

Direct seeding technologies for *Eucalyptus*

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Direct seeding technologies for cost effective revegetation

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Summary

The high initial cost of establishment of *Eucalyptus* species through the use of tubestock has led to the need to investigate direct seeding technologies as a means of reducing this cost. Direct seeding operations have generally met with low rates of success. This report describes a series of experiments designed to evaluate a number of seed treatments which have the potential to enhance the success of direct seeding.

The use of solutions of polyethylene glycol were able to be used to prime seeds of *E. albens*, *E. fibrosa*, *E. melliodora*, *E. moluccana*, *E. polyanthemos*, *E. sideroxylon* and *E. tereticornis*. In laboratory tests, primed seed germinated more quickly, particularly at lower temperatures, than did non-primed control seeds. The use of solutions of KNO₃ to prime seeds did not prove as effective as polyethylene glycol solutions.

Primed seeds of all *Eucalyptus* species, except *E. albens*, emerged more quickly and produced a greater number, or did not affect the final number, of seedlings in the greenhouse. Seedlings produced from primed seeds of *E. albens* appeared to be affected by the disease causing organism *Phythium*. This infection was not apparent in other experiments using this species. It is most likely that priming of *E. albens* seeds would have been as effective as priming of the other species should the disease causing organism not have been present.

Field trials which were dependent on natural rainfall were not successful due to either inadequate or no rainfall within several months of direct seeding or due to the effects of heavy weed infestation. In field trials using irrigation, we were able to demonstrate that seed priming could enhance the establishment of direct seeded *E. tereticornis*, but seed priming was detrimental to the establishment of *E. fibrosa* and *E. moluccana*. In order to successfully conduct this field trial, the plots had to be hand weeded. Irrigation proved beneficial by increasing the number of seedlings establishing, but was not necessary to ensure the establishment of some seedlings.

In a large scale field trial, those irrigation treatments involving approximately seven days of daily irrigation resulted in an increase in the number of seedlings to emerge. In this trial control of weeds was attempted through several applications of the herbicide glyphosate to the plots prior to direct seeding and to the weeds and grasses adjacent to the seedlings subsequent to emergence. This method of weed control proved totally ineffective in the longer term and consequently all seedlings which had emerged from the approximately 192,000 *Eucalyptus* seeds sown succumbed to the competitive pressure of the weeds and grasses.

In a series of smaller trials, we were able to demonstrate that so long as the soil moisture content remains at or above 50% of field capacity, *Eucalyptus* seeds should be able to germinate. Seed priming proved to be detrimental to seedling emergence under these conditions, as fewer seedlings emerged from primed seeds at the lower soil moisture contents of 30% and 40% of field capacity than emerged from the non-primed control seeds. We were able to document high rates of seed predation by ants of *Eucalyptus* seeds sown in the field. This predation occurred irrespective of whether the seeds were not treated, were treated with the insecticide permethrin, or were given the commercial seed coating “treecote” which includes the insecticide permethrin.

In a final field trial we evaluated a wide range of seed coating treatments including dusting the seeds with a fungicide, an insecticide, or both, pelleting the seeds with a fungicide, or with an insecticide, polymer coating the seeds with a fungicide, an insecticide or both, polymer coating with nutrients or the use of the commercial seeding coating “treecote”. We were unable to find any lasting effects of any of these treatments on the establishment of direct seeded *E. tereticornis*. However, during this field trial, we used weed matting to control weeds and grasses beside the rows into which the *Eucalyptus* seeds were sown. As a consequence of the reduction in competitive pressure from weeds and grasses almost all emerged *E. tereticornis* seedling have survived.

In comparison to the costs of using tubestock for establishment, direct seeding of *Eucalyptus* into prepared beds coated with weed matting should prove more economical.

1. INTRODUCTION

1.1 Background

Australia has lost over 50% of its original tall and medium forests, 35% of its woodlands and 75% of its rainforests since European settlement began. Moreover, as a result of our past land management practices, 51% of agricultural and pastoral land in Australia requires remediation work to reverse the effects of land degradation (McTainsh and Boughton 1993). These have included increasing soil salinity levels and soil erosion. Reduction in the areas of native habitat is also aggravating efforts to maintain the country's biodiversity. The combination of these issues press for ongoing re-establishment of trees. Reforestation and revegetation is now required in many situations, including along newly constructed roadsides, on farmlands and on minesites. This revegetation work can also take the form of development of agroforestry plantations.

Agroforestry has the potential to improve the profit margins and the sustainability of Australian agriculture. Agroforestry can also provide a range of wood products for the timber industry. It is estimated that more than a quarter of all farmers in Australia are actively involved in the establishment of trees on their farms (Vanderwoude 1995). A major impediment to the establishment of trees on farms, in agroforestry projects and on roadsides is the high up front cost. Most tree establishment programs, whether on farm, commercial forestry or roadside revegetation work, involved the use of expensive tubestock seedlings and a large labour component.

Two possible methods of establishment which can be used for revegetation include direct seeding and the transplanting of young plants. Seeds may be sown by broadcast sowing by hand or machine, direct drilling using conventional drilling equipment or direct drilling using specially developed seeder for native plant seed. Their adoption of direct seeding over transplanting may be one means of reducing the cost of large scale revegetation work. The adoption of direct seeding methods will be influenced not only by cost but also by the levels of successful plant establishment achieved.

Though direct seeding has been less reliable and is more dependent on seasonal conditions than planted tubestock, it may result in a higher density of plants. Weaker plants may also be selected out by competition (Curtis 1991). Currently direct seeding requires larger quantities of seed than tubestocks, to compensate for these lower establishment rates. When regularly spaced trees are required, planted tubestocks are currently suggested as a better option (Curtis 1991). The development of precision planting equipment should enable adequate control over seed placement to ensure desired plant spacings similar to the way that this has occurred for many horticultural and agricultural species.

Inconsistency in the numbers of plants established through direct seeding, has been combined with low establishment success, regularly reported as below five percent (Venning 1988; Bird *et al* 1992). However, the potential benefits of using direct seeding methods for plant establishment include: reduction in costs; improved tree performance; improved root development; better stem form; and the development of stands which have a more natural appearance (Gardner 1985). The investigation of techniques which have been shown to improve the establishment of horticultural crop species may provide methods to sufficiently increase the establishment of eucalypts in revegetation projects.

The seed treatment technology of seed priming has been investigated for a range of species and has proved to be beneficial in establishing a wide range of species (Heydecker and Coolbear 1977). This treatment offers a potential strategy that may assist in improving the success of direct seeding of eucalypts.

Seed priming involves the controlled hydration of seed so as to permit the commencement of various physiological and biochemical processes which lead to germination, but such that the final step of germination, protrusion of the radicle, is prevented. Seed priming treatments have been adopted for a number of horticultural crops for use in situations where improvements in germination are sought.

1.1.1 Seedling Establishment

The successful establishment of a seedling from seeds sown in a field will depend on a large number of factors. These can be grouped into factors which affect the quality of the seed and environmental factors which affect the capacity of a seed to germinate or a seedling to emerge and successfully establish.

Seed quality is largely determined by the processes occurring during the development of the seed. Quality can also be affected by the way in which the seed is handled after harvest or collection. During development, many environmental factors can affect the capacity of a parent plant to support the development of its seed crop. Factors which affect the availability to the seed of carbohydrates, nutrients or water will greatly affect the quantity and quality of seeds which develop. Because Eucalypt seed, used for revegetation work, is collected from trees growing under natural environmental fluctuations, there will be considerable fluctuations in the quality of the seed collected from season to season. In poorer seasons, many developing seeds may abort, thus reducing the viability of the seedlot.

There are a large number of environmental factors which can influence seed germination and seedling emergence. For successful establishment of direct-seeded crops, these factors need to be within favourable limits. The temperatures to which the seeds are exposed will determine whether germination will occur or not. The availability of water to commence and sustain the germination and emergence processes can have a great influence. Competition from weed seeds may limit the success of germination and establishment. Weed species may utilise water and nutrients more quickly than do Eucalypts. There are limited options available for control of weeds in large scale weed revegetation projects. Pest and disease organisms may decrease the success of germination or may deplete the numbers of seedlings soon after emergence. Because of the small size of Eucalypt seeds and their limited store of reserve material, it is also important to control the depth at which they are sown so that the germinated seed can become an established seedling before the reserves are exhausted.

When pest and disease organisms are not limiting, the availability of water in the seedbed is often the primary factor in determining the success of seedling emergence (Roberts 1984). Soil moisture content and the cultivation of the surface layers of a

soil have a strong influence on the number of seedlings emerging for such horticultural crops as carrot and parsley (Biniek 1994). In a detailed study of the effects of timing of rainfall and irrigation events, Finch-Savage (1990) was able to demonstrate that the patterns of seedling emergence were largely determined by the influence of water availability and temperature on seed germination. For some vegetable crops, it is possible to develop models to predict the optimum time of irrigation to ensure maximum success of germination and seedling emergence (Finch-Savage *et al* 1995). For *Eucalyptus*, no such models nor the information upon which they are built are currently available.

Seeds should be sown as early as possible following the onset of reliable rainfall to enhance seedling survival (Venning 1988). Soil water content is particularly variable near the surface and wide fluctuations in soil water content occur with natural cycles of rainfall and evaporation (Bradford 1995). However, the nature of the Australian environment may, for many locations, prevent the prediction of reliable rainfall and thus limit the effectiveness of direct seeding operations.

A number of practical measures may be used to address the problem of optimising soil moisture levels. These include timing the seed sowing in areas with more reliable rainfall, the reduction in competition from weed species through the use of herbicides and various mulches and the provision of water through irrigation.

1.1.2 Direct Seeding Methods

Direct seeding is becoming an increasingly popular technique of establishing tree, shrub and grass species throughout Australia. The main use of direct seeding has been for the reintroduction of native tree and shrub species to areas where the natural vegetation cover has been cleared or degraded through activities such as mining, road and dam construction, logging and agricultural mismanagement. Live-stock shelter-belts and fodder trees such as Tagasaste (*Chamaecytisus proliifer*) and Saltbush (*Atriplex* spp) are also commonly established through direct seeding. The use of current direct seeding technology is, however, limited where orderly configurations of trees is required, such as in production forests and orchard shelter-belts. This is due to

unreliable establishment arising from weed competition, soil moisture availability, degraded soils, herbivory and vagaries in germination of native tree seeds.

There are a number of methods used for direct seeding of species used for revegetation work. These include:

- a. Aerial sowing - Generally used to revegetate large areas. Seed is mixed with fertiliser and sown by fixed-wing aircraft or helicopter.
- b. Hydroseeding - A mixture of seed, fertiliser and water is sprayed onto the surface to be revegetated.
- c. Hydromulching - A mixture of seed, fertiliser, paper mulch, water and often polymer glue and indicator dye is sprayed onto the surface. This and hydroseeding are common methods of revegetating embankments, road-cuttings and dam faces.
- d. Hand sowing - Manual dispersal of seed and fertiliser.
- e. Direct drilling - Seed with or without fertiliser is sown into the soil using purpose-built equipment towed by tractor or 4WD vehicle.

The advantages of establishing tree and shrub species by direct seeding rather than planting of nursery raised tube-stock include:

- a. No transplanting shock - The nursery environment is often greatly different from the environment to which the seedling is transferred. A direct seeded plant is more adapted than transplanted tubestock to its immediate environment and thus survivorship in periods of stress is often greater.
- b. Less labour and time input - The raising and planting out of tubestock is labour intensive and time consuming. Direct seeding usually has a far lower labour and time demand, depending upon amount of site preparation and the seeding

method used. The major labour input is often in seed collection which can be spread throughout the year.

- c. Convenience - Distance from supplying nurseries may be a problem, particularly in the more isolated rural areas.
- d. More natural spatial distribution of resultant vegetation - In revegetation of disturbed areas, direct seeding with a cocktail of shrub and canopy species more closely follows natural patterns of regeneration than does planting of tubestock.
- e. Economic efficiency - Costly factors such as labour and nursery inputs are reduced or absent when direct seeding is performed.

Low establishment rate is considered to be the major impediment to the wider acceptance of direct seeding as a method of propagating trees particularly for commercial production forests. Low establishment rates may arise from either or both low germination rates and low seedling survivorship. The most influential recognised factors affecting establishment are; weed competition, degraded soil, soil moisture availability, herbivory and seed quality.

1.1.3 Weed Competition

Competition from other plants can severely hinder establishment of direct seeded species, particularly on highly fertile soils (Pinkard 1990) and improved grassland. Davis (1989) found survival of lodge-pole pine (*Pinus contorta*) seedlings from direct drilled seed on New Zealand high country grassland to be zero in improved pasture and 99% in unimproved pasture, and concluded this to be due to competition with the grassland species. A great deal of research has been conducted into both chemical and physical methods of weed control. Herbicides are widely used, both to clear land prior to sowing and, using residual herbicides, to maintain long term weed free conditions. Problems, however, can arise with desirable species, both those germinating from the existing seed pool and those direct seeded, becoming adversely

affected by residual herbicides (Weatherly 1993). The most commonly used mechanical method of weed control is scalping, where the upper few centimetres of topsoil is shaved aside, taking the bulk of weed seeds with it (Loney 1990).

1.1.4 Seed Bed Quality

Seed bed quality is considered a highly influential factor in determining seedling establishment after direct seeding (Foster and Dahl 1990). Seed bed preparation is especially important where activities such as mining and road and dam construction have greatly altered the soil environment, producing unsuitable physical structure, low fertility, biological sterility and, often, high salt content. Mining companies are especially active in research and application of soil amelioration techniques. Some strip the top soil by horizons before beginning mining and either stockpile it for future replacement or use it to rehabilitate a previous mine site. Various techniques such as moon-scaping of steep slopes (Walker 1990) and ripping of compacted or crusted soil, are applied to enhance soil stability, water and wind erosion control, water harvesting, seed lodging, root growth and protection for establishment.

1.1.5 Soil Moisture Availability

Soil moisture availability is an important factor for the success of direct seeding in environments where rainfall is infrequent and/or unreliable. As most direct seeding operations are performed over a large area, irrigation is usually not viable. Where soil moisture availability is a dominant problem, the timing of sowing to coincide with periods of sufficient rainfall for establishment is often critical. The combination of rainfall and soil type must also be considered. Pinkard (1990) reported establishment of aerial sown tree and shrub species in midland Tasmania to be better on heavier soils and suggested unreliable rainfall patterns may be more of a problem in areas where the soil is of a high sand component, which is more prone to rapid drying resulting in desiccation of seedlings.

1.1.6 Herbivory

A number of invertebrate and vertebrate herbivores can be responsible for high seedling mortality. Snails, wingless grasshoppers, red legged earthmites, rabbits, kangaroos and feral and uncontrolled livestock are often cited as major problem species. Consumption and dispersal of seeds by ants (seed robbing) is a common phenomenon throughout Australia (Majer 1990). This behaviour can be a mixed blessing. Consumption of seeds (granivory) is obviously detrimental, however, dispersal of seeds (through myrmecochory or, less commonly, for nest decoration) can benefit the seed by placing it in a protective environment, away from temperature extremes and predators (Majer 1990). Methods for the control of herbivory may range from the application of pesticides to construction of fences, depending on the organisms involved in the herbivory.

1.1.7 Seed Quality

Seed quality is often stressed as being a key factor in the success of direct seeding. Factors such as inbreeding, parent tree vigour, seed handling and storage time can affect germination and seedling vigour. Selection of a suitable ecotype (provenance type) to suit the environment where seeding is to take place is also considered critical (Harwood 1990). These problems are usually overcome by the direct seeders undertaking their own collecting or buying from a reputable seed collector.

For the survival of undomesticated species, at least some seeds need to germinate under conditions favourable for seedling establishment. This is commonly achieved through the evolution of uneven germination rates and seed dormancy. These characteristics are perhaps the major impediments to the use of direct seeding where precise establishment of native trees is desired. Currently, direct seeding operators wishing to establish orderly configurations of trees by-pass the problem by using high seeding rates and later thinning or transplanting seedlings as required. High seeding rates are, however, not feasible when rare species or ecotypes are used.

1.1.8 Direct Drilling Methods

There are two main methods employed for the direct drilling of seeds:

1. Mass seeding - Sowing of a cocktail of, usually, canopy and shrub species for a) revegetation intended to resemble previous vegetation cover and b) stock shelter-belts as a barrier to cold winds and other conditions which may cause stock discomfort or losses.
2. Precision drilling - Sowing of a particular species intended to create a uniform configuration of that species as in production forests and orchard shelter-belts.

Successful precision drilling requires:

1. Consistent percentage germination, so that an accurate sowing rate can be calculated for precise distance between propagules.
2. Synchronous germination, so that seeds germinate when conditions are most favourable for establishment, may be immediate or delayed. Also, to get a uniform aged stand.
3. Equal and high seed vigour, so that resultant propagules are of a uniform condition.

There are a number of treatments which can be applied to enhance desirable germination characteristics in undomesticated species. The most common classes of treatment are dormancy release, seed priming and pelleting.

1.1.9 Seed Priming

Seed priming, briefly, involves placing seeds for a specific period in a solution of known water potential which permits imbibition but prevents germination. The seeds are then, usually, removed and dried to facilitate storage and handling. This holding of seeds at the intermediate stage of water uptake results in a number of benefits upon reimbibition. Germination of a seedlot so treated may be more rapid, more synchronous, more complete throughout the seedlot and, in some cases, more vigorous (Karssen *et al.* 1989). Battaglia (1993), reported that seeds of *E.*

delegatensis preimbibed in solutions of water potential down to -2 MPa showed a shorter time to germination and more synchronous and rapid germination than untreated seeds. Such attributes are considered highly desirable in a species to be successfully direct seeded (Harwood 1990).

1.1.10 Pelleting

Coating of seeds was originally designed to facilitate handling of fine seeds (Heydecker and Coolbear 1977). Substances such as nutrients, beneficial microorganisms, insecticides and fungicides can be incorporated into the encapsulation material to enhance germination and establishment. In a series of field trials at Weipa, Queensland, establishment was not improved by encapsulation, despite a variety of materials being used (Gunness and Lawrie 1987). Weatherly (1993), however, reported enhanced germination and establishment of direct seeded species with "nutrient powders" incorporated with the encapsulation material.

1.1.11 *Eucalyptus* Species used in this Study

The *Eucalyptus* genus belongs to the sub-family Leptospermoideae, part of the Myrtaceae family (Turnbull and Doran 1987). *Eucalyptus* species make up about 95% of the forest trees, dominate the woodlands and have been described as a conspicuous element of the Australian vegetation (Turnbull and Doran 1987). Their extensive range, from rainforest regions to semiarid deserts, along watercourses of central Australia, and to the tree-line (1,800 metres) in the Snowy Mountains, make them an integral part of any remedial revegetation work.

Past research into the germination of eucalypt seeds has highlighted the importance of soil moisture stress, stratification, temperature, light and relative humidity (Grose and Zimmer 1957; Beardsell and Mullett 1984; Bachelard 1985; Gibson and Bachelard 1986; Donald and Jacobs 1994). Where several treatments have been applied, interactions between environmental variables have arisen eg. Zohar *et al.* (1975), Battaglia (1993). Thus to gain a full understanding of the effects of environment on germination of a species all major environmental variables plus their interactions should be investigated (Battaglia 1993).

Initially only four *Eucalyptus* species were included in this study: *E. fibrosa* ssp. *fibrosa* F. Muell. (broad leaved ironbark), *E. moluccana* Roxb. (grey box), *E. sideroxylon* A. Cunn. ex Woolls ssp. *sideroxylon* (mugga) and *E. tereticornis* Sm. (forest red gum). These species were selected for their potential for revegetation by direct seeding of road cuttings by the Roads and Traffic Authority (NSW) and “green corridors” by Greening Australia (NSW) in the Western Sydney region. Following the completion of the first two sets of laboratory and field studies, further work with *E. fibrosa* was abandoned due to the unavailability of seed and an additional three species were included in experimentation. These additional species were *E. albens* Benth. (white box), *E. melliodora* A. Cunn. ex Schau. (yellow box), *E. polyanthemus* Schau. (red box). These additional species were included because of their potential as agroforestry species for use in western New South Wales.

The species selected for experimental work do not display dormancy and do not need dormancy breaking treatments (Boland *et al.* 1980; Langkamp 1987). Nor has their seed or chaff been reported to contain inhibitors which may lead to radicle deformation (Langkamp 1987). In germination studies, Langkamp (1987) suggests that at least ten minutes of light be given daily, with light being essential for *E. sideroxylon* and *E. tereticornis*. It is anticipated that there are no special environmental conditions which need to be met for the chosen species to be able to germinate.

1.2 Objectives

This project was designed with the overall objective of developing seed treatments to enhance the germination percentage and subsequent establishment of *Eucalyptus* species, thereby significantly improving the economics of direct seeding methods for tree establishment.

More specifically, there were four objectives to be addressed:

1. to attempt to improve the germination percentage of *Eucalyptus* species through the use of seed treatments;

2. to develop seed priming treatments which will enhance the rate and uniformity of seed germination;
3. to determine the effectiveness of these germination enhancement procedures in promoting seedling establishment by direct seeding in field experiments; and
4. to undertake an economic analysis of direct seeding compared to seedling establishment via tubestock.

The first three objectives were addressed through the conduct of a number of experiments in the laboratory, in the greenhouse and in the field. The last objective was addressed through an economic analysis of the experimental work undertaken together with some commercial revegetation work.

2. EVALUATION OF SEED PRIMING TREATMENTS

2.1 Introduction

Seed treatments may be divided into categories, based on the means by which they address germination and establishment issues. The treatments may be designed to reduce the stress associated with the soil environment, abiotic or biotic, or to improve the percentage of germination or to increase the rate of plant growth (Taylor and Harman 1990).

