11 Radiata pine on farms

While radiata pine can be grown in large parts of New Zealand, it has a much more limited potential distribution in Australia, Chile, South Africa and Spain, where climatic conditions are much more variable. The range of tree species and agroforestry systems in these countries are thus far greater than in New Zealand. Where it is grown on farms, radiata pine is most commonly used in silvopastoral systems, as windbreaks or planted in woodlots, primarily for timber production. Even in areas suitable for radiata pine, it is only one of several species commonly planted on farms, but farm-grown radiata pine is often an important regional timber resource. In New Zealand, for example, almost 15 000 owners have about 20 percent of the radiata resource in scattered woodlots on farms. A survey of these farms found that ninety percent of their woodlots were in radiata pine, and they averaged 9 percent of the farm area (Rodenberg and Manley, 2011). In Australia, about 9 percent of the plantation resource is on farms (Nuberg, Reid and George, 2009). In Spain, most of the radiata resource is in small holdings and community forests (Rodríguez *et al.*, 2002a). Some 6 percent of the radiata pine plantations in Chile are less than 100 ha in size, making up 84 percent of landowners growing radiata pine (Censo Agropecuario, 2007). Many of these smallholders grow their trees under contract for larger industrial companies.

Growing trees on farms can help improve farm production. When farming profitability is considered on a reasonably long time-frame, trees can play a critical role. Trees can ameliorate the climate, reduce erosion, harness water runoff, improve water quality and increase biodiversity, as well as provide additional revenue and recreation and amenity benefits (see chapters 2 and 3). The planned use of trees can diversify farm income and spread the risks that arise from commodity price fluctuations. Furthermore, while the broad landscape is governed by the underlying topography, the size, colour, texture, variety and placement of trees can markedly alter perceptions and enhance landscape values.

This chapter focuses on the ecological processes that underlie agroforestry and the experience of radiata pine as a farm forestry and agroforestry tree. It covers the use of radiata pine:

- in windbreaks and as a shelter tree;
- as widely spaced trees with pasture beneath or as belts with pasture between them;
- in woodlots, including stock havens.

Farm planning issues and guidelines are also covered.

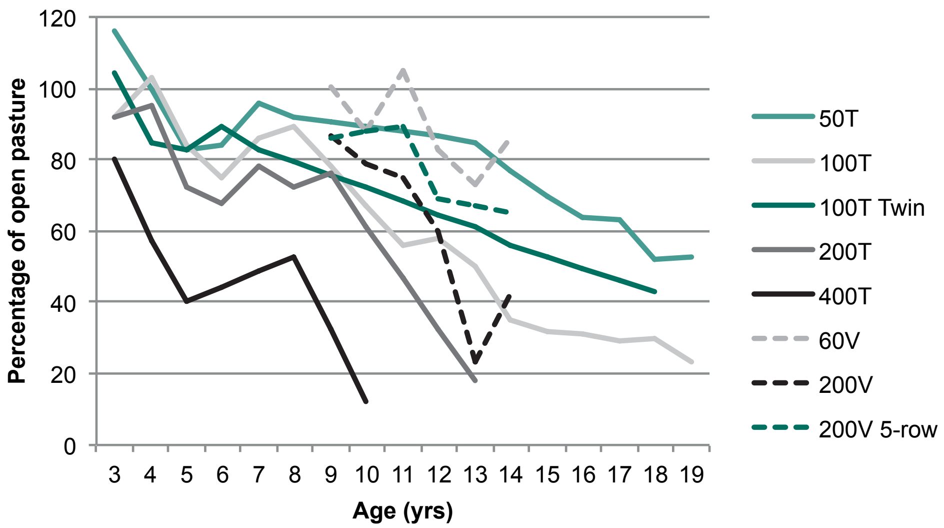
ECOLOGICAL PROCESSES IN RADIATA PINE SILVOPASTORAL SYSTEMS

Agroforestry systems should be based on a firm understanding of ecological processes. Silvopastoral systems have five main components that can readily be manipulated: trees, pastures, animals, soil and, to a lesser extent, water use. There is also a strong time element because interactions between trees and agriculture change as the trees grow and are harvested.

