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Designing Silvicultural Research Trials

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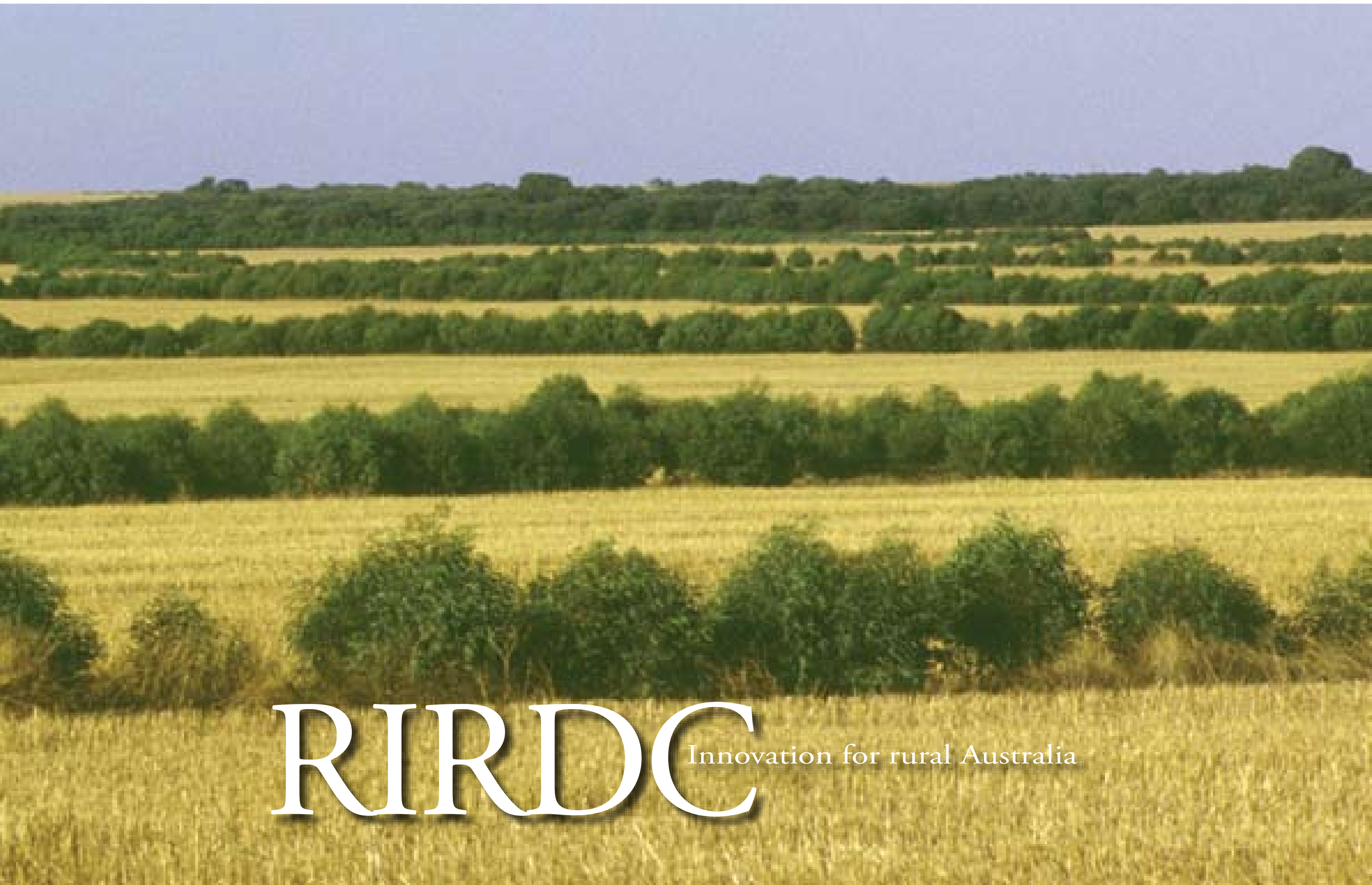

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An Australian Government Initiative

JOINT VENTURE AGROFORESTRY PROGRAM

RURAL INDUSTRIES
LAND & WATER
FOREST AND WOOD PRODUCTS
RESEARCH AND DEVELOPMENT CORPORATIONS

Designing Silvicultural Research Trials

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Foreword

Australian Federal and State government policies are supporting the development of plantations on cleared farmland for wood production as part of their *2020 Vision*. With an increased interest in plantations of Australian native trees, there is a need for information on species performance over a range of sites, grown with suitable silvicultural management. To provide this information, research and demonstration trials should be well designed and, where possible, allow comparison among trials. This manual provides guidelines for the design and reporting of silvicultural field experiments, focusing on hardwoods in plantation. It has been compiled using contemporary literature and advice from silvicultural researchers throughout Australia.

This manual is a product of the National Farm Forestry Silviculture project. The project was funded by the Farm Forestry Program (Department of Agriculture, Fisheries and Forestry Australia) and coordinated by RIRDC under the Joint Venture Agroforestry Program (JVAP). The JVAP is supported by three R&D corporations—RIRDC, Land & Water Australia and Forest & Wood Products Research and Development Corporation[1]. The Murray-Darling Basin Commission (MDBC) also contributed to the program at this time. The R&D Corporations are funded principally by the Australian Government. State and Australian Governments contribute funds to the MDBC.

This manual is one in a series produced by the Joint Venture Agroforestry Program. The aim of the series is to provide practical guidance for people wishing to establish successful farm forestry projects. The other manuals are:

- *Site selection for farm forestry* by Harper et al. 2008, RIRDC publication No. 08/152
- *Designing farm forestry trials for species and provenance selection* by McLeod et al. 2009, RIRDC publication No 09/016
- *Growing rainforest timber trees: a farm forestry manual for north Queensland* by Bristow et al. 2005, RIRDC publication No 03/010

This report is an addition to RIRDC's diverse range of over 1800 research publications. It forms part of our Agroforestry and Farm Forestry R&D program, which aims to integrate sustainable and productive agroforestry within Australian farming systems. The JVAP, under this program, is managed by RIRDC.

Most of our publications are available for viewing, downloading or purchasing online through our website <www.rirdc.gov.au>.

Peter O'Brien
Managing Director
Rural Industries Research and Development Corporation

[1] Now Forest & Wood Products Australia (FWPA)

Executive summary

What the report is about

This manual provides guidelines for the design of silvicultural research trials. It also discusses trial measurement and reporting requirements and lists the types of information that should be provided in internal reports and published material to ensure adequate provision of information to other research users. This includes minimum requirements for site and soil descriptions.

Who is the report targeted at?

The manual aims to assist farm forestry extension officers and silvicultural researchers to design and document silvicultural field experiments.

Background

The manual is designed for practical use, and ranges from general principles for designing an experiment, to guidelines for designing silvicultural trials, site description, measurement and reporting. The manual differs from others available in that it gives guidelines for designing specific types of silvicultural research trials. The types of experiments considered are those testing site preparation, weed control, fertiliser application, initial spacing, irrigation, thinning and pruning, low rainfall sites, saline sites, wood properties and assessment of insect and pathogen attack, as well as species, provenance and progeny trials.

Aims/objectives

The aims of this document are to:

1. ensure future trials are well designed to create a reliable research base
2. standardise research trial design and reporting to allow easier comparison of results among trials
3. assist staff training and enhance inter-organisational consistency.

Implications for relevant stakeholders

In designing a trial, the researcher should consider silvicultural requirements as well as site characteristics, soil nutrition and results of previous research which used similar sites, silvicultural factors or species. For each type of trial, this manual recommends appropriate designs, plot sizes and numbers of buffer rows and discusses factors which may interact with those being tested. As each trial has its unique set of conditions, each trial may need some modifications from the guidelines provided in this document, and the design should be checked with a biometrician prior to implementation. However, ensuring adequate replication, randomisation and blocking, and including benchmark species or treatments common to other trials, will mean that the results will be easier to interpret and compare with other sites. This improves the quality of advice for growing trees.

This manual is one part of the National Farm Forestry Silviculture project. It has been compiled using contemporary literature, advice from silviculture researchers throughout Australia, and results of formal discussions amongst the 45 people who attended the project’s national silviculture workshop which was held on 13 and 14 June 2001 at the Queensland Forestry Research Institute at Indooroopilly, Brisbane. A brief update on insect and carbon assessment was added in February 2009.

Abbreviations

ALRTIG	Australian Low Rainfall Tree Improvement Group
CFTT	Centre for Forest Tree Technology, Department of Sustainability and Environment, Victoria
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DBH	Diameter at breast height
DGL	Diameter at ground level
NFFI	National Farm Forestry Inventory, Bureau of Resource Sciences, Canberra (now Bureau of Rural Sciences)
QDPI—F	Queensland Department of Primary Industries—Forestry
QFRI	Queensland Forestry Research Institute, now Horticulture and Forestry Science, Department of Primary Industries, Queensland
sph	Stems per hectare
tph	Trees per hectare

Acknowledgments

The need for a national review of silviculture research in hardwood plantations and farm forestry was proposed at the Research Priorities Coordinating Committee in 1996. Drs Rod Keenan and Russell Haines (Queensland Forestry Research Institute) wrote the proposal which was successful in obtaining funding. The project was set up with collaboration from representatives from state forestry research organisations in Australia, and became known as the National Farm Forestry Silviculture project. Project coordination and research was managed by Dr Rosemary Lott (then Queensland Forestry Research Institute). This manual is a product of the National Farm Forestry Silviculture project. Another is *A bibliography of hardwood plantation and farm forestry silviculture research trials in Australia* by Lott (2001), RIRDC publication 01/101.

Many people assisted with the silviculture manual. Tim Wardlaw wrote the section on designing pest and pathogen trials (Section 4.3.9) and Chris Beadle wrote Appendix 2 on measuring leaf area index. Fay Lewis provided technical editing and formatting. The following people provided information or comments on research trial design or reporting. Note that the organisation names were current in 2002 when the manual was written, and many have since changed:

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Barnes, Chris (Gunns Ltd, Tas. (formerly North Forest Products))
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Review comments on this document were received prior to, during and subsequent to this project's national silviculture workshop held on 13 and 14 June 2001. We have not listed the 45 silviculture researchers and farm forestry extension officers who attended the workshop but thank them for their participation in the discussion session.

We particularly thank those who provided written comments on the draft document. They were:

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In February 2009 a brief update on insect and carbon assessment was added to the report, prior to its availability on the internet. Background information was provided by S. Lawson (QDPI&F), Philip Polglase, Keryn Paul and Jacqui England (CSIRO), Trevor Hobbs (FloraSearch project, Department of Water Land and Biodiversity Conservation, South Australia) and a second Paul Ryan (Australian Government Department of Climate Change).

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1. Introduction and definitions

Sites being used for farm forestry plantations vary considerably, both in their existing physical conditions (e.g. soils, slope, elevation and aspect) and the climatic environment that they experience (e.g. high rainfall, drought, frost, low rainfall and cyclones). These farm forestry plantations range from one or two hectares to thousands of hectares. This results in a wide range of situations where people require advice and relevant research . The range of organisations conducting silvicultural research to provide such information now spans state government forestry agencies, private companies, the CSIRO, universities, regional plantation committees (now called private forestry development committees), non government organisations such as Greening Australia and Landcare, and motivated farm foresters. Trial designs and duration vary considerably, and trials are not always designed with long-term applications in mind. This influences the quality and applicability of the information derived. There is a need for consistent design and reporting standards so that experimental results from different organisations**,** experiments, sites, and years can be compared.

This manual provides a guide for researchers and extension officers who are designing plantation trials and reporting results from trials. Basic design principles for both genotype trials (species and provenance) and different types of silvicultural trials are considered. The manual focuses on, but is not limited to, silviculture of plantation-grown hardwoods. Information has been compiled from research manuals and publications, along with advice from silvicultural researchers around Australia.

There are four main reasons why this manual is needed. They are:

1. There is no Australian manual on the design of silvicultural trials. Although some government forestry organisations have internal research manuals, these manuals often do not address the design of silvicultural trials and in any case are not consistent among organisations. Most government forestry research manuals are not available to the public. Several publications do address the design of genetics trials and provide relevant general principles for research, but they do not deal with aspects particular to silviculture trials.

2. To promote farm forestry in the long term, good quality and reliable advice on tree growth and management across a range of sites must be based on research trials that are well designed. That is, researchers should design trials which answer their silvicultural questions with minimum interference from unexplained variation. This manual uses experience from previous silvicultural trials in Australia to give advice for designing new trials.

3. Where possible, research trials should use standard designs so that they are clearly comparable across sites, species and years. This gives a greater scope for applying the results to a range of scenarios. Similarly, consistent, adequate reporting styles will aid dissemination of information and use of research results. With a wider range of research organisations than existed 25 years ago, exchange of information (on research design and results) among organisations is more complex. This is due to larger networks and sometimes, greater competition. For example, governments sometimes have research and extension services in separate departments, and are often under-resourced to disseminate research outcomes between staff and to the public. In the long term, well-designed trials which are comparable with others are also a more efficient use of available funding and other resources.

4. Within forestry organisations, staff have more variable backgrounds in silvicultural research and forestry operations than previously. With the absence of forestry traineeships, employees are less likely to receive long-term, comprehensive training in silviculture experimental design within one organisation. Guidelines are required for the purposes of training staff and to encourage consistent and comparable designs within and among organisations.

1.1 Scope of the manual

This manual is suitable for use by farm forestry extension officers and silvicultural researchers who are designing field research trials (as distinct from unmeasured demonstration plots). A trial is a carefully designed and documented experiment which compares at least two aspects of tree management (silvicultural or genetic) under carefully controlled conditions. The trial may compare management, genetic material, or both for performance on one or more sites, and is measured over time. For the purposes of this manual, silviculture is defined as field management of trees—that is, management after the nursery stock and site have been chosen. Section 1.2 contains definitions that are used in this manual.

This manual differs from other material available in that it focuses on aspects of design for specific types of silvicultural research trial, such as site preparation or fertiliser trials. Topics include requirements for buffer and isolation rows, plot size, replication, factors likely to interact with the treatments imposed, silvicultural management and measurements particular to each type of trial. Where possible, example references are given. Some coverage of genetics trials is also provided. Further information on the design of genetics trials is given in Williams and Matheson (1994), Eldridge et al. (1993), Burley and Wood (1976), Carter (1987) and the companion JVAP manual *Designing farm forestry trials for species and provenance selection* (McLeod et al. 2009). In some situations, specific advice on the design of genetics trials can also be provided by the Australian Tree Seed Centre (CSIRO) or the Southern Tree Breeding Association. This manual includes a chapter on general issues for experimental design and common types of field designs.

Appropriate descriptions of the site and trial design are important to ensure adequate provision of information to other research users. This manual covers tree measurement, minimum requirements for site and soil description, and reporting guidelines. Checklists for preparing internal reports and research publications are provided. Further sources of reading are recommended where available.

Within regional organisations, the recording of consistent data sets will allow future researchers to compare and analyse long-term research trials and then use models to predict yield, improvements resulting from silviculture, and economic outputs. Minimum data sets recommended in this document meet the requirements of three national databases currently in use: the National Farm Forestry Inventory (NFFI), the CSIRO’s TREDAT database, and SILVDAT, the database produced by this National Farm Forestry Silviculture project. The NFFI project has compiled information on the areas and locations of farm forestry plantings. TREDAT and SILVDAT are databases which store information on the locations, site details and designs of research trials and some farm forestry demonstration plots, along with some summary growth data.

This manual does not deal with technical aspects of nursery management, trial establishment or silvicultural methods. For information on technical aspects of labelling nursery stock, and methods of pegging and establishing plots, refer to Carter (1987) and the JVAP manual *Designing farm forestry trials for species and provenance selection* (McLeod et al. 2009). Up-to-date nursery techniques are best discussed with a nearby large commercial nursery. General information on establishment and silvicultural management of farm forestry plots is provided by regional farm forestry extension groups and extension literature produced by relevant state government departments. Background information on plantation silviculture is provided in Chapter 13 of Florence (1996).

This manual should form a starting point in designing research trials. Of course, each experimental situation should be considered on its own merits and because requirements are variable, there will be some exceptions to the guidelines provided in this document. We also know that there will be times that ideal measurement schedules may not be met, soil descriptions are costly, and previous fertiliser history relies on word of mouth which may be biased—but we urge the reader to try to follow this manual’s recommendations to help promote consistency and improve design standards!

Personal communications cited throughout this manual occurred between 1998 and 2001. The manual was prepared and submitted to RIRDC in 2002, and the reader should be aware that silvicultural research has been conducted since. Contemporary issues include mixed species trials, growing mallees in alley belts, measurement of tree physiology and water use, measurement of biomass, allometry and carbon sequestration, and research on tree-agriculture interactions. In February 2009 a brief update on carbon and insect assessment was added to the report, prior to its availability on the internet. Feedback on changes and updates may be provided to the senior author.

1.2 Definitions

A range of terms which are relevant to genetic and silvicultural trials are used in this manual. Box 1-1 contains some key definitions.

Box 1-1 - Definitions

Definitions

Silviculture: "the art and science of controlling the establishment, growth, composition, health and quality of forests and woodlands to meet the diverse needs and values of landowners on a sustainable basis" (Helms 1998). For the purposes of this manual, silviculture is defined as the field management of trees—that is, management after the nursery stock and site have been chosen.

Genetics or taxa trial: a trial which is testing plant material of different genetic composition (taxa) at one or several levels—that is, species, provenance, progeny or clone. Ideally, species and provenances are sequenced through a series of trials, first selecting and proving the most suitable species, and then the most suitable provenances and progeny (Carter 1987).

Species elimination trial: a trial which tests a large number (typically 20 or more) of different species on a given site (McLeod et al. 2002). Usually the differences in survival and growth among species are large and will show up quickly, so the trial duration is short. In species with a wide natural distribution, it may be advisable to include several different provenances in the trial (Carter 1987).

Provenance trial: a trial which compares the performance of different provenances of a species—that is, seed collected from different regions of the species' distribution. Differences between provenances are generally small to moderate, and the trial design needs to be large enough to detect these differences accurately (McLeod et al. 2002). Specific designs are therefore necessary (see Williams and Matheson 1994, and the JVAP manual *Designing farm forestry trials for species and provenance selection* by McLeod et al. 2009). Provenance trials are usually maintained for at least half a rotation, and often a full rotation.

Species-provenance trial: a trial that tests several provenances of a few species.

***Progeny trial*:** a trial that generally tests 50 or more families from one or more provenances of a species (McLeod et al. 2002). A family is represented in a seedlot collected from a known mother tree. Progeny trials are often designed to be selectively thinned to convert them to a seedling seed orchard.

Clone: a plant genetically identical to its source, obtained by striking roots from a cutting, grafting a young shoot onto appropriate rootstock, or by tissue culture. The original plant is the *ortet*; all subsequent plants are *ramets*.

Factor: an aspect of management being tested in an experiment, such as fertiliser application, species or thinning. A group of treatments is used to test different levels of the factor—for example, different rates of nitrogen fertiliser.

Treatment: each factor in an experiment is tested at two or more levels or rates (e.g. with and without irrigation) and each treatment is a combinations of one rate for each factor in the experiment.

Plot: the basic unit in field trials. All trees in the plot come from the same seedlot. The plot contains one treatment, usually replicated across the experiment.

Block plot: a group of trees of the same seedlot, all under the same treatment and planted in square, rectangular or circular configuration.

Line or row plot: a group of trees of the same seedlot, all under the same treatment, planted in a row.

Single tree plot**:** each individual tree represents a separate treatment and the 'plots' must be replicated across the experiment.

Initial tree spacing: the spacing at which trees are planted on the site. The resulting density is also termed *initial stocking rate*. Subsequent thinning is often used to remove the poorer trees and allow the best trees to grow to optimum yield. In this manual, spacing distances will be listed in the form:

(*between-row distance*) × (*within-row distance*)

An example is 4.0 m × 2.0 m.

Dominant: "a tree whose crown extends above the general level of the main canopy of even-aged stands or, in uneven-aged stands, above the crowns of the tree's immediate neighbours and receiving full light from above and partial light from the sides" (Helms 1998).

Predominant: "a tree whose crown has grown above the general level of the upper canopy" (Helms 1998).

Codominant: "a tree whose crown helps to form the general level of the main canopy in even-aged stands or, in uneven-aged stands, the main canopy of the tree's immediate neighbours, receiving full light from above and comparatively little from the sides" (Helms 1998).

Sampling variation: uncontrollable genetic and environmental variation (Burley and Wood 1976).

Experimental error: inaccuracies in assessment and recording and resulting from random variation within the plant (e.g. oil content of adjacent two leaves) and mistakes in management of the experiment (Burley and Wood 1976).

Residual variation**:** sampling variation and experimental error combined. Burley and Wood (1976) made the point that residual variation is often wrongly termed 'experimental error' (see definition above).

1.3 Structure of the manual

Chapters 2, 3 and 4 deal with the principles, practical issues and details of designing trials, and then Chapter 5 discusses the measurements which should be made. The site details that should be described in order to characterise the trial locations are outlined in Chapter 6. The last two chapters give guidelines for documenting the trial design, establishment, management and results in internal reports and articles intended for publication.

To highlight and distinguish between different types of information, two types of boxes have been used:

Summaries, definitions and general information

Guidelines

2. General principles of experimental design

Chapter outline

This chapter introduces some fundamental principles for planning and designing trials. The first step is to define the objectives of the trial and identify designs which can achieve the objectives. The principles are then used to define appropriate trial designs including control treatments, the variables to be assessed, replication of treatments and how to randomise locations of treatments. The most commonly used experimental designs are described.

2.1 Identifying trial objectives

When designing a research trial, one must have clear objectives. The objectives should answer the following questions:

- what aspect of silvicultural management is to be tested (e.g. fertiliser application, provenance selection) and what is the best way to do this?
- which species is being tested?
- which timber products are expected?
- what is the intended life span of the trial?
- can results from the trial be generalised to other situations?
- what benefits will this trial provide to the forestry industry, land managers, consumers and the environment? What are likely to be the economic returns to the research organisation and will the trial require follow-on research?
- what resources are required to undertake this trial?

An experiment may build upon results and conclusions from previous experiments or be designed to answer new questions. Before designing a trial, the researcher must clearly define the **question** that they wish **this** trial to answer. From this question, the hypotheses should be formulated and the objectives stated.

2.2 Designs that address the objective

The trial should use an effective yet affordable design to achieve a desired goal. An experimental design should be based on creating a fair comparison of treatments, such as species, provenance, establishment practices or level of pruning (Bird 2000). It is also essential that the researcher uses a design that distinguishes between genuine treatment differences and differences due to environment or chance (Williams and Matheson 1994). Careful design and experiment management will be able to minimise undesirable variations due to environment, chance and human inaccuracies and this will help increase the likelihood that differences due to treatments are identified.

It is recommended that the final design is both peer reviewed and reviewed by a biometrician which will help to ensure that the latest research knowledge and statistically sound designs are included. Peer review can include review by people from related disciplines. It is also important to check whether the same trial has previously been conducted in the region using the same species and trial objectives (McLeod et al. 2002).

There may be benefits from implementing a multi-disciplinary approach to the experimental design and analysis, for example planting additional trees for biomass or destructive wood sampling. However, designs should not be multi-disciplinary at the cost of trial robustness and reliability. A simple design that only tests a range of site preparation treatments may be much more valuable than one that is limited to testing one or two site preparation treatments in order to include other factors, such as fertiliser, weed control, and stock type (G. Holz, pers. comm.). This is because it can be difficult to determine the ways in which different factors are interacting and whether the correct levels for each factor have been tested.

2.3 Fundamental principles of experimental design

The basic unit of field trials is the plot, which contains trees all of the same seedlot (Harwood and Williams 1999). Plots are a group of trees planted in a line (line or row plot) or an adjacent series of rows (block planting). The exception is where specialist trials use replicated single-tree plots (see Section 3.6.3). A single treatment is applied to each plot.

To create a design that will answer the trial objectives, certain steps should be followed (see Box 2-1). The steps involve making decisions about control treatments, trial factors and treatments, methods of assessing effects, treatment replications, block layouts and the locations of plots within blocks.

Replication and *randomisation* are required to estimate natural variation (which is required for statistical analyses). *Blocking*, proper plot technique (during establishment and management) and appropriate choice of measurement data and data analyses are needed to minimise experimental error. Factor and treatment choice should be appropriate to the site and questions being asked and relevant to potential users of the research results.

It is generally desirable that the control plots have the same size and shape as the other treatment plots (although there are exceptions). In general, the control plots should have the same amount of replication as other treatments, but there are exceptions to this—for example, in some situations the control treatments should have more replication. A checklist of things to consider when designing an experiment is given in Appendix 1.

Box 2-1 Principles for designing trials to meet the given objectives

Principles for designing trials to meet the given objectives

1. ***Adequate control treatments*** should be included in the trial design (Hairston 1989; M. Webb, pers. comm.). A control treatment is one which provides a baseline comparison to describe how the stand would perform 'untreated', as if the experiment had not been performed. Control treatments can take several forms. The most frequently used options are *nil*, *standard operational* and *unconstrained*.

   The ***nil control treatment*** omits the treatments otherwise being tested. It is the most commonly used option.

   The ***standard operational control treatment*** is the 'current operational practice' used for the site in the region.

   The ***unconstrained control treatment*** removes, as far as practicable, all constraints to growth.

   Each option has advantages and disadvantages, but a nil control treatment should be included in most trials and, where appropriate, a standard operational treatment also (ForestrySA, pers. comm.). However, standard operational control treatments tend to be difficult to define in a meaningful way or are irrelevant to the questions being asked; invariably operations that are routine at the time that the experiment is designed are no longer so by the time the trials conclude (P.A. Ryan, pers. comm.).

2. ***Conditions*** that may influence results throughout the experimental process should be identified and standardised if possible. Important sources of variability among plots are (Gomez and Gomez 1984):

   - soil heterogeneity,
   - competition effects, and
   - mechanical errors.

   Within sites, areas with similar growth conditions should be grouped together as a single stratum (i.e. block, see point 7 below) in the design. This makes comparisons of performance between treatments valid as it separates them from species-site interactions (Burley and Wood 1976).

   Mechanical errors are errors in the execution of an experiment and in data collection. Proper plot management during establishment and the life of the trial will ensure that the variability among experimental plots is limited, as far as possible, to that of the treatments.

3. ***Initial conditions***. Conditions existing before the start of the experiment should be described, and if relevant, monitored for a while (Hairston 1989). This information will assist analysis and interpretation of the results. The information could include slope and soil type variation, salinity, fertiliser history, seedling condition, and rainfall run-off. Sometimes, measurements of characters known to influence results, for example initial seedling size, can be used as covariates in statistical analysis.

