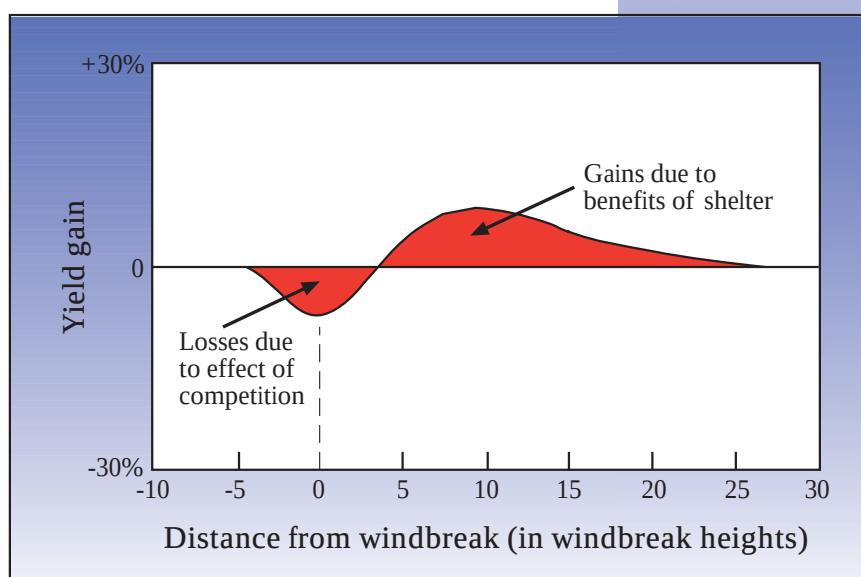
Sheltering crops that are well supplied with water (such as irrigated crops) from hot, dry winds will reduce evaporative water losses, conserving soil water and improving grain yields. In dryland agriculture, shelter may reduce soil evaporation early in the season, leaving more water available for plant growth later in the season.

The microclimate near trees is also modified by shading from direct sunlight by day, and protection from radiation losses at night, leading to lower maximum and higher minimum air temperatures. While plants growing next to trees may be protected from frost at night, shading in the early morning could prolong frost duration in other parts of the paddock. Providing shade from direct sunlight prolongs unirrigated pasture growth into summer because the rate of soil water loss is reduced.

An example of the effects of shade and shelter on crop growth is illustrated in Figure 18 which shows crop yields plotted against distance from a windbreak (positioned at the zero line in the graph). Distances from the windbreak are given in units of windbreak heights (H) – negative to indicate upwind and positive to indicate downwind of the windbreak. Using this, we see that crops growing next to a 10 m tall windbreak will have lower yields in the zone within 20 m of the windbreak because of competition for light, water and nutrients (see below). Away from the windbreak, the more favourable microclimate created by shelter can lead to yield gains in a zone that extends from 30 m

(3H) to 150 m (15H) downwind of the windbreak. For a crop growing next to a 10 m tall windbreak, this means that yield may be increased as far as 150 m downwind. These yield gains usually balance, or even outweigh, the losses due to competition and land taken up by the windbreak.

Figure 18:
The effect of a
windbreak on
crop yields



Competition for light, water and nutrients

Tree windbreaks compete with neighbouring plants – pasture or crops – for light, water and nutrients. Competition effects can extend several tree heights away from the tree canopy, as illustrated in Figure 18.

Competition is not always bad. For example, increased water use by trees may reduce a waterlogging problem and so improve productivity. If, however, the soil moisture store must sustain plant growth through spring and/or summer then increased competition for moisture may limit crop or pasture growth.

Shading, which is competition for light, is beneficial if plants already have sufficient quantities of light for growth and water is limited, because of lower evaporative water losses. However, shade may be limiting if there is insufficient light for growth, if shading increases the duration of frost, or if it leads to waterlogging.

Reduced soil losses through wind erosion

Wind erosion not only damages plants directly, but removes the nutrient-rich topsoil (see 'Trees for soil conservation'). This and the fact that the wind's ability to transport soil increases exponentially with wind speed mean that using shelter to reduce soil losses is an efficient way to achieve enhanced, sustainable agricultural productivity in Australia.

Other effects

Wind is a means of transport for many pests – shelter reduces the transport of pests away from a particular area and so may simplify spraying. Windbreaks make effective buffer strips for reducing the risk of spray drift. Trees attract predatory birds and insects which feed on pests, and pollination can also be improved by shelter. A negative effect of attracting birds and animals is that they may also damage or feed on the sheltered crops. The warmer, humid microclimate created with shelter may also increase the incidence of fungal diseases.

H I N T

Fleece rot and fly strike

Grazing of woolly sheep in paddocks with high tree numbers can cause fleece-related problems. Either stock these paddocks with freshly shorn sheep or allow free access to adjoining open paddocks.

Windbreaks grown in pasture or cropping areas can be very effective firebreaks, especially if the windbreak trees have low combustibility.

How do tree windbreaks affect shade and shelter?

Trees provide shade by intercepting the sun's direct rays (Figure 19a). The area of shade depends on the height of the tree and the elevation of the sun above the ground. Figure 19b illustrates the shaded area cast by a north–south oriented windbreak at a range of latitudes and for different times of the day. The insets show examples of distance shaded (in windbreak heights) for a location at 35°S (eg Wagga Wagga, NSW).

For a location at 40°S, say Hobart, we can use Figure 19b to calculate the area shaded by a 10 m tall windbreak oriented north–south. In summer, the shaded area is less than 5 m at midday and 10 m at 9 am or 3 pm. By mid winter, a 20 m strip is shaded at midday and this grows to 40 m in the morning and afternoon. This shaded area in winter occupies the entire sheltered zone described below.

Windbreaks provide shelter by deflecting the approaching wind up and over the windbreak, around the edges and through any gaps within the windbreak. As a result, wind speeds are reduced.

The greatest wind speed reductions are found in a 'quiet' zone immediately behind the windbreak (see Figures 20 and 21). The % of upwind wind speed used in Figure 21 is a measure of this wind speed reduction – it is simply the actual wind speed at a particular location expressed as a fraction of the wind speed far upwind of the windbreak.

Extending beyond the quiet zone is a sheltered area where wind speeds are still somewhat reduced, but the air may be slightly more turbulent. This sheltered area extends to at least 20 windbreak heights (20H) downwind of the windbreak.

Trees for shade and shelter

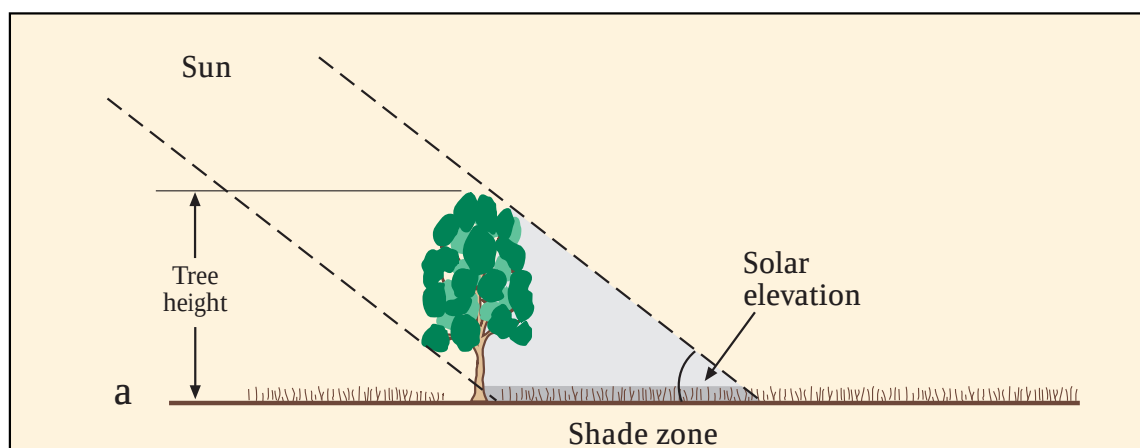


Figure 19:
Tree windbreaks
provide shade

The amount of wind speed reduction depends on the gaps, or 'openness', of the windbreak (called the porosity) and its length. The size of the sheltered area depends on the height of the windbreak.

These points can be seen by using the example in Figure 21 which is for a windbreak with roughly 50% foliage and 50% gaps. For a 10 m tall windbreak, the lowest wind speeds will be felt 50 m (5H) downwind. At this spot, the wind speed is about 50% of its upwind value. A location 150 m (15H) m downwind of the 10 m tall windbreak will still be sheltered, but the wind will have increased to 80% of its upwind speed. Note also that the wind begins to slow even before the windbreak is reached – at about 50 m (5H) upwind for a 10 m tall windbreak.

The approaching wind direction is important for shelter. Figures 20 and 21 assume that the wind is blowing almost at right angles (within about 40°) to the windbreak. If the wind blows at a large angle across the windbreak then the sheltered area may be reduced in size.

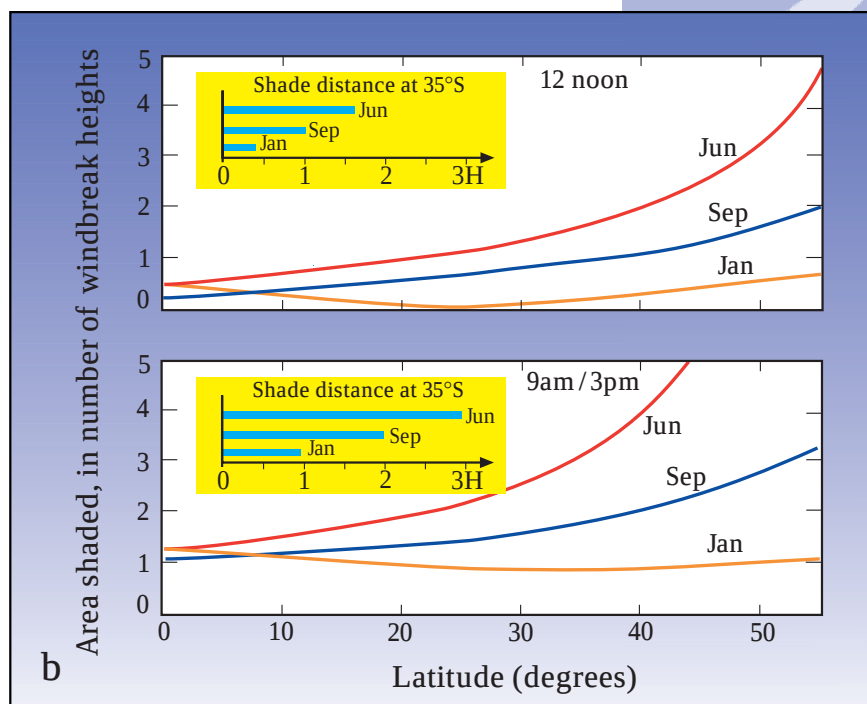
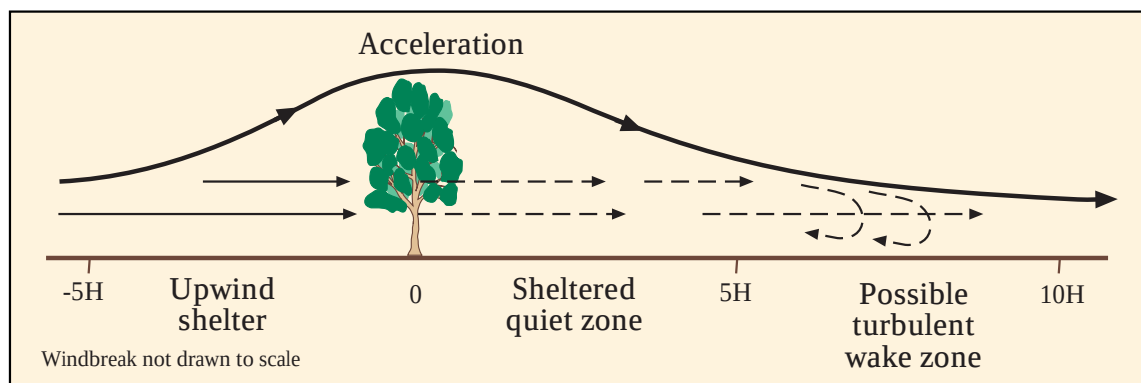


Figure 20: The effect of a tree windbreak on airflow



Key questions to consider before you start planning and designing windbreaks on your farm

Before even beginning to design a windbreak system for your farm, you need to consider the following questions.

Why do I need a windbreak?

Is your aim to provide maximum shelter over a small distance, perhaps to protect a small number of stock or a high value horticultural crop? Or are you willing to have a smaller, but adequate, shelter effect over a larger area? The latter option might be more appropriate for sheltering broadacre cropping areas. Alternatively, you might be most interested in providing shade for stock and pasture production, in which case closely spaced, tall windbreaks or scattered trees may be required.

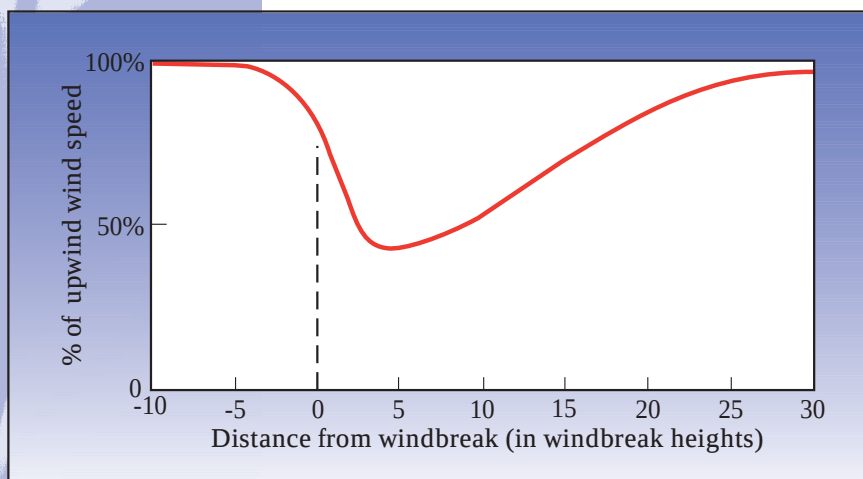
What are the climate extremes from which I require protection?

Do you require shelter from a particular wind direction? Do these winds vary seasonally? For example, many parts of southeastern Australia need shelter from hot, dry north-westerlies in the summer and cold south-westerlies in the winter. A familiarity with the local climate and topography of your property is needed to determine those places most exposed to damaging winds.

What is the nature of the return I expect from my windbreak?

Shade and shelter affect productivity in two ways. Firstly, shelter can provide protection from

Figure 21: The effect of a windbreak on wind speed and shelter



Trees for shade and shelter

extremely damaging, but infrequent, weather events. If such events are likely on your farm then a windbreak is like an insurance policy. It will reduce large productivity losses due to crop damage or livestock deaths, but this may happen only once in a decade. The benefits of the windbreak in this example are infrequent and unpredictable, but they are very large when they occur.

On the other hand, the greatest benefit from shade and shelter may be a gradual improvement in productivity over the course of all growing seasons. The return from your windbreak in this scenario may not be large on an annual basis, but it is more reliable and will realise a long-term financial gain.

Will competition improve or limit productivity?

Planting tree windbreaks can introduce competition between the trees, soil and other plants (pasture, crops) for light, water and nutrients. Productivity will sometimes be improved as a result of competition, as illustrated in the earlier example of waterlogging or in the case of dryland salinity (see chapters on soil conservation and salinity). The principle here is to consider carefully, in consultation with an agricultural extension officer, those factors that limit productivity in your enterprise. This will enable you to decide whether you need to encourage or restrict competition for water, nutrients and light. Three examples of ways to manage competition are discussed below.

Careful selection of windbreak tree species. For example, if shading is a concern then deciduous trees often have sufficient stems and trunks to act as an effective windbreak but with less shading in winter. Select tree species whose root growth and architecture reduces or enhances competition as appropriate.

Manage your windbreak. Consider using management practices such as root pruning or

thinning of the canopy if your aim is to reduce water uptake by the trees.

Design an appropriate windbreak arrangement. The effects of competition can be managed by considering the spacing and configuration of your windbreaks or by selecting an alternative arrangement for trees on your property.

The last is by far the most effective way to manage competition and is taken up in the following discussion on windbreak design.

Designing a windbreak to maximise shade and shelter benefits

There are two main factors to consider when designing a windbreak system to provide shade and shelter – windbreak structure (porosity, shape, width, length and height) and windbreak layout (orientation, spacing and configuration).

1) Windbreak structure

Porosity

A windbreak's ability to reduce wind speeds depends primarily on its porosity. A more open or porous windbreak allows more air to flow through the trees and so provides less shelter – that is, there is a smaller reduction in the wind speed downwind. This effect is illustrated in Figure 22.

A windbreak's porosity can be assessed in the paddock. Simply stand at a spot in front of, and at right angles to, the windbreak and estimate the relative percentages of foliage and gaps (see Figure 22). This visual estimate is a fairly good guide to the porosity of the windbreak.

Maximum shelter is best achieved with a dense windbreak (less than 30% porosity).



Trees for shade and shelter

The most sheltered location will be close to the windbreak, within about 3 windbreak heights. The airflow beyond this point may become more turbulent with a possible increased risk of damage to plants – especially easily damaged horticultural crops.

A medium porosity windbreak (roughly 50–60% open spaces and 40–50% tree when viewed from directly in front) will also provide adequate shelter. The most sheltered location may be slightly further away from the windbreak (around 5–6 H) and there is less risk of damage to horticultural plants.

The size of the sheltered area will be very similar for both high and low porosity windbreaks – as shown in Figure 22. Claims that porous windbreaks provide shelter over larger areas than dense windbreaks have been exaggerated in the past.

Thus, managing the porosity of your windbreak is probably less important than managing the windbreak height (which determines the shelter distance) and maintaining a uniform porosity.

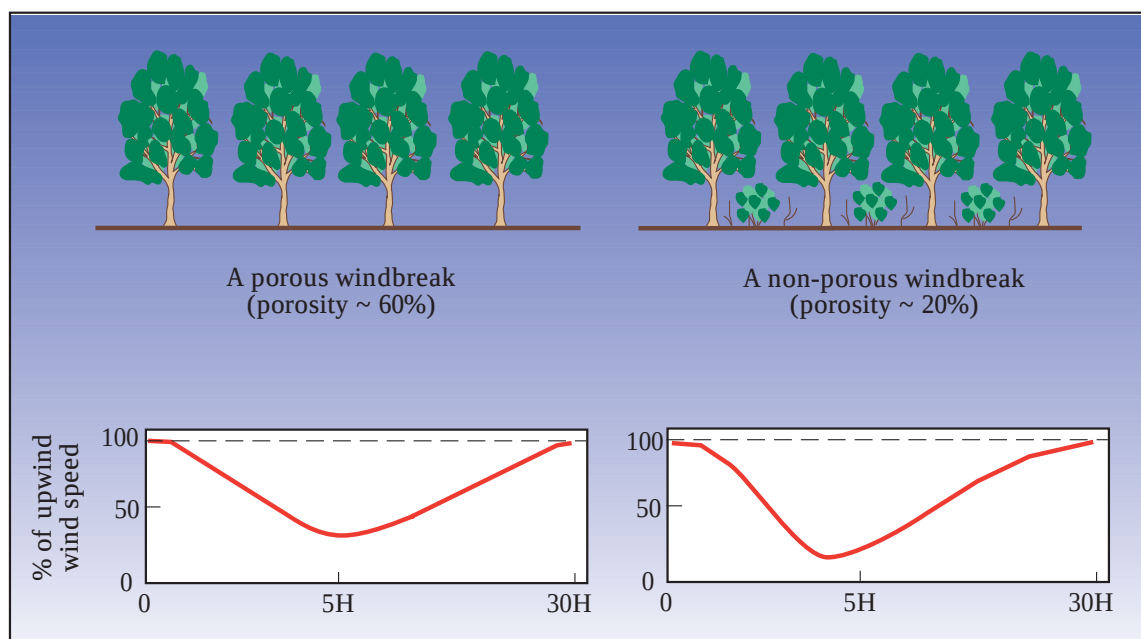
Height and length

The size of both the shaded and sheltered zone behind a windbreak depends more on windbreak height than it does on porosity, which is why shade and shelter effects are expressed in terms of windbreak heights.