Light competition

Light becomes the dominant competitive process between widely spaced radiata pine and pasture after 5–10 years (Mead, 2009). The amount of shade cast by trees is related to canopy density, which changes with tree vigour, stocking, the pattern of planting and age as the canopy closes. On the fertile Tikiteri site in New Zealand, for example, pasture disappeared after 14–15 years under evenly distributed radiata pine

FIGURE 11.1
Pasture production under radiata pine trees, as influenced by final crop stocking, stand arrangement and site



Note: T = Tikitere, New Zealand (site index = 33 m), for stockings of 50, 100, 200 and 400 stems per ha, plus 200 stems per ha in twin rows; V = Victoria, Australia (site index = 20 m), for stockings of 60, 200 and 200 stems per ha in 5-row bands 33 m apart.
Sources: Hawke, 2011; Bird *et al.*, 2010.

at a final crop stocking of 200 stems per ha (Figure 11.1). On a slower-growing site in Victoria, Australia, the disappearance of pasture was delayed by 3–4 years (Figure 11.1), while at a higher-latitude site in New Zealand, the pasture production decrease was delayed for 6 years (Hawke, 1997; Hawke and Knowles, 1997). Studies in Western Australia confirmed that reduced pasture growth is the result of shading as the trees age (Anderson, Moore and Jenkins, 1988). Reducing tree stocking to 100 stems per ha or less allows pasture to persist longer into the rotation (Figure 11.1). Pasture growth and retention can also be helped by planting trees in double rows or strips, or even more widely apart as shelterbelts. At the Victorian site, at age 25 years there was still some pasture between bands of trees spaced at 33 m (Bird *et al.*, 2010). For a given age and stocking, canopy closure is usually greater in radiata pine than for many other tree species (Rozados-Lorenzo, González-Hernández and Silva-Pando, 2007). The degree of canopy closure at which pasture disappears (70–85 percent) does not vary greatly between species (Knowles *et al.*, 1999; Mead, 2010b). Pasture productivity under radiata pine has also been related to stand basal area and site index (Pasalodos-Tato *et al.*, 2009).

Associated with decreased pasture productivity under trees is a reduction in pasture leaf area, fewer stems or tillers per plant, greater etiolation due to a decrease in ratio of red to far-red light, and lower bulk densities (Peri *et al.*, 2001; Peri, Lucas and Moot, 2007). Foliage nitrogen concentrations and crude protein increase slightly in temperate grasses but not lucerne (*Medicago sativa*). However, the reduction in productivity is more important than these small compensatory responses.

Pruning and thinning slash and tree foliage litter also smother pasture and interfere with grazing (Hawke, 1991, 1997; Hawke and Knowles, 1997). For radiata pine, litter fall becomes important after age 10–12 years, while most thinning and pruning occurs before this age. The decay of thinning and pruning slash is relatively rapid for the first two years. Heaping thinning and pruning slash will also assist pasture growth and use by animals. Green radiata pine foliage is not particularly palatable, with fresh young needles equivalent to oaten hay (Anderson, 1985). To reap any benefit from foliage on pruned branches, stands should be heavily stocked. The heavy grazing of slash and the understorey also reduces the risk of fire, a factor that is considered very important in Spain (Pasalodos-Tato *et al.*, 2009). Slash can be reduced by using the best genetic material and by timely pruning and thinning (Hawke and Knowles, 1997).

Shade tolerance varies with pasture species. Nitrogen-fixing clovers (*Trifolium* spp.) and some grasses, such as perennial ryegrass (*Lolium perenne*), are light-demanding. Light-demanding grasses are often replaced with more shade-tolerant, less valuable species such as Yorkshire fog (*Holcus lanatus*) or native grasses (Hawke and Gillingham, 1997; Kellas *et al.*, 1995; Mead, 2010b). Although cocksfoot (*Dactylis glomerata*) is relatively shade-tolerant, research comparing it with light-demanding lucerne found that lucerne grown under radiata pine was the more productive species (Peri *et al.*, 2001). The cocksfoot became nitrogen-deficient after the clover had died out, but this did not occur with lucerne because it is a nitrogen-fixing legume.

Moisture competition

Moisture competition is usually the second most dominant factor after light (Mead, 2009). The extent of moisture competition is related to climate, soil moisture storage potential and the pastures used. In the establishment phase, moisture competition can result in tree mortality and reduced tree growth unless pastures and weeds are controlled with spot or strip weedicide spraying (see Chapter 8). Some pasture species compete more than others with trees for moisture (Pollock and Mead, 2008). In an experiment in Canterbury, New Zealand, lucerne and phalaris (*Phalaris aquatica*) roots also exploited the sprayed zone more than species such as ryegrass or cocksfoot (Mead, 2010b). Animals can benefit when used to control weeds such as pampas grass (*Cortaderia* spp.), while controlling the pampas decreases the moisture competition that reduces radiata pine tree growth (see Chapter 8).

