PACKAGING AND COOL STORAGE OF TREE SEEDLINGS

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ABSTRACT

Modern forest nursery and establishment operations demand a single package for seedlings from lifting to planting. Once in a package, cool storage is essential to prevent deterioration in seedling quality through heat build-up and excessive rates of respiration. Packaging in kraft paper bags with a polythene lining 8–10 μm thick provides a package which restricts moisture loss but allows sufficient gas exchange at low temperatures to maintain healthy seedlings. With the moisture barrier built in to the package, cool store construction is simplified. Maximum duration of cool storage for seedlings depends on species characteristics of foliage and winter dormancy.

INTRODUCTION

Several forms of seedling storage have been used since the advent of plantation forestry in New Zealand. The most common has been the open or shaded pit storage of seedlings, bundled in counted lots with roots laid in trenches of wet soil and/or sawdust. Several hundred thousand hectares of *Pinus radiata* plantation have been established from seedlings stored in this manner, and any change to a more expensive system, particularly one involving cool storage, must have compelling arguments in its favour. Also, with increased planting targets the planting season is being steadily extended into spring and autumn with all the associated risks of drier soil and air conditions. Seedling failure through an inadequate packaging and storage system is an unnecessary additional hazard.

The size of forest nurseries has vastly increased since pit storage techniques evolved. The number of seedlings produced necessitates that they be handled in bulk in some convenient form of package. Once a seedling is enclosed in a package, the procedure of handling must be adapted to prevent the deterioration of vigour that can occur rapidly as a consequence of restricted ventilation.

The seedling is a living organism and not an inert object capable of switching on vigorous growth following a succes-

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sion of assaults from root stripping, bashing, mauling, suffocation and dehydration. As a living organism it must respire to remain alive and vigorous, and for this a suitable environment must be provided without disruption from lifting to establishment. In a package without cool storage this is impossible.

For respiration a seedling requires carbohydrate and oxygen (O_2) and gives off carbon dioxide (CO_2), water and heat. The data of McCracken (1979) gives some idea of the quantities involved at a temperature of 2°C. For example, a 1/0 *Pinus radiata* seedling has a dry weight of around 10 g. Of this, 1.22 g was found to be carbohydrate (starch and soluble sugars). During 6 weeks of cool storage, 0.52 g of carbohydrate was consumed, equivalent to 12.4 mg per day. To respire at this daily rate the seedling would have required 9 ml of O_2 and would have evolved 9 ml of CO_2, a trace of water (8 μl) and 44 calories of heat.

A 200-seedling package (which we will use as a basic standard package for calculations) at 2°C would therefore require 1.8 litres of O_2 and would evolve an identical volume of CO_2, 1.6 ml of water and 0.4 W of heat each day.

If the temperature had been 25°C, which is not uncommon in unchilled packages, the respiration rate would be increased some 15 times (U. Benecke, pers. comm.). Assuming O_2 could be maintained to the seedlings, the carbohydrate resource that lasted 6 weeks at 2°C would not last *3 days*. Should O_2 supply to the seedlings be restricted, conditions would become anaerobic. In addition, the heat produced (6 W/day) would further raise the temperature and increase the respiration rate. The prevention of moisture loss and the maintenance of ventilation for respiration are the essential requirements of good storage.

The recommendations that follow are drawn from a combination of experimentation and experience with species for Protection Forestry Division revegetation work. The primary objective has been to achieve long-term storage of 4 to 6 months to allow seedlings grown in low-altitude nurseries to be held until planting sites at high altitude are accessible and snow-free. The principles that have evolved are pertinent to any bare-rooted seedling for which there is a delay of 1 day or more between lifting and planting.

TYPES OF COOL STORE

Two basic designs of cool store exist: the standard directly chilled store and the indirectly chilled or jacketed store.

Directly chilled cool stores have the cooling coils exposed to the atmosphere within the storage chamber. As the coils must be cooler than the atmosphere in order to achieve the necessary absorption of heat, condensation as water or ice forms on the coils, and the air within the cool store is dried. The degree of drying, or water vapour deficit, of the air within the store is not great, but when seedlings are exposed to it for a long period desiccation will occur. A large surface area in the cooling coils will increase their efficiency and minimise the temperature difference and consequent drying. Packaging of seedlings is essential in these stores to prevent desiccation.