H I N T

Woolly sheep often don't take advantage of shelter at lambing time. Handfeeding next to the trees will help overcome this problem.

Figure 22: The effects of a high porosity and low porosity windbreak on wind speed



Trees for shade and shelter

The area of sheltered land per unit area of windbreak can be maximised by growing relatively narrow, tall tree windbreaks. A fast-growing windbreak, or planting a windbreak on a bank, is the quickest way to increase the size of the shaded and sheltered area. If shade for stock is required, the large shaded area provided by a tall windbreak will reduce the negative effects of stock camps on soil erosion.

A windbreak should be as long as possible, at least 20H, because flow around windbreak ends will erode the sheltered zone.

Linking the windbreak into existing shelter, woodlots or forests is another way of achieving shelter over as large an area as possible.

Shape and width

An ideal windbreak will have a uniform porosity along both its length and height. Gaps either in the trunk space or along the break due to dead trees or a gateway can lead to strong 'jets' of wind that may be more harmful than an absence of shelter. More than a single row of trees will usually be needed to maintain an adequate and uniform porosity. A streamlined cross section is, however, not necessary for a medium porosity windbreak. Windbreaks also should be protected from grazing animals to prevent gaps at the base of the tree trunks.

Windbreak width is of secondary importance, apart from the need to have enough tree rows to ensure the health of the windbreak trees and to maintain an appropriate porosity. Very wide blocks of trees, where width greatly exceeds height, are still an effective windbreak except that the sheltered area downwind may be smaller.

An example of planning windbreak structure

Figures 21 and 22 can be used as a guide to planning windbreak structure. Say you wish to

shelter an area extending from your windbreak out to 100 m and you have planted a windbreak which will grow to a maximum height of 5 m. Planting and maintaining a medium porosity windbreak which is at least 100 m in length will be your best chance of getting a shelter effect to 100 m (20H). The maximum wind speed reduction that you can achieve with this windbreak will be about 50% and this will be experienced about 25 m downwind of your windbreak. If you allow your windbreak to become more dense, as in the second panel in Figure 22, then you will have achieved a greater reduction in wind speed – to about 20% of the wind's strength upwind. This latter scenario is probably most appropriate if you wish to achieve maximum shelter (such as for sheltering stock or a homestead) and increased levels of turbulence are not important.

2) Windbreak layout

Orientation

The best windbreak orientation is at right angles to the prevailing winds. If the wind blows at an angle across the windbreak, then the sheltered zone may be smaller (Figure 23). However, the last graph in Figure 23 illustrates the important point that some degree of shelter is experienced for a large range of approaching wind directions as long as your windbreak has adequate length.

Choosing the right orientation for a windbreak requires a knowledge of the local wind climate – from which winds do you require the most shelter? If you are fortunate and only require protection from one prevailing direction then a single windbreak will be adequate.

Unfortunately, damaging winds often vary with the seasons – for example, hot, dry north-westerlies in the summer and cold south-westerlies in the winter. You must then choose between a single windbreak orientation which provides some shelter



Trees for shade and shelter

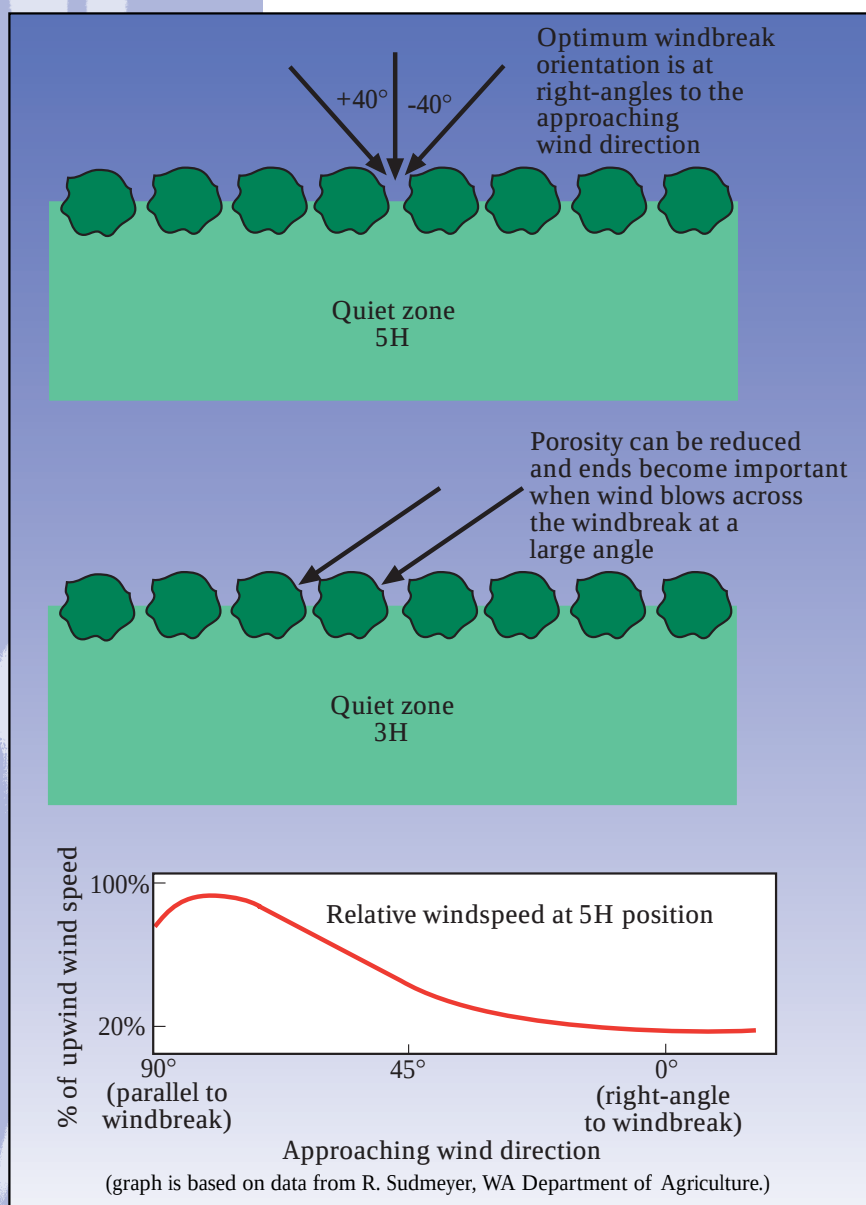


Figure 23: Orienting your windbreak to achieve the maximum shelter

in both seasons, or establishing a grid of windbreaks to maximise shelter from all wind directions (Figure 24). This latter option requires a carefully designed windbreak system which minimises costs and productivity losses: some alternatives are described below. You should also refer to the chapter on capturing multiple benefits.

Spacing between windbreaks

In selecting an optimum spacing of individual trees or windbreaks, you need to consider how much competition is appropriate; what other activities will be affected by the location of trees (mustering of stock, spraying, sowing and harvesting); and for what purpose shade and shelter are required.

Shading only extends over a few windbreak heights, so closely spaced trees (around 5H) may be needed for maximum shading.

A very sheltered environment can also be created by using a 5H spacing, but much wider spacings will be needed if competition is a problem.

Fortunately, a sizeable shelter benefit is achieved even with spacings of 20H.

Windbreaks spaced more than 20H apart have little influence on each other except for one important effect. As the density of windbreaks increases, not just on your farm but across the region, the greater is the regional-scale sheltering. This means that the shelter felt in a particular paddock results not just from the windbreak on that paddock, but also from any other trees and topography on your own and your neighbours' farms. Converting as little as 2% (20 m tall windbreaks spaced 25H apart) of a landscape into tree windbreaks could achieve a 30% reduction in wind speed.

Trees for shade and shelter

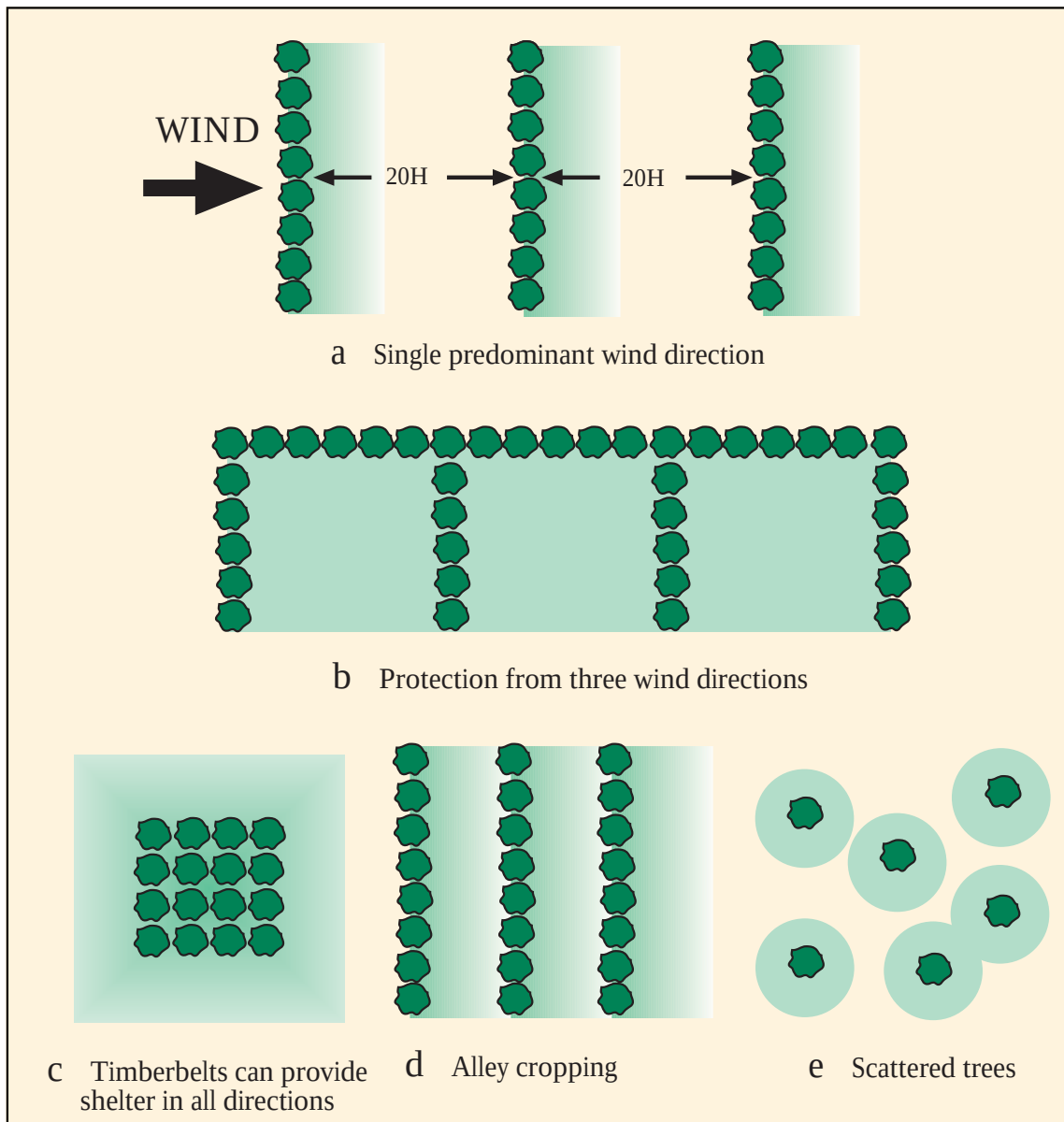


Figure 24:
Choices of
windbreak
configurations:

- (a) parallel windbreaks for a single, predominant wind direction;
- (b) a windbreak grid for protection from 3 wind directions;
- (c) a timber block, which provides shelter and shade in all directions;
- (d) alley cropping; and
- (e) scattered trees, which provide maximum shade, shelter and competition

Alternative tree arrangements to achieve shelter and shade

The potential for competition increases as the windbreak/crop (or pasture) interface becomes larger. Tall, single windbreaks, less than 3 rows wide, have the smallest ratio of interface length to sheltered distance and so are a good option to minimise productivity losses from competition and to maximise shade and shelter.

Planting windbreaks around paddock edges in a grid (Figure 24b) also maximises the area sheltered compared to the area affected by competition. Timber blocks (see ‘Trees for wood products’) are similar, simply because the effects of competition inside the block of trees do not limit the timber yield. Planting large areas with trees to provide timber can increase water use (see ‘Trees for controlling dryland salinity and waterlogging’) and provides shade and shelter.

If your aim is to maximise competition either to achieve shade or increase water use, then alternative configurations would include alley cropping (see ‘Trees and shrubs for fodder’) and possibly scattered trees. Trees scattered across a paddock, either in clumps or as single trees, provide most of the shade and shelter benefits described above if an adequate density is established. Such an arrangement may not be suitable for broadacre cropping and can be expensive to establish in grazed pasture where seedlings must be protected from stock.

For any of these alternative tree configurations, different management practices will be needed to ensure that the shade and shelter benefits are not compromised. For example, some alternatives to pruning lower branches in woodlots (which create unwanted gaps in the lower trunk space) include:

- planting an appropriate composite of species;
- leaving a buffer row around the downwind edge of the tree lot; and
- enclosing the tree lot with a medium porosity fence.

Monitoring

Once you have established windbreaks on your property, a monitoring program is a useful way of checking whether the benefits described earlier are being achieved.

You should compare all your observations against a control: ie observations of stock or paddocks that are not receiving shade or shelter. Long-term records will be needed. Some useful details to monitor and record include:

- sheep deaths in sheltered and unsheltered paddocks;
- milk yields from stock in sheltered and unsheltered paddocks;
- stocking rates and length of time between rotating stock;
- bales of hay per paddock – compare sheltered with unsheltered;
- whether harvester bins fill more quickly in sheltered paddocks;
- use a yield mapper (available for hire in some agricultural districts) to see whether windbreaks affect yield across the paddock, especially in a year with extreme weather; and
- obvious signs of plant damage after extreme events such as rain and wind storms.

References / Further reading

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Heinjus, D. (1992). *Farm Tree Planting*. Department of Agriculture South Australia and Inkata Press, 84 pp.

The following volume has many interesting research articles:

Brandle, J. R. and Hintz, D. L. (1988). "Windbreak Technology", (Eds.) *Agric. Ecosystems Environ.* 22/23.



Capturing benefits in addition to shade and shelter

Good windbreak design and layout can achieve a considerable amount of shelter with only a small percentage of land under trees – say less than 5%. This provides an opportunity to capture other benefits, particularly those associated with wind erosion and nature conservation.

Other benefits to capture	Opportunity	Thing to look out for
Wood	Timber can be produced from multi-row windbreaks, particularly for high value managed trees	The requirement for uniformity of a windbreak may conflict with timber management practices such as thinning and pruning
Salinity and waterlogging	Windbreaks which can access laterally moving groundwater may have some benefit on water-tables immediately downslope	The minimum area planted to trees which will give a windbreak effect may be too small to impact on local water-table levels
Soil conservation	Design for shelter and reduction of wind erosion are entirely compatible	Apart from wind erosion, serious attempts to rehabilitate or protect degraded land will require more trees than single row windbreaks
Fodder	Trees in a windbreak could be browsed or lopped during drought periods Pruning and thinnings can produce fodder (usually of low quality)	Windbreaks are unlikely to produce a significant volume of feed Browsing will affect windbreak porosity and uniformity
Nature conservation	Windbreaks linking remnants can act as wildlife corridors Windbreaks composed of multiple species will improve habitat diversity Some tree species act as fire retardants	
Scenic quality	Positive impact if vegetation shelter layout follows natural and/or cultural landscape characteristics Species diversity (grasses, shrubs & trees) will increase scenic quality	Straight windbreak rows planted at right angles to prevailing winds may conflict with the often curved lines of the natural landscape (ridges, creeks)

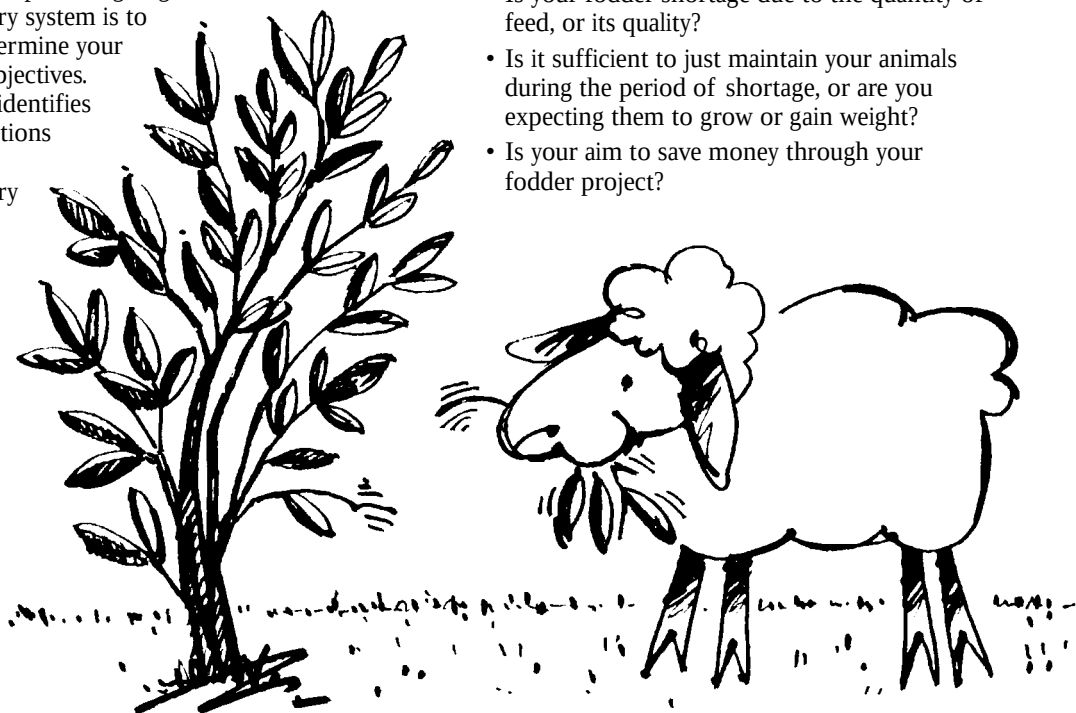
Trees and shrubs for fodder

Introduction

Trees and shrubs can supplement the quantity and quality of pastures for grazing livestock. They are an effective insurance against seasonal feed shortages or the risk of drought.