Seed priming is one treatment which can advance and synchronise germination. It is essentially a physical treatment which permits all germinable seeds to complete the first stage of their germination process prior to sowing (Heydecker and Coolbear 1977; Taylor and Harman 1990). A number of other treatments have also been used to advance seed germination. These include fluid drilling and use of pregerminated seed sown through the use of gels such as Laponite or Liquagel. However, fluid drilling has been found to be unable to improve establishment under stressful environmental conditions (Hassell and Kretchman 1987; Perkins-Veazie *et al.* 1987).

Seed priming treatments have been found to have an advantage over fluid drilling treatments. Seed priming allows the metabolic activity necessary to prepare seeds for germination to proceed but because the treatment restricts the amount of water available to the seed the final act of germination, protrusion of the radicle through the seed coat, is not completed. Through this manipulation of water availability, it is possible for those seed which would normally take longer to germinate to be able to catch up to the faster germinating seeds. In essence, during seed priming, all seeds get to the barrier which prevents germination. The time require to arrive at this barrier differs between individuals. Because of this effect, primed seeds are able to germinate in much less time than non-primed seeds (Haigh and Barlow 1987; Fujikura *et al.* 1993; Bradford 1995). This shorter time period will leave the seed exposed to environmental stresses for a shorter period. For some horticultural crops, this reduced time to seedling emergence can also lead to reduced inputs of irrigation. For revegetation projects, this may mean that primed seeds may be able to establish seedlings on shorter or lesser rainfall events than those required for non-primed seeds.

Seed priming treatments have been found to improve the rate (Haigh *et al.* 1987; Drew and Dearman 1993) and uniformity of seed germination (Szafirowska *et al.* 1981), as well as seed viability (Heydecker and Coolbear 1977) in a wide range of horticultural crop plants. Treatments have been reported to assist seeds in overcoming adverse conditions (Danneberger *et al.* 1992), such as increasing the percentage of normal seedlings from aged cauliflower seeds (Fujikura *et al.* 1993), or reducing the incidence of pre-emergent damping-off (Rush 1992). Primed seeds of many species can be redesiccated to allow for ease of storage and handling (Karssen *et al.* 1989).

Investigations into the priming of *Eucalyptus* seeds have been limited. Seed priming treatments of *Eucalyptus regnans* have been investigated at the University of Tasmania for their potential to improve nursery practices. Forestry nurseries establish plants through sowing multiple seeds into containers. These later require thinning of excess emerging seedlings. It was found that through the use of seed priming treatments it was possible to reduce the number of seeds sown per tube from five to two (Smith 1996).

2.2 Laboratory Studies of Priming Treatments

Seeds of the species: *Eucalyptus tereticornis*, *E. moluccana*, *E. fibrosa* and *E. sideroxylon* were treated with nine concentrations each of potassium nitrate (KNO₃) and Polyethylene glycol (PEG), molecular weight 6000. The osmotic potentials examined were 0 MPa, -0.25 MPa, -0.50 MPa, -0.75 MPa, -1.00 MPa, -1.25 MPa, -1.50 MPa, -1.75 MPa, -2.00 MPa. The solutions also contained Benlate (0.003 % w/v) to reduce fungal the possibility of fungal attack.

The concentrations of KNO₃ used were based on the following relationship between osmotic potential and freezing depression of known molal solutions (Weast 1968):

$$y \text{ MPa} = \frac{\Delta^{\circ}\text{C}}{1.86^{\circ}\text{C}} * 2.27 \text{ MPa} * \frac{^{\circ}\text{K}}{273^{\circ}\text{K}}$$

where $\Delta^{\circ}\text{C}$ is the freezing point depression of the compound in solution, $^{\circ}\text{K}$ is the temperature expressed in degrees Kelvin, and the constants for a 1 molal solution of 1.86 $^{\circ}\text{C}$ freezing point depression and -2.27 MPa osmotic potential at 0 $^{\circ}\text{C}$ were used. This relationship was graphed and molal concentration determined for the required osmotic potentials. The concentrations of PEG used were calculated from the Michel (1983) equation:

$$(\text{PEG}) = (4 - (5.16 \Psi T - 560\Psi + 16)^{0.5}) / (2.58T - 280)$$

where (PEG) is the required concentration (g / H₂O g) of polyethylene glycol, Ψ is the desired osmotic potential, and T is the temperature in $^{\circ}\text{C}$. Seeds were placed on filter paper in petri dishes containing 5 ml of solution at 20 $^{\circ}\text{C}$ with 12 hours of light each day. Three replicates were used for each treatment. Those concentrations which inhibited germination were identified through observations for radicle emergence made daily. These treatments were selected after no germination had been seen to start in a treatment for a period of three days. The seeds from the treatments which inhibited germination were rinsed with distilled water then air dried at room temperature.

The effectiveness of the seed priming treatments was evaluated by placing samples consisting of three replicates each of 50 seeds on filter paper wetted with 5 ml of

distilled water in petri dishes at 20°C with 12 hours of light each day. Radicle emergence was monitored daily until germination was complete.

A subsequent series of laboratory and greenhouse trials were undertaken. The species used were *E. albens*, *E. melliodora*, *E. moluccana*, *E. polyanthemos*, *E. sideroxylon*, and *E. tereticornis*. All seeds were primed under the same conditions: in -1.25 MPa PEG solutions in 10 L plastic containers lined with filter paper stored at 20°C with 12 hours of light per day for 7 days. The solution also contained 0.03% (w/v) thiram fungicide as the fungicide Benlate was no longer commercially available. The choice of this osmotic potential of the PEG solution was based on the results of the first laboratory trial. Following priming seeds were air dried at room temperature. The efficacy of this priming treatment was evaluated at a range of constant temperatures: 15, 20, 25 and 35°C and in seedling flats under ambient greenhouse conditions. At the constant temperatures, seeds were germinated in petri dishes containing 5 ml of water. Approximately 100 seeds were placed into each of four replicate dishes and germination was observed daily until complete. For the greenhouse trial, each replicate consisted of exactly 100 seeds sown into seedling flats containing media composed of sand, composted pine bark fines, and composted horticultural bark. Seedling emergence was observed daily for 31 days.

2.2.1 Results and Discussion

For all four species, either eight or nine treatments prevented seed germination (Table 1). There was a difference in effect of the two osmotica used, with the PEG treatments effectively preventing germination at higher osmotic potentials than those required to prevent germination in the KNO₃ solutions. Such differences between osmotica have been demonstrated for other species and were attributed to the uptake of the ions by the seeds placed in the salt solutions (Haigh *et al.* 1987).

With the PEG solutions, an osmotic potential of at least -1.00 MPa was required to inhibit germination in three of the eucalypt species, while a potential of -1.25 MPa was required for *E. sideroxylon*. The adoption of a single solution for use for a range

of *Eucalyptus* species would require the use of a solution with an osmotic potential of at least -1.25 MPa. An osmotic potential of -1.25 MPa was required for the KNO₃ solutions to prevent germination of *E. fibrosa* and *E. sideroxylon* seeds, while -1.50 MPa was needed for *E. tereticornis* and *E. moluccana*.

When the seeds which had been inhibited from germinating were later exposed to conditions suitable for germination, these seeds had a reduced time required for germination to begin (Figs 1-8). This advancement was evident for all species and for all priming treatments. All seeds from the priming treatments reached 50% germination at least one day ahead of seeds from the control treatments. *E. fibrosa* and *E. moluccana* reached this stage two days faster than did seed given the control treatments. However, there were marked differences in response to the two osmotica for the different species.

Table 1. *The osmotic potentials of solutions of KNO₃ or polyethylene glycol which inhibited Eucalyptus seeds from germinating at 20 °C. The duration of the priming treatment is also shown.*

Species	KNO ₃	Polyethylene glycol
(days)	(MPa)	(MPa)
<i>E. fibrosa</i>		-1.00
(8)	-1.25	-1.25
	-1.50	-1.50
	-1.75	-1.75
	-2.00	-2.00
<i>E. moluccana</i>		-1.00
(8)		-1.25
	-1.50	-1.50
	-1.75	-1.75
	-2.00	-2.00
<i>E. sideroxylon</i>	-1.25	-1.25
(9)	-1.50	-1.50
	-1.75	-1.75
	-2.00	-2.00
<i>E. tereticornis</i>		-1.00
(9)		-1.25

-1.50	-1.50
-1.75	-1.75
-2.00	-2.00

The maximum percentage germination achieved was markedly lower for the seeds primed in the KNO₃ solutions than for those primed in PEG solutions or for the control seeds. The maximum percentage germination can be considered a measure of the viability of the primed seeds. This reduction, where significant, could be considered a loss in viability. The final percentage germination of each of the control treatment seeds were: *E. tereticornis* 96 %; *E. moluccana* 88-94 %; *E. fibrosa* 96-98 %; and *E. sideroxylon* 94 %. Control treatments of *E. tereticornis* and *E. sideroxylon* had higher viabilities than did seeds primed with KNO₃ solutions. These latter reached only 70-74% and 78-82 %, respectively. Potassium nitrate treatments of *E. tereticornis* and *E. sideroxylon* also reduced viability in comparison to PEG treatments. PEG treatments, at the highest osmotic potential which prevented germination during pretreatment, did not significantly reduce the viability of any species.

Priming treatments accelerated seed germination in the laboratory. This finding agreed with the responses found for other species (Drew and Dearman 1993; Fujikura *et al.* 1993; Bradford 1995). For some species, increases have also been found in seed viability following priming treatments (Heydecker and Coolbear 1977). The seed priming treatments used in this investigation have resulted in a wide range of responses. Some treatments have increased the percentage of seeds germinating over that achieved by the untreated controls, whereas, other treatments have resulted in marked reductions in the final percentage of seeds to germinate. Suggestions that solutions of lower osmotic potential may adversely affect germination (Hardegree and Emmerich 1992) were supported by the poorer responses seen for some species when treated with KNO₃ solutions. This is in marked contrast with certain horticultural species, such as tomato and carrot, where KNO₃ solutions were found to give superior performance over PEG solutions (Haigh *et al.* 1987).

In these trials, we were able to demonstrate that seed priming using PEG solutions generally gave greater enhancement to germination of a range of *Eucalyptus* species than was achieved by the use of solutions of KNO_3 .

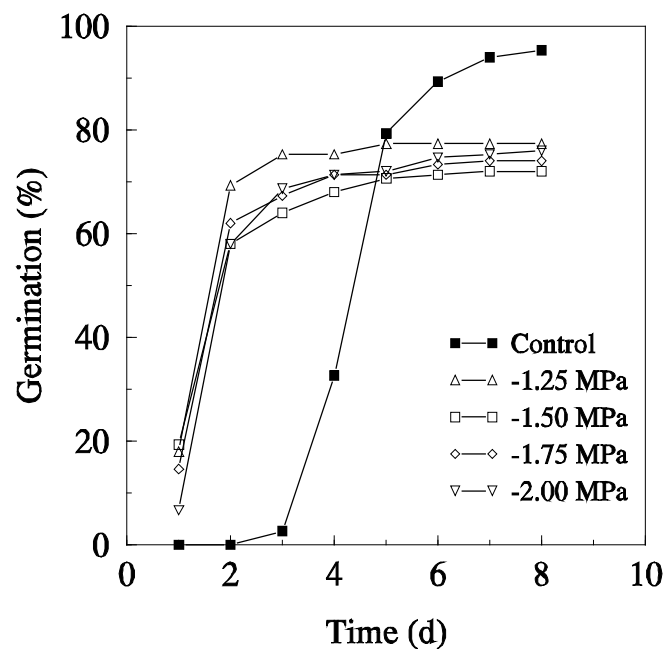


Figure 1. Germination of primed and non-primed (control) seeds of *Eucalyptus fibrosa* at 20°C under laboratory conditions. Seeds were primed at 20°C in solutions of KNO_3 then air dried at room temperature.

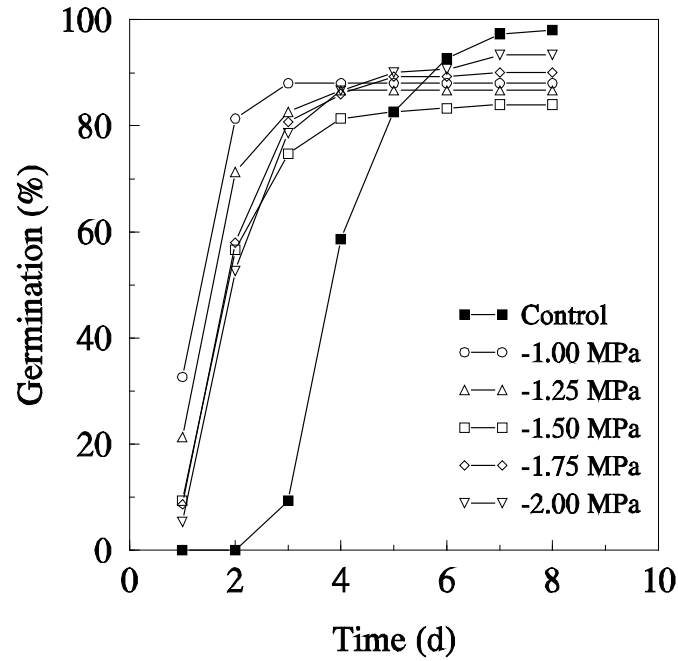


Figure 2. Germination of primed and non-primed (control) seeds of *Eucalyptus fibrosa* at 20°C under laboratory conditions. Seeds were primed at 20°C in solutions of polyethylene glycol then air dried at room temperature.

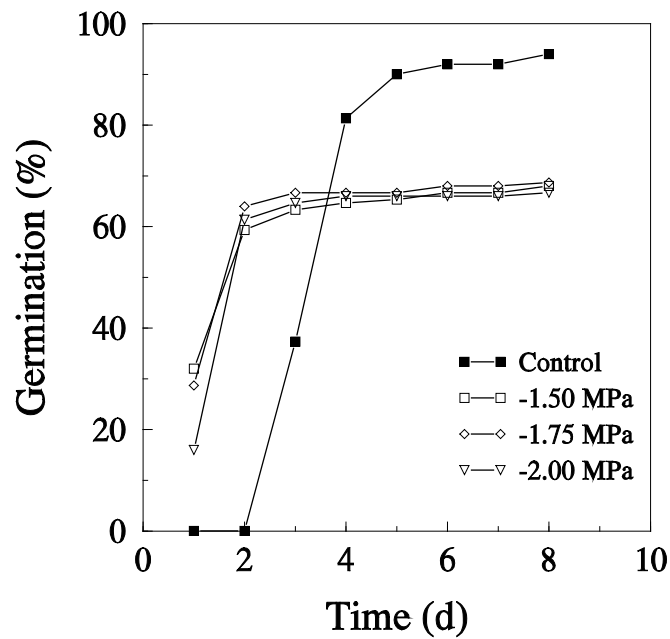


Figure 3. Germination of primed and non-primed (control) seeds of *Eucalyptus moluccana* at 20°C under laboratory conditions. Seeds were primed at 20°C in solutions of KNO₃ then air dried at room temperature.

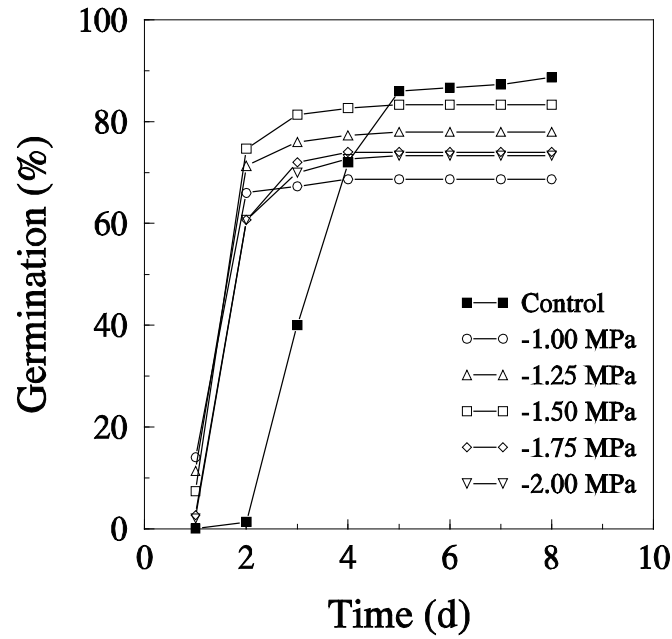


Figure 4. Germination of primed and non-primed (control) seeds of *Eucalyptus moluccana* at 20°C under laboratory conditions. Seeds were primed at 20°C in solutions of polyethylene glycol then air dried at room temperature.

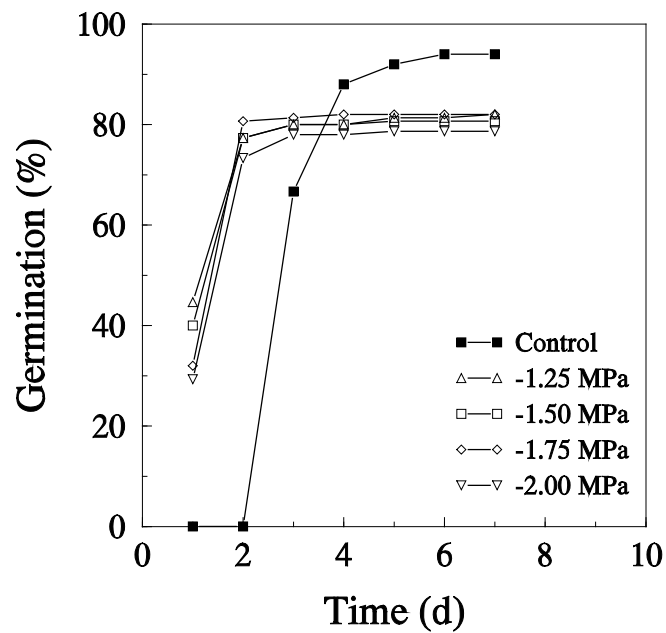


Figure 5. Germination of primed and non-primed (control) seeds of *Eucalyptus sideroxylon* at 20°C under laboratory conditions. Seeds were primed at 20°C in solutions of KNO_3 then air dried at room temperature.

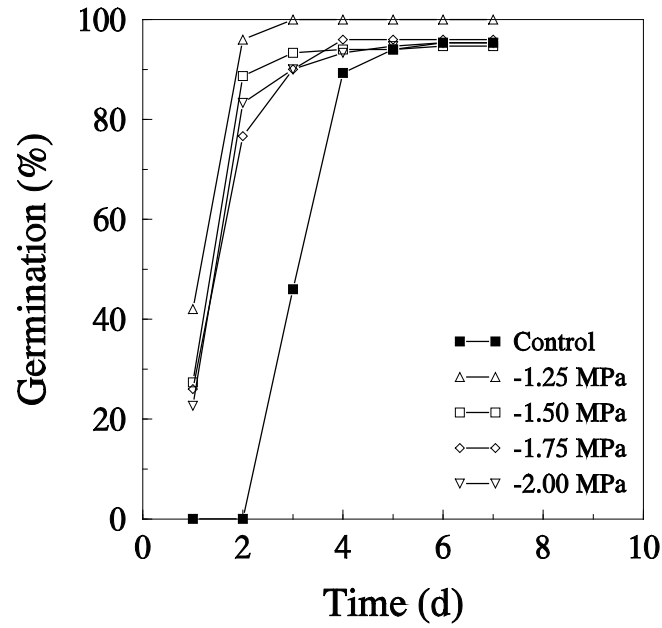


Figure 6. Germination of primed and non-primed (control) seeds of *Eucalyptus sideroxylon* at 20°C under laboratory conditions. Seeds were primed at 20°C in solutions of polyethylene glycol then air dried at room temperature.

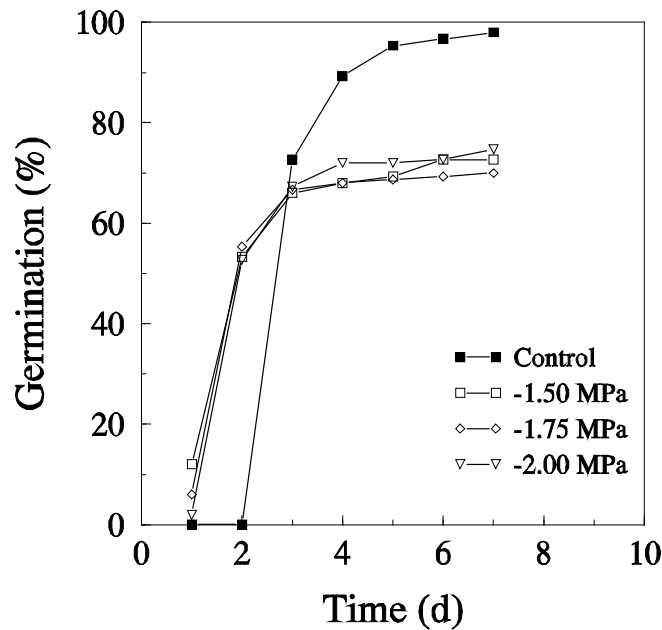


Figure 7. Germination of primed and non-primed (control) seeds of *Eucalyptus tereticornis* at 20°C under laboratory conditions. Seeds were primed at 20°C in solutions of KNO_3 then air dried at room temperature.