4. ***Factor and treatment selection*** should be based on as much information as possible. Factors are aspects of management (e.g. site preparation or addition of fertiliser) and treatments are specific levels and combinations of these (e.g. different amounts of a complete fertiliser added). While research to determine which are the best factors and treatments to use is often the most time consuming part of designing an experiment, many researchers would agree that it is one of the most important aspects of a successful trial (G. Holz, pers. comm.).

5. ***Variables chosen for assessment*** must be measurable and indicative of the treatment differences (M. Webb, pers. comm.).

To ensure that the trial is statistically valid and is laid out appropriately on the site, the following factors are critical:

6. ***Replication of treatments*** (including the control) allows the effects of natural variation to be distinguished from treatment effects. Most experimental designs require replication for valid statistical conclusions to be drawn. For each treatment, this involves replicating the plots at each site. This should not be confused with planting a single plot of each treatment at several sites, which is called *repetition* (Carter 1987). The number of replications required depends on (Gomez and Gomez 1984):

- the inherent variability of the material being tested;
- the experimental design used;
- the number of treatments; and
- the degree of precision desired

For most designs, three to four treatment replicates are necessary to provide adequate precision for estimation of treatment mean values. More replicates are required if the soil or site is very heterogeneous, and if greater precision of results is required (Gomez and Gomez 1984).

Replication of treatment plots is required to estimate natural site variability, and is needed despite the replication of trees within each plot. Section 3.6.2 gives recommendations for the minimum number of trees per plot to ensure adequate replication within the treatment and buffering from adjacent treatments.

6. ***Blocking of plots*** is carried out to minimise the effects of site variation on treatment differences. Blocks are used where there is an environmental gradient across the site. Blocks are **replicated along environmental gradients** and treatments are randomly assigned to plots **within each block**. It is of primary importance to **minimise all variation within each block**. Individual blocks should be chosen to be as uniform as possible with **no** major physical or environmental differences **within** their area. As a secondary priority, the size, shape, orientation and location of blocks should then maximise as much physical and environmental variation **between blocks** as possible.

7. ***Randomisation of the treatments within each block*** aims to eliminate unconscious or conscious bias by the researcher, and to minimise any unknown sources of variation on the site which may advantage or disadvantage some treatments unduly (M. Nester, pers. comm.). A random number table, dice, computer software like *CycDesigN* (Whitaker et al. 1998) or even a calculator can be used to determine the random position of plots within each block. Randomisation should be performed **separately** for each block or replicate. This will minimise any bias caused by arranging treatments in a similar pattern in each block.

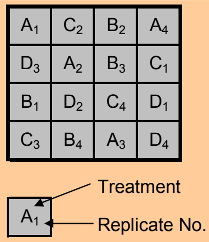
2.4 Common experimental designs for silviculture

Five experimental designs commonly used by plantation researchers are outlined below. The suitability and method of applying these designs is covered in numerous texts (such as Cochran and Cox 1956; Burley and Wood 1976; Roger and Rao 1990; and Williams and Matheson 1994). Chapter 4 gives examples of their use.

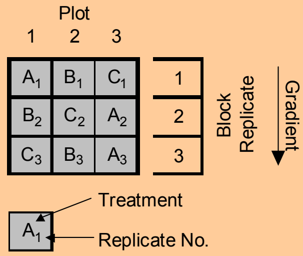
Box 2-2 Commonly used experimental designs

Commonly used experimental designs

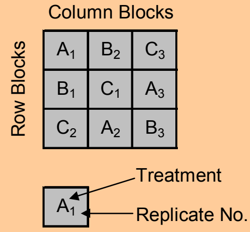
1. ***Completely randomised design***: Treatments are randomly assigned to plots **within an homogeneous experimental site**. The same number of replicates should be applied to each treatment. This design is rarely recommended for field trials as site conditions (soil, slope, fertility, etc.) generally vary across an experimental site.



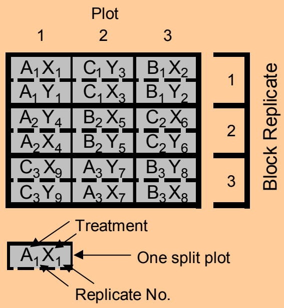
2. ***Randomised complete block design***: Blocks are used where there is an **environmental gradient across the site**. Treatments are randomly assigned to plots within a block, which are further replicated across environmental gradients at an experimental site. (Treatments may be replicated within blocks if required.) First priority in determining the trial layout is to ensure **minimal variation within blocks**. As a second priority, the location of blocks should then **maximise** physical and environmental **variation between blocks**. Block size, shape and orientation need not necessarily be the same as they depend on site topography and environmental variability, and the required plot size.



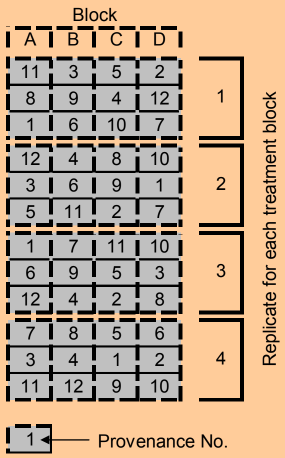
3. ***Latin square design***: Each treatment must be represented in each row-block and column-block, and treatments are randomly assigned within each 'stratum' (see points 2 and 7 in Box 2-1). This allows variation among rows and among columns to be removed from the experimental error. The disadvantage is that the number of treatments must equal the number of replicates, and this can lead to unnecessarily large experiments if many treatments are being investigated. For this reason experiments which involve Latin squares are generally limited to four to eight treatments.



4. ***Split plot design***: Split plots are used where one treatment is best applied across one continuous area (e.g. deep ripping), rather than in separate randomly-assigned plots. Treatments are randomly assigned to main plots and secondary treatments are randomly applied to subplots within the main plot. Comparisons of the main plot treatments are less precise than those of the subplot treatments, making the assignment of treatments to main or subplots critical. Split plot designs are sometimes suitable for overlaying later age treatments such as pruning and thinning.



5. ***Incomplete block design***: This type of design is useful when the number of treatments is large and/or the site variation is large. Each block is an incomplete replication—that is, each block contains a reduced number of treatments instead of containing all treatments. By careful allocation of treatments to blocks, the comparison between treatments can be optimised for maximum precision. There are several types of incomplete block designs which are further outlined in Williams and Matheson (1994). The example to the right is a lattice design from Carter (1987)—if used, it cannot be modified in any way due to the statistical nature of its design.



3. Practical issues affecting design

Chapter outline

This chapter builds on the principles presented in Chapter 2 by describing the practical decisions that have to be made to design successful trials. These include selecting sites, factors and treatments, species, layout, plot sizes, tree spacing, silvicultural operations and appropriate statistical analyses, as well as planning for quality control problems that may arise. Use of a benchmark species or treatment in common with other experiments is also suggested.

3.1 Choosing a suitable site

It is important that sites chosen for research trials include both routinely planted site types as well as non-traditional sites likely to be planted in the future. This will test the plasticity of species to sites and treatments and allow for future scenarios. Overall, trials should span the relevant ranges of soils, levels of exposure, slope aspects and rainfall and should also include features such as frost hollows. A research trial site should be chosen based on the following (Burley and Wood 1976):

1. Is the trial site representative of an area that is likely to be used for farm forestry or plantations?

2. If not, does it represent part of the climatic or soil range that should be tested?

The availability of representative and suitable sites is a constraint for site selection. The site should be appropriate for the treatments to be tested (e.g. to test the effect of mounding, the chosen trial site should have drainage problems) and of sufficient area. Unless the experiment is intentionally targeting poor soils, it is wise to avoid unproductive sites as they may not produce sufficient growth or survival to detect treatment differences (Gomez and Gomez 1984).

In an experiment, the ability to successfully detect the differences among treatments increases if the sites chosen are reasonably uniform. One of the main causes of site variability is soil. Some of the features that magnify soil differences are slope, areas used for previous experiments, graded areas, and large trees, poles and structures (Gomez and Gomez 1984). The guidelines in Box 3-1 explain these issues further.

An adequate characterisation of soil heterogeneity is an important guide to choosing good experimental technique (Gomez and Gomez 1984). It is also essential that the climatic and physical attributes of the site are characterised, both initially and during the research trial (see Chapter 6 and the JVAP manual titled *Site selection for farm forestry* by Harper et al. 2008).

The research plan for the site should address any environmental issues. In particular, soils should be assessed for erodibility (see the review by Ryan et al. 1998) and the site preparation techniques should be chosen accordingly. Relevant codes of practice for site preparation, roads and stream crossings must be adhered to. Buffer widths for watercourses should be implemented in an environmentally responsible manner, and according to state government legislation.

Access roads and firebreaks should be planned for, and the alignment of the trial should allow for future access by ground-based machinery for thinning and harvesting. Once the research site is chosen, operations staff should be informed of the trial’s location, purpose and management restrictions.

Box 3-1 Guidelines for selecting trial sites

Guidelines for selecting trial sites

- Fertility gradients are generally more pronounced in sloping areas, with lower areas more fertile than upper slopes. If a flat site is not available, a uniform and gentle slope will tend to have more predictable fertility gradients and can be managed through the use of proper blocking (Gomez and Gomez 1984)—see point 2 in Box 2-1.
- Areas used for previous experiments have usually had different treatments applied and their subsequent conditions will therefore vary. These areas should be avoided. Similarly, when establishing an experiment in an existing plantation, ensure that the site contains no management differences such as changes in fertiliser applications, seed batches or thinning intensities (QFRI 2002).
- Areas that have had any kind of soil disturbance (e.g. graded areas) should be avoided. Grading an area usually removes top soil from elevated areas and deposits it in the lower areas of a site. Although this operation reduces the slope, it results in an uneven depth of surface soil and it may expose infertile soils. These differences persist for a long time (Gomez and Gomez 1984). For example, near Deniliquin in New South Wales laser levelling of sites can produce marked undulations in tree height in young plantations due to differences in soil depth (R. Lott, pers. obs.).
- Large structures should be avoided because of the shade they produce and the possibility that soil was moved during their construction. Ash heaps from burning of logging residue should also be avoided.

3.2 Factor and treatment choice

A *factor* is an aspect of management, such as fertiliser application, species or thinning, which is to be tested in the experiment. The different rates or levels of each factor that are tested are called *treatments*. As outlined in point 4 of Box 2-1, factor and treatment choices are critical for successful trial design and should be based on as much information as possible. Treatment choice should always be determined after the site and soil have been adequately characterised, so that treatments are appropriate to the site. Preferably, treatments should be chosen after consultation with someone who is knowledgeable about the site, the region, the factors proposed for testing and the previous research history on that topic.

The range of treatments selected should consider the intended product, for example silvicultural treatments differ between fibre and sawlog production. The design chosen should also consider long-term requirements for the data. For example, one should consider whether to replicate the trial at other sites, on other soils and over time. This is because "a well-designed trial established in isolation might produce locally valuable information but may contribute little to understanding at a regional or national level" (Anon 1999). In such a case, inclusion of a nil control treatment will provide a description of the site's 'baseline' conditions. Note that an experiment repeated on different site types (e.g. a ridge and a swamp) is structurally a split plot design, with sites as the main plots (QFRI 2002).

A coordinated research program should also consider the possibility that economic constraints will change. For example, a research program could include some baseline trials which test a broad range of rates for fertiliser and thinning. These can identify both the maximum growth possible, and a broad trend line or response surface to various silvicultural options. This would include treatments above and below what is currently considered optimal. Subsequent wood quality and economic analyses may well demonstrate that something other than the current norm is now optimum. However, many research trials are designed to answer more immediate problems.

Box 3-2 outlines the procedures for selecting factors and treatments.

Box 3-2 Procedures for selecting trial factors and treatments

Procedures for selecting trial factors and treatments

- Collect previously known site information. Collect any additional site characterisation data required, based on advice from a regionally experienced researcher.
- Check for any constraints to growth that might complicate the results or disguise the interaction effects. For example, on some infertile sands plantations will not respond to weed control unless they have adequate phosphorus (J. Simpson, pers. comm.). This requires a prior understanding of the importance of phosphorus.
- Based on site information and species requirements, carefully choose a range of rates or levels for each silvicultural factor. Too many factors (e.g. fertiliser, weed control, site preparation and stock type) should be avoided as they may limit the range of treatments selected for each factor. For example, if you only choose two fertiliser levels, are they the best for that species and site? It is better to understand each factor well first.
- If more than one factor is being tested, consider if these factors are likely to have interaction effects. Sometimes it can be too difficult to interpret the interaction, especially without good prior understanding of the effects of each individual factor. For example, there can be an interaction between site preparation and response to fertiliser and weed control (e.g. Borschmann 1997; Keenan and Bristow 2001). This requires a prior understanding of the susceptibility of a particular species to weed competition before testing the effect of fertiliser rates.

3.2.1 Factorial experiments

In factorial experiments the researcher is looking at a number of factors in combination. An example might be where two factors are chosen (e.g. fertiliser and site preparation), each with three treatment levels (as shown in Figure 3-1). In a complete factorial experiment each level of one factor is combined with each level of the other factors, so that every combination is tested. The importance of factorial experiments is that they allow interactions between factors to be tested. This gives more information than running separate experiments to test each factor individually. In most forestry experiments, a complete factorial is applied to completely randomised, randomised complete block or split plot designs.

		Fertiliser factor		
	Treatment level	**Nil**	**N & P**	**Complete**
	Nil	**Nil fert. and nil prep.**	**N & P and nil prep.**	**Complete and nil prep.**
Site preparation factor	**Rip**	**Nil fert. and rip**	**N & P and rip**	**Complete and rip**
	Mound	**Nil fert. and mound**	**N & P and mound**	**Complete and mound**

Figure 3-1: An example of a factorial experiment with two factors (fertiliser and site preparation), each with three treatment levels. 'N & P' is nitrogen and phosphorus fertiliser; 'complete' is fertiliser with nitrogen and phosphorus and macronutrients and micronutrients; 'fert.' is fertiliser; 'prep.' is preparation.

The example in Figure 3-1 has three levels of each of two factors, resulting in nine treatment combinations, each of which should be randomly assigned to a plot (not shown in the above example), and replicated at least three times. The resulting trial would be large. With a plot size of 10 rows × 10 trees (see Section 3.6.2), 2700 trees would need to be planted. Supposing the spacing was 5.0 m × 2.0 m (1000 sph), then an area of 2.7 ha would be needed for the trial without including any buffer rows, isolation rows or guard areas (see Section 3.6.1 for the definitions of these terms, and Box 3-5) or any infrastructure such as access roads or fire breaks.

If treatments are omitted or added to the complete factorial design outlined above, it is termed an incomplete factorial. For example, additional fertiliser treatments could be added to both of the ripping and mounding site preparation treatments. Incomplete factorials are used in nutrition, establishment and some thinning trials (D. Stackpole, pers. comm.). If an incomplete factorial experiment is planned, it is wise to seek statistical advice because the design and analysis may require special techniques.

3.3 Choice of species

Choice of species for a region should be based on local knowledge and research experience. Consult appropriate forestry and extension advice. In addition, descriptions of species requirements are given in various Australian books and journal articles, and also in the *Forestry compendium—global module CD-Rom* (CABI 2000). In the compact disc, most of the descriptions for Australian species were prepared by CSIRO staff (T. Booth, pers. comm.). Some recent JVAP reports also contain relevant information:

- *Improved species climatic profiles* (Jovanovic and Booth 2002) gives improved species climatic profiles for key eucalypt species in Australia;
- *Potential productivity assessment* (Booth et al. 2007) assesses the potential productivity of selected species
- *Trees for farm forestry – 22 promising species (*Clarke et al., 2009) gives descriptions of 22 key Australian plantation species with notes on wood characteristics, uses and silviculture
- *Greening Australia species trials on the Northern Tablelands, Slopes and Plains and Dorrigo Plateau of New South Wales.* Carr (2006)
- *Greening Australia low rainfall species trials* (Carr et al.2007)
- *Greening Australia species trials in the Northern Territory* (Clark et al. 2007)

When testing unknown species, the trial should also include material which is likely to grow best on that site in the long term, as a benchmark (see Section 3.4 below).

3.4 Benchmark taxa and treatments

3.4.1 Purpose

Benchmark taxa or treatments provide a control treatment which allows comparison between trials established for different reasons or at different times.

A *benchmark taxon* is a particular provenance, seedlot or clone of a species which is routinely included in a range of trials in order to compare results between years or among sites across a region. Use of a particular seedlot or clone is preferable, as provenance performance can vary with year of seed collection and the mix of individual source trees. Often, benchmark taxa have not been included in trials due to the cost and space required to include additional plots. However, they give a reference point from which comparisons of site potential and gain in tree improvement programs can be made over full rotations, **if** the same silvicultural management is used. In particular, the same silviculture must be used between blocks, sites and years, and trials must have uniform weed control if they and their benchmark taxa are to be compared.

Benchmark taxa can be a good visual tool for demonstration plots (A. Lyons, pers. comm.). For example, demonstration plantings often use bad examples (as well as good ones) to show how some species, despite their 'emotional value', will not grow successfully (D. Carr, pers. comm.). In addition, trials which include benchmark taxa or treatments can provide valuable information for use in predictive economic models.

The incorporation of benchmark taxa into the research design should follow the standard experimental design principles previously outlined in this document and in Box 3-3.

Box 3-3 Guidelines for benchmark genotypes

Guidelines for benchmark genotypes

Benchmark genotypes should be:

- managed in the same way silviculturally across blocks, sites and years;
- replicated equally, relative to other species treatments;
- included in each block, to gain representative variation from the site;
- randomised equally, along with other treatment plots; and
- sufficiently isolated from other species, to prevent interaction effects.

In silvicultural trials, a *benchmark silvicultural treatment* (e.g. an operational practice) could be compared with new prescriptions in order to demonstrate actual improvement in forestry techniques over time or the effect of planting date or year on growth (see Section 3.8). The benchmark and new treatments would use the same seedlot or clone. The inclusion of a benchmark treatment can provide a reference point from which to advise farm foresters or operational forestry on the relative benefits of particular silvicultural management and on where improvement is needed. Note that silvicultural trials testing specific questions about management of a target species would not require a separate benchmark taxon.

3.4.2 Selection of benchmark taxa

Benchmark taxa should be well recognised as being of superior quality, with site tolerance and hardiness and resistance to insect and pathogen attack. The benchmarks should be the best performers for the desired outcomes from the region. Once chosen, genetic material (clones or seed) should be stored for research purposes over time. That is, when the same trial is to be compared across years, the same seedlot should be kept aside for subsequent use. Benchmarks become more useful as improved genetic stock becomes available. Some genetics trials have already employed benchmarks in order to compare mean annual increment (MAI) and current annual increment (CAI) data from less superior genetic material with the latest tree breeding material. In some cases, it is relevant to use native forest seedlots as control treatments in the experiment (North Forest Products, pers. comm.).

Box 3-4 lists **suggestions** for benchmark species. Suggestions are based on discussions with researchers and a review of species used in published trials. When designing a trial, an appropriate provenance, seedlot or clone should be identified for consistent use across trials in each region. This will avoid the risk of confusing actual large differences in growth between provenances (or other genetic material) within a species, with supposed site or treatment differences. For example, at one research project site, overbark volume of 30 *Eucalyptus camaldulensis* provenance clones ranged from 15 m^3/ha to 210 m^3/ha at age six years (S. Shaw, pers. comm.). Choice of the particular provenance, clone or seedlot to use as a benchmark taxon may differ from region to region and will depend on results of the latest research.

Box 3-4 Suggestions for benchmark species for hardwood genetics and silvicultural trials

Suggestions for benchmark species for hardwood genetics and silvicultural trials

Every effort should be made to choose a benchmark provenance, seedlot or clone appropriate to the region. Check a current authoritative source for the best provenance to date—for instance, the ALRTIG web site <www.ffp.csiro.au/alrtig/> recommends provenances for low rainfall sites. The following summarises suggestions current in 2001.

Benchmark species	Common name	Site conditions	Suitable region
Corymbia citriodora subsp. *variegata*	Spotted gum	600 – 1000 mm MAR*	North-eastern Australia
Corymbia maculata	Spotted gum	600 – 1000 mm MAR*	Southern Australia
Eucalyptus camaldulensis (e.g. Petford provenance)	River red gum	Low rainfall, subhumid and monsoonal zones	Northern Australia
Eucalyptus camaldulensis (e.g. Lake Albacutya provenance)	River red gum	Low rainfall	Southern Australia
Eucalyptus camaldulensis (e.g. Silverton provenance)	River red gum	Low rainfall inland areas	WA, northern NSW and Liverpool Plains NSW (inferior to Lake Albacutya in southern Australia)
Eucalyptus cladocalyx (e.g. Wirrabara provenance)	Sugar gum	Low rainfall (400 – 700 mm MAR*) Mediterranean climate Not severe frosts or heavy soils	Southern Australia
Eucalyptus dunnii	Dunn's white gum	>800 mm MAR* Soils with fair structure Not in heavily frosted, dry or seasonally waterlogged areas	Subtropical NSW and Qld
Eucalyptus globulus	Tasmanian blue gum	>600 mm MAR* (ideally >800 mm)	Tas., Vic., SA, WA

Eucalyptus grandis	Flooded gum	>1000 mm MAR* for good growth Mean minimum coldest month 0^0C to 16^0C Can be grown with irrigation in dry uniform rainfall areas, e.g. NSW and Vic.**	Eastern Australia with uniform to summer rainfall (tropical to temperate)
Eucalyptus nitens	Shining gum	≥800 mm MAR* Includes frost sites Fertile, friable deep soils Not waterlogged sites, black cracking clays, dry sites or deep sands	South-eastern Australia
Eucalyptus pellita	Red mahogany	>1200 mm MAR* below 450 m altitude Most soil types in tropical areas north of Mackay	North-eastern Australia
Flindersia brayleyana (benchmark for rainforest species trials)	Queensland maple	>800 mm MAR*	North-eastern Australia
Pinus pinaster	Maritime pine	400 mm to 600 mm MAR* Sandy soils	NSW, Vic., Tas., SA, WA
Pinus radiata	Radiata pine	>600 mm MAR* Sandy soils	Tas., Vic., SA, NSW, WA

* MAR is mean annual rainfall
** Jovanovic and Booth (2002)

3.5 Trial layout

For valid conclusions to be made from the research trial, correct trial layout is critical. Careful site characterisation is needed to evaluate where blocks should be situated. As discussed in previous sections, blocks of treatment replicates should be positioned such that **variation within each block is minimised** and differences between blocks are maximised. In an area known to have a fertility gradient in a single direction only, the length of the block should be oriented perpendicular to the direction of the fertility gradient. In contrast, when the fertility pattern is patchy, or is not known, blocks should be kept as compact, or as nearly square as possible (Gomez and Gomez 1984).

Trial layout should also consider the contours of the site (see Section 3.1 and McLeod et al. 2009). Figure 3-2 demonstrates a hypothetical layout for an incomplete block design for twelve provenances and four replicates.

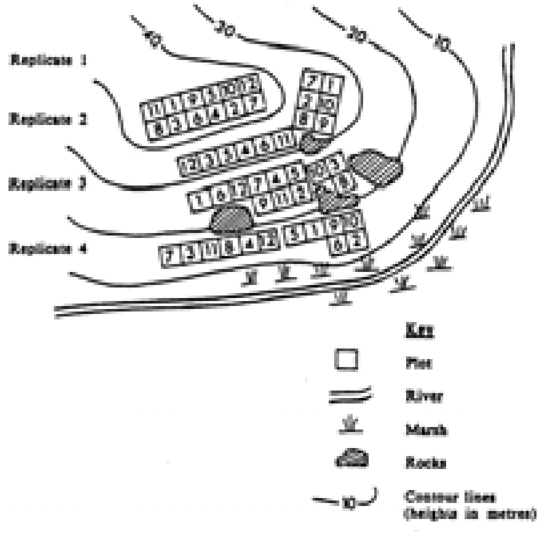


Figure 3-2: A hypothetical layout for an incomplete block design for twelve provenances and four replicates. Source: Carter (1987).

Individual plot size, shape and between-tree spacing (when not being tested) should in most cases remain constant; however the pattern of plots across the trial site does not need to be regular (see Figure 3-2). Plot shape should be considered once plot size has been determined (Section 3.6). As for blocks, plot shape should be as square as possible when the fertility pattern is patchy or unknown, or when border effects are expected to be large. In areas with a distinct fertility gradient, long and narrow plots may be more appropriate (Gomez and Gomez 1984). In this case, the length of the plot should be positioned parallel to the fertility gradient of the site.

3.6 Plot size

Plot size will depend on the objectives of the experiment, the requirements for isolation and buffer rows, initial tree spacing, the expected life span of the trial, the ultimate size of the species used, and the types of measurements to be made (Rao and Roger 1990; Roger and Rao 1990). Plot size should also be chosen based on soil variability across the site. For example, although the QFRI[1] regards plot sizes of 8 rows × 30 – 40 m as ideal for silviculture trials, soil variability across the site can prevent correct blocking unless plots are smaller than this. This often results in plot sizes of 6 rows × 7 trees (G. Dickinson, pers. comm.).

For statistical purposes the plot size should be uniform for all treatments and as large as the largest required plot (Roger and Rao 1990)—a uniform plot size allows within-plot variation to be minimised. The exceptions are spacing trials which may require a common number of trees per treatment and therefore different plot sizes.

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[1] QFRI is now Horticulture and Forestry Science, Department of Primary Industries & Fisheries, Queensland

3.6.1 Buffer rows, isolation rows and guard areas

Plot size is also constrained by the need for *buffer rows, isolation rows* and *guard areas*. These terms are often used inconsistently in the literature. For clarification, the definitions of isolation rows, buffer rows and guard areas in Box 3-5 will be used throughout this document.

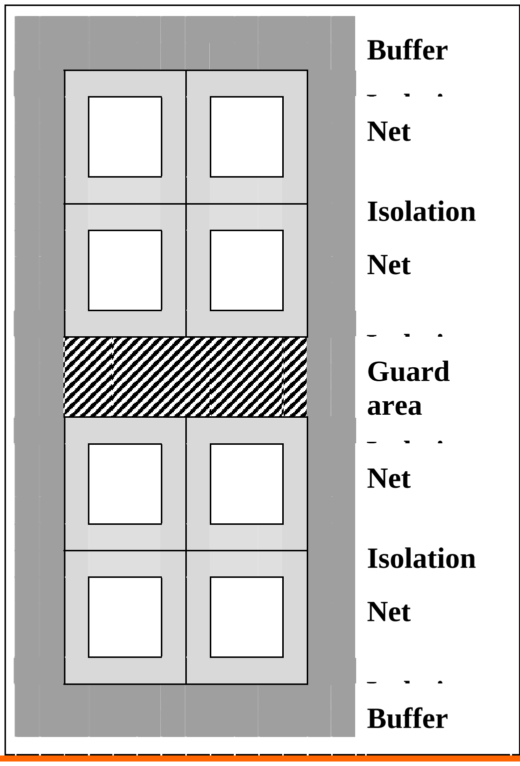
Box 3-5 Buffer rows, isolation rows and guard areas

Buffer rows, isolation rows and guard areas

Buffer rows: These are the external rows of trees surrounding a research trial, used to reduce the effect of the surrounding environment on tree growth. At a minimum, two rows should always surround a research plantation.