Fodder or browse production from trees and shrubs is one of the benefits of agroforestry. Fodder agroforestry systems can be designed to deliver additional benefits such as shelter, soil conservation, rough timber and habitat.

The first step in designing a fodder agroforestry system is to clearly determine your farming objectives. Figure 25 identifies various options for fodder agroforestry available to you.

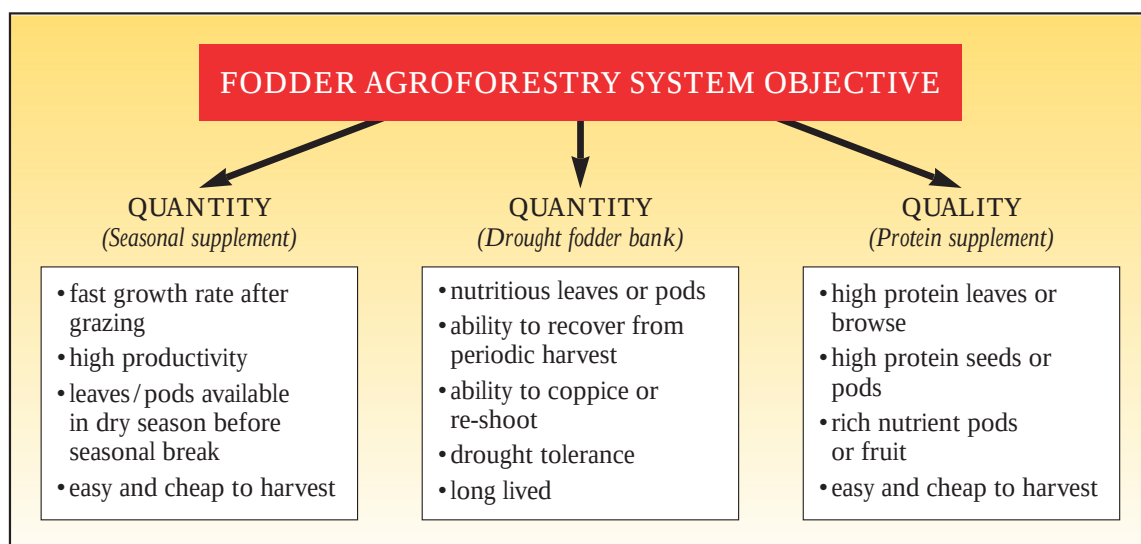


Objectives

The following questions may help you decide your fodder agroforestry system objectives.

- Do you have a fodder shortage at a particular time of year? How long does this period last? How often do you expect an atypical shortfall in a ten year period?
- Is the problem due to annual variability of supply because of seasonal drought such as in a climate with wet winters and dry summers?
- Is your fodder shortage due to the quantity of feed, or its quality?
- Is it sufficient to just maintain your animals during the period of shortage, or are you expecting them to grow or gain weight?
- Is your aim to save money through your fodder project?

Figure 25:
Fodder agroforestry
options



- Are you expecting the fodder agroforestry system to increase the quantity of feed available to livestock?
- Are you expecting the fodder agroforestry system to increase the quality of feed available to livestock?

Design principles

Design principles are rules of thumb to help guide you through the many choices that can be made as you design your fodder agroforestry system. These principles help to guide your decisions about:

- quantity and quality of forage production;
- consumption, nutrition and animal production;
- layout of plantings;
- what species of trees and shrubs to plant;

- the costs and benefits of alternative fodder agroforestry options; and
- additional benefits because of interactions with other activities.

It is worth remembering that some fodder trees or shrubs can suppress pasture growth, although there are others which will stimulate pastures. The quality of fodder produced by trees and shrubs is usually different from that of pasture feed.

You may need to take the change in the seasonal distribution of fodder quality into account.

For example, by planting fodder shrubs you may be replacing some of the output of high quality spring feed with a supply of higher quality summer feed. This could have implications for stocking rates or stock management.

Potential of fodder agroforestry systems

Figure 26 shows typical seasonal feed production by annual pastures, perennial pastures, autumn fodder agroforestry crops and summer fodder agroforestry systems.

The aim of planting a fodder agroforestry system is usually to overcome the effects of the troughs or to insure against the risk of drought or fire.

Figure 26 demonstrates the potential for summer and autumn fodder trees and shrubs to balance out the seasonal feed shortages which occur with annual and perennial pastures.

The right fodder trees and shrubs for the job are the ones which produce feed during the troughs or accumulate feed which can be used after a disaster such as drought or fire. Because most trees and shrubs have more extensive root systems than grasses and forage legumes they are able to maintain growth during seasonal dry periods and the early period of droughts.

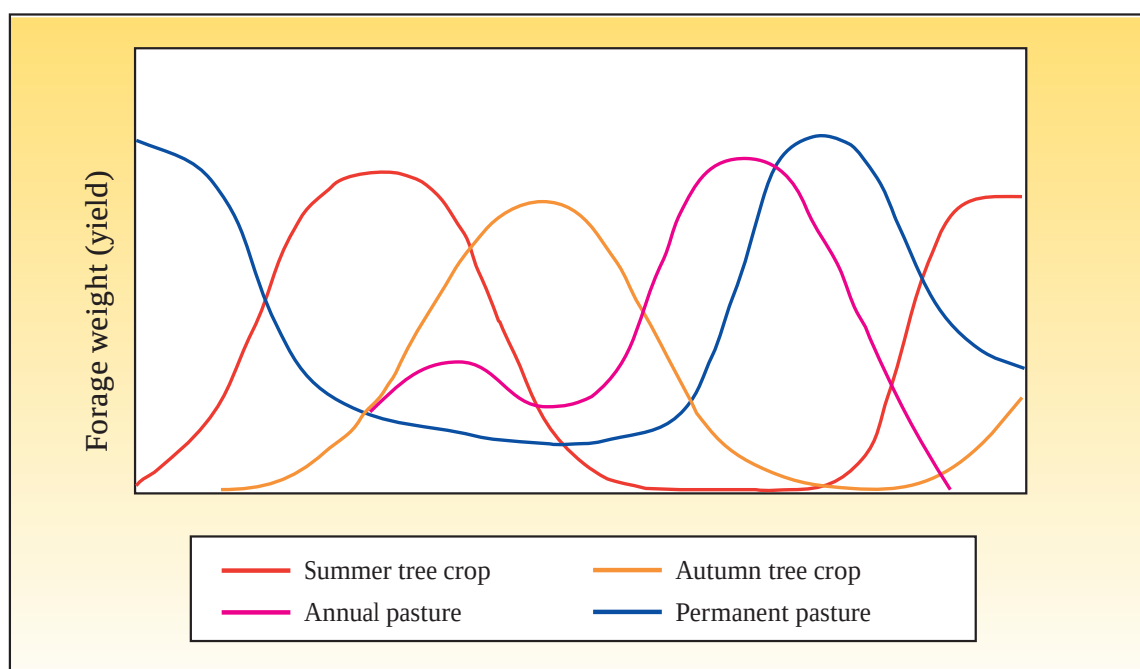
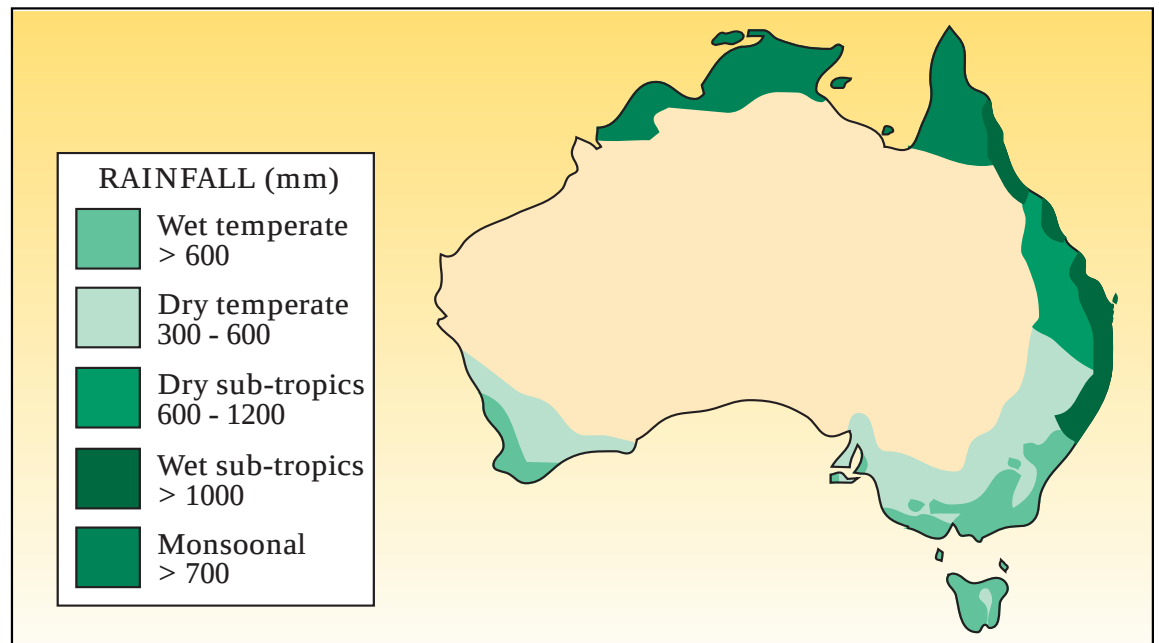


Figure 26:
The potential for
fodder from
various systems

Figure 27:
Agroecological
zones of Australia



Typical feed problems which can be managed with fodder agroforestry systems in each agroecological zone include:

- Wet temperate zone (>600 mm) – *quality* protein supplements in late autumn just before or after the autumn break to give a boost to pregnant ewes and cows;
- Dry temperate zone (300–600 mm) – *quantity* (seasonal supplement) to provide additional feed during the dry season and *quantity* (drought bank) to provide a long-term feed reserve to maintain stock for the first year of a drought
- Dry sub-tropics (600–1200 mm) – *quality* protein supplements in late autumn just before or after the autumn break to give a boost to pregnant cows and *quantity* (drought bank) to provide a long-term feed reserve to maintain stock for the first year of a drought;

- Wet sub-tropics (>1000 mm) – *quantity* (seasonal supplement) to provide additional feed during the dry season and *quality* protein supplements just before the end of the dry season to give a boost to pregnant cows or finish off live cattle before export; and
- Monsoonal (>700 mm) – *quality* protein supplements just before the end of the dry season to give a boost to pregnant cows or live cattle before export and *quantity* (drought bank) to provide a long-term feed reserve to maintain stock for the first year of a drought.

Based on the principles illustrated in Figures 26 and 27, Table 2 shows some examples of the potential for fodder trees and shrubs to meet the needs of livestock producers.

Trees and shrubs for fodder

Agroecological Zone	Fodder Species	Fodder Production	Animal Production
Dry and wet sub-tropics	<i>Leucaena leucocephala</i>	Supplies high quality feed April to October when pasture quality is low. Rainfed or irrigated.	Cattle gain 200–300 kg/ha/yr. Under irrigation, gains of 1000 kg/ha/yr have been achieved.
Monsoonal	<i>Leucaena leucocephala</i>	Rainfed regrowth estimated at 500 kg/ha/yr edible dry matter in the late dry and 4400 kg/ha/yr in the early wet.	Cattle gains of 5.6 kg/head/day from irrigated fodder.
Dry temperate	Tagasaste (<i>Chamaecytisus palmensis</i>)	Needs 500 mm of rain or more to produce a significant forage reserve. Prone to high mortality rates in dry years.	
Dry temperate	Saltbush (<i>Atriplex</i> , <i>Maireana</i> species)	Supplies summer and autumn shortfall.	Can maintain summer and autumn condition, but best fed in combination with grass or hay due to high salt content.
Dry temperate	Tagasaste (<i>Chamaecytisus palmensis</i>)	Supplies autumn and early winter shortfall. Produces 3 t/ha/yr of edible dry matter on 450 mm rainfall, and up to 9 t/ha/yr on 1100 mm. A combination of shrubs and inter-row pasture produces 1 t/ha/yr per 100 mm of rain.	On 450 mm of rain sheep have been maintained at the same or better condition than animals on dry annual pasture with grain supplement. Wool production was better, but quality was inconsistent. Mass gains of 500–600 g/day have been achieved for cattle, but sheep appear to be only maintained.
Dry temperate	Willow (<i>Salix</i> species)	200 kg of fresh leaves and fine stems harvested on one occasion from one tree.	Weaners and hoggets fed a sole diet of 0.94 kg/head/day of foliage and stems gained 1.9 kg/head over 6 weeks.
Dry temperate	<i>Acacia saligna</i>	Has produced 4 t/ha/yr of edible dry matter.	Digestibility is reported to be low.
Wet temperate	Willow (<i>Salix</i> species)		Gains of 43 g/day reported over a six week period for young sheep when willow was the sole feed.
Wet temperate	Tagasaste (<i>Chamaecytisus palmensis</i>)	12–17 t/ha/yr of edible dry matter at 100 mm rainfall over 3 years.	Leguminous leaves have high digestible protein content.
Wet temperate	Honey locust (<i>Gleditsia triachanthos</i>)	100 kg/tree/yr of leguminous fruit pods reported.	Legume pods drop in autumn prior to seasonal break and provide high energy feed when paddocks are bare.
Dry temperate	Carob (<i>Ceratonia siliqua</i>)	100 kg/tree/yr of fruit reported from trees after 10 years in areas with 400–650 mm rainfall.	Legume pods drop in autumn prior to seasonal break and provide high energy feed when paddocks are bare.

Table 2: Examples of fodder production rates and animal responses

The following sections identify species for the three key objectives of fodder agroforestry systems.

Quantity – seasonal supplement

Many regions of Australia experience seasonal dry periods each year when paddock feed stops growing and livestock production relies on dry paddock feed or forage conserved from periods of high pasture growth. Options available to livestock producers for managing seasonal feed shortages include:

- **managing livestock breeding cycles** – sheep and cattle breeding can be managed to coincide with the growing season with weaners being sold early in the dry season;
- **managing livestock stocking rates** – the number of sheep or cattle carried can be managed so that there is enough standing paddock feed at the beginning of the dry season to maintain stock until the next growing season;
- **feeding conserved forage** – paddock feed harvested during the peak growing season as hay or silage can be fed to livestock during the dry period;
- **seasonal agistment** – livestock can be agisted off the property during seasonal dry periods; and
- **use of fodder trees and shrubs** – fodder trees and shrubs are less affected by seasonal dry conditions because of their more extensive root systems and longer life-span.

Conventional techniques for management of seasonal dry periods often result in regional peaks and troughs in the number and class of livestock being sold. This often depresses prices and means that conventional but sustainable management may not lead to the best returns.

Using conserved feed or fodder agroforestry systems to maintain stock during seasonal dry periods increases the marketing and

management choices available to livestock producers.

Table 3 gives examples of tree and shrub species which can provide seasonal supplement fodder for each agroecological zone.

Quantity – drought fodder bank

Drought is a risk which needs to be managed by all livestock producers. The extent of the risk and the amount of effort which is sensible for managing drought varies with location. Options available to livestock producers for hedging against the risk of drought include:

- **conservation of paddock feed** – storing hay and silage made on the property during good seasons or buying it to maintain breeding stock through a drought;
- **feeding grain** – feeding grain to maintain breeding stock through a drought;
- **agistment** – moving breeding stock to areas not affected by drought to maintain breeding stock through a drought; and
- **growing drought fodder banks** – establishing blocks of fodder trees and shrubs, perhaps as shelter belts or erosion control plantings, which can be selectively harvested during a drought.

Fodder from any one tree and shrub species in isolation is unlikely to contain sufficient energy, protein and nutrients to meet the maintenance needs of livestock.

A mixture of fodder trees and shrubs is more likely to provide an effective drought bank.

Mixing leguminous trees such as acacias, tagasaste or *Leucaena leucocephala* with other trees such as kurrajongs, sheoaks or willows is likely to provide the best fodder balance.

Table 4 gives examples of seasonal fodder tree and shrub species which are suitable for hedging against the risk of drought for each agroecological zone.

Trees and shrubs for fodder

Agroecological zone	Fodder tree or shrub	Comments
Wet temperate (>600 mm)	Willow (<i>Salix</i> species)	Fast recovery from harvest
	Poplar (<i>Populus</i> species)	Less vigorous than willow
Dry temperate (300–600 mm)	Tagasaste (<i>Chamaecytisus palmensis</i>)	Requires careful browse management for high production
	Salt bush (<i>Atriplex</i> species)	May not be easily digested by sheep and cattle
	Mulga (<i>Acacia aneura</i>)	Highly palatable
Dry sub-tropics (600–1200 mm)	Kurrajong (<i>Brachychiton populneum</i>)	Best harvested on 3–5 year rotation
	Leucaena (<i>Leucaena leucocephala</i>)	Marginal in drier areas but effective for finishing store cattle
Wet sub-tropics (>1000 mm)	Leucaena (<i>Leucaena leucocephala</i>)	Fast growth rates, may be attacked by sucking insects
Monsoonal (>700 mm)	Sesbania (<i>Sesbania grandiflora</i>)	Moderate recovery from cutting or browsing
	Gliricidia (<i>Gliricidia sepium</i>)	High digestibility and palatability

Table 3: Fodder tree and shrub species which can provide seasonal supplement

Quality – protein supplement

The quality of forage depends on the nutrient and energy content of the feed and its digestibility. Most feed types are not sufficiently digestible or nutritious to meet all an animal's needs in isolation. This is why pastures typically mix legumes such as clover or stylo with grasses such as ryegrass or panic. During the dry season or southern summer, paddock feed usually has poor digestibility because dry grass is rich in fibre (cellulose and lignin) and poor in sugar and protein. Providing protein and energy supplements helps animals, especially cattle and sheep, make use of dry season pastures. In this way supplements increase the quality of dry pastures.

Protein supplements to improve the quality of dry pastures can be provided in the form of:

- high protein conserved feed – such as lucerne hay;
- manufactured high energy / high protein supplements – such as urea/molasses licks; or
- quality fodder banks – managed as part of a fodder agroforestry system.

Conserved feed and manufactured supplements are expensive and can have hidden costs such as weed seeds in hay or urea poisoning in stock from too much lick. Quality fodder banks, on the other hand, can be established as fodder agroforestry systems with a relatively low cost per unit of protein or extra energy produced.