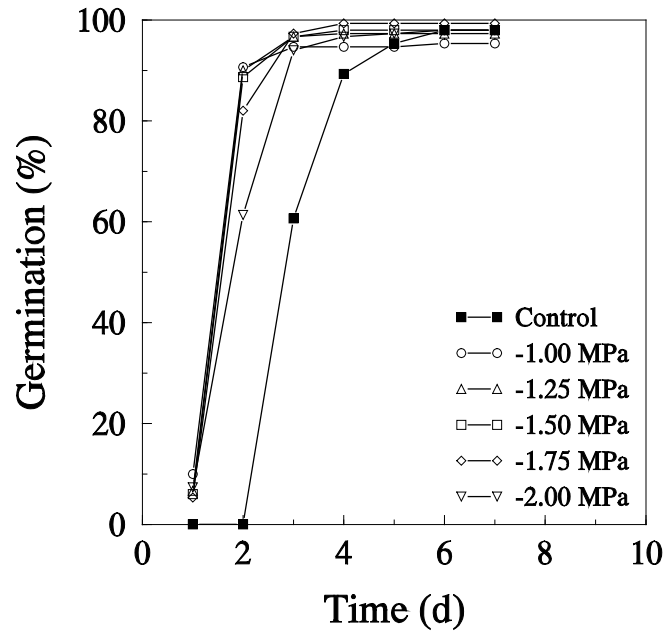


Figure 8. Germination of primed and non-primed (control) seeds of *Eucalyptus tereticornis* at 20°C under laboratory conditions. Seeds were primed at 20°C in solutions of polyethylene glycol then air dried at room temperature.

Following the success of the priming treatments evaluated in this first laboratory trial, the solutions shown to be optimum for priming under these conditions were used to prime seeds for use in field trials. These first field trials met with no success (see below). Subsequent to this, further laboratory and greenhouse evaluations of seed priming treatments were undertaken. For these trials, a single priming solution was used: -1.25 MPa PEG.

All six *Eucalyptus* species showed faster rates of germination due to priming. This advancement in the timing of germination was particularly evident at 15°C (Figs 9, 13, 17, 21, 25 and 29). The benefits to germination of seed priming appeared to decrease at higher germination temperatures (Figs 9 to 32). In only one case, *E. albens* germinated at 30°C, did priming result in a reduction in final percentage of germination (Fig 12). For all other species and all other conditions, priming did not affect the final percentage of germination attained. Clearly, priming *Eucalyptus* seeds can decrease the time required for germination to occur at the temperatures expected to be experienced in the field.

The greenhouse evaluation of the effects of a seed priming treatment gave markedly varied results when compared to the laboratory evaluation. The six species differed in their responses to seed priming. Priming was detrimental to the timing and to the final percentage of seedlings to emerge for *E. albens* (Fig 33). While it promoted earlier emergence of *E. melliodora* seeds, priming did not affect the final percentage attained (Fig 34). In contrast, priming promoted the earlier emergence and the attainment of higher final percentages for the other four species: *E. moluccana*, *E. polyanthemos*, *E. sideroxylon* and *E. tereticornis*.

Seed priming appears to offer considerable benefits to enhance the successful establishment of certain *Eucalyptus* species. Whether the benefits evident in the greenhouse can be translated to the field will be the subject of further experimentation. However, there are clear and readily apparent benefits of seed priming to the production of seedlings in the greenhouse. A similar finding has recently been made at the University of Tasmania (Smith pers. comm.)

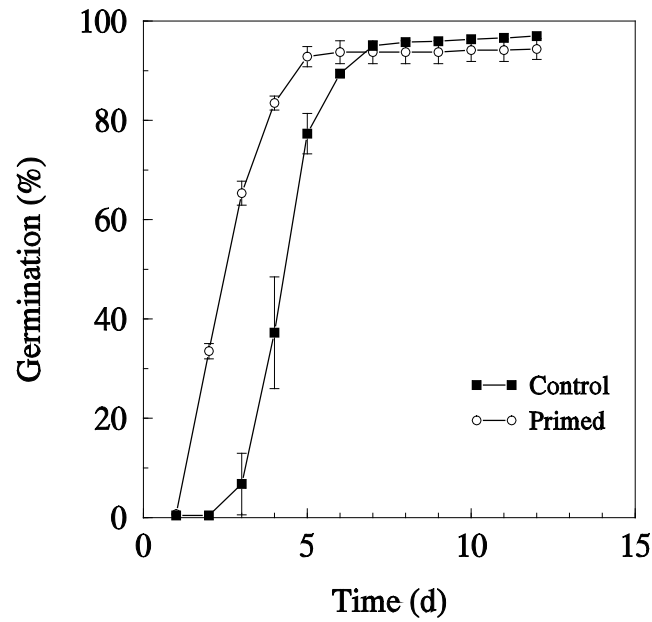


Figure 9. Germination of primed and non-primed (control) seeds of *Eucalyptus albens* at 15°C under laboratory conditions. Seeds were primed at 20°C in solutions of -1.25 MPa PEG then air dried at room temperature.

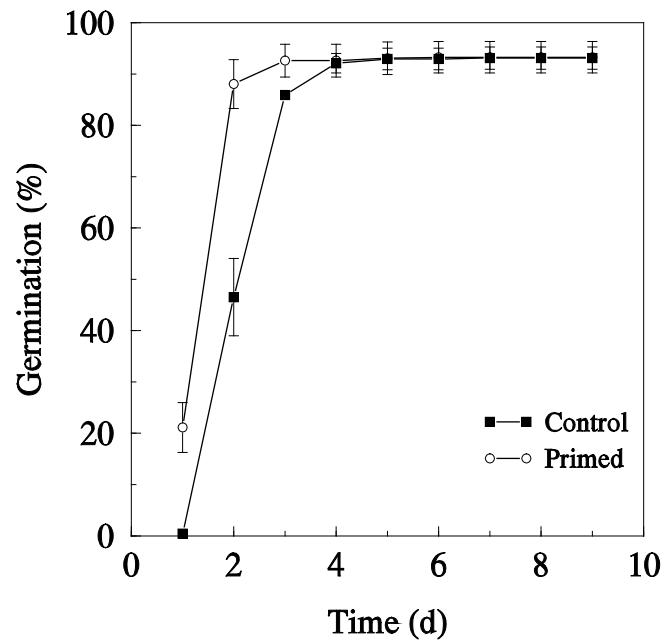


Figure 10. Germination of primed and non-primed (control) seeds of *Eucalyptus albens* at 20°C under laboratory conditions. Seeds were primed at 20°C in solutions of -1.25 MPa PEG then air dried at room temperature.

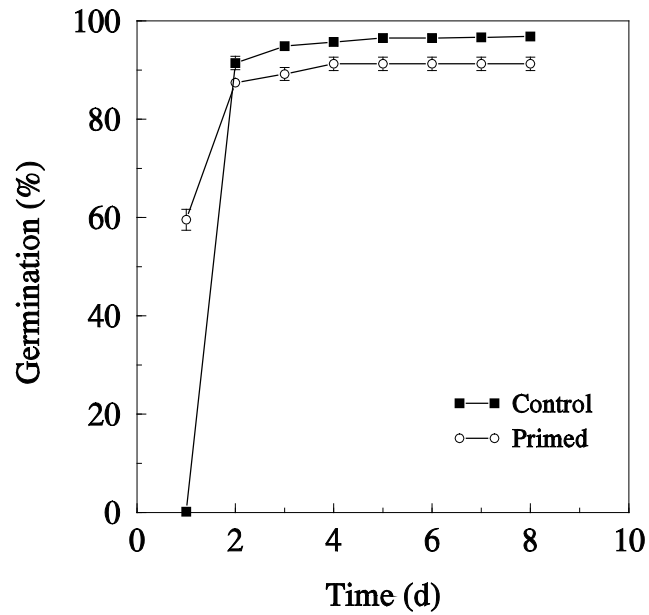


Figure 11. Germination of primed and non-primed (control) seeds of *Eucalyptus albens* at 25°C under laboratory conditions. Seeds were primed at 20°C in solutions of -1.25 MPa PEG then air dried at room temperature.

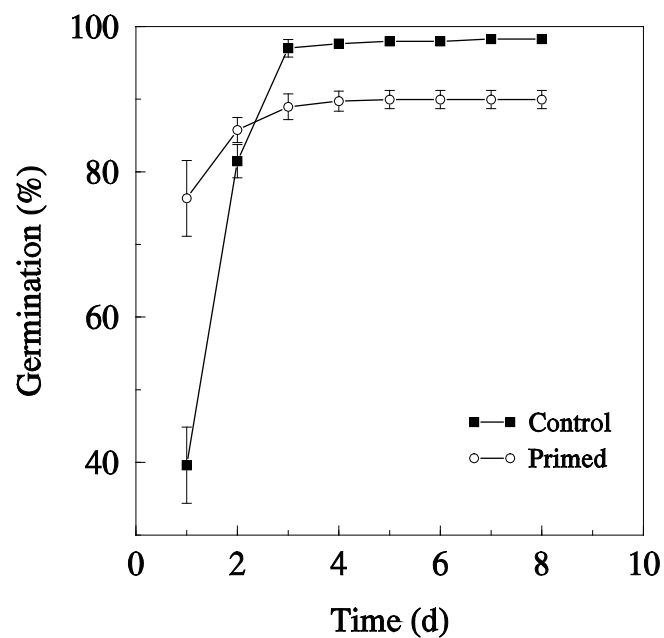


Figure 12. Germination of primed and non-primed (control) seeds of *Eucalyptus albens* at 30°C under laboratory conditions. Seeds were primed at 20°C in solutions of -1.25 MPa PEG then air dried at room temperature.

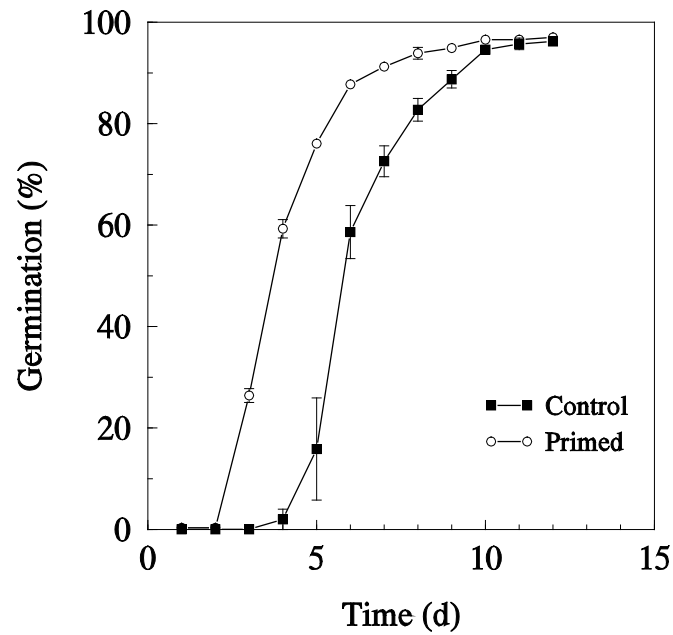


Figure 13. Germination of primed and non-primed (control) seeds of *Eucalyptus melliodora* at 15°C under laboratory conditions. Seeds were primed at 20°C in solutions of -1.25 MPa PEG then air dried at room temperature.

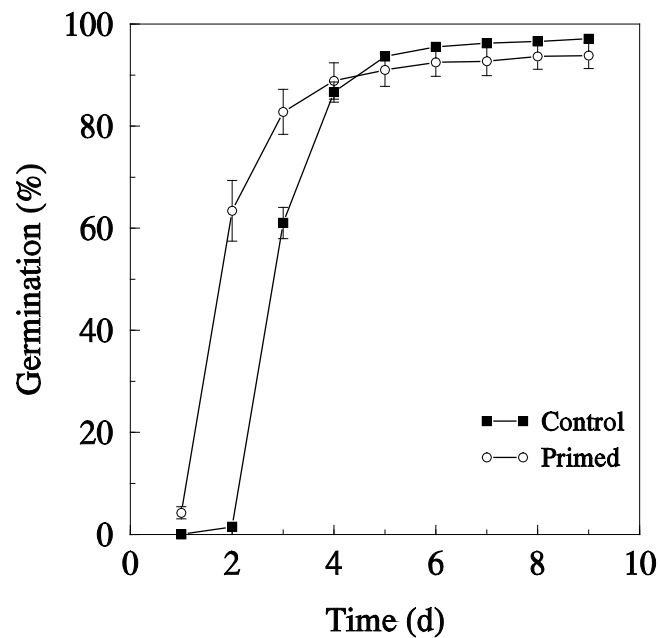


Figure 14. Germination of primed and non-primed (control) seeds of *Eucalyptus melliodora* at 20°C under laboratory conditions. Seeds were primed at 20°C in solutions of -1.25 MPa PEG then air dried at room temperature.

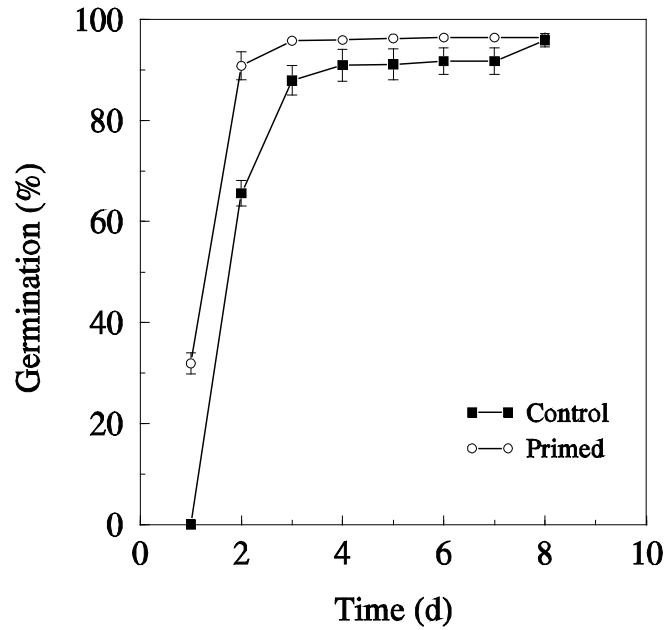


Figure 15. Germination of primed and non-primed (control) seeds of *Eucalyptus melliodora* at 25°C under laboratory conditions. Seeds were primed at 20°C in solutions of -1.25 MPa PEG then air dried at room temperature.

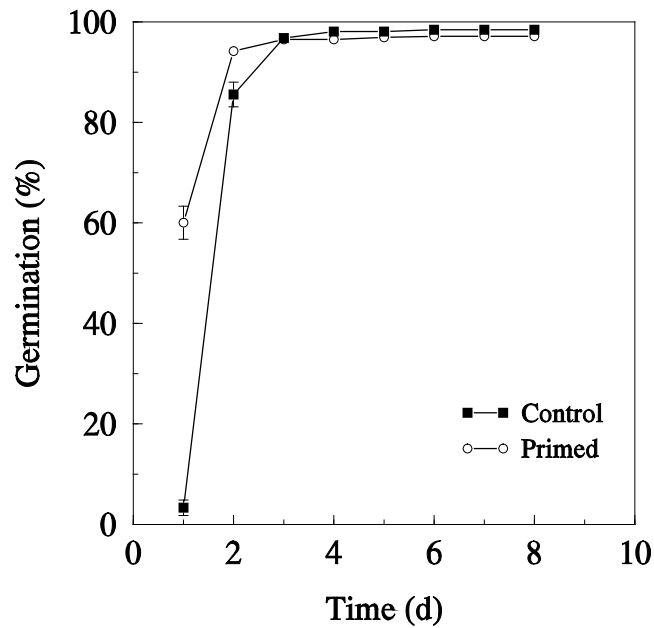


Figure 16. Germination of primed and non-primed (control) seeds of *Eucalyptus melliodora* at 30°C under laboratory conditions. Seeds were primed at 20°C in solutions of -1.25 MPa PEG then air dried at room temperature.

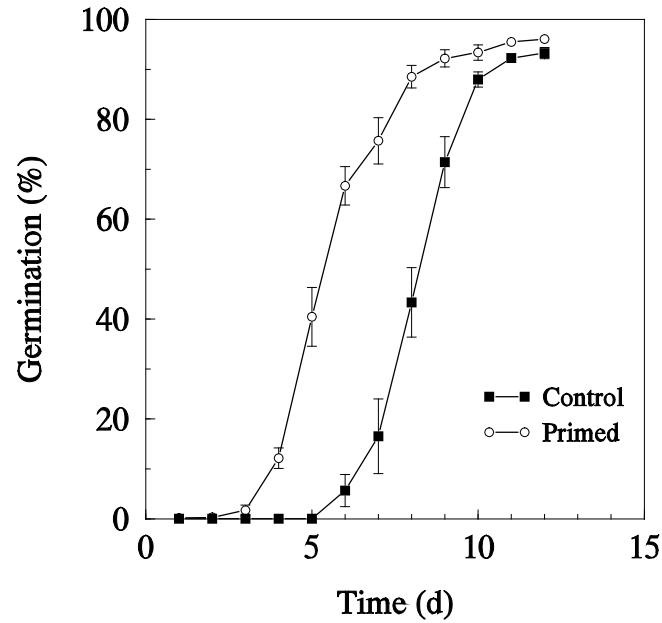


Figure 17. Germination of primed and non-primed (control) seeds of *Eucalyptus moluccana* at 15°C under laboratory conditions. Seeds were primed at 20°C in solutions of -1.25 MPa PEG then air dried at room temperature.

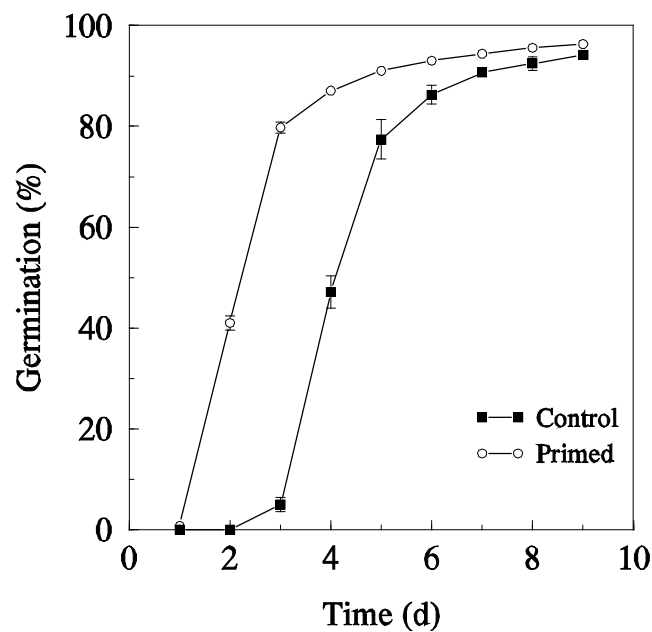


Figure 18. Germination of primed and non-primed (control) seeds of *Eucalyptus moluccana* at 20°C under laboratory conditions. Seeds were primed at 20°C in solutions of -1.25 MPa PEG then air dried at room temperature.

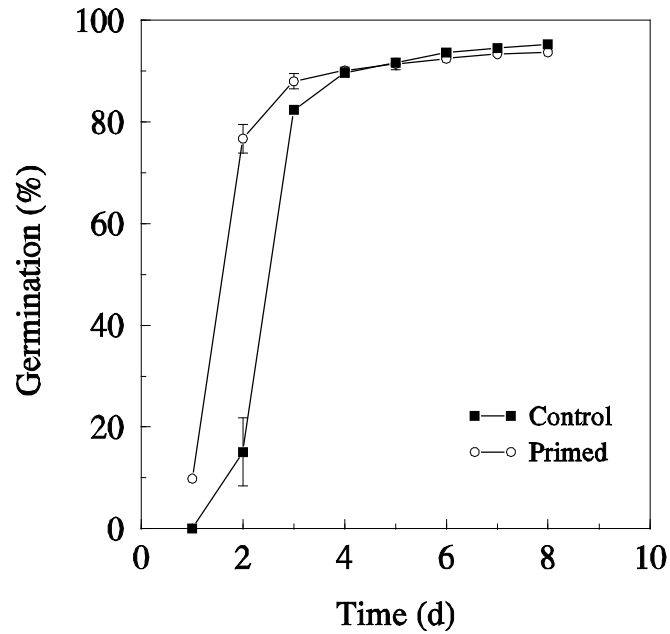


Figure 19. Germination of primed and non-primed (control) seeds of *Eucalyptus moluccana* at 25°C under laboratory conditions. Seeds were primed at 20°C in solutions of -1.25 MPa PEG then air dried at room temperature.

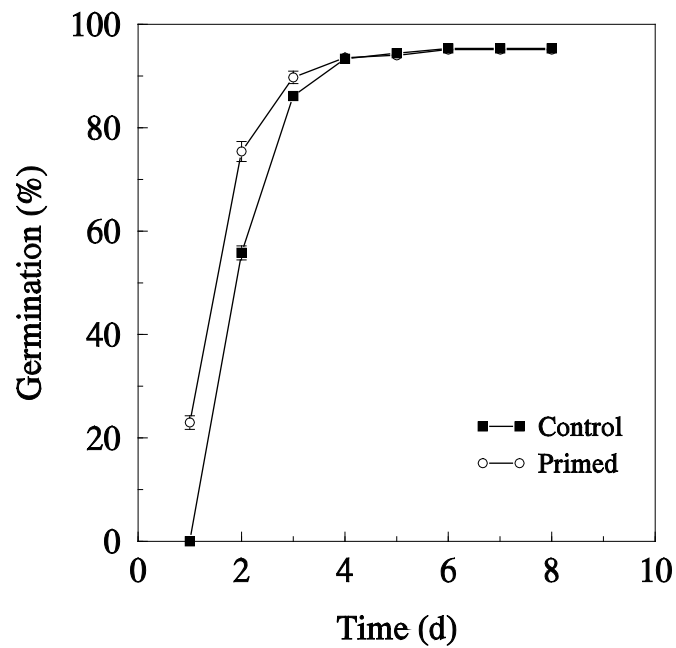


Figure 20. Germination of primed and non-primed (control) seeds of *Eucalyptus moluccana* at 30°C under laboratory conditions. Seeds were primed at 20°C in solutions of -1.25 MPa PEG then air dried at room temperature.

