TARGETING PLANTED FORESTS FOR DRYLAND SALINITY CONTROL

By Peter Walsh
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BACKGROUND TO THE OPERATIONAL SCALE TREE PLANTING PILOT PROJECT AND THE ASSOCIATED RESEARCH TRIALS ON THE LIVERPOOL PLAINS, NEW SOUTH WALES

by

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SUMMARY

Dryland salinity directly affects approximately 120,000 ha of land in New South Wales. Importantly, while New South Wales has only 5% of the land currently affected by dryland salinity in Australia, with Western Australia accounting for more than 70%, New South Wales has almost 50% of the potentially affected land. As a consequence action to address this long-term threat is required. The New South Wales State Government recognised the need for early action through the release of the New South Wales Salinity Strategy Taking on the Challenge in August 2000. The aim of the strategy is to slow down the increase in salinity in New South Wales over the next 10 years. One of the major challenges is facilitating change in the way we use our land to reduce the threat of salinity.

Under the New South Wales Salinity Strategy, State Forests undertook an operational scale pilot project to establish a significant area (up to 400 ha) of planted forests on private land in the Liverpool Plains. The activity had two principal objectives. Firstly, to develop new products and environmental service markets for planted forests in priority salinity hazard landscapes and, secondly, to act as a lever to attract additional investment in planted forests through the stimulation of markets for non-traditional wood products and environmental services. When undertaken, the planting was the largest in Australia using native species to address dryland salinity.

The plantings were established in the low rainfall (<700 mm year\(^{-1}\)) areas of the catchment, targeting recharge areas. State Forests of New South Wales had limited experience in establishing operational scale plantings in these environments, with traditional plantation operations occurring above 750 mm year\(^{-1}\) rainfall. In order to guide decisions as to the siting of future planted forests in low rainfall environments and to determine the benefits that may be derived, a number of research trials were incorporated into the Liverpool Plains pilot project. This report documents the establishment of the operational scale tree planting and the associated research trials.
INTRODUCTION

1. THE CHALLENGE

Salinity is a major threat to the productivity and health of many New South Wales' catchments. Its impacts are felt both on-farm, through degradation of cropping and grazing areas, and off-farm, through degradation of infrastructure (roads, bridges, urban houses) and increases in stream-borne salt loads reducing the suitability of water for drinking and irrigation. Salinity also represents a threat to biodiversity if habitats are damaged or destroyed.

The impacts of salinity go beyond catchment and State boundaries. The export of salt from catchments has significant effects on downstream water users. For example, the salt content of Adelaide's drinking water, drawn from the Murray River, may exceed the desirable standards two out of every five days within 20 years if current trends continue.

Dryland salinity directly affects approximately 120 000 ha of land in New South Wales (Bradd and Gates, 1996). Importantly, while New South Wales has only 5% of the land currently affected by dryland salinity in Australia, with Western Australia accounting for more than 70%, New South Wales has almost 50% of the potentially affected land. As a consequence action to address this long-term threat is required.

The New South Wales State Government recognised the need for early action through the release of the New South Wales Salinity Strategy Taking on the Challenge in August 2000. The aim of the strategy is to slow down the increase in salinity in New South Wales over the next 10 years. One of the major challenges is facilitating change in the way we use our land to reduce the threat of salinity.

2. LAND USE CHANGE AND DRYLAND SALINITY

Dryland salinity is brought about by the replacement of native vegetation with “leaky” agricultural systems resulting in the remobilisation of previously stored salt. Extensive areas have been cleared for grazing and cropping along the New South Wales western slopes and plains. Benson (1998) estimated that almost half of the western slopes and plains had been cleared of native vegetation, amounting to more than 20 million ha of cleared land. The replacement of the deep rooted perennial native vegetation with grasses and cereals has modified the hydrological cycle. These agricultural systems use less water or in a different seasonal pattern than the native vegetation. As a result, water movement through catchments has increased. While this has produced some benefits through increased water yields from cleared catchments, it has also remobilised salt previously stored in aquifers or deep in the soil below the rooting zone. The salts are then reintroduced to the landscape in the form of saline seeps in discharge areas or flushing of stored salts directly into streams.

Re-establishing trees can restore the hydrological balance, reducing the remobilisation of stored salt. For example, a 2.5% reduction of salt load in the Murrumbidgee River at Wagga Wagga was predicted from modelled re-afforestation of 50% of the Kyeamba catchment (Tuteja et al. 2002). To achieve this, approximately 30 000 ha of re-afforestation would have to be undertaken in the Kyeamba Valley which has a mean rainfall of 683 mm year⁻¹. Currently, tree growth rates sufficient to support commercial forestry are marginal below 750 mm year⁻¹. The greater water use by trees than by pastures and crops means that re-afforestation over such a large proportion of a catchment...
will reduce river flows and recharge to aquifers, which may reduce the water available to downstream users as well as increase stream salinity concentrations (Gerrand et al. 2003). To mitigate these potential negative effects on water yield and stream salinity Stirzaker et al. (2002) and Vertessy et al. (2003) suggested the following practices:

• concentrate the establishment of planted forests in lower rainfall areas (< 800 mm y⁻¹) where reductions in water yields are smaller and salinity is a greater problem;

• spread the planted forests across the landscape in mosaics and keep them to less than 20% of any catchment, as catchments with less than this area planted exhibit little effect on water yield;

• phase the plantings to ensure a spread of age classes, and plant away from drainage lines in areas likely to lie outside the main runoff-producing zones.

3. STATE FORESTS OF NEW SOUTH WALES - TAKING ON THE CHALLENGE

Under the New South Wales' State Salinity Strategy, State Forests undertook an operational scale pilot project to establish a significant area (up to 400 ha) of planted forests on private land in the Liverpool Plains. The activity had two principal objectives. Firstly, to develop new products and environmental service markets for planted forests in priority salinity hazard landscapes and secondly, to act as a lever to attract additional investment in planted forests through the stimulation of markets for non-traditional wood products and environmental services, for example, biomass for energy generation, biodiversity enhancement and carbon sequestration. When undertaken, the planting was the largest in Australia using native species to address dryland salinity.

The plantings were established in the low rainfall (<700 mm year⁻¹) areas of the catchment, targeting recharge areas. State Forests of New South Wales had limited experience in establishing operational scale plantings in these environments, with traditional plantation operations occurring above 750 mm year⁻¹ rainfall. In order to guide decisions as to the siting of future planted forests in low rainfall environments and to determine the benefits that may be derived, a number of research trials were incorporated into the Liverpool Plains pilot project. These trials will begin to address a range of operational and environmental issues in low rainfall environments including:

• the optimum planting density to maximise tree water use and biomass accumulation;

• type of planting configuration and position in the landscape that optimises plantation productivity whilst minimising recharge to aquifers;

• the level of site preparation required to establish seedlings in this environment;

• the effect of planting time (season) on the survival and early growth of seedlings;

• the interaction between soil type, tree species and landscape position; and

• the value of eucalypt planted forests for wildlife and how biodiversity is influenced by plantation design and management practices.

When viewed together with State Forest's other dryland salinity related projects (e.g. the 48 species demonstration trials across New South Wales, Benchmarking tree water use and carbon sequestration potential and the pilot salinity trade in the Macquarie catchment, see Walsh et al. 2003 for details), these activities represent a significant contribution to the essential scientific and...
technical knowledge required to underpin natural resource planning across salinity affected regions of New South Wales.