Trees and shrubs for fodder

Agroecological zone	Fodder tree or shrub	Comments
Wet temperate (>600 mm)	Drooping sheoak (<i>Allocasuarina verticillata</i>)	Coppices well, moderate growth rate
	Willow (<i>Salix</i> species)	Fast recovery after harvest
	Poplar (<i>Populus</i> species)	May sucker
Dry temperate (300–600 mm)	Belah (<i>Casuarina cristata</i>)	Moderate growth rate
	Saltbush (<i>Atriplex</i> species)	Some species have poor digestibility
	Tagasaste (<i>Chamaecytisus palmensis</i>)	Highly palatable and digestible
	Mulga (<i>Acacia aneura</i>)	Moderate protein
	Whitewood (<i>Atalaya hemiglauca</i>)	Palatable but has low digestibility
	Supplejack (<i>Ventilago viminalis</i>)	Readily browsed by cattle, good protein
	Kurrajong (<i>Brachychiton populneum</i>)	High protein and good digestibility
	Wilga (<i>Geijera parviflora</i>)	High available protein
Dry sub-tropics (600–1200 mm)	Mulga (<i>Acacia aneura</i>)	Readily browsed by cattle
	Kurrajong (<i>Brachychiton populneum</i>)	High protein and good digestibility
	Wilga (<i>Geijera parviflora</i>)	High available protein
Wet sub-tropics (>1000 mm)	Leucaena (<i>Leucaena leucocephala</i>)	Fast growth rates, may be attacked by sucking insects
Monsoonal (>700 mm)	Sesbania (<i>Sesbania grandiflora</i>)	High digestibility and palatability
	Gliricidia (<i>Gliricidia sepium</i>)	High digestibility and palatability

Table 4: Fodder tree and shrub species which can provide drought bank

Trees and shrubs for fodder

Quality protein supplements are most likely to come from high protein trees and shrubs such as legumes.

These produce:

- high energy and protein seed pods – which normally ripen and fall in late summer or autumn before the break of season when there is typically a shortage of paddock feed and pregnant stock are nearing lambing or calving or starting lactation; or

- high protein leaves – which can be fed or grazed whenever additional protein is needed.

Table 5 gives examples of fodder tree and shrub species useful for quality supplements in each agroecological zone.

Agroecological zone	Fodder tree or shrub	Comments
Wet temperate (>600 mm)	Tagasaste (<i>Chamaecytisus palmensis</i>)	Leaf dry matter is about 24% crude protein
	Honey locust (<i>Gleditsia triacanthos</i>)	Pods fall in autumn, 20–30 kg per tree, providing 17% protein, 60% carbohydrate and 7% fat
Dry temperate (300–600 mm)	Tagasaste (<i>Chamaecytisus palmensis</i>)	Leaf dry matter is about 24% crude protein
	Carob (<i>Ceratonia siliqua</i>)	Pods fall in autumn, 20–50 kg per tree, providing 5% protein, 70% carbohydrate and 3% fat
	<i>Acacia saligna</i>	Leaf dry matter is about 15% crude protein
Dry sub-tropics (600–1200 mm)	Gliricidia (<i>Gliricidia sepium</i>)	High digestibility and palatability
	Leucaena (<i>Leucaena leucocephala</i>)	Moderate growth rates in areas with 800–1200 mm rainfall
Wet sub-tropics (>1000 mm)	Leucaena (<i>Leucaena leucocephala</i>)	Fast growth rates, may be attacked by sucking insects
Monsoonal (>700 mm)	Sesbania (<i>Sesbania grandiflora</i>)	High digestibility and palatability
	Gliricidia (<i>Gliricidia sepium</i>)	High digestibility and palatability

Table 5:
Fodder tree and shrub species useful for quality supplements

Designing fodder agroforestry systems

Layout

There are three commonly used layouts for fodder agroforestry systems:

- rows or alleys – where rows of fodder trees and shrubs are planted across a paddock to form alleys for grazing or cropping;
- widely-spaced trees – where individual trees are widely spaced across a paddock to allow cropping or grazing in between the trees; and
- blocks – where a particular paddock or area is fully planted as a fodder reserve.

Your decision will be affected by whether you intend to cut and carry fodder from a protected plantation. You might do this if you are trying to redistribute soil nutrients (see chapter on trees for soil conservation), or if the animals are damaging your fodder plants. This can be time consuming. If animals are to feed directly from the fodder plants, you should also consider the effects of spacing on

the efficiency of foraging. You also need to consider access to all sides of each plant.

The most important consideration, though, is the influence of trees on shelter.

Fodder trees can provide shade or shelter for stock and reduce wind erosion. They will affect pasture growth too, sometimes negatively and sometimes positively, depending on species, site and distance from tree. In general, the wider the spacing the greater the amount of grass that will grow between rows. Examples of spacings are presented in Table 6 below. They are not necessarily optimal.

What species or provenance?

Criteria for the selection of species depend on your objectives. Some of the factors you might take into account are presented in Table 7.

Financial benefits and costs

The calculation of financial benefits and costs is discussed in detail in a later chapter. Some financial benefits of trees and shrubs for fodder are:

- the net change in the value of livestock output, remembering that some output is lost because of the suppression of pasture;
- the value of any sales of fodder to other consumers; and
- any other benefits expected (eg salinity control, soil conservation). These other benefits are discussed in the interactions at the end of this chapter.

Cash flow may be an important consideration. You need to estimate the time to first use – there will be no fodder benefits in this period. Calculations should be carried out over the expected life of the project – a convenient time horizon might be the expected life of the fodder plants.

Table 6:
Examples of
spacings of
fodder shrubs

Agroecological zone	Species	Spacing used (not necessarily optimum)
Sub-tropics	<i>Leucaena leucocephala</i>	Rows 5–10 m apart under rainfed conditions or 2 m apart under irrigation. Sometimes pasture grasses such as panic planted between rows
Dry temperate	Tagasaste (<i>Chamaecytisus palmensis</i>)	Rows 5–10 m apart, 1000–2000 stems per ha
Dry temperate	<i>Acacia saligna</i>	Rows 10 m apart
Wet temperate	Poplar (<i>Populus deltoides</i>)	300 stems per ha

Risk and uncertainty

Fodder trees and shrubs can reduce drought risk. They have access to water from deeper in the soil profile and may be able to obtain water for longer periods than grasses. They can therefore often supply survival feed. The danger of land degradation may be increased if animals do not die during drought, so care must be taken that in the long term providing drought feed is not detrimental to the land.

Financial risk and uncertainty may be reduced because fodder trees and shrubs supply home

grown feed, removing the need to purchase during times of high cost. If a surplus is produced it can be sold, further reducing financial risk and uncertainty.

Warning

Australia has a major problem with woody weeds. The attributes of rapid growth and ease of establishment that characterise some fodder plants are also properties of weeds.

Forage value	Financial benefits and costs	Conservation	Other considerations
Accessibility to livestock Palatability Dry matter digestibility (in vitro) >55% for supplement or maintenance; >70% as main feed or for production Energy, protein and mineral content Toxicity Quantity of annual production Seasonal variations in quality and quantity relative to animals' needs Variability between plants and over time in all these factors Ease of storage	Establishment cost Management cost Time to first use Rotation time Cash flow Complementary and competitive indirect effects Net present value compared with options	Erosion Nutrient cycling Addition of nitrogen and carbon to soil Effect on soil structure Water use for salinity control Effects on microclimate Risk of becoming a weed	Suitability to local climate and land Reliability of information on which I am making my choice. Am I pioneering, and do I want to be? Ease of obtaining planting material Can I provide necessary labour at the right times? Does it fit with existing enterprises? Persistence under browsing Riskiness (fire, disease, pests, climatic change etc)

Table 7:
Considerations in the selection of species

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Capturing benefits in addition to fodder

Fodder trees can often be economically viable when planted over a considerable percentage of the farm and thus could give significant salinity, waterlogging and soil conservation benefits. With careful design, some shelter and nature conservation benefits could also be captured.

Other benefits to capture	Opportunity	Things to look out for
Wood	Some fodder species in northern Australia also have timber potential	Management for fodder could be in direct conflict with timber production
Salinity and waterlogging	The rooting depth of fodder trees generally exceeds that of pastures giving a positive impact on rising water-tables An alley crop layout for fodder trees gives a wide spacing of trees over the landscape which is a compatible design for salinity management	Not all fodder species are tolerant of waterlogged or saline soils
Soil conservation	Belts of fodder shrubs or an alley crop design are compatible with designs to reduce wind and sheet erosion	Grazing would need to be managed carefully to reduce damage by stock
Shade and shelter	Belts of fodder shrubs or an alley crop design are appropriate designs for shelter	Heavy grazing or lopping would reduce effectiveness
Nature conservation	Strips of trees will increase habitat diversity and act as corridors for some species	Restricted choice of species reduces nature conservation value Constant livestock impact will reduce habitat quality
Scenic quality	Careful design layout can have a positive impact on scenic quality	Exotic and/or heavily grazed shrubs and geometrically shaped plantings can be visually obtrusive in the landscape, especially in foreground areas

Trees for nature conservation

Introduction

If you have decided to use trees to maintain nature conservation values in your landscape, it is important to be clear about what you are trying to achieve. The actions that you take will vary considerably, depending on your objective.



There are two broad approaches that you can take:

- the 'easy' option, which aims to 'make the landscape better' for nature conservation. This approach, sometimes called 'general enhancement', provides a wide range of general ecological principles that can be applied to your agroforestry enterprise; or
- a 'species retention' strategy. This has the more ambitious goal of keeping all of the species that currently occur in the landscape. General guidelines will not be sufficient for this task. Instead you will have to manage your landscape so that it meets the needs of the species that are there. This means knowing something about those species and any additional management which may be required to meet this type of objective.

The design principles for these two approaches differ considerably. This chapter focuses on design principles for general enhancement, as these require less knowledge about the plants and animals and are easier to apply within the context of an agroforestry enterprise.

It is not possible, within the scope of this chapter, to provide procedures for the more ambitious goal of retaining all of the species in your landscape. A brief outline of the species-retention approach is presented in the box on page 71.

It is important to remember that guidelines for general enhancement will not necessarily prevent species from disappearing from your area. These principles will simply reduce the probability of species disappearing and may reduce the rate at which they decline.

Design principles for general enhancement

Broadly speaking, agroforestry can help to protect plants and animals in two ways:

- it can provide habitat for native species to occupy; and
- it can protect existing habitat that is occupied by the species that you want to keep.

As a general rule, agroforestry is more likely to provide habitat for animals than plants, and even then only a limited suite of animals with fairly general habitat requirements will be likely to use it. The main benefits for plants and more specialised animals will be the protection of existing habitat that agroforestry trees can provide. The following principles will assist with both the provision of new habitat and the protection of that which already exists.

Vegetation structure

In general, more layers of vegetation will support more species by providing a greater range of habitats.

Try to incorporate a number of structural layers into your planting.

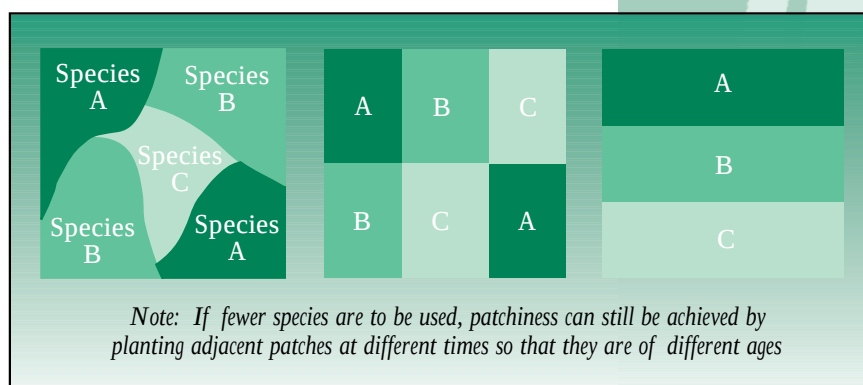
Ideally, these would include understorey shrubs, taller middle-storey shrubs or small trees, and an upper canopy of taller tree species.

Patchiness

Patchiness can be achieved by planting clumps or strips of different tree species next to each other or, where a single species is being used, by having trees of different ages in adjacent patches.

Patchiness in a landscape provides a greater range of habitats which can be occupied by more species.

As well as having a range of patch types, it is also useful to provide a number of patches of each type



(Figure 28). This means that after a disturbance such as fire or harvesting, the biota in the less affected patches can recolonise the more affected patches.

Configuration

Two important aspects of configuration include the distance between patches and the characteristics of the connecting vegetation between patches. Both of these factors affect the ability of animals to move around a landscape.

Patches that are close together and which are connected by suitable habitat are more likely to sustain populations of the species that live in them than are isolated patches.

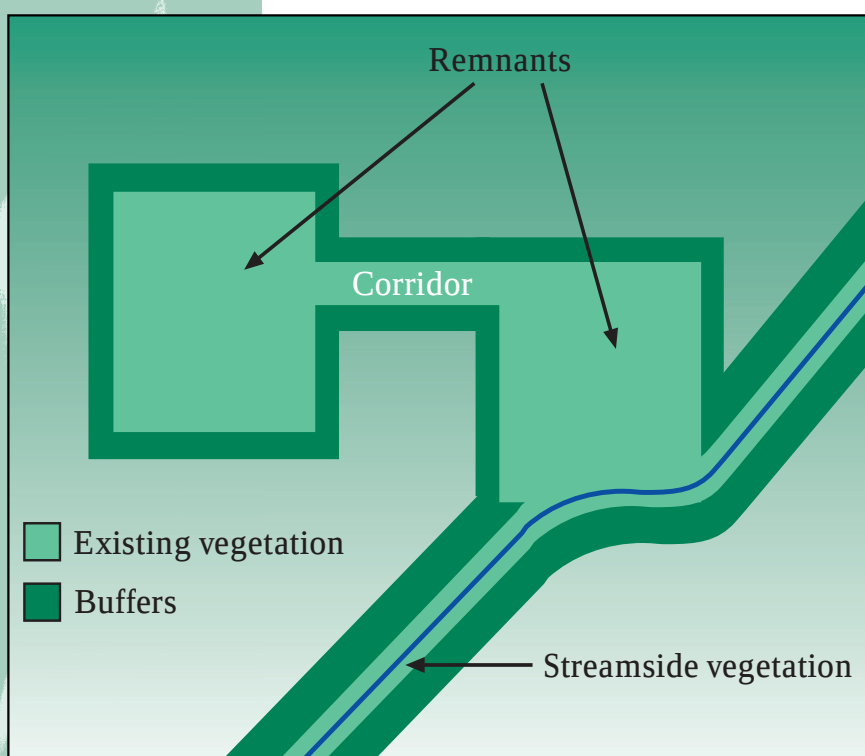
The careful planting of trees in an agroforestry system can reduce the isolation of existing remnant vegetation or can create new habitat patches, provided that they are linked to each other or to existing vegetation. Whenever possible, avoid creating corridors that lead nowhere unless they are sufficiently wide and diverse that they act as habitat for the species that occupy them.

Area

In general, there tend to be more species in bigger areas of habitat than there are in smaller areas. However, the number of species also depends upon

Figure 28: Different ways of achieving habitat patchiness using three different tree species

Figure 29:
Potential uses of
agroforestry to
protect remnants,
corridors and
streams



the patchiness of those areas. Smaller areas may support more species than larger areas if the smaller ones are more diverse.

Aim for bigger rather than smaller areas but also incorporate patchiness into the design where possible.

Shape

Long, thin remnants have much more edge relative to their area and hence are more vulnerable to degrading edge effects such as increased nest predation and weed invasion. Riparian vegetation and corridors will be particularly susceptible to these edge effects because of their linear characteristics.

Compact areas will be better than long, thin areas for providing habitat and for protection against impacts from adjoining land uses.

Patches should have the least possible edge, and linking vegetation should be as wide as practically feasible.

Buffers

Many of the recommendations listed above refer specifically to providing habitat for animals. Opportunities to conserve native plants are more limited. One obvious role is to use agroforestry to protect existing native vegetation from edge effects. Native vegetation can be protected by planting buffers of trees around the margins of existing remnant vegetation or along the edges of riparian vegetation and corridors (Figure 29).

You need to be careful that the species used are not potential weeds which could threaten the plant communities they were intended to protect.

Species selection

A general enhancement strategy tells us little about the tree species to use. The important thing is to provide the habitat attributes described above. Selecting a range of different plant species will contribute to greater habitat diversity and using local species will maximise the chances of meeting the needs of local fauna.

In general, native plants will be of more value to a wider range of animals than will exotics.

A diversity of plant species which produce fruits or flowers throughout the year will increase the diversity of animals that will be supported. If you choose to adopt a species retention strategy then the choice of species will be much more important, as they will have to meet the resource needs of the plants and animals that you are trying to retain.

Management

Many of the processes which threaten biological diversity in remnant vegetation are also likely to have an impact in an agroforestry system. For example, grazing by stock can prevent regeneration of many plant species and can modify understorey, litter and soil characteristics. These changes alter the habitat quality for numerous mammal, bird, reptile and invertebrate species.

Stock should be excluded from any areas that are considered to have a nature conservation function.

Invasion by exotic weeds can restrict germination of a range of plant species and can alter microhabitats for small ground-dwelling animals. Feral predators such as cats and foxes also impact on the native fauna, particularly small to medium sized mammals and ground-dwelling birds. Predator control is hard to achieve if your neighbours are not also controlling their pests. It may be possible to coordinate predator control with neighbours or other members of your catchment group.

Fire management may present a conflict between agroforestry and nature conservation objectives.

Fire is an important part of natural ecosystems, with many plant communities reliant on occasional fires to maintain plant populations.

Obviously fire at the wrong time will present a problem for your agroforestry trees. Consequently, if you plan to use fire as a tool for managing your natural remnant vegetation it will be important to ensure that your design enables you to protect your agroforestry products. For example, you may be able to time the fire after harvesting the adjoining trees. Fire, however, is not a conservation tool to be used haphazardly and should only be used if there is a clear need. This may be the case if there are plants which are known to rely on fire for recruitment.

Harvesting plantation trees will obviously remove the habitat that you have previously created. If large areas are all cleared at once there is the potential to cause declines in populations of species that have occupied those areas.

Population decline can be avoided by planting trees in a pattern and at time intervals which will ensure that any harvested patch is adjacent to another patch that is not yet ready to be harvested.

Where to start

Agroforestry is likely to make the biggest contribution to nature conservation in a landscape if it is added to areas of existing conservation value.

- First identify the biggest and healthiest blocks of remnant vegetation on your property. These should form the core of your conservation network.
- Plant your trees in a way that increases the size of these blocks, buffers them from adjoining land uses and links them to other patches in the landscape.
- Consider coordinating your planning with neighbours or other members of your catchment group to link vegetation remnants on different properties.

Monitoring

How do you know if your nature conservation efforts are working?

Success for nature conservation means either that the number of species in your landscape increases, or that there is an increase in the number of individuals of the species that are currently there. In the latter case, your success would be greater if you had more of the species that were uncommon before you started than if you simply had a lot more of things that were already abundant.

Some species are easier to monitor than others. For example, it is easier to detect changes in the number of birds and plants than it is for reptiles and invertebrates. To monitor changes in bird numbers, all you need is a pair of binoculars, a field guide and a note book. Select a few different locations which you would expect to benefit from your conservation actions and visit them early in the morning for three or four days over the course of a week or two.