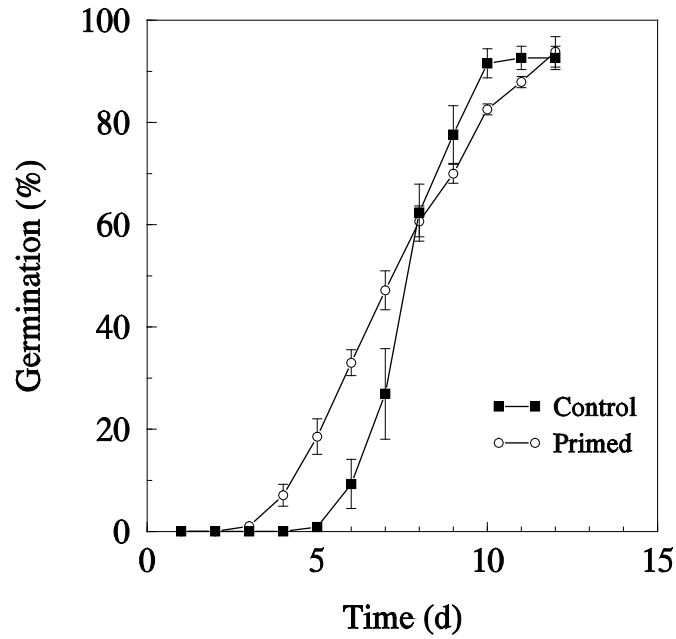


Figure 21. Germination of primed and non-primed (control) seeds of *Eucalyptus polythemos* at 15°C under laboratory conditions. Seeds were primed at 20°C in solutions of -1.25 MPa PEG then air dried at room temperature.

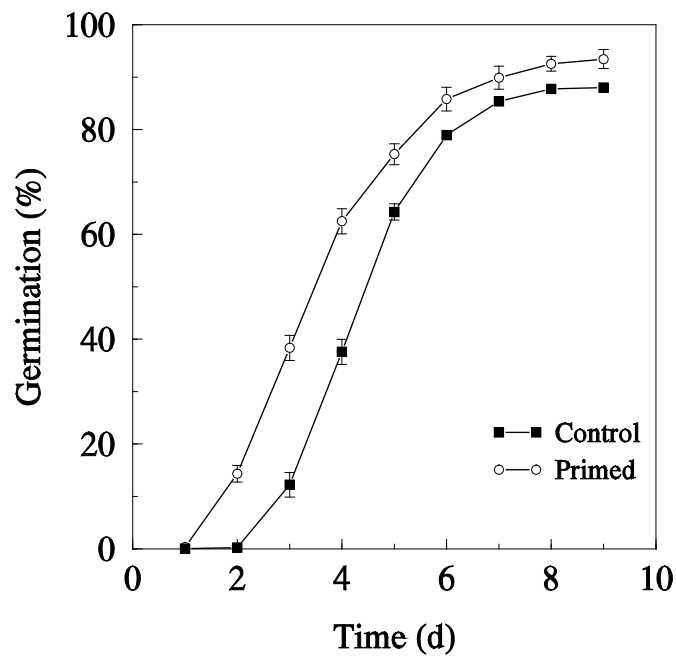


Figure 22. Germination of primed and non-primed (control) seeds of *Eucalyptus ploythemos* at 20°C under laboratory conditions. Seeds were primed at 20°C in solutions of -1.25 MPa PEG then air dried at room temperature.

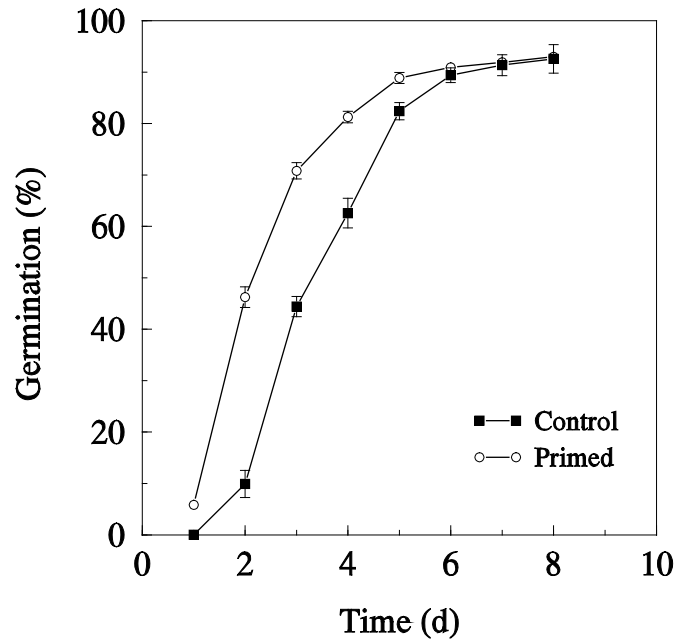


Figure 23. Germination of primed and non-primed (control) seeds of *Eucalyptus polythemos* at 25°C under laboratory conditions. Seeds were primed at 20°C in solutions of -1.25 MPa PEG then air dried at room temperature.

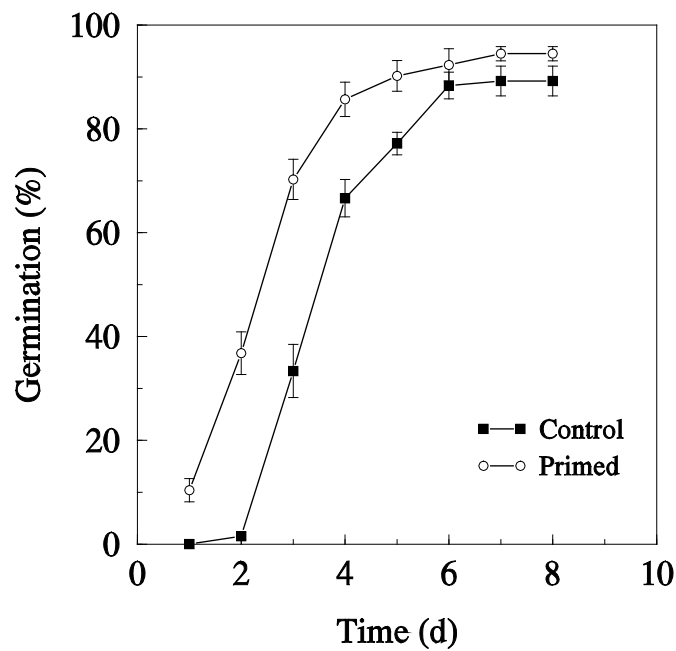


Figure 24. Germination of primed and non-primed (control) seeds of *Eucalyptus polythemos* at 30°C under laboratory conditions. Seeds were primed at 20°C in solutions of -1.25 MPa PEG then air dried at room temperature.

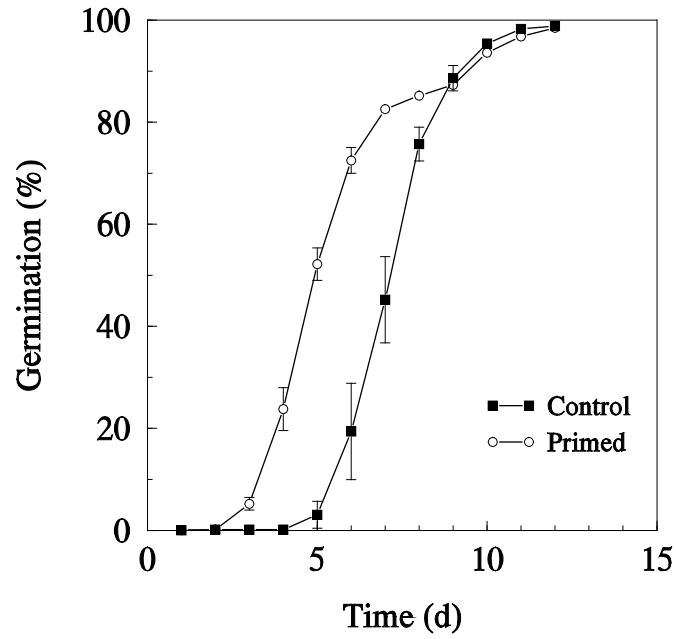


Figure 25. Germination of primed and non-primed (control) seeds of *Eucalyptus sideroxylon* at 15°C under laboratory conditions. Seeds were primed at 20°C in solutions of -1.25 MPa PEG then air dried at room temperature.

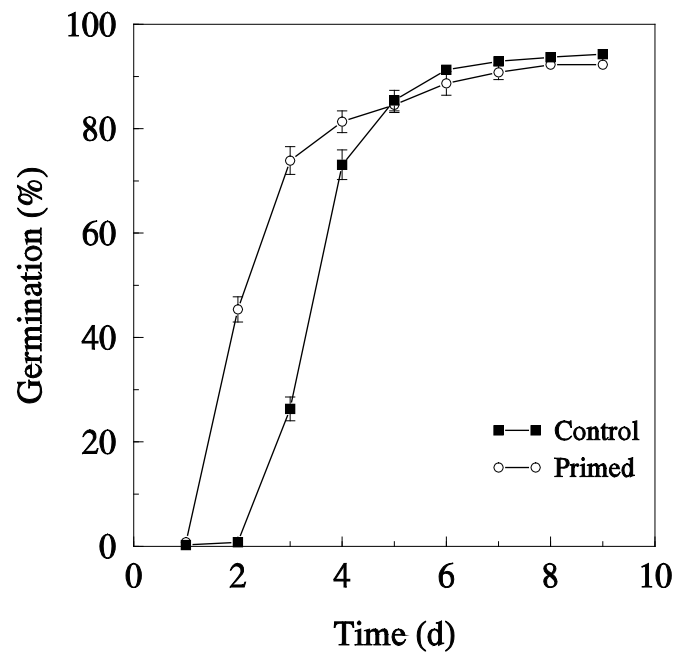


Figure 26. Germination of primed and non-primed (control) seeds of *Eucalyptus sideroxylon* at 20°C under laboratory conditions. Seeds were primed at 20°C in solutions of -1.25 MPa PEG then air dried at room temperature.

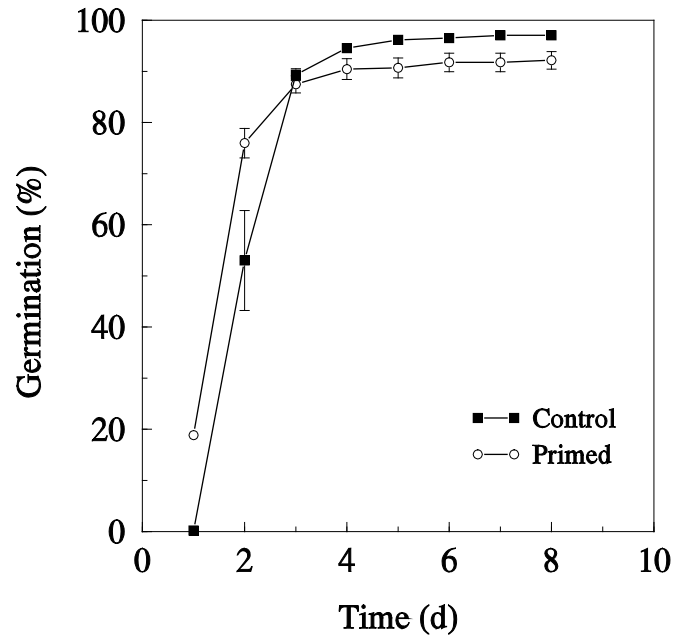


Figure 27. Germination of primed and non-primed (control) seeds of *Eucalyptus sideroxylon* at 25°C under laboratory conditions. Seeds were primed at 20°C in solutions of -1.25 MPa PEG then air dried at room temperature.

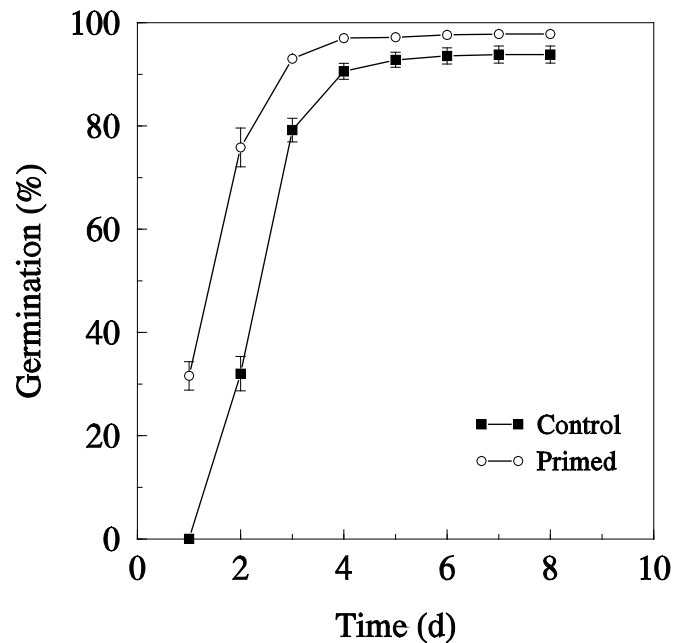


Figure 28. Germination of primed and non-primed (control) seeds of *Eucalyptus sideroxylon* at 30°C under laboratory conditions. Seeds were primed at 20°C in solutions of -1.25 MPa PEG then air dried at room temperature.

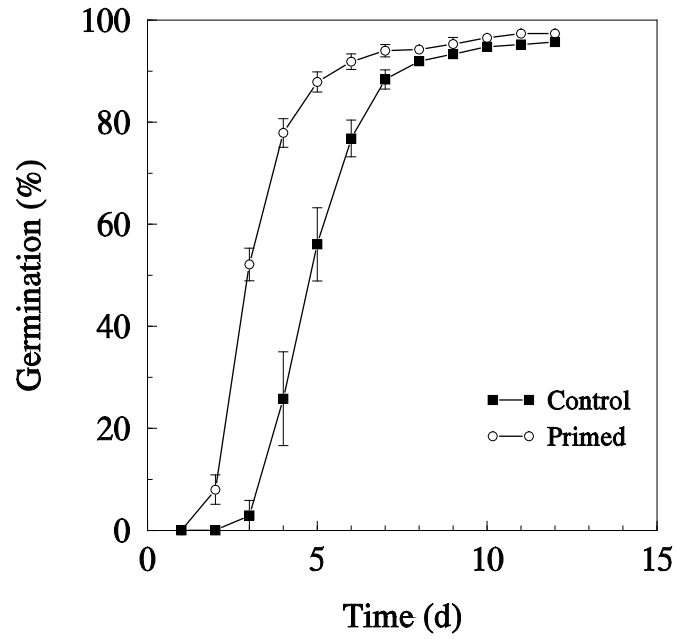


Figure 29. Germination of primed and non-primed (control) seeds of *Eucalyptus tereticornis* at 15°C under laboratory conditions. Seeds were primed at 20°C in solutions of -1.25 MPa PEG then air dried at room temperature.

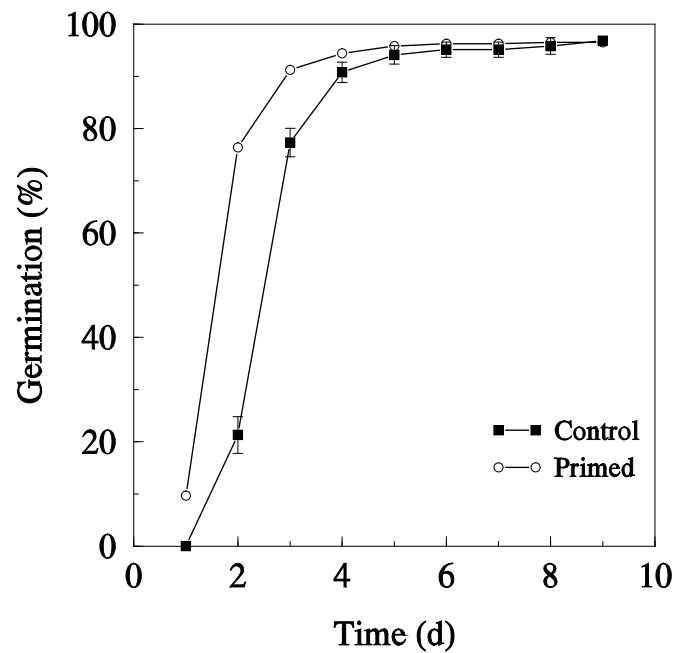


Figure 30. Germination of primed and non-primed (control) seeds of *Eucalyptus tereticornis* at 20°C under laboratory conditions. Seeds were primed at 20°C in solutions of -1.25 MPa PEG then air dried at room temperature.

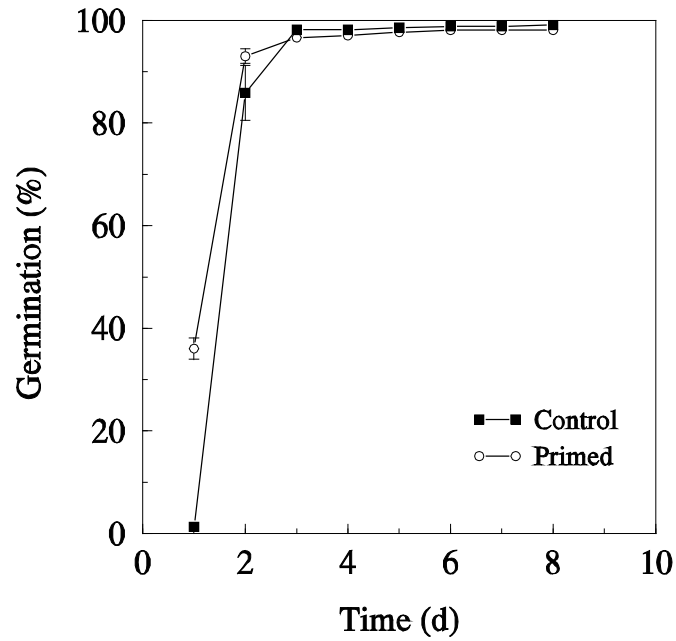


Figure 31. Germination of primed and non-primed (control) seeds of *Eucalyptus tereticornis* at 25°C under laboratory conditions. Seeds were primed at 20°C in solutions of -1.25 MPa PEG then air dried at room temperature.

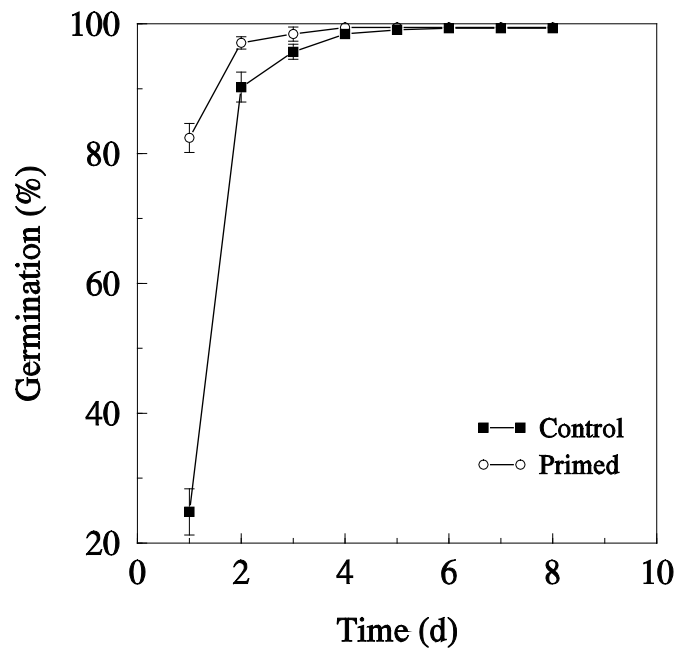


Figure 32. Germination of primed and non-primed (control) seeds of *Eucalyptus tereticornis* at 30°C under laboratory conditions. Seeds were primed at 20°C in solutions of -1.25 MPa PEG then air dried at room temperature.

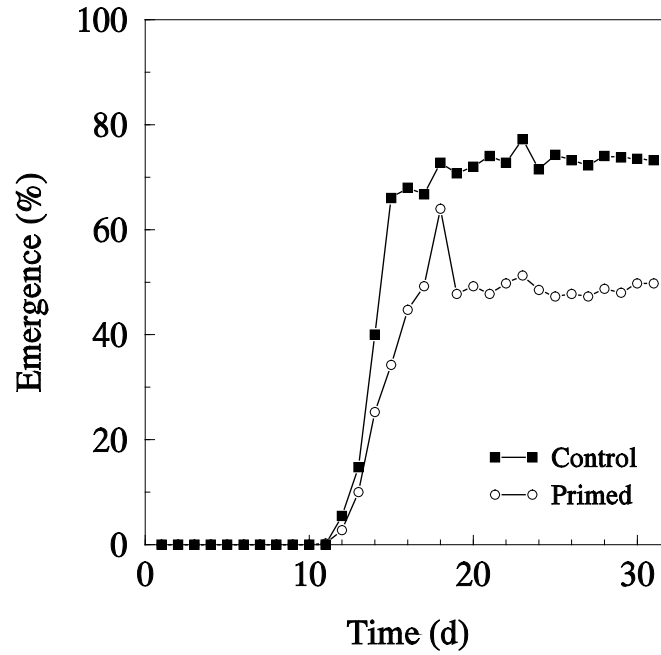


Figure 33. Emergence of seedlings of primed and non-primed (control) seeds of *Eucalyptus albens* under greenhouse conditions. Seeds were primed at 20°C in solutions of -1.25 MPa PEG then air dried at room temperature.