Isolation rows: These are rows of trees that isolate different treatment plots to reduce the effects of neighbouring treatments. At a minimum, for nearly all trial types, one row (preferably two) should always surround each treatment. Isolation rows are considered part of the *gross plot* and generally receive the same management. Those trees within the isolation rows are the *net plot* trees and these are generally considered the measurement trees in trials exceeding 12 months duration (see Section 5.3.1).

Guard areas: These are areas that isolate treatments and have no trees planted within them. The term guard is often confused with isolation but should only be used to describe areas where no trees are planted.



Where neighbouring treatments are likely to affect other treatments over the life of the trial, isolation rows are needed. The number of rows will depend on the treatment type (a minimum of one row). This is especially important in fertiliser or species trials where competition between adjacent treatments may increase the treatment differences. In such cases, extra isolation rows should be included in the design. In trials where the interactions between treatments are expected to be large in the long term, guard areas should be used (Langton 1990).

For trials with only a short expected lifespan, generally less than 12 months, where interactions between isolation trees and those of the adjacent treatments are not expected, isolation trees can be included as measurement trees. The measurement of gross versus net plots is discussed in Section 5.3.1.

If a trial is adjacent to cleared land or other contrasting land use, the border trees can be expected to suffer stronger winds, desiccation and other edge effects compared with the interior of the woodlot. This is why it is essential to have buffer rows around a research trial or permanent monitoring plot. The need for buffer rows in trial design was clearly demonstrated by Albertsen et al. (2000) who analysed alley belts of varying width, shape and age in Western Australia. They found that by age 4.7 years the edge effect was clear, with the first edge row having a markedly higher volume (calculated from DBH and height) in most stands. However, wood properties were not analysed in this situation;

other research indicates that buffer trees can have larger branches and greater growth stress from wind shear (R. Knowles, pers. comm.).

Buffer rows should use one of the seedlots used in the trial known to give good growth and survival (Harwood and Williams 1999). Border effects may affect different treatments to different extents (Langton 1990) and so treatment data should not be collected from buffer trees.

3.6.2 Number of trees per plot

Plot size should be chosen based on the required sample size and degrees of freedom at the end of the experiment. Initial spacing and number of trees can be varied depending on the purpose and duration of the trial. For each experiment, a recommended minimum is 60 measured trees per treatment spread over a number of replications which can be measured over the life of the trial (P. A. Ryan and W. Neilson, pers. comms.). For example, if net plot sizes are initially 100 trees per plot in an area of 0.1 ha (i.e. 1000 sph) and there are three replicates, when thinned to 200 sph in the long term, the requirement for 60 trees will be met.

Often there is a trade-off between plot size and replication due to limited space for the overall trial. A higher number of replicates (greater than four replicates) should be used in conjunction with small plot sizes (ForestrySA, pers. comm.). However, the larger the number of replicates the higher the proportion of the trial space occupied by isolation trees. This increases costs and can introduce more site variability. Some adjustment to plot area can be made by reducing the initial tree spacing slightly.

The above recommendation for 60 measured trees per treatment is not always met by forestry research organisations due to space limitations and varying trial objectives. However, where possible the above recommendations should be used for reasons outlined in the introduction, in particular to provide results relevant in the long term. Smaller sample sizes may mean that the results are only applicable in the short to medium term, and such data should be interpreted with caution. Plot sizes approaching those recommended are already used for short- to medium-term trials: for example, the CFTT uses plots of at least 7 × 7 trees, the QFRI uses plots of 6 × 7 trees, and the New Zealand Forest Research Institute uses 3 to 4 replicates of 12 to 15 trees and prefers to have 15 retained trees at the end of the trial (D. Stackpole, G. Dickinson, A. Shelbourne, pers. comms.). Box 3-8 and Chapter 4 give typical numbers of trees per plot for different types of trials.

3.6.3 Single-tree plots

Single-tree plots, as opposed to the block plots described above, have been used in specialised silviculture and genetics designs. In silviculture, some systematic designs such as Nelder wheels, plaid designs, and some mixed species trials, use each tree as a plot. However, if this tree dies or growth is inhibited due to insect attack for example, all adjacent trees (plots in this case) are compromised and need to be removed from the analyses. Due to the broad range of variables that can affect growth and survival in a non-uniform manner, it is relatively easy for the trial to be rendered useless. These problems can however be reduced through adequate replication. With replication, these systematic designs can be useful because:

- they use space very efficiently;
- they are good for identifying trends and selecting a reduced range for more thorough testing; and
- they are visually clear so they are very good for demonstration purposes.

However, in choosing to use single-tree plot designs, one must be aware of limitations and plan to minimise potential problems. The design limitations must be kept in mind when interpreting the data—something that applies to the analysis of all trials (P. A. Ryan, pers. comm.).

The use of single-tree plots in genetic trials should be limited because the between-tree interactions tend to exaggerate the differences between taxa, especially for traits which are sensitive to competition, such as DBH and stem volume (M. Nester, pers. comm.; Rockwood 2000). For example, New Zealand experience is that inclusion of benchmark species as a control in progeny trials using single-tree plot designs has always been unsatisfactory. This is because either the control or the main species will dominate, especially if the growth rate is different when young (A. Shelbourne, pers. comm.). Single-tree plots have other disadvantages for data analysis (Williams and Matheson 1994), but they are used in certain cases, particularly for ranking families in progeny trials (Cotterill and James 1984; see Section 4.2.1). Note that block plantings are much more suitable for forestry trials which aim to achieve anything other than an early ranking of the best species (M. Dieters, pers. comm.).

3.7 Initial tree spacing

Spacing is an important silvicultural tool as it affects competition between trees for resources, and tree form. Close spacing is used to promote better form in some species through encouraging vertical growth, reducing taper, branch retention and branch size, and promoting stem straightness (e.g. Jacobs 1955; Opie et al. 1984; Kearney 1999; Neilsen and Gerrand 1999). A higher initial stocking density may be used where planting stock is from unimproved genetic material and a heavy early thin is anticipated. A wider spacing may be used for low rainfall or agroforestry sites. Nevertheless, it is important to select a spacing and management regime for the desired product. Wide spacing generally requires more pruning, but the intensity depends on the species. For example, *Corymbia maculata* self-prunes even when opn-grown, while *E. nitens* has lots of branches even at 2 m × 3 m spacing (C. Harwood, pers. comm.). Throughout this document, tree spacing is listed as (*between-row distance*) × (*within-row distance*).

Researchers have to decide whether to adopt spacings used in routine plantations or spacings chosen specifically for the trial. If the trial is medium- to long-term and verifying routine practice, routine initial spacing is often used. A variation from routine initial stocking rate may be chosen where poor survival is anticipated, or to minimise branch development or the size of the juvenile core, or to give intermediate thinnings for a return on the investment. The tree spacing within trials will depend on the type of trial, the required timber product (e.g. pulp, poles or sawlogs), the species selected, the anticipated life span of the trial, the intended thinning and pruning regimes, the amount of land available and possibly the site’s resources (e.g. nutrients and rainfall). Box 3-6 shows initial stocking densities used in routine forestry. Box 3-7 shows initial spacings used in routine plantations.

In some trials, alternative tree spacings may be appropriate—that is, spacings not currently in operational broad-scale forestry. For example, close spacing is sometimes used in short-term trials which test herbicide products and rates, weed competition, fertiliser products, as well as species elimination and progeny trials. Close spacing can also be used to increase the competition and rate of response in nutrition trials. Close spacing minimises the land area required, and sometimes means that once poor stock is thinned, a conventional spacing remains (this case would suit a genetics trials which is to be converted to a seed orchard). The disadvantage is that such trials are not comparable with routine plantations in the long term. Wider spacings are used in dry sites, low rainfall areas, some agroforestry trials and some seed orchards. Box 3-8 gives general guidelines for initial tree spacing for a range of research trial types, from very short-term herbicide evaluation trials to longer-term thinning trials. Thinning can extend the life span of these initial spacings. However, in choosing an initial tree spacing for a trial, the research must consider whether this will change the effect of other treatments being tested or compromise future silvicultural management.

Box 3-6 Initial stocking densities used for major hardwood plantation species of Australia, based on operational forestry on conventional sites

Initial stocking densities used for major hardwood plantation species of Australia, based on operational forestry on conventional sites

The following data are based on individual comments from silviculture researchers in Australia in 2001 and may not be representative of all organisations or planting situations.

Region	**Species**	**Purpose**	**Initial stocking rate (sph)**	**Reference**
NSW	*Eucalyptus* spp.	Solid wood	1000–1250	Bruskin (1999)
NSW	*Eucalyptus* spp.	Solid wood (dryland planting with more improved stock)	650–850	B. Royal, pers. comm.
NSW, Vic.	*E. grandis, E. maculata, E. globulus* and others	Irrigated trials (solid wood, pulp)	1250–2500	*
NSW, other states	*Eucalyptus* spp.	Low rainfall sites	625–1000	Depends on species (C. Harwood, pers. comm.)
Qld	*Eucalyptus* spp.	Solid wood	1000–1250	G. Dickinson and M. Bristow, pers. comms.; QDPI—F joint ventures
Qld	*Eucalyptus* spp.	Pulp	1250	G. Dickinson, pers. comm.
Qld, NSW	Rainforest cabinet spp.	Solid wood	1000–1667 Sometimes as high as 3090 initially	*
SA	*E. globulus*	Pulp	1000–1200	ForestrySA
SA	*Pinus radiata*	Solid wood	1600	ForestrySA
Tas.	*Eucalyptus* spp.	Pulp	1100	E. Pinkard, pers. comm.
Tas.	*Eucalyptus* spp.	Solid wood	1100	E. Pinkard, pers. comm.
Vic.	*E. globulus*	Solid wood	1100	M. Duncan, pers. comm.*
Vic.	*E. grandis*	Solid wood	1100	M. Duncan pers. comm.*
WA	*E. globulus*	Pulp	1250	R. Harper, pers. comm.
WA	*E. globulus*	Solid wood	1250	R. Harper, pers. comm.
WA	*Pinus pinaster*	Solid wood	1500–1800	Shea and Hewett (1997)
WA	*Pinus radiata*	Solid wood	1500	Shea and Hewett (1997)
WA	*E. globulus; E. grandis hybrids and others*	Pulp and solid wood	850	S. Collins, pers. comm.

* Based on the data contributed to SILVDAT, a national database of hardwood plantation silviculture research trials produced by the National Farm Forestry Silviculture Project and funded by JVAP

Box 3-7 Initial spacings used in current routine hardwood plantations (and research trials) in Australia

Initial spacings used in current routine hardwood plantations (and research trials) in Australia

Initial spacing (m)	Initial stocking density (sph)	State or organisation	Location and purpose
4.0 × 2.0 4.0 × 2.5 5.0 × 2.0	1000–1250	QDPI-F and QFRI	South east and north-east Queensland; for routine plantations and most hardwood research trials (G. Dickinson, pers. comm.)
4.0 × 2.0 4.0 × 2.5	1000–1250	State Forests of NSW	Tree improvement trials in coastal and northern NSW for *E. pilularis*, *C. variegata*, *E. grandis*, hybrids, recent trials (I. Johnson, pers. comm.)
4.0 × 2.5	1000	State Forests of NSW	Low rainfall salinity-prone sites (for rapid water uptake) (B. Royal, pers. comm.)
4.0 × 2.0 3.0 × 3.0 4.0 × 2.5	1000–1250	Victoria	*E. globulus* production on sites with adequate rainfall in southern Australia (Bird 2000).
4.0 × 2.0 4.0 × 2.5 4.0 × 3.0 4.0 × 4.0	625–1250	ALRTIG	Evaluation of eucalypt provenances and progeny in low rainfall sites in southern Australia (C. Harwood, pers. comm.)
3.0 × 3.0	1100	Greening Australia >600 mm trials	>600 mm MAR*, with subsequent intensive thin (D. Carr, pers. comm)
4.0 × 3.0	833	Greening Australia low rainfall trials	States (except WA) with drier areas <600 mm MAR* (D. Carr, pers. comm)
4.0 × 2.0	1250	Greening Australia low rainfall trials	WA drier areas <600 mm MAR* (D. Carr, pers. comm)
4.0 × 2.5 (3 to 3.5) × (2 to 2.5)	1000–1430	Forestry Tasmania	Plantations and research trials (*E. nitens*, *E. globulus*, *E. regnans*)**
4.0 × 2.0 (5.0 × 1.6)	1250	Forest Products Commission of WA	*E. globulus* chipwood regime (5.0 × 1.6 used where access between rows restricted by surface lateritic rocks; I. Dumbrell, pers. comm.)
4.0 × 2.5	1000	Forest Products Commission of WA	Proposed plantings of sawlog *E. globulus* at sites with 600 mm to 750 mm MAR*
4.0 × 3.0	833	Forest Products Commission of WA	Proposed plantings of sawlog *E. globulus* at sites with 450 mm to 600 mm MAR*
3.0 × 3.0	1100	Department of Primary Industries, NT	Research trials (D. Reilly, pers. comm.)

* MAR is mean annual rainfall

** Gerrand et al. (1997), Medhurst et al. (2001), Neilsen and Ringrose (2001)

Box 3-8 Suggested use and life span of trials planted at a range of initial spacings

Suggested use and life span of trials planted at a range of initial spacings

Initial spacing (m)	Initial stocking rate (tph)	Implications and uses
1.0 × 1.0	10 000	Suitable for very short-term trials (12–18 months) Used for some competition and effluent trials
2.0 × 1.0 3.0 × 1.0	5000 3333	Suitable for very short-term trials (12–18 months). Used for some herbicide screening trials
2.0 × 2.0	2500	Suitable for short-term trials (2–5 years) Used for herbicide and competition trials; trials for small wood products as end use
3.0 × 2.0	1667	Suitable for medium-term trials (3–8 years) Allows mechanical access Used for species, provenance and progeny trials
3.0 × 3.0* 4.0 × 2.5	1111 1000	Suitable for medium-term trials (5–10 years) Allows mechanical access (both directions) Used for silvicultural and plantation trials
5.0 × 2.5 4.0 × 3.0	800 833	Suitable for long-term trials (10–15 years) Allows mechanical access (both directions) Used for silvicultural and plantation trials
5.0 × 3.0	667	Suitable for low rainfall or long-term trials (15–20 years) Operational harvesting machinery access Used for silvicultural and plantation trials (depending on branching characteristics of species)
4.0 × 4.0** (or greater)	625 (or less)	Appropriate for agroforestry or long-term trials in low rainfall climates

* Spacings of 3.0 m × 3.0 m (1111 tph) or 4.0 m× 2.5 m (1000 tph) allow good early mutual sheltering and promote good form, and give ample selection for final stocking after thinning. Spacings of 3.0 m × 3.0 m, 4.0 m × 2.5 m, or 4.0 m × 2.0 m are required for *E. globulus* production on sites with adequate rainfall in southern Australia (Bird 2000).

**Williams and Matheson (1994). Note that the ALRTIG chose from (4.0 m × 2.0 m), (4.0 m × 2.5 m), (4.0 m × 3.0 m) or (4.0 m × 4.0 m) spacings for evaluation of eucalypt provenances and progeny in low rainfall sites in southern Australia (C. Harwood, pers. comm.).

Source: adapted from Burley and Wood (1976), Williams and Matheson (1994), Bird 2000 and McLeod et al. (2002).

3.8 Choice of silvicultural management—general comments

Whichever baseline management practice is chosen for the trial site, becomes (one of) the control treatments. Depending on the situation, either *current best operational* forestry practice or *best feasible* silviculture is used. Use of current best operational forestry practice will allow the trial to be compared with tree growth in other plantations and research trials of the same age. It will also give the opportunity to judge any improvement shown by the research trial results against current operational silviculture. However, there are several limitations to the use of current operational forestry practice in research trials. Firstly, operational silviculture is dictated by economic expediency, and silvicultural practice may be less than optimum for maximum tree growth or yield. Secondly, operational techniques change, which can render the trial out-of-date. Thirdly, operational practices may not be appropriate for the species being tested. Fourthly, to adequately assess the effect of some treatments, it may be desirable to remove other possible impediments to tree growth from the trial. For example, it may be necessary to add micronutrients to remove deficiencies in the soil, in order to allow uptake of other nutrients being tested.

Whichever standard is adopted, it should be defined and preferably used across a group of trials, so that they are comparable in the long term. Researchers who have compared a series of long-term trials have found them difficult to analyse meaningfully because different operational management or control treatments were used and sometimes not defined or written down.

In some cases it is sufficient to use current best operational silviculture practice for each aspect of management *not* being tested in the research trial. For example, thinning and pruning trials tend to be conducted in routine stands. Later-stage species and provenance proving trials can be established using operational practices. However the implications if operational silviculture is not optimal for research outcomes need to be considered. For example, good weed control is essential to properly detect the effect of fertiliser applications on tree growth. Poor weed control can result in strong weed competition, which often masks the effect of fertiliser application, and sometimes that of site preparation treatments (Borschmann 1997; Duncan and Baker 1997; Keenan and Bristow 2001). Similarly, appropriate nutrition is important.

In species and provenance evaluation trials, best feasible silviculture should be used. This will allow the trees to show their full genetic differences and response to the site, rather than being hampered by inadequate silvicultural management. However, it is generally recommended that current practice with regard to initial stocking densities is used (Box 3-6 and Box 3-7).

For certain types of trials, alternative silviculture may be appropriate. For example, high rates of fertiliser are occasionally used (for reasons stated above), although this is too expensive for current operational practice. In some trials, alternative tree spacings may be appropriate—that is, spacings not currently in operational broad-scale forestry.

Other factors that can affect either the management, treatment choice or the success of the trial include site fertility, slope, soil type, weed densities, planting stock size and health, and choice of seedlot or cross-pollination family. These should be planned for accordingly. Bear in mind that there may be situations where different site preparation is required for each trial site (unless site preparation is being investigated), to provide optimum tilth and prevent problems with erosion or waterlogging.

3.9 Quality control

It is important that during trial establishment the trial design is implemented exactly as planned. Should changes be required at planting due to unforseen circumstances, the re-alignment should be checked with the trial's designer, and the changes carefully documented. Any refills should be done within a few months and be of the same species, provenance and nursery practice. The trial should be measured soon after planting and refills recorded. Human error can introduce more variation into an experiment, and it is best to plan to minimise this. Some common causes are shown in Box 3-9.

Box 3-9 Guidelines for avoiding common causes of error

Guidelines for avoiding common causes of error

- Site preparation and row spacing should be kept as consistent as possible to maintain correct plot sizes and yield estimates.
- Good quality planting stock is required for research trials, especially genetics trials. Poor survival rates affect the growth of the remaining trees and the effectiveness of the plot-level data, especially for longer-term trials.
- Similarly, the effect on tree growth of spacing after thinning should be considered. Thinning should be carried out using the same system across the trial.

- Uniform application of fertiliser and weed control is important.
- Care should be taken in measuring plot dimensions (Section 5.5.13) and in labelling plants in the nursery and plots in the field so that planting and data collection is accurate.
- Particularly when measurement is monotonous, data should be checked at the end of each measuring day while the trees are still nearby for re-evaluation. If transferring data to another system, proof-reading is recommended.
- Field workers should understand the purpose of the experiment so that actions taken are consistent with the goals of the experiment.

Source: Gomez and Gomez (1984).

It is also worth considering the possibility of mishaps. For example, is replacement planting stock available if survival is poor or browsing levels are high? Can the plots be re-aligned if necessary? In some regions particular attention must be paid to time of planting and management with regard to the local environment, for example drought and severe frosts in the Tasmanian midlands, or fire, storms, termites and seasonal waterlogging in the Northern Territory.

Remember that funding limitations will determine the length of the trial and whether long-term maintenance is available. The planning of the trial should provide for future management and measurement.

3.10 Statistical analysis and documentation

An integral part of any research trial is statistical analysis. Appropriate methods of statistical analysis should be chosen when the experiment is being designed and checked with a biometrician. Once collected, the measurement and assessment data from the trial should be analysed or checked by a statistician or biometrician. In presenting the results, it is necessary to use statistics to verify whether treatment means are significantly different—it is not sufficient to graph the means without showing an estimate of variability or error. If there is significant interaction between the tested factors, this must be reported first before discussing the effect of individual treatments. Methods of statistical analysis for research trials are well covered in numerous texts (e.g. Cochran and Cox 1956; Gomez and Gomez 1984).

To achieve a conclusion from your trial which is statistically valid (i.e. not due to chance) and with the level of confidence that you require, minimum statistical requirements will need to be met, based on your desired level of precision (Stamps and Linit 1999). These were discussed in Chapter 1 and 2 are summarised in Box 3-10.

For all trials, adequate site description and management records must be kept. Site description, trial establishment and subsequent management should be documented in a series of reports (see Chapter 7 and Appendix 5 and Appendix 6). The planning for the project should allow time to analyse data and to report—once the funding runs out, it becomes difficult to write or obtain the final results!

Box 3-10 Minimum trial requirements for statistically valid conclusions

Minimum trial requirements for statistically valid conclusions

To derive statistically valid conclusions, the following are required:

- proper controls, where control plots should preferably have the same size and shape as the other plots and be equally randomised and managed. Often treatments are equally replicated, but sometimes controls should have more replication than other treatments;
- sufficient replication of treatments;
- proper randomisation of treatments without bias (see point 8 in Box 2-1);
- assessment of potential interactions between treatments and blocks (see Section 3.2);
- selection of treatments and management operations appropriate to the site and questions being asked;
- reduction of edge effects though maximising plot size and including isolation rows between treatments (i.e. plots), blocks and adjacent trials (see Section 3.6.1);
- sufficient plot size to overlay future treatments where required—this means designing for future sampling for the given objectives (i.e. certain designs may limit future analysis—see Section 3.6);
- optimum silvicultural management and tree spacing for all aspects of management not being tested in the trial; and
- selection of the appropriate statistical analyses for the chosen design—for example, multivariate analyses can be used for complex trials to provide more robust conclusions.

4. Designing for specific trial types

Chapter outline

This chapter focuses on aspect of design for specific types of silvicultural research trials, such as site preparation or fertiliser trials, as well as species and provenance evaluation trials. Topics include requirements for buffer and isolation rows, plot size, minimum replication, factors likely to interact with the treatments imposed, silvicultural management and measurements particular to each type of trial. The guidelines are based on designs currently in use in silvicultural research experiments, as well as experience from past research by silvicultural researchers in Australia.

4.1 Introduction

Final trial designs are often compromises between available resources and the statistical robustness of trials. Reasons for the compromises include:

- high land prices and limited availability of land
- lack of land units of suitable size with appropriately homogeneous climate and soil types (this may compromise the required replication for trial robustness)
- occurrence of gradients across the site
- cost of establishment and maintenance of a research trial
- limited availability of appropriate genetic material;
- difficulty in applying some treatments to randomised plots
- requirements for soil erosion mitigation or drainage
- requirements for fire breaks and access roads.

Due to the range of resource and design limitations and the individuality of each experiment, some exceptions or variations to the recommendations provided in this document can be expected. It is advisable to consult a regionally experienced researcher as well as a statistician or biometrician to review each proposed experimental design prior to implementation. This will provide a second opinion, prompt for missed considerations, give advice regarding advances in experimental design and statistical analysis, and at worst, avoid invalidating the results of the trial due to inadequate design through inexperience or cost-cutting. If adhered to, the guidelines provided here will provide consistent, reliable and useful research results for use into the future.

The pages that follow give separate guidelines for different types of silvicultural trials.

4.2 Genetics trials

Genetics research which aims to identify the best material for a site should be designed as a sequence of trials (Eldridge et al. 1993). Where little information is available for a site, the first step is a species elimination trial to identify the best species for a site. Often only two or three species are chosen for further research. This is followed by species-provenance or provenance trials. Later tree-breeding work can evaluate progeny or clones.

Species elimination trials test a large number of different species on a chosen site over a short term. Even at this early stage, it is best to include, say, three or more provenances for species which have a wide distribution (Eldridge et al. 1993). Realistically this will be two to three provenances per species in a large trial, but if line plots are used, more provenances can be included and replicated (G. Nikles, pers. comm.). Provenance trials test differences between different provenances of a species. Provenances can be tested along with progeny if sufficient resources are available for large trials (Eldridge et al. 1993).

Seed orchards are a special type of trial made up of multiple provenances, clones or seedlings from selected trees, isolated to reduce external pollination, for the early production of seed. They are designed to maximise interbreeding of distantly related trees. The QFRI uses an in-house computer package called *Seed orchard designs* (SOD) written by Vanclay (1991) for clonal seed orchards (D. Lee, pers. comm.). This software allocates single-tree planting positions to maximise genetic differences between adjacent trees across the site. The trees in the centre have the most rigorous genetic variance maximisation (neighbours are most distantly related based on their genetic history) based on available planting material (D. Lee, pers. comm.). The program also ensures that the probability of inbreeding is reduced by allocating families (or clones) to different positions within the replicate, block or site (S. Hetherington, pers. comm.). Initial seed orchards should avoid bulking seed from different seed parents as knowledge of individual seed parents will be lost after thinning (G. Nikles, pers. comm.). It may be suitable to bulk seed after the performance of seed parents or provenances is proven (G. Nikles, pers. comm.).

The plot size used in genetics trials will vary depending on the type of trial and its duration. Line plots are often used for species elimination trials and single-species trials which evaluate progeny or clones. Larger plot sizes should be used for longer-term species-provenance or provenance trials because the trial should run for at least half the rotation. In progeny trials, small plots are effective in short-term experiments concluded by age 5 years—single-tree plots should only be used when very high survival (more than 95%) can be expected (Eldridge et al. 1993). In such trials, the number of replicates is equal to the number of trees per family.

Analysis of data from long-term trials has shown a large edge effect in species trials. New Zealand experience with 49-tree and 64-tree plots with 3 or 4 replicates (Low and Shelbourne 1999; Shelbourne et al. 2000) is that by age 11, large edge effects are evident. The conclusion reached is that larger plot sizes are required with 2 isolation rows between plots and 12-tree to 15-tree net plots; preferably, the net plots should have 15 trees remaining at the end of the trial (A. Shelbourne, pers. comm.). This means initial plot sizes of 81 to 144 trees at planting, including the two isolation rows. A recent proposal is for two isolation rows between species with even moderate variation in growth and a buffer area of at least four rows surrounding the trial (A. Shelbourne, pers. comm.).