At each site, record the number of species that you see and, if possible, count or estimate the number of individuals of each species.

If it is a small site, you can search the whole area for birds. If it is a big area, you can walk slowly along a defined route and record what you see along the way.

It's important to visit each site a few times because bird numbers tend to fluctuate from day to day. You can then calculate an average for your counts over the three days. This process should be repeated at least once a year to detect changes from year to year or, if you want to detect seasonal changes, four surveys per year would be appropriate.

The best indicator of plants benefiting from your actions is the presence of individuals of different height classes in the area you are protecting.

If all of the trees are old then there may be a problem. Often some form of disturbance is necessary for new seedlings to establish.

Unfortunately, plant species in different areas don't all respond in the same way to disturbance so there are no general rules to apply. It will be necessary to seek advice from local conservation experts if you have this problem.

Monitoring other species is more difficult and may require trapping or searching under fallen rocks and litter. You may need permits from the state conservation agencies if you want to trap. It is best to consult with local conservation agencies if you are interested in more detailed monitoring of this sort.

Benefits and costs

Benefits

The economic benefits of nature conservation may come directly from the provision of products that can be bought or sold in the marketplace, such as cut flowers or honey, or they may arise indirectly from the contribution that conservation makes to the value of other products. Because any marketable components of our natural biodiversity can simply be viewed as a new product and assessed by conventional marketplace economics, the market value of individual species will not be addressed further here.

It is worth recognising, however, that nature conservation itself can have market value if it can be 'sold' in the form of ecotourism. This requires either the availability of extensive areas of relatively pristine natural habitat, the presence of charismatic species which are of interest to tourists, or the combination of production and native elements in a configuration that is aesthetically pleasing. Agroforestry itself is unlikely to produce these values but may help to protect them where they exist.

Indirect benefits from nature conservation may arise where increased levels of biodiversity provide a greater number of species which participate in important ecosystem processes. Increased diversity may generate more pathways through which water, nutrients and energy can flow and thereby enhance ecosystem stability under conditions of environmental variability. More diverse systems may also have a wider array of pollinators and predators which can enhance the productivity of agroecosystems.

The major benefit that accrues from increased diversity, be it biological or productive, is an increase in future options. The continued loss of species from our agricultural landscapes contributes to a reduction in these options for future generations.

Costs

Costs associated with protecting or enhancing biodiversity will include management costs, costs associated with foregone production, or costs attributable to reduced returns from other farm products.

Increasing the diversity of plants used in an agroforestry system to enhance conservation value will result in a range of agroforestry products that will have different market values at any given time. This diversity means that a proportion of the land will be allocated to some uses or species that generate lower financial returns than others. At any point in time, the total returns from a more diverse business may be less than that which could be obtained from an enterprise specialising in a single product which has a higher market value. Consequently, strategies based on a wider range of plant species may cause a decline in short-term economic returns.

However, if this increased diversity results in more sustained levels of production under fluctuating environmental and market conditions, the

Requirements for a species retention strategy

The main steps in a species retention strategy are:

- determine which species will be lost from your landscape if you do nothing
- identify the processes that threaten their persistence. These will include habitat loss, isolation, predation, grazing by stock, fire, weeds, etc
- group species according to the process that threatens them
- for each threatening process identify those species which are most sensitive to the threat
- determine the level at which that threat must be managed to protect the most sensitive species.

After going through this process, you end up with a set of species, each of which is the most demanding for different landscape attributes. By meeting the needs of these species, you should also meet the needs of all other species in the landscape. Area-limited species are used to define the minimum patch size for each patch type; dispersal-limited species define the minimum acceptable distance between patches; and 'process-limited' species define the appropriate rates or intensities of fire, grazing, weeds etc. Such an approach will obviously require a knowledge of the species in your landscape and their habitat requirements. Consequently, it will generally be necessary to seek expert advice if such an approach is to be adopted.

associated costs may decline over time. In fact, a diversity of products can provide insurance against market collapse or pest outbreaks and may return a significant economic benefit in the longer term.

If conservation actions require plant species that do not produce maximum market returns or, in some cases, may not have any direct market value, the costs of these actions must be estimated in terms of the income foregone as a result of not selecting the most productive land use.

Paradoxically, these costs and benefits may not be clear cut. Actions which may reduce economic returns in the short-term by reducing the area allocated to other productive uses may generate benefits in the medium to longer term by creating more sustainable production systems. The benefits

of protecting biodiversity therefore lie in the contribution that a greater array of plants and animals makes to achieving more ecologically sustainable agricultural systems.

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Capturing benefits in addition to nature conservation

If you have chosen to set aside land for nature conservation purposes there are many other benefits to capture. The land to be set aside could be the least productive agricultural land yet still grow adequate native vegetation to provide habitats for animals, insects and birds as well as improve the scenic beauty of the farm. This lower productivity land may have been degraded and could well be rehabilitated by shrub and tree planting. Shelter and salinity benefits could also be captured.

Other benefits to capture	Opportunity	Things to look out for
Wood	Trees planted for nature conservation can be selectively or sequentially harvested if replaced Timber trees can be planted around remnant vegetation for protection and to buffer the remnant against extreme environmental conditions	Need for structural diversity and patchiness conflicts with easy management for timber plantations
Salinity and waterlogging	Tree planting for wildlife habitats can be located in important recharge or discharge areas Multiple wide strips of trees across the landscape for wildlife corridors is a design compatible with intercepting laterally moving subsurface water for salinity control	The nature conservation guideline to minimise edge effects conflicts with the benefit of spreading trees out across the landscape for the purpose of using more water
Soil conservation	Strips of trees planted as wildlife corridors could be effective against sheet erosion Native species may be the best option for degraded paddocks or eroded areas where agricultural productivity is low	Degraded areas may produce poor growth of natural vegetation Native vegetation may need to be managed with fire
Shade and shelter	Trees planted for nature conservation will give shelter to stock, pasture or crops in surrounding paddocks Wildlife corridors will act as shelterbelts	Fencing (to keep stock out) may be required to maintain high nature conservation value
Fodder	Planting a mix of warm and cool season species to provide reliable fodder supplies will potentially enhance wildlife habitat diversity and hence resource availability	Constant livestock impact will reduce habitat quality Some fodder species have the potential to become weeds and invade remnant vegetation, thereby diminishing its conservation value
Scenic quality	Conserving or reconstructing native vegetation will always add scenic quality to the landscape	Planting for nature conservation and scenic beauty are never in conflict

Trees for scenic quality management

Introduction

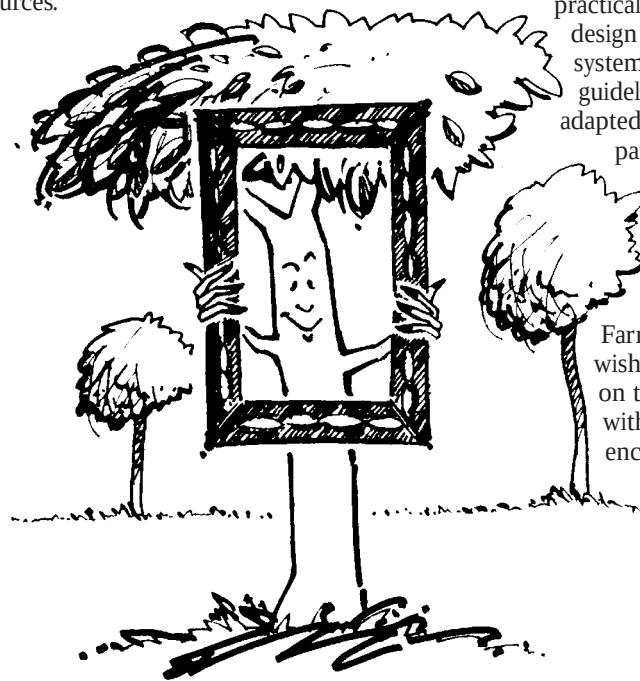
Agroforestry systems are fast becoming major features of Australian rural landscapes. Their type and placement in the landscape can significantly improve a farm or catchment's scenic value or, conversely, degrade it.

Often, scenic improvements can only be achieved if suitable landscape designing is integrated into the overall agroforestry planning process. Failure to do this may cause unacceptable levels of social, environmental and economic impact whilst reducing the potential multiple use value of agroforestry resources.

From the outset, it should be noted that the management of scenic quality on farms must follow sound ecological design principles and is usually site specific. Whilst farm landscapes can be appreciated as large 'gardens' they should not be designed to significantly compromise conservation requirements of the wider catchment environment. Often, the aesthetic character of farms can be simply and creatively managed as a designed by-product of tree planting for wildlife and soil conservation, salinity control, shelter, fodder, and windbreak and timber production requirements.

The aim of this chapter is to provide a general, practical background to the landscape design requirements of agroforestry systems. The design principles and guidelines presented have been adapted from various works, in particular Revell (1994), Van Pelt (1980) and Crowe (1978). Details of these publications and others are provided as further reading at the end of the chapter.

Farmers and land managers who wish to obtain more information on this topic and who are working within sensitive landscapes are encouraged to seek further assistance from qualified landscape architects, environmental designers and/or land conservation agencies working in your farming region.



The what, why, how and when of scenic quality design

Here are the most commonly asked questions (and the answers) to the needs and practices of scenic quality management of agroforestry landscapes.

What is scenic quality management?

Scenic quality management is a positive and integral component of agroforestry planning and management processes. Its prime goal is to ensure that all agroforestry uses and activities are planned and implemented so as to complement rather than detract from the inherent visual qualities of the environments in which they occur.

Why should we design for scenic values in agroforestry management?

The Australian countryside has a wide range of visual qualities. As a part of multiple resource land management farmers are often committed to sensitively managing such landscape scenic qualities. Some areas are scenically outstanding, and there are others that are severely degraded and are major visual blights on the landscape. When tree planting areas are selected, planned and designed, established and harvested, such landscape scenic qualities should be taken into account. With proper planning, we can visually protect, maintain, or enhance natural or cultural landscapes with tree plantations.

When is a farm landscape scenic?

Scenic qualities vary from district to district depending upon such factors as landform, vegetation, waterform and landuse patterns. As a general rule, scenic quality increases with:

- greater degrees of uniqueness in rock outcropping, water and other natural features;
- greater degrees of naturalness and lesser degrees of human alteration;
- greater degrees of relative topographic relief and ruggedness;



- greater degrees of vegetation diversity and general landscape variety;
- greater degrees of naturally appearing transitions between open agricultural landuses and adjacent forested land; and
- greater degrees of vegetation mixture (species, age, height and/or density) and edge diversity in plantations.

Landscape appreciation should also consider the position and numbers of viewers – both public and private. Generally speaking, scenic views from major travel routes or look-out areas are more visually sensitive than from the ‘back-blocks’. However, local communities or individual farmers may insist that their landscapes be as sensitively managed as the more populated and visited areas of the countryside.

Classifying farm areas into ‘scenic importance zones’ and whether they are seen in the foreground, middleground or background from prime viewing locations will help determine management priorities and attention to planting design detail.

Scenic agroforestry setting with a mixture of exotic pine and native vegetation cover

When does a landscape become scenically degraded?

Scenic degradation is usually due to changes in landscape naturalness. Examples include over-clearing, excessive planting, over-grazing, soil erosion, poor paddock design, the construction of buildings, roads, dams and other structures and the impacts associated with mining, harvesting, fire and disease.

The scenic significance of tree planting and management

The following aspects of agroforestry need to be considered for their scenic significance:

- plantation planning – location, scale, species selection, age class, etc;
- planting boundary definition – are plantation boundaries straight or curvilinear?
- fire protection – are firebreaks straight, curvilinear, mown, slashed, or bare-earthed? Do they become major focal points?
- spraying – if possible, select a time when vegetation colour contrasts are minimal;
- thinning and subsequent vegetation debris management; and
- harvesting – location, scale and shape of harvest area. Gaps should reflect the open space patterns of the surrounding landscape. If necessary, use harvest sequencing techniques to avoid major vegetation cover contrasts.

Major landscape design principles and guidelines to consider

Design principles and guidelines for background scale landscapes

The scale of the plantation should reflect the scale of the surrounding landscape. For example, large

open valley type landscapes can accommodate a greater area of plantation establishment and harvest area than smaller ones. Scale impacts can be minimised by separating plantation areas with existing vegetation or by creating cells of varying age classes.

Patterns of the plantation areas should reflect or imitate surrounding landuse patterns.

Plantation design should, where possible, follow existing landscape lines – treeline, roadline, fenceline, creekline, ridgeline, etc. The delineation of the plantation establishment or harvest area should respect these lines. Avoid reinforcing lines if they are incongruous with the surrounding landscape. For example, in a landscape setting which predominantly exhibits free-flowing lines, avoid breaking skylines and reinforcing property and fencelines that are geometric in nature.

Plantation access roads and firebreaks should be of low visual impact, preferably screened, with alignments following contours, existing road patterns or vegetation lines as opposed to artificial property boundaries.

In visually sensitive areas, potential plantation impacts can be reduced by enhancing and extending existing vegetation areas with similar species plantings. These plantings could be protected from future harvesting, optimising wildlife, soil, water and recreation values. If harvested, the sequence and timing of cut should be separate from the main plantation harvest schedule.

Design principles and guidelines for middleground scale landscapes

At this scale, middleground areas dominate the landscape. The local appreciation of ridges, valleys and plains is offered. In comparison to background scale plantation areas, the whole plantation is unlikely to be viewed at one time. Perception of detail increases, colour and texture replaces shape,

and pattern and line become the major visual or scenic elements.

The outline of the plantation area at this scale should be defined by gullies, spurs and ridges and borrow from the lines offered by the surrounding landscape. Plantation areas should be defined as individual units broken up by ridges, drainage lines and dominant landuse patterns.

Avoid over-reinforcing areas of maximum visual contrast such as treelines, skylines, vegetation changes, etc. Ensure that such contrasts are reflecting other contrasts (if present) in the surrounding landscape. For example, in 'natural' settings, edges of vegetation change can be softened by sympathetic boundary lines, gradual changes in density or age class across the interface or with the use of species of different form, colour and texture.

For skyline edges, maintain ridges with species typically dominant within the surrounding landscape. For example, avoid pines in a hardwood forest setting. If pines are necessary then locate them below the skyline and vary age class and planting density where possible. The harvesting of ridge or skyline plantation areas should be sequenced to reduce the extent of clearing disturbance visible at any one time or to enable adjoining areas to be regenerated successfully.

The upper margins of any planted area are prominent components of the planting design. In settings of a strong 'natural' character these margins should rise and point up in the valleys and depressions and fall or point down on the spurs. The upper margin should be located so that any open ground above the planting area is of sufficient size to reflect the scale of the hill cap, knoll or ridge.

The visual impacts of powerlines, transmission towers and corridors can be reduced by creating a series of irregular planting spaces. Trees can be

planted closer to powerlines opposite pylons or towers than in mid-span, while smaller trees and shrubs can be grown closer still.

Design principles and guidelines for foreground scale landscapes

At this scale, foreground areas dominate the landscape. All perception of the background and middleground landscapes is lost. The microscale dominates with occasional glimpses extending to the middle and background areas. The observer is virtually in the plantation or revegetated landscape. There is total perception of details of individual trees, their colours and textures, their diversity or uniformity. Visual change to the plantation is most easily detected at this scale. These plantation landscapes require a high degree of scenic quality management throughout all stages of the plantation program.

Follow the visual expression of the surrounding foreground landscape. Avoid contrasts to these details. For example, in a uniform, colourful patchwork, geometric, foreground agricultural landscape setting the visual character of an exotic, regimented-looking belt of blue gums or pines could enhance the local landscape.

In 'natural', non-uniform settings encourage diversity through the physical separation of plantation sections or compartments. These areas may differ with age, species mix, planting density or thinning regime.

Maintaining visual penetration through the plantation can enhance visual quality of the plantation landscape. This can be achieved by an open or clumped planting density or through thinning techniques. In 'naturally' appearing landscape settings, thinning regimes should be non-uniform. Conversely, in geometric or culturally dominated landscapes thinning regimes should be regular and uniform.

Access tracks and firebreaks should be designed and constructed with low visual impact.

Within sensitive areas, avoid visual impacts created by plantation debris or slashed material. Reduce impacts by screening, burning, mulching or scattering debris away from seen areas.

In visually sensitive areas, harvest areas should be of minimal size in relation to the overall plantation landscape. Felled areas should not dominate over unfelled areas.

In visually sensitive areas, employ harvest sequencing techniques. Near-roadside vegetation, for example, can reduce the visual impacts of adjoining harvest areas. Final harvesting of near-roadside vegetation should take place after surrounding coupe areas have been regenerated or replanted and have grown to become a strong visual element. Near-roadside vegetation could also be treated as multi-aged stands and harvested sequentially within themselves.

The essential steps in the scenic quality design of agroforestry landscapes

In summary, the major steps to follow in the scenic quality design process are:

- observe the plantation landscape setting. Take some time to see and appreciate the visual character of the surrounding landscape. What are the local, district or regional scenic attributes or features of these landscapes? Try mapping these features on suitably scaled topographic maps and aerial photographs. Try to identify any patterns in landform, hydrography or vegetation cover;
- ask yourself – will the proposed tree planting maintain, enhance or have a negative visual impact on these natural or cultural landscape features? How will the planting area look in 5, 15, or 30 years time? What impacts will the plantation have on major private or public views and vistas of the landscape during all establishment and harvest periods?
- are there any other local community landscape design ideas and aspirations that should be respected?
- how then can the planting area be planned and designed to accommodate such scenic quality considerations?
- refer to guidelines and principles noted above;
- prepare preliminary planting design plans and prescriptions to suit integrated agroforestry management objectives and share these with neighbouring property owners/residents; and
- in scenically sensitive areas, maintain a landscape evaluation and monitoring program. Take periodic photographs and monitor public and private feedback.

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Capturing benefits in addition to scenic qualities

If you have chosen to plant trees to enhance the scenic beauty of the farm, nature conservation benefits are the easiest next benefit to capture. With careful design, shelter, timber and soil conservation benefits can also be captured.

Other benefits to capture	Opportunity	Conflict
Wood	The need to maintain and improve scenic quality may require alternative and creative silvicultural and harvesting practices but these need not affect economic output	Visual impacts of standard silvicultural prescriptions and harvest operations can lower scenic quality
Salinity and waterlogging	Appropriate tree species planted around discharge areas for management of scenic quality could help stabilise these areas	Poor tree growth and potential death in discharge areas will reduce scenic quality
Soil conservation	Good planting locations for the purpose of scenic quality often coincide with good locations for soil conservation (vegetation along valleys, ridgelines, streamlines and around water bodies and discharge areas)	A desire to locate tree planting in harmony with natural landscapes may be in conflict with areas most in need of conservation management
Shade and shelter	Planting locations for scenic quality are likely to be compatible with locations requiring shelter	A need to locate tree planting in harmony with the natural landscape may be in conflict with optimal windbreak position and layout
Fodder	With careful choice of location and layout, fodder species could be used to improve the scenic quality of the farm	Exotic and/or heavily grazed stands can be visually obtrusive in the landscape, especially in foreground areas
Nature conservation	Planting for scenic beauty gives the opportunity to add to, protect and link remnant vegetation	There is no conflict between planting for nature conservation and scenic beauty

Capturing multiple benefits from agroforestry

Introduction

Trees have been cleared from the Australian landscape in the past because they competed with crops and pastures for light, water and nutrients. Will the same happen again if we put the trees back? Agroforestry design is about getting the right number of trees, of the right species, into the right parts of a catchment. It is about maximising all the benefits of trees and minimising the disadvantages. Careful design is paramount.