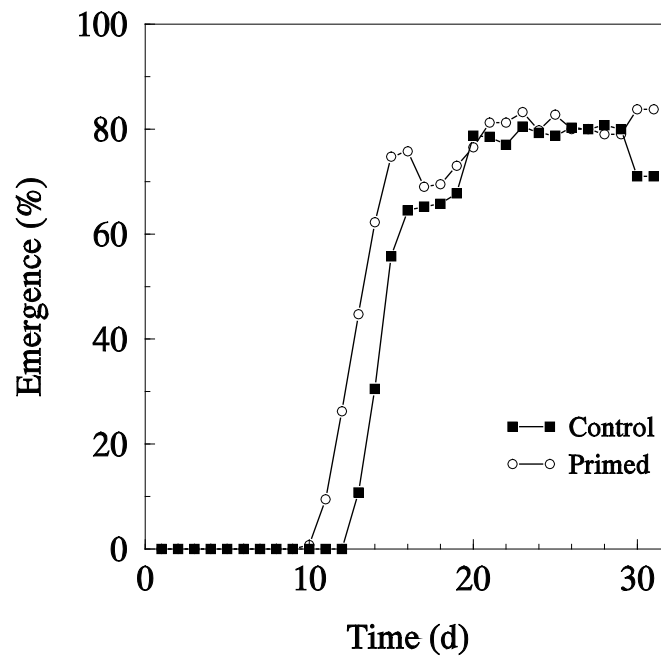


Figure 34. Emergence of seedlings of primed and non-primed (control) seeds of *Eucalyptus melliodora* under greenhouse conditions. Seeds were primed at 20°C in solutions of -1.25 MPa PEG then air dried at room temperature.

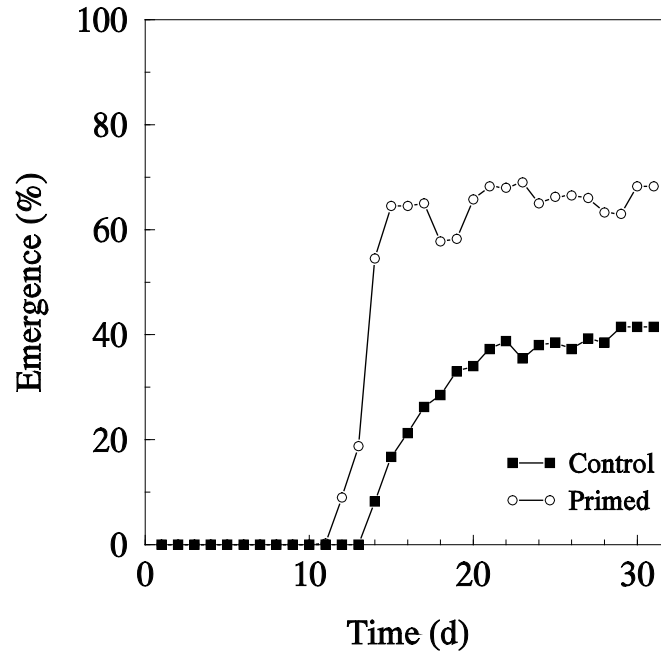


Figure 35. Emergence of seedlings of primed and non-primed (control) seeds of *Eucalyptus moluccana* under greenhouse conditions. Seeds were primed at 20°C in solutions of -1.25 MPa PEG then air dried at room temperature.

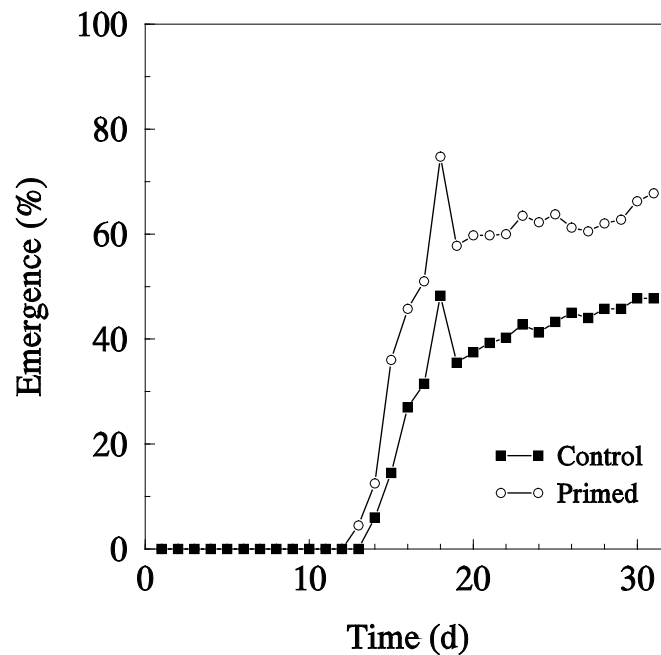


Figure 36. Emergence of seedlings of primed and non-primed (control) seeds of *Eucalyptus polyanthemos* under greenhouse conditions. Seeds were primed at 20°C in solutions of -1.25 MPa PEG then air dried at room temperature.

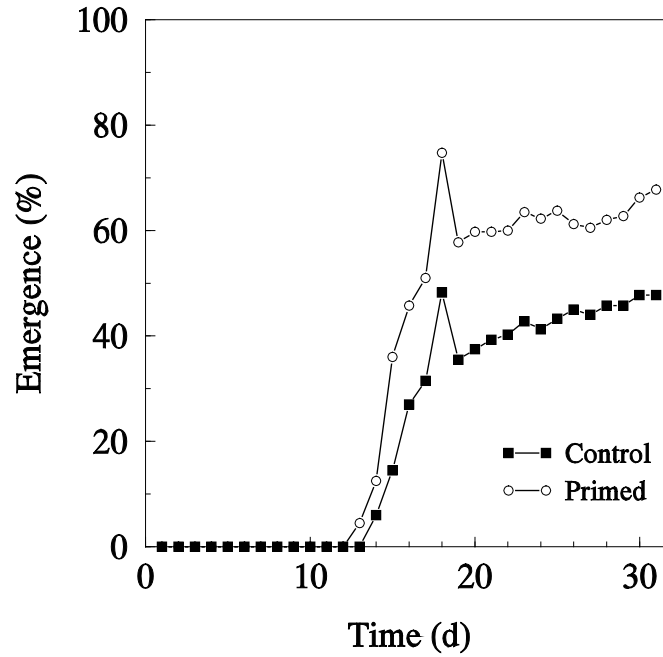


Figure 37. Emergence of seedlings of primed and non-primed (control) seeds of *Eucalyptus sideroxylon* under greenhouse conditions. Seeds were primed at 20°C in solutions of -1.25 MPa PEG then air dried at room temperature.

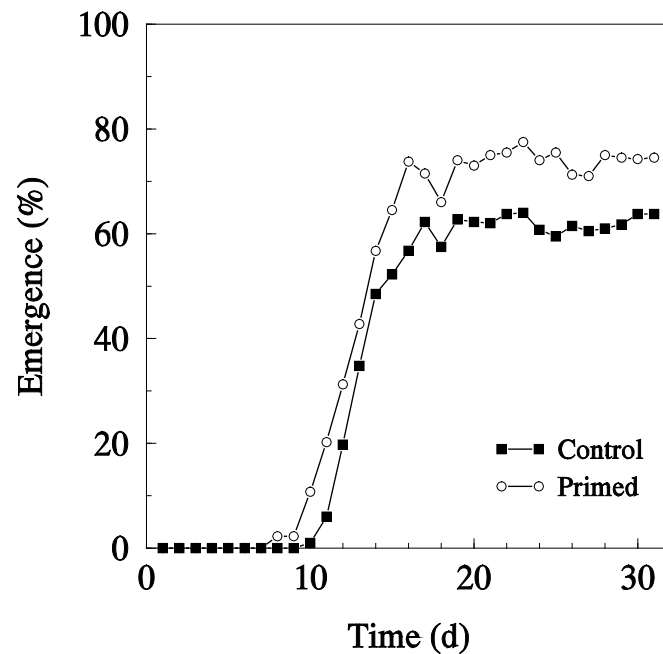


Figure 38. Emergence of seedlings of primed and non-primed (control) seeds of *Eucalyptus tereticornis* under greenhouse conditions. Seeds were primed at 20°C in solutions of -1.25 MPa PEG then air dried at room temperature.

2.3 Conclusions

We have been able to clearly demonstrate that seed priming using solutions of polyethylene glycol with an osmotic potential of about -1.25 MPa is an effective methods of improving germination of the seeds of some species of *Eucalyptus*. Unlike seeds of vegetable crops solutions of KNO₃ did not prove to be as effective as PEG solutions for *Eucalyptus*.

We have also demonstrated that the use of primed *Eucalyptus* seeds can result in higher percentages of seedlings establishing in the greenhouse for some species. This finding will be of benefit to seedling producers.

We shall investigate the efficacy of seed priming for the enhancement of direct seeded *Eucalyptus* in a series of field trials to be reported in the next chapter.

3. FIELD EVALUATION OF PRIMING TREATMENTS

3.1 Field Trials

Direct seeding trials using a Rodden 111 were undertaken at sites along the southern side of the M4 motorway in western Sydney in June 1994 and on the northern side of the motorway in October 1994. These sites were west of Kent Road. Additional direct seeding operations were undertaken on the Richmond campus of the University of Western Sydney, Hawkesbury in June and October 1994. The priming treatments used were those that required the lowest concentrations of PEG. Seeds were primed in bulk using 10 litre plastic containers. The bases of the containers were lined with sheets of filter paper and the seeds were primed using the following treatments:

<i>Eucalyptus fibrosa</i>	-1.00 MPa PEG, primed for eight days;
<i>Eucalyptus moluccana</i>	-1.00 MPa PEG primed for eight days;
<i>Eucalyptus sideroxylon</i>	-1.25 MPa PEG, primed for nine days;
<i>Eucalyptus tereticornis</i>	-1.00 MPa PEG, primed for nine days.

The locations of the sites and the actual sowing dates used were:

- Site 1 Southern side of M4, west of Kent Rd, sown 1/6/94;
- Site 2 University of Western Sydney, Richmond, sown 9/6/94;
- Site 3 University of Western Sydney, Richmond, sown 13/10/94;
- Site 4 Northern side of M4, west of Kent Rd, sown 25/10/94.

The M4 sites were prepared with a 2 metre wide scalping of the site by grader. This resulted in the removal of weeds and grasses and initial weed control, but some loss of topsoil. At the University sites, 2 metre widths were sprayed with glyphosate herbicide for initial weed control, and vegetation slashed around the rows.

At all locations seeds were sown using a Roden 111 direct seeding machine to sow primed and non-primed seeds through the hopper designed for fine seed. Seeded sites were also mulched or not with 225 Curak. All seed lots were dusted with permethrin (Coopex) to reduce the potential impact of seed predation by ants. Each replicate consisted of a ten metre plot of the particular seed and mulch treatment combination. Four replicate plots were used for each treatment at each site.

The Roden 111 direct seeding machine has a series of setting used to control the rate of seed delivery to the soil. The setting, recommended for *Eucalyptus* (2) was used for the sites sown in June. Observation of the quantity of seed being sown at this setting led to a change in the setting to increase the sowing rate during the October sowings. At this later time, the Roden 111 settings used were as follows: for the species *E. tereticornis*, *E. moluccana* and *E. sideroxylon* a setting of 5 was used, and for *E. fibrosa* (due to a lower seed weight) a setting of 9 was used.

3.1.1 Results and Discussion

Sites 1 and 2 sown in June 1994

These sites were initially monitored fortnightly. No occurrences of emergence of any *Eucalyptus* seedlings were noted during the winter months. Three *E. moluccana* seedlings, in both primed and non-primed treatments were observed in September 1994. These seedlings had disappeared by December 1994.

Sites 3 and 4 sown in October 1994

No emergence of any *Eucalyptus* seedlings was observed during October, November or by mid December. During this period low rainfall conditions were prevalent. In late December 1994 and early January 1995, rainfall coincided with temperatures of 25°C and above. This encouraged rapid weed growth at all field sites, particularly Site 4. Though this created difficulties in closely monitoring emergence of *Eucalyptus* seedlings, it was apparent that establishment of *Eucalyptus* seedlings was unsuccessful at all sites.

The Roden 111 may prove to be an effective method of direct seeding for revegetation purposes in certain locations. However, it has proved to be unsuitable at the sites where our field trials were conducted. All subsequent field trials were sown by hand with precisely measured numbers or weights of seeds used for each treatment. These sowing methods provided the accuracy necessary to assess the performance of the various treatments. The inconclusive nature of the field trials, due to both drought and weed competition factors, indicated that future trials needed to be undertaken with irrigation facilities and in a manner where weed competition may be reduced.

3.2 Effect of Irrigation on Establishment

Treatments identified as advancing seed germination under laboratory conditions were selected for assessment of seedling establishment under field conditions. Selection of priming treatments were on the basis that where no statistical difference was found between the efficacy of KNO₃ and PEG solutions, the treatment utilising the lower cost KNO₃ salt was chosen. Seeds were primed in bulk using 10 litre plastic container. The base of the container was lined with filter paper and the seeds were primed using the following treatments:

Eucalyptus fibrosa -1.25 MPa KNO₃ primed for eight days;

Eucalyptus moluccana -1.50 MPa KNO₃ primed for eight days;

<i>Eucalyptus sideroxylon</i>	-1.25 MPa PEG primed for nine days;
<i>Eucalyptus tereticornis</i>	-1.00 MPa PEG primed for nine days.

An autumn field trial, established in March 1995, involved sample sizes of two hundred seeds per replicate. Five replicates were used per treatment. The seeds were hand sown into weed free, cultivated rows of a sandy loam soil at about 5 mm depth. The field experiment included an irrigation treatment, in which half of the plots were irrigated to field capacity weekly using mini-sprinklers. The irrigation treatment was included to evaluate the role of soil moisture content on the success of seed germination and seedling establishment. Weed competition was reduced throughout the trial by means of regular hand weeding.

Sensory equipment, positioned in the irrigated and non-irrigated treatments, was used to monitor continuously soil suction at depths of 2.5 cm, 10 cm and 20 cm. Seedling emergence was observed weekly for 8 weeks, then survivorship of these seedlings was monitored every 4 weeks for a further 20 weeks.

3.2.1 Results and Discussion

Irrigation significantly increased emergence of all four species. The irrigated treatment resulted in *E. moluccana*, *E. sideroxylon* and *E. tereticornis* having at least 30% higher establishment than did the non-irrigated treatment (Figs 40 to 42). *Eucalyptus fibrosa* had 20% higher establishment in the irrigated treatment than in the non-irrigated control treatment (Fig 39). In the plots given the irrigation treatment, seedlings of *E. tereticornis*, *E. fibrosa* and *E. sideroxylon* were first visible two weeks after sowing, and further establishment occurred in the third week. The highest levels of establishment were achieved in weeks 5 to 6: *E. tereticornis* 48 %; *E. moluccana* 38 %; *E. fibrosa* 28 %; and *E. sideroxylon* 36.5 %. Seedling emergence of *E. tereticornis*, *E. fibrosa* and *E. sideroxylon* in non-irrigated plots, was not observed until six weeks after sowing. The highest levels of seedling emergence for the non-irrigated plots were achieved by week 12: *E. tereticornis* 10.5 %; *E. moluccana* 11.4 %; *E. fibrosa* 0.9 %; and *E. sideroxylon* 7.5%. However, for all treatments there were some losses of seedlings as the experiment progressed. These losses were similar for seedling established with and without irrigation.

Seed priming significantly increased the emergence of *E. tereticornis* seeds, but significantly reduced emergence of *E. fibrosa* and *E. moluccana* seeds while it did not affect the emergence of *E. sideroxylon* seeds. The species differed in their capacities to establish successfully in the field even when maintained at high water availability. Without irrigation, there were still small but significant effects of seed priming. The use of KNO_3 priming solutions may have reduced the success of establishment.

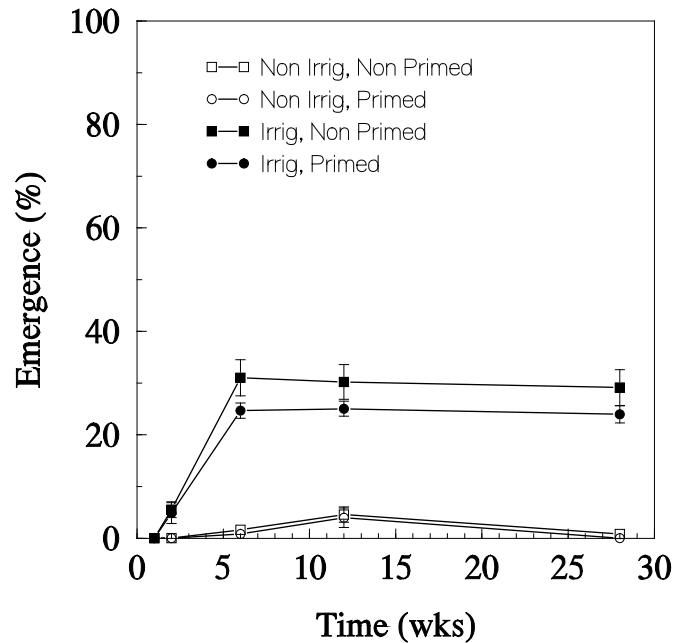


Figure 39. Field emergence of primed and non-primed (control) seedlings of *Eucalyptus fibrosa* under irrigation or natural rainfall conditions at the Richmond campus of UWSH.

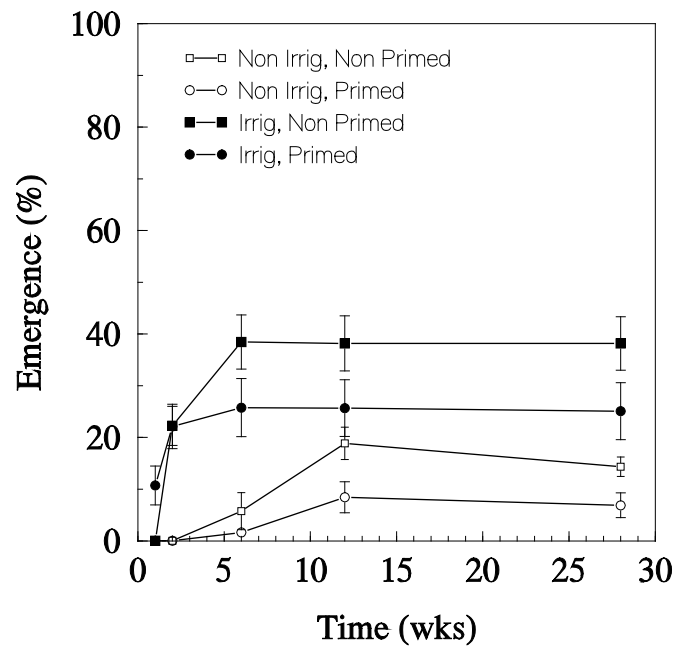


Figure 40. Field emergence of primed and non-primed (control) seedlings of *Eucalyptus moluccana* under irrigation or natural rainfall conditions at the Richmond campus of UWSH.

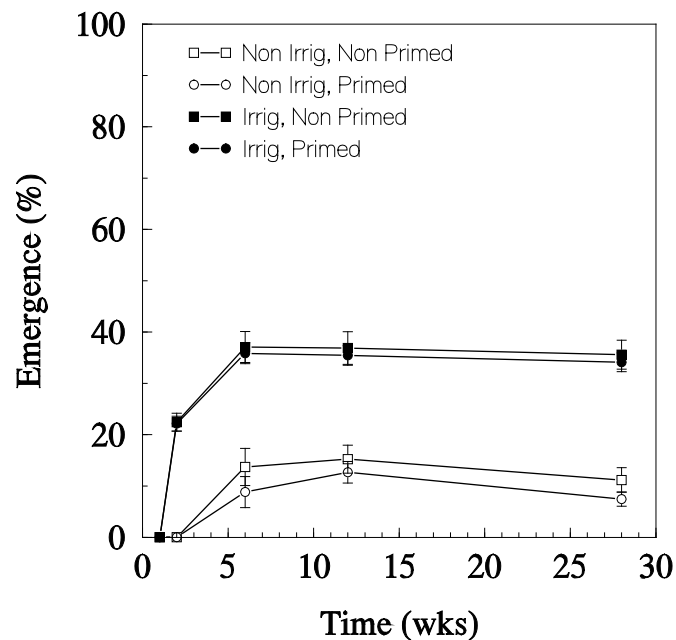


Figure 41. Field emergence of primed and non-primed (control) seedlings of *Eucalyptus sideroxylon* under irrigation or natural rainfall conditions at the Richmond campus of UWSH.

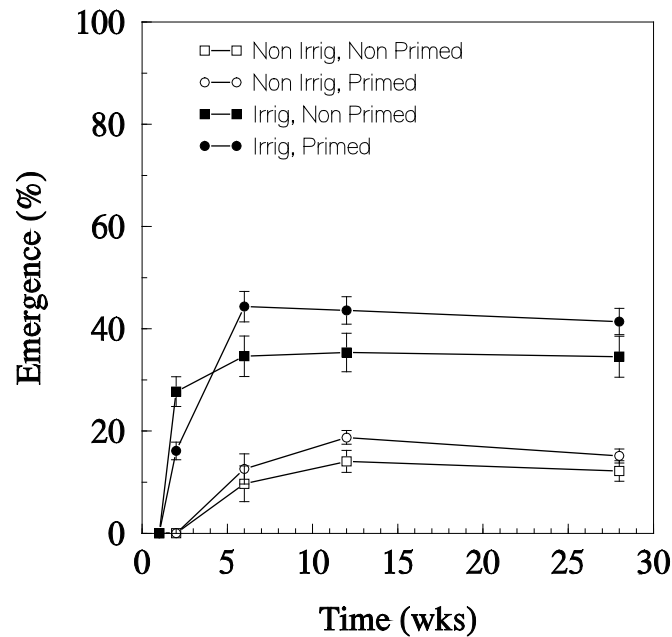


Figure 42. Field emergence of primed and non-primed (control) seedlings of *Eucalyptus tereticornis* under irrigation or natural rainfall conditions at the Richmond campus of UWSH.