The aim of this report is to document the establishment of the operational scale tree planting and the associated research trials. The report is structured in the following way:

- Section 2 provides the background to the procurement of the planted forests sites and the details of the Forestry Right Agreement that was negotiated with the participating landowners.

- Section 3 outlines the physical environment of the Liverpool Plains.

- Section 4 provides a description of the design, location, size and species composition of the planted forests and trials and the physical attributes (ie soils, geology) of the country/properties on which they were established.

- Section 5 provides an outline of a collaborative project that was undertaken with the Department of Infrastructure, Planning and Natural Resources (DIPNR) to determine salt levels in the soils beneath some of the planted forests.

- Section 6 provides the timeframes over which the trials should be monitored.

The designs for each of the trials are provided as Appendix 1. All of the trial designs were subject to scrutiny by a biometrician prior to their establishment and suggestions as to the appropriate statistical techniques to employ for analysing the results of the trials are provided as Appendix 2. Recommendations for fertiliser application for a number of soils representative of the soil types on which the plantings were established are provided as Appendix 3. The Australian Map Grid (AMG) coordinates and the relevant 1:100 000 topographic map sheet on which each of the properties are located are provided as Appendix 4.
LAND SELECTION

In selecting land for the inclusion in the pilot project, preference was given to land in the Liverpool Plains south of Gunnedah. In particular, State Forests was hoping to target the plantings to the sedimentary slopes which had been identified as recharge zones by the then Department of Land and Water Conservation (DLWC). Research on the Liverpool Plains identified these areas as being suitable for tree planting to deliver a range of environmental outcomes including salinity control (Dames and Moore 2000). The following criteria, each of which will exert an influence on the likely success of the plantings, were also considered:

- soil type, structure, depth and nutrient balance;
- rainfall, including yearly averages and pattern;
- terrain features such as the existence of rock, slope steepness and non-uniformity;
- vehicle access for heavy machinery and future harvesting/haulage requirements and ease of access for management purposes;
- bushfire threat and ease of providing fire protection and suppression; and
- threats from pest animals.

In locating the plantings on a property, State Forests tried to accommodate farm management requirements, such as:

- existing fencelines, stock movement routes and watering points;
- powerlines, existing roads, gateways etc;
- planned tree plantings for stock or pasture shelter, windbreaks, woodlots or commercial forestry plantings; and
- visual impact such that the landscape is enhanced and views from existing dwellings are not blocked.

1. FORESTRY RIGHT AGREEMENT

Landowners whose land was accepted for the pilot project trial were required to sign a Forestry Right Agreement with State Forests. A Forestry Right Agreement is a legal transfer on the title of the planted area to enable State Forests to conduct forestry activity on that land. The Forestry Right Agreement also sets out the terms of the agreement between State Forests and the landowner for the management of the planted forest and for the allocation of costs and revenues.

2. INITIAL PAYMENT

Landowners whose land was accepted into the trial received $100 per planted hectare as a once-off payment once the Forestry Right of Agreement had been signed and planting had been completed.

3. SUBSEQUENT REVENUE

(a) Calculation of Fixed Share

The land procurement offer to landowners is a Fixed Share 75:25% (State Forests/landowner) of net proceeds received from the sale of all products at the time of sale. It is envisaged the revenue will be obtained both from timber/wood products and from the sale of “environmental credits” such as carbon credits or salinity credits. The percentage split reflects the nominal inputs of State Forests and the landowner to the establishment and management of the tree plantings over the first ten years.

(b) Application of Fixed Share

State Forests will incur and account for the following:

- All silvicultural costs (pruning, non commercial thinning etc) after 10 years. These operations will only proceed by agreement, however that agreement cannot be unreasonably withheld.
- All costs associated with inventory, marketing, haulage roading, harvest and haulage of wood products.
- All costs associated with inventory, marketing and accounting for environmental credits.

These costs will be subtracted from the sale price of all products. Twenty-five percent of the net proceeds will then go to the landowner within 30 days of receipt of final payment for the products by the relevant customer.

If a net loss is made on any sale of products prior to clearfall, after taking the above costs into consideration, then the landowner will have the option of paying State Forests the 25% share of this net loss within 30 days of that loss being notified to the landowner, OR, alternatively, the net loss plus interest (as defined in the Forestry Right Agreement) can be debited against future net returns from the sale of products. If at the time of final sale of the timber products (clearfall), there is still no net profit, then the landowner will not be required to contribute their 25% share of this loss to State Forests.

(c) Estimated Value of Products

State Forests will provide an estimate of the current market value of each product group. No guarantee can be given that these values will be achieved. State Forests will provide these estimates on a without prejudice basis and will retain the right to vary these estimates in the light of new or improved market information at any time during the term of the agreement. Where no current market value exists, this will be indicated.

State Forests recommended that landowners seek independent advice on potential costs and returns and take a conservative approach in so doing. In evaluating the proposal, landowners were encouraged to take into account other potential on-farm benefits that will be provided by the tree plantings, such as stock and pasture protection from wind, inclement weather, decreased erosion potential and salinity control.
4. RESPONSIBILITIES

State Forests of New South Wales is responsible for:

- All establishment costs. These include legal, land and survey costs to establish the tree plantings on the Forestry Right Land.
- Writing the management plan and monitoring crop development and requirement for silvicultural works, such as pruning or non-commercial thinning.
- All costs in the first 10 years for pruning, non-commercial thinning and tree pest and disease control measures as required.
- Assisting as practicable with bushfire suppression activities or planned hazard reduction burning on Forestry Right Land or adjacent land.
- Establishment, management and measurement of any operational or research trials (such trials only to be established with the consent of the landowner).

The landowner is responsible for:

- All personal legal costs to enter into the Forestry Right Agreement.
- All land rates, Rural Lands Protection Board rates etc.
- Construction of new fencing and maintenance as required with all costs.
- Noxious animal and weed control on Forestry Right Land.
- Monitoring (only) for tree pest and disease damage on an infrequent basis.
- Firebreak and road maintenance by slashing or application of herbicide to keep free of combustible material over 10 cm high and open to traffic, during the declared bushfire period,
- Bushfire suppression and planned hazard reduction burning on the Forestry Right Land and adjacent land in consultation with State Forests.
- All costs associated with grazing by stock once it is agreed that the trees can withstand grazing pressure.

5. TERM OF AGREEMENT

The Forestry Right Agreement will be for a term of 35 years. At 35 years, each party may exercise the option to enter into a further 15 years. Facility will exist within the Forestry Right Agreement for either party to terminate at any time, provided agreed notice, valuation and compensation/rehabilitation procedures are detailed. The agreement will have a mechanism for negotiation on a variety of issues, such as timing and intensity of thinning/logging or products produced.

6. TRADE TO THIRD PARTY

State Forests may only sell interest to a third party with the agreement of the landowner, which agreement cannot be unreasonably withheld. The landowner can only sell their interest in the tree crop as part of a land sale or transfer of title.
The Liverpool Plains catchment is situated in north western New South Wales (Figure 1) covering an area of 11,728 km² (Dawes et al. 2000), and is bounded to the south by the Liverpool Ranges, to the west by the Warrumbungle Range and Pilliga State Forests and to the east by the Melville Ranges. The Plains lie in the Gunnedah Basin, a structural trough within the Sydney Bowen Basin which extends for 1,700 km along the eastern margin of Australia, from the edge of the continental shelf in south-eastern New South Wales to central Queensland (Tadros 1993).