Growing trees is different from other farm enterprises because a tree exerts an influence for a considerable distance and/or depth away from where it is planted. For example:

- trees explore layers of soil 1–5 m or more below the rooting depth of annual crop and pasture species and thus recycle water and nutrients that were 'lost' from the traditional agricultural system;
- tall trees may shade or compete for water with crops growing tens of metres away;
- trees can reduce wind erosion or modify microclimates hundreds of metres away; and
- trees can extract water from shallow water-tables that may have risen as a consequence of rain falling thousands of metres away.

Reasons for planting trees

The preceding chapters have covered the major reasons why a farmer may start to plant trees. We recognise that a farmer will have some main purpose (trigger) in mind for planting trees but there will often be secondary benefits that can be obtained. We call this 'capturing multiple benefits' and it is important to the success of any agroforestry venture.



Capturing multiple benefits from agroforestry

Broadly speaking, the four main reasons for planting trees are as follows:

- **new product diversification:** tree products such as wood, pulp or oils provide new income streams to buffer against the cyclical downturns in the profitability of other farm enterprises. In this case the trees are planted for their direct cash value;
- **enhancement of existing enterprises:** agroforestry can increase the productivity of a traditional pasture-based enterprise through, for example, the provision of shelter for animals or fodder shrubs to fill a seasonal feed gap. Other examples include windbreaks to protect crops or tree planting to alleviate waterlogging in low-lying paddocks. In this case, the primary value of the tree is in adding value to some other enterprise rather than the direct value of the tree itself;
- **resource protection:** the resource base (quality of the soil and water resources) of the farm must be protected and enhanced so that traditional farming enterprises can survive long-term. Trees may be planted to address wind and water erosion or salinity. In this case, the primary purpose of planting trees is to ensure the long-term viability of some other enterprise; and
- **conservation and beauty:** trees add horizontal and vertical structure to the landscape and provide new niches for other plants and animals. Trees can be planted to buffer remnant vegetation, to provide wildlife corridors, and to make the landscape more pleasing for human habitation.

Designs to capture multiple benefits

The skill of agroforestry design is to identify the main reason for planting trees and then to capture as many other benefits as possible. For example,

the trigger for planting trees may be the need to diversify into a new product and hence the establishment of a plantation of sawlog trees. This plantation could also use up excess water and therefore give a salinity benefit (resource management) as well as provide shelter to an adjacent wheat paddock from damaging winds (enhancement of existing enterprise). Tree planting for sawlogs may be only marginally profitable, but the extra benefits of resource management and enhancement of crop growth could make the enterprise well worth the investment.

The location, size, shape and orientation of the sawlog plantation will determine how much of these 'extra' benefits are achieved. For example, it may be possible to change the layout of a plantation to get a greater windbreak benefit. But there are always limits. A long, thin plantation may incur management costs such as pruning which will outweigh the benefit of more wind protection.

Once the trigger for planting trees has been identified, two questions arise:

- how flexible are the design criteria to achieve my primary objective? and
- how can I modify the planting design to capture other benefits but still achieve my primary objective?

In general, the design becomes more flexible when you are planting large areas of trees. If, for example, you have a market for wood products and 20% of the farm will eventually be planted to trees, there is ample scope for capturing benefits of resource protection, enhancement of existing enterprises and nature conservation. Conversely, it is possible to get adequate shelter protection on the farm with as little as 5% of the land area planted to trees. In this case it would be difficult to capture many other benefits with such a small planting.

Competition and complementarity

Trees are in competition with crops when both species are struggling to get as much as they can of a limited resource. An example is the poorer growth of a crop near a tree during a hot dry spring or summer. Although trees do have access to water much deeper in the soil than crops, the water held in the topsoil is used first. In this case, trees and crops are in direct competition for surface water, and the tree generally comes off best. In addition, trees that use water during the fallow period between successive crops will reduce the amount of water stored in the soil for the crop at planting. Competition can be above ground too. Shade can be beneficial during summer but is likely to be a problem with winter crops, particularly in higher latitudes.

But competition is only half the story. Trees, crops and pastures are often complementary to each other and that is what most of this book is about. Complementarity occurs when a mixture of trees and crops or pastures on a farm is more productive than either trees or crops alone. Trees and crops are complementary when:

- there is greater capture of a limiting resource – for example, trees can use more water than crops by virtue of spatial (deeper rooting habit) or temporal (using rain that falls in summer in a paddock growing winter crops) complementarity. There may also be a functional complementarity – for example, some trees can extract phosphorus from low P soils or fix atmospheric nitrogen and make these nutrients available to crops through the litter;
- the limiting resource is used more efficiently – for example, in the lee of a windbreak, crop productivity per unit water used can be higher. Similarly, the productivity of animals per unit

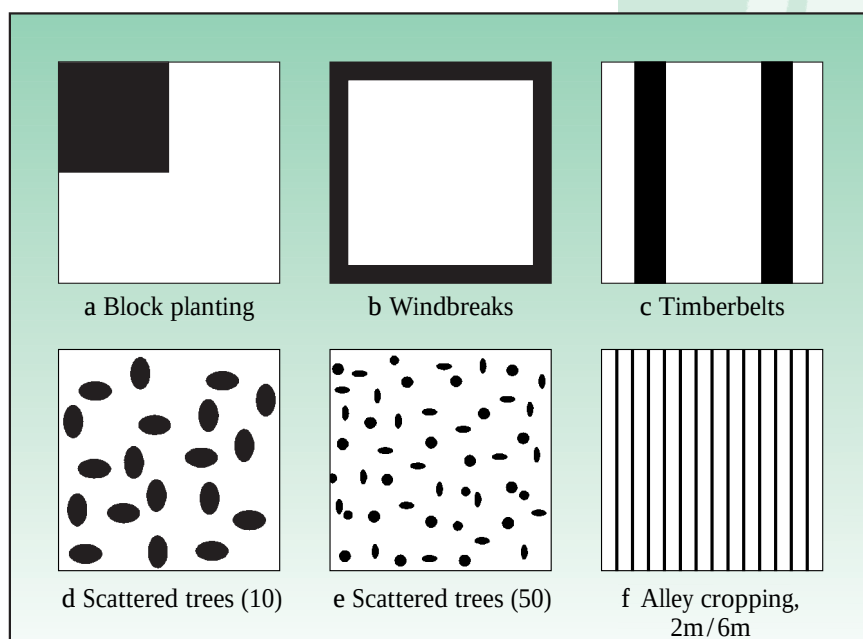


Figure 30: There are a number of different ways to put one quarter of a paddock (or farm) under trees. Above are six examples, from block plantings to belts to scattered trees (redrawn from Young 1987).

Agroforestry practice	Design	Tree/crop interface (m per hectare)
Block planting	block 50 x 50 m	200
Windbreaks	Belts, 6.25 m wide	750
Timberbelts	2 belts, 12.5 m wide	450
Trees in field	10 trees, radius 8.9 m	560
Trees in field	100 trees, radius 2.8 m	1770
Alley cropping	Rows: 2 m tree, 6 m crop	2500

Table 8: The length of the tree/crop interface for six arrangements of planting 25% of land to trees

Figure 31: Three scenarios showing the productivity of trees and crops along a tree/crop interface: (a) trees growing adjacent to a cereal crop; (b) trees growing adjacent to a perennial pasture; (c) deciduous trees growing adjacent to a winter crop (redrawn from Young 1987)

feed consumed can be higher if the animals have protection from adverse weather; and

- the trees protect a crop or livestock from an extreme event – such as a wild storm.

How to quantify competition and complementarity

Complementarity between trees and crops is a subtle but positive effect that occurs widely over the farm but it is often hard to measure because the benefits accrue continuously at a low level. Competition, on the other hand, is restricted to the immediate vicinity of the trees and is easier to recognise. That is why trees sometimes get bad press: it is easier to see the small area where trees

have competed with crops than the much larger area where growth may have been enhanced.

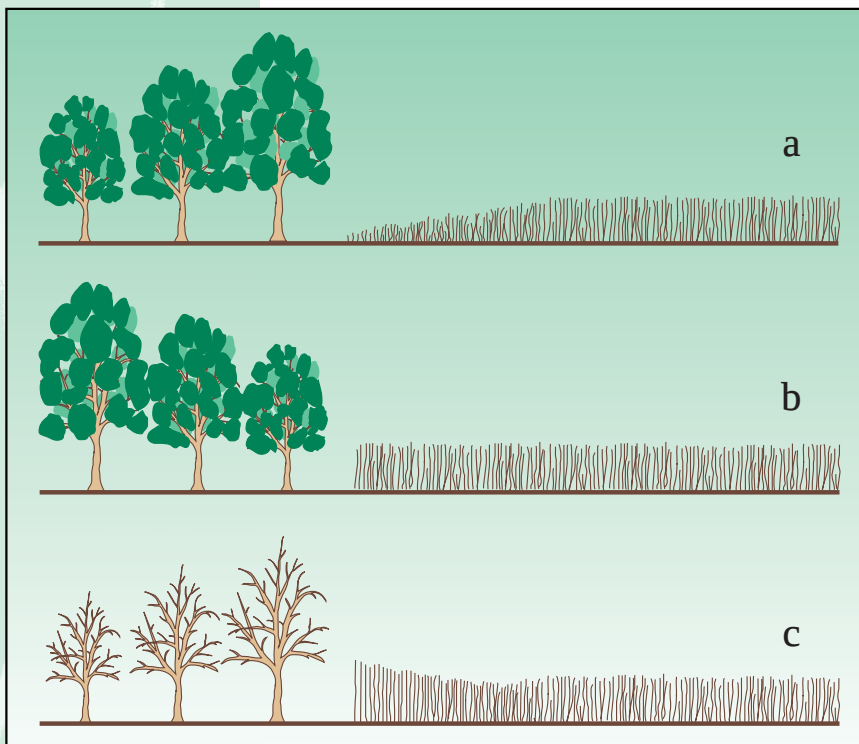
Because competition is restricted to the immediate vicinity of the trees, the degree of tree/crop competition depends largely on the length of contact between the trees and the crop. If we consider each diagram in Figure 30 to be a field of 1 hectare (100 m x 100 m), the length of the tree/crop interface (the distance along which trees and crops meet) can vary from 200 m to 2 500 m (Table 8), for the same area of land occupied by trees. Thus our first guess would be that competition is minimised by having a short tree/crop interface length – that is, block planting would be less competitive than scattered trees.

What happens when trees and crops meet?

The length of the tree/crop interface is not the end of the competition story. Just as important is the productivity of both the trees and crops at the interface, as shown in Figure 31. Case (a) shows an annual cereal crop adjacent to a timber belt. In this example, crop yield is reduced at the interface because of competition for water, nutrients or light by the tree. Tree growth is enhanced because of access to these extra resources. At a distance of 2 to 10 times the height of the trees away from the treeline, yield may be higher than in an open paddock because of positive shelter effects.

Case (b) shows perennial pasture adjacent to a timber belt. In this case the deep-rooted pasture is little affected by the trees, but the economic value of the trees may be lower at the edge because of increased branching.

In Case (c), both tree and crop growth are enhanced at the interface. This is a rarer event but can occur where the tree and crop growth cycles and hence demand for resources are out of phase (eg deciduous trees growing adjacent to a winter crop) so that only the beneficial interactions are expressed in each season.



Case (a), yield reduction close to trees and yield enhancement further away, is the most commonly observed scenario to date, but as we gain more understanding of tree/crop interactions it is likely that we will uncover more situations similar to Case (c).

The principle for maximising productivity is as follows: if the interaction at the tree/crop interface is negative, then we should minimise the length of the interface. However, we often plant trees to enhance existing enterprises (eg windbreaks), resource management (eg control of water-tables) or nature conservation (eg wildlife corridors). In these cases we may need to spread the trees out. Thus there is a fundamental tension between tree and crop monocultures – which make management easier – and the need to spread trees out to capture other benefits. Once we have a feel for what happens at the tree/crop interface we can find compromises between keeping the trees in blocks and spreading them out.

Balancing productivity and resource management

Balancing the need to be productive with the need to maintain the quality of soil and water resources is the greatest challenge facing farmers in Australia. We can try to reach this balance in two steps. First, we concentrate on issues that affect productivity and, second, we look at issues of resource management or sustainability.

Step 1: Productivity

We can explore the productivity of an agroforestry system by looking at an example of wheat growing in alleys between rows of tagasaste (Figure 32). The tagasaste displaces wheat from part of the field and this represents a loss of income to the farmer. The tagasaste may also decrease the yield of the wheat growing close to the tree line.

On the positive side the tagasaste may increase the growth of the crop further away because of a

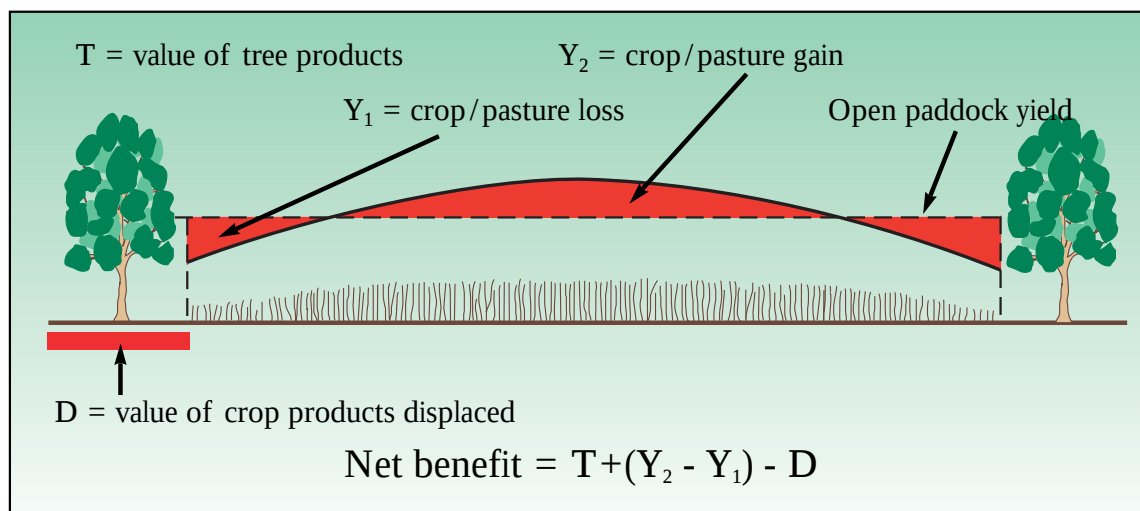


Figure 32: Tagasaste displaces wheat from part of the paddock, and may decrease wheat yield close in and increase it further out. It also provides fodder during the autumn feed gap. The net benefit of the agroforestry system depends on the balance between the above factors (redrawn from Lefroy and Scott 1994)

reduction in wind speed. The tagasaste also has a value of its own as a feed source during the autumn feed gap. If the value of the fodder plus the enhanced microclimate effect exceeds the costs of establishment, crop displacement and competition, then alley cropping wheat plus pasture will be a more productive wheat/sheep farming system than monocultures of wheat and annual pastures alone.

Step 2: Resource management

There will be times when the net short-term benefit (productivity) of the agroforestry system is the same as or even less than that of the conventional system. Then we have to decide on the value of the trees (or the tagasaste in the above example) as a means of resource management. The trees may be helping to keep a water-table down. This will not give a productivity increase in the short term but over the long haul may ensure that cropping can continue. Similarly, the trees may be stopping erosion or providing habitats for other plants and animals. These benefits are much more difficult to put a dollar value on, but will often tip the scales in favour of agroforestry.

Case studies

Following are examples where agroforestry has made a difference in both productivity and resource management. The examples highlight how agroforestry can capture multiple benefits when carefully designed for particular problems and locations. These case studies are not exact representations of particular farms but are drawn from experiences that are showing promise around the country.

Case Study 1

Location:
southwest Western Australia
First trigger for planting trees:
reclamation of waterlogged paddocks

Additional benefits captured:
timber, nature conservation, windbreaks

In southwest Western Australia, wheat and lupins are grown in rotation with annual pastures. The climate is strongly Mediterranean, with almost all the annual rainfall occurring within the six winter months. Early in the rainy season, when the leaf area of annual crops is low, rainfall generally exceeds crop water use. Soil becomes waterlogged when water piles up above a soil layer (usually clay) which has a very low permeability. This is called a perched water-table. Often the water-table of a whole region rises. This is a more serious problem than a perched water-table, because water-tables that were deep but have become shallow after tree clearing are often salty.

Waterlogging is usually first seen in low areas on the farm, although certain landscape features can make 'wet spots' show up in unexpected places. In this example, the farmer noticed that two low-lying paddocks were becoming severely waterlogged in winter and remained boggy right through the summer months as well. The farmer knew that water was moving down the slope to the waterlogged area, so he set about planting trees upslope.