Monitoring of soil moisture levels at 2.5 cm showed that there were considerable fluctuations in soil suction (Fig 43). Smaller fluctuations occurred in the irrigated plots than in the non-irrigated plots. These latter ones experienced soil suctions in excess of 600 KPa at times. At greater depths, the fluctuations in soil suction disappeared in the irrigated plots, but were still evident in the non-irrigated plots (Figs 44 and 45). Throughout the period of observation, the non-irrigated plots always had higher soil suctions than did the irrigated plots. Significant rainfall events were reflected in changes in the soil suction levels at 2.5 cm. These occurred in weeks three, six, sixteen, nineteen, twenty-three, twenty-five and twenty-six. Rainfall had less influence over soil suction levels at the greater depths. Even with these events, soil suction levels reached between 700-800 KPa at all monitored soil depths, during weeks twenty-three and twenty-five.

Indications of the soil moisture requirements for successful establishment can be found by examining the seedling emergence patterns over time. Irrigation greatly improved the success of seedling emergence in comparison with the low levels of seedling emergence observed for the plots which experienced only natural rainfall.

Eucalyptus tereticornis, *E. moluccana* and *E. sideroxylon* in the irrigated plots had more than 30% higher establishment than the non-irrigated treatment, while *E. fibrosa* had 20% higher emergence. The lower level of establishment of *E. fibrosa* was not reflective of an initially lower seed viability. This species had similar germination characteristics to the other species when examined under laboratory conditions. Clearly this species may have been less well adapted to the soil type and moisture regime experienced in this location.

The dramatic response to water availability observed in this trial agrees with the recognition of the significance of water to seedling establishment given by other workers (Roberts 1984; Biniek 1994). Under both watering treatments, seedlings were observed to emerge approximately two weeks after soil moisture content increased towards field capacity. For seeds sown in the irrigated treatments, with average soil suctions of approximately 50 KPa, seedling emergence occurred during week two. During week three, in the non-irrigated treatments, a soil suction of 300 KPa was reduced to approximately 100 KPa. For these treatments, seedling emergence started in week five and six. Lower levels of water availability at shallower depths were reflected in the higher soil suction readings. Less available water may have prevented higher numbers of seedlings establishing. However, with a subsequent rainfall in week five, there was only a small increase in establishment levels in non-irrigated plots. Other factors may have intervened by this time to reduce the potential emergence.

Between weeks six and sixteen, there was no rainfall to reduce soil suctions in the non-irrigated treatments. Even when rain periods occurred at later dates, no further establishment was seen. Soil temperatures suitable for germination and similar to those at the beginning of the trial, occurred in weeks twenty-three and twenty-five. This lack of any subsequent emergence suggests that the soil no longer contained any viable seeds. Factors which may have contributed to this may include reduced seed viability, or losses of seed to pests and diseases.

After an initial period of seedling emergence, there were comparable losses in numbers of seedlings for both the irrigated and non-irrigated plots. This generally occurred between week twelve and twenty-four, during the colder weeks. During this

period there was little rainfall, and soil suction in the non-irrigated plots increased greatly. In the irrigated plots, soil suction levels were kept below 100 KPa. As similar losses occurred in both treatments, it would appear that they were associated with the low soil temperature conditions rather than be directly associated with water stress.

Further investigations need to be undertaken to understand the specific water requirements which promote and maintain the highest levels of establishment of these seedlings. This knowledge would assist in ensuring the provision of optimum conditions, prior to detrimental factors reducing the level of viable seed within the soil environment. With this understanding, there may be the hope of achieving the goal of direct seeding *Eucalyptus* with consistently high levels of successful establishment.

3.3 Effect of Irrigation Frequencies on Establishment

The frequency and amount of irrigation determines the availability of soil moisture for a seed or seedling. Too frequent and too large an amount of irrigation will lead to water logging and eventual death of the plant. Too infrequent and too small an amount of irrigation will lead to drought stress and eventual death of the plant. Determining the amount of water required to be applied at each irrigation and the frequency of irrigation is in many ways site and season specific. However, it can be reasoned that any plant, other than an aquatic one, will have an optimum period of time at which it can tolerate soil moisture at field capacity and also a maximum period of time which it can survive between irrigations. For tree species, this period of time between irrigations is generally much larger than for annual species not adapted to drought.

3.3.1 Materials and Methods

Approximately 100 seeds (by weight) of six *Eucalyptus* species: *E. albens*, *E. melliodora*, *E. moluccana*, *E. polyanthemos*, *E. sideroxylon* and *E. tereticornis* were hand sown into 2 m plots randomly arranged in rows of 192 m length in a field at the Richmond campus of University of Western Sydney, Hawkesbury on 1 November 1995. There were 16 replicates of each species in each row. Each row was allocated to one of the irrigation treatments listed below. The first 16 rows constituted one area of the field to which a t-tape irrigation system was available. The remaining 4 rows constituted a separate area to which overhead irrigation was available. This latter area was sufficiently removed from the former area so that spray drift could be avoided, but it was still within the same field. All rows constituted 1 m wide strips which had had two applications of glyphosate herbicide and had been mown prior to sowing. During the period of observation, some degree of weed control was attempted through later applications of glyphosate to the weeds overshadowing the *Eucalyptus* seedlings and to the weeds and grasses growing into the plots from the adjacent pasture.

The irrigation treatments applied were:

1. No irrigation, control;

2. Daily irrigation for 7 days, followed by no further irrigation;
3. Irrigation every 4 weeks;
4. Daily irrigation for 7 days, then irrigation every 4 weeks;
5. Irrigation every 3 weeks;
6. Daily irrigation for 7 days, then irrigation every 3 weeks;
7. Irrigation every 2 weeks;
8. Daily irrigation for 1 day, then irrigation every 2 weeks;
9. Daily irrigation for 3 days, then irrigation every 2 weeks;
10. Daily irrigation for 7 days, then irrigation every 2 weeks;
11. Irrigation every week;
12. Irrigation on first day, then every week;
13. Daily irrigation for 3 days, then irrigation every week;
14. Daily irrigation for 7 days, then irrigation every week;
15. Daily irrigation for 14 days, then irrigation every week;
16. No irrigation;
17. Overhead irrigation every week;
18. Overhead irrigation every 3 weeks;
19. Overhead irrigation every 2 weeks;
20. Overhead irrigation every 4 weeks.

All applications of irrigation water were sufficient to return the soil in the immediate vicinity of the t-tape or beneath the overhead sprinklers to field capacity. Soil moisture content was monitored daily by time domain reflectrometry. On several occasions, when sufficient or excess rainfall occurred irrigation was unnecessary and the irrigation schedule was recalculated in an attempt to impose the planned frequencies.

Seedling emergence was observed after 2 weeks and 4 weeks. After 8 weeks the number of seedlings surviving was monitored and similarly after 20 weeks.

3.3.2 Results and Discussion

Heavy rain, totalling 23 mm, fell over the site on 5 and 6 November 1995. This was followed by 74 mm of rain over the period 20-23 November. These two rainfall events negated many of the irrigation treatments planned for this experiment. Those treatments which involved delays of up to 4 weeks before irrigation began were all brought to field capacity within one week of sowing. Because of rainfall in excess of 25 mm at approximately weekly intervals for the first 8 weeks of observation, it was not possible to impose the longer irrigation intervals planned until after this stage. Weed control through the use of glyphosate proved ineffective once the trial was established. Weeds which had been killed by one application of glyphosate were immediately replaced by newly emerging weeds or by growth into the plots of weeds and grasses from the adjacent pasture.

In the longer term, none of the treatments were successful in establishing trees. No surviving *Eucalyptus* seedlings could be found 20 weeks after the experiment began. It is readily apparent that by 8 weeks survivorship was declining for all species (Figs 46 to 51). The loss of all seedlings was attributed to competition from weeds.

The species differed markedly in their responsiveness to irrigation. While all species established some seedlings quickly in those rows kept at field capacity for 7 days (particularly treatments 2, 4 and 6), the fast growing *E. albens* was able to establish more seedlings than any of the other species. Establishment of *Eucalyptus polyanthemos* was particularly poor.

It was apparent from this large scale trial (involving the sowing of approximately 192,000 seeds) that maintenance of the soil at or near field capacity for at least one week will assist *Eucalyptus* seed germination. However, irrigation alone will not enable a relatively slow growing plant such as *Eucalyptus* to compete with more rapidly growing weed and grass species found in pastures.

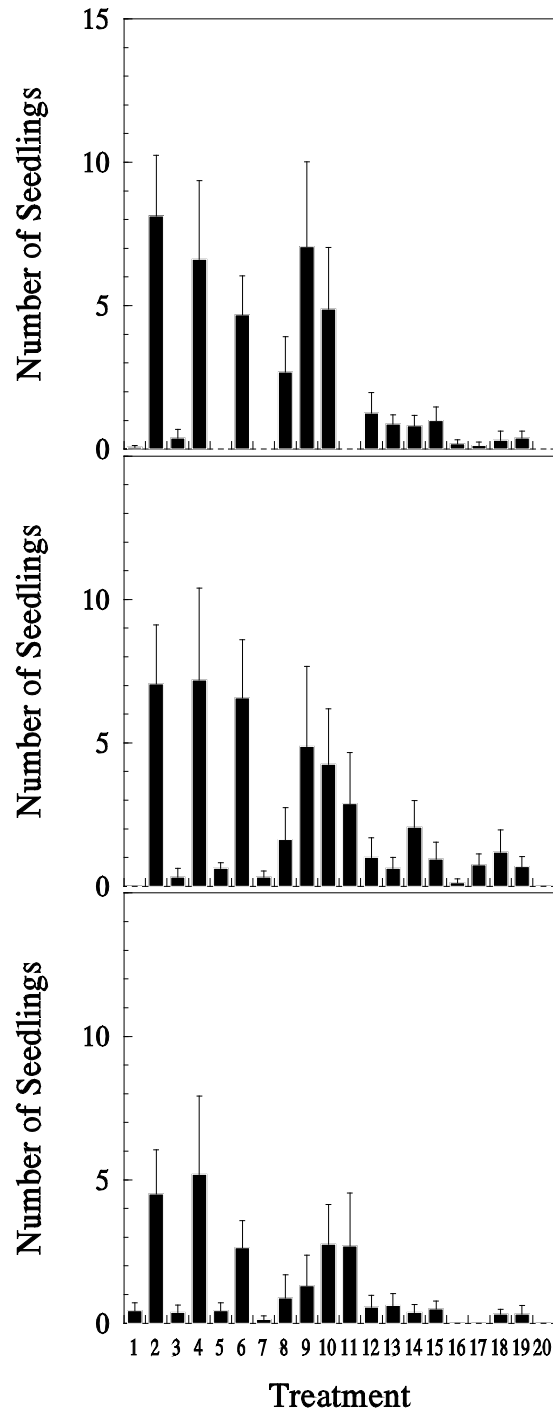


Figure 46. Field emergence of *Eucalyptus albens* under various irrigation frequencies at the Richmond campus of UWSH. Treatments used are detailed in the text. The top figure shows the number of seedlings emerged after 2 weeks, the middle figure shows the number of seedlings present after 4 weeks and the bottom figure shows the number of seedlings present after 8 weeks.

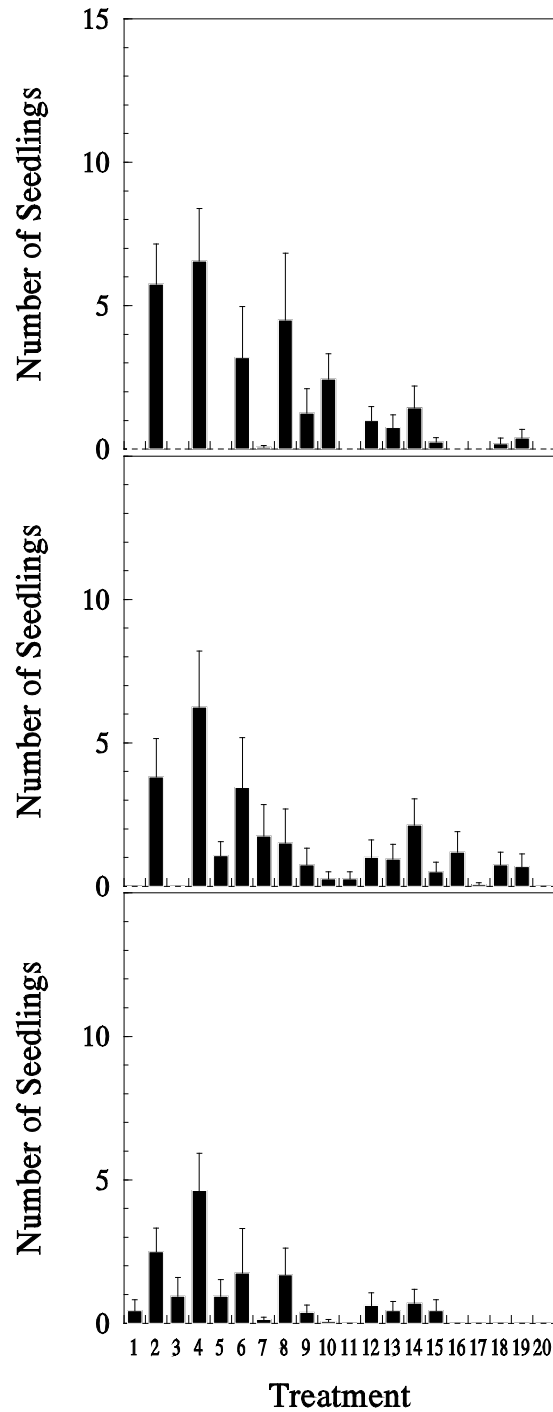


Figure 47. Field emergence of *Eucalyptus melliodora* under various irrigation frequencies at the Richmond campus of UWSH. Treatments used are detailed in the text. The top figure shows the number of seedlings emerged after 2 weeks, the middle figure shows the number of seedlings present after 4 weeks and the bottom figure shows the number of seedlings present after 8 weeks.

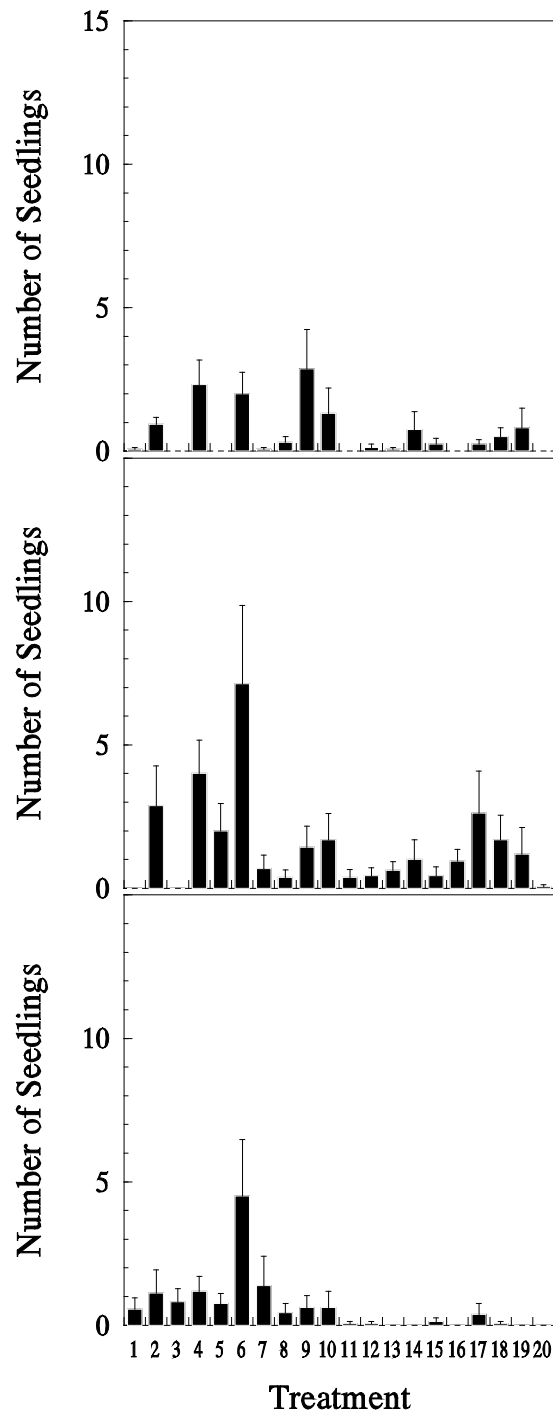


Figure 48. Field emergence of *Eucalyptus moluccana* under various irrigation frequencies at the Richmond campus of UWSH. Treatments used are detailed in the text. The top figure shows the number of seedlings emerged after 2 weeks, the middle figure shows the number of seedlings present after 4 weeks and the bottom figure shows the number of seedlings present after 8 weeks.

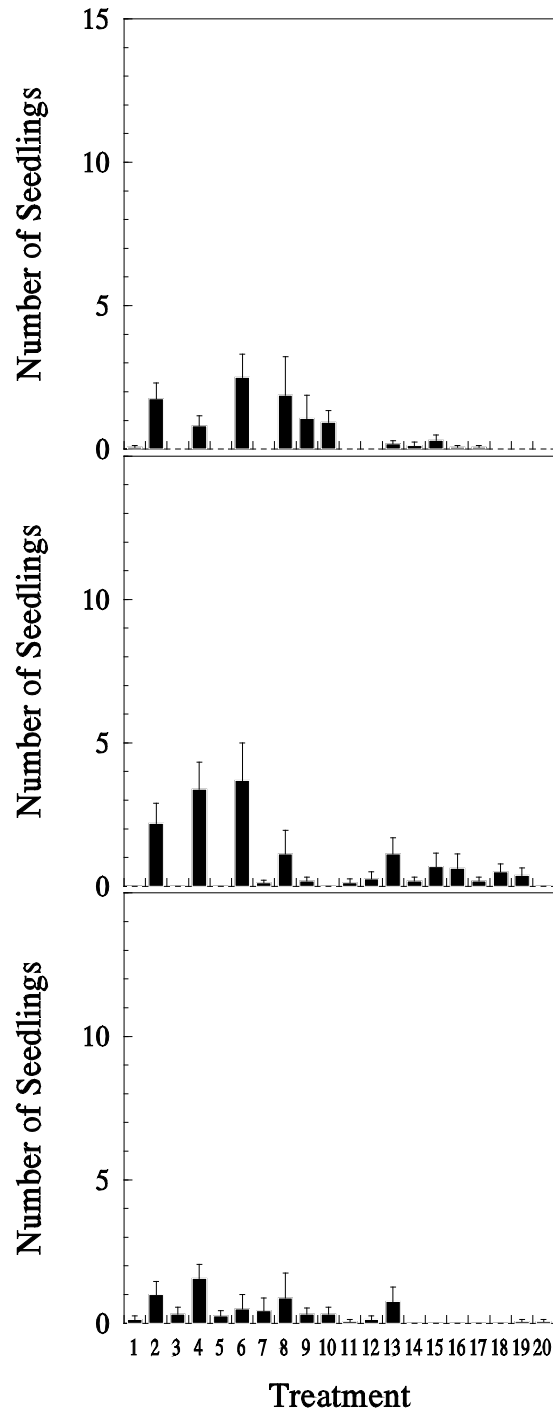


Figure 49. Field emergence of *Eucalyptus polyanthemos* under various irrigation frequencies at the Richmond campus of UWSH. Treatments used are detailed in the text. The top figure shows the number of seedlings emerged after 2 weeks, the middle figure shows the number of seedlings present after 4 weeks and the bottom figure shows the number of seedlings present after 8 weeks.

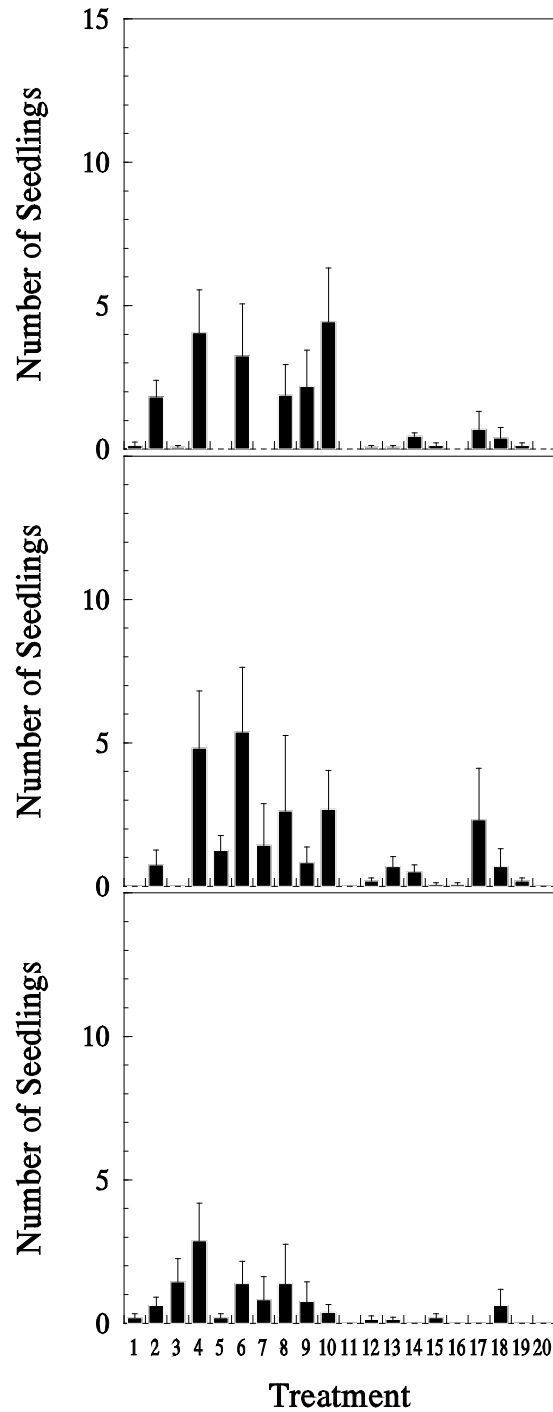


Figure 50. Field emergence of *Eucalyptus sideroxylon* under various irrigation frequencies at the Richmond campus of UWSH. Treatments used are detailed in the text. The top figure shows the number of seedlings emerged after 2 weeks, the middle figure shows the number of seedlings present after 4 weeks and the bottom figure shows the number of seedlings present after 8 weeks.