Jacketed stores have a light alloy storage chamber constructed within an outer chamber or jacket of chilled air. The cooling coils are in the outer jacket and chilled air is forced around the storage chamber. Heat exchange through all the walls of the storage chamber gives a very large chilling surface and a minimal temperature differential with the atmosphere of the storage chamber. Consequently, condensation within the storage chamber is minimised, drying of the atmosphere is prevented, and seedlings can be stored with part or all of their tissues exposed for unimpeded access to oxygen. Packaging against desiccation loss is unnecessary. These stores were originally developed in Europe for the storage of fully exposed seedlings.

With an effective seedling package the jacketed cool store offers no additional protection. Directly chilled stores are cheaper to construct and have the added advantage of vigorous and continuous air circulation which minimises the boundary layer of still air close to the package surface, thereby ensuring rapid chilling and the clearing of warm or O_2-depleted air that can build up between stacks of packages.

With the mild climates of New Zealand and the nature of establishment operations, the single package from lifting to planting is desirable, and for this a directly chilled store is recommended (Fig. 1).

PACKAGING SEEDLINGS

Good packaging is the key to success in any bulk handling system. The package or container must provide for three basic requirements:

(1) the conservation of moisture;

(2) the demands of seedling respiration (oxygen and carbon dioxide exchange and heat dissipation);

(3) the planter's needs in seedling numbers, light weight and ease of handling.

Providing adequately for respiratory demands without allowing excessive moisture loss from a package is virtually impossible by direct ventilation. Seedling packages from non-

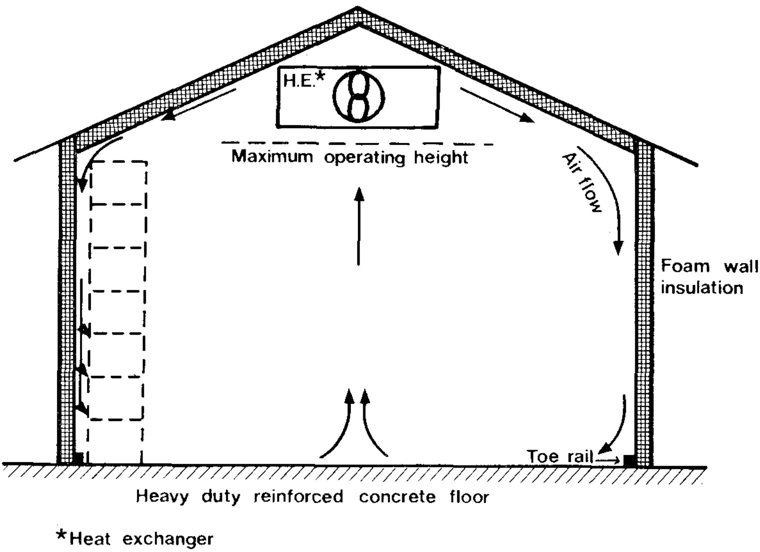

FIG. 1: *Basic design features of a directly chilled cool store.*

or low-permeability materials (high-density plastics or waxed cardboard) must have direct ventilation. The standard 200-seedling pack would need two holes 3 cm in diameter which must remain unobstructed in stacking to allow for respiration. Seedlings adjacent to vent holes would dry out within a few days.

Packages from semi-permeable materials are more desirable, as effective diffusion of essential gases is possible through the walls of the whole package. Only a small proportion of direct ventilation is required and water vapour loss is virtually eliminated. Polyethylene (polythene) film is commonly used in seedling packages to achieve this, but it is usually inadequate in thickness and cover. To be effective the polythene film has to be very thin and completely enclose the seedlings. In practice this means a thickness of 8-10 μm (as against usual polythene bag thicknesses of 50 μm), and the film must be supported on kraft paper for strength and durability. The barrier effect (resistance to diffusion) of several layers of paper in relation to the polythene is negligible.