Section 4.2.1 gives general guidelines for the design of genetics trials. Further information on design of genetics trials is provided in Burley and Wood (1976), Carter (1987), Cotterill and Dean (1990), Eldridge et al. (1993) and Harwood and Williams (1999). Advice targeting species and provenance trials is provided in the JVAP manual *Designing farm forestry trials for species and provenance selection* (McLeod et al. 2009). Specific advice on the design of trials can be provided by the Australian Tree Seed Centre (CSIRO) or the Southern Tree Breeding Association.

4.2.1 Species, provenance and progeny evaluation trials

Purpose — Genotype trials test species, provenance, progeny or clones to identify the best material for a site and required product. A variety of traits, including height, diameter, survival, form, branch diameter, internode length, insect and pathogen resistance and wood quality may be assessed. Especially when working with short rotation species, survival is an important parameter whilst attempting to maximise productivity. Therefore survival needs to be considered in selection programs[1]. If information is required on the expression of these traits in plantation, measurements must be made accordingly. In tree breeding programs, research is also concerned with estimating the variability within families of progeny produced from individual trees. Trees with desirable traits are selected for further breeding or incorporation into propagation populations for the production of seed, hybrids or clones.

Design — ***Species and provenance evaluation***: Species and provenance trials generally use randomised complete block or incomplete block designs[2]. If more than 10 large seedlot plots or 20 small seedlot plots are to be planted then an incomplete block design is essential[3]. Species trials should consider including a number of provenances (chosen relative to the breadth of the species' natural distribution). Provenance samples should be a balanced bulk from, preferably, seven or more seed parents and this should be documented[4]. Sometimes a trial will test several provenances of a few species over a longer term. As the growth rates will often differ more among species than among the provenances within species, this should be laid out as a split plot design[3]. There are several computer programs which assist with design of tree breeding trials. Of these, *CycDesigN*[5] and *ALPHA+*[6] are mostly used in QFRI[7]. On some occasions, block plantings each of different species have been overlaid with silviculture treatments, such as establishment method[8]; fertiliser[9]; irrigation[10] or later age thinning—these are therefore split plot designs.

Progeny trials: In progeny testing there are usually very large numbers of entries (families) and a randomised complete block design is rarely appropriate. Some form of incomplete block design is necessary[3].

Isolation — Buffer rows should be a minimum of one entire row (preferably two) around sites and the last two trees at ends of each row. For long-term species–provenance trials, at least four buffer rows are optimum where adjoining open space or younger tree crops[11]. As species elimination and provenance trials generally test large numbers of species or provenances, making trial size large, isolation rows are not used as these increase plot size, adding more potential site variation to plots[12]. However, for long-term species–provenance trials A. Shelbourne recommends at least two isolation rows between different species likely to have even modest variation.

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1 Chambers and Borralho (1997)
2 McLeod et al. (2002)
3 Eldridge et al. (1993)
4 G. Nikles, pers. comm.
5 Whitaker et al. (1998)
6 Williams and Talbot (1993)
7 D. Lee, pers. comm.
8 Marcar et al. (2000)
9 Cromer et al. (1981)
10 Milthorpe et al. (1994)
11 A. Shelbourne, pers. comm.
12 C. Harwood, pers. comm.

Plot size — Box 4–1 indicates plot sizes and the replications used in common types of genetic trials. Some further comments are:

Species elimination: If the trial is purely for early ranking of a large number of seedlots (e.g. 100), after which a new trial will be started, then small plots may be justified, e.g. 6-tree line plots with 10 replicates or 12-tree rectangular plots replicated 5 times[1] (see Box 4–1).

Species and provenance trials: For short- and medium-term assessments of hardwood species and provenance trials QFRI uses randomised complete block designs, with gross plots consisting of 4 rows × 10 trees or 6 rows × 12 trees[2]. The larger plots are preferred as these can be thinned and still have a relatively long lifespan. For species proving, a net plot size of 10 rows × 10 trees[3] is recommended, which is consistent with the number of trees per plot recommended in Section 3.6.2.

Progeny trials: The QFRI guidelines for progeny and clonal trials usually consist of four-tree line plots. Single-tree plots are considered too risky as less than 100% survival reduces replicates and creates difficulties for analysis (see Section 3.6.3). In addition, the inner two trees of a four-tree row will tend to be more representative of a real plantation situation than single-tree plots[4].

Single-tree plots: The use of single-tree plots should be limited because the between-tree interaction tends to exaggerate the differences between taxa, especially for traits which are sensitive to competition, such as DBH and stem volume[5]. Single-tree plots can be used for progeny trials within a single species trial providing they are well replicated across the site, for example 20 to 50 replicates per set, with a set comprising 20 to 40 families[6].

Replication — An absolute minimum of four replicates should be used for well-conducted species or provenance trials on good sites, and preferably five or more for provenance trials[1]. More replicates are required for variable sites. Around 20 to 25 trees per family will allow ranking of families with reasonable accuracy[7].

Life span — Life span varies depending on trial type (see Box 4–1). Species and provenance evaluation trials are often assessed initially after less than five year's duration. However Clayton and Bartlett (1998) showed that ranking of eucalypt species by height clearly changed between two, three, five and twelve years of age. Similarly, Low and Shelbourne (1999) found changes in relative performance between four and seven years. Therefore, care should be take to consider the intended life of the trial.

Silviculture — It is essential that silvicultural techniques are implemented evenly and thoroughly across the whole experiment at correct time intervals to minimise experimental error[8]. Any silviculture treatment such as thinning, pruning or fertilising should be done at the same time as scheduled measurements[9]. Best-practice silviculture should be used rather than other research practices, as genetic trials (often with small plot sizes) need to clearly identify differences due to genotype and site rather than inadequate silvicultural management. Spacing should generally be representative of routine

1 Eldridge et al. (1993)
2 D. Lee, pers. comm.
3 Burley and Wood (1976); Shelbourne, A., pers. comm.
4 M. Nester, pers. comm.
5 M. Nester, pers. comm; Rockwood (2000)
6 A. Shelbourne, pers. comm.
7 Cotterill and James (1984)
8 P. A. Ryan, pers. comm.
9 J. Huth, pers. comm.

practice for the species used, as selection from non-routine spacing may not be beneficial.

Other uses — Trials for insect and pathogen resistance or wood quality can be overlaid on provenance or progeny trials providing there is sufficient replication. Provenance or seedlot trials can be culled and converted to a seed orchard.

Box 4-1 Common types of genetic trials and recommended designs

Common types of genetic trials and recommended designs

Type of trial	Replicates	Plot size	Useful life of trial
Species elimination	6 to 8	6-tree row*	3 to 6 years, perhaps longer where growth is slow**
Provenance	4 or 5	25-, 36- or 49-tree block	At least half a rotation
Progeny	4 to 6	4- to 8-tree row	Half a rotation (systematic thinning if required)
Seedling seed orchard	5 to 8 (or more, to increase orchard size)	3- to 5-tree row	Developed from progeny trial by selective thinning—only pre-thinning assessments give accurate genetic information
Clone—initial screening of many clones	4 to 6	2-, 3- or 4-tree row	3 to 6 years, perhaps longer where growth is slow
Clone—proving best clones	4 or 5	25-tree block	half a rotation

* 5–10 tree rows are common (Burley and Wood 1976; McLeod et al. 2009).

** In faster-growing trials, a maximum of two years for valid growth data, but can be useful for observational data up to 10 to 15 years (P. A. Ryan, pers. comm.).

Source: Harwood and Williams (1999).

4.3 Silviculture trials

4.3.1 Site preparation trials

<u>Purpose</u> To investigate the usefulness of different methods of modifying the soil substrate to improve tree growth, either by cultivation, ripping, mounding, or some combination of these treatments.

<u>Design</u> Randomised complete block design is frequently used[1]. Split plot designs are used where it is impractical to apply one treatment factor to small plot areas due to the size of machinery[2]. Appropriate treatments will depend on the questions being asked, but also the conditions at the site including slope, soil type, salinity, waterlogging, drought proneness, weed density, and previous land use. Where an experiment extends across more than one site, site preparation techniques should be appropriate for changes in soil type. For this reason, care should be taken when selecting sites as soil type will influence erosion prevention requirements and therefore design. If possible, trees should be planted in parallel and perpendicular rows (i.e. “on the square”). However, where designs require ripping and mounding on the contour for environmental reasons (e.g. soil type), plot area should be accurately calculated and the reported spacing adjusted accordingly. When spot treatments are compared with line or other treatments, ensure that the same stocking rate is used. There is a strong interaction between soil type, site preparation and machinery, so it is very important to report what machinery is used and its effectiveness at each site (e.g. actual ripping depth), as well as soil moisture status.

<u>Isolation</u> Guard areas are essential when conducting mounding trials, as water dispersal patterns within sites are altered[3].

<u>Plot size</u> Design and plot size should take small scale variation within the site into account, especially variations in soil, as this may give misleading results with regard to site preparation treatments[4]. Plot size should be large enough so that experiments will have a lifespan of an entire rotation. For QFRI hardwood trials, a fairly routine gross plot size is 6 rows × 7 trees for short-term trials[3].

<u>Replication</u> An absolute minimum of three, but usually four, replicates is required[5].

<u>Life span</u> Life span is from a minimum of three years through to a full rotation.

<u>Measurement</u> It is important to take measurements over the long term as effects may take some time to show[6].

<u>Other uses</u> Assessing species tolerance to saline sites.

1 e.g. Huth and Nester (1997); Holz et al. (1999); O'Connell and Grove (1999)
2 e.g. Keenan and Bristow (2001)
3 G. Dickinson, pers. comm.
4 P. Sands, pers. comm; e.g. Mummery et al. (1999)
5 ForestrySA, pers. comm.
6 G. Holz, pers. comm.

4.3.2 Weed control and herbicide trials

<u>Purpose</u> There are three main reasons for weed control experiments:

- phytotoxicity of the herbicide
- effectiveness of the herbicide on target weed spectrum
- impact of weed competition on tree growth.

These aspects are often confused and addressed in one trial when they are best addressed individually[1].

<u>Design</u> Randomised complete block design is frequently used[2]. Trials should avoid or design for chemicals which move laterally. Chemical rates chosen as treatments should be checked with regional experts. For example, recommendations vary from one region to another (e.g. rates recommended in the tropics differ from those for southern Australia).

For field ***evaluation of herbicides***, guidelines are given by Australian Weeds Committee (1979). For herbicide screening, at least three rates for each product should be tested in addition to the control treatment (Australian Weeds Committee 1979). Spray nozzles and containers should be washed out between different treatments[3]. Logarithmic sprayers are generally only suitable if there is one target weed species, with a uniform spread of the plant[3]. Logarithmic sprayers can be useful to get an initial feel for appropriate rates to test further, particularly for pasture sites, but they give problems statistically due to uneven replication[4]. Where an array of weed species and abundances occurs, replicated treatment plots are preferable. Herbicide trials should be tested on a range of sites or environmental conditions.

Weed competition experiments require uniform land and a sizeable area to allow replication of larger treatment plots. Square, rectangular or line plots are used depending on the life of the trial[3].

<u>Isolation</u> For chemical trials, isolation is usually small or absent if an interaction between treatments is not expected and trial life span is short[5]. Isolation rows are often not required if treatments are only applied under ideal conditions and trial life span is short[3]. If weeds are very aggressive or off-target herbicide movement is likely then a one-or two-tree isolation row is used[6]. In longer-term trials at routine spacing (e.g. 5 m × 2 m or 5 m × 2.5 m), the QFRI uses two-tree isolation within the rows but not between rows[3]. In trials testing competition effects, isolation rows are definitely required. At a routine spacing of (3.5 m to 4.0 m row spacing) × (2.2 m to 2.3 m tree spacing) (i.e. 1100 sph), a one-row isolation either side of the net plots and one tree at the front and back end of the row can be used[7].

<u>Plot size</u> Plot sizes vary depending on application technique and proposed life span. For herbicide product and rate trials, QFRI uses a minimum per treatment of three replications of 20-tree line plots. A between-row spacing of 2 m is common (but varies up to 5 m)[3]. A 2 m band for spraying is fairly standard. For weed control trials of less

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1 G. Holz, pers. comm.
2 e.g. Fagg (1988); Wilkinson and Neilsen (1990); ForestrySA, pers. comm.
3 M. Podberscek, M., pers. comm.
4 C. Barnes, C., pers. comm.
5 R. Fremlin,; ForestrySA, M. Podberscek, C. Barnes, pers. comms.
6 ForestrySA, pers. comm.
7 C. Barnes, pers. comm.

than two years duration, ForestrySA usually uses 12-tree plots (strip, square or rectangular; minimum of four replications). For trials longer than two years duration, square or rectangular plots of 16, 25 or 36 measured trees are used depending on the length of the trial. These are often incorporated within routine plantations. For longer-term trials, the QFRI uses square or rectangular plots at routine spacing, with generally 100 trees planted per treatment and a total of 60 trees measured[1].

Note: Herbicide trials often try to minimise the land area required, and close spacings are often used (Box 3-8). However a between-row spacing of 1 m is not recommended. This is because a narrow spray-width (<0.5 m) is not wide enough to sample weed control. Although 1 m x 1 m spacing has previously been used for screening for phytotoxicity effects[2], this is not recommended—a 1 m x 1 m spacing does not represent commercial planting situations, neighbouring treatments can receive a phytotoxic effect if chemicals move laterally, and in Queensland the herbicide gets a row shade benefit within 6 months[1]. This prevents accurate measures of the extent of weed control.

Replication — An absolute minimum of three, but preferably four, replicates is required for screening trials[3].

Life span — The life span is generally 12 to 24 months for herbicide screening trials, but up to a full rotation for weed competition experiments. Trials should be of sufficient duration to determine whether the relative benefit of weed control treatments declines with time[4].

Silviculture — Ensure that the sites have adequate nutrition, otherwise the seedlings may not respond to weed control treatments[5]. Operational site preparation is used, but be aware that planting stock and good quality site preparation can reduce the necessity for weed control[4]. In weed competition experiments, spacing and management is usually routine[6]. Herbicide tolerance trials should be sited on weed-free areas so that direct effects on tree yield can be measured[3].

Measurement — Herbicide screening trials should assess crop tolerance (i.e. phytotoxicity, growth) and efficacy of weed control. A minimum of three recording times during the growing season should be aimed for, and one in the next growing season to assess long-term effects on e.g. perennial weeds, or residual effects on target weed populations and tree seedlings[3]. For example, Australian Weeds Committee (1979) recommend that pre-emergence and post-emergence applications to young transplants should be assessed for weed efficacy at between 10 and 20 days, 1–2 months, 2–4 months and in the next growing season. Plantation trials should be assessed at 30 days and at 2, 3, 6, 9 and 12 months and possibly later.

Weed competition experiments assess weed species composition and abundance as well as tree growth[7].

Other uses — Estimates can be made of the effectiveness of treatments on different weed species.

1 M. Podberscek, pers. comm.
2 M. Ferguson, , pers. comm.
3 Australian Weeds Committee (1979)
4 see Neilsen and Ringrose (2001)
5 J. Simpson, pers. comm.
6M. Podberscek,and C. Barnes, pers. comms.
7 e.g. Baker et al. (2000)

4.3.3 Fertiliser trials

Purpose — Fertiliser application can be an opportunity to cost-effectively increase productivity without increasing the area of the plantation[1]. Fertiliser trials are established to identify limiting nutrients and to quantify optimum rates, methods and timing of application to improve tree growth. Ideally, a nutrition research program includes early glasshouse and short-term field trials that modify the available soil nutrients or elements to quantify the effect on tree growth and/or deficiency symptoms. Pot and field trials can also test seedling response to a range of soils. Frequently, early trials use nutrient omission or addition treatments to identify which nutrients may be affecting tree growth. Results from these trials can then be used to design factorial trials (short- to medium-term) to more fully investigate the interactions between limiting nutrients[1]. The results from these trials can then be used to design long-term trials, established under operational conditions. These are designed to provide long-term response data which allow economics of fertiliser options to be derived[1]. The general nutrition of eucalypts has already been the subject of substantial research in Australia and overseas (Attiwill and Adams 1996; Dell 1996; Kriedemann and Cromer 1996). However requirements for different species and sites is still inadequately understood.

Design — Randomised complete block designs are most frequently used[2]. The trial should be designed after analysis of soil samples from the sites and using prior knowledge on nutritional requirements of the species. Because elements and quantities interact[3], it is wise to seek sound nutritional advice early in the design of the experiment. This will establish which elements and combinations are appropriate to your species and site.

When designing experiments[1], nutritional advice and individual research should aim to:

- identify limiting nutrients for particular sites and species;
- determine the size, pattern, and type of response to nutrients;
- if optimising fertiliser regime, identify which nutrients, when to apply them, which form of the element to apply and how to apply the fertiliser; and
- work within an economic context that is environmentally sustainable and incurs minimum adverse off-site effects.

Factorial experiments are particularly useful in tree nutrition research because interactions between nutrients are common[4]. Treatment selections can be complete[5] or incomplete factorials. Frequency of nutrient application depends on the mobility of different elements; for example nitrogen is mobile and often requires repeat applications.

Isolation — Isolation rows are essential, especially for longer-term trials, but their extent depends on the soil profile as well as the mobility of applied nutrients. If there is a hard clay pan then lateral movement is likely (and greater lateral extension of tree roots). If the site is a deep sand the lateral mobility of nutrients is reduced[6]. Movement of different

1 J. Simpson, pers. comm.
2 e.g. Ritson et al. (1991); Birk and Turner (1992); Bennett et al. (1996); Bennett et al. (1997); Khanna (1997)
3 Birk (1994)
4 Webb (manuscript)
5 e.g. Turnbull et al. (1994)
6 P. Polglase, pers. comm.

elements varies; for example, nitrogen and potassium exhibit high mobility, whereas phosphorus is less mobile. Effects of *nutrient recycling* (dropping of leaves and spreading roots) should also be considered as this allows the progressive movement of applied nutrients throughout a trial.

The isolation area needs to be of sufficient width to contain edge effects so that treatments are not compromised[1]. For longer-term trials, recommendations vary from one to four rows, depending on the situation[1]. In Queensland, nitrogen trials require three isolation rows whereas phosphorus requires one[2]. For their sites, ForestrySA recommend at least four rows of isolation trees between plots (fertilised in the same way as plots) for mid to late rotation fertiliser trials. Even of there is no apparent movement of nutrients, one or two isolation rows are useful because competition effects may increase the differences between treatments[3]. A general rule of thumb is that the width of isolation areas should be one third of the predicted height of the trees at the termination of the trial[4].

Plot size — Plot size should be chosen with the final sample size and degrees of freedom in mind. Initial spacing and number of trees can be varied depending on the purpose and length of the trial. A very short-term nutrition trial might use very close spacings with, say, 7 rows × 7 trees. Intermediate-term trials might have 20 m × 20 m plots at 4 m × 2 m spacing[1]. QFRI often uses a gross plot of 6 rows × 7 trees for fertiliser trials up to five years duration[5]. ForestrySA uses square and rectangular measurement plots of 16 or 25 trees depending on the length of the trial[6]. In limited cases, single-tree plots have been used where fertiliser is applied in a slot next to the tree, with adjacent buffer trees (in early measurements) to improve precision of the treatment means[7].

Replication — Replication depends on the number of treatments. Where a fertiliser trial intends to test a large number of elemental rates to obtain a trend in growth response, the design may opt for fewer replicates and more treatments[2]. Generally at least four replicates are recommended for longer-term trials.

Life span — The trial life span is limited unless large isolation rows or guard areas are employed[8]. The longevity of the trial will be increased by the number of isolation rows as lateral movement of nutrients increases with time[9].

Silviculture — Best silvicultural practice should be used for fertiliser trials in order to clearly identify tree growth response due to the applied elements, their quantity and interactions. Of particular importance is good weed control, as fertiliser response can be strongly influenced by interaction with weed competition[10]. This is especially important for eucalypts which are more susceptible to chemical treatment and weed competition than pines[11].

Measurement — Chemical analysis of soils and particularly foliage collected from various experimental treatments assists greatly in the interpretation of results and provides a means of predicting future response patterns. Foliar nutrient analysis can also diagnose ‘hidden

1 J. Simpson, pers. comm.
2 P.A. Ryan, pers. comm.
3 G. Holz, pers. comm.
4 J. Simpson, and T. Smith, pers. comms.
5 G. Dickinson, pers. comm.
6 S. Shaw, and D. McGuire, D, pers. comms.
7 ForestrySA, pers. comm.
8 P. Polglase, pers. comm.
9 C. Beadle, pers. comm.
10 e.g. Borschmann (1997)
11 Birk (1994)

hunger'. Height, diameter and tree form are the most important growth measures, and can also be used to estimate biomass. The more trees are measured, the greater the chance of detecting small responses to fertiliser. As a best practice standard, maximum branch diameter, crown depth ratio and perhaps leaf area index should also be measured. A measure of the biomass of weeds and grass within each treatment should be given.

Other uses — Water use studies (physiology and groundwater table), however these require a minimum plot size of 45 m × 45 m[1].

4.3.4 Initial spacing trials

Purpose — Initial spacing trials are used to determine the tree density which is optimum for rapid growth, good form and productivity for a desired product. For sawlog regimes, spacing trials can also be used to determine the optimum timing and intensity of thinning. Appropriate spacings depend on the species chosen, its form, branchiness and degree of genetic improvement, and the site.

Design — Randomised block designs are often used for research purposes[2]. Each block or plot is planted at a different square or rectangular spacing, sometimes in a split plot design within species[3]. The trial may keep the between-row distance constant, e.g. 3 m, and vary the intra-row spacing to give rectangular spacings. Other designs used in research and farm forestry demonstrations include the Nelder fan or wheel[4], modified Nelder[5], scotch plaid[6], Lin and Morse[7] and Latin squares[8].

Isolation — Isolation rows can be included in scotch plaid and Nelder fans.

Plot size — Plot size varies, depending on whether block plantings or other 'graduated' designs are used. In Nelder and scotch plaid designs, treatments can be planted as a continuous plot with radii or rows having trees at increasing distances apart[9]. Graduated designs allow a greater range of spacings to be tested; however, they generally have less replication.

Life span — Life span depends on the rate of self thinning of the species. This can be up to a full rotation.

Replication — Generally, an absolute minimum of three replicates is required. A reduced number of replicates in spacing and thinning trials will sometimes suffice if a **broad** range of treatments is present[10].

Silviculture — For spacing trials, survival at all positions is essential. Achieving this can be a problem, especially in harsh environments (low rainfall, saline or frosted areas). Where survival is a problem, duplicate trees should be planted 20 cm apart at each tree location to allow for mortality[11]. Once survival is assured, one of each surviving

1 I. Dumbrell, pers. comm.
2 Hall (1959); Schuster (1978); Shea et al. (1979); Incoll and McKimm (1985); Dunn et al. (1994); Dickinson and Swift (1998); Neilsen and Gerrand (1999)
3 Milthorpe et al. (1998)
4 Nelder (1962); e.g. Cameron et al. (1989); Lamb et al. (1998); Lamb and Borschmann (1997)
5 Taylor et al.(1996)
6 Gerrand and Neilsen (2000)
7 Lin and Morse (1975)
8 Wisniewski (1996)
9 Nelder (1962), Gerrand and Neilsen (2000)
10 M. Nester, M., pers. comm.
11 B. Myers, and D. McGuire, pers. comms.; Gerrand and Neilsen 2000

duplicate can be thinned (e.g. at 12 months). For the duration of the initial spacing trial, trees are not generally thinned or pruned. However, once satisfactory information on competition and growth at the initial spacings has been obtained, thinning and pruning can be carried out, providing the treatments are sufficiently replicated and are thinned to maintain consistent differences between each spacing treatment.

Measurement — Frequent measurement is especially important in spacing experiments as competition effects are non-linear and growth curves may be different shapes for different species. Initially, plants in spacing trials do not compete, but as they grow and occupy more space competition increases. Growth will eventually slow considerably. Frequent measurement beyond 5 years of age is especially important to detect stress from competition. As best practice, growth should be measured once or twice in the first year to record survival, refilling, frost incidence and effects from weed control. Measurement should be frequent (e.g. annual) while the graph of time versus growth is curved. Once growth increments slow considerably, measurement should be regular until the end of the full rotation for the species[1]. Unless site conditions or resources change, competing trees can become "locked" or alternatively self-thin and die depending on species. It is prior to this stage that systematic thinning can be carried out to extend the life of a spacing trial.

Other uses — Plot-based spacing trials can be converted to thinning trials if the initial plot size is large enough. Spacing trials can also be used to measure pasture production under trees, and to study self-thinning by trees.

4.3.5 Thinning and pruning trials

Purpose — Thinning and pruning trials investigate improvements in growth rate and wood quality respectively. Thinning reduces the between-tree competition and improves stand quality, while pruning reduces knot formation to produce clearwood.

Design — Randomised complete block design is often used[2]. A split plot design may be appropriate where timing of thinning or pruning is combined with thinning intensity[3]. If a selective pruning regime is anticipated, the pruning experiment should be designed so that pruned trees are surrounded with unpruned trees so that likely competition from unpruned trees can take effect[4]. Alternatively, if all trees in the stand are to be pruned, the experiment should be designed accordingly[5]. Thinning trials test either or both timing and intensity of thinning.

Isolation — At least two isolation rows are required for thinning and pruning trials[6]. Isolation rows must be thinned to the same prescription of the same proportions as the treatment net plots[5].

Plot size — Initial plot size should be as large as possible to allow adequate sample sizes after thinning. A minimum recommendation is 60 measurement trees per spacing or thinning treatment over the life of the trial (spread over a number of replications). The CFTT prefers plots to have at least 7 trees x 7 trees for thinning trials[7]. Forestry Tasmania uses a 40 m x 40 m plot with an internal measurement plot of 30 m x 30 m[4].

1 D. Taylor, pers. comm.
2 Faunt (1998); Pinkard and Beadle (1998a); Dickinson et al. (2000); Mohammed et al. (2000); Medhurst et al. (2001)
3 e.g. Stackpole et al. (1999)
4 e.g. Pinkard and Beadle (1998a)
5 E. Pinkard, pers. comm.
6 QFRI internal research manual (QFRI 2002)
7 D. Stackpole, pers. comm.

Replication — An absolute minimum of three replicates is required. However, where a thinning trial intends to test a large number of treatments to obtain a trend in growth response, the design may opt for fewer replicates and more treatments[1].

Life span — For thinning and pruning experiments, life span is generally a full rotation. Pruning trials can, however, produce good indications of growth responses within a few years (often as little as one to two years), from which wood quality issues can be determined[4]. Good indications of growth responses to thinning also become apparent within five to six years, but measurement should continue until harvest[4].

