7 Producing planting stock

Raising radiata pine plants in nurseries is a vital component of the plantation cycle because direct sowing and natural regeneration are now seldom employed. A range of techniques has been used to raise radiata pine planting stock (Table 7.1). In Australia, New Zealand and Chile, bare-rooted plant production predominates, but container-grown stock is more common in South Africa and Spain. South Africa experimented with bare-rooted stock in the 1970s but has since moved to container stock (Donald *et al.*, 1994); this has also occurred in Western Australia. Micropropagation techniques are gradually becoming more common but currently provide only relatively small numbers of planting stock. Some methods, such as grafting, have been employed for specialist uses such as seed orchards.

Today's nurseries can produce radiata pine plants that will both survive and quickly begin rapid growth. The techniques are firmly based on seedling physiology, including nutrition, a century of practical experience, and more recent technical innovations in sowing, plant conditioning, container design and micropropagation. Further, a systems approach allows nursery and forest managers to integrate silviculture, beginning at the seed source through nurseries to the establishment phase and beyond. It is important that the key people running the nursery have a close association with the plant users and appropriate research scientists who can advise on plant physiology, soils, diseases and other potential problems. The nursery gate should be an administrative boundary, not a silvicultural one.

In this chapter, the terms plants and planting stock are used generically, while the terms seedlings, cuttings and plantlets are used to describe particular types of plants raised in nursery facilities.

THE SYSTEMS APPROACH AND SETTING OBJECTIVES

The integration of the nursery with other parts of the establishment phase and with management in general implies that the nursery is part of a larger structure, making a

TABLE 7.1
Plant types and their key characteristics available for planting *Pinus radiata*

Type	Characteristics
Direct from seed	
Bare-rooted seedlings	1+0[a] (1.5+0); large scale
(Transplants)	(1+1 – 1+3); infrequent
Container seedlings	Often <1 year; medium to large scale
Vegetative methods	
Grafts	~2 years; special uses only (e.g. seed orchards)
Juvenile cuttings	C1+0[b] year; common; collect from field or nursery stools; often bare-rooted; small to large scale
(Cuttings – old trees)	Special uses only
(Fascicle plantlets)	Started in greenhouse; occasional
Tissue culture / embryogenesis	Laboratory + nursery; often bare-rooted; ~1 year; moderate scale; being developed

Note: a = number of years as a seedling, plus the number of years as a transplant; b = the "C" prefix indicates rooted cuttings; those types in brackets are rarely used on a routine basis.

systems approach vital (Trewin and Cullen, 1985; Toro, 2004). The nursery phase of this larger system should be designed to produce the types and quantities of plants required at the times required. The value of such an approach was demonstrated by South *et al.* (1993), who showed that nursery practices that resulted in greater seedling diameter were less costly than later silvicultural practices, such as weed control, used to obtain the same growth after several years.

A key to the nursery phase is to define the type of plant required. Generally, the main objective is to produce plants that will survive the rigours of being transferred from the nursery to the field as well as the particular site conditions and will grow rapidly after planting. These objectives should be quantative – for example, demanding a minimum one-year survival rate of 90 percent. Such performance objectives then need to be reinterpreted into practical objectives and criteria for raising the plants in a nursery.

Optimum planting stock

For radiata pine, research has established that a number of plant features as well as nursery practices can be used to describe those plants that are likely to have a high chance of survival and rapid initial growth in the field (Table 7.2). They identify the ideotype that should be aimed for and expected by the plantation manager or buyer.

Planting stock height, by itself, is a poor indicator of subsequent performance and there is no advantage associated with plants over 30 cm tall (Menzies *et al.*, 2005). However, for bare-rooted stock, a minimum size of 20 cm is needed to ease handling. Container seedlings are typically smaller than bare-rooted stock (15–25 cm). Tree collar diameter, sturdiness and oven dry weight are better indicators of planting stock quality (Balneaves and Fredric, 1973; Menzies, Holden and Klomp, 2001). While physical measures are useful indicators of underlying physiological conditions, they

TABLE 7.2
Specifications for bare-root radiata pine seedlings and cuttings*

Indicator	Specification	Measuring technique	Achieved by
Root growth potential[a]	4–5 on a 0–5 visual scale	Lift, grow, lift and assess new roots	Wide spacing; regular conditioning; hand-lifting
Fine roots and myorrhizae at lifting[b]	Abundant – some soil on roots (vertically trained, non-spiralling for container stock)	Inspection	Mycorrhizal inoculation; regular conditioning; hand-lifting
Root length	~10 cm	Inspection	Careful trimming
Seedling nutrients	See Table 2.1	Analysis of tops	Fertilizer application
Soil nutrients	See chapters 2 and 7	Soil analyses	Fertilizer application
Water potential[a]	<0.5 Mpa	Pressure bomb	Adequate water before and during lifting; wet and cool storage; careful handling
Height	20–40 cm (15–25 cm for container stock)	Root collar to top	Timing of sowing and undercutting or topping
Diameter[b]	>5 mm (3–5 mm for container stock)	At root collar	Wide spacing; regular conditioning
Sturdiness	40-60	Height/diameter	Wide spacing; regular conditioning
Frost tolerance[a]	-12 °C winter; -6 °C summer	Test using artificial frost rooms	Grow seedlings at high elevation or inland nurseries
Pests or diseases	Absent	Inspection	Control measures

Note: * Height, diameter and root specifications for container stock are also presented; a = used less commonly, although important; b = cuttings should have roots in two or more quadrants and a collar diameter of 8–10 mm.
Sources: Maclaren, 1993; Menzies, Holden and Klomp, 2001.

do not unveil the full story. For example, seedlings of the same diameter, grown at wide seed-bed spacing, outperform those grown close together, presumably because of better root growth potential (Figure 7.1). How plants are grown and handled in the nursery is as important as the physical attributes of seedlings.

Table 7.2 lists tests of whole seedlings, sometimes under controlled conditions, although such tests are not used readily on a day-to-day basis. However, they can be translated into schedules that may be followed in the nursery and that are likely to produce the required type of plant. For example, root growth potential is related to good survival and growth after planting, while the root system needs to be compact and able to be lifted easily. This has been translated into undercutting, wrenching, lifting, root trimming and subsequent handling systems for open-grown plants.