As the trees grow and are tended, their roots spread laterally and their changing crowns intercept rainfall, causing fluctuating zones with lower throughfall (rain shadows). Pastures under older trees receive less precipitation than open pastures (Sotomayor and Teuber, 2011). Throughfall patterns, tree root expansion and other shelter effects influence pasture growth. In young silvopastoral stands there may be complementarity, where pasture production is greater with trees than where pastures and trees are grown separately. In the Canterbury experiment, this moisture complementarity disappeared after age 4–5 years (Pollock and Mead, 2008). However, differences in stocking, site, climate and year-to-year variation will alter these patterns and be reflected in pasture dry matter production (Figure 11.1). Rain shadows and tree root competition are also important for shelterbelts (Mead, Millner and Smail, 1999).

Nutrient competition

Although nutrient uptake is facilitated by soil moisture, nutrient competition is usually less important than moisture.

The reduction of clover under trees may result in nitrogen stress in both pastures and trees (Mead, 2010b). In addition, forage harvesting may remove more nitrogen than is fixed by pasture legumes, even when the legumes grow vigorously (Goh *et al.*, 1996). When animals graze the pasture they recycle most of the nutrients, and nitrogen stress is less evident. The results of foliage vector analysis in the Canterbury experiment confirmed that both moisture and nitrogen stress occurred with the more competitive lucerne and phalaris-clover pastures (Mead, Scott and Chang, 2010). Furthermore, understorey competition resulted in an accumulation of phosphorus in the pine needles, probably due to changes in soil phosphous availability.

Animals using shelterbelts, shade trees or woodlots for protection often transfer fertility from the open field to areas where they congregate (Hawke and Gillingham, 1996).

Soil–plant interactions

As discussed in Chapter 2, plantation forests and other types of tree-planting can markedly reduce erosion and alter stream flow and water quality. Tree-planting and earthworks on farms can also increase water infiltration while reducing soil erosion; this is particularly useful in lower-rainfall areas (Figures 11.2 and 11.3; INFOR, 2008). Both trees and pastures can alter soil-nutrient capital, depending on the amounts removed from the site compared with replacements from weathering, aerial deposition, nitrogen fixation and fertilizers (see Chapter 10). The establishment of trees may also reduce moisture movement through the profile, which together with the uptake of nutrients by deep tree roots can lead to lower leaching losses of soluble ions such as nitrates than in open pastures (Mead, Scott and Chang, 2010). In Western Australia, radiata pine agroforestry plantings lowered water tables and reduced salinization (Bari and Schofield, 1991).

Growing radiata pine on improved pastures or abandoned agricultural land often leads to reductions in pH, nitrogen, organic phosphorus and sometimes total carbon and exchangeable cations (Perrott *et al.*, 1999; Ross *et al.*, 2002; Rigueiro-Rodríguez, Mosquera-Losada and Fernández-Núñez, 2011). In contrast, the establishment of radiata pine silvopastoral systems on former arable land has been shown to increase carbon, nitrogen, the carbon: nitrogen ratio, organic phosphorus and pH (Mead, Scott and Chang, 2010). The direction of soil changes depends on the starting point as the ecosystem moves towards a new equilibrium.

Animal–plant interactions

Animals often damage young trees, particularly close to gates, so sheep must be monitored closely in radiata pine stands less than 2–4 years of age (Hawke and Knowles, 1997; Mead, Millner and Smail, 1999). Shelterbelts and individual trees in paddocks also need to be protected from animal grazing. Animal live-weight production, including wool production, is related to the availability of feed and so decreases over time and

FIGURE 11.2
Contour soil bund to collect runoff in a low-rainfall area in Chile

A. Sotomayor

with higher stockings (Hawke and Knowles, 1997; Peri *et al.*, 2001; Bird *et al.*, 2010). Decreased animal bite size offsets any improvement in palatability under trees. There can be higher parasite loads in sheep grazing under radiata pine stands (Hawke, 1991).