Silviculture — Rather than pruning to a set height, pruning experiments should remove a consistent percentage of the crown. This allows the calculation of an optimum proportion of the crown to be removed and then the development of optimum operational pruning heights[4]. In thinning experiments, the optimum final stocking rate depends on the region and species (e.g. 200 sph to 300 sph for CFTT and Tasmania and 100 sph to 250 sph for the QDPI—F).

Measurement — For pruning studies, it is essential that green and pruned height are measured, together with total height, to allow calculation of the percentage of crown removed. In addition, the measurement or classification of branch size should also be routine to determine wood quality responses to pruning[4]. For thinning trials, assessment of individual tree canopy dominance class prior to thinning can be used to show which trees had the greatest response to thinning[2].

Other Uses — Timber formation studies can use a series of measurements taken along the bole to examine the relationship between external tree morphology and internal wood formation. These trials measure a range of branching characters, such as branch height, position, angle, diameter and live status, to be compared with results from destructive wood analysis techniques[3] using cut sections for example[4].

4.3.6 Irrigation trials

Purpose — The purpose of irrigation trials can range from effluent water utilisation to production of pulp, firewood or sawlogs in lower rainfall areas. Irrigated research trials can be used to study tree water use, growth response to water saturation, and benefits of adding nutrient-enriched effluent.

Design — Often split plot designs are used due to the infrastructure required to apply irrigation[5]. Site quality, including soil characteristics, will determine the magnitude of response to the addition of water and nutrients through effluent. Selection of irrigation rates is critical if using effluent or groundwater, as too low a rate may result in salt accumulation at surface levels leading to reduced growth rates for some species[6]. Design and measurement guidelines can be found in *Sustainable effluent-irrigated plantations*: *an Australian guideline*[7].

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1 M. Nester, pers. comm.
2 e.g. Medhurst et al. (2001)
3 see Downes et al. (1997) for techniques
4 Cromer et al. (1998); Mohammed et al. (2000)
5 e.g. HIAT trial, S. Shaw, pers. comm.; B. Myers, pers. comm.; Milthorpe et al. (1994); Honeysett et al. (1996)
6 e.g. *E. grandis* at Wagga Wagga, P. Polglase, pers. comm.
7 Myers et al. (1999)

Isolation — Isolation rows are very important. At least two isolation rows around each block or 12 m between trees in adjacent treatment net plots is recommended[1]. At least two rows of buffer trees should surround an irrigation trial as they generally demonstrate substantial edge effects[4].

Replication — An absolute minimum of three replicates is required.

Life span — Life span is determined by the purpose of the trial. Water use in older plantations is highly species-dependent but is generally less per tree than in younger fast-growing juvenile plantation trees[5]. Therefore, trials set up for water utilisation may require a shorter lifespan than pulp production or sawlog production, but this will vary depending on the species, site and design characteristics.

Silviculture — Closer spacing (higher stocking rate) is possible due to addition of water and nutrients (in effluent). Early thinning needs to be incorporated due to fast growth rates, but this can be very expensive depending on the type of irrigation system used[2].

Measurement — Soil water and sodicity should be measured regularly to determine changes between seasons and over time[3].

Other Uses — The *Biology of Forest Growth*[3] and *Flushing Meadows*[4] experiments included detailed studies of water use and growth in response to irrigation and fertiliser application, which aided understanding of irrigated plantation management.

4.3.7 Low rainfall and cold climate trials

Purpose — To identify suitable planting material and silvicultural techniques for the wide range of available sites in Australia with low rainfall or which experience frosts or very low temperatures. Each design may need to be adjusted according to specific site conditions.

Design — If the trial is testing spacing, survival at all positions is essential. In sites where survival is questionable (e.g. low rainfall or cold climate areas), duplicate trees should be planted 20 cm apart at each tree location to allow for mortality[5]. For low rainfall trials where available soil moisture is low, wide spacing can be beneficial to reduce water competition[6] (but see comments below on silviculture). Alternatively, low rainfall trials might use different thinning rates to test the balance between stand productivity and water use[7]. The design of trials for low rainfall and cold-climate sites is the same as other silvicultural trials and is a split plot design if comparing the same trial on different sites.

Isolation — Two to three buffer rows surrounding the plantation are recommended for low rainfall sites, and preferably three on sites exposed to high winds[8]. More would be better but this is often impractical.

Replication — An absolute minimum of three replicates is required.

1 P. Polglase, , pers. comm.
2 B. Myers, pers. comm.
3 e.g. Myers and Talsma (1992)
4 e.g. Myers et al. (1996)
5 e.g. B. Myers, pers. comm. regarding Heartland project; Gerrand and Neilsen (2000)
6 Carter (1987); Williams and Matheson (1994); Bird (2000)
7 N. Marcar, pers. comm.
8 R. Bird, pers. comm.

Life span — Life span will vary depending on growth rate (modified by site conditions). For low rainfall trials, it is recommended that the trial is run through at least one severe dry year before definite conclusions are drawn[1].

Silviculture — The appropriate silviculture for **low rainfall** areas depends on the water use of the plantation, which is driven by leaf area index. Leaf area and water use depend on a combination of the species' characteristics[2], rainfall, soil water storage, fertiliser application and stocking density. For example, in some trials in WA, *P. pinaster* and *P. radiata* died due to water stress, while on another site, 13-year-old *P. radiata* (mean tree height of 13 m; stand volume of 70 m^3/ha) at 500 sph in the 400 mm mean annual rainfall zone showed no drought deaths after no rain for nine months[3]. The reason was that where soil depth was shallow (and therefore soil water storage was low) or fertiliser application had allowed leaf production which could not be sustained by the site, the plantation's relative water use was high and water stress occurred[7]. In low rainfall sites without significant subsoil moisture, initial spacings of 4 m x 2.5 m to 4 m x 4 m have been suggested depending on the species, to minimise competition for water[4]. If planting occurs at a higher initial stocking density, thinning may be required once a minimum log length is reached to prevent loss of the entire trial from competition due to water stress. In low rainfall sites in Victoria for example, early and progressive thinning to a final stocking density of 100 sph to 200 sph at about year 10 seems to be vital[5].

For **cold climate** sites, shelter can be a major concern. Seedlings should be hardened in the nursery prior to planting and can be planted with tree guards[6] or nurse species[7]. Prior planting of a windbreak on the upwind side of the trial may assist. For some species, problems of early frost sensitivity can be minimised by choice of planting time. For example, in inland Victoria planting of *E. cladocalyx* in winter is avoided[8]. In summer rainfall zones, frost sensitive species can be planted early in the growth season (and watered in, if necessary) to maximise growth before winter frosts arrive. Tree guards or fences can be used to minimise browsing damage where it is a problem.

Other Uses — Species evaluation and species adaptability can be assessed across a range of sites. Water use studies.

1 Harwood and Williams (1999)
2 Honeysett et al. (1992); Honeysett et al. (1996); White et al. (1996); White et al. (1998); Benyon et al. (1999); White et al. (2000)
3 Dumbrell, I., pers. comm.
4 C. Harwood, pers. comm.
5 R. Bird, pers. comm.
6 Holly et al. (1994); Neilsen and Brown (1996); Ajoy Kumar et al. (2000); Andrews (2000)
7 e.g. Neilsen and Brown (1997)
8 R. Bird, pers. comm.

4.3.8 Saline sites and salinity trials

Purpose

There are many saline sites in Australia. Trials are established to:

- identify suitable tree species and provenances to withstand saline sites;
- determine appropriate silvicultural techniques for saline sites; and to
- determine the responses of suitable planting material to different salinity levels.

Each design may need to be adjusted according to specific site conditions.

Design

A grid survey of salinity levels is necessary prior to design of the trial—for example, a point measure at each 20 m × 20 m grid node may be made. The salinity contours can then be mapped and the site blocked accordingly[1]. As salinity levels tend to vary over short distances, small plot sizes with high replication are the best approach[2]. Small block plots are more compact than line plots, hence they have less internal variation. On saline sites, the design is sometimes a split plot to allow separation of different salinity levels on the site. Alternatively, a latin square design is powerful if there is an environmental gradient in two directions[3]. On sites where survival is questionable, duplicate trees should be planted 20 cm apart at each tree location to allow for mortality[4].

Isolation

At least one buffer row, preferably two, surrounding the trial is required. One or two isolation rows are used between treatment net plots. In addition, a two-row planted guard area is used to separate different species ratios in mixed-species plantings (e.g. eucalypt and acacia mixes)[1].

Plot size

Block size depends on salinity contours. If not constrained by small-scale variability (see above), plot size tends to be the same as for silvicultural trials on non-saline sites. For example, species elimination trials typically use 5–10-tree plots with, say, 50 seedlots; and ‘best bet’ species-provenance trials use gross plot sizes between 25 and 49 trees with approximately 10 seedlots, as in non-saline sites[1].

Replication

An absolute minimum of three replicates is required.

Life span

Life span will vary depending on growth rate (modified by site conditions), and the ability of the species to exclude or to exude salts. Some species will perform reasonably well initially, but subsequently decline due to salt and waterlogging stress[5].

Silviculture

Saline sites often have plentiful water but the problem is that it is often too wet (waterlogged) or too salty. Plant stress is from salt alone or salt in combination with waterlogging. The conditions produce a physiological drought[1]. Therefore stocking rate will not relieve the problem. Rather, choice of genetic material for planting is very important. A standard stocking density is often chosen. For example, 4 m × 2 m initial spacing, or closer spacing for progeny trials. However, for saline, low rainfall sites, wide spacing can be beneficial if available soil moisture is low as it reduces water competition[1] (see comments in low rainfall section).

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1 N. Marcar, pers. comm.
2 J. Morris, pers. comm.
3 R. Bird, pers. comm.
4 e.g. B. Myers, pers. comm. concerning Heartland project; Gerrand and Neilsen (2000)
5 e.g. Hoy et al. (1994)

	Mounding and mulching can improve root drainage and growth[1]. Nutrient deficiencies can occur due to uptake of salts[2]. For further information on silviculture for saline sites, see Marcar et al. (1995), House et al. (1998) and Marcar and Crawford (2004).
<u>Measurement</u>	With variable salinity levels present, assessment of soil salinity at the plot level is highly desirable[3].
<u>Other uses</u>	Species evaluation and species adaptability across a range of sites; effect of salinity on wood properties; water use studies.

4.3.9 Pest and pathogen trials (Author: T. Wardlaw)

<u>Purpose</u>	Research trials studying the effects of, and operations for managing, pests and pathogens generally do not require special design considerations. Both surveys and designed field trials are used in pest and pathogen research. Surveys are primarily a tool used to establish the incidence and extent of pest and disease problems[4]. Surveys can also be used to identify factors associated with the development of pest and disease problems[5]. This knowledge can then be used to formulate hypotheses for testing in designed experiments.
<u>Design</u>	Experimental designs used include: single-tree plots with treatments randomly assigned (common for artificial defoliation studies) with replication in blocks[6] or replication without blocking[7]; randomised complete blocks including lattice squares[8 & 6] and split plots.
<u>Isolation</u>	In spray trials, isolation rows are essential. They may be specified as a number of planting rows[9] or minimum distances to allow for drift[4]. Another consideration is ensuring trial areas are well buffered (4 to 5 rows) from edge effects when the pest or disease under investigation responds to edge effects (particularly leaf diseases), or when thinning is being tested as a treatment.
<u>Plot size</u>	Single-tree plots are commonly used in artificial defoliation trials. Paired-tree plots can be used when one tree of the pair is healthy and one affected by the pest or disease under study[5]. Exclusion trials commonly use 25-tree to 75-tree plots[4 & 6].
<u>Replication</u>	In artificial defoliation trials using single-tree plots a minimum total of 15 to 20 trees is required. In trials designed with many-tree plots, at least three replicates are desired but two replications have been used in some exclusion trials[4].
<u>Life span</u>	Maintaining exclusion trials (using insecticides or fungicides) beyond ages 2–3 years has practical difficulties as tree crowns grow beyond the range of ground-based spray applicators. Where trials have been designed to measure impact on growth, the longevity of the trial depends upon whether the experimental design allows impacts to be extended from single-tree to stand level. Experiments designed to measure growth impact on single trees (e.g. artificial defoliation) only provide meaningful information up until the time of canopy closure. Stand-level impacts measured over the length of

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1 Ritson and Pettit (1989a); Ritson and Pettit (1989b); Ritson and Pettit (1990); Hoy et al. (1994); Marcar et al. (2000)
2 Marcar et al. (1995)
3 J. Morris, pers. comm.
4 e.g. Wardlaw and Neilsen (1999)
5 e.g. Wardlaw (1999)
6 e.g. Candy (1999)
7 e.g. Elliott et al. (1993)
8 e.g. Podger and Wardlaw (1989)
9 e.g. Stone et al. (1998)

the rotation require sufficient treatment area to allow the dynamics of inter-tree competition to be included in the overall stand-level impact.

<u>Silviculture</u> Silvicultural treatment may be built into trial design as a treatment effect. Typical examples include thinning as a treatment option for leaf diseases[5] and pruning as a risk factor in fungal wood decay[1]. Nutrition and weed control may also be important as factors affecting leaf retention in trials examining leaf diseases.

<u>Other uses</u> Wood quality studies.

4.4 Wood characterisation research trials

In recent wood quality research, trees have been sampled retrospectively from other trials, and therefore there have been few trials which have been able to sample the effects of silviculture on the quality of plantation grown hardwood (A. Muneri, and W. Leggate , pers. comms.). When designing new trials, researchers should add extra plots or increase the plot size to provide trees for future wood sampling. The silviculture researcher and wood analyst should collaborate to ensure that the removal of trees does not affect the trials' statistical robustness. Timing of wood samples and silvicultural treatments should be decided at the time of trial design so that sampling can be incorporated into the silvicultural regime. The extra plots and trees are managed in the same way as the main trial even though they are intended for wood cores, destructive sampling or biomass estimates using leaf area indices.

A guide to sampling plantation eucalypts for wood and fibre properties is Downes et al. (1997). This should be read before starting any wood quality research as it sets out the required protocols for site description, wood sampling and analysis.

The number of trees to be sampled for wood characterisation should be chosen based on the statistical mean and variance for each trait (e.g. wood density) at each site. Often a pilot study will need to be completed to allow a suitable estimate of the number of trees to be sampled. Often wood density is used as an initial indicator of wood quality for end use**.** As a rule of thumb (A. Muneri and K. Harding, pers. comms.), 30 trees per treatment from a plantation stand is often adequate for estimating wood basic density and sapwood proportion from wood cores (see Raymond and Muneri (2001) for method). A separate sample is required for each treatment for each species and site. For example, 30 trees could be sampled from one spacing (400 sph) from an *E. grandis* spacing trial at a site near Gympie.

Non-destructive sampling can evaluate the following wood properties: wood basic density, growth strain, heartwood proportion, extractive content and anatomical properties such as fibre length and, vessel size and frequency (see Raymond (2000) and Downes et al. (1997) for choosing methods). These traits are measured at breast height (1.3 m above ground level). For some traits there is a potential degree of error in relating the results of non-destructive sampling to the whole tree, therefore a more intensive within-tree investigation is required to determine the correction factor.

1 Mohammed 1999

5. Minimum measurement: how and when to measure

Chapter outline

Once the trial is established, measurements must be made so that the differences between treatments can be identified. Chapter 4 outlined some designs and measurements which are particularly relevant for different types of silvicultural trials, for example green, pruned and total height for pruning trials. This chapter outlines methods for monitoring and measuring stand and tree performance.

5.1 Measurement codes of practice

The following sections give a general outline of stand monitoring and tree measurement methods. For further information refer to guidelines for tree measurement in Reid and Stephen (1999), Wood et al. (1999), Bird (2000), MacLaren (2000) and Abed and Stephens (2002). Texts on forest measurement include Carron (1968) and Husch et al. (1972). Comprehensive guidelines have been developed by several government forestry research organisations for their employees. Staff should refer to these for detailed information (e.g. QFRI (2002); State Forests of New South Wales (1995); Carter (1987); Wong and Baker (1999)). The JVAP manual *Designing farm forestry trials for species and provenance selection* (McLeod et al. 2009) also has additional information.

5.2 Appropriate variables to measure

Variables chosen for trial measurement must be quantitative indicators of yield and provide information on the differences between treatments (M. Webb, pers. comm.). Until harvest, direct measurement of stand performance is impractical or unnecessary and so reasonable predictors are chosen (see Box 5-1).

The most commonly measured variables are those which predict stem volume and stand condition (see Section 5.2.1) but it is also important to regularly monitor predictors of tree health and wood quality and to assess weed burdens (see Section 5.2.2).

Box 5-1 Common predictors of stand performance used in forestry

Common predictors of stand performance used in forestry

Stand information	Predictors
Stem volume	Bole height Diameter at breast height (DBH) Diameter at ground level (DGL)
Biomass	None (measure directly)
Stand condition	Survival Height DBH DGL Canopy class (dominant, co-dominant, etc.) Green crown height Crown diameter
Tree health	Visual symptoms Foliar nutrient analysis Crown shape (cylindrical, conic, flat top, etc.) % crown volume defoliated or affected % leaf area damaged Presence or absence of damage (e.g. wounds, stem borers) Length or width of wound (e.g. stem cankers) Leaf retention (crown transparency, leaf area index) Length of dead top (dieback diseases) Pre-dawn water potentials
Wood quality	Wood density Fibre length Tracheid length

Source: modified from an unpublished manuscript written by M. Webb (CSIRO).

5.2.1 Main indicators of stand performance

The most common tree measures are survival, diameter (usually DBH) and height (Section 5.5). Volume is estimated from height and diameter, based on one of several equations. For yield estimates, further detail can be obtained by felling a sample of trees for stem volume and biomass.

Height is measured on all stems during the early years of each trial, but can be subsampled at later ages. In Queensland, stands under 6 m in average height must have heights of all living stems measured. Stands over 6 m must have DBH of all living stems measured and the heights of sufficient stems to enable predominant height to be calculated (QFRI 2002). It is preferable to do a total height measure at the time of the first DBH measure and then proceed with predominant height for subsequent measures. The DBH and height measurements **must** be carried out at the same time.

Green crown length has recently been included as a routine measure by researchers in several states. It is readily determined with the use of a vertex, whilst measuring total tree height. Green crown length should become a standard plot measurement as it is fundamental to interpreting growth responses to treatment (E. Pinkard, pers. comm.). For example, it is now routinely measured in pre-prune assessments in all Forestry Tasmania eucalypt plantations (E. Pinkard, pers. comm.). Monitoring of green crown length can be used to assist management to prune branches when green (R. James, pers. comm.) and is relevant for fertiliser trials and some insect trials where defoliation is measured (S. Hetherington, pers. comm.). It is also a useful measure when sampling biomass.

Leaf area index (LAI) is also useful in interpreting growth responses. While LAI is not routinely measured at the moment, there is growing acceptance of its importance, and organisations such as Forestry Tasmania are seriously considering purchasing equipment to routinely measure LAI in plantations (E. Pinkard, pers. comm., 2001). Our current understanding of the dynamics of leaf area, litterfall and root turnover is inadequate, although the relevance of these to tree growth and productivity is clearer than the relationships between detailed soil profile descriptions and tree growth (J. Morris, pers. comm.).

5.2.2 Plantation monitoring strategies

Along with routine measurement of tree growth and survival, stands should be routinely monitored for nutrition, weed infestation and signs of pests and disease. General nutrition issues are covered by Attiwill and Adams (1996) and diagnosis of nutrient disorders in eucalypts is discussed by Dell et al. (2001) and Dell (1996).

Routine measurement of experiments should include inspections for signs of pest and disease damage. Crown damage should be scored if it is severe enough to have a measurable effect on growth (approximately >25% crown affected). In Tasmania, forest health is recognised as a major influence on plantation growth and quality, and is an important consideration in formulating appropriate silvicultural prescriptions (e.g. Elliott et al. 1992; Elek 1998; Candy 1999; and T. Wardlaw, pers. comm.). In Queensland and northern New South Wales, stems should be inspected for presence or absence of borer damage as part of routine assessment (S. Lawson, pers. comm.). In general, borer infestations appear to be more common in stressed trees and may correlate with tree species, site-matching and silvicultural management (S. Lawson, pers. comm.). Northern Territory research also requires regular pathogen and insect monitoring, especially for borers and termites (H. Neitzel, pers. comm.). In some areas, particularly in Tasmania, browsing by mammals can also have a significant effect on early seedling survival.

Methods of assessing damage caused by pests and pathogens vary depending on the nature of the injury (e.g. stem decay, stem wounds, leaf infection and chewing, defoliation). A national scoring system for insect and pathogen damage in hardwood plantations which was under development in

2001 (C. Stone, and S. Lawson, pers. comms.); is now in use as the Crown Damage Index (Stone et al. 2003; or see http://affashop.gov.au/product.asp?prodid=12783). Measurement of plantation health is discussed further in Section 5.5.11.

Stands can also be measured for tree form, physiology, wood properties, agroforestry interactions, non-wood properties, wind damage and other environmental influences. Tree form is important and can be affected by factors such as genetic material, wind stress, nutrient deficiencies, damage by vertebrates (e.g. parrots in WA; Ritson 1995a,b) and numerous other site-related factors. Tree form is discussed further in Section 5.5.12.

5.3 Measurement of research trials

5.3.1 Gross plots versus net plots

As outlined in Section 3.6.1, net or internal plots represent all of the 'core' data trees in a plot. Net plots are surrounded by designated isolation rows and together they form the gross plot for each treatment. Net plots only are measured once edge effects have been established. For most research plots less than 12 months of age, gross plots can be measured. At this stage, competition between trees is not expected to be significant.

In some circumstances, gross plots for trials of age two or three years are measured to provide more data. However this is not recommended for trials with large differences in growth between treatments—for example species trials or fertiliser trials. Having isolation rows is especially important when combining fertiliser treatment with fast-growing species such as *Eucalyptus globulus* and *Pinus radiata* (I. Dumbrell, pers. comm.). If gross plots are measured past 12 months of age, the data from isolation trees should be analysed for edge effects from neighbouring treatments and surrounding farmland (if buffer rows are not used). This will determine whether the inclusion of isolation trees in the analysis is warranted.

Data which measures the edge effects on buffer trees is important for farm forestry or small plantings because a large proportion of the planted trees can be subject to edge effects. However, in practice edge effects are rarely analysed.

5.3.2 Measurement frequency

The timing of tree measurements will vary depending on the trial type, aims, the questions being asked, the amount of prior knowledge, the types of measurements being made, the local climatic conditions, growing season and the availability of labour (McLeod et al. 2002). **Measurement should be frequent enough to detect the differences among treatments, and the response to major events in the life of the plantation, such as thinning and fertiliser application.**

Frequent measurement is appropriate for fast-growing species or where rapid or different rates of response to silvicultural treatment are expected. For example, after treatment, pruning and thinning trials are measured annually, and possibly six-monthly initially (G. Dickinson, pers. comm.).

Theoretically, the timing of measure should be based on the stand's growth curve, with frequent measurements during periods of rapid growth or when growth patterns change and regular measurements during regular growth increments. In practice, growth is either measured annually, or intensively for the first 1 to 3 years, and then every 2 to 5 years depending on the purpose of the trial and the organisation's routine practice. Annual measures are ideal and should occur preferably in winter, or when growth is at its slowest and is more uniform between species (I. Dumbrell and G.Smith, pers. comms.).

Early measures are more frequent. After planting, survival should be checked within 1 to 2 months to allow refill planting where necessary. ForestrySA recommends that as a minimum, height and diameter should be measured at 1, 12 and 24 months after planting. Measures at 3 and 6 months after planting are often included for short-term trials (ForestrySA). With possibly more rapid early growth rates, the QFRI measures generally at 2, 6, 12, 18, and 24 months and then yearly for typical responses to fertiliser and establishment techniques (G. Dickinson, pers. comm.)

Tree health should be assessed frequently during the first six months after planting or after treatment, and preferably up to two years of age. For weed control trials, percentage weed cover is usually assessed immediately prior to treatment application, then monthly to two monthly during the first six to eight months, after which assessments may occur less frequently up to 18 months after treatment (ForestrySA). Other measurements will depend on the type of trial. For example, water use experiments might measure a subset of trees every few weeks (e.g. Morris and Wehner 1987; Honeysett et al. 1996; White et al. 1996).

Long-term trials are often measured annually up to five years then biennially or associated with operational activities (e.g. thinning) thereafter (ForestrySA). For example, several researchers recommend that trials are measured for survival, height and DBH at a minimum of 2-yearly intervals until at least age 10 to 12 years—that is, at ages 2, 4, 8, 12, 16 years and so on (R. Bird, E. Pinkard, D. Stackpole, pers. comms.). Alternatively, the early annual measures may continue until canopy closure, and then less frequently (e.g. 5-yearly) afterwards (S. Hetherington, pers. comm.). Measurements should be more frequent after thinning or pruning treatments to distinguish growth effects.

As an illustration, an **example** measurement plan for species and provenance trials (adapted from McLeod et al. 2002) follows:

- Survival should be measured at 12 months, then every 2 to 3 years.
- Height, health and vigour should be measured in the nursery, at 12 months, and annually thereafter until trees reach a height of 7 m, and then every 2 to 5 years.
- DBH or DGL for some species should first be measured when the tree height averages 4 m. Thereafter it should be measured in conjunction with height.
- Stem straightness, form and axis persistence should be measured when the tree height averages 6 m and thereafter at 5-year intervals.
- Branching habit should be measured when the trees average 6 m in height and thereafter at 3- to 5-yearly intervals.

5.4 Sampling strategies for large stands

Sampling of routine plots in large stands is used to obtain yield estimates and to model growth. Measured plots can also be used as a genetic resource for selection of individual trees for breeding and as a source of logs for product evaluation (A. Shelbourne, pers. comm.). Plots can sometimes be placed in nearby stands with a different management or species in order to obtain comparisons. For more information on sampling in large stands see MacLaren (2000) or other references listed in Section 5.1. The following are factors which influence the sampling strategy chosen:

- Ensure the minimum statistical requirements for plot size, replication, and randomisation are met.
- In large-scale forestry it is best to avoid measurement near the edge of the stand, which has differential growth and can distort estimates of the stand’s performance. (For the same reason, buffer trees are advised for research trials.) Two or more buffer rows should be employed around the edge of woodlots (Bird 2000) and preferably five (C. Shedley, pers. comm.). If more than two edge rows are suspected to have significantly different growth, analyse the edge effects prior to commencing the stand assessment. Select plots appropriate to the edge effects exhibited in the stand.