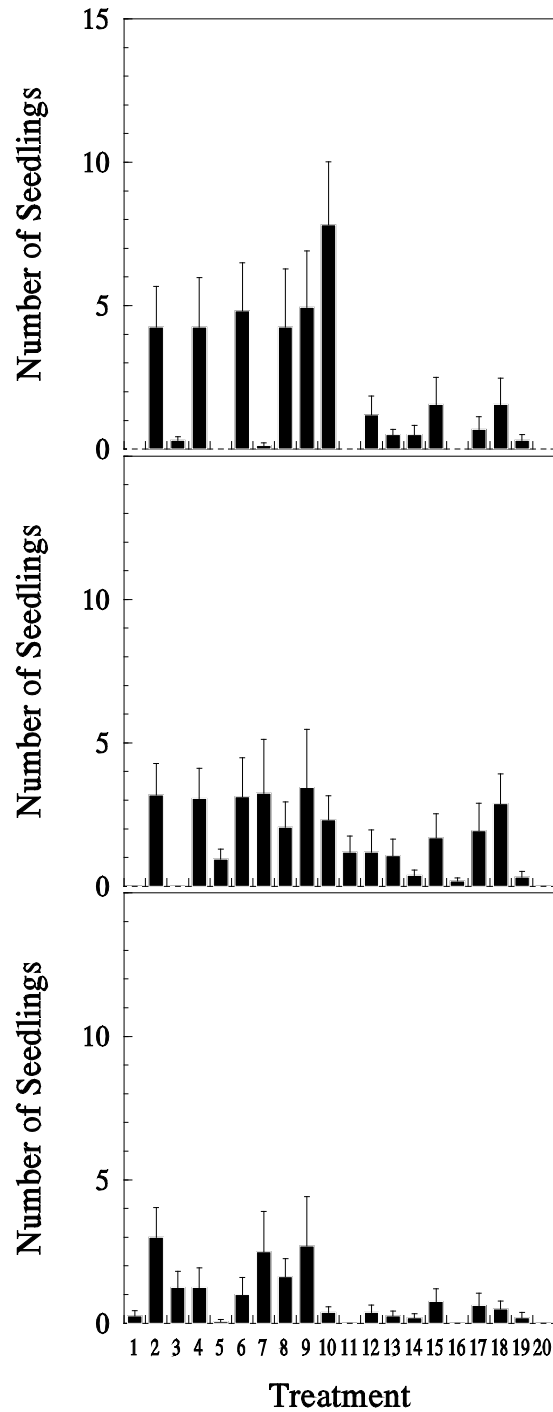


Figure 51. Field emergence of *Eucalyptus tereticornis* under various irrigation frequencies at the Richmond campus of UWSH. Treatments used are detailed in the text. The top figure shows the number of seedlings emerged after 2 weeks, the middle figure shows the number of seedlings present after 4 weeks and the bottom figure shows the number of seedlings present after 8 weeks.

3.4 Conclusions

We have been able to successfully establish *Eucalyptus* seedlings in the field in the longer term by direct seeding methods. However, in order to be successful it was necessary to irrigate the plots and to remove weeds by hand.

Our attempts to use direct seeding equipment were unsuccessful because of inadequate moisture in the fields at the time of sowing and subsequently. Our attempt to control weeds in an irrigated field by the use of the herbicide glyphosate were also unsuccessful. This latter trial clearly demonstrated the need for effective weed control for large scale direct seeding activities. The development of effective methods of weed control for use with direct seeding technologies should be the focus of a separate research project.

4. FACTORS AFFECTING THE SUCCESS OF SEEDLING ESTABLISHMENT

The results obtained in the various field trials undertaken to evaluate the effectiveness of seed priming treatments have revealed that many other factors may influence the outcome of the field trial. Despite our best efforts we were unable to successfully establish any seedlings at any site in any of our trials. This lack of success led us to examine in more detail, through laboratory, greenhouse and small scale field trials, a number of factors we considered to be of overriding importance to the success of direct seeding operations.

The main factors which we have examined in this series of experiments were: water availability and seed predation. As a corollary to our final field trial we were able to demonstrate that direct seeding can lead to successful establishment of *Eucalyptus* when competition from weeds is greatly reduced.

4.1 Soil Moisture Content Required for Germination

One of the important limiting factors for the establishment of seedlings in any field is the availability of soil moisture. While it is well documented that plants differ in their capacities to tolerate different levels of water stress, much less is known about the abilities of different species to germinate and establish at differing soil moisture contents. While Doneen and McGillivray (1943) have shown that final germination percentage decreased with soil moisture content in a wide range of vegetable species, little is known of the responses of other species. *Eucalyptus sieberi* has been shown to be tolerant of a series of wetting and drying cycles (Gibson and Bachelard 1986), however, the minimum soil moisture content required for germination is not known for this or other species of *Eucalyptus*.

Sandy loam soil from a field of the Richmond campus of UWSH was removed with minimal disturbance. The field capacity of this soil was determined by gravimetric methods to be 24.14% of the soil weight. Ten gram samples of this soil were placed in small glass jars and sufficient water was added to raise the soil moisture content to between 10 and 90% of field capacity. Nine levels of soil moisture content were used. There were four replicates of each treatment. Into each jar, 25 seeds of either *E. albens* or *E. tereticornis* were placed. The jars were sealed with a breathable membrane (Sigma Film, Sigma) and stored at 20°C with 12 hours light per day. Germination was observed daily for 19 days.

4.1.2 Results and Discussion

The two species differed in their capacities to germinate at varying soil moisture contents. The rate and final percentage of germination were largely unaffected by differences in soil moisture content from 90% of field capacity to as low as 60% of field capacity (Figs 52 to 55). At 50% of field capacity the final percentage of germination attained was slightly reduced from that attained at the higher soil moisture contents. Soil moisture contents of 40% of field capacity or 30% of field capacity greatly reduced the final percentage of germination attained. At soil moisture contents of 20% of field capacity or 10% of field capacity no germination occurred.

While seed priming resulted in earlier commencement of germination, it did not result in earlier completion of germination within the population of seeds (Figs 53 and 55). This is in contrast to the results obtained in the greenhouse study where primed seeds of *E. tereticornis* germinated earlier and attained a higher final percentage of germination (Fig 38). This observed detrimental effect on germination at low soil moisture content is in contrast to the claims of improved germination under stressful conditions often attributed to seed priming (Heydecker and Coolbear 1977). Also in contrast to the greenhouse study, the germination of the primed *E. albens* seeds, at the high soil moisture contents, was not greatly reduced from that of the non-primed controls (Figs 33 and 53).

The marked differences in responses observed in this trial and in the greenhouse trial indicate that a large degree of variation can always be expected when working with *Eucalyptus* species.

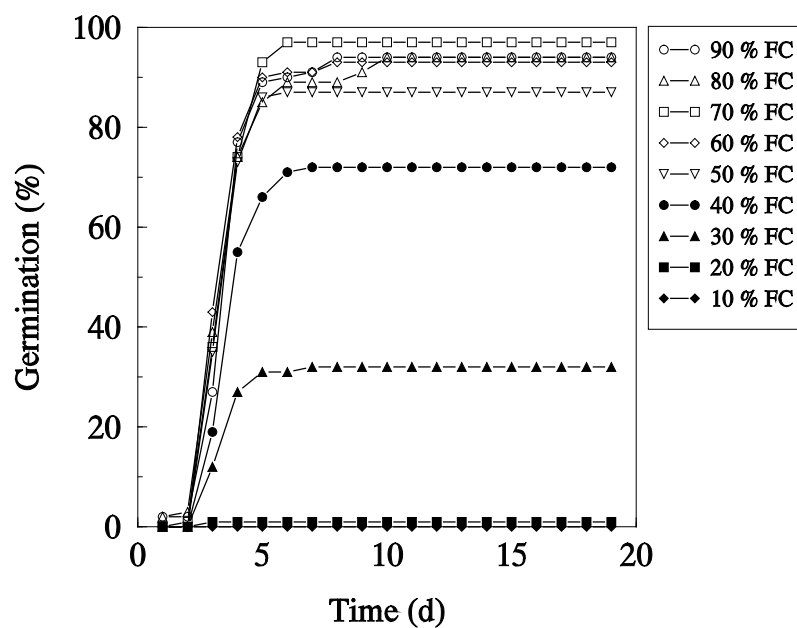


Figure 52. Germination of seeds of *Eucalyptus albens* from soil of defined moisture contents. The seedlings were established from seed which were untreated controls.

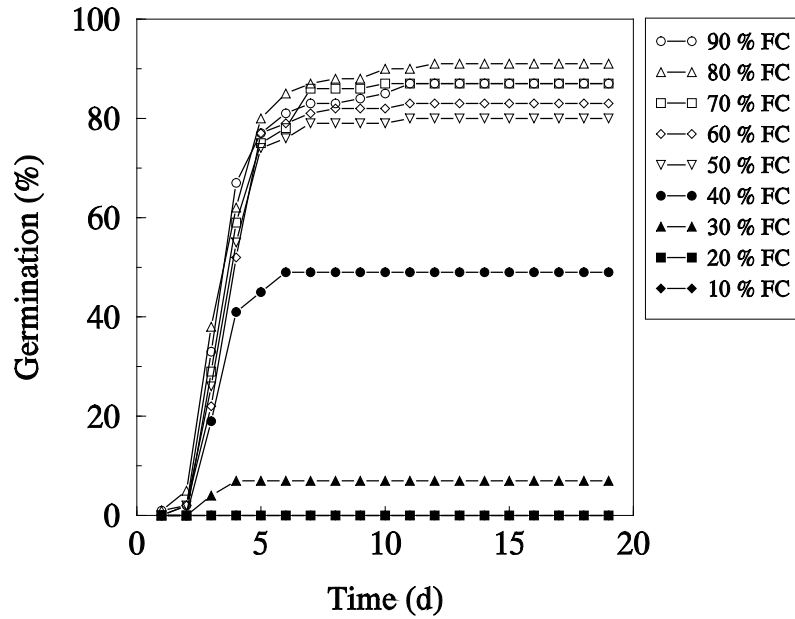


Figure 53. Germination of seeds of *Eucalyptus albens* from soil of defined moisture contents. The seedlings were established from seed which had been primed in a -1.25 MPa PEG solution.

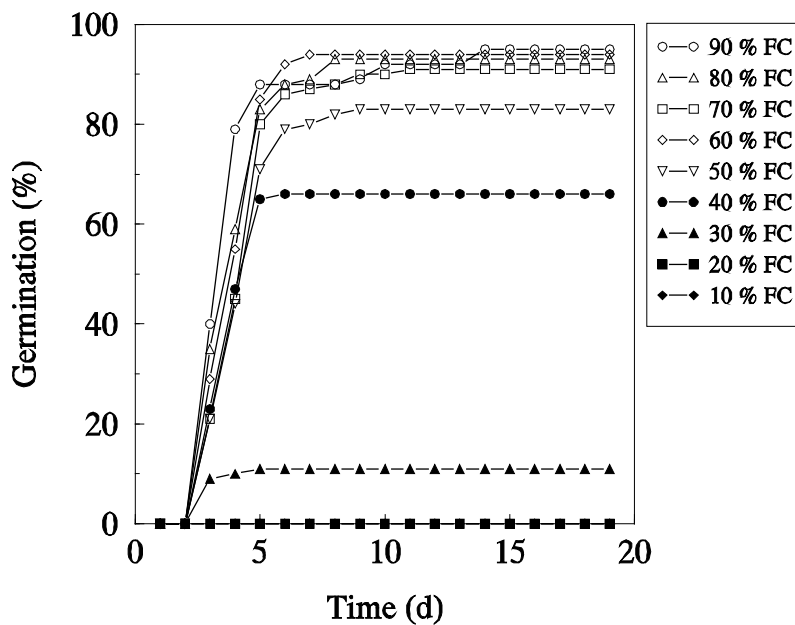


Figure 54. Germination of seeds of *Eucalyptus tereticornis* from soil of defined moisture contents. The seedlings were established from seed which were untreated controls.

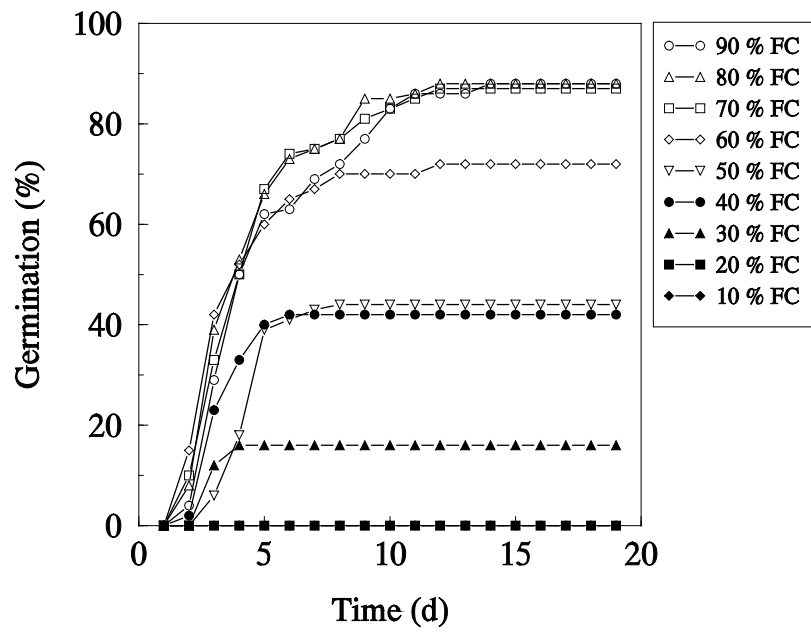


Figure 55. Germination of seeds of *Eucalyptus tereticornis* from soil of defined moisture contents. The seedlings were established from seed which had been primed in a -1.25 MPa PEG solution.

4.2 Water Requirements for Seedling Survival

Differences in the distribution of *Eucalyptus* species may partially result from their adaptation or tolerance of various climatic conditions. This would include the suitability of the levels of available water for seedling establishment.

A plants requirement for water and the capacity of a seedling to survive for extended periods between irrigations may influence the survival of the seedling during establishment.

4.2.1 Material and Methods

Primed and non-primed seed of *E. tereticornis*, *E. moluccana*, *E. fibrosa* and *E. sideroxylon* was used to examine longevity and growth of seedlings under four different watering regimes. There were five replicates each of primed and non-primed seeds of each species grown in pots containing 1,995g of silt loam soil. Container water capacity was determined as being 454 g of water, and chilli plants in these pot conditions wilted when pots contained 55.7 g of water. Seeds were primed in -1.25 MPa PEG solutions for 7 days at 20°C with 12 hours of light each day.

Seeds of each species were planted into separate pots and initially all treatments were returned to container capacity for five consecutive days. This ensured that the seed was exposed to sufficient water to permit germination. Following this, pots were returned to container capacity at weekly, fortnightly, three or four weekly intervals. Pots from each treatment were weighed daily and all treatments were monitored for signs of plant water stress and death. With observation of severe plant stress, as indicated by severe wilting and changes in leaf colour and brittleness, plant death was judged to have occurred and pots were weighed to determine the quantities of water remaining. The irrigation treatments continued for six weeks, after which time all pots were allowed to dry. Shoot dry weights were determined after drying at 80°C for 3 days.

4.2.2 Results and Discussion

The species differed markedly in their capacities for growth under the different irrigation regimes. No seedlings of any species were able to survive in the pots which were irrigated at the four weekly interval. *Eucalyptus moluccana* produced the largest seedlings at the 7 day irrigation frequency (Fig 57). Priming of seeds resulted in larger seedlings at the 7 day irrigation frequency for all species except *E. fibrosa* (Figs 56 to 59), however, there was little or no advantage conferred by priming to plants grown at the longer intervals between irrigations. At the 14 and 21 day intervals, priming proved detrimental to the growth of *E. tereticornis* (Fig 59).

Interestingly all plants of all species under all irrigation regimes died when the soil moisture content reached 6.25 % of the measured field capacity. Whilst there was a small amount of variation between individuals, there were no significant differences amongst the treatments. This clearly suggests that the soil characteristics are dominant over any differences between these species.

This critical value of 6.25 % of field capacity is considerably lower than that at which germination was inhibited, 20 % of field capacity (Figs 52 to 55). It is also considerably lower than the soil moisture contents measured in the field when seedling deaths were observed.

The field measurements were determined as a measure of the soil moisture content of the top 20 cm of soil. Thus these measurements would not accurately record the soil moisture content of the top soil layers in which the young *Eucalyptus* seedlings were growing. Such coarse measurements of environmental parameters clearly result in inadequate characterisation of the heterogeneity of the microenvironment in which seeds germinate and seedlings establish.

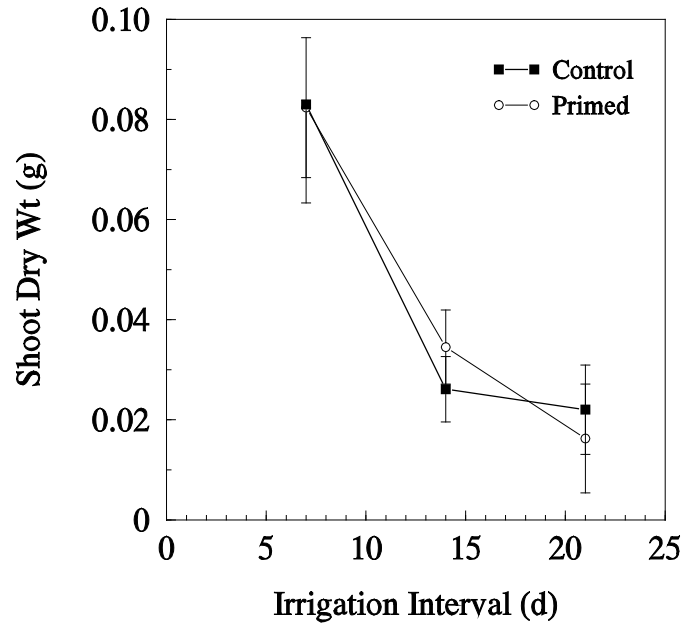


Figure 56. Dry weight of shoots of seedlings of *Eucalyptus fibrosa* after six weeks growth in pots irrigated at 7, 14 or 21 day intervals. The seedlings were established from seed which had either been primed in PEG or were untreated controls.

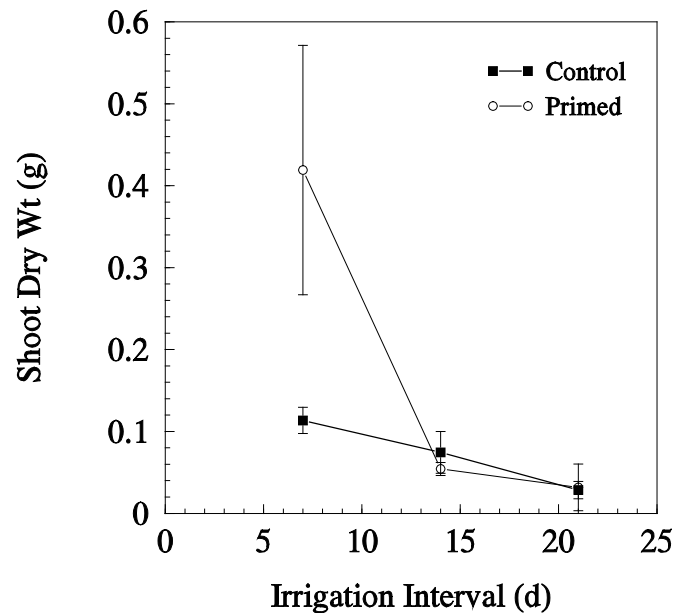


Figure 57. Dry weight of shoots of seedlings of *Eucalyptus moluccana* after six weeks growth in pots irrigated at 7, 14 or 21 day intervals. The seedlings were established from seed which had either been primed in PEG or were untreated controls.

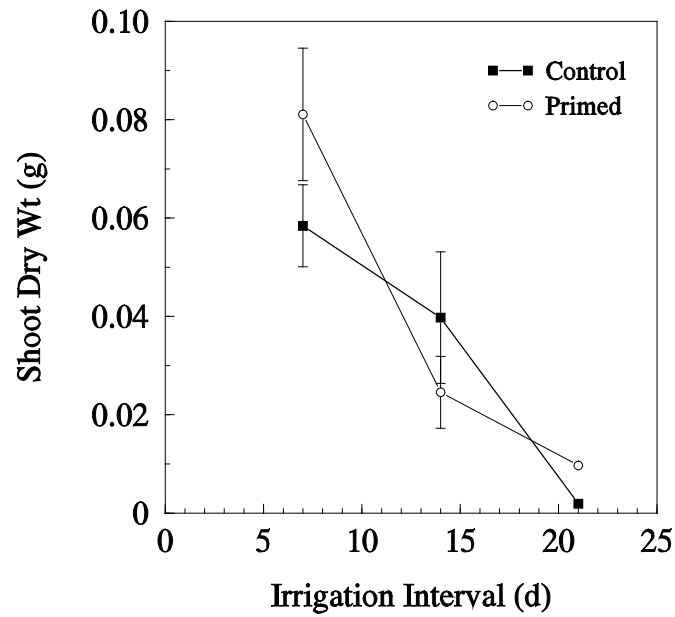


Figure 58. Dry weight of shoots of seedlings of *Eucalyptus sideroxylon* after six weeks growth in pots irrigated at 7, 14 or 21 day intervals. The seedlings were established from seed which had either been primed in PEG or were untreated controls.