SEED HANDLING

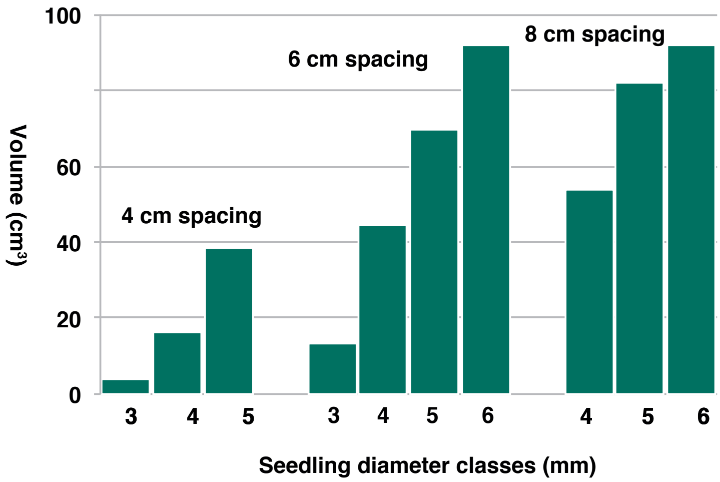
Seed handling in radiata pine is straightforward compared with many other species. The serotinous, prickly, persistent cones are hand-picked with gloves, often with the assistance of a simple tool. If necessary, the cones can be artificially ripened under mild drying conditions, such as in a well-ventilated shed, and can be stored in sacks prior to seed extraction (Rimbawanto, Coolbear and Firth, 1988), although some seed orchards are moving away from this practice. Green cones should not be kept in conditions of high humidity, however.

Cones are generally opened in well-ventilated kilns, solar kilns or glasshouses at 60–65 °C for six hours (Burdon and Miller, 1992). An actual cone temperature of 65 °C for four hours does not decrease viability. This heating breaks the resinous seal between scales and opens the scales enough to release the seeds. After opening, the cones are tumbled to extract the seeds, which, after de-winging, are usually cleaned by air flotation. If required, the seeds can be sorted by size.

The longer the seed has to be stored, the more exacting are the required conditions. The retention of viability is higher at lower temperatures and lower oxygen levels. Radiata pine seeds stored in airtight containers at ambient temperatures (23 °C maximum) will remain viable for several years, provided they do not have a high moisture content (Burdon and Miller, 1992). A seed moisture content of 9 percent is often recommended. Alternatively, keeping the seeds in a vacuum or replacing the oxygen with carbon dioxide or nitrogen will maintain germinating capacity and vigour for a long period. This latter technique has been used in Western Australia. Note that many other species need to be stored at lower temperatures than radiata pine (e.g. 2–3 °C).

FIGURE 7.1

The effects of spacing within the nursery bed and seedling diameters at lifting, on volume index (D^2H) at the end of the first growing season after planting



Source: Adapted from Balneaves and Fredric, 1983

For radiata pine, there are usually 25 000–40 000 seeds per kg, although numbers outside this range have been reported (Burdon and Miller, 1992). Viability is usually in excess of 75 percent; many growers use this figure as a basis for estimating seed requirements, but individual experiences with losses and culling practices should also be taken into account. In the absence of suitable information, it would be reasonable to assume about 15 000 saleable seedlings per kg of seed. About 20 percent of radiata seeds may be expected to show dormancy, meaning that such seeds do not geminate quickly if not stratified.

The traditional stratification procedure has been to soak the seed in water for 24–48 hours (removing the empty seeds, which float), drain and then seal in plastic bags at 2–4 °C for 30–40 days. This treatment breaks the dormancy by simulating what would happen naturally if the seed fell in autumn. Stratification ensures rapid, even and complete germination, although this can be vitiated if the soils dry out or are excessively wet at, or after, sowing. However, most radiata pine growers have found that the coolstore period is unnecessary and now soak the seeds in water for only 24 hours, particularly if they are fresh and have good germination energy (Burdon and Miller, 1992; Escobar, Sanchez and Pereira, 2002). Prior to sowing, seeds may be coated with fungicides or bird repellents.

BARE-ROOTED PLANTING STOCK PRODUCTION

Bare-rooted radiata pine is usually grown as 1+0[1] , sown in spring for planting the following winter, or occasionally as 1½+0 seedlings, sown in autumn (Figure 7.2; Menzies, van Dorsser and Balneaves, 1985; Escobar, Sanchez and Pereira, 2002). To obtain satisfactory seedlings, the nursery manager must pay particular attention to:

- choice of nursery site;
- seed bed preparation;
- seed sowing (both depth and spacing are critical);
- conditioning through root pruning and wrenching;
- soil and nutrient management;
- control of weeds and pests.

Considerable care is required in choosing the nursery site and its layout, as it can make a very large difference to the ease and cost of raising acceptable planting stock (Shepherd, 1986). Important attributes for the nursery site are:

- climate and microclimate – avoid very exposed or frosty sites and ensure there is adequate protection from erosive and desiccating winds. Rainfall and its seasonal pattern are important if irrigation is unavailable;
- topography – reasonably level, ideally with a slight slope (less than 5 degrees) to ensure good water and air drainage;
- the availability of ample water supplies;
- proximity to labour and servicing facilities and other infrastructure such as roads and electric power;
- soil, particularly its physical rather than fertility status – it needs to be capable of withstanding considerable mechanical usage and the weight of tractors in the winter. Well-drained, deep, stone-free, coarse-textured soils such as loamy sands or sandy loams with a silt and clay content of 10–25 percent have the most suitable trafficability, workability and root penetrability. Soils that are alkaline, saline, derived from ultrabasic rock or have other toxicity problems should be avoided. However, some unusual parent materials have proved to be acceptable, such as rhyolitic pumice and peat;
- low risk of erosion (wind and water) or flood;
- no known disease problems, such as *Phytophthora* root rot.

1 The two-number system (e.g. 1+0) denotes the number of years in the seedbed followed by the number of years as lined-out plants in the nursery.

FIGURE 7.2
Bare-rooted radiata plants are grown in long raised beds

Note the fallowed area in grass to the left.

The layout of the nursery requires careful planning. The main points to consider are access, the location of buildings, water storage and reticulation facilities, shelter requirements, the length of the beds (usually best at 200 m or more in length; Figure 7.2) and their relation to topography.

Seedbed preparation

Good nursery-bed preparation and forming is necessary to ensure accurate sowing of seed; good conditions for plant growth; the use of specialist machinery; and ease of harvesting. It involves preparing raised seedbeds of fine tilth, ensuring that soil fertility is correct, and controlling weeds or other pathogens.

New or fallowed land has to be ploughed prior to seed-bed preparation (Shepherd, 1986). This is usually carried out the previous autumn to allow the ploughed-in vegetation to break down. All areas will normally require further cultivation, several weeks prior to sowing, in order to produce a fine tilth. A base fertilizer dressing is evenly spread and worked into the top 10–15 cm at about the time of spring cultivation, although it may be delayed to the time of bed formation if slow-release fertilizers are being used.