- Based on objectives and resources determine whether fixed plots or new plots are more appropriate.
- In fixed plots, remember to use large plot sizes to accommodate thinning.
- The required number of plots can be calculated manually using formulas provided by MacLaren (2000) or using *MARVL* or another computer program.
- Sampling should be undertaken to encompass site variation such as topography, soils and moisture availability. One method that may reduce inventory work is sequential sampling (10-tree to 20-tree line plots) with systematic selection (regions within plantation) using a randomly selected starting point (Brack and Marshall 1998). Alternatively conventional circular, rectangular or transect plots can be used to estimate the stand or treatment means.

5.5 Standard plot measurements

The following plot measurements are commonly used for assessing research trial performance. While not all will be measured for each research trial, most are recommended. **It is critical that tree age or the date is recorded at the time of each measurement.**

5.5.1 Height

The usual measurement taken is total tree height, from the green tip to the highest ground level at the tree base. Other measurements may include green height or bole height. The bole is specified as the length of a desired section of a stem, based on defined criteria such as top end diameter or degree of branching. For statistical purposes, it is best to measure all trees in an experiment. However in larger stands, DBH is measured for all trees, and height for a sample of, say, 40 to 60 trees. A regression equation (height versus DBH) is then used to calculate basal area and volume for economic purposes. Whenever calculating height, the technique and any underlying formulas should be described. When means are calculated, the number of stems measured should be given.

5.5.2 Green height and pruned height

Green height is the height from the ground to the junction with the trunk of the lowest healthy branch forming part of the main crown (i.e. excluding epicormic shoots). For pines and other species with branches in whorls, green crown should be the position where at least 50% of the branches in a whorl are green (I. Dumbrell, pers. comm.). *Pruned height* is the height of the trunk to the lowest unpruned branch. Green height and pruned height may or may not coincide, but pruned height can never be the larger (Figure 5-1).

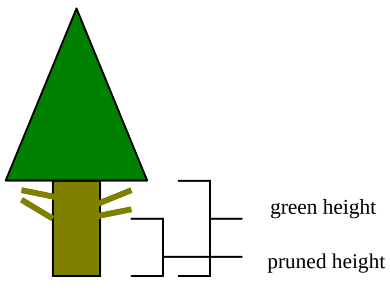


Figure 5-1: Green height and pruned height. Source: Wong and Baker (1999).

5.5.3 Diameter at breast height and diameter over bark

Diameter at breast height (DBH) or diameter over bark (DOB) should be used wherever possible. They are nominally measured 1.3 m above ground level on the uphill side of the tree (after removing loose bark). On level ground, leaning trees are measured on the under side of the bole and on a plane at right angles to the axis of the stem. Figure 5-2 gives some examples of how to measure DBH. When recording and reporting, the measurer should clearly state whether DBH or some other diameter measure is used. If the diameter is not measured at 1.3 m height, then the point measured should be clearly stated and its reason. A consensus among researchers is that DBH should be measured once trees reach a height of at least 4 m. If trees are below 4 m then another measure near ground level can be taken if girth measurements are required for your objectives.

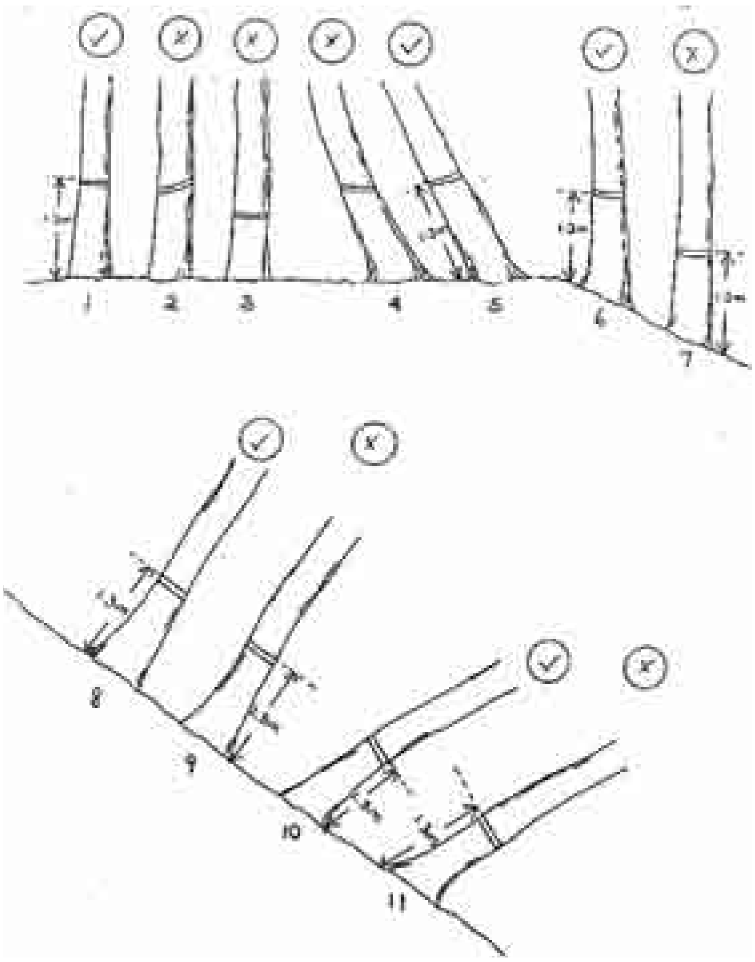


Figure 5-2: Correct (ticks) and incorrect (crosses) measurement locations for recording DBH. Source*:* DPI Forestry (1998).

Where swelling, bumps or branches affect the measurement point, the diameter of an unaffected part of the stem within 0.1 m of 1.3 m height should be measured. This position should be alternated above and below 1.3 m on the trees requiring the measurement. For malformations affecting the stem beyond 0.1 m above or below the 1.3 m height level, two diameters should be measured at equal distances above and below 1.3 m and the two diameters averaged (Wong and Baker 1999).

For forking trees or trees with multiple leaders, DBH is measured on all stems which originate less than 1.3 m above the ground. DBH is calculated using:

$$DBH = \left(d_1^2 + d_2^2 + \cdots d_n^2\right)^{1/2},$$

where d_i is the diameter of the stem measured 1.3 m above ground level.

5.5.4 Diameter

Diameter at ground level (DGL) or at 10–30 cm above ground (Brack 1999, and R. Bird, pers. comm.) can be measured on young stems (less than 4 m in height) until trees are of a sufficient size to measure DBH. Measures at 10 cm to 20 cm are preferred to avoid any swellings at ground level which may develop on eucalypt butts during early years (R. Bird, pers. comm.). The height at which the diameter measurement is taken must be specified and should be consistent.

DGL or similar is not often measured in plantation trials. However it can be useful for certain types of trials. These include trials dealing with slow-growing species or species grown on low rainfall sites, genetic evaluation trials before DBH measures can be taken, measures of species that have multiple-leaders (e.g. shrubs and bushy woody perennials), or trials incorporating coppicing or treatments which involve cutting the stems below 1.5 m above ground level. Depending on the species and site, this may apply to measurements up to ages between 2 and 5 years. Some measure of diameter at early ages is useful for modelling growth (A. Goodwin, pers. comm.). An alternative is to measure the diameter at one-third the height of the stem, until the tree has reached 4 m height (A. Goodwin, pers. comm.); however, this method would be more time consuming.

5.5.5 Bark thickness

Bark thickness varies with species, genotype, age, rate of growth and position along the bole. It is especially useful when measuring species trials. It is measured indirectly using a bark gauge, probe, or graduated scale and is probably the most error-prone of all forest measurement operations because it relies heavily on feel. Considerable experience, skill and care are required to obtain reliable results. The following guidelines are from Wong and Baker (1999):

- When pushing the gauge through the bark, use palm and shoulder or forearm pressure only depending on the manufacturers' recommendations and do not twist the gauge at any time.
- At least four measurements at roughly equidistant points around the bole should be made.
- On trees with fissured bark (see Figure 5-3), measurements **should bc made at positions such as point A** rather than point B. This is because for trees with fissured bark, bark thickness is defined as the radial distance from the cambium to the over bark circumference defined by the diameter tape.
- If callipers were used to measure diameter, measure bark thickness at the points of contact of the calliper arms with the stem.

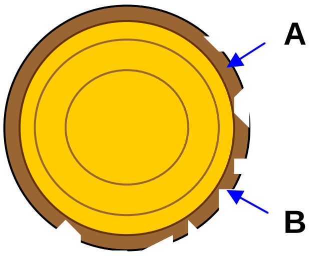


Figure 5-3: Correct (A) and incorrect (B) positions for measurements of bark thickness on trees with fissured bark. Source: Wong and Baker (1999).

5.5.6 Diameter over stubs

The diameter over stubs (DOS) or diameter over the largest branch whorl is measured at each pruning lift. This measurement is used mostly for pines because their branches grow in whorls. It is measured at the widest part of the knotty core, including pruned stubs (Bird 2000), and is a routine component of measurement for pruned stand certification schemes (see Figure 5-4). In addition the DOS height (height from the ground to DOS) is estimated to allow future calculations of clearwood (MacLaren 2000).

Figure 5-4: Measuring diameter over stubs. Source: MacLaren (2000).

5.5.7 Maximum branch diameter

After it has been removed through pruning, the horizontal diameter of the largest branches should be measured at the point where the branch joins the stem, excluding the bark (MacLaren 2000).

5.5.8 Stocking density

The number of trees or stems per hectare (tph or sph respectively) can be calculated by dividing the number of trees by the area in hectares from which they were sampled. Measurements must be from inter-row to inter-row, not from row to row, when measuring area (see Section 5.5.13).

5.5.9 Survival

Survival of all trees in each net plot should be recorded at each measurement time, even if other measurements are then taken from a sample of trees. Survival is important, especially for longer-term trials as it affects the growth of remaining trees.

5.5.10 Status and canopy class

Some organisations routinely record tree status—that is, whether the tree is standing, leaning or fallen, broken, dead, cut or replaced. This is useful for general interpretation of results, for example yield, and competition effects on individual tree growth. Canopy or crown class is also frequently recorded—that is, whether each tree is dominant in the canopy relative to its neighbours. This is useful to indicate growth relative to neighbours, to indicate any site variation, and to evaluate select trees for tree breeding.

5.5.11 Plantation health – entomology and pathology

Crown damage index should be assessed when crown damage is severe enough to have a measurable effect on growth (i.e., when it is approximately >25%; T. Wardlaw, pers.comm.). Standards for assessment have been developed (S. Lawson, pers. comm 2009). Stone and Bi (2001) recommend inspections made on a yearly basis and when there is a likelihood of maximum cumulative damage (due to insects or pathogens) on the dominant leaf age class. The timing of damage will be specific to local insects and pathogens and quite possibly specific to different regions, and will require local knowledge or regular visits to detect critical times. Where possible the upper and lower crown indices should remain separate for more comprehensive analysis (S. Lawson, pers. comm.). Where stem borers occur, routine assessment should include inspecting stems for presence of borer damage when tree DBH reaches 10 cm or when trees are approximately three years old (S. Lawson, pers. comm.).

5.5.12 Tree form

Tree form can be scored for attributes such as forking, stem erectness, stem straightness, branch number, branch thickness, branch angle, self-pruning status and health. There is a range of qualitative methods for estimating form. Scoring is subjective, and may be an overall appraisal of the tree form, or to assess individual traits used when selecting trees for breeding purposes. Many schemes do not have a strictly linear gradation of classes, and therefore an average score for a group of trees should **not** be given. Rather, the percentage of trees in each class should be used (Bird 2000).

Before applying an individual trait scoring system, the assessor should walk around the trial to view the range of tree responses to growing conditions (Cotterill and Dean 1990). A description of tree condition at the top and bottom scale should be given for the particular site being assessed. It may be that even the best trees on a poor site are less-than-straight. The site is then assessed (independent of other sites), so that the scores given reflect the variability of the trait **for that site** (Cotterill and Dean 1990). The scale is used to assess variation within one trial and it is not appropriate to compare results between different trials, especially for silviculture which requires a quantitative scale. Note that pruning complicates tree form scoring as early form pruning and pre-emptive pruning often occurs before the tree is 6 m in height (R. Bird, pers. comm.).

The number of categories used should adequately describe the range of variation for the individual trait being assessed. Some researchers suggest that the scoring system should have an even number of classes to avoid the tendency to allocate trees to the middle score, however there is not universal agreement on this. Providing the scoring system has, say, five to nine categories and is relatively simple, an uneven number of categories is easier to use and has few problems with consistency (R. Bird pers. comm.). The scoring system by Cotterill and Dean (1990) has even numbers of classes to avoid middle lumping. This scheme has been adopted by the Australian Low Rainfall Tree Improvement Group (ALRTIG), the Southern Tree Breeders Association, ForestrySA and Greening Australia (C. Harwood, and D. Bush, pers. comms.). Another system was developed by Pinyopusarerk et al. (1993) at the CSIRO for use on Casuarina provenance trials and has been used with slight adaptations on eucalypt and acacia trials (C. Harwood, pers. comm.). A variation on this has been used and quoted by Bird (2000). Other schemes have been used in the *Australian Master Tree Grower*

Manual (Reid and Stephen 1999) and by the Pastoral Veterinary Institute (Bird 2000), the Centre for Forest Tree Technology (CFTT) and the QFRI.

The attributes scored can vary depending on the type of trial. For fertiliser trials, assessment of forking and maximum branch diameter is recommended. Branch size is needed because it shows a classic response to fertiliser. In wind-prone areas, an estimate of sweep is needed. Where browsing is a problem, a measure of forking and multiple-leaders is required. A minimum general assessment should address forks and branchiness.

5.5.13 Plot area

Plot area should be calculated from the centre of one inter-row to the centre of another inter-row. QFRI (2002) proposed three methods of measuring the dimensions of a plot to calculate its area. They are shown in Box 5-2. Methods 1 and 2 in Box 5-2 require the calculation of the area of a triangle. These calculations are outlined in Box 5-3.

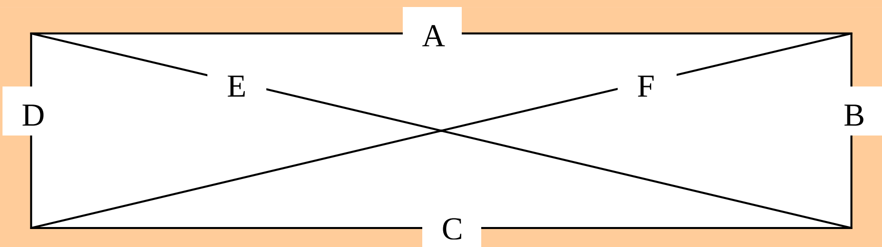
All plot areas should be expressed as **horizontal** area; and dimensions of plots on sloping sites should be corrected for slope (see Box 5–4).

The dimensions of plots for which the four sides and both diagonals have been measured should be checked by calculating the sum of the angles formed by the side and diagonal of each corner and comparing this with the mathematically correct sum of 360°. A method of calculating angles of a triangle using the lengths of its sides is given in Box 5-3. If the resulting internal angle error is ≥5°, a check on plot measurements must be made (QFRI 2002).

In general, Method 1 in Box 5-2 should be used to calculate plot areas. If this is not practical, then Method 2 should be used in preference to Method 3 as the latter is less accurate. Regardless of method, lengths should be measured to the nearest centimetre and slopes measured in degrees (°) and minutes (′) to the nearest 30′, with slopes less than 30′ being recorded as level. The slope to be measured is the elevation or depression from plot corner to plot corner even if the slope changes between them. In the rare case of plot corners not being in line of sight then slopes are to be determined from an intermediate point whose distance from each corner must be measured.

Box 5-2 Three methods of calculating plot area (source QFRI 2002)

Three methods of calculating plot area



If the **area** of the plot is *ABCD,* and the triangle bounded by sides labelled A, B and E has area *ABE*, etc., then:

Method 1: Measure the length and slope of the four sides plus two diagonals

$$ABCD = \frac{ABE + CDE + ADF + BCF}{2}$$

Method 2: Measure the length of the four sides plus one diagonal

$$ABCD = ABE + CDE$$

or

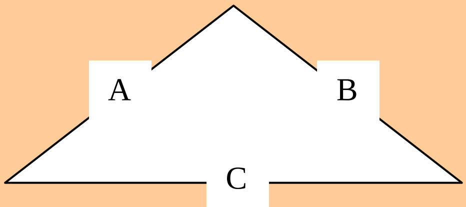
$$ABCD = ADF + BCF$$

Method 3: Measure the length of the four sides only

$$ABCD = \left(\frac{A+C}{2}\right) \times \left(\frac{B+D}{2}\right)$$

Box 5-3 Calculating the area of a triangle and any of its angles

Calculating the area of a triangle and any of its angles



If the **area** of the triangle is *ABC* and the lengths of its sides are *a*, *b* and *c*, then

$$ABC = \sqrt{s(s-a)(s-b)(s-c)}$$

where

$$s = \tfrac{1}{2}(a+b+c)$$

If the **internal angle** bounded by sides A and B is *AB*, then

$$AB = \cos^{-1}\left(\frac{a^2 + b^2 - c^2}{2ab}\right)$$

Box 5-4 Calculating horizontal distances for sloping sites

Calculating horizontal distances for sloping sites

To convert measured length to horizontal distance, use the formula:

$$\textit{horizontal distance} = \textit{slope distance} \times \cos(\textit{slope angle})$$

For example, a distance of 26.3 m measured along the ground on a slope of 18° equates to a horizontal distance of 25 m.

5.6 Standard plot calculations

5.6.1 Mean dominant height

Mean dominant height (*MDH*) (also known as *predominant mean height*) is the mean height of trees subjectively assessed as dominant or codominant and of good form (see definitions in Chapter 1). The number of stems measured varies for each State. In routine stands, the recommended number ranges between 40 sph and 75 stems per hectare. In New South Wales and the Australian Capital Territory 40 stems per hectare are measured; in Queensland, 50 stems; and in South Australia, 75 stems (Wood et al. 1999). Either the tallest trees or those with the largest diameter are measured. In Queensland, predominant mean height is defined as the average height of 50 of the tallest stems per hectare ignoring those stems with damaged leaders (QFRI 2002). It is usually found by measuring the height of at least the tallest tree in each 1/50 ha quadrat (i.e. 0.02 ha) within a plot—that is, the measurements are made on stratified sample. The stratified sampling of tallest trees gives a more representative description of the site, particularly in large plots where there can be a site gradient which produces a clumping of the absolute tallest trees in one area.

In research trials, a greater percentage of trees is usually measured in order to retain a reasonable sample size. For example, at a stocking density of 1000 sph, the CFTT bases its dominant height measurements on the heights of 200 largest single-stemmed trees per hectare, which adequately samples internal treatment plots of, say, 40 trees each (J. Wong, pers. comm.).

5.6.2 Volume

The technique and associated formula used for calculating volume should be clearly stated. Selection of a suitable formula depends on the accuracy of diameter and length estimations and the species for which calculations are being made. It is important that diameter under bark is used due to the large differences between species in bark thickness. Diameter under bark equals the diameter over bark minus twice the average bark thickness (for measurement see above). Several formulae are given in Neilsen (1990), Bird (2000) and MacLaren (2000). Examples of calculations and modelling volume and yield are given in West and Mattay (1993); Bi and Hamilton (1998); Bi (1999) and Battaglia et al. (1999).

5.6.3 Basal area

Basal area (*BA*) is the combined area of all trees estimated from their DBH measurements (Bird 2000):

$$BA = \pi\left(\frac{DBH_1^2 + DBH_2^2 + \cdots DBH_n^2}{4A}\right)$$

where n is the number of trees in the sample area of A hectares. Basal area is expressed in units of square metres per hectare.

5.6.4 Stand volume

The estimation of stand volume is based on the multiplication of stocking density (e.g. sph) and mean tree volume of a stand (Bird 2000). Stand volume can also be estimated using various New Zealand Forest Research computer programs (FFCALC, STANDIN, WOODI and MARVL; MacLaren 2000). When reporting this parameter, it is essential that the method of estimation and the number of sample trees used are given.

5.6.5 Mean annual increment

Mean annual increment (MAI) is the total volume growth of timber divided by the number of years from establishment to the time of measurement. MAI must be defined when reported and is usually expressed as cubic metres per hectare (Bird 2000).

5.6.6 Current annual increment

Current annual increment (CAI) is the volume growth of timber in the current year. *CAI* must be defined when reported and is usually expressed as cubic metres per hectare (Bird 2000).

5.6.7 Periodic annual increment

Periodic annual increment is the volume growth over a nominated period. It must be defined when reported and is usually expressed as cubic metres per hectare.

5.7 Other measurements

5.7.1 Leaf area index

Tree canopies use photosynthesis to convert solar energy into biomass. Canopy size changes in response to the environment and the changes are visible as episodes of leaf growth and leaf fall. In a stand of trees, canopy size increases up to and often beyond canopy closure (Beadle 1997). Usually, the arrangement of leaves and branches will also change. Canopy size and shape influences the amount of light which is intercepted and there is a linear relationship between light interception and biomass production (Cannell 1989). Therefore, a key issue in plantation silviculture is to manage canopies so that they maximise light interception throughout the rotation (Beadle 1997).

The size of a tree canopy at any one time is defined by its *leaf area index* (LAI), which is the leaf area per unit land area. In general, the leaf area that can be maintained at a site is determined by the level of available water and nutrients (Beadle 1997). Silvicultural practices are used to modify the potential productivity of the site and this is often expressed as an increase in LAI.

Soil water balance during the growing season (which is influenced by precipitation and pan evaporation) is an important determinant of leaf area (Gholz 1982). Water stress can reduce the rate of development of leaf area, and the effect differs between species (e.g. White 1996; White et al. 1996). The continued availability of water is critical to the long-term retention of leaf area. Under prolonged drought, eucalypts lose leaves as a means of reducing transpiration. Canopies generally recover, but the potential size of the canopy (LAI) in the next growing season may be reduced (Beadle 1997).

As outlined in Hunt (1998), a description of canopy architecture is necessary to understand patterns of stand production (McCrady and Jokela 1996), water use (Grier and Running 1997), interception of radiation (Linder 1985) and precipitation (Dufrene and Breda 1995) and turbulent transport (Jarvis and Leverenz 1983). In recent years this has become more important because of the use of physiological and hybrid models for predicting actual or potential forest productivity (e.g. Battaglia and Sands 1998; Sands et al. 2000). As well as being useful in commercial forestry, such models are required for estimates of non-wood values, such as total or actual carbon estimates (M. Hunt, pers. comm.). Leaf area index (*LAI*) is the most commonly used mathematical description of the temporal and spatial distribution of leaves in these models (Landsberg 1986).

Leaf area index is oftenn measured annually in research trials involving tree water use and soil water depletion, as leaf area rather than stocking density is the main driver behind plantation water use (I. Dumbrell, pers. comm.). This assists with determining appropriate silviculture for the species and site types used in plantations. Leaf area varies with season and over time (Beadle 1997) and sampling methodology should allow for this.

An outline of methods of sampling leaf area is given in Hunt (1998) as follows:

> "Tree or stand leaf areas (and calculation of LAI) may be estimated using a range of direct and indirect methods (Campbell and Norman 1989; Goel and Norman 1990). Direct measurements may be destructive, relying on leaf sampling, but are labour intensive and time consuming. These methods are very difficult in large forest canopies (Welles and Norman 1991), primarily due to logistical difficulties in sampling and adequate characterisation of foliage distribution (Smith et al. 1993). A variety of destructive methods has been developed including the stratified clip method (Hutchison et al. 1996); the dispersed individual plant method (Norman and Campbell 1989) and the litterfall collection method (e.g. Neumann et al. 1989).
>
> Non-destructive direct methods include the point quadrat method (Warren-Wilson 1960); the use of fisheye photographs (Anderson 1970) and the use of digital videography (e.g. Law 1995)."

Indirect methods consider the relationship between the radiation environment below or within the tree canopy and the leaf area of the canopy. Indirect methods overcome many of the logistical problems of direct methods but require calibrations which can be as demanding as direct approaches. Mathematical techniques include the direct inversion method (e.g. Perry et al. 1988) and the bisection method (Campbell and Norman 1989). Campbell and Norman (1989); Goel and Norman (1990) and Welles and Norman (1991) review the above measurement and instrumentation respectively.

A common method for estimating leaf area at the stand scale uses a combination approach (Hunt 1998): "Destructive sampling of trees is used to develop allometric relationships between leaf area (or leaf mass) and sapwood area for each canopy element that is being examined (i.e. species, size classes or crown layers). The allometric relationships are then used in combination with tree basal area (or sapwood area determined by cores) to scale up to the stand level. The method relies on the causal relationship between sapwood area and leaf area as interpreted by the pipe model (Shinozaki et al. 1964)."

Where a combined approach is used, a commonly used piece of equipment is the Li-Cor LAI-2000 which measures light interception from the canopy to the ground (as photosynthetic photon flux density intercepted) and gives an indirect estimate of leaf area. Because of marked variation in foliage clumping and light interception between different forests, such indirect equipment should be calibrated for species and forest types prior to use (e.g. Cherry et al. 1998; Battaglia et al. 1998). The best practice is to first determine actual leaf area for the required species and forest type (by destructive sampling) to give accurate estimates of *LAI* over a range of values of *LAI* for a given forest type. The data can then be calibrated for plots and finally for the *LAI-2000* (M. Hunt, pers. comm.). The instrument can then be used to obtain rapid and accurate estimation of *LAI* in other structurally similar stands, without further recourse to mensuration data and allometric calculations.

Appendix 2 gives the method recommended for direct determination of leaf area index and site variables. The regression equation so derived can then be used to calibrate the LAI-2000.

5.7.2 Classification of soil salinity

On saline sites, soil salinity should be measured before the trial is designed and planted. Measurements can be taken in a grid pattern for example a point measure at each node of a 20 m × 20 m grid. The results can then be used to map the salinity contours and the site can be blocked accordingly.

Salinity should also be assessed just after the first tree measurement and again in association with a later tree measurement, for example, at ages 3 and 5 years and perhaps later, depending on the goal of the project (N. Marcar, pers. comm.). This frequency of assessment will not measure the changes taking place during a year but will detect changes in salinity over time and these can be related to tree growth. A salinity measure is taken in the middle of each plot in the case of small plots, or near each tree (N. Marcar, pers. comm.). Tree growth can then be related to different levels of salinity within the site (e.g. Benyon et al. 1999).

Salinity is best described in terms of electrical conductivity (*EC*). The best measure is ECe, which is based on conductivity of a saturated soil paste and is recorded in decisiemens per metre (dS/m) (but note that WA often uses millisiemens per metre (mS/m) (Marcar and Crawford 2004)). *EC*e is a meaningful measure to compare across sites (other things being equal). An easier method is to measure the conductivity of a 1:5 soil water extract. This can be converted to *EC*e (for method see Marcar et al. 1995, Marcar and Crawford 2004 or Harper et al. 2008). For rapid assessment, hand-held and vehicle-based meters (e.g. a portable EM38) which measure the apparent electrical conductivity of a volume of the ground can be used to assess salinity in the tree root zone. These should be calibrated against *EC*e measurements at a relevant range of depths for each site as ECe depends on soil texture (Marcar et al. 1995).