Actual rates of diffusion depend on (a) the differences in concentration either side of the polythene, and (b) the temperature (Stannett *et al.*, 1962). At 2°C a bag with a 10 μm layer of polythene and a wall area of 1 m^2 would keep water losses below 10% of that generated by respiration. Oxygen diffusion could provide at least 50% of the total daily demand, and CO_2 concentration in the bag would not exceed 1% before diffusion through the plastic would maintain an equilibrium.

To achieve this, the surface area/volume ratio of kraft bags should be 25 : 1 (m^2/m^3) or higher. The bags should be closed by folding once and stapling at 10 cm intervals to allow some direct diffusion.

Heat dissipation is also an important quality, especially in the initial chilling stage of cool storage. Here also the surface area/volume ratio can be used to define package proportions. The semi-permeable packages discussed above have a very favourable specification of 25 : 1, and this ratio should not fall below 15 : 1 (m^2/m^3) in directly ventilated packages to ensure rapid chilling of the contents.

Excessive crushing or compaction of seedlings within the package can quickly nullify any advantages of good package design. Compaction restricts air circulation, creating pockets of warm, oxygen-depleted air in which moulds and fungi rapidly develop. Infected tissue cannot recover and seedling vigour is rapidly destroyed. Deciduous species can be packed quite densely, as bark and buds cannot easily be smothered and respiration is less in plants without foliage. Seedlings with stiff bristly foliage hold themselves apart and allow essential circulation and diffusion. Lank, floppy foliage smothers itself and quickly develops pockets of mould. No hard and fast criterion exists to cover compaction, but experience suggests that each kilogram of seedlings would require a volume of about 8 litres.

Advantages with packaging weigh heavily in favour of the semi-permeable polythene-lined kraft paper bags. These provide an optimised micro-environment for seedlings at all times. irrespective of the type of cool store. In addition, they are light, easily handled and can be varied in size according to seedling dimensions and numbers required. They are also cheap to produce and biodegradable. Most importantly, they need only be opened at the moment of planting. Their only limitation is the lack of rigidity for stacking. Bulk handling would therefore need a suitable stacking pallet.

EFFECT OF COOL STORAGE ON SEEDLINGS

Figure 2 illustrates how the growth of *Pinus mugo* seedlings was affected by lifting in July (J) and September (S) and cool storage for 0, 6 and 12 weeks. This gave four planting dates: July for J0, September for J6 and S0, October for J12 and S6, and early December for S12. Growth response relates much more to date of planting than to cool storage or lifting treatment. *Pinus mugo* thus shows little deterioration that is

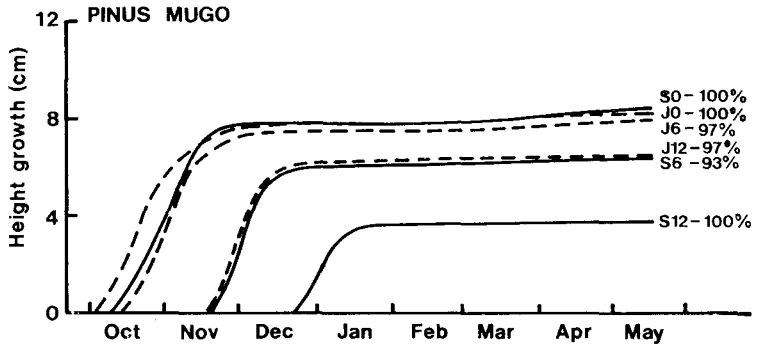

FIG. 2: *Height growth of* Pinus mugo *seedlings in the season following cool storage. Seedlings were lifted in July (J) and September (S) and cool-stored for 0, 6 and 12 weeks. Percent survival is given with each treatment notation.*

directly attributable to cool storage over these periods. The date-of-planting effect is attributed to warmer and drier site conditions imposing increasing moisture stress durng the establishment of successive plantings.

Pinus radiata in the same trial showed quite distinct storage and lifting effects (Fig. 3). Delaying lifting until September caused a greater reduction in growth than cool storing July-lifted seedlings for September planting. In other words, the cool-stored seedlings were better equipped to survive the stresses associated with planting than were those left in the seedbed for late planting.

The effect of storage is determined by the physiological characteristics of the species. It is most important that the seedling has a food reserve capable of sustaining it through the storage period, and that the photosynthetic process can survive a long period of cold, dark conditions (McCracken, 1978, 1979).