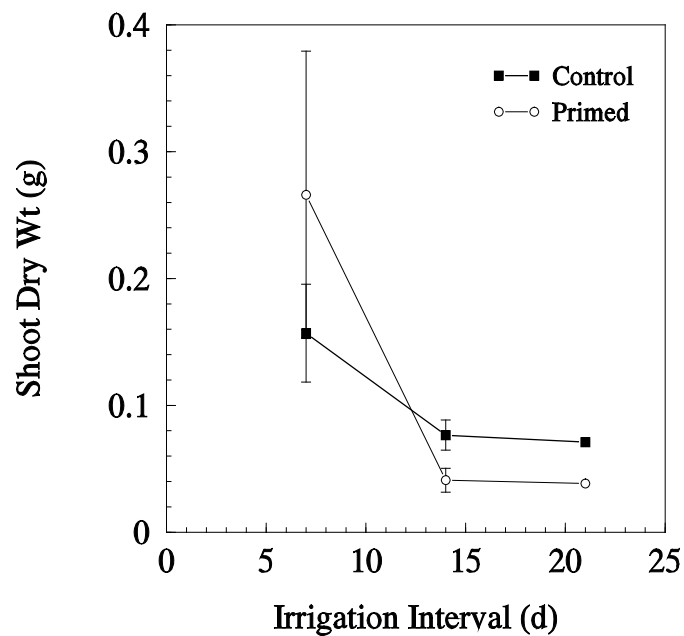


Figure 59. Dry weight of shoots of seedlings of *Eucalyptus tereticornis* after six weeks growth in pots irrigated at 7, 14 or 21 day intervals. The seedlings were established from seed which had either been primed in PEG or were untreated controls.

4.3 Seed Predation

Seed predation in direct seeding field situations may limit the establishment of trees. Seed harvesting ants occur throughout Australia (Curtis 1991), but ant activity may vary both temporally and spatially (Rogerson, pers. comm.). Ants, such as *Rhytidoponera*, *Pheidole* and *Chelaner* have been reported to be able to rapidly remove many seeds from the ground. Where there has been light seed fall and ants were eliminated from the area, a fifteen-fold increase in seedling densities of *E. baxteri* has been noted. Estimations from this showed that ants removed 93% of broadcast seed (Andersen 1987). Large quantities of seed may be harvested if conditions remain dry after sowing (Curtis 1991). With heavy seed falls, as occur after fires, high numbers of seedlings still eventuated due to satiation of the predators. However, elimination of ants from this area also resulted in increased numbers of seedlings (Andersen 1987).

There are various ideas concerning seed loss control. Sowing seed using bran as a bulking agent has been suggested as a strategy to reduce the levels of predation, with the mechanism of predator satiation reducing seed losses (Perkins, pers. comm.). A method suggested to be the most successful is the coating or dusting of seed with insecticides prior to sowing (Curtis 1991). These may include permethrin or bendiocarb (Campbell 1982), and can be formulated as wettable powders. Seeds of *Phalaris aquatica* and *Medicago sativa* coated with permethrin at 1.5 and 2.25 g/ kg seed and bendiocarb at 0.75, 1.5 and 2.25 g/ kg seed significantly reduced seed removal by *Pheidole*. Untreated seed was removed at > 150 seeds / nest / day, while treated seed was removed at an average of 5 seeds / nest / day, over a fourteen day period (Campbell and Gilmour 1979).

It has also been suggested that at sites where direct seeding of surface sown seed is being undertaken, the site should be initially monitored for seed predators. If seed loss is found to be significant, baited seed may then be distributed prior to sowing the seeds of the desired species (Clements, pers. comm.). If seed is buried in the sowing process this may reduce losses to predators (Rogerson, pers. comm.).

In field investigations to examine the effects of water availability and priming treatments (undertaken for this paper), it is possible that seed predation was a significant factor in the resulting establishment levels. No prior to sowing monitoring for predators or baiting treatment was attempted. In light of the possible significance to that trial's results, this investigation examined the possible presence of predators in the site region.

During May 1994, trials were set up to determine the amount of seed removal which may occur in the field. Seeds of *Eucalyptus tereticornis* were placed on the ground surface, in containers which allowed insect access, but limited disruption from weather and larger animals. The samples were all located in a 5 m² site in which ants had been observed to be active foragers. At three randomly chosen locations within this site, six replicates of ten *Eucalyptus tereticornis* seeds each were placed. The treatments used were a control, seeds dusted with an insecticide (1.25 g permethrin / kg seed) and a commercial seed coating, 'treecote' (Heritage Seeds, Toowoomba). The seeds were placed on the ground, on indented wooden plates which had their upper surface protected by plastic and the sides meshed with wire. This apparatus allowed ants and other insects easy access, but limited disruption from the weather and larger animals. These were monitored daily to determine amounts of seed removal.

4.3.1 Results and Discussion

Seeds were witnessed to be removed from the site by ants. These were identified as being of the genus *Pheidole*. At the seeding rates used in this experiment, the use of the insecticide permethrin appeared to have little deterrent effect on seed predation by ants. This is in contrast to what has been suggested by other workers (Curtis 1991; Campbell 1982). If insecticide dusted seed is distributed in large quantities, further seed removal levels may then be influenced through insecticidal action reducing predator populations. This would support the use of a baiting treatment prior to sowing of seeds, such as has been suggested by Clements (1995). The efficacy of such a protocol may be limited to minesites or other areas of disturbed ground where populations of ants and other predators could be expected to be low. The adoption of

such baiting treatments may be limited in areas which provide the only natural or near natural habitat for a range of plant and animal species.

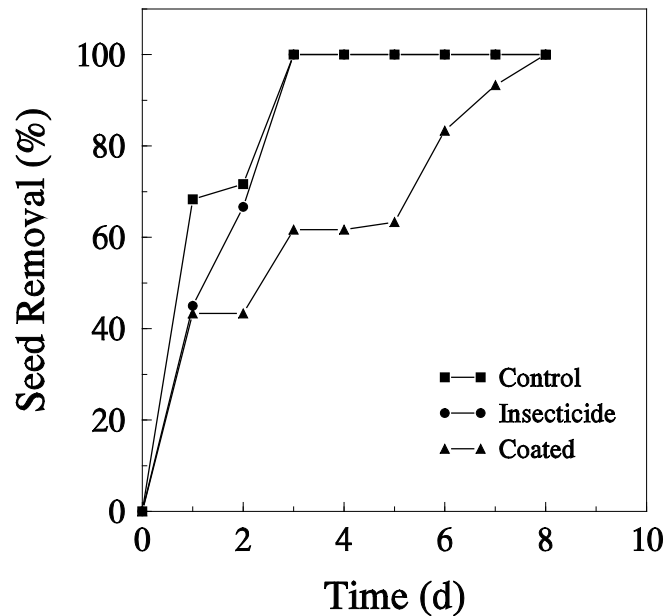


Figure 60. Removal of seeds by ants, or other insects, from a field site at UWS Hawkesbury. Seeds were either dusted with an permethrin (insecticide), coated with the commercial coating treatment, treecote (coated) or left untreated (control).

Larger pelleted seed, though not removed as quickly as were the untreated seed, were still removed such that there were no seed remaining after eight days. This pelleting treatment may offer some initial protection, but this protection would not persist if predators are in the vicinity of surface sown seed. The results of the study highlight the need for timing of seeding operations to occur with optimum conditions for germination and establishment. These levels of seed predation demonstrate the potential significance to seedling establishment of such activities, especially if suitable conditions for germination do not occur soon immediately upon sowing.

4.4 Seed Coating Treatments

Applications of various chemicals to the seedcoat, try to reduce the stresses that a germinating seed encounters, and give the seed advantages that will assist establishment after germination. Alteration to the seed shape or size has also been used to assist in seed sowing processes.

Seed pelleting involves coating seeds with an inert medium, such as kaolin, to enable incorporation of a range of ingredients. It is hoped that this may enhance early seedling performance, and for this purpose the coating may also include herbicides, safeners (detoxifiers), fungicides, insecticides, fertilisers, micronutrients and moisture absorbers (Venning 1988).

Seed coating of *Eucalyptus* seed has been used by forestry operators. These treatments typically involve coating seeds with kaolin clay incorporating fertiliser. Success from this treatment has not been universal, but has reportedly increased seedling establishment from broadcast seed (Curtis 1991). The Victorian Department of Conservation, Forests and Lands has developed a protocol for coating which is detailed in their publication Seed Coating - Eucalypts, Operational Information No. 9, published by the Forests Commission Victoria, 1981. This procedure involves the cleaning of the seeds, incorporation of fungicide and insecticide and coating with kaolin clays.

Pellets containing gels that hold moisture have been reported to have some success (Curtis 1991). The initial promise that such treatments would improve establishment on drier sites were not fulfilled (Venning 1988).

Seed coating with a polymer film and seed pelleting (which involves bulking of the size of the seed through application of a thicker coat), are processes that are currently available through Heritage Seeds. Applications onto the seeds may include nutrients: nitrogen, potassium, phosphorus and trace elements; insecticides; fungicides; and growth hormones (Kalm, pers. comm.). These applications may have some influence on the germination of the seed, probably through changes to water relationships

(Vanderwoude, pers. comm.), or possibly through stimulating changes in the seed coat (Weatherly, pers. comm.).

Precise descriptions of commercial methods are not available for pelleting and polymer coating procedures. This includes the ‘treecote’ method available through Heritage Seeds. There is some evidence to suggest that for small seeds, such as some species of *Eucalyptus*, pelleting may be detrimental for plant establishment (Vanderwoude, pers. comm.). Vanderwoude (1994) examined the effects of various seed treatments: non- treated seeds; seeds pelleted with calcium carbonate and methyl cellulose; seeds pelleted with calcium carbonate, methyl cellulose and nutrients; seeds pelleted with nutrients, bendiocarb (an insecticide) and metalaxyl (a fungicide); seeds pelleted with a very large pellet (approximately 40x size); and seeds dusted with bendiocarb and metalaxyl. Differences in emergence of seedlings between these various treatments was not consistent at different sites. Where differences occurred, seeds dusted with insecticide and fungicide; and seeds pelleted with nutrients, insecticide and fungicide emerged in greater amounts than did those seeds given other treatments (Vanderwoude 1994).

The inconclusive nature of the results described above suggest that there is a need for further examination of the various coating and chemical applications. This examination should include the application methods of polymer, pelleting and dusting and chemicals such as insecticide, fungicide and nutrient components.

4.4.1 Materials and Methods

A variety of methods of application of seed coatings including pelleting, polymer coating or dusting of insecticide, fungicide and nutrient treatments were examined for their effects on seedling establishment of *Eucalyptus tereticornis* seeds. Pelleting and polymer coating treatments were conducted at commercial facilities (Yates Seeds, Milperra and Heritage Seeds, Toowoomba). The insecticidal and fungicidal chemicals (Coopex and Thiram) were selected for their availability under current registration and their relative safety when handling. Both were applied at a rate of 5 g / kg seed.

The following treatments were used:

1. untreated control untreated;
2. seeds pelleted with insecticide (Yates Seeds);
3. seeds pelleted with fungicide (Yates Seeds);
4. seeds pelleted with insecticide and fungicide (Yates Seeds);
5. seeds polymer coated with insecticide (Heritage Seeds);
6. seeds polymer coated with fungicide (Heritage Seeds);
7. seeds polymer coated with insecticide and fungicide (Heritage Seeds);
8. seeds polymer coated with nutrients (Heritage Seeds);
9. seeds dusted with insecticide;
10. seeds dusted with fungicide;
11. seeds dusted with insecticide and fungicide;
12. Heritage Seeds 'treecote' treatment.

Samples of one hundred seeds per treatment were randomly allocated to one metre rows and hand sown into a silt loam soil at approximately 5 mm depth. Fifteen replicates were used. Prior to sowing, the ground was prepared by use of a rotary hoe and sprayed with the herbicide glyphosate. The ground surface near all treatments was watered by rainfall or via t-tape irrigation system. Irrigation or rainfall occurred daily for seven days, then every second day for a further seven days. Following this time, rainfall was supplemented to provide at least a weekly return to field capacity. Weed growth in the area beside the rows was controlled through the use of weed matting. Seedling emergence was monitored weekly for four weeks then after eight weeks.

4.4.2 Results and Discussion

Whilst there were some differences in the percentage of seedlings to emerge from the various treatments at the first observation, four weeks after sowing (Fig 61) these differences were no longer apparent at the second observation, eight weeks after sowing. Therefore, we are unable to conclude that any of the coating treatment were beneficial to the success of establishment. It would appear that the use of insecticides

and fungicides and the application of the various coating materials does not lead to more successful seedling establishment over the use of cleaned bare seeds.

This experiment was commenced in January 1995, at the same time as the final field trial described in section 3.3 was proceeding. This coating experiment was conducted in a field adjacent to the one used for the last field trial and one which had had a similar history of usage as pasture. Consequently, the weed pressure in this field was similar to that in the adjacent field. However, the placement of weed matting adjacent to the rows into which the seeds were sown resulted in very few weeds establishing in the coating experiment.

As a consequence of the presence of weed matting, no further losses in the numbers of plants have occurred since the observations made eight weeks after the experiment commenced. Thus while this experiment has not shown any positive effects of seed coating treatments, it has confirmed our finding that competition from weeds is the major cause of lack of successful seedling establishment for direct seeding.

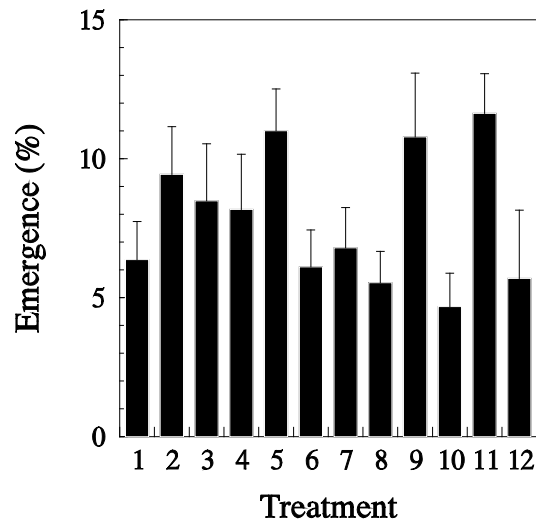


Figure 61. Emergence of seedlings of *Eucalyptus tereticornis* as affected by a range of seed treatments 4 weeks after sowing at the Richmond campus of UWSH. The seed treatments used were: (1) control, (2) insecticide pelleting, (3) fungicide pelleting, (4) insecticide and fungicide pelleting, (5) insecticide polymer coating, (6) fungicide polymer coating, (7) insecticide and fungicide polymer coating, (8) nutrient polymer coating, (9) insecticide dusting, (10) fungicide dusting, (11) insecticide and fungicide dusting, and (12) 'treecote'.

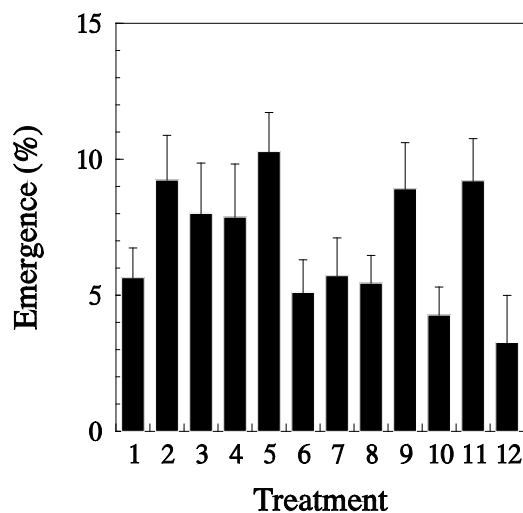


Figure 62. Emergence of seedlings of *Eucalyptus tereticornis* as affected by a range of seed treatments 8 weeks after sowing at the Richmond campus of UWSH. The seed treatments used were: (1) control, (2) insecticide pelleting, (3) fungicide pelleting, (4) insecticide and fungicide pelleting, (5) insecticide polymer coating, (6) fungicide polymer coating, (7) insecticide and fungicide polymer coating, (8) nutrient polymer coating, (9) insecticide dusting, (10) fungicide dusting, (11) insecticide and fungicide dusting, and (12) 'treecote'.

5. GENERAL DISCUSSION

In terms of the objectives of this work, we have demonstrated that seed priming treatments are able to improve the laboratory germination of a range of *Eucalyptus* species by decreasing the time required for germination to commence. There was no reduction in final percentage of germination attained except for *E. albens*, on some occasions, or when solutions of KNO_3 were used to prime some species.

Further, we were able to demonstrate that by the use of primed seeds it was possible to increase the number of seedlings established in the greenhouse for *E. moluccana*, *E. polyanthemos*, *E. sideroxylon* and *E. tereticornis*. Priming had no effect on the number of seedlings of *E. melliodora* produced, but did reduce the final number of *E. albens* seedlings established in the greenhouse. This reduction appeared to be due to infection by the disease causing organism *Phythium*.

Therefore, we have been able to successfully address the first two objectives concerned with developing and evaluating seed priming treatments which would enhance the rate and uniformity of seed germination.

We were able to demonstrate only a limited effect of seed priming on the emergence of seedlings in the field. Small increases in the number of seedlings successfully established in the field were found for *E. tereticornis*. However, seed priming did not affect the establishment of *E. sideroxylon*, but adversely affected the establishment of *E. fibrosa* and *E. moluccana*.

We were unable to observe any quantifiable effects of a range of other seed coating and encapsulation treatments. These included polymer coatings, the use of insecticides and fungicides and the incorporation of essential nutrients. Consequently, these coating treatments could not be recommended as methods which would enhance the success of direct seeding.

We have thus addressed the third objective of this project, that of evaluating the effectiveness of both the seed priming and other seed treatment in the field. Our finding of limited success of seed priming most likely indicates that it will be of

limited use in direct seeding operations. However, the very positive outcomes of the greenhouse trials clearly demonstrated that seed priming could be of considerable benefit in this situation.

In all of the field experimentation which we undertook, the overriding factor determining the success of direct seeding was competition from weed species. Only when this competition was reduced either through hand weeding of plots or through the use of weed matting were we able to establish seedlings successfully. The presence of many weed species and fast growing introduced grass species in pasture lands and the invasion of roadsides by these species will ensure that the establishment of *Eucalyptus* species is extremely limited where the seeds or propagules of these other species persist.

Eucalyptus species have evolved in environments which either have relatively low competition from grass species, such as the woodlands of Australia. They have also evolved strategies involving the shedding of very large numbers of seed often following fire. This strategy is one which would enable *Eucalyptus* species to effectively compete in periods following fires when competition from other species would be limited. This strategy of producing large numbers of seeds and shedding them at the one time would also assist these species in coping with the predation pressure of ants and other foragers. We were able to document the heavy predation pressure of ants at one of the field site which we used. This predation continued to occur when seeds were coated with an insecticide recommended for use to deter predation by ants

The usefulness of direct seeding operations for the establishment of *Eucalyptus* species will be limited to areas where weed competition can be effectively removed for a period of at least several months, probably about six months. We have not attempted to determine what the length of this competition free period may have to be.

The outcomes of the field trials demonstrate the need for extensive research into the development of suitable methods of weed control. While selective herbicides may present one option for control, because of the small size of the direct seeding industry, there is little likelihood of adequate commercial interest in the development of a

herbicide designed specifically for use with *Eucalyptus*. Alternative methods of weed control such as through the development of appropriate types of slowly degradable weed matting may prove more effective and acceptable to those likely to use them.

With regard to the final objective of this project, we have limited financial information upon which to conduct an analysis of the economics of direct seeding compared with seedling establishment via tubestock. Based on current commercial charges for the planting of tubestock on roadsides, in Sydney, or on minesites in central New South Wales, the cost per transplanted tree ranges from \$4.50 to about \$9.00. The difference in cost reflecting the amount of preparatory work required to be undertaken by the contractor revegetating a roadside compared to the large scale landforming common in minesite rehabilitation. Additional differences in operation would involve the number of times a planted tree is watered per site. Based on 2500 trees per ha (4 m² per tree) these charges would result in total costs per ha ranging between \$11,250.00 and \$22,000.00, approximately.

By way of a comparison, it is possible to estimate the likely costs of the use of weed matting laid by a modified plastic mulch layer drawn by tractor together with the necessary cultivation of the land to permit laying of the weed matting. The costing of these materials and operations would be similar to those involved in the establishment of vegetable crops grown on plastic mulch. As a guide, for one ha land preparation should be able to be completed in about 12 hours (3 cultivations) with another 4 hours required for laying of the weed matting and a further 4 hours to initially spray the area with herbicide. Based on a cost of \$12.50 per hour for labour, these operations would cost about \$250, approximately. The cost of weed matting would be about \$2,000 for 3,500 m of matting. Excluding the cost of equipment and with seed costs of about \$200, there should be a considerably lower cost of establishing *Eucalyptus* species by direct seeding. However, the necessary modifications to existing plastic mulch laying equipment need to be developed. Similarly, an effective means of sowing the seeds into the weed-mat covered ground needs to be developed. In vegetable cropping, this is commonly achieved through either manual or mechanical cutting of holes in the plastic mulch for the placement of the seedlings. No equipment currently exists which is designed to sow seeds into the soil through holes cut in plastic mulch or weed matting.

A combination of mechanical placement of the weed matting, manual cutting of holes and hand sowing of the seed would be a feasible operation. Allowing 50 hours of casual labour for manual hole cutting and hand seeding would produce a total cost of direct seeding of less than \$3,500 per ha when equipment costs are excluded or about \$4,000 if equipment has to be hired.

There would appear to be the possibility of a considerable financial saving in the cost of establishing *Eucalyptus* by a direct seeding operation as outlined above when compared with the current commercial costs of transplanting for areas which have sufficient soil depth and are flat enough to permit tractor operations. However, the feasibility of modifying existing plastic-mulch laying equipment and the environmental and community acceptability of covering large areas of land with weed matting require considerable further investigation. A more community acceptable form of weed matting may be one based on cellulose fibre. This also would require considerable research and development activity before it would be able to replace the current woven plastic weed matting.

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