5.7.3 Other measures

For specialised trials a range of additional samples and measurements are relevant, including biomass sampling, levels of browsing, water use, soil water storage, and carbon assessment. Notes on flowering and fruiting status of the stand can be useful for later seed collection or tree improvement work. Biomass sampling has been conducted as part of fertiliser, irrigation and coppice and mallee oil trials (see Box 5-5). Browsing studies should, as a minimum, measure seedling survival, forks and multi-leaders (see Box 5-5).

A large number of water use studies have been conducted on eucalypt species grown on irrigated, low rainfall and saline sites. The reader is referred to such studies for design and measurement methods. Some references are provided in Box 5-5 and Sections 4.3.6 and 4.3.7.

Projects which wish to assess carbon stocks should ensure they refer to recent rules, tools and research, because the area is evolving rapidly. The Australian Government Department of Climate Change, through the National Carbon Accounting Toolbox (NCAT), provides tools for tracking carbon stock changes and greenhouse gas emissions from land use and management, including forest plantings. Using NCAT, users can identify changes in emissions resulting from changes in management and climate variability and reliability. The National Carbon Accounting System uses the FULLCAM model and NCAT is readily available for estimating carbon sequestration for a range of species and systems.

Growers wishing to assess forest carbon may also refer to literature produced by the former Australian Greenhouse Office (now Department of Climate Change). For example, the technical reports by Snowdon et al. (2002) and McKenzie et al. (2000) provide information on methods for assessing carbon in tree, stand, soils, leaf litter and coarse woody debris.

The rate of carbon sequestration differs between plant species and sites, and is influenced by growth rate, wood density and plant species biomass partitioning (allometry). There are currently reasonable equations for key plantation forestry species, but a lack of data on growth performance and net primary productivity for low rainfall species, northern Australia, and mixed species and environmental plantings.

The accuracy of the carbon estimates required will determine the sampling method used. As with wood characterisation research (section 4.4), some biomass and carbon sequestration estimates can be obtained by measuring existing forestry trials and farm forestry plantings. General estimates may be based on tree growth data such as tree mean annual increment (MAI), particularly for the major plantation species where reasonable predictive equations for allometry already exist and wood density is known. More accurate estimates require data on net primary productivity and species allometry as they provide better indicators of carbon sequestration than MAI. Data on species allometry generally requires destructive sampling, and is used to convert height and diameter data to biomass and carbon ratios. Such data can be used to develop equations for new species and types of plantings.

A review of some methods for estimating biomass and carbon sequestration is provided in FloraSearch reports 2 and 3A (Hobbs et al. 2009a,b). The FloraSearch project has measured allometry (biomass partitioning) and collated growth data for a range of species from various trials in southern Australia (Hobbs et al. 2009a,b) This data provides a comprehensive data set for non traditional tree and shrub species, although some measures come from small plantings and may over-represent growth potential. The FloraSearch project has grouped species into functional groups (eucalypt trees, non-eucalypt trees, mallee eucalypts and shrubs) for the purpose of modelling regional biomass production potential.

Various projects are currently calculating and predicting carbon sequestration for a range of species, vegetation types and regions of Australia. Recent work by CSIRO has calibrated the carbon accounting model FULLCAM to *Eucalyptus cladocalyx* and *Corymbia maculat*a plantations and used this to predict sequestration in low rainfall plantations of southern Australia (Paul et al. 2007, 2008). Models have also been used to predict soil carbon following afforestation and reforestation (Paul et al. 2002; 2003a,b), calibrate for soil carbon decomposition under eucalypt and pine plantations (Paul & Polglase 2004), and evaluate forest management regimes for firewood (Paul et al. 2006).

In the future, it would be appropriate to develop guidelines for research trials which aim to estimate carbon sequestration and other factors.

Box 5-5 Selected Australian studies which sampled tree water use, browsing or biomass in plantations

Selected Australian studies which sampled tree water use, browsing or biomass in plantations

Topic	Reference (chronological order)	
Biomass sampling	Cromer and Williams 1982;	Bennett et al. 1997;
	Cromer et al. 1983;	Delgado and Tome 1997;
	DeBell et al. 1985;	Hingston and Galbraith 1998;
	Pereira et al. 1989;	Hingston et al. 1998;
	Hopmans et al. 1990;	Misra et al. 1998;
	Rance et al. 1990;	Pinkard and Beadle 1998b;
	Stewart et al. 1990;	Harrison et al. 2000;
	Milthorpe et al. 1994;	Wildy et al. 2000
Browsing	Montague et al. 1989;	McArthur and Beadle 1998;
	Montague 1993;	Bulinski and McArthur 1999;
	Haines et al. 1994;	Bulinski 1999;
	Montague 1994;	Armstrong 2000;
	Wilkinson and Neilsen 1995;	Bulinski and McArthur 2000;
	Parsons et al. 1997;	Lees 2000;
	Bulinski and McArthur 1998;	McArthur et al. 2000
	Marks and Moore 1998;	
Water use	Butcher 1977;	Silberstein et al. 1997;
	Eastham et al. 1990;	Collopy and Morris 1998;
	Eastham et al. 1990a;	Hatton et al. 1998;
	Morris 1991;	Hunt and Beadle 1998;
	Boden 1992;	Morris et al. 1998;
	Eastham et al. 1994;	White et al. 1998;
	Nicoll 1994;	Wilson and Clark 1998;
	Benyon et al. 1996;	Benyon et al. 1999;
	Dye 1996;	Cramer et al. 1999;
	Honeysett et al. 1996;	Morris and Collopy 1999;
	Marcar et al. 1996;	Stevens et al. 1999;
	Myers et al. 1996;	Morris and Collopy 2000;
	White 1996;	White et al. 2000
	White et al. 1996;	

6. Guidelines for site characterisation

Chapter outline

Trial results cannot be interpreted reliably without relating them to the site's characteristics and any variations in properties across its extent. This chapter provides guidelines on how to collect the relevant information.

It is important to describe the trial site to aid the interpretation of tree growth in response to environmental variables. Good site characterisation is particularly necessary if tree growth in response to soil, rainfall, nutrition or silvicultural treatments at different sites is to be compared between sites. The following sections outline a minimum data set that should be collected for a research trial. The JVAP manual titled *Site selection for farm forestry* (Harper et al. 2008) provides more detailed guidance on assessing sites for farm forestry.

6.1 Site description

The site description should identify any limitations to tree growth associated with the site conditions and provides a means of comparing different trial locations. The description should include:

- locality maps—for the property, the local district, the region and the state;
- the location in terms of latitude and longitude (or Australian Map Grid coordinates (AMG easting and northing) and AMG zone);
- aspect;
- slope;
- elevation;
- position in landscape relevant to exposure and surrounding vegetation;
- landform element (e.g. hillcrest, hillslope, valley flat; see McDonald et al. (1990) for a comprehensive list and definitions) and slope shape (concave, convex, even) if relevant;
- previous land use, including previous vegetation type and history of fertiliser use (preferably give details of the aggregate amounts of fertiliser applied in kilograms per hectare over time);
- climate, soil and hydrology descriptions (see Sections 6.2 to 6.4); and
- a chosen site name. Once a site name is published for a trial, it should be consistently applied and cross-referenced by following researchers.

The position of the trial and the treatments with respect to the landscape should be unambiguously described. This should include whether different experiments or treatments are adjacent or distant, and whether sites differ or vary in topography, soils or climate. The best method would be to provide a map and diagram of the layout, indicating species and provenances and treatment plot locations and stocking densities. The latitude and longitude or AMG coordinates of the site should be stated, including the method used to determine these (usually map reading or global positioning system instrument).

6.2 Climate description

The climate should be clearly described both to explain the conditions under which this trial plantation grew, and to enable comparison with other trials and sites. Ideally a weather station or rain gauge (measured regularly) and maximum-minimum thermometer or hydrograph is placed at the site. Otherwise records from the nearest Meteorological Bureau station should be used. Estimates of mean monthly climate data can also be generated by the program ESOCLIM using latitude and longitude (or AGM coordinates) and altitude.

Often mean rainfall data is given in research reports, but this is hardly ever what trees experience. Where accessible, median (also called decile 5 or 50th percentile) rainfall data should be reported. The median is the rainfall that is expected to be equalled or exceeded for 50% of the time, based on averages of yearly data collected to date and is a slightly lower and more realistic figure. Medians reinforce the concept of the probability and variability of climate in a much more meaningful way (G. Holz, pers. comm.).

For each site, the description should include:

- median annual rainfall;
- actual recorded annual rainfall up to two years prior to and since establishment;
- median monthly rainfall;
- actual recorded monthly rainfall;
- median dry season length;
- median monthly temperature;
- actual recorded monthly maximum and minimum temperatures;
- pan evaporation;
- average number of frost days per year and absolute minimum temperature;
- actual number of frost days per year and absolute minimum temperature each year of the trial;
- wind speed and prevailing direction.

The relevance and interpretation of these characteristics is discussed in the JVAP manual *Site evaluation for farm forestry* (Harper et al. 2008).

6.3 Soil description

While a comprehensive soil chemical analysis may be too expensive for each site, the recording and reporting of soil physical characteristics are essential. Australian standard texts are McDonald et al. (1990) for field description and Isbell (1996) and Jacquier et al. (2000) for classifying soil (an interactive compact disc can be used to assist the process of soil classification). Other background references are Gunn et al. (1988); Foster and Costantini (1991a,b,c); and McKenzie et al. (1995). If detailed soil descriptions are required they should be undertaken by a person with relevant experience in soil sampling and analysis. The minimum set of parameters to describe at a research site is:

- total depth sampled (and method);
- bedrock and regolith geology;
- surface condition;
- type and depth of any materials likely to restrict root growth;
- pH and salinity at appropriate depths;
- for each soil layer:
    - 6.4 depth, boundaries and hardness for each soil layer;
    - 6.5 colour;
    - 6.6 texture;
    - 6.7 structure, strength, stickiness, type and degree of plasticity;
    - 6.8 moisture status at time of description (note the presence of any free-flowing water);
    - 6.9 inclusions;
    - 6.10 soil profile classification.

Preferably, the soil profile should be examined to the depth of any root-impeding layer. However, in practice the depth of examination often does not exceed 1.5 m to 2 m. At the QFRI and Queensland Department of Forestry, the standard measuring depth is only 1 m, but in Western Australia and South Australia, sampling to depths of 3 m to 4 m is common (especially in sandy soils to reach the moisture holding layer).

The soil sampling intensity (number of assessment sites per hectare) should be stated. Preferably, sampling should include extreme site conditions so that the scale and direction of any gradients in soil properties can be identified. Of note is that saline sites tend to be very variable over short distances. An intensive assessment of soil at plot level or even individual tree level may be required (J. Morris, pers. comm.; see Section 5.7.2).

As part of the documentation of each trial, a commencement report should be written (see Chapter 7) and it should include a detailed soil data sheet. McDonald et al. (1990) provided a standard soil description sheet. An example of a comprehensive soil data sheet from QFRI is shown in Appendix 3. Where nutrient status or chemical analyses have been performed, reports should indicate the collection and analysis procedure, nutrients analysed and the results. Trace elements are not generally measured as the relationships between trace element concentration in the soil and availability or uptake by trees are commonly unclear or inconsistent (I. Dumbrell, pers. comm.). However, where a site × species interaction is known to limit growth due to nutrient deficiency, trace elements should be measured. The QFRI soil data sheet includes manganese because it is readily analysed using the same methods as those used for the macronutrient cations (e.g. calcium, sodium).

6.11 Hydrology

A statement describing the hydrology of a research site may provide information which can be used to assess:

- the erosion risk associated with site preparation;
- long-term productivity associated with rainfall and soil storage;
- hazards such as salinity and waterlogging; and
- the potential long-term water availability and stress.

These issues are discussed in the JVAP *Site evaluation for farm forestry* manual (Harper et al.2008). The hydrology description should include:

- watertable depth;
- the groundwater salinity if the watertable is shallow enough to influence tree performance;
- an estimate of plant-available soil water storage based on the texture and depth of each soil layer; and
- an indication of the frequency of flooding or waterlogging at the site.

In each case, the source of the information should be recorded with comments on its accuracy and the likely variability of the property across the research site and with time.

In regions where the evaporation rates exceed the rainfall for periods of several weeks or months, the role of the soil profile as a reservoir to store excess rainfall from the wetter months is particularly important. If the soil profile is shallow, it may not be able to store all of the rain that is available during some periods and this means that less water will be available for the tree during following dry periods. For low rainfall sites, it is important that the soil description is sampled to much deeper depths, for example 3–4 metres in southern states. The JVAP manual titled *Site evaluation for farm forestry* (Harper et al.2008) discusses soil depth and water balances and the sources of rainfall and evaporation data. Interpreting the hydrology and soil water store is important in understanding the tree growth (e.g. see Edwards and Harper 1996).

7. Reporting the establishment and management of experiments

Chapter outline

This chapter discusses recording, storing and reporting details about each trial. It lists the main reasons for taking the time and trouble to do these tasks well, and provides guidelines on the most important data to collect.

Records should be kept in the form of written reports and in a database accessible by others in the research organisation. Researchers and research organisations should ensure trials are well documented so that:

- the trial designs can be easily understood by others
- the results can be validly compared with those from other trials
- the reasoning behind the interpretation of results is transparent
- results are more easily accessed for comparison with other trials
- information gained can be used by others designing further trials
- the details of the experimental design and results can readily be transferred to databases within and outside the organisation (e.g. see Appendix 4).

Improved availability of information about trial design, management, and results, will also help achieve more consistent design quality over time.

Good, accessible documentation should prevent unnecessary repetition of experiments (which has periodically happened throughout Australia’s forestry research history). Clear descriptions of experimental methods should help other researchers decide whether a similar approach would suit their own requirements.

Another reason for documenting all aspects of an experiment is that structural and staff changes are now common in organisations and without good records it is likely that important information will be lost.

Records should be completed as events occur to avoid loss of detail or errors of fact. In particular, details that cannot be retrieved retrospectively should be recorded immediately—for example, planting date, site preparation, ground conditions at time of planting, local climatic conditions and seedling condition. Trials should be given a number or name when designed and this should be recorded in a register for future reference. This unique identifier for the given trial should then be used in all further research referring to that trial.

It is recommended that a commencement report is completed soon after the trial is established while the researcher’s memory is still fresh (that is, within a few months of establishment!). Appendix 5 contains an example form for recording experiment establishment details , based on a QFRI commencement report. Subsequent reports should be prepared every year or two and should contain interim data analyses, a description of the management operations carried out and any events or factors which will influence trial outcomes and management decisions. The report should refer to any previous reports and allied experiments.

Storing trial data in well-designed central databases should mean that the details from many trials are in consistent forms. As a minimum the experiment number, trial description and management history should be stored, but preferably also the measurement data. Data from different trials and research projects can then easily be collated for inventory, statistical analyses or simulation modelling.

The following sections of this chapter list the information that we suggest should be included in internal reports and for published reports (even if the requirements of technical journals are less).

7.1 Site and soil description

Experiment commencement reports should include a detailed soil data sheet. The report should state the number of soil samples taken. Where nutrient status or soil chemical analyses have been performed reports should indicate the collection and analysis procedures, nutrients analysed and the results. Hydrology and climate should also briefly be described (see Chapter 6).

7.2 Trial location, design and establishment

Reports must include the location of the trial, experimental layout, plot areas, planting date, species tested, stocking density at time of planting, condition of planting stock and tree age at times of measurements.

Authors should firstly state the aims of the trial. Care should be taken to describe the type of experimental design (e.g. randomised complete block), the factors tested and the various treatment levels applied. Reports are easier to read when there is a clear statement or list of the purposes of the different treatments. Note the dates that treatments were applied, the method of application and the environmental conditions before, during and directly after the application.

For the trial establishment report, describe site preparation as well as pre- and post-planting herbicide application, planting technique, soil moisture status, initial watering, fertilising or mulching applications. If routine operational procedures are used then refer to a previously published description for each.

7.3 Site preparation

Reporting on site preparation should include a detailed description of machinery and how the procedures were carried out. For example, if ripping was conducted, report the size and type of bulldozer, the number of rippers and whether they had wings, the actual depth reached by the ripper, and the soil moisture at the time of ripping. If mounding is conducted, then the size and width of the resultant mound and the soil conditions (such as friability) should be reported. In addition, a description of the soil moisture throughout the profile should be included to indicate the effectiveness of site preparation treatments. To identify planting conditions, a climatic description including rainfall for the month prior and the 6 to 12 months following planting should also be included (J. Huth, pers. comm.).

7.4 Irrigation

Irrigated trial descriptions should outline:

- the method of water delivery;
- the type of water (e.g. effluent, fresh, bore, saline);
- the rate and frequency of application;

- site-specific actual rainfall measurements (preferred) or median annual rainfall measurements; and
- an estimate or description of additional water applied to the site by other means such as run-off and underground flows.

When water application is irregular, a statement of tree age for each of the irrigation dates can be useful to the reader. A detailed description of the properties of the irrigation water should also be included.

7.5 Weed control and herbicides

Due to the strong effect of weed competition on tree growth (Ryan 1982; Borschmann 1997; Dredge 1997; Duncan and Baker 1997; Ryan 1997; Keenan and Bristow 2001), the reporting of any type of weed control carried out in the first three years of trial establishment is necessary. The report should state the method, rate, date applied and application conditions, percent weed cover and where it was measured. For chemical control, active ingredients and herbicide brand name should be clearly listed, along with application rate.

7.6 Fertiliser application

When experiments receive fertiliser, the frequency of application, the application rate, method, date and application conditions should be outlined, along with the type of fertiliser or brand name and the elemental composition and percentage.

7.7 Thinning and pruning

The date of thinning and number of stems retained should be reported, and preferably the product from thinnings. For pruning, report the percentage of crown retained, height to which pruned and pruning method (saw, shears, etc.), season and date.

7.8 Additional management techniques

The use of non-standard or site-specific management techniques is often necessary throughout the life of an experiment to minimise within-trial variation. These operations **must** be reported. Examples include fencing, tree guards, staking, watering, animal control (shooting, baiting, feeding), insect and pathogen control (insecticide and fungicide application) and replanting. These should be recorded at the time of management, rather than relying on later memory.

To assist in standardised reporting of silvicultural research, a checklist of reporting requirements is given in Appendix 6.

8. Publication guidelines

Chapter outline

The results of research trials are usually published in concise articles so that they are available outside the research organisation. This chapter summarises the essential material to include in such publications.

While a full report should be kept for internal records (see Chapter 7), publication generally requires a much more concise description of experimental methods and results. This should be given without compromising necessary detail. A survey of publications on hardwood plantation silviculture shows considerable inconsistency in the detail reported for experimental design and results. Guidelines here are adequate for formal publications in scientific format. Much of this information should also be provided in extension articles, which tend to omit or provide insufficient information on soil and site type, provenance, tree age, plot size, replication and treatments used.

8.1 Keywords

Keywords are useful indicators of the content of the research. For example, indicating whether the trial is a species or silvicultural trial allows a silvicultural researcher or extension officer an easy way to select relevant papers. Keywords can also indicate the trial location, species, and factors tested in the experiment.

8.2 Introduction, trial description and methods

Silvicultural research can incorporate a complex array of treatments, both during establishment and over time. As a result, a clear definition of the project aims needs to be given in the introduction.

The introduction should have a concise yet comprehensive description of the trial. This should include at least:

- the treatments;
- the species being tested and their provenances;
- the trial location;
- site characteristics;
- the date established;
- trial and plot areas and the number of trees.

Background information on trial establishment and management (see Chapter 7) will set the context for the results with respect to other trials and sites.

The methods section should describe the experimental design (e.g. randomised complete block) and clearly define each of the specific treatments and treatment levels tested for each factor. For papers that only report one part of an experiment, the reader should be informed of the larger design as well as being referred to other relevant published work which describes the experiment.

Any author reporting on a trial that has already been described in published articles should refer to the earlier articles, allowing the reader to easily access further information about the trial—in particular, the site description, the full experimental design and any tree growth measures. Cross-referencing between different types of research conducted on a single stand has not often been seen as important in the past. For example, papers which discuss soil analysis (Aggangan et al. 1998), physiology (Hunt and Beadle 1998), or models (e.g. Pinkard and Beadle 1998b) have not stated whether there are corresponding tree growth measures (DBH, height) available for the experiments or plantations used. Growth data is sometimes published without reference to earlier measures; for example, Keenan (1998) gives a later measure than that reported by Cameron et al. (1989) but does not mention the earlier results; and measures of growth of an *E. regnans* trial at ages one, six and eight are given in Leon (1989); Elliott et al. (1993) and Elek (1997) respectively. However, cross-referencing the different aspects of an experiment should be regarded as important for the reasons outlined in the introduction to Chapter 7.

In the methods section the author should state why the data that is described was collected. Measurements that were taken but reported elsewhere should be noted. Tables and graphs should be referred to in the body of the text. This allows the reader to establish how and why the data was collected, and where it is being discussed.

8.3 Results section

The results section should clearly, concisely and accurately report results and treatment interactions. It should maximise the amount of relevant information within any space limitations. Where figures, graphs and tables are included they should have clear titles which refer to the treatments applied and the age of the trees measured, and describe the components of any statistical analyses.

Multiple treatments can require complex statistical analyses. There can be non-linear responses to applied treatments. There can also be an interaction between the different factors tested in the experiment—that is, the shape or slope of the response curve may change depending on the combinations of treatments being analysed. The researcher must **first** determine whether any interaction components have a significant effect on the results. If so, it is **not** appropriate to pool these treatments to increase the number of replicates in an analysis. Data from different treatments should only be pooled if the interaction effect is statistically not significant, and the reader should be informed of this. In addition, where provenances are included in silvicultural trials, it is desirable that their differences are reported separately, rather than pooling results across different taxa. In this way, best provenances and potential benchmark taxa can be identified for use in future experiments or plantings.

8.4 Discussion section

The researcher should aim to discuss only the most important results so that the reader is left with a clear view of the significance of the research. A good rule of thumb is to aim to leave the reader with three or four important points.

8.5 Conclusion and future implications

A brief and clear statement of the direct implications of the results is useful. Avoid repeating a summary of the results section. Recommendations should be given to indicate whether the trial will be terminated or whether further research is required to clarify the results.

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Appendix 1. Experimental design checklist

Source: adapted from an unpublished manuscript titled *Tropical tree nutrition—research and techniques* written by M. Webb (CSIRO) in 2000

Have you:

Developed a workable hypothesis?

Checked the availability of resources—fertilisers, planting stock, site, labour?

Ensured adequate control treatments are in place?

Standardised all other factors as far as possible?

Considered factors which may be limiting, and attended to them where possible?

Taken steps to avoid contamination?

Chosen appropriate variables and measurement intervals?

Determined the sampling strategy—what, when, how much, how many?

Replicated the experiment?

Randomised the allocation of treatments?

Considered non-significance (if the results were not significant, why not?)?

Chosen the statistical methods to be used?

Prepared adequate documentation?

Determined who will be responsible for and have ownership of the trial?

Identified collaborators?

Scheduled activities?

Appendix 2. Leaf area sampling

Author: Chris Beadle (CSIRO Forestry and Forest Products, Tasmania)

Destructive sampling procedure

The following procedure will yield regression relationships between leaf area and branch basal area based on 30 branches for three zones in the crown based on equal one-thirds of green crown length.

Selecting the trees for leaf area determination

1. Identify growth plots which are representative of the distribution of the trees being targeted by the *LAI-2000*.

2. Measure the distribution of diameters of trees in the growth plot.

3. Rank the trees by diameter (*d*), calculate (d^2) and divide into six size classes of equal or approximately equal number.

4. Select one tree from each size class for leaf area determination. Trees should be selected from areas away from the growth plot and exclude trees within the intended sampling area of the LAI-200*0*.

Harvesting

1. Each tree should be felled at ground level with a chainsaw. Only operators with a chainsaw licence for felling trees should do this task. Under no circumstances should this rule be ignored.

2. Once felled, the total height and height to the lowest green branch (i.e. carrying live foliage) should be measured. The difference is the green crown length.

3. Divide the green crown into three parts of equal length. Measure each live branch along the crown from the base to tip of the live crown in the following manner: Using a tape and caliper, measure the branche's height above ground (its distance from the main stem base) and its diameter over bark (to nearest 0.5 mm) at 4 cm from the base of each branch.

4. On the basis of the diameter distribution within each one-third of the live crown, select five branches representative of that distribution. Clearly label each branch to identify site, tree, section of green crown length and branch number. Excise at base of branch and place immediately into plastic bags.

5. Using chainsaw (chainsaw operator only) remove two 25 mm-thick discs at 1.3 m and two 25 mm-thick discs at the base of the live crown (immediately above and below the measurement centre point). These discs are called stem sections. Place them immediately into labelled plastic bags.

Sapwood area

1. Sapwood area can be determined by painting 0.2% dimethyl yellow solution on to one surface of the stem section. Allow dye to penetrate. Only heartwood should react to a darker colour. Trace the outline of the sapwood (without bark) and use a *Delta-T* leaf area meter to measure its area (this can be done by measuring the (sapwood + heartwood) area, then the heartwood area, and calculating the difference).

2. The sapwood area may appear obvious, but can be confirmed using a staining technique. Using 0.25 g toluidine blue in 100 ml water. Apply dye to the stem section and allow it to penetrate. Sapwood only should take up the dye.

Dry weight and specific leaf area

1. Remove all leaves (without petioles) from each branch in turn.

2. Select 10 leaves randomly from those on each branch for determination of specific leaf area. Place remaining leaves in a clearly labelled brown paper bag, dry at 40°C for 72 hours and 70°C for 24 hours. Weigh dry leaves. Add to weight of bulk leaves for each branch.