The Liverpool Ranges are the remnants of a basaltic shield volcano which covered an area of 6,000 km² with a thickness of up to 500 m (Dawes et al. 2000). Tertiary basalt flows extended over much of the catchment, which today have been eroded to form basalt caps on sandstone hills in the north and long stratified hills and mountains to the south (Banks 1995). The western and eastern margins of the plains are formed from ridges of older sediments of Triassic and Jurassic age such as the Narrabeen and Pilliga groups of sediments.

Figure 1. Location map of the Liverpool Plains Catchment, New South Wales (map supplied by Di Bentley and produced by the Dept. Infrastructure Planning and Natural Resources).
Of the 725,000 ha of agricultural land in the Liverpool Plains, 195,000 ha are estimated to have groundwater levels within five metres of the surface and a further 30,000 ha have water levels within two metres of the ground surface (Timms 1998). Schroder et al. (1991 cited by Timms 1998) predicted that approximately 50,000 ha of agricultural land within the Liverpool Plains could become non-productive within 10 years due to dryland salinity, with the cost of lost production totalling $70 million.

Stauffacher et al. (1997) divided the Liverpool Plains catchment into five almost independent subcatchments (Figure 2). The Lake Goran and Pine Ridge subcatchments are characterised by a geologically constricted groundwater system, where there are few streams exiting the catchment. The alluvial system in these subcatchments has a low permeability and high clay content and is characterised by high saline watertables, low groundwater fluxes and evaporative salt concentration at the soil surface. In contrast, the Lower Mooki, Upper Mooki and Cox's Creek subcatchments have well-defined streams exiting their catchments. The alluvial system has a high permeability and is characterised by deep and usually non-saline watertables, high groundwater fluxes and evaporative concentrations of salt only along the fringes of the catchment. The planted forests established by State Forests are located in the Lake Goran, Pine Ridge and Upper Mooki subcatchments.

![Figure 2. The five almost independent groundwater systems of the Liverpool Plains catchment (taken from Stauffacher et al. 1997).](image)

The Liverpool Plains are dominated by deep Quaternary alluvium with a thickness up to 110 m. The lower part of the alluvium, known as the Gunnedah Formation, contains gravels and sands, whilst the upper part of the alluvium contains mostly clays and silts and is called the Narrabri Formation. Dawes et al. (2000) reported that these two aquifers were in partial hydraulic contact, with the Narrabri Formation acting as a semi-confining layer. In the lower half of the catchment, groundwater in the Narrabri aquifer is saline, with electrical conductivity (EC) values up to 35 dS m⁻¹, whilst groundwater in the Gunnedah Formation is fresh with EC values less than 2 dS m⁻¹.
Acworth and Beasley (1998) suggested that these alluvial deposits may be best described as one aquifer with varying sedimentological units, because some bores showed clay to basement while others possessed a more complete succession of clastic material with little clay. Lavitt and Janowski (1998), on re-examination of available lithological data, concluded that no clear boundary exists between the Narrabri and Gunnedah Formations.

In a study of shallow (≤5 m) groundwater dynamics, Timms et al. (2001) reported salinity levels approaching that of sea water within the Yarramanbah sub-catchment (located in the Upper Mooki groundwater system in Figure 2). They concluded that, whilst the shallow groundwater system responded to recharge, over the medium term it was in hydrologic balance, with no evidence of increased water storage. A proportion of the potential recharge was lost through discharge into deeply incised surface channels with flushing of salts from the channel banks related to an increased flux of fresh water. They suggested that the increase in salt fluxes in these shallow groundwater systems must be related to factors other than rising watertables given that the plains appeared to be in hydrologic equilibrium over the medium term.

Timms (1998) attributed the worsening dryland salinisation on the Liverpool Plains to a 10% increase in rainfall over the past 50 years, increased deep drainage beneath fallow and cropland, soil erosion exposing subsurface saline clay and rising groundwater pressures in deep aquifers as a result of greater recharge on the footslopes of the Ranges. She argued that a range of practices would be required to stem the spread of dryland salinity and that management solutions should be focused on both the plains and footslopes incorporating such practices as reducing fallow, opportunity cropping and introducing high water use perennial crops.

1. CLIMATE

The average annual rainfall decreases from over 1 000 mm at the top of the Liverpool Ranges in the south of the catchment to 600 mm on the plains near Pine Ridge (Dawes et al. 2000). Rainfall has a summer dominance with summer storms characterised by short high intensity events. Rainfall is extremely variable between years and seasons, resulting in flood conditions or drought and low river flows. Soil moisture storage is greatest for the winter and spring periods and least for summer and autumn (Banks 1998). Temperatures on the plains range between 9°C and 43°C in summer and 0°C and 25°C in winter. Average annual potential evaporation is 1900 mm, with a maximum monthly average in December of 275 mm and a minimum in June of 65 mm.

2. SOILS

Soil landscape units covering the extent of the plantings on the Liverpool Plains have been described by Banks (1995 and 1998) for the Blackville and Curlewis 1:100 000 sheets respectively and McInnes-Clarke (2002) for the Murrurundi 1:100 000 sheet. The alluvial plains are dominated by black cracking clays (Vertosols), which are derived from the Tertiary basalts of the Liverpool Ranges. The Vertosols are characterised by a high shrink-swell potential and low permeability with localised seasonal water logging and a high flood hazard. On the slopes and ridges where the majority of the plantings are located, Chromosols, Sodosols, Kurosols, Rudosols and Tenosols are common where the parent material is comprised of the sandstone/mudstone units of either the Triassic Narrabeen Group or the Jurassic Purlewaugh Beds and Pilliga Sandstone. Where the slopes and ridges have been formed from Tertiary or Jurassic volcanics, the soils are commonly Ferrosols, Calcarosols, Dermosols and Kandosols.
3. **VEGETATION**

A number of State forests are located within the southern portion of the Liverpool Plains catchment and include Breeza, Trinkey, Doona, Goran, Wondaba and Spring Ridge State Forests. The forests are all classified as woodland communities (Forestry Commission New South Wales 1985) and are comprised of the following tree species; *Eucalyptus fibrosa* (broad-leaved ironbark), *E. crebra* (narrow-leaved ironbark), *E. melanophloia* (silverleaf ironbark), *E. albens* (white box), *E. melliodora* (yellow box), *E. pillaigensis* (Pilliga box), *E. conica* (fuzzy box), *E. blakelyi* (forest red gum), *E. trachyploia* (brown bloodwood), *Callitris glaucophylla* (white cypress pine), *C. erdlicheri* (black cypress pine), *Casuarina leuhmanii* (forest oak) and *Brachychiton populneus* (kurrajong).

The Goran Basin Plains and Liverpool Plains prior to the 1950s were closed grasslands dominated by *Stipa aristiglumis* (plains grass), with *Panicum* spp. (panics), *Danthonia* spp. (wallaby grasses), *Stipa* spp. (spear grasses), *Dicanthium sericeum* (blue grass), *Chloris* spp. (windmill grasses) and *Aristida* spp. (wire grasses) occurring as sub-dominant species (Banks 1995). Occasional scattered clumps of *Acacia pendula* (myall) and *Eucalyptus camaldulensis* (river red gum) occurred along drainage lines and in swamps. The Plains are now dominated by dryland cropping systems.