The raised beds may be formed before sowing, although many nurseries use machinery which both raises the bed and sows the seed in one operation. Nursery beds are raised to about 10 cm to assist drainage and subsequent operations such as undercutting and wrenching. The formed beds are lightly rolled before the seed is sown. On some sites, where weeds are a problem it may pay to allow the seeds to germinate and to spray them before sowing. Soil fumigation before sowing is rarely undertaken and, unless essential, is best avoided as it can kill mycorrhizae.

Seed-sowing

In all the larger radiata pine nurseries, the seed is mechanically drill-sown. The old “Stanhay” drill-sower has been supplanted by vacuum precision drum-sowers developed in New Zealand, as these allow greater control of spacing within the drill row. The vacuum drum-sower produces over 90 percent singles, with an average placement error of less than 1 cm.

The critical factors to control are depth of placement, spacing between seeds, and the timing of sowing (Menzies, van Dorsser and Balneaves, 1985). Depth influences germination percent, bird predation and uniformity. Spacing has a major influence on the morphological characteristics of the seedlings and their subsequent performance in the field. It is important to provide the plants with space to intercept light and to minimize other competition effects. Well-spaced trees are also easier to lift and, because the roots are less intertwined, there is reduced damage to fine root systems and less loss of mycorrhizae. The timing of sowing influences final seedling size.

Sowing depth is usually 5–10 mm for radiata pine, although it may need to be a little deeper in soils where the surface is likely to dry out. Interdrill distances are usually 12–15 cm, and 5–6 cm along the rows (Menzies *et al.*, 2005; Escobar, Sanchez and Pereira, 2002). Autumn-sown seeds are often planted at wider spacing.

Spacing may also be controlled by thinning the nursery beds when the seedlings are 10–20 cm tall or even earlier (Menzies, van Dorsser and Balneaves, 1985). Such culling practices not only allow for higher-than-anticipated germination or where more than one seed has been sown, it also allows for the removal of less desirable seedlings. Some seedlings, perhaps as a result of bird or insect damage, are forked near the ground, and it is easier and cheaper to remove malforms and runts by in-bed culling than at lifting.

A seed covering is sometimes applied over the drill-sown beds to avoid soil cracking and to assist seedling emergence. Pine sawdust works well and is preferred to sand or fine gravel, which can promote damping-off or heat damage in summer (E. Appleton, personal communication, 2012).

Conditioning

The conditioning of bare-rooted plants is aimed at ensuring immediate prolific new root growth after planting, which in turn will help to ensure high survival and rapid initial growth (Menzies, van Dorsser and Balneaves, 1985). Conditioned planting stock is able to withstand the stresses of lifting, transportation, transplanting and mishandling. The development of conditioning techniques is based on understanding the growth habits of the species, including natural conditioning processes, and how various treatments influence conditioning.

In their first year, radiata pine seedlings make most of their height and diameter growth in the latter half of the growing season. Growth (more so height than diameter) slows during autumn and winter, but seedlings do not form a true dormant bud. These changes at the end of the growing season are a result of natural conditioning caused first by a shortening photoperiod, followed by a second stage of acclimatization to lower temperatures and particularly frost. This natural conditioning produces sturdier seedlings, influencing height more than diameter, and varies depending on the climate and latitude of the nursery. With radiata pine, natural conditioning needs to be augmented by the mechanical undercutting, wrenching and topping of seedlings. Some nurseries design their schedules to partly use natural conditioning.

In contrast to many slower-growing evergreen species (e.g. firs, spruces, Douglas fir and podocarps), it is necessary to induce radiata pine to produce fibrous root systems. Thus, mechanical conditioning with radiata pine has a twofold aim: to slow height growth and to produce a more fibrous root system. Before the development of the mechanical techniques described below, radiata pine seedlings were wrenched using spades (Matthews, 1905). Little wrenching is required for those species that produce fibrous root systems or store reserves in their stems and roots (e.g. deciduous trees), apart from undercutting to sever sinker roots.

Three types of operation are involved currently in the mechanical conditioning of radiata pine (Menzies, van Dorsser and Balneaves, 1985; Menzies *et al.*, 2005; Escobar, Sanchez and Pereira, 2002):

- Undercutting – the passing of a reciprocating, horizontal, flat, thin, very sharp blade beneath the seedbed to sever the taproots. Radiata pine is usually undercut at a depth of 5–8 cm when seedlings are about 20 cm tall. The operation is first undertaken prior to the first wrenching. Sometimes if the seedlings are not tall enough or the soil is too dry, the seedlings may first be undercut at a depth greater than 10 cm, and perhaps undercut at a shallower depth only in autumn. This later undercut will also remove any damaged taproots, allowing a new callus to form, which, provided that it is timed right, should allow rapid sinker-root development after planting. In Chile, radiata pine is usually undercut at a depth of 12–15 cm (Escobar, Sanchez and Pereira, 2002).
- Wrenching – the passing of a horizontal, thicker, tilted (at approximately 20 degrees), generally blunt blade beneath the seedbed. This severs any small roots growing below that point, aerates the root zone and encourages fibrous and mycorrhizal root development. Wrenching is repeated at intervals. To avoid bending the taproot, the blade is usually passed just below the undercutting depth and in opposite directions at successive wrenchings.
- Lateral root pruning – the passing of coulters (in preference to vertical knives) between rows of trees to sever lateral roots so as to restrict fibrous root development within a more limited volume of soil. This is often performed at six-week intervals. The concept of boxing involves lateral pruning across as well as along the rows but is not used in practice.

The physiological effects of these operations have been studied intensively and are summarized by Menzies, van Dorsser and Balneaves (1985). The effect of shallow undercutting is to impose a sudden shock, often causing wilting in dry weather. Some nurseries irrigate. Once the plants recover from this shock, the photosynthates are preferentially channelled to the root system, away from the shoot. The growth of both height and diameter slows, although the net effect is a tree with a lower height-to-diameter ratio. Root growth proliferates, particularly if temperatures are above 11–14 °C and if wrenching is also undertaken. Stomatal resistance in the needles is higher than in unwrenched seedlings. Undercutting and wrenching can cause yellowing, which can be corrected by applying nitrogen before and during the conditioning period. Very chlorotic seedlings may stagnate after planting. On planting out, conditioned seedlings are better able to maintain a favourable water balance and to readily absorb nutrients.

The timing of these operations is important. If undercutting or wrenching is done too early, seedlings may not reach a plantable size, as shoot growth slows considerably following the severing of the tap root. If the operations are delayed to autumn, seedlings are unlikely to become conditioned because they are not photosynthesizing rapidly enough and a smaller proportion of the photosynthates are translocated to the roots (e.g. 15 percent instead of 30 percent).