Respiratory consumption of the food resource of a seedling can be substantial during cool storage. This resource of carbohydrate was also found to be of importance to shoot extension growth following cool storage in *Pinus mugo*. Figure 2 illustrates the rapid uninodal growth of this species that occurred entirely at the beginning of the season or immediately following planting and is typical of species with determinate growth characteristics. Current photosynthesis at the time of shoot extension possibly contributes little to the extent of that growth.

Pinus radiata has a similar level of carbohydrate at lifting but utilises this much more rapidly during storage. Initially, growth is slow following planting (Fig. 3) and is related more to the recovery of photosynthetic activity. The carbohydrate resource is clearly vital to the seedling but its precise role in establishment and growth is not as clearly defined in *P. radiata* as it is in *P. mugo.*

The potential for photosynthesis is also affected by cool storage and declines steadily over storage periods of up to 12 weeks. In *P. radiata,* recovery of photosynthesis only occurs with alleviation of the water stress that typically follows planting. Under the conditions of the experiment this was found to take at least 4 weeks. In *Pinus mugo* seedlings, post-planting moisture stress is less and recovery of photosynthesis is steady from the time of planting.

DURATION OF COOL STORAGE

Experience with the wide range of genera and species available to forestry operations is limited. However, the essential characteristics that determine the maximum period of storage can be defined, and storage duration for important genera and species is given in the accompanying table against these characteristics.

Characteristics	*Genus or Species*	*Maximum Storage Period*	*Remarks*
Deciduous	*Larix* *Alnus* *Betula*	20 weeks	Good packaging characteristics with stiff branches and no foliage.
Evergreen (1) Broadleaf	*Eucalyptus* *Nothofagus*	3 weeks	Seedlings must be given ample space in the package to avoid leaves smothering each other.
(2) Coniferous (needle form foliage)	*Pinus mugo* *P. contorta* *P. ponderosa* *P. sylvestris*	18 weeks	Determinate growth species with intense winter dormancy.
	Pseudotsuga menziesii *Pinus nigra*	12 weeks	
	Pinus radiata (*P. muricata*)	6 weeks	Indeterminate growth in seedling stages. Intensity of winter dormancy dependent on local climate and wrenching regime.

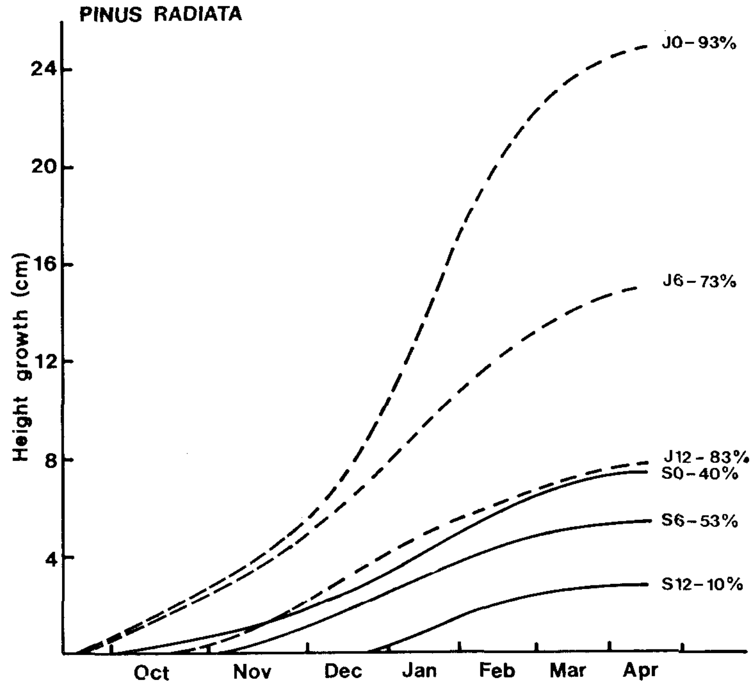

FIG. 3: *Height growth of* Pinus radiata *seedlings in the season following cool storage. Seedlings were lifted in July (J) and September (S) and cool-stored for 0, 6 and 12 weeks. Percent survival is given with each treatment notation.*

In the absence of other information the climatic zoning of the origin of a species or provenance can be a useful indicator of maximum cool storage period: subtropical and warm-temperate species, 1 week; cool-temperate, 8 weeks; alpine or arctic origin species, 12 weeks. Longer periods should only be used after suitable experimentation.