4. **LANDUSE**

The main land uses in the region are grazing and dryland and irrigation farming of cereals, oil seeds and cotton (Banks 1995). In the early 1950s technological advances enabled cultivation of the heavy textured basalt derived alluvial soils which had previously been used for grazing. Prior to the 1950s cropping was focused on the hill-slopes which had been extensively cleared between the 1890s and 1930s. The hillslopes today are used primarily for grazing. The clay soils of the Liverpool Plains are some of the most agriculturally productive soils in Australia.
LOCATION, SPECIES, SIZE AND PHYSICAL ATTRIBUTES OF THE PLANTED FORESTS AND TRIALS

Figure 3 shows the location of 13 of the 14 properties on which planted forests are established. The Atkinson property, not shown in Figure 3, is located 45 km north of Gunnedah, adjacent Vickery State Forest. Table 1 provides details of the size, species mix and establishment dates of the planted forests and the location and type of trial/s and the dates they were established. The geology of the plantation sites comprise four major units - Tertiary basalts, Triassic and Jurassic sandstones, siltstones and mudstones, and Lower Permian polymictic conglomerate and sandstone (Table 2). The range of soil types shown in Table 2 is largely a reflection of the variation in the lithology within each of the four geological units and their surface expression. The majority of the soil types shown in Table 2 were assigned to each of the properties/planted forests based on information obtained from the Soil Landscape Sheets shown in Table 2 and are a guide only. More accurate information for the soils on the Duncan, Brownhill and Carter properties was obtained from sampling prior to the establishment of these planted forests, details of which are provided as Appendix 3.

1. THE RESEARCH TRIALS

Of the 14 properties participating in the pilot project, 10 of the properties have research trials established on them (Table 1). The siting of the trials was dependent on the availability of suitable land and the landowners consent, hence none of the trials are replicated across all of the soil types present in the south-eastern margin of the Liverpool Plains. The trial details are outlined below and the designs and suggestions for statistical analysis are provided as Appendices 1 and 2. All data collected from the trials will be stored in State Forests of New South Wales Research and Experiment and Survey data management system (RESDAT).

(a) Selection of Tree Species

Except for Pinus pinaster (maritime pine), all of the tree species in each of the trials were selected from the following species chosen by Investment Services Division for the operational scale pilot project: Corymbia maculata (spotted gum), Eucalyptus camaldulensis (river red gum), E. pilligaensis (Pilliga box), E. crebra (narrow-leaved ironbark), E. camaldulensis sub spp. silverton (silverton red gum) and E. sideroxylon (mugga ironbark). These species are all considered to be drought tolerant, with some (spotted gum, river red gum and mugga ironbark) having possible commercial potential. The Australian Low Rainfall Tree Improvement Group identified these three species has having demonstrated good growth capacity on diverse site types in low rainfall areas (Harwood et al. 2001). They note that spotted gum has very good natural form, and produces excellent timber on better quality low rainfall sites whilst mugga ironbark has demonstrated good sawn timber properties.

(b) Soil Type, Landscape Position and Species Interactions

The planted forests are sited across a broad range of possible landscape positions and soil types within the Liverpool Plains catchment (Table 2). Where possible, each species was planted within each of the combinations of soil type and landscape position outlined in Table 2 (with the exception of the two floodplain sites which were planted to Eucalyptus camaldulensis). At present there are few data available as to the performance of different tree species on the soil types and landscape
positions outlined in Table 2. Therefore, the establishment of Permanent Sample Plots within these plantings will provide growth data from which the relationship between tree growth, soil type and landscape position for each of the species planted can be explored. The results will provide State Forests with potential growth rates for each species across a range of landscape units. This information can be used to target those landscape units in the southeast of the Liverpool Plains with greatest potential for medium to high plantation productivity.

(c) Planting Time

(i) Background

Broadly speaking, two seasons are available for planting eucalypt seedlings in New South Wales: autumn and spring. Planting in spring potentially exposes the seedling to an increased risk of moisture stress. Following spring planting evaporative demand can rise rapidly due to hot dry winds. Thus even if soil moisture conditions are favourable, seedlings may not be able to access this moisture due to insufficient time for the roots to establish. Potentially the dehydration risk may result in significant mortality if atmospheric conditions are unfavourable.

Local landowners (eg Cudmores) have generally favoured autumn as the optimum season to plant trees. Planting at this time of the year would expose the seedlings to frosts over winter. However the seedlings would have time to establish a root system prior to the high evaporative demand period in late spring early summer.

(ii) Objectives

To determine the optimum planting season (autumn/spring) to maximise seedling survival over the following summer. Without replication through time to capture climatic variability, this trial will not provide definitive answers as to the optimum season to plant in the Liverpool Plains. However, the results can be viewed as a first step in establishing a dataset from which a decision support tool can be developed to assist with future decisions as to when to plant on the Liverpool Plains.

(iii) Site details

Location: Cudmore/Paringa and Cobcroft/Parraweena
Soil type: Kurosol (Cudmore), Vertosol (Cobcroft)

(iv) Experimental details

Establishment date: May and September 2003
Design: Randomised complete block split plot with four replicates
Planting density: 4.0 m x 2.5 m = 1000 stems/ha
Plot size/area: Four rows x nine trees = 0.036 ha
Trial size: 0.86 ha

(v) Treatments

Pinus pinaster autumn/spring
Corymbia maculata autumn/spring
Eucalyptus camaldulensis autumn/spring

These three species were all chosen for their potential commercial value, range of expected growth rates and tolerance to frost and drought conditions.
Figure 3. Location of the planted forests and research trials on the Liverpool Plains, New South Wales.
Table 1. Outline of the size and species mix of the planted forests, when they were established and the type of research trials on the respective properties.