3. Repeat for other branches and trees.

Appendix 3. QFRI soil description sheet

Soil Chemical Analysis

Plot No.	Depth (cm)	Lab I.D.	QFRI No.	pH units	Ntot %	Ptot mg/kg	Pav mg/kg	Na cmol/kg	K cmol/kg
11	0–10								
11	10–35								
11	40–50								
11	60–90+								

Plot No.	Depth (cm)	QFRI No.	Ca cmol/kg	Mg cmol/kg	Mn mg/kg	CEC cmol/kg	Cond dS/m	OC %	Ktot mg/kg
11	0–10								
11	10–35								
11	40–50								
11	60–90+								

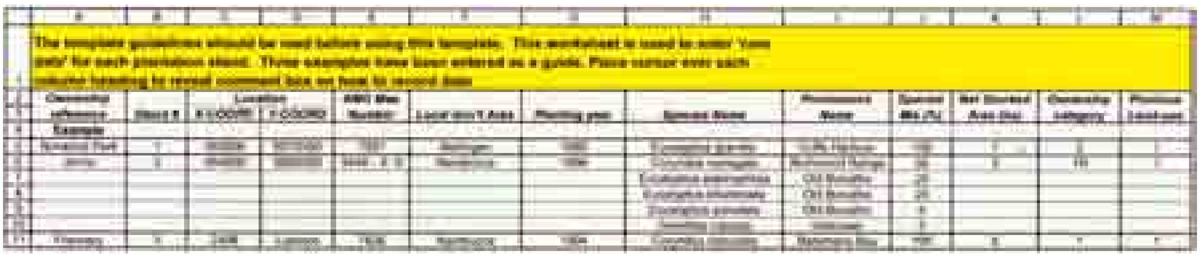
Soil Physical Characterisation *(Example)*

Plot Number	Plot 11			
Forestry Soil Type:	Soloth			
Great Soil Group:				
Australian:	Yellow Chromosol/Sodosol			
Layer Number:	**1**	**2**	**3**	**4**
Horizon	A11	A2	B21	B22
Lower depth (cm)	10	35	60	90+
Lower boundary (mm)	50–100	5–20	50–100	
Colour – Matrix	5YR 3/3	5YR 5/3	10YR 6/4	2.5Y 7/3
Colour – Description	Dark reddish brown	Dull reddish brown	Dull yellow orange	Light yellow
Mottle 1 – Colour			10R 3/6	10R 4/6
Mottle 1 – Description			Dark red	Red
Mottle 1 – Abund/contrast			10–20%, distinct	10–20%, distinct
Mottle 2 – Colour				5YR 6/6
Mottle 2 – Description				Orange
Mottle 2 –				2–10% faint

Abund/contrast				
Texture	SCLKS	SCLKS	MC	MC
Moisture status	Dry	Dry	Mod. Moist	Mod. Moist
Inclusions – Nature	Quartz	Quartz	Quartz	Quartz
Inclusions – Abund./size	10–20%, 2–6 mm	10–20%, 2–6 mm	2–10%, 2–6 mm	2–10%, 2–6 mm
Restrictions			Rocky, slight	
Field pH	6.5	6.0	5.5	4.5
Sample (cm)	0–10	10–35	40–50	60–90+

Appendix 4. NFFI data recording forms

Farm Forestry resource details using NFFI core dataset (Source: Bureau of Resource Science)



Cell: A2
Comment: Ownership reference:
Enter a unique code which will allow you to recognise the owner of each stand in your region. This can be used for future reference and allow future users of this database to track owners. It will also enable you to link data in this spreadsheet with any additional information kept at the local level (for example, full ownership and landholder contact details). In this way you can maintain the NFF1 Core Dataset as a sub-component within a larger database.
1 = Landowner's trees on landowner's land.
2 = Joint venture between landowner and private investor.
3 = Joint venture between landowner and Crown investor.
4 = Private company trees on private company land.
5 = Private company trees on Crown land.
6 = Crown owned trees on Crown land.
7 = Crown owned trees on leased private land.
8 = Annuity or lease arrangement between landowner and private investor
9 = Annuity or lease arrangement between landowner and Crown investor
10 = Other
11 = Unknown

Cell: B2
Comment: Stand number:
Enter a unique number for each stand. Please number consecutively from 1 to n, or use the same number from your existing database. You may have more than one stand for each owner. Each stand should all be planted in the same year. For continuous areas of plantings over more than one year, try to break them into individual stands according to the year planted.

Cell: C2
Comment: Location of plantings:
Use the two location columns to enter either
A) Australian Map Grid X and Y coordinates.
OR B) Latitude and longitude coordinates.
OR C) Postcode and nearest town. (Least preferable option)

See comments for cells D2 and E2 for entering X and Y coordinates.

Cell: E2
Comment: AMG Map Number:
Enter the number of the AMG map used to derive X and Y or latitudeand longitude coordinates. It is not necessary to complete if postcode and nearest town are provided instead of AMG coordinates.

Cell: F2
Comment: Local Government Area:
Enter the name of the Local Government Area (LGA), or Shire, in which the stand exists.

Cell: G2
Comment: Planting Year:
Enter the year in which trees were planted. This must be entered as 4 digit number, e.g. 1988. All trees should be planted in the same year for each stand.

Cell: H2
Comment: Species Name:
Enter the full scientific name of each species in the plantation stand. For mixed species stands, list each species one under the other.

Cell: I2
Comment: Provenance Name:
Enter the full name of species provenance in the plantation (where known).

Cell: J2
Comment: Species Mix
Enter the percentage attributed to each species in the stand (as listed under Species Name).

Cell: K2
Comment: Net Stocked Area:
Enter your best estimation of total net stocked area of the stand (in hectares). This is the area actually planted with trees and excludes sections with the plantation boundary which have roads, dams or failed plantings.

Cell: L2
Comment: Ownership category:
Code for land and resource ownership categories; use codes (i.e. 1 to 11) in look-up table below to describe the relevant arrangement. Add a TV to the code if the plantation has been set up as a research trial. * 'Landowner' describes private individual landowners and growers.

From the look-up table below, enter a code which best describes the immediate previous land use, prior to planting:
1 - cleared agriculture
2 - plantation forest
3 - native grassland
4 - native forest
5 - other

Cell: C3
Comment: X-COORD:
Full AMG map grid easting coordinate of the centre of the plantation stand; this must be a 6 digit number. Please use 1:25 000, 1:50 000 or 1:100 000 scale maps. Written instructions on deriving full AMG coordinates can be provided by Nick Stephens 02 6272 4583[1]. A latitude coordinate may be placed in this column instead, or if no coordinates can be provided, provide the postcode in which the plantation stands exists.

Cell: D3
Comment: Y-COORD:
Full AMG map grid northing coordinate of the centre of the plantation stand; this must be a 7 digit number. Please use 1:25 000, 1:50 000 or 1:100 000 scale maps. Written instructions on deriving full AMG coordinates can be provided by Nick Stephens 02 6272 4583[2]. A longitude coordinate may be placed in this column instead, or if no coordinates can be provided, provide the nearest town in which the plantation stands exists.

Cell: M2
Comment: Previous Land Use:
This category is important for identifying stands which are Kyoto-compliant. This applies only to stands established since 1 January 1990.

---

[1] Contact Bureau of Rural Sciences

Farm Forestry resource details using NFFI additional data fields (Source: Bureau of Resource Science)

Use this worksheet to record site, growth and management data on selected stands in core dataset

It is desirable that a minimum 15% sample of stands be selected to record this information

TREE PARAMETERS & SILVICULTURE

Stand #	Average tree height (m)	Average DBH (cm)	Date of meas	Stems per hectare	Stem Form 1	2	3	4	5	Thinning Year	Thinning type	Pruning Year	Pruning Type
Example													
1	16.0	20.00	[illegible]	800	50	20	25	10	0	1990	t1	1990	p1
2	4.0	10.50	[illegible]	1000	50	20	20	10	0	none		none	
3	8.0	12.00	[illegible]	1200	40	25	10	10	0	none		none	

Expected products (PRODUCTS)	Expected values (VALUES)	Altitude (m) (SITE CHARACTERISTICS)	Mean Ann. Rainfall (mm)	Soil Type surface	Soil Type subsoil	Topography	Site Preparation (ESTABLISHMENT)	Weed Control	Fertiliser	Tree protection	Planting stock
1	2,3,4	420	750	2	3	2	2	1	4	1	1
1	2,3,5	625	800	2	3	1	2	2	4	3	1
4	2,4,5	700	700	1	3	2	1	2	2	2	1

Enter data in the first 5 columns only, from core data sheet

Ownership reference	Stand #	Area (ha)	Stocking (stems/ha)	Year Planted	Average tree Basal Area	Average tree total volume	Total volume per hectare	Total volume for stand	Mean Annual Increment	Age at Meas
Norwood Park	1	7	800	1985	0.03 m2	0.17 m3	134.0 m3/ha	938.2 m3	8.9 m3/ha/yr	15
Jenni	2	5	1000	1996	0.01 m2	0.01 m3	11.5 m3/ha	57.7 m3	2.9 m3/ha/yr	4
Flannery	3	6	1200	1994	0.01 m2	0.03 m3	36.2 m3/ha	217.1 m3	6.6 m3/ha/yr	6

Cell: A4
Comment: Stand number:
Enter the corresponding stand number for the same stand in the core dataset sheet. This will allow you to easily cross-reference the core and additional data.

Cell: B4
Comment: Average tree height:
Enter the best estimate of average total tree height within the stand. Ensure date of height measurement is recorded in the 'date of measurement' column. Use the plot sheet provided if you wish to record field measurements.

Cell: C4
Comment: Average diameter at breast height over bark (DBHOB): Enter the average DBHOB (in centimetres) of trees measured within the stand. Use a minimum of 20 trees randomly selected within the stand.

Cell: D4
Comment: Date of measurement:
Date on which height and diameter measurements were taken, provide as day/month/year. For example, the 6th of January 1998 is entered as '6/1/98' and will be displayed as 060198. Ensure date of diameter measurement is recorded in the 'date of measurement' column. Use the field sheet provided if you wish to record field measurements.

Cell: E4
Comment: Stems per hectare or stocking rate:
Enter the current number of living stems per hectare. This is usually in the range of 150 to 2000 stems per hectare. If you know the planting spacing you can estimate stocking density (S) using the formula: S = 10000/(distance between rows in metres x distance between trees in rows in metres)

Cell: F4 to J4
Comment: Stem form:
Estimate the percentage of trees within the stand corresponding to the following stem form categories:
1 - single straight stem
2 - single crooked stem
3 - forked below 6 metres
4 - multi-stemmed below 6 metres
5 - dead/fallen

Ensure total is equal to 100%

Cell: K4
Comment: Thinning year:
Enter the year in which the most recent thinning treatment occurred. If no thinning, type 'none'.

Cell: L4
Comment: Thinning type:
Enter one of the codes below which corresponds to the most recent thinning treatment:
T1 - 1st thinning
T2 - 2nd thinning
T3 - 3rd thinning
T4 - 4th thinning

Cell: M4
Comment: Pruning year:
Enter the year in which the most recent pruning treatment occurred. If no pruning, type 'none'.

Cell: N4
Comment: Pruning type:
Enter one of the codes below which corresponds to the most recent pruning treatment:
P2 - Pruned to 2 metres
P4 - Pruned to 4 metres
P6 - Pruned to 6 metres
P8 - pruned to 8 metres or above

Cell: O4
Comment: End-use products:
Enter a code from the look-up table below which best describes your intended forest products. You can enter more than one code.
1 - specialty/cabinet timber
2 - structural timber
3 - fencing/posts/rounds
4 - pulpwood
5 - firewood
6 - charcoal
7 - non-wood (e.g. oil/flowers)
8 - fodder
9 - other

Cell: P4
Comment: Expected values:
Enter the codes from the look-up table below which best describe your expected forest values. You can enter more than one code.
1 - biological conservation
2 - salinity
3 - soil protection/ rehabilitation
4 - stock protection
5 - increased crop production
6 - carbon sequestration
7 - aesthetic values
8 - other

Cell: Q4
Comment: Altitude:
Average altitude, in metres, of the planted site.

Cell: R4
Comment: Mean annual rainfall:
The mean (or average) level of annual rainfall, in millimetres, that the planted site receives.

Cell: S4
Comment: Soil type:
Enter a code from 1-7 (for both the surface soil and subsoil) from the look-up table below. Soil type categories have been derived from the 'Australian Soil & Land Survey - Field Handbook' (McDonald et al 1990).
1 - sand
2 - sandy loam
3 - loam
4 - clay loam
5 - light clay
6 - medium clay
7 - heavy clay

Cell: U4
Comment: Topography:
Choose the code (1-5) from the look-up table below which best describes the position of the planted stand.
1 - ridge
2 - upper slope
3 - mid slope
4 - lower slope
5 – flat

Cell: V4
Comment: Site preparation:
Enter a code from the look-up table below:
1 - ripping
2 - mounding
3 - disc ploughing
4 -others/combinations.

Cell: W4
Comment: Weed control:
Enter a code from the look-up table below:
1 - herbicide knockdown
2 - herbicide residual
3 - slashing
4 - mechanical cultivation
5 - hand cultivation
6 - controlled grazing
7 - burning
8 - nil

Cell: X4
Comment: Fertiliser:
Enter a code from the look-up table below:
1 - High phosphorus chemical
2 - Low phosphorus chemical
3 - Slow release
4 - Fast release
5 - Liquid
6 - Trace elements
7 - Organic
8 - Nil

Cell: Y4
Comment: Tree protection:
Enter a code from the look-up table below:
1 - Tree guards
2 - Fencing (stock proof)
3 - Fencing (vermin proof)
4 - Herbivore repellent
5 - Lethal vermin control
6 - Tree hiding (e.g. cover crops)
7 - Nil

Cell: Z4
Comment: Planting stock:
Enter a code from the look-up table below:
1 - Tube stock
2 - Cell trays
3 - Open rooted
4 - Direct seeding - hand
5 - Direct seeding – mechanical

Cell: AF4
Comment: Average tree basal area (BA):
This figure is calculated using the formula:
$3.142 \times (DBH/200)^2$

Cell: AG4
Comment: Average tree total volume:
This figure is calculates total bole volume using the cone formula:
(*basal area* x *height*)/3

Cell: AH4
Comment: Total volume per hectare:
This figure is estimated by the formula:
average tree volume x *the total number of living trees per hectare* (stocking).

Cell: AI4
Comment: Total volume for the whole stand:
This is estimated using the formula:
(*total volume per hectare* x *net stocked area*)

Cell: AJ4
Comment: Mean annual increment (MAI):
This is calculated using the formula:
(*total volume per hectare* / *age at measurement*)
It provides an estimation of average volume production per year.

Appendix 5. Commencement report template

Source: based on the QFRI *Commencement report* form

[Title of experiment] - *where possible, this should include type of trial, factors tested, product end use, duration of trial, species used and location*

[Experiment code]: COMMENCEMENT REPORT

Prepared by [author, date]

Species code:–[species codes], Subject code:–[subject codes].

INTRODUCTION

This is a standard introduction which should provide links to published papers and allied experiments and answer questions such as the following:

- Why was the trial developed?
- Why were these species and provenances chosen?
- Why were the specific treatments chosen?
- How was this site chosen and why?
- On what research was site selection based?
- What products and what specifications are the trials aimed at?
- Which institutions and funding agencies control the experiment?
- If there are other collaborators, who are they and what are their roles?
- How does each collaborator benefit from the research or what are the anticipated outcomes of the trial?

OBJECTIVES

The objectives section should answer the following questions:

- What type of trial is planned (e.g. fertiliser addition, provenance selection)?
- What product or specifications does the trial aim to produce and from which species?
- What is the intended life span of the trial?
- How will the outcomes of this trial benefit further research?

Examples:

- To quantify the effects of silvicultural treatments on the early growth of selected species at this site and other sites.
- To provide a recommendation for an economic silvicultural regime for various site types.
- To provide base data and results from which to formulate future experiments.

LOCATION DESCRIPTION

Exp. [experiment code, site owner, nearest township]

Include description of site's locality, giving reference to property tenure, property owner, distance and direction from nearest township and reference to maps (Attachment 1 for district, Attachment 2 for site in relation to topography and local roads). Describe access to the site, surrounding tenure and owners. Describe ownership status of trial and agreements between research institution and landowners.

SITE DESCRIPTION

Exp. [experiment code, site owner, nearest township]

Describe site locality in relation to property landforms. Describe previous land use and fertiliser history. Include brief description of soil profile and a detailed description of the implications of the profile to the experiment *(a detailed soil description form is included in Appendix 3)*. Describe surrounding land use and vegetation communities as well as any possible threats to the trial such as herbivory or fire.

Trial Location Name: …………………………….
Topography:
Aspect: …………………………….
Slope: ………°
Location:
Country: …………………………….
Latitude: …..…°….…′……..″ S
Longitude: …..… °….…′……..″ E
AMG reference: …………….m E, …………….m N
Altitude: …………. metres above sea level
Previous land use: …………………………….
Surrounding vegetation type- …………………………….
Soil type: ………………(full description attached – soil form)
Soil depth: ………………m (full description attached – soil form)
Groundwater depth: ……………...m
Geology: ………………
Annual rainfall: ………………mm (estimated, or from named weather station)

GENETIC RESOURCES

Describe the species, provenances, progeny or clonal material used in the trial and the origin of the collection. If the list is very extensive, refer the reader to Attachment 4, containing information on each individual seedlot provenance and entry number.

NURSERY PHASE

Describe the nursery procedures used prior to establishment including name and location of the nursery; type of stock; sowing methods and dates; types of pots and potting mixes used; the watering regimes; any pruning or thinning procedures; fungicide, pesticide or herbicide treatments; and methods of delivery and care immediately prior to planting.

EXPERIMENTAL DESIGN AND LAYOUT

Type of design: …………….(layout maps and factor keys in Attachments 3 and 5).
Number of treatments: …………….(attach table listing each treatment or see Attachment 5)
Number of replicates: …………….
Number of blocks: …………….
Size of blocks: …………….rows × …………….trees
Block spacing: …………….metres (between rows) × …………metres (within rows)
Initial stocking density: …………….trees per hectare
Dimensions of block: …………….metres × …………….metres
Areas of blocks: …………….hectares
Number of plots: …………….
Size of plots: …………….rows × …….trees
Gross plot area: …………….hectares
Net plot area: …………….hectares
Total experiment area: …………….hectares
If a fertiliser trial, describe the form in which each element is applied, the method and position of application and refer to a table for the rates and timing intervals. If irrigated, supply details of dates of application and the rate and frequency.

SITE PREPARATION AND PLANTING

Describe the dates and methods of site preparation including initial site clearing, method of site cultivation and equipment used including type of ripper and depth, layout of rows in relation to the contour and the rate and frequency of each type of pre-plant and pre-emergent herbicide used and their active ingredients.

Describe the dates and methods used for layout of plots, planting of trees, initial tree measurement, fertiliser applications, refilling (including details for any discrepancies). Give site and soil conditions at time of planting, details of watering or mulching, and the rate and frequency of each type of post-plant herbicide and pre-emergent used and their active ingredients.

DATES OF ESTABLISHMENT

Clearing of regrowth/remnant trees:	………/………/…..……
Cultivation of rows:	………/………/…..……
Plot survey and pegging:	………/………/…..……
Tree planting:	………/………/…..……
Initial measurement:	………/………/…..……
Tree refilling:	………/………/…..……
Addition of treatments (eg fertiliser):	………/………/…..……

MANAGEMENT

Describe management procedures and application methods for:

Disease and pest control
Weed control/fertiliser application
Thinning/pruning

MEASUREMENT

Describe which parameters are to be measured, on which trees, the methods employed and the frequency with which each will be done. For example, see table below.

	Age					
	Initial	**6 months**	**12 months**	**18 months**	**2 years**	**Annually after 2 years**
Height	✓	✓	✓	✓	✓	✓
DBH	–	–	✓	✓	✓	✓
Foliar analysis	–	–	✓	–	✓	✓

RESULTS

Include any preliminary results that have been collected to date such as nursery heights and health, survival and height at age two months.

HEALTH OF THE EXPERIMENT

Describe health of experiment to date and methods used for this determination. Include any details of damage including extent, frequency of attack and control measures.

REPORTING

Interim summary: ………/………/…..…….
Completion report: ………/………/…..…….

COSTS

Refer to individual institution requirements.

RESPONSIBILITY

Provide details of which institutions and principal scientists have responsibility for each task and the roles of landholders and or contractors. Include contact details (name, institution, address, and phone number) for the site management, and general manager of project. (Experiment file should include contact details for the nursery, site establishment, and measurement team.)

ATTACHMENT 1 – REGIONAL AND DISTRICT SITE MAPS for EXPERIMENT [experiment code]

Elements to include:
Trial name and location
Date planted
North point and scale
Nearest major townships

ATTACHMENT 2 – LOCAL SITE MAP for EXPERIMENT [Experiment code]

Elements to include:
Trial name and location
Date planted
North point and scale
Rivers/creeks/streams affecting site
Local roads and their names
Nearest local townships
Distance from nearest township to closest gateway along road
Distance and bearing directly from Post Office to closest gateway
Details of site locality within property.

ATTACHMENT 3 – LAYOUT MAP for EXPERIMENT [Experiment code]

Elements to include:
Trial name and location
Date planted
North point and scale
Layout of replicates and treatments
Direction of planting
Layout of buffer rows, isolation rows and guard areas
Location and type of fencing
Surrounding elements (e.g. access roads, fire breaks, ash beds, stumps, plantations, vegetation)
Gross plot size
Net plot size
Tree spacing
Initial stocking
Number of plants
Key to plot codes used
Table which list treatments and codes

ATTACHMENT 4 – GENETIC RESOURCES for EXPERIMENT [Experiment code]

Elements to include:
Trial name and location
Planting entry number
Seedlot number
Tree number

Provenance
Number of parent trees
Provenance details (state, stand type, latitude, longitude and altitude)
Seed batch number
Seed supplier

ATTACHMENT 5 – FACTOR KEYS for EXPERIMENT [Experiment code]

An example:

Replication:

1 = Replicate 1
2 = Replicate 2

Nitrogen Treatment:

1 = 0 kg/ha
2 = 50 kg/ha over 6 months
3 = 75 kg/ha over 6 months
4 = 200 kg/ha over 12 months

Plot No.	Treatment No.	Replicate	Nitrogen
1	1	1	1
2	2	1	2
16	8	2	4

Appendix 6. Reporting checklist

The following list was compiled and adapted from QFRI internal commencement reports, Carter (1987); McLeod et al. (2002); Australian Weeds Committee (1979) and comments from researchers across Australia.

Site Characterisation

Site description

- Site name (use the name that occurred in the first publication from that site)
- Locality maps - property, local, regional and state
- Position (latitude and longitude or Australian Map Grid units, with method of determination)
- Landscape position (altitude, aspect, slope and position relative to exposure, surrounding vegetation)
- Land shape (either concave or convex or even slope)
- Previous land use (including previous vegetation cover and history of fertiliser use with details of the aggregate amounts applied in kg/ha over time)

Soil

- Total depth sampled
- Parent geology and depth
- Boundaries and hardness for each horizon
- Colour, texture, structure
- Moisture status
- Inclusions, type and depth of restrictions
- Surface condition, salinity and pH
- Soil classification
- Hydrology (watertable depth, groundwater salinity, subsoil moisture estimation and frequency of flooding)
- Nutrient status and chemical analysis where measured

Climate

- Median annual rainfall
- Median monthly rainfall and temperature
- Actual recorded annual rainfall two years prior to and since establishment
- Actual recorded monthly rainfall
- Actual monthly maximum and minimum temperatures
- Pan evaporation
- Average number of frosts or absolute minimum temperature for the year
- Wind speed and prevailing direction

Planting Material

Genetic material

- Seedlot number and number of parent trees represented
- Provenance name
- Provenance details (state, locality, stand type, latitude, longitude, and altitude)
- Seed batch number and supplier
- List of all species tested (or clearly note failures within methods or results section)

Nursery preparation techniques

Describe for nursery trials, and consider carefully when reporting other trial types.

- Name and location of nursery
- Stock type with description (i.e. bare-root or container, container type, direct seed)
- Sowing method and dates
- Nursery substrate (soil mix type, description of ingredients and their ratios)
- Watering procedures
- Descriptions of additions to potting mix e.g. water crystals
- Fertiliser application (give brand, active ingredients—elemental composition and percentage, quantity, application date)
- Description of rhizobia/mycorrhiza inoculation and symbiont (includes actinorhiza) if required
- Details of any thinning, pruning or potting-on methods
- Details of fungicide, pesticide or herbicide treatments
- Details for hardening off seedlings and age at planting out
- Method of delivery and care immediately prior to planting

Experimental design and layout

Experimental design and layout

- Locality map with access roads near the woodlot or plantation
- Experiment layout map, or clear identification of the treatments applied to each of the plots in the experiment
- A layout map or associated text should include:
  - Trial name, location
  - North point, scale, date of map, direction of rip lines, location and type of fencing
  - Surrounding elements (e.g. access roads, fire breaks, ash beds, stumps, vegetation)
  - Layout of replicates, treatments, plots, buffer rows, isolation rows and guard areas
  - Gross and net plot sizes
  - Key to plot codes used and a table which lists treatments and codes
  - Pegging system, scale, date of map
- Type of experimental design, date planted and tree spacing and initial stocking rate
- Number of treatments, replicates, blocks, and plots
- Area and dimensions of blocks, plots (gross and net) and total experiment area

Trial and management

- Management regimes, dates applied and climatic conditions (especially during first three years)
- Species/provenance/progeny/clone trials:
  - Description of genetic material used and source (if not given under planting material section)
  - Trial management (see silvicultural trials below)
- Silviculture trials:
  - Establishment:
    - For each herbicide, the description should include:
      - Application type (i.e. pre-rip, pre-plant, post-plant, pre-emergent)
      - Brand and its active ingredients and concentration (these can change)
      - Application method, quantity and dates (plus tree age at application)
      - Environmental conditions before, during and after application (for three months) and percent weed cover where measured
    - For each fertiliser, the description should include:

Brand and/or its active ingredients (elemental composition and percentage)

The form in which each element is applied

Application method, position of application relative to tree, rate

Timing intervals or application dates (plus tree age at application)

Environmental conditions before, during and after application (for three months)

Later-age weed control and fertiliser application—as above

Thinning and pruning:

Methods used (e.g. percentage crown removed, pruning height)

Number of stems treated and untreated (remaining)

Environmental conditions before, during and after application (for three months)

Irrigation trials:

Dates of water application, rate, frequency

Method of water delivery

Type of water (e.g. effluent, fresh, bore, saline)

Chemical description of applied water

Site specific mean annual rainfall measurements

Estimate of additional site water by drainage and subsoil water

Tree age for each application date.

Low rainfall and salinity trials:

Evaporation

Rainfall

Soil type in all blocks

Soil salinity

Watertable depth and salinity of watertable in summer and winter

Additional management techniques – describe the use of:

fencing, tree guards, staking, additional watering

animal control (shooting, baiting, feeding)

insect and pathogen control (insecticide and fungicide application)

replanting

any others

Designing Silvicultural Research Trials

RIRDC Publication No. 08/197

With an increased interest in plantations of Australian native trees, a need has developed for information on species performance over a range of sites, grown with suitable silvicultural management. To provide this information, research and demonstration trials should be well designed and, where possible, allow comparison among trials.

This manual provides guidelines for the design and reporting of silvicultural field experiments, focusing on hardwoods in plantations. It has been compiled using contemporary literature and advice from silvicultural researchers throughout Australia.

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