From the limited information on the physiological effect of cool storage it is clear that long-term storage is made at some expense to vigour. Reduced food reserves and slower recovery of photosynthetic potential are contributing factors. This disadvantage must be weighed against any advantage in carrying planting to later in the season. In protection forestry operations at higher altitudes (above 1000 m) there is no choice, as planting is impossible at virtually any stage of winter and well into spring on many sites. In production forest operations, cool moist sites should be held for late plantings of cool-stored seedlings to minimise post-planting water stress and give the seedlings the opportunity to establish before the severe stress of summer.

THE SYSTEMS APPROACH

Seedling handling must be viewed as a system designed to provide maximum protection to the seedling from lifting through packaging, storage and transport, right to the moment of planting. Systems that attempt to achieve this are in operation from a number of nurseries, but in the author's opinion all have some shortcomings that are likely to result in reduced growth or poor survival of seedlings following planting.

For virtually all forest nursery production in New Zealand a system including the following features would provide the maximum protection to seedlings right to the moment of planting.

Pretreatment should promote the production of hardy seedlings with mature, dormant shoots and strong, fibrous roots. Root wrenching is essential and mycorrhizal associations should be encouraged. Treatments that may promote new growth late in the season should be avoided.

Culling wherever possible should be completed before lifting. Seedlings with poor root systems should be rejected before packaging.

Lifting should be carried out with a belt lifter delivering directly into the package. Low stature or easily damaged species that have to be hand-lifted can be packed at the packing shed, but root systems must be kept moist in transit and during packaging. Seedlings for long-term storage (6 weeks plus) must be lifted in midwinter (June and July) when dormancy is most intense.

The package, a polythene-lined kraft paper bag. Two layers of paper with the inner one coated ("Capcote"; registered process of N.Z. Forest Products Ltd) with an 8 μm film of polythene. Bag dimensions to suit a minimum of 200 seedlings (around 600 × 600 × 120 mm for 200 1/0 *P. radiata*). Top of bag folded once and stapled four times.

Stacking would require containers (1.2 × 1.2 × 0.5 m with open slatted sides), each carrying 18 to 20 bags or around 4000 seedlings. These should be light enough to be individually manhandled and capable of being stacked up to six to eight high by forklift.

Cool store directly chilled and set for 2°C with minimum fluctuation. Double access doors will avoid load-in/load-out confusion. The ceiling should be pitched up to allow the chillers to hang in the ceiling, above the height of storing operations, and blowing out either side. Freshly chilled air then tracks down the walls, the main source of heat gain. To minimise condensation and water loss from the store, the chillers need a large surface area. To store 1 000 000 seedlings (*i.e.*, 250 containers as described above), the basic dimensions would need to be around 10 × 10 × 4 m (400 m^3), allowing for stacking containers eight high and a 3 m aisle for forklift operations. The forklift is the simplest and most versatile unit for load-in/load-out operations. Store dimensions could be more cuboid and therefore more efficient on a volume for surface area basis if stacks could be made higher. This would depend on the stacking stability of the containers and the reach of the forklift.

Transport to local forests less than 2 hours' drive away would be by covered truck. For more distant forests refrigerated trucks should be used. Temperatures should be the same as in the cool store (2°C).

Forest storage would be in portable, insulated shelters that can be replenished every 1 to 2 days. Forests distant from the nursery should have a small cool store to hold up to 1 week's planting needs.

Planting is direct from the kraft bags that can be slung on the waist in normal planting bags or some adaptation thereof.

To gain full benefit from such a handling system the actual planting operation must be closely supervised and bags must not be bashed around and sat on. This damages foliage and destroys any control the seedling may have over moisture loss following planting. Standards of planting must be high to capitalise on the benefits gained from improved handling. Cool storage in no way compensates for poor quality at any other stage of seedling production or establishment.

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