<table>
<thead>
<tr>
<th>Property owner/name</th>
<th>Plantation size (ha)</th>
<th>Species</th>
<th>Month/year established</th>
<th>Research trials</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>() = size in ha planted to each species</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cudmore/Paringa</td>
<td>10.4</td>
<td>Red gum (1), narrow-leaved ironbark (5.4), spotted gum (1)</td>
<td>spring 03</td>
<td>planting time, biodiversity</td>
</tr>
<tr>
<td>Carter/Connamara</td>
<td>28.8</td>
<td>Silverton red gum (13.3), red gum (5.7), Pilliga box (4), narrow-leaved ironbark (2)</td>
<td>spring 01 and spring 03</td>
<td>belt width, genetic gain¹, hybrids¹</td>
</tr>
<tr>
<td>Barrie/Knockadirrah</td>
<td>2</td>
<td>Red gum (8.5), Pilliga box (9), narrow-leaved ironbark (2), spotted gum (9)</td>
<td>spring 01</td>
<td>biodiversity</td>
</tr>
<tr>
<td>Wilkinson/Bona Vista</td>
<td>13.1</td>
<td>Red gum (6), Pilliga box (3.1), narrow-leaved ironbark (2), spotted gum (2)</td>
<td>spring 01</td>
<td>No trial</td>
</tr>
<tr>
<td>Symonds/Silsoe</td>
<td>14.6</td>
<td>Silverton red gum (4.6), red gum (1), Pilliga box (1), mugga ironbark (1), narrow-leaved ironbark (2.5), spotted gum (2)</td>
<td>spring 01</td>
<td>biodiversity</td>
</tr>
<tr>
<td>Duddy/Hudson</td>
<td>40.6</td>
<td>Silverton red gum (9.6), red gum (21), Pilliga box (10)</td>
<td>spring 03</td>
<td>No trial</td>
</tr>
<tr>
<td>Cobcroft/Parraweeena Park</td>
<td>48.1</td>
<td>Silverton red gum (12.1), red gum (12), Pilliga box (9), narrow-leaved ironbark (10)</td>
<td>spring 03</td>
<td>establishment techniques, planting time</td>
</tr>
<tr>
<td>Brownhill/Merriong</td>
<td>31.4</td>
<td>Silverton red gum (10.1), red gum (6.6), Pilliga box (14.7)</td>
<td>spring 03</td>
<td>belt width, establishment techniques</td>
</tr>
<tr>
<td>Burns/Oxley Park</td>
<td>16.2</td>
<td>Silverton red gum (6.2), red gum (4), Pilliga box (4), narrow-leaved ironbark (2)</td>
<td>spring 01</td>
<td>autumn 03</td>
</tr>
<tr>
<td>Malden/Ramajon</td>
<td>9.4</td>
<td>Mugga ironbark (1.5), Pilliga box (1.5), spotted gum (4.1)</td>
<td>spring 01</td>
<td>No trial</td>
</tr>
<tr>
<td>Duncan/Andamooka</td>
<td>57.6</td>
<td>Silverton red gum (22), red gum (8.8), Pilliga box (9.5), mugga ironbark (7)</td>
<td>spring 01 and spring 03</td>
<td>spacing, biodiversity</td>
</tr>
<tr>
<td>Duncan/Oaklands</td>
<td>16.7</td>
<td>Silverton red gum (2), red gum (2), Pilliga box (2), mugga ironbark (2), narrow-leaved ironbark (2), spotted gum (3)</td>
<td>spring 01 and autumn 03</td>
<td>No trial</td>
</tr>
<tr>
<td>Atkinson/Gundawarra</td>
<td>30.0</td>
<td>Silverton red gum (6), red gum (8), Pilliga box (10), narrow-leaved ironbark (3.1)</td>
<td>autumn and spring 03</td>
<td>spacing/demonstration</td>
</tr>
</tbody>
</table>

¹ Details of these trials are not included in this report. For further information contact the State Forests of New South Wales Tree Improvement Program Manager.
Table 2. Physical attributes of the properties involved in the 400 ha Gunnedah plantings (property owner/name in bold).

<table>
<thead>
<tr>
<th>Geology</th>
<th>Soil Type</th>
<th>Landscape Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triassic sandstone</td>
<td>Sodosol, Kurosol</td>
<td>Upper, mid and lower slopes and floodplain</td>
</tr>
<tr>
<td>Triassic sandstone/capped by Tertiary basalt</td>
<td>Dermosol</td>
<td>Toe slope</td>
</tr>
<tr>
<td>Triassic sandstone and Tertiary basalt</td>
<td>Kurosol, Vertosol</td>
<td>Upper, mid and lower slopes and floodplain</td>
</tr>
<tr>
<td>Jurassic sandstone and Tertiary basalt</td>
<td>Kurosol, Chromosol</td>
<td>Mid and lower slopes</td>
</tr>
<tr>
<td>Jurassic sandstone and Tertiary basalt</td>
<td>Rudosol, Kurosol</td>
<td>Mid and lower slope</td>
</tr>
<tr>
<td>Jurassic sandstone and Tertiary basalt</td>
<td>Sodosol</td>
<td>Lower slope</td>
</tr>
<tr>
<td>Jurassic sandstone and Jurassic basalt and dolerite</td>
<td>Tenosol, Kurosol, Calcarosol, Vertosol</td>
<td>Mid and lower slope</td>
</tr>
<tr>
<td>Lower Permian polymictic conglomerate, shale and labile sandstone</td>
<td>Sodosol</td>
<td>Lower slope</td>
</tr>
</tbody>
</table>
(c) Establishment Techniques

(i) Background

Site preparation is a major expense in establishing planted forests. State Forests has utilised intensive cultivation techniques to establish plantings in low rainfall areas with good success (e.g., species demonstration trials across New South Wales, 100 ha established in the Macquarie River catchment). Intensive cultivation techniques are however expensive and, given the probable long rotation/low return from these plantations even after factoring in any income derived from environmental services, such high establishment cost may not be justified. Hence this trial was established to determine if lower cost establishment techniques could be used and what the trade-off might be with regard to seedling survival and early growth.

(ii) Objectives

To assess the effect of four levels of mechanical site preparation on seedling survival and early growth rates on two soil types in the Liverpool Plains region.

(iii) Site details

Location: Cobcroft/Parraweena and Burns/Kookera Cottage
Soil type: Red Vertosol (Cobcroft), Kandosol (Burns).

(iv) Experimental details

Establishment date: May 2003
Design: Randomised complete block with four replicates
Planting density: 4.0 m x 2.5 m = 1000 stems/ha
Plot size/area: Five rows x 16 trees = 0.08 ha
Trial size: 1.8 ha (including buffers)
Tree species: Eucalyptus camaldulensis (chosen for potential commercial value and a fast growth rate, therefore most likely to show an early response).

(v) Treatments

1. Ripping and mounding (using a D7 bulldozer and savannah plough, ripping with a winged tine to a depth of 70 cm)
2. Ripping only (using a D7 bulldozer ripping with a winged tine to a depth of 70 cm)
3. Mounding only (using a D7 bulldozer and savannah plough)
4. Minimum till (using D7 bulldozer and ripping with a winged tine to a depth of 30-35 cm).

(d) Spacing

(i) Background

In low rainfall environments, tree stands will be water limited for substantial periods. Lowering the planting density is one method for reducing the water limitation of the stand and enabling tree growth rates to be sustained. However, there may be a trade-off between stand and tree productivity and potential environmental benefits. This trial provides a basis for exploring these trade-offs. It also provides scope to implement different thinning regimes at a later age.
(ii) Objectives

To examine the effect of planting density on tree growth in the Liverpool Plains region. Health/vigour and growth measurements (dbh, height) will provide the basis for comparing the effect of each treatment on four eucalypt species.

(iii) Site details

Location: Duncan/Andamooka
Soil type: Rudosol

(iv) Experimental details

Establishment date: May 2003
Design: Randomised complete block split plot with four replicates
Trial size: 7.1 ha (including buffers)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Plot size/area</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>625 stems/ha⁻¹</td>
<td>64m*32m (0.20 ha)</td>
<td><em>Eucalyptus pilligaensis</em></td>
</tr>
<tr>
<td>1250 stems/ha⁻¹</td>
<td>32m*32m (0.10 ha)</td>
<td><em>E. crebra</em></td>
</tr>
<tr>
<td>1875 stems/ha⁻¹</td>
<td>43.2m*32m (0.14 ha)</td>
<td><em>E. camaldulensis</em> subsp. silverton</td>
</tr>
</tbody>
</table>

The two red gum species and the ironbark were chosen for their potential commercial value. The box species was chosen for comparison of its growth rate to that of the other three species. The trial design was supplied by Dr Ross Dickson (State Forests of New South Wales, Tablelands Research) where it has been established on three sites in southern New South Wales using a range of pine species.

(e) Scotch Plaid Spacing

(i) Objectives

This trial was established primarily for demonstration purposes, however it can be used to investigate the effect of square and rectangular spacings on tree growth and branching habit (see Gerrand and Neilsen (2000) for further details).