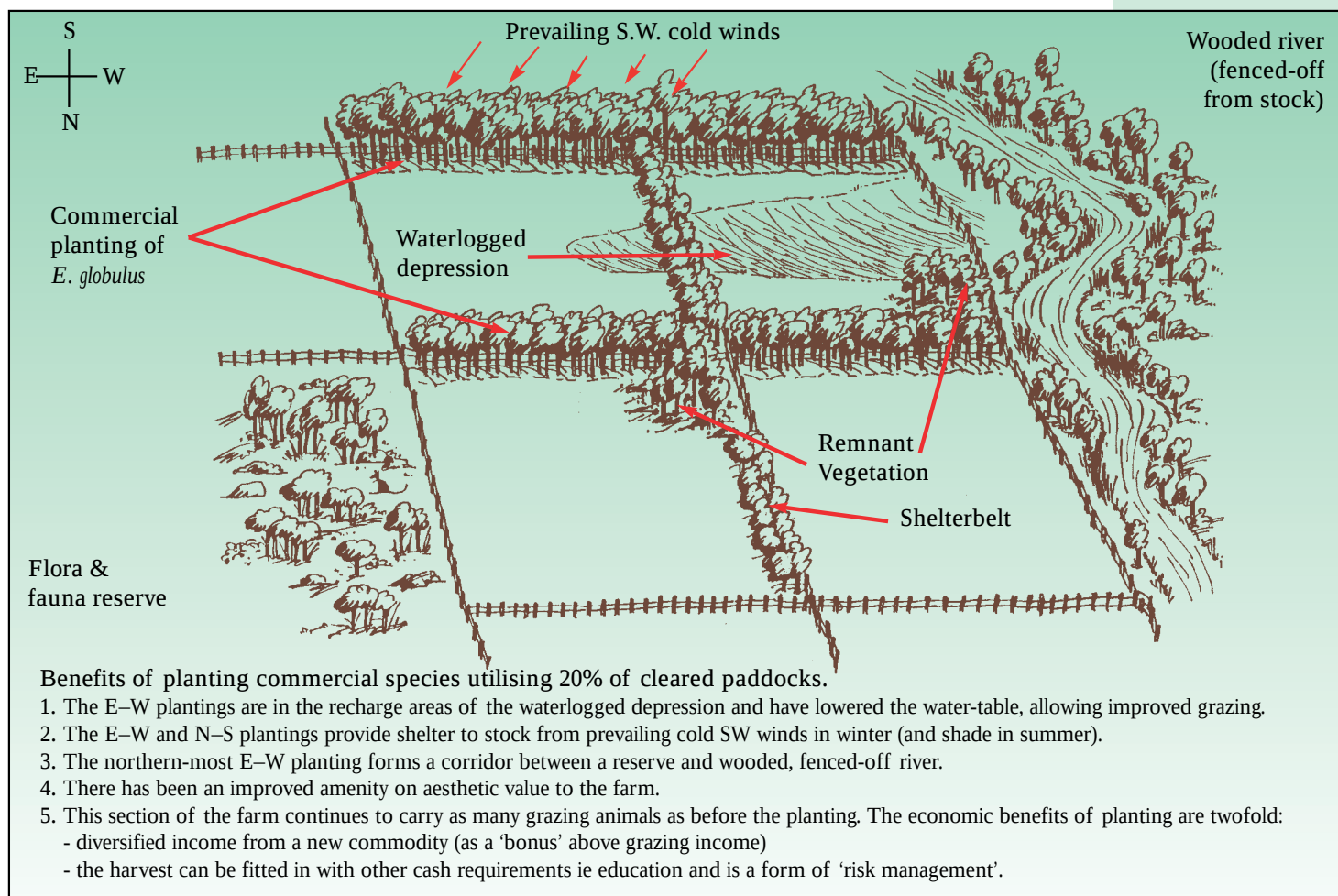
Waterlogged pasture is unproductive, so the trigger for planting trees was to reclaim the affected paddocks. Intuitively the farmer knew that quite a large area of trees would be needed to control the problem. He didn't know how many, but reasoned that if he was going to plant a number of trees he should manage them for timber. There was a blue gum industry close by, so that made the choice easy. The farmer planted the trees upslope and parallel to the depression of waterlogged land. The exact location of the planting was dictated by the existing fencelines. Another factor for the location of the timber belts was the presence of remnant native bush. There were three pockets of remnant

Capturing multiple benefits from agroforestry

vegetation in the area, each 1–2 hectares in size. The farmer knew that the best way to protect remnant vegetation was to plant trees around them as a buffer. Also, by connecting remnants with timber trees, he made corridors between the remnants so birds and animals could move from one remnant to the other.

The final tree planting design (shown in Figure 33) produced two belts of trees about 1 400 m long and 140 m wide on both sides of the depression. But one problem remained. The timberbelts were orientated east–west (because of the lie of the land and existing fences), but the prevailing winds came from the southwest. The farmer decided to plant

Figure 33:
A schematic representation of case study 1 – a farmer's solution to waterlogging, with several added benefits



narrower timberbelts in the north–south direction to give better protection to stock. The shelterbelts were much narrower than the timberbelts. They required more management because trees at the edges required more pruning but could be managed and marketed together with the main timberbelts.

The waterlogged area is now disappearing. The farmer ended up putting 20% of his land to trees. He may have been able to do the job with fewer trees but he is unconcerned because he may well make more money from the trees than from the reclaimed paddocks. His carrying capacity on 80% of the land is the same as it was when he could graze the whole farm because the waterlogged areas have been reclaimed and the stock are more sheltered. In addition, remnant vegetation has been protected and nature conservation value enhanced. Some uncertainties remain; if the water-tables are salty, the salt might concentrate under the trees because trees only use fresh water and leave the salt behind. But for now the tree planting strategy is working extremely well.

Case Study 2

Location:
central Queensland

First trigger for planting trees:
fodder for cattle during dry periods

Additional benefits captured:
soil fertility, soil conservation

In parts of central Queensland there is no reliable annual forage legume, particularly on the heavier clay soils. *Leucaena leucocephala* is a shrub legume that produces both high biomass and high quality forage. It has also proved itself to be drought tolerant during years of below average rainfall.

The farmer's trigger for planting leucaena was to provide fodder for cattle, especially in periods of drought. Opportunity cropping was also carried out on the farm; sorghum in summer and wheat in

winter, depending on the availability of stored water. The farmer had heard about alley farming from the southern states and Western Australia where crops are grown between rows of shrubs such as tagasaste or saltbush, and wanted to try cropping between strips of leucaena.

Leucaena could also play the role that annual legumes play in a conventional rotation. The idea was that nitrogen from the leucaena would be distributed over the whole field by grazing cattle when no crops were being grown.

Leucaena is usually planted in rows 5 m apart when grown for cattle fodder. The farmer increased this width to 30 m so that there would be enough space to get the agricultural equipment between the tree rows. A leucaena paddock must be locked up for up to 12 months after sowing. This is usually a considerable disincentive, but as it was possible to crop between the rows this was no longer an issue.

The paddock chosen for the leucaena alley cropping was on a slight slope which eroded during heavy rain. Thus the farmer planted in strips along the contours. The leaf fall from the leucaena and weed growth under the shrubs formed an effective barrier against overland flow of water and hence helped limit erosion.

The farmer chose the site for planting leucaena carefully. The prime cropping soils on the farm were too valuable to be taken up by leucaena – fertilising soils was a better option for nitrogen management. However, on the less fertile sloping soils the leucaena played multiple roles. It provided a high quality fodder bank, allowed the option of cropping when water was available, provided some nitrogen input to the crops and gave some control over erosion. This multiple role was important, as planting leucaena for any one of the above reasons alone would not have been economic.

The farmer is aware that there will be some competition between the leucaena and the crops for

Capturing multiple benefits from agroforestry

water and other resources and that no one is quite sure how serious the competition will turn out to be. However, the relative importance of drought fodder compared to the amount of grain that could be grown on these poorer soils means that it was worth taking the risk. If necessary, the farmer will use the management option of ripping the tree roots at the edge of the treeline before sowing crops.

Nearby graziers have tried a completely different approach to improving the profitability of their enterprise. Instead of planting trees they have found benefits in conserving existing natural vegetation. The family were busy with the expensive business of clearing brigalow country. To cut down on expenses, they decided to clear strips 50 m wide and to leave 50 m strips of brigalow standing. They were amazed to find that the productivity of paddocks that were half-cleared was similar to fully cleared paddocks. This example shows that you do not have to plant trees to be successful in agroforestry. Encouraging natural regrowth or partial clearing of timbered country are important options.

Case study 3

Location:
southern Victoria

First trigger for planting trees:
management of an eroded creek

Additional benefits captured:
timber, shelter, nature conservation

The family farming this sheep and cattle property in Victoria had decided to embark on a new whole farm plan. This involved re-fencing land classes and management of the eroded creek which had become an unsightly gully right through the middle of the farm. There were several soil types along the creek, from areas of heavy clay which became waterlogged and were prone to slumping to sandy banks which were eroded by cattle where they

gained access to the creek for water. The local landcare group, of which the family was an active member, decided something needed to be done about the eroded creek because of its importance to the catchment as a whole.

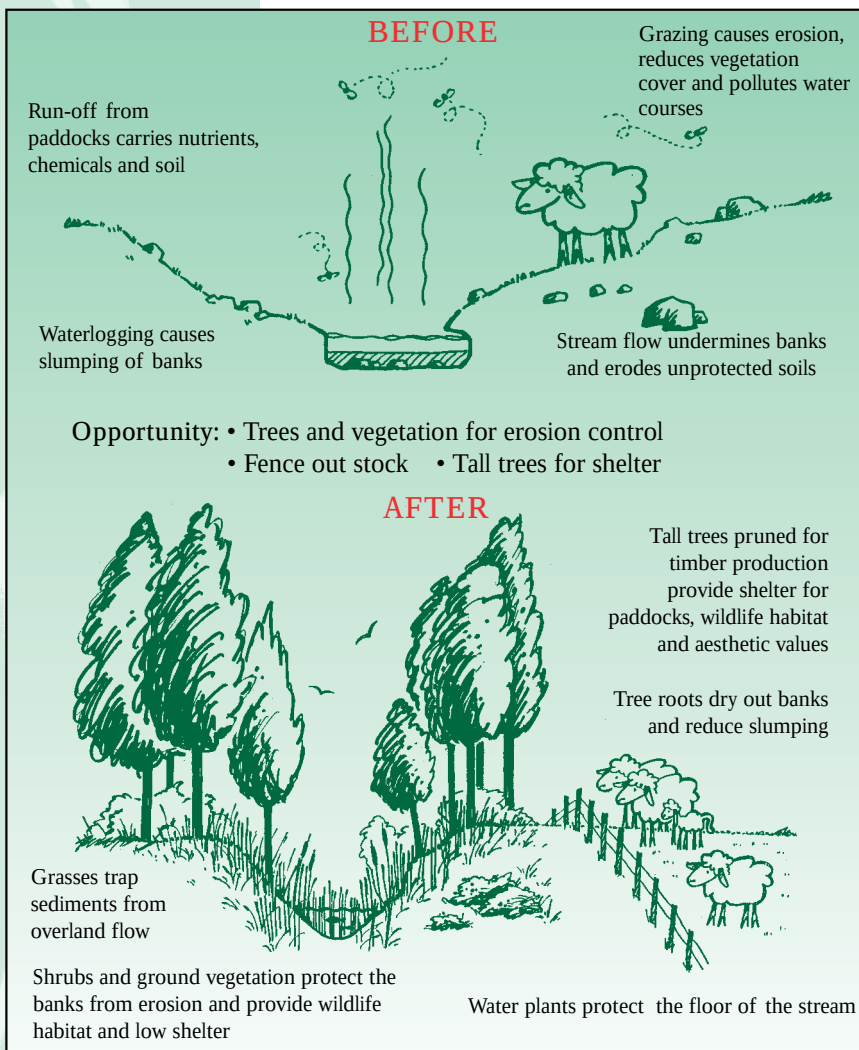
A grant was obtained that would pay for the creek to be fenced off. This was the impetus that opened up a whole range of possibilities. The first objective of preventing cattle access to the creek was easily reached, especially as there were alternative watering points. The next objective was to address the 'wet spots' along the creek bank. In these areas the fence was moved much further back from the creek so that trees could be planted in the hope that they would use the extra water.

Fencing took care of the underlying problem, but the now-vulnerable creek banks required stabilisation. The choice of species was important. The family needed something that would quickly cover the eroded banks but would not grow in the water itself and choke the flow of the creek. They chose an indigenous multi-stemmed shrub for the steep banks because this shrub had the ability to withstand being undermined and rapidly re-suckered from its roots. Other indigenous tree and shrub species were also used along the bank. A particular favourite was *Bursaria*, which is an important source of nectar for the parasitic wasps that feed on pasture grubs. Grass was used on gentle slopes and rushes and water plants in the creek bed itself (Figure 34).

Once the bank had been stabilised there was the option of using the fenced-off land on either side of the creek more creatively. Shelter and shade were obvious needs, particularly from cold winter winds for the shorn sheep and for cattle from the summer heat. Trees planted along the bank would provide shelter and had the advantage of not concentrating cattle in just a few areas of the paddock during harsh weather. The pasture too could benefit from the protection that trees

Capturing multiple benefits from agroforestry

Figure 34:
Stabilising the
creek has a number
of benefits



The family was keen to diversify farm income and evaluated the possibilities of harvesting the tall windbreak trees. Their calculations showed that quality sawlogs should be viable. This option presented a few challenges. Trees in a thin strip would not self-prune as in a plantation, so manual pruning to 6 m was required. Pruning let the wind through and reduced the shelter benefit, but this was compensated by the thick bush planted adjacent to the creek. Of course, a continuous harvesting and replanting schedule would be needed to combine windbreaks and timber. The family intends to alternate the timber harvest from one side of the creek to the other to ensure that there is a continuous standing windbreak. The family hope to recoup much of their investment from better pasture and animal production through shelter. They are well aware that the diversification into trees presents new challenges. The strip of native vegetation and trees along the creek could become a refuge for feral animals and weeds. Fire will be difficult to control in the area. Management and harvesting of trees close to a river will not be easy when the goal is to protect banks and improve water quality. However, these are challenges the family is willing to meet in the knowledge that they are protecting the creek, enhancing the biodiversity of the farm and have healed what was once an ugly scar on the landscape.

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Establishment

Introduction

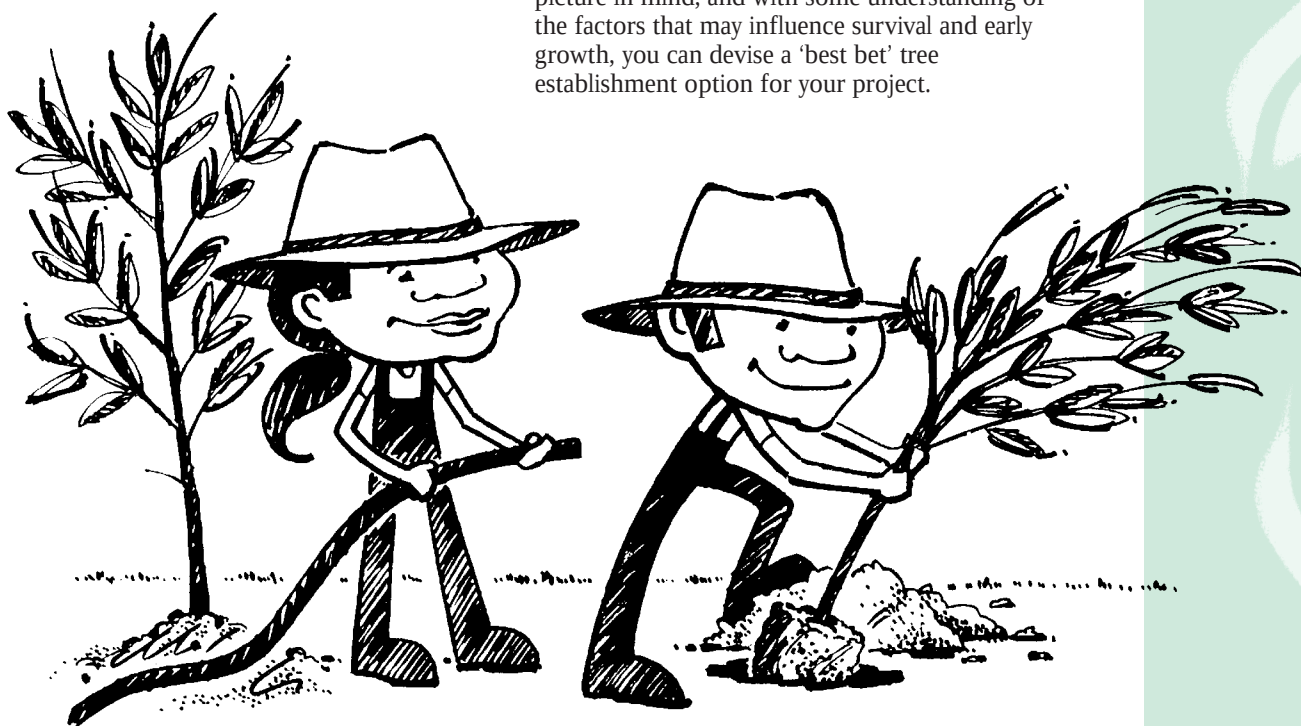
This book has highlighted many issues and we hope that you have gained a greater appreciation for the potential of making trees work for you. Many of the most important agroforestry decisions need to be made before the first tree is planted, but it is only by planting trees and getting started that you'll really gain an appreciation for the possibilities that agroforestry may offer.

How do I plant a tree?

The answer to this commonly asked question is always 'it depends': it depends on what you hope to achieve and on your skills and resources.

Try drawing a picture of what your plantation will look like in 10–20 years time, the distance between the trees and the relative size of trees of different species.

Think about how much variation in tree form or growth rate you are willing to accept. With this picture in mind, and with some understanding of the factors that may influence survival and early growth, you can devise a 'best bet' tree establishment option for your project.



Let's start by identifying some of the issues that will influence your choice.

Is the 'best' also the most 'appropriate'?

Intensive site preparation (soil cultivation, weed control, irrigation) can increase growth rates in the early years and ensure more even growth across the plantation. It is common practice in industrial forestry, for example, to deep rip and mound before planting. However, intensive site preparation is expensive, particularly for small areas or difficult sites.

Before simply copying the methods for site preparation used by other growers, landowners need to decide whether intensive preparation is really necessary.

For some plantation types, uniformity of growth is a critical requirement to ensure even log size and branch control. For many other purposes, including many commercial ventures, uniformity and maximum early growth rates are not so critical and the 'best' option may be to save some money on the establishment costs by doing the minimum required to achieve acceptable results.

Limiting factors

The key to determining the most appropriate establishment method lies in identifying the limiting factors for your project. There are two issues here:

- what are your limiting resources – time, cash, equipment or land?
- what are the limiting factors that will influence tree survival and growth on the site?

For an investment forestry company leasing or buying land for timber production, the limiting factor will generally be land. If the company is able

to justify its investment on the basis of projected returns then funds for establishment will probably be available. Under these circumstances it will use measures such as net present value (NPV) per hectare or internal rate of return to assess options and justify investment decisions.

For a farmer looking to grow trees for land conservation, shelter and income, limiting resources are more often time and money – not land.

Having identified the areas on the farm where trees are needed, the farmer's aim is to achieve the establishment of trees within a reasonable time given limited resources. The farmer therefore needs to assess his or her options. For example, if farmers can achieve 2 hectares of established trees for shelter or land protection at the same cost as the timber company spends on one hectare, they might be happy to accept reduced growth and timber returns in return for shelter and land protection benefits.

The quality of what you plant – tree genetics

Having decided to plant a particular species you may then be faced with choosing seedlings available in a range of pot sizes or as open-rooted stock. The choice largely depends on:

- initial cost;
- site preparation;
- planting technique;
- time of planting; and
- how quickly the trees can be planted out.

Of greater importance is the genetic quality of the stock.

Within almost every tree species there is enormous genetic variability. Whether you are interested in

Establishment

growth rates, frost resistance, branching habit, flowering times or wood characteristics you may be able to select a provenance (seedlot), improved seed or even clone that has the more desirable characteristics for your situation.

The use of indigenous seed to preserve or encourage native flora and wildlife is often considered important in farm planting. Where this is not critical, landowners need to consider their genetic options.

Intensive tree breeding and clonal selection can be complex and expensive. Many industrial forestry organisations are involved in cooperative breeding programs which concentrate on the improvement of particular traits in a limited range of species.

Landowners may be able to benefit from this work if they can buy stock selected for criteria similar or compatible with their own needs.

For example, a pulpwood company may select trees of high wood density, small branches and high growth rates. For a landowner interested in the same species for sawlog production these characteristics are also desirable. The stock may be more expensive but this needs to be considered in the light of better performance and, possibly, the need to plant fewer trees initially to ensure a good stand.