Thus, undercutting and wrenching are performed when the climate is favourable for growth and when there is vigorous height growth (Menzies, van Dorsser and Balneaves, 1985). Undercutting is often initiated to allow 2.5 months of active growing. Thus, the time of sowing needs to be prescribed so that the seedlings reach the desired size for undercutting and to obtain the required size of planting stock. In some circumstances, such as in locations where the growing season is short or larger planting stock is required, there can be advantages in sowing in autumn.

The frequency of wrenching has an influence on the type of planting stock produced (Menzies, van Dorsser and Balneaves, 1985). Wrenching at weekly to biweekly intervals produces stock with a high root/shoot ratio; wrenching less frequently at, say, monthly intervals does not produce as high a ratio but does increase carbohydrate reserves. Very frequent wrenching promotes fine roots at the expense of larger-diameter roots, which can be a disadvantage when planting on very fertile sites (A.R.D. Trewin, personal communication, 2012). Many nurseries wrench at about three-week intervals and some rely on topping seedlings as well. Seedlings can be held in a conditioned state for several months by continued wrenching, if required.

Topping is also practised to control height growth (Menzies, van Dorsser and Balneaves, 1985; Escobar, Sanchez and Pereira, 2002; A.R.D. Trewin, personal communication, 2012). If it has to be done more than once, it is best to top successively downward to final seedling height. Topping has the added benefit that the trees are not so readily browsed after planting.

Thus, the nursery operator is able to manipulate the type of plant stock being raised. Moreover, the type of plant produced and the way it is planted are related. Conditioning by wrenching can be reduced, but not eliminated, to encourage larger roots when trees are planted deeply using the positive pull-up technique (see Chapter 8; A.R.D. Trewin, personal communication, 2012). Together, they may result in greater tree stability.

Soil and nutrient management

Growing bare-rooted planting stock places considerable stress on the nursery site because nutrients, together with some soil adhering to the roots, are removed with each crop. Soil organic matter also decreases over time, and this, together with the use of machines, may degrade the soil structure and nutrient buffering capacity. Considerable care is therefore required to ensure that crops do not suffer from nutrient stress and that the soil structure does not deteriorate.

The basic principles of nutrient management, outlined in Chapter 10, also apply in nurseries. In nurseries, the role of nutrient cycling is minimal, except where cover crops or organic matter are deliberately used in a fallow phase. However, removed nutrients need to be replaced. Another major difference is that the annual nutrient demand is high (Table 7.3), although the uptake of added fertilizer is higher than that often observed in plantations. Studies in Victoria, Australia, found that, in nurseries, seedlings used 27–46, 4–8 and 32–41 percent of the fertilizer-applied nitrogen, phosphorus and potassium, respectively (Hopmans and Flinn, 1983). Knight (1978a) suggested that the total application of fertilizers needed to be 2–3 times the actual removal for nitrogen and potassium and about ten times for phosphorus.

Usually, nitrogen, phosphorus and potassium need to be applied to each crop, and on some sites magnesium and some micronutrients will be required as well. In New Zealand, for example, foliar-applied boron is sometimes used because it promotes root growth and is a common forest deficiency (E. Appleton, personal communication, 2012). Usually, the trees will receive enough calcium and sulphur from the soil or from the fertilizers used to supply other nutrients.

TABLE 7.3
Mean nutrient content in open-grown seedlings, at lifting

Age class	Height	Diameter	Dry weight	N	P	K	Mg	Ca
	cm	mm	kg per 1 000 seedlings	grams per 1 000 seedlings				
1/0	34	59	10	120	13	75	7	28
1½/0	49	86	24	278	32	151	17	81
			tonnes per ha	kg per ha				
1/0	34	59	4.3	52	6	33	3	14
1½/0	49	86	9.6	100	12	54	6	31

Note: Data are reported in two ways (per 1 000 plants and per ha). There was considerable variability between the nurseries sampled. See Knight (1978b) and Hopmans and Flinn (1983) for further details.

Generally, fertilizer applications are split into two distinct phases:

- Pre-sowing applications (so-called basal dressings) – this will often include those nutrients or forms of nutrients that are unlikely to be lost in leaching and that will be available over a significant proportion of the growing season; the objective is to top up the soil reserves. The use of soil tests is valuable in this phase. In New Zealand and Chile, a common procedure is to apply superphosphate (phosphorus and its secondary nutrients, sulphur and calcium), and perhaps other slower-acting and inexpensive fertilizers such as calcined magnesite (for magnesium) and lime (to correct pH), on the basis of soil tests (Knight, 1978a; Menzies *et al.*, 2005; Escobar, Sanchez and Pereira, 2002). Some nurseries in Australia have opted for the more costly alternative of applying specially formulated, slower-release, balanced fertilizers. In both cases, rates are fairly high and the fertilizer is mixed into the top 10–15 cm of the soil, allowing sufficient time (up to one month) prior to sowing to avoid injury to the germinating seedlings from high concentrations of dissolved fertilizer.
- Maintenance dressings – as the crop develops, the demand for nutrients increases so that additional nutrients are normally needed. Usually, the more soluble nutrients are required most frequently. To ensure the balanced nutrition of the growing crop and to counter the depletion of the soil nutrient capital, multi-nutrient, granulated fertilizers are often applied to the soil surface between rows (Knight, 1978a; Menzies *et al.*, 2005; Escobar, Sanchez and Pereira, 2002). Many nurseries apply 2–4 side dressings. Foliar applications of liquid fertilizers may also be used. Fertilizer rates are adjusted as the plants develop.

Foliar analysis is seldom used on a regular basis for prescribing maintenance dressings because of the delay in getting results, although they are used when a nutrient problem appears. Rather, maintenance dressings are prescribed on the basis of anticipated nutrient demand, the careful observation of the crop (colour, uniformity and rate of growth, etc.), the limitations of the application technique, and, for soluble and liquid fertilizers, the advisability of erring on the "sparing" rather than "generous" side. The symptoms of nutrient deficiencies in seedlings are described in detail by Will (1985); see also Table 2.1. The nutrient status of seedlings may affect their drought resistance and survival (Knight, 1978a).

Soil management also involves caring for organic matter and soil physical condition. The two are linked, because humic materials produced by the microbial breakdown of organic matter influence the stability of soil pores and soil structure. The workability of heavier soils, with higher clay content, is very dependent on their structure – a friable structure is important for good aeration, water movement and root development and penetration. Soil organic matter is also a store for nutrients and has, like many minerals, cation-exchange properties that prevent the leaching of cations while allowing them to be available for plant uptake. Sandy soils, which are often used in nurseries, are heavily dependent on this property of organic matter.