(ii) Site details

Location: Atkinson/Gundawarra
Soil type: Sodosol

(f) Experimental Details

Establishment date: May 2003
Design: Scotch plaid (double planted, ie two trees per planting location)
Planting density: 278-2500 stems/ha
Trial size: 0.6 ha
Tree species: *Corymbia maculata* (chosen for potential commercial value).
(f) **Tree Belt Width**

(i) **Background**

A key issue in the design of planted forests to be established on hillslopes in dryland salinity prone landscapes is how to reduce recharge to aquifers whilst maintaining stand productivity. Current theory suggests that on hillslopes in these low rainfall landscapes, tree belts planted on the contour in strips so as to intercept laterally flowing surface and subsurface water from upslope are the best design. This surface and subsurface water is additional to rainwater and, therefore, its capture will enhance growth rates whilst alleviating waterlogging and salinity problems downslope (Silberstein et al. 2002). It should be stressed that this model is conceptual, and that at the time of writing this report had not being validated in the field.

(ii) **Objectives**

The aim of this trial is to examine the relationship between tree belt width and the length of the unplanted upslope contributing area and how this affects tree growth. The trial has been designed to take advantage of considerable site characterisation by New South Wales Agriculture prior to the site being established to trees. Neutron probe access tubes previously installed by New South Wales Agriculture will be used to monitor changes in soil moisture across the plantation after significant rainfall events. This information, coupled with measurements on tree growth, will provide the basis for recommending optimum tree belt widths on this soil type in the Liverpool Plains region.

(iii) **Site details**

Location: Carter/Connamara

Soil type: Kurosol

(iv) **Experimental details**

Establishment date: October 2003

Design: See Appendix 2

Planting density: 4×2.5 m (1000 stems/ha)

Trial size: 5.8 ha

Tree species: *Eucalyptus camaldulensis* (chosen for potential commercial value).

These same design issues will be examined on two other soil types common to the Liverpool Plains. Parts of the Brownhill and McDonald plantings have been established on slopes and at the base of slopes in fairly wide (up to 20 rows) strips. By monitoring growth across these belts, gradients in tree growth may be detected from which can be inferred the optimum tree belt widths for these combinations of soil type and landscape position.

(g) **Biodiversity**

Biodiversity research in Liverpool Plains pilot project will be undertaken with the objective of determining the value of eucalypt planted forests for wildlife and how this is influenced by plantation design and management practices. The research will identify the animal species which benefit from eucalypt planted forests. It will also investigate the relationships between species occurrence and the age, area and plant species mix of the planted forests, as well as the effect of proximity to native forest remnants. The biodiversity values of eucalypt planted forests will be placed in context with those currently existing in forest remnants and farmland in the region. The main outcomes
will be knowledge about how eucalypt planted forests can best be used to enhance nature conservation in the landscape and data to underpin benchmarking of a biodiversity benefits scheme to encourage investment.

Related research has been completed in 10-25-year-old eucalypt planted forests established near Albury-Wodonga to improve landscape amenity. Such advanced-age planted forests are rare west of the Great Dividing Range and, accordingly, they provide an opportunity to gain insights into expected levels of biodiversity from new planted forests established primarily to control salinity. This work forms part of a collaborative study with the National Parks and Wildlife Service in which the objective is to benchmark biodiversity levels in planted and native forests and woodlands in areas subject to dryland salinity.
COLLABORATIVE PROJECT

1. MEASURING SALT CONCENTRATIONS BENEATH PLANTED FORESTS

The Department of Infrastructure Planning and Natural Resources has carried out an electromagnetic (EM) survey of the Carter, Cudmore and McDonald properties to determine the current salt concentrations in the soils beneath these planted forests. A separate EM survey has also been carried out by DIPNR on the Duncan properties, however the data had not been processed at the time of finalising this report. Portions of the Carter planted forests are established on floodplains adjacent to and/or on discharge areas. The highly saline and shallow nature of the watertable in this area of the Yarramanbah catchment where part of the Carter plantation is established is well documented (eg Timms 2000, Acworth and Beasley 1998). The results of the EM survey have shown that the silverton red gum planted on a section of the floodplain on the Carter property is at risk of salinisation, thus over time the productivity of this plantation may be compromised due to accumulation of salts in the root zone. A copy of the report (Spanswick 2002) detailing the main findings of the EM survey and nature of the soils on the Carter, Cudmore and McDonald properties is held in the State Forests of New South Wales library.

TIMEFRAME FOR MONITORING THE TRIALS

The timeframe for monitoring the trials presented in Table 3 represents the optimum measurement schedule assuming funds are not limiting. Guidelines for measuring the health/vigour of the trials are provided as a footnote below Table 3. As well as using the four codes described below to assess mortality, the health/vigour measurement should also incorporate the Crown Damage Index developed by Stone et al. (2003).

Table 3. Proposed timeframe for monitoring of the research trials.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Measurement</th>
<th>Measurement Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planting time</td>
<td>• health/vigour¹, height</td>
<td>• 1</td>
</tr>
<tr>
<td>Establishment</td>
<td>• health/vigour, height², dbhob</td>
<td>• 1, 2, 3, 5</td>
</tr>
<tr>
<td>Belt width</td>
<td>• health/vigour, height², dbhob</td>
<td>• 1, 2, 3, 5, 7, 10</td>
</tr>
<tr>
<td></td>
<td>• soil moisture (Carter only)</td>
<td>• monthly</td>
</tr>
<tr>
<td></td>
<td>• leaf area index</td>
<td>• biannually</td>
</tr>
<tr>
<td>Spacing trial</td>
<td>• health/vigour, height², dbhob</td>
<td>• 1, 2, 3, 5, 7, 10</td>
</tr>
<tr>
<td>Biodiversity</td>
<td>• biodiversity assessment</td>
<td>• 1, 3, 5</td>
</tr>
<tr>
<td>Soil type, landscape position</td>
<td>• health/vigour, height², dbhob</td>
<td>• 1, 2, 3, 5, 7, 10</td>
</tr>
</tbody>
</table>

¹ = health/vigour to be measured using the following categories; 1 – dead, 2 – poor, 3 – good, 4 – very good.
² = due to the large size of the plots, height should be measured on a subset of the trees in each plot which are representative of the diameter range.
ACKNOWLEDGEMENTS

The establishment of these plantings and trials was funded by the New South Wales Government under the State Salinity Strategy. Thanks to Drs Andrew Haywood (State Forests) and Idris Barchia (NSW Agriculture) for their suggestions for statistical analysis of the various trials and Brendan George (NSW Agriculture) and Di Bentley (Liverpool Plains Land Management Committee) for their constructive reviews of this report. Thanks also to Joy Gardner for publication assistance.

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APPENDIX 1

TRIAL DESIGNS - PLANTING TIME

Layout of the planting time trial at Cudmore/Paringa

Letters in brackets beside the plot numbers refer to the time of planting (ie a = autumn, s = spring).
Appendix 1. (cont.)

Layout of the planting time trial at Cobcroft/Parraweena Park

Letters in brackets beside the plot numbers refer to the time of planting (i.e., a = autumn, s = spring).
Appendix 1. (cont.)

ESTABLISHMENT TECHNIQUES

Layout of the establishment techniques trial at Cobroft/Parraweena Park
Appendix 1. (cont.)