Be aware of what is on offer and, where you are unsure, you might choose to incorporate a range of genetic material. Keep records of seed sources and over time you'll identify the best seedlots. You may even be able to collect seeds or cuttings from the best trees for sale to nurseries or for your own use.

Weed control

The most important factor affecting survival and early tree growth is weed competition.

In this context a weed is anything that competes with a young tree for moisture or light. Removing competition using chemicals, mulch or cultivation will encourage more rapid early growth. The amount and timing of weed control required depend on the rate of growth of the trees and the weed type. For most purposes trees provided with a full growing season of weed control (within 1 m of the tree) will then be strong enough to fend for themselves.

Weed control in the second and subsequent years is usually only justified where tree growth is very slow or where there is extremely vigorous competition from deep-rooted grasses or woody weeds.

The most appropriate means of achieving effective weed control depends on many factors. Compare the costs, labour needs, period of effective control and the risk of environmental hazard in deciding on your best option.

Soil constraints

Waterlogging, hard pans and low fertility will all influence the selection of site preparation and planting technique. On some sites, survival and growth will be very poor without adequate soil preparation.

If your site has severe problems you may need to invest in deep ripping, mounding or cultivation to ensure any level of success.

The best methods will depend on the nature of the problem and your access to machinery or contractors that can do the work. On many sites, however, intensive soil preparation simply improves growth rates and uniformity.

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For most purposes, farmers may find that soil preparation is not essential and, for difficult sites or small areas, they may choose to save on costs and accept slower growth.

Many industrial plantation managers choose to use intensive ripping and mounding not so much to overcome soil problems but to reduce the costs of planting. Planting crews can work faster when planting into well worked soil. Good tilth may also allow open-rooted or very small seedlings to be planted instead of those in large pots which are more expensive to handle.

Protection

The final important point to consider is the protection of young trees from browsing and severe climatic conditions.

Rabbits, hares, deer, kangaroos and wallabies are common browsers of young trees. Domestic stock can be a serious problem if poorly controlled and this includes the landowner's own stock as well as those of neighbours.

Options for browsing control might include shooting and poisoning (where acceptable), repellents, tree guards, fencing or deterrents and will depend on the area, period of risk and the landowner's resources.

Insect damage to young trees can be extensive, especially during late summer when the trees might suffer moisture stress or when insect populations are high. Landowners should be aware of the risks and watch for signs of excessive defoliation. Although most species can tolerate quite high levels of defoliation, treatment may be warranted if trees are attacked repeatedly.

On some sites, promoting very rapid early height growth can lead to problems of windthrow. Tree form may not be critical when planting for conservation or shelter values but, for timber trees,

form is often the primary criterion affecting commercial value and even a small lean can make a tree uneconomic. Windthrow can occur on a range of soil types, especially waterlogged clays; although intensive soil cultivation may help overcome the problem on some sites it may encourage windthrow on others.

Frosts, hot winds, sand blasting and hail can destroy young trees. Guards are often used to reduce these risks although effective frost control is difficult. Once again, landowners need to assess the risks and make a judgement as to whether control is necessary.

Plant it and see

As farmers gain experience in tree growing they are refining their tree establishment methods. Low cost options, such as direct seeding, are often effective ways of developing agroforestry areas. For other landowners, seemingly uneconomic techniques involving a high labour requirement (such as mulching or guarding) might be considered appropriate.

Landowners should attend field days and visit other farms and industrial plantations in their area to see what seems to work for others.

At each site try to identify what the grower's objectives are, their limiting resources and note how they have chosen to deal with the issues of weed competition, soil factors and protection. Then, if possible, start small and learn from your own experience. You might also choose to trial different techniques to determine if, for example, ripping is necessary before tackling large areas.

Establishment check list

- Prior spraying is often necessary for establishment
- Planting should be done when soil moisture is sufficient to sustain developing roots. A soil conditioning mixture will help establishment
- Fertilising may be necessary. Placing fertiliser in the planting hole reduces weeds
- Leguminous plants require inoculation with root bacteria
- Seeds may need scarification before planting
- Fencing will be needed to protect plants from stock during establishment and resting
- Protection from pests may be necessary. Pelleting may prevent consumption of smaller seeds by ants. Mixing species and planting only in small blocks reduce pest hazard and also lower the probability of diseases spreading
- Spraying may be needed, but you should think of alternatives if possible. Spraying may increase dependence on sprays because it kills predators. It may be better in the long term to tolerate some pest damage
- Protection from stock is usually necessary until plants are around 1.5 m high for sheep and about 2 m for cattle

Is the design you have selected viable on your farm?

Introduction

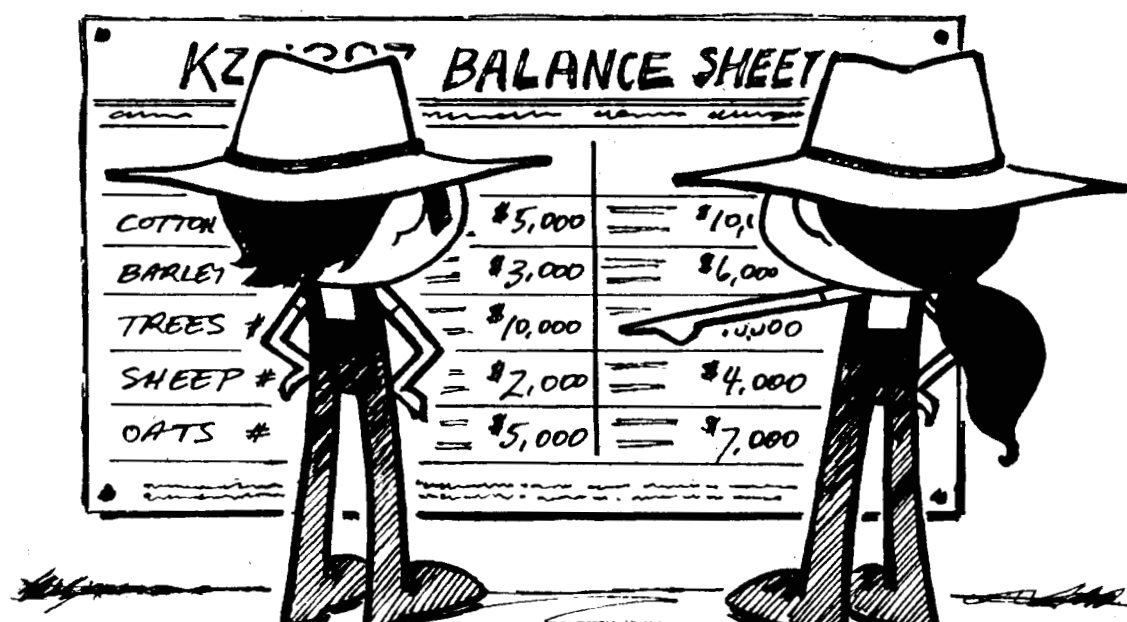
Cost benefit analysis, if done accurately, can be very complex and may need professional advice (ie taking into account discount rates, taxation issues etc). However, for the purposes of comparing alternative agroforestry designs, the following will be useful.

Let us assume that a farmer plants a shelterbelt with a total area of one hectare across the windward side of a paddock. The trees will provide shade and shelter and help decrease soil erosion. They will also help lower the rising water-table which is causing salinity problems and will assist in improving the habitat for native species as they

will form a corridor between two areas of remnant vegetation. The trees will be harvested sequentially for firewood and fence posts.

Because the trees will be used for shelter and low value wood products, the farmer will keep costs down by direct seeding the trees and by using the existing fence to protect trees from stock at the back of the shelter belt. An electric fence will be used across the front of the trees to protect them from stock until the trees are larger.

Let us assume that the trees will grow to 15 m high and will provide maximum protection for ten tree heights (ie 150 m) downwind. Thus, a total area of three hectares will be protected (Figure 35).



Is the design you have selected viable on your farm?



Figure 35: Plan diagram for worked example. 1 ha of trees is planted to provide 3 ha of shade

Identifying benefits and costs

Identifying costs and benefits is easiest if we draw up a table. In the first column of Table 9 we state what we are going to do, and then identify the benefits. Next we identify the costs associated with what we would like to do.

Table 9: Indicative framework for identifying benefits and costs

Activity	Benefits	Costs
	On-Farm	On-Farm
Trees planted	Increased production (shade/shelter)	Short-term production foregone
	Lowered water-table	Tree establishment
	Reduced soil erosion	Tree fencing
	Added aesthetic value	
	Increased production (biodiversity contribution)	

Is the design you have selected viable on your farm?

Valuing benefits and costs

Now that we have identified the benefits and costs, we can put dollar values on them.

In addition to income from the agricultural enterprise on the 3-hectare area, we need to include agroforestry income from firewood and fence posts as well as production increases due to shelter, biodiversity activity, lowered groundwater and reduced soil erosion.

These values vary between sites and seasons: for example, sheep farmers may receive great benefit from shelter at lambing in winter, but few from shelter in summer. (However, they may receive benefit from shade in summer.) The values are also different for cropping and livestock enterprises. While the values are not 'fixed', quite a lot of research work has been done which provides an indication of what these values are for many regions. You can take two approaches to determining these values:

- think about how much (lambs, tons of grain, kg of extra stock feed) you currently lose or have to

buy per hectare each year from not having the benefits of trees, and use this figure; or

- ask your regional economist/farm adviser/consultant to give you some idea of these values.

Comparing income

To see if agroforestry is going to increase your income you will need to compare the income from agroforestry with your current farming system. Because a dollar today (from harvesting a crop or selling stock) is worth more than a dollar received in the future (from harvesting trees), it is important when making decisions regarding future benefits and costs that their valuation takes explicit account of the time at which they occur.

The standard approach to valuing items which occur at different times is to reduce the stream of future benefits or costs to represent an equivalent amount of today's dollars. This discounted figure represents the net present value (NPV) of future benefits or costs.

Table 10: Indicative value of benefits and costs resulting from planting trees

Item	Unit	Farm income	Farm Costs	Information Source
TREES				
Direct seeding trees	\$/ha		100	Existing regional data
Electric Fencing	\$/100 m		200	Existing regional data
Tree maintenance	\$/ha/yr		25	Existing regional data
Tree harvest (yr 5)	\$/ha	400		Net market value
Trees harvest (yr 10)	\$/ha	400		Net market value
Lowered water-table	\$/3 ha/yr	15		Regional and research precedents
Shelter/shade	\$/3 ha/yr	50		
Reduced soil erosion	\$/3 ha/yr	25		
Added aesthetic value	\$/3 ha/yr	24		
Biodiversity benefits to production	\$/3 ha/yr	15		
				Real estate agent Estimate

Is the design you have selected viable on your farm?

Year	1	2	3	4	5	6	7	8	9	10
Enterprise income (\$/4 ha)	680	680	680	680	680	680	680	680	680	680
Enterprise costs (\$/4 ha)	160	160	160	160	160	160	160	160	160	160
Enterprise margin (\$/4 ha)	520	520	520	520	520	520	520	520	520	520
Discount factor (6%)	1	.94	.89	.84	.79	.75	.71	.67	.63	.59
Discount x margin (\$/4 ha)	520	490.4	462.8	436.3	411.8	388.4	366.6	345.8	326.0	307.3

Calculating NPV for the current farming system

Step 1

First you have to know when the trees will be harvested because this is when you will receive the bulk of your income. In our worked example, we will harvest our trees every 5 years – the first in 5 years, the second in 10 years and so on. We calculate the NPV over 20 years, a suitable time horizon for many farmers. A table is constructed to tabulate the data. Note that in the sample tables – 11 & 12 – data for only ten of the twenty years are shown.

Step 2

Enter your normal yearly income per hectare on the land you wish to put into trees. In this example the farmer normally uses the land for livestock grazing which returns \$170 per hectare per year. This is income in the 'no trees' scenario.

Step 3

Enter your normal costs per year for each year.

Step 4

Subtract your costs from your income to calculate your margin over 4 hectares (ie the area to be affected under the agroforestry option).

Step 5

Multiply the margin by the discount figure for each year to calculate the discounted return.

Step 6

If we add up the discounted return figures, we get the NPV for the usual farming system which is \$6 319 for 4 hectares over 20 years.

This NPV is the figure that we use to compare with the NPV from the farming system with shelter trees.

Calculating the NPV with trees

To calculate the NPV for the enterprise with shelter trees we simply follow the same steps.

Step 1

Once again we make up a table for 10 years.

Step 2

In the income column we put the dollar value of the benefits which we have determined for the trees in the year in which they occur. In this example we will plant one hectare of the trees on the windward side of a paddock, producing benefits of shade and shelter. If we add together lowered water-table, shade/shelter, decreased erosion, increased property amenity and biodiversity benefits to production they come to \$129 per year over the 3 hectares.

However, it will be about 3 years before the trees are big enough to provide the full value, so we do not identify agroforestry benefits to production until year 3.

Table 11:
Calculating the
financial NPV of
your current
farming system
without trees

Is the design you have selected viable on your farm?

Table 12:
Calculating the
NPV of your
current farming
system with trees

Year	1	2	3	4	5	6	7	8	9	10
Enterprise income (\$/3 ha)	510	510	510	510	510	510	510	510	510	510
Enterprise costs (\$/3 ha)	120	120	120	120	120	120	120	120	120	120
Enterprise margin (\$/3 ha)	390	390	390	390	390	390	390	390	390	390
Agroforestry income (\$/ha)	—	—	—	—	500	—	—	—	—	500
Agroforestry costs (\$/ha)	300	25	25	25	25	25	25	25	25	25
Agroforestry margin (\$/ha)	-300	-25	-25	-25	475	-25	-25	-25	-25	475
Agroforestry benefits to production	0	0	129	129	129	129	129	129	129	129
Gross margin (\$/4 ha)	90	365	494	494	994	494	494	494	494	994
Discount factor (6%)	1	.94	.89	.84	.79	.75	.71	.67	.63	.59
Discount x margin (\$/4 ha)	90	344	440	414	787	369	348	329	310	587

The farmer will harvest half of the trees in year 5 (for firewood and fence posts). This gives a net income of \$400. The other half of the trees will be harvested in year 10 for the same products.

Note: because we have taken 1 hectare of land out of production to plant trees, we only count farming system income for 3 hectares but add to it the agroforestry income from the 1-hectare shelterbelt.

Step 3

Enter the costs associated with the trees in the years in which they occur.

Step 4

Subtract the costs from the benefits for each year.

Step 5

Multiply the margin by the discount rate.

Step 6

Add the discounted figures together to give the NPV, which is \$6 544 for the 4 hectares over 20 years.

Since the NPV with shelter trees is greater than the

H I N T

As a rough rule it is usually worthwhile to plant up to 10% of the farm to trees, even if the trees bring in little income from the wood. This is because of the benefits trees give from shade and shelter, erosion and salinity control

NPV of the 'no trees' option, it is worthwhile to invest in this agroforestry design. Different designs may give quite different answers. For example, if the windbreak was only 15 m wide (as opposed to 50 m in the worked example), a wider area of grazed land would be sheltered and less would be occupied by trees. In this case and using similar assumptions to those above, the NPV would be \$6 976 over 20 years. If the tree crop was managed for sawlogs, higher management costs would be incurred but there would also be a higher cash return on harvest. An NPV of \$7 435 after 20 years might be expected.

Is the design you have selected viable on your farm?

Try doing a 'sensitivity analysis', too – by changing the values of different benefits or costs we can test how 'sensitive' our analysis is to these factors and determine whether differences make a significant impact on financial viability.

What discount rate should I use?

There is ongoing debate about which discount rates to use. In the example above, we have used an 6% discount rate, as this is the figure often used in government forecasting.

To complicate matters further, the discount rates for natural resource such as timber may be different to those for agricultural commodities. Therefore, to allow for these variations you may wish to use either higher or lower discount rates than the ones used above.

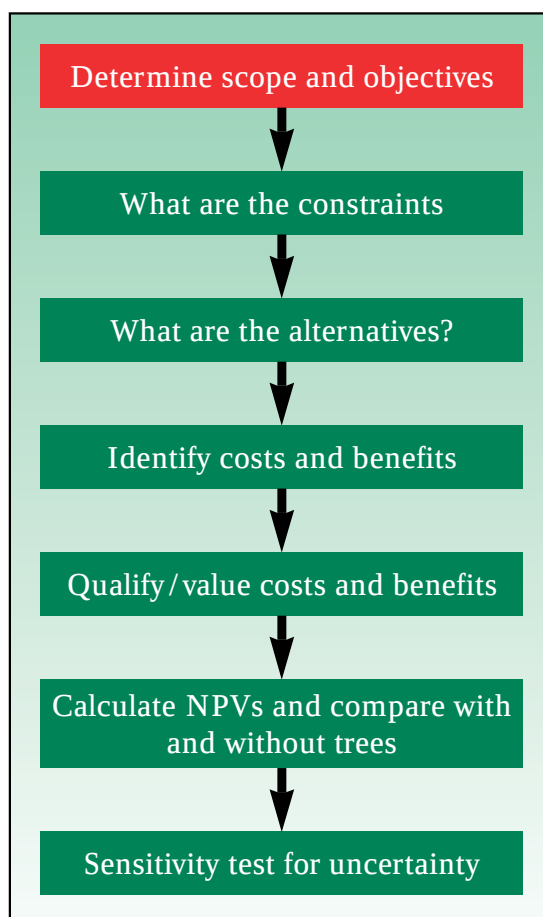
However, unless you think that the price of wood is going to rise substantially more than agricultural commodities it may be wisest to use the same discount rate in all scenarios when doing a comparison of income.

Figure 36 summarises the steps we have just undertaken in our benefit cost analysis.

Economic models

If you require a more complex analysis of agroforestry income there are a range of agricultural economic models on the market. While many have been designed to analysis general farm income only, the model FARMTREE has been specifically designed to estimate the financial returns from agroforestry.

FARMTREE provides rough projections for a fairly wide range of species and layouts for which there are few data. It includes the benefits from timber and shelter but excludes other benefits (unless you are able to put them in yourself).



FARMTREE covers:

- the type of spatial layout – whether shelterbelt, woodlot etc;
- species;
- thinning and pruning regime;
- age at harvest;

Figure 36: Key steps in benefit cost analysis
Adapted from: Department of Finance (1991)

Is the design you have selected viable on your farm?

- likely costs;
- effects on other enterprises through competition or enhancement;
- growth rates – these are based on available measurements, not models of growth processes. Points are fitted to a sigmoid curve selected as a 'best bet' by matching with similar species, sites and spacings;
- trees are partitioned at harvest into debris, firewood, posts, sawlogs and clear sawlogs;
- value of products based on current prices, allowing for species, type of wood, diameter, defect, distance from mill and other factors. Alternatively, costs of harvesting, processing, transporting and marketing are deducted from revenue based on current prices, or the user can specify prices.

The agroforestry enterprise is appraised in the context of other enterprises, so trade-offs can be estimated. The model runs on IBM-compatible personal computers.

FARMTREE is currently being tested by extension officers and farmforestry advisors and a Windows version is being developed. For more information, contact: Bill Loane; Ph (03) 9412 4787.

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