Continuous planting-stock production usually leads to the depletion of humus through increased organic matter oxidation brought about by tillage and the lack of return of crop resides. Thus, an essential part of good soil management involves maintaining adequate levels of organic matter. Although soils with very low organic matter status can be managed successfully through the careful use of chemical fertilizers and skilled cultivation, it is easier to maintain a high level of productivity in soils richer in organic matter. The risk of crop failure is reduced if a good level of organic matter is maintained.

The nursery manager therefore needs to accept that extended periods of cropping will lead to the deterioration of the soil's physical condition. Adding organic wastes may not be feasible for some nurseries and can pose other problems (Shepherd, 1986). The usual policy is to take all practical measures to conserve soil structure and rejuvenate areas at regular intervals using restorative crops (Figure 7.2).

Practical conservation measures include:

- reducing tillage – weedicides rather than cultivation may have a role;
- the use of surface mulches to prevent damage of aggregates by intense rains and to minimize erosion – mulches also have other advantages, such as reducing moisture loss, frost heave and crusting;
- avoiding unnecessary machinery traffic and resulting compaction;
- cultivating when soil conditions are optimal;
- keeping the exposure of soil to erosion and leaching to a minimum;
- using windbreaks to prevent wind erosion;
- controlling pH –decomposition may be too slow in very acid soils but too rapid in near-neutral conditions;
- maintaining nutrient levels that will promote root growth and consequently assist pore formation in the soil.

The soil structure may be rejuvenated by resting fallow areas for extended periods (2–3 years, at a minimum) under a perennial grassland such as a ryegrass–clover sward. Regular mowing is required to increase the litter cycle, promote fine root growth and sustain the associated legume. Fertilizers, particularly phosphate, may be required. While helpful, the use of annual green crops that are ploughed in, and the addition of off-site organic matter, are not always as good as pasture (Shepherd, 1986). However, New Zealand nurseries established on heavier soils have successfully rotary-hoed 5–8 cm of composted pine bark into seedbeds at the time of the application of the basal fertilizer over several decades (E. Appleton, personal communication, 2012). Deep ripping can also be used to improve drainage on heavy soils.

Mycorrhizae

Ectotropic mycorrhizae benefit radiata pine by aiding nutrient uptake, decreasing the effects of soil toxicity, deterring root pathogens, increasing drought resistance and improving soil structure (see Chapter 2; Shepherd, 1986; Madgwick, 1994; Duñabeitia *et al.*, 2004). The lack of mycorrhizae in a nursery can be seen soon after germination and is most common when a new nursery area is brought into production or after soil sterilization. The seedlings do not develop at the normal rate and often appear to be suffering from acute phosphate deficiency. At a later stage, when there may have been some fortuitous inoculation, nursery beds may show very uneven growth, with patches of healthy and unhealthy seedlings. An inspection of the root systems will quickly show if a lack of mycorrhizae is the problem.

There are four main methods for introducing mycorrhizae, but some are preferred over others:

- Soil or duff inoculation – with this traditional method, surface soil and raw humus are collected from established plantations and incorporated into the surface of the seed beds. In this method there is no control over the mycorrhizal species and there is a risk of introducing pathogens. Transport costs can be high.
- Planting mycorrhizal seedlings – planting infected seedlings at 1–2 m intervals a year or two prior to raising a crop has been found to be reliable. There is a lower risk of introducing disease, but there is unlikely to be good control over the strain of mycorrhizae introduced.
- Spores and fruiting bodies – common ectomycorrhizal fungi produce readily identifiable sporocarps (fruiting bodies) that can be collected from other nurseries or from plantations and their basidiospores extracted. This technique is a big improvement over the first two techniques because the species of fungus can be chosen, the spores are readily stored from one year to the next and the amount of material required is small. Seeds may be inoculated prior to sowing if no fungicide is used, or the beds may be inoculated shortly after seed germination.

- Pure cultures of vegetative mycelia – mycelia inoculation has the advantages of being free from contaminants and mycorrhizae are formed sooner and in greater numbers compared with the use of basidiospores. The mycelia can also be supplied in the desired species or strain. Despite these advantages, however, this technique has not been widely adopted for radiata pine because it requires specialized cultural and laboratory techniques. There are sometimes difficulties in obtaining pure cultures, or they may grow slowly in medium and there can be logistical problems associated with incorporating the considerable volume of moist-inert carrier, such as vermiculate, in the soil. Liquid application of cultures has proved to be as good as solid applications and better than spores, at least for some species of mycorrhizae (Chávez, Pereira and Machuca, 2009). To obtain the real advantages of this technique, species and strains need be selected for their efficiency and their ability to compete with other mycorrhizae and fungi.

Irrigation

Many nurseries have irrigation systems, particularly where rainfall is unreliable or where greater flexibility is required (Shepherd, 1986; Escobar, Sanchez and Pereira, 2002). Adequate soil moisture is important for sustained plant growth and stock uniformity. There are also a number of critical points in the nursery cycle at which it is very useful to have irrigation, such as during and immediately after germination when the seedlings are very susceptible to drought, and at wrenching, when the plants are susceptible to moisture stress. Nutrients and some pesticides may be applied through irrigation systems. Irrigation can also be used to control wind erosion.

Irrigation systems need to be able to apply the right amount of water at the right rate and uniformly across beds. At times, too much water can be just as harmful as too little, for example by promoting damping off or causing excessive nutrient leaching.

Control of nursery weeds, diseases and pests

Weed control is important for ensuring high, uniform growth rates. Weeds compete strongly for moisture, nutrients and light. Modern nursery practice relies largely on the use of chemical weedicides rather than on hand or mechanical weeding (South, 1995). However, where labour is cheap, hand-weeding is frequently used, and many nursery managers will hand-weed if the problem is minor or where there are difficult weeds. It is essential that weedicide-resistant weed species are hand-weeded before flowering and seeding. Failure to do this can cause a rapid build-up of the weed and make them difficult to control.

Weedicides used in radiata nurseries can be categorized into three broad groups depending on their use:

- those that assist in the breaking in of new or fallowed areas, for example where a major objective is to reduce the weed seed population;
- those used in pre-emergence weed control – applied after sowing and aimed at a broad spectrum of germinating weeds;
- those used in post-emergence weed control – these are more selective and can be applied over seedlings when weeds are small and easy to kill and before they have seeded or pose significant competition.

Weedicide schedules vary according to the weeds being controlled, soil type and climatic condition. South (1995), Escobar, Sanchez and Pereira (2002) and Menzies *et al.* (2005) list the common nursery weedicides used in radiata pine-growing countries. It is important to consider the potential contamination of groundwater by weedicides, as well as their mammalian toxicity. Glyphosate is frequently used as a knockdown weedicide applied prior to seed germination. Propazine and oxyfluorfen are pre-emergence sprays that prevent weeds from becoming established.

The following pest insects and diseases occur in some radiata pine nurseries: thrips, *Colletotrichum acutatum* (terminal crook disease), *Sphaeropsis sapinea* (diplodia), *Dothistroma pini* and various *Botrytis*, *Fusarium* and *Phytophthora* species. These are usually controlled by improved hygiene, applying chemicals and quarantining. Recent research using selected *Trichoderma* and *Bacillus* isolates as biological controls have demonstrated increased seedling growth in the presence of some nursery diseases (Hill *et al.*, 2007; Donoso, Lobos and Rojas, 2008; Regliński *et al.*, 2012). These new techniques have the potential to reduce the use of fungicides. In Spain, nurseries are required to obtain health certificates (Fernández and Sarmiento, 2004).

VEGETATIVE PROPAGATION TECHNIQUES

Vegetative propagules – created either by cuttings or micropropagation – have been used at a large scale since the late 1980s (Table 7.1). Vegetatively produced trees have some different characteristics to seedlings, with these differences increasing with physiological age (Table 7.4). Thus, differences are greatest with cuttings from field-grown trees over five years old compared with those from stool beds and from micropropagation.

TABLE 7.4
Characteristics of cuttings compared with seedlings of *Pinus radiata*

Aspect/factor	Characteristics
Morphology	• Appreciable maturation reflecting the length along the stem axis from the seedling collar, although many comparisons quote tree (ortet) age • An earlier shift to produce sealed buds • Thinner, smoother bark • Greater apical control • Straighter stems, including less butt sweep • Improved branch habit such as fewer, smaller branches (or smaller branch mean basal area) with flatter branch angles • Less malformation • Less stem taper • Larger root systems, although rooting ability decreases with ortet age
Growth	• Reduced height and diameter growth (although not necessarily underbark diameter) if cuttings are taken from older trees • Reduced volume growth under bark with ramets older than 4 years (19 percent for ramets aged 5 years), and becoming more marked with ramets from older trees • Improved stand uniformity
Silvicultural aspects	• Differences in disease incidence has been reported, including less dothistroma and more *Armillaria* root rot • Sometimes increased susceptibility to browsing • Increased ability to withstand droughts, cold and wind • faster pruning
Use	• Changes in intrinsic wood properties – lower wood density and increased spiral grain and tracheid length from older ortets • Smaller knots • Stem cones form lower on the bole, but seedlings have more places to produce cones once this begins to occur • Increased log value has been reported based on sawing studies

Note: Most characteristics are more pronounced with older ortets and are reduced where the physiological age differences are small

Cuttings have been grown widely as bare-rooted plants, although they can also be grown in containers (Menzies *et al.*, 2005; Escobar, Sanchez and Pereira, 2002). In New Zealand, Chile and Australia, over half the production of radiata plants is obtained using cuttings, and some nurseries no longer grow many seedlings. Cuttings are not widely used in Western Australia, South Africa or Spain. Micropropagated plantlets may also be on-grown as open grown stock.

For large-scale production, cuttings are restricted to trees under four years of age (Escobar, Sanchez and Pereira, 2002; Menzies *et al.*, 2005). Shoot-tip cuttings may be taken from healthy, lateral branches of trees in the field or from stool beds in the nursery. The latter are seedlings grown at wide spacings (approximately 50 cm between plants) using the very best seeds – indeed, a major objective has been to multiply scarce, high-value seed or plantlets resulting from somatic embryogenesis. The mother stool plants are topped in midsummer just above the top side shoot (about 15 cm) and the first cuttings are taken in winter (May through July in the Southern Hemisphere). Subsequently, the stool plants are topped from October to November to form bushy plants. Nutrient, weedicide and pest-control practices are followed as for normal seedlings. These stools may be used for up to five years; as they become bushy, the number of cuttings per stool increases to typically about 40 per plant from a three-year-old stool. The hedging of stool plants slows their maturity, so that cutting material from four-year-old plants is similar to 1.5–2.5 year-old field material.

The size of cuttings varies. Typically those taken from field trees are 10–15 cm long, with a basal diameter of 6 mm or greater (Menzies *et al.*, 2005). Stool cuttings are usually 7–10 cm long, with a basal diameter of 3 mm or more. According to Escobar, Sanchez and Pereira (2002), the ideal cutting for growing as bare-rooted nursery stock is 12 cm long and 4 mm in diameter. Cuttings are planted directly into normal nursery beds in winter without hormone treatment. Setting spacing is wider than that used for seedlings. Beds need to be irrigated and should not be allowed to dry out; shade or shelter cloth is often used (Figure 7.3). After setting, cuttings often show signs of

FIGURE 7.3
Cuttings of radiata pine from stool beds set directly into beds and protected by plastic covers

wilting; rooting and top growth begin in the spring. In New Zealand, magnesium–ammonium–phosphate fertilizer, applied prior to setting, has proved to be preferable to normal fertilizers; other fertilizers are also applied during the growing season. After the trees are about 20 cm in height they are conditioned in the same way as seedlings, although this conditioning process has been modified in Chile (Escobar, Sanchez and Pereira, 2002). This generally results in satisfactory large-diameter planting stock with good root systems (Figure 7.4). The cost to produce cuttings is higher than it is for seedlings but when they are used to multiply control-pollinated seed there are large savings (Menzies, Holden and Klomp, 2001).

Short fascicle cuttings (5–15 mm long with a basal diameter of >2 mm) may also be rooted, but because of their size it is usual to root them under mist in a greenhouse. It has been possible to root short-fascicle cuttings throughout the year, although greater success has been achieved with those rooted in summer. After rooting, fascicle cuttings may be lined out in beds and grown as bare-rooted stock or in containers. The multiplication rate for fascicle cuttings is higher than for cuttings from stool beds but the cost is also higher. Fascicle cuttings are not used on a routine basis.

In tissue culture, undifferentiated embryonic tissue is multiplied in sterile culture in laboratory conditions (Gleed, 1993; Hargreaves and Menzies, 2007). Subsequently, the unrooted plantlets are transferred out of the sterile conditions into misted greenhouses for three months, where they develop roots and adjust to non-sterile conditions. Finally, the plants may be transferred to the nursery for the production of bare-rooted or container stock. They are often used as stools for cuttings.