**SPACING TRIAL**

Layout of the spacing trial at Duncan/Andamooka

Species A = *E. camaldulensis 'silverton'
Species B = *E. pilligaensis*
Species C = *E. camaldulensis*
Species D = *E. crebm*

<table>
<thead>
<tr>
<th>Stems/ha (Plot Size)</th>
<th>Rep 1</th>
<th>Rep 2</th>
<th>Rep 3</th>
<th>Rep 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1875/ha (32m x 43.2m)</td>
<td>B (plot 1)</td>
<td>B (plot 12)</td>
<td>D (plot 1)</td>
<td>B (plot 12)</td>
</tr>
<tr>
<td>1250/ha (32m x 32m)</td>
<td>B (plot 2)</td>
<td>A (plot 1)</td>
<td>C (plot 1)</td>
<td>B (plot 11)</td>
</tr>
<tr>
<td>625/ha (32m x 64m)</td>
<td>A (plot 3)</td>
<td>D (plot 10)</td>
<td>B (plot 11)</td>
<td>C (plot 3)</td>
</tr>
<tr>
<td>375/ha (32m x 128m)</td>
<td>D (plot 4)</td>
<td>A (plot 9)</td>
<td>C (plot 9)</td>
<td>D (plot 5)</td>
</tr>
<tr>
<td>250/ha (32m x 256m)</td>
<td>A (plot 5)</td>
<td>C (plot 8)</td>
<td>B (plot 4)</td>
<td>A (plot 9)</td>
</tr>
<tr>
<td>125/ha (32m x 512m)</td>
<td>C (plot 6)</td>
<td>B (plot 5)</td>
<td>A (plot 5)</td>
<td>B (plot 6)</td>
</tr>
<tr>
<td>62.5/ha (32m x 1024m)</td>
<td>C (plot 7)</td>
<td>A (plot 6)</td>
<td>A (plot 7)</td>
<td>D (plot 8)</td>
</tr>
</tbody>
</table>
Appendix 1. (cont.)

*SCOTCH PLAID SPACING*

Layout of the demonstration spacing trial at Atkinson/Gundawarra

![Diagram showing the layout of the demonstration spacing trial with 10 rows per plot and specific distances between plots.]
APPENDIX 2

SUGGESTIONS FOR STATISTICAL ANALYSIS OF THE TRIALS

Tree Belt With Trial

EXPERIMENTAL DESIGN OF HILL-SLOPE PLANTATION DESIGN IN A DRYLAND OF LIVERPOOL PLAINS NEW SOUTH WALES

Requested by

State Forests of New South Wales – Research and Development Division

April 2001

Biometrical consultant

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Senior Biometrician

NSW Agriculture

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AUSTRALIA
Objective of study

Hill-slope area has problems in relation to water reserve in soil, particularly in dryland area with low annual rainfall. If the area is left unused for plantation the rainwater would flow through the soil rapidly to lowland and this could cause salinity or waterlogging problems in the lowland area. If the area is fully-planted, plants may not sustain on the available rain water. As a result the plants may grow poorly. This study is looking for an optimal design of planted forests that maximises the use of soil and rain water.

Hill-slope tree belt design

CSIRO’s team has introduced belt like plantation design along contours. For long slope areas belts of plants are flanked by grass area which acts as absorbent for rainwater. An optimum plantation design that would maximise the use of soil and rain-water should have optimal widths of tree belts.

Experimental Design for the Hill-slope area at Liverpool Plains site

Background of the site
The site has an area of approximately 200 m wide and 300 m long (downhill). The average slope is about 3%. The lower area of the site has variable depths of soil where rock is found at depth 1.5 m within west side and at depth 3 m within east side.

Trial design
A grass area is a truncated triangular shape pointing uphill with base = 200 m, height = 150 m and 50 m truncation at each side (see diagram below). The lower part of the site will be planted with trees within a rectangular shape area measuring 200 m wide and 90 m side-length. The lowest area will be sown with grass (200 m x 10 m). The triangular shape of grass area is designed to vary the water infiltration area (r) with expectation that water availability will vary for the tree belt. Since the east and west parts are identical, these parts make up replication for the design treatment. For the control group designated areas in both right and left side of the site would be selected from the fully- tree planted area.

Data analysis

Modelling tree growth
Tree size will be related to their corresponding grass areas and their distances from the top edge of the tree-belt by using a regression analysis (multivariate regression analysis since trees are planted in rows at different altitudes).
Modelling optimum tree-belt width
Using "normal" growth, tree distance from the top line will be measured and modelled as a function of the length of uphill grass area and other environmental characteristics.

Plantation design comparison
Trees from the rectangular block of tree-belt design will be compared with trees of the designated control group using an analysis of variance technique.

Recommendation
The design shown below can be adopted to check whether the concept of tree-belt introduced by CSIRO's team is efficient. However, conclusive findings require more replication of this kind. The comparison between tree-belt design and the control group will be based on pseudo-replications where individual trees or plots of trees will be treated as experimental units.

Planting time
The data obtained from this trial can be analysed using analysis of variance (anova), where site can be treated as a random or fixed effect. This will affect the analysis undertaken. If there is no interaction between site and species then site is a random effect. If there is an interaction between site and species then site is a fixed effect. The structure of the anova should be as follows;

<table>
<thead>
<tr>
<th></th>
<th>site = random effect</th>
<th>site = fixed effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>site (random)</td>
<td>df 2-1</td>
<td>site (fixed)</td>
</tr>
<tr>
<td>block within site</td>
<td>df 4-1</td>
<td>block within site</td>
</tr>
<tr>
<td>species</td>
<td>df 3-1</td>
<td>species</td>
</tr>
<tr>
<td>error (a)</td>
<td>df 17</td>
<td>species*site</td>
</tr>
<tr>
<td>season</td>
<td>df 2-1</td>
<td>error (a)</td>
</tr>
<tr>
<td>season *species</td>
<td>df (2-1)</td>
<td>season</td>
</tr>
<tr>
<td>error (b)</td>
<td>df 21</td>
<td>season*site</td>
</tr>
<tr>
<td>total (n-1)</td>
<td>df 47</td>
<td>season*species</td>
</tr>
<tr>
<td></td>
<td></td>
<td>season<em>site</em>species</td>
</tr>
<tr>
<td></td>
<td></td>
<td>error (b)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>total (n-1)</td>
</tr>
</tbody>
</table>

Establishment techniques
As with the planting time trial site can be treated as a random or fixed effect depending on whether there is or is not an interaction between site and species.

<table>
<thead>
<tr>
<th></th>
<th>site = random effect</th>
<th>site = fixed effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>site (random)</td>
<td>df (2-1)</td>
<td>site (fixed)</td>
</tr>
<tr>
<td>block within site</td>
<td>df (4-1)</td>
<td>block within site</td>
</tr>
<tr>
<td>site prep</td>
<td>df (4-1)</td>
<td>site prep</td>
</tr>
<tr>
<td>error (a)</td>
<td>df 24</td>
<td>site prep*site</td>
</tr>
<tr>
<td>total (n-1)</td>
<td>df 31</td>
<td>error (a)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>total (n-1)</td>
</tr>
</tbody>
</table>
Spacing trial
The variable plot sizes could confound treatment effects due to spatial variation, i.e., in the 625 stems/ha treatment the distance between the furthest trees is twice that of the 1250 stems/ha treatment. Hence if spatial variability is high then the variability in the 625 stems/ha treatment would be greater than observed in the 1250 stems/ha treatment. To overcome this concern measure the spatial variability of the treatments using transects through the measurement plots. If the variation is the same across the different treatment plots then the differing plot sizes can be ignored. If the spatial variability is a problem then restrict the size of the measurement plot so that they are equal in size across the three treatments. A repeat-measures analyses, using a mixed modelling approach (mortality, biomass), should be used to analyse the trial with the aid of a statistical advisor.