Trees can alter the microclimate through shelter and shade, which can be advantageous to animal health and performance, especially at critical times (Mead, Millner and Smail, 1999; Fisher, 2007; Sotomayor and Teuber, 2011). Trees typically reduce wind speed and wind chill compared with open pastures. General animal performance is reduced when the temperature is outside the optimal thermal well-being zone for an animal species. Both cold and heat stress reduce animal production. With cold stress, feed intake is increased to maintain body temperature, while heat stress leads to a reduction in feed intake. Thus, trees can be used to optimize animal productivity as well as to protect newborn animals from storms or prevent sunburn or cold stress in shorn sheep.

Tree age effects

With widely spaced trees in pastures, the net effect is frequently to increase pasture productivity compared with open pasture for the first few years after planting (Figure 11.1). However, pasture growth and quality decrease as the trees close canopy following final pruning and thinning.

Shelter effects tend to improve with time. With shelterbelts, the amount of shelter is related directly to tree height, so shelter benefits increase with time (Mead, Millner and Smail, 1999). Young trees provide only limited shelter and, because they displace pasture, the net effects are usually negative. However, net effects improve as the shelterbelts increase in height.

FIGURE 11.3
Radiata pine in Chile, at age 5 years, planted in twin rows spaced 7m apart. The ripping rows follow the contour to encourage water infiltration

WINDBREAKS

When Europeans first settled in Canterbury, New Zealand, the combination of wind and a lack of native trees prompted settlers to use radiata pine as a shelter tree (see Chapter 1). Hall (1898) vividly described the need to plant seven-row-wide radiata pine shelterbelts at 2.74 × 2.74 m spacing (1 330 stems per ha). He described those shelterbelts as increasing crop and grass growth, as well as being extremely valuable for stock shelter. Incidentally, Hall also used these belts as stock havens when the trees were big enough. Indeed, it is still possible to find shelter trees planted in Canterbury between the 1870s and 1900, a living testimony to the species' potential as a windbreak. It also demonstrates that when the tree is grown deliberately for shelter it can be stable, contrary to its performance in plantations.

Wind can reduce plant growth through mechanical damage, sand blasting, suboptimal temperatures, increased moisture loss and the loss of topsoil from potentially erodible soils (Nuberg and Bennell, 2009; Mead, Millner and Smail, 1999). The consequences are lower crop yield and lower crop quality, particularly in horticultural crops and to a lesser extent in cereal crops and pastures. Some effects may be infrequent but severe, while complex microclimatic changes can result in variable growth and fluctuations in the time of crop maturity, lodging, etc., making economic assessments of shelterbelts difficult. The effect of cold wind on animals include increased heat loss and higher critical cold temperatures (because of wind chill), which increases the mortality of newborn lambs, calves and recently shorn sheep (Reid, 2009). Newborn lambs are particularly susceptible to hypothermia induced by wet, windy weather. Shelterbelts can also protect animals from snow. While the effects of shelterbelts on reducing lamb mortality are variable (Pollard, 2006), research has confirmed the importance of shelter and shade for animal welfare (Fisher, 2007; Reid, 2009). Shade from trees is important for keeping animals cool in hot weather, especially so when stock is concentrated in yards for long periods in hot weather.

However, shelterbelts and shade trees also compete with adjacent pastures and crops for light, moisture and nutrients. These competitive effects may extend on either side of a shelterbelt for a distance of one to two times the height of the windbreak and can be exacerbated by the rain shadow in the lee of the windbreak. Thus, it is important to take into account the effects of shading and rain shadows when planning where to establish shelterbelts and to acknowledge that tree roots will invade the field. There can be reduced frost close to the trees. Stock will also transfer fertility nearer to the shelterbelts or shelter trees when they congregate around them (Hawke and Gillingham, 1996).

Shelterbelts are only one way of protecting animals or crops, and so their use should be evaluated as part of an overall farm strategy. Other plants, topography, artificial shelter, animal management and diet can all play roles in ensuring animal health (Fisher, 2007). Shelterbelts may also be used to improve working conditions and energy conservation in buildings, as well as protecting roads on farms. Models have been developed to assist decision-making.

The basic principles of shelterbelt design are (Nuberg and Bennell, 2009; Mead, Millner and Smail, 1999):

- The area sheltered to the lee is in direct proportion to the height of shelter.
- For shelterbelts to be effective, they need to be long and free of gaps.
- Shelterbelts should be green to their base so that wind does not funnel under them.
- For windbreaks, 30–70 percent porosity is preferred over very dense belts.
- The shelterbelt should be oriented so that it is at right angles to the direction of the most damaging wind, although there is some leeway with orientation. Sometimes the damaging wind(s) is not the predominant wind of an area. Topography needs to be considered in shelterbelt orientation. If wind funnels along a valley, then the

FIGURE 11.4
The effects of windbreak porosity on windflow at different distances from the windbreak for porous, single-row and multiple-row conifers and for a solid barrier

Source: Brandle, Hodges and Zhou, 2004

trees should be planted up and down the slope. Planting on ridgelines and where topography concentrates the wind is often recommended (Cleugh and Hughes, 2002). However, soil depth and fertility may limit tree growth and stability on ridges.

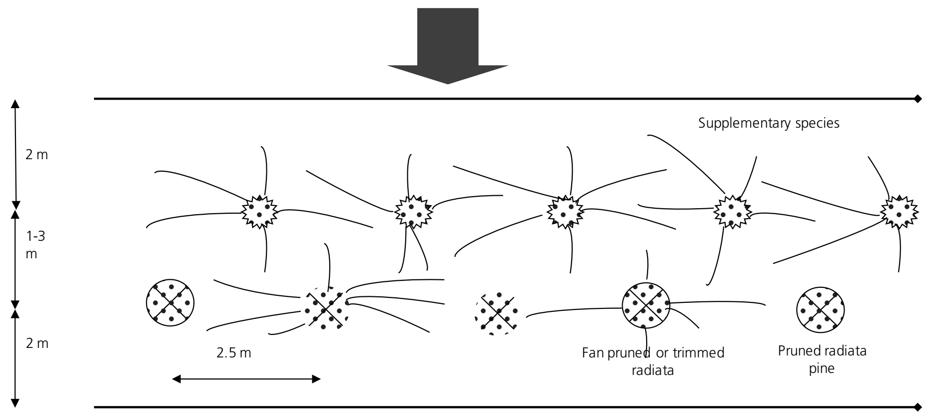
- Continuity over time needs to be designed for.
- Mixed tree species can be used to increase biodiversity and amenity, to provide forage for bees and to supply other non-wood products. They may also reduce certain risks.

Shelterbelts deflect wind upward, causing reduced wind speed in the lee. The quiet zone is 2–8 times the height of the shelterbelt, with the lowest wind speeds at 4–6 times the height; there is less effect in the wake zone beyond the quiet zone up to 20 –30 times the height (Nuberg and Bennell, 2009). A porosity of 30 percent will reduce wind speeds by up to 70 percent in the most sheltered location, while a higher-porosity (less-dense) shelterbelt has a lesser effect (Figure 11.4). A solid barrier creates a very sheltered area immediately behind it but causes increased turbulence further away. Thus, where a high degree of shelter is required, as with horticultural crops, shelterbelts should be closely spaced and have relatively low porosity. For pastures, they are frequently spaced at 15–20 times the shelterbelt height.

With species like radiata pine it pays to manage the crowns to prevent large branches from developing and from leaning out and shading the pasture or crop. If necessary, root spread can be controlled by deep ripping at 3–5 m from the shelterbelt. It is also possible to manage shelterbelts for timber, and indeed there are designs, called timberbelts, where the provision of timber is given higher priority than sheltering effects (Maclaren, 1993; Hawke and Knowles, 1997).

For porosity control and the provision of wood, single or double-row shelterbelts are usually more effective, as well as more stable, than wider, multi-row belts. With two-row belts, a proven design is to grow slower-growing species such as *Cedrus*, *Cryptomeria*, *Cupressus* or *Thujia* species to windward, with the faster-growing species (radiata pine) on the leeward side (Figures 11.5 and 11.6). This design allows for species with different rotation lengths; thus, when the pine is felled for timber the shelter continues. The slower-growing windward species are usually not high-pruned and are given only minimal tending. Mechanical side-trimming up to 12 m of the radiata pine every few years controls branch development and porosity. It is also possible to high-prune alternate radiata trees, although it is likely the wood will not be as good as in normal plantations. Another alternative to side-trimming is to fan-prune. With

FIGURE 11.5
Representation of a two-row shelterbelt layout, with supplementary species to windward