With somatic embryogenesis (Figure 7.5), the selected genetic material is held at very cold temperatures (-140 °C to -196 °C) for long periods to overcome the inevitable physiological aging that continues to occur with tissue culture. Holding the material this way gives time for the specific crosses to be field-tested before multiplication (Figure 7.6). Details on radiata pine somatic embryogenesis can be found in Klimaszewska *et al.* (2007) and Hargreaves and Menzies (2007). Smith (1999) suggested

FIGURE 7.4

One-year-old cuttings with a good diameter stem and a vigorous root system with mycorrhizae

FIGURE 7.5
Somatic embryogenesis plants in a misted greenhouse in Chile before being on-grown

that it may be possible to rejuvenate tissue taken from older trees, but this is yet to be confirmed.

Both micropropagation and somatic embryogenesis allow high multiplication rates of valuable genetic material, but capital and production costs are relatively high compared with seedlings and normal cuttings. Plant costs reflect this, but even so the economic advantages are large (Smith, 1999; Carson and Carson, 2011).

CONTAINER PLANTS

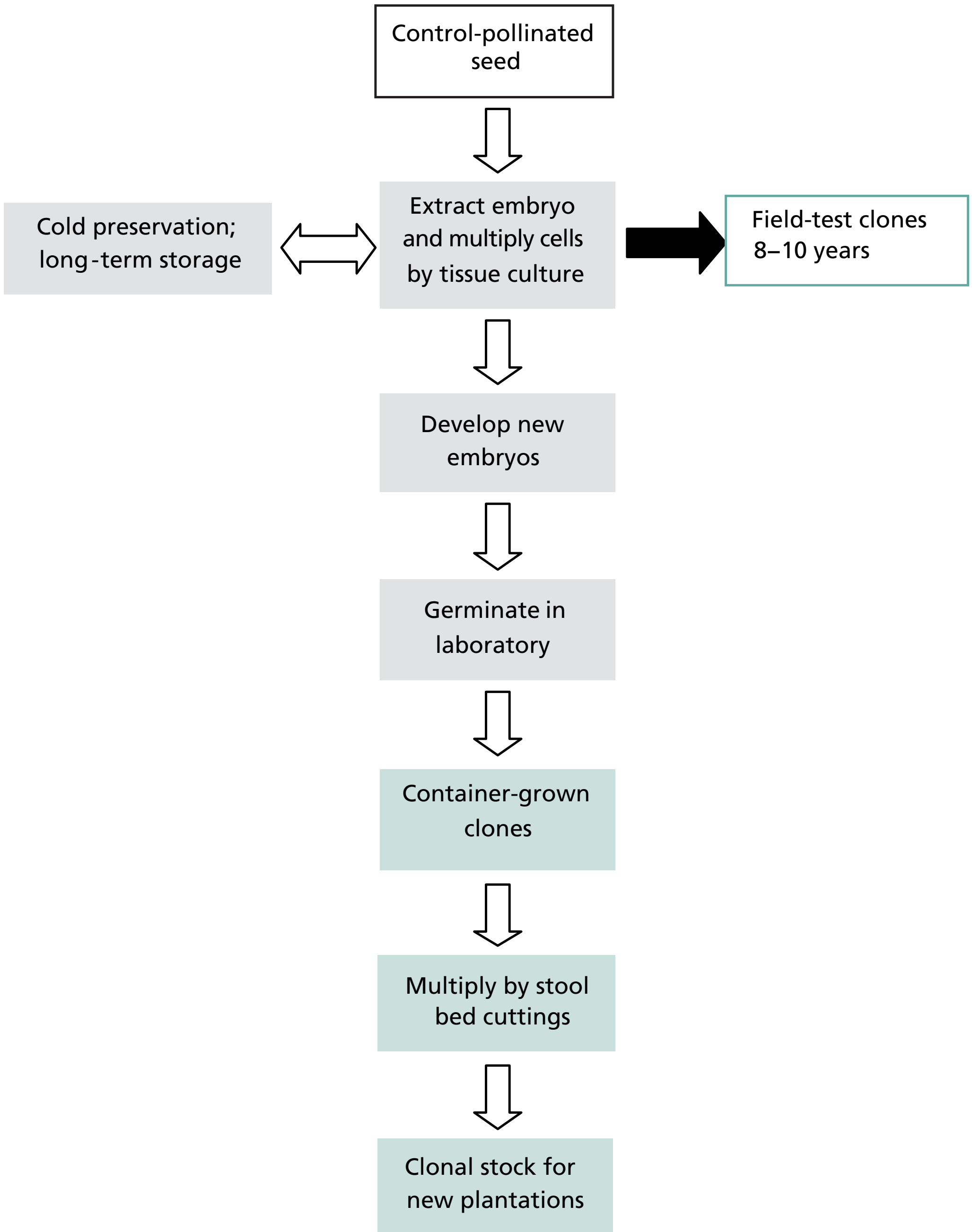
Seedlings, cuttings and tissue culture plantlets may be produced in containers, a practice that is increasingly common in most radiata pine-growing countries. The cited advantages with containers are that they:

- allow slightly quicker production of planting stock;
- possibly extend the planting season;
- may show less transplanting stress and higher survival rates;
- overcome difficulties in obtaining and maintaining sites for bare-rooted nurseries;
- are compact in nature and can easily be mechanized;
- allow the setting of smaller vegetative propagules (1–5 cm long).

The methods are similar to those used for many other tree species. Most growers use polyethylene trays and, for seedlings, sow directly into these rather than pricking out after germination. Where polystyrene trays are used, copper hydroxide paint is needed to prevent roots from binding with them. Container sizes vary between countries, from 80 cm^3 to over 200 cm^3 (Donald *et al.*, 1994; Escobar, Sanchez and Pereira, 2002; Menzies *et al.*, 2005; Ortega *et al.*, 2006). Minimal container depth should be 10 cm. Cells should be tapered, ribbed or have vertical slots to prevent root spiralling, and drainage holes are needed in the bottom to ensure the air pruning of roots. For air pruning, the trays are put on benches (Figure 7.7). There is a good relationship between container size and size of planting stock, and ideally plants should have a diameter of 3 mm or more and not be too tall (Table 7.2).

Potting mixes should have good aeration, readily hold moisture and produce a stable root plug. Thus, many mixtures include peat, composted pine bark, perlite,

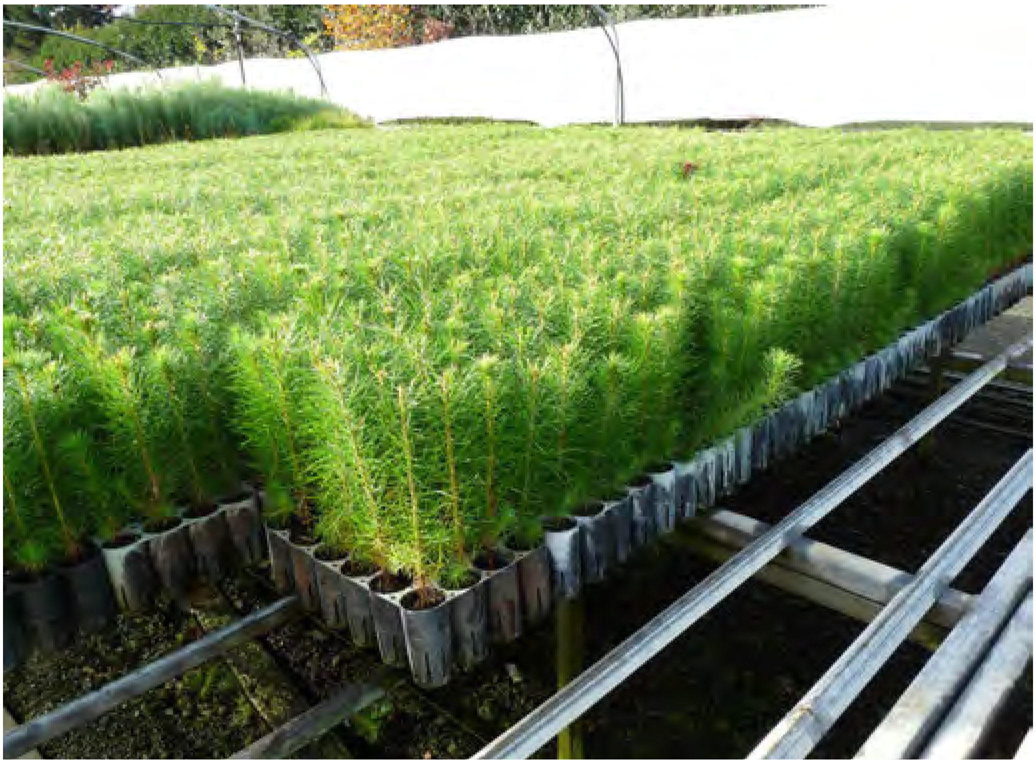
FIGURE 7.6
Typical flowchart of growing clones of radiata pine, starting from control-pollinated seed, through laboratory multiplication and storage to nursery



Note: The stage of laboratory multiplication and storage is depicted in grey and the nursery stage in green. The field test of clones is produced by the same laboratory/nursery system.
Source: Carson and Carson (2011)

vermiculite and pumice in various combinations. Actual potting mixes depend on local sources of suitable material. Composted pulverized pine bark is frequently a major component. Temperatures should reach 65 °C during composting to ensure sterilization (Donald *et al.*, 1994). Slow-release fertilizers are often added to the mix, but additional fertilizers are usually required during the growing season and this may be applied in liquid form. Mycorrhizal inoculation is important (Martinez-Amores, Valdes and Quintosz, 1991; Donald *et al.*, 1994; Escobar, Sanchez and Pereira, 2002). Hardening off is usually done by reducing nutrients and/or irrigation. Machines can be used to assist with filling pots, sowing seed, etc.

FIGURE 7.7
Container grown radiata pine employing air-pruning of roots



Sometimes, small plantlets are started on benches in greenhouses, for example with bottom heat, and subsequently moved outdoors to harden off. In other cases they are grown on raised frames covered with shade. Irrigation is carried out by misting or travelling booms.

PACKAGING AND TRANSPORT OF PLANTING STOCK

The handling and transport of planting stock between the nursery and planting sites should be done quickly and with care. An integrated system ensures:

- minimal handling;
- minimal time between lifting or removal from containers and planting;
- no crushing of the planting stock;
- minimal damage to root systems;
- root systems that are not deformed and are easy to plant;
- capacity to store under cool, humid conditions;
- application of careful planting techniques.

Trewin and Cullen (1985) described the following integrated system for bare-rooted stock in New Zealand:

- in-bed culling of precision-spaced plants to avoid handling at lifting;
- conditioning, as this overcomes planting shock;
- soil loosening by wrenching prior to lifting;
- lifting by hand or machine directly into cartons with the plants laid horizontally (Figure 7.8);
- avoiding root damage or loss of mycorrhizae;
- trimming off roots longer than 10 cm using sharp shears (Figure 7.9);
- closing boxes quickly and placing them in insulated crates;
- storing the boxes in a cool store if they are not going directly to a planting site;
- checking the quality of plants before planting;
- avoiding long storage in the field;
- planting the stock directly from the carton.

FIGURE 7.8
Bare-rooted stock lifted and placed horizontally into boxes

Note: The forest planters take the seedlings direct from these boxes to minimize handling.

Roots may be moistened after lifting in New Zealand, while they are often sprayed with a hydrogel to help maintain moisture in Australia and Chile. However, in dry weather it is often preferable to water the nursery beds the evening before lifting so the trees are fully hydrated and roots retain damp soil particles (A.R.D Trewin, personal communication, 2012). Moisture pads placed over the top layer of the stock in the planting box can also reduce desiccation. Refrigerated trucks are used occasionally to transport stock from the nursery to the field (Escobar, Sanchez and Pereira, 2002).

Container stock may be transported directly to the site in trays. Alternatively, they can be removed from the containers in the nursery and laid on their side in boxes – and thereafter handled much like bare-root stock.

SYNTHESIS AND TRENDS

Based firmly on basic and applied research, *Pinus radiata* plant propagation and breeding has evolved rapidly in the past 40 years, and with recent developments in biotechnology is moving into a new phase. The implications of these recent developments are only beginning to emerge, but it is clear that they offer radiata pine managers improved flexibility, higher production and further economic gains.

Nursery techniques have developed to the point where there is confidence in how to produce and handle both bare-rooted and containerized stock. However, more research on defining and improving the quality of container stock has been advocated, as it is expensive to raise large stock in containers (Menzies, Holden and Klomp, 2001). Recently developed micropropagation techniques, which interact closely with tree-breeding and the need to improve wood quality and crop protection, may lead to the greater use of containerized stock. However, transgenic plants are unlikely to be used widely in the near future because of possible environmental risks, consumer resistance and prohibition by FSC certification.

Research and development on mycorrhizae and other fungi or bacteria to compete with soil pathogens will have an impact on nursery techniques and forest management. There will be continued emphasis, moreover, on integrating the growing of radiata pine from seed orchards through nurseries, to field establishment and silviculture, and ultimately to the production of marketable products.

FIGURE 7.9
Trimming the roots to 10 cm length

Note that shears have been used to cleanly cut this bundle of radiata pine seedlings