Scotch plaid spacing
See Gerrand and Neilsen (2000) for appropriate statistical methods.
FERTILISER RECOMMENDATIONS

The fertiliser requirements for planted forests established on ex-pasture in low rainfall (<700 mm) areas are not known. Below are some recommendations to guide initial fertiliser practice based on the results of a chemical analysis on a range of soils sampled from a number of pits on 4 properties (Table 4) and previous experience. These recommendations are “best guesses” and will require modification as experience with the land resource in this environment increases.

In interpreting the soil tests, additional general background information was used including:

• pines planted on ex-pasture sites in >700 mm rainfall areas receive no fertiliser due to the residual soil nutrient levels;
• most sites have previously been cropped and will mostly likely have had fertiliser applied, particularly superphosphate;
• the slower growth rates, due to water limitations, will reduce the nutrient demand compared with planted forests in higher rainfall regions;
• soil organic matter is used to indicate general soil fertility, particularly the likely nitrogen (N) supplying capacity of the soil.

Consideration should be given to establishing operational fertiliser trials to test the initial recommendations.

General Comments
Soils from the four sites were sampled and tested. The topsoil pH ranged from 5.0 - 6.1 indicating a good general soil chemical environment with no major cation imbalances. Soils at all sites were non-saline. Apart from DuncanlAndamooka, all topsoils had moderate to high soil organic matter levels indicating good general soil fertility. Moderate to very high levels of phosphorus (P) were observed reflecting either previous fertiliser application or natural high levels in the parent material of the soil (i.e. basalt).

Duncan/Andamooka
The soil on Andamooka is derived from sandstone collium which would be expected to have a low natural fertility. This is apparent in the first site (Pit 1) sampled where soils had low P and organic matter content. Downslope of Pit 1 soil P and organic matter levels were 300 and 700% higher respectively. This is probably due to the higher clay content in Pit 2 (determined from field texturing).

Fertiliser recommendations
It is likely that the soil will be unable to supply sufficient levels of N and P across large areas of the site. 50 g tree⁻¹ of DAP (diammonium phosphate) is recommended to be applied in a slit no closer than 30 cm from the base of the tree. If possible, fertiliser should be applied three to six months after planting.
**Duncan/Oakland**

Three sites were sampled across Oakland (top, middle and lower). The soils sampled on Oakland are sandstone/basalt derived and are of moderate fertility. Generally, soil P and organic matter levels across the three sites are moderate to high and would be expected to be able to supply sufficient N and P to sustain good tree growth. In addition the narrow belts of trees planned would limit competition between trees for nutrients and further reduce the need for fertiliser application.

**Fertiliser recommendations**
No fertiliser application is recommended.

**Brownhills/Merrilong**

Only the bottom section of Brownhills was sampled. At this site, soil P and organic matter levels were very high reflecting the basalt parent material and possibly previous fertiliser practices. The upper slopes on Brownhills that were not sampled would be expected to have lower nutrient levels than observed on the bottom section but these soils would be expected to contain sufficient N and P to sustain good tree growth.

**Fertiliser recommendations**
No fertiliser application is recommended.

**Carter/Connamara**

The soil is a sandstone derived duplex. The topsoil has moderate levels of P and organic matter and would be expected to supply sufficient levels of nutrients to sustain good tree growth.

**Fertiliser recommendations**
No fertiliser application is recommended.

**Properties Not Sampled**

Where properties have not been sampled, the following guidelines are suggested.

Fertiliser be applied to sandstone derived soil at a rate of 50 g tree$^{-1}$ of DAP (diammonium phosphate)  
No fertiliser is required on basalt derived soils.

These recommended rates are formulated to ensure adequate nutrient supply on the lower fertility sites. Lower rates may be adequate on some sandstone soils.
Table 1. Soil chemical analysis of four properties on which planted forests are to be established on the Liverpool Plains.

<table>
<thead>
<tr>
<th>Property</th>
<th>Location</th>
<th>Soil depth</th>
<th>pH</th>
<th>E.C.</th>
<th>Org. Mat</th>
<th>Total C</th>
<th>Bray 1-P</th>
<th>Total P</th>
<th>Exch cations (meq/100g)</th>
<th>Ca: Mg</th>
<th>Percentage cations</th>
<th>ESP</th>
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<td></td>
<td></td>
<td>(cm)</td>
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<td>CaCl₂</td>
<td>(dS/m)</td>
<td>(% w/w)</td>
<td>(mg/kg)</td>
<td>Ca</td>
<td>Mg</td>
<td>Na</td>
<td>K</td>
<td>Al</td>
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<td>6.2</td>
<td>5.2</td>
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<td>0.8</td>
<td>0.4</td>
<td>5</td>
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<td>1.6</td>
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<td>20-60</td>
<td>6.7</td>
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<td>&lt;0.05</td>
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<td>0.12</td>
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<td>83</td>
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<td>0.05</td>
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<td>420</td>
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<td></td>
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<td></td>
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<td>20-27</td>
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<td>5</td>
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<td>2.5</td>
<td>10</td>
<td>720</td>
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<td>5.4</td>
<td>0.1</td>
<td>1.2</td>
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<td>310</td>
<td>3.7</td>
<td>9.4</td>
<td>1.5</td>
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</table>
## APPENDIX 4

### PROPERTY LOCATIONS

<table>
<thead>
<tr>
<th>Name</th>
<th>Property/Location</th>
<th>AMG coordinates</th>
<th>Topographic map sheet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colin and Barbara Atkinson</td>
<td>Gundawarra 2382, via Boggabri, NSW</td>
<td>231 045, 6598 005</td>
<td>Boggabri 8936</td>
</tr>
<tr>
<td>John and Betty Barrie</td>
<td>Knockadirrah, Quirindi, NSW 2343</td>
<td>265 950, 6506 950</td>
<td>Murrurundi 9034</td>
</tr>
<tr>
<td>Contact: Renya Barrie</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>David Brownhill</td>
<td>Gowrie Office, Spring Ridge, NSW 2343</td>
<td>233 900, 6507 210</td>
<td>Blackville 8934</td>
</tr>
<tr>
<td>Richard and Robina Burns</td>
<td>Kookera Cottage, Spring Ridge, NSW 2343</td>
<td>236 400, 6515 500</td>
<td>Curlewis 8935</td>
</tr>
<tr>
<td>Ian and Marilyn Carter</td>
<td>Connamara, via Quirindi, NSW 2343</td>
<td>260 520, 6508 300</td>
<td>Blackville 8934</td>
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<tr>
<td>Brian and Jenny Cobcroft</td>
<td>Parraweena Park, Millers Creek, NSW 2339</td>
<td>254 650, 6488 450</td>
<td>Blackville 8934</td>
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<tr>
<td>David and Wendy Cudmore</td>
<td>Paringa, via Quirindi, NSW 2343</td>
<td>261 720, 6507 120</td>
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<tr>
<td>Robert and Edwina Duddy</td>
<td>Hudson, Willow Tree, NSW 2339</td>
<td>258 000, 6489 310</td>
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<tr>
<td>Ian and Faye Duncan</td>
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<td>Linda Malden</td>
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<td>Jim and Katrina McDonald</td>
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</tr>
</tbody>
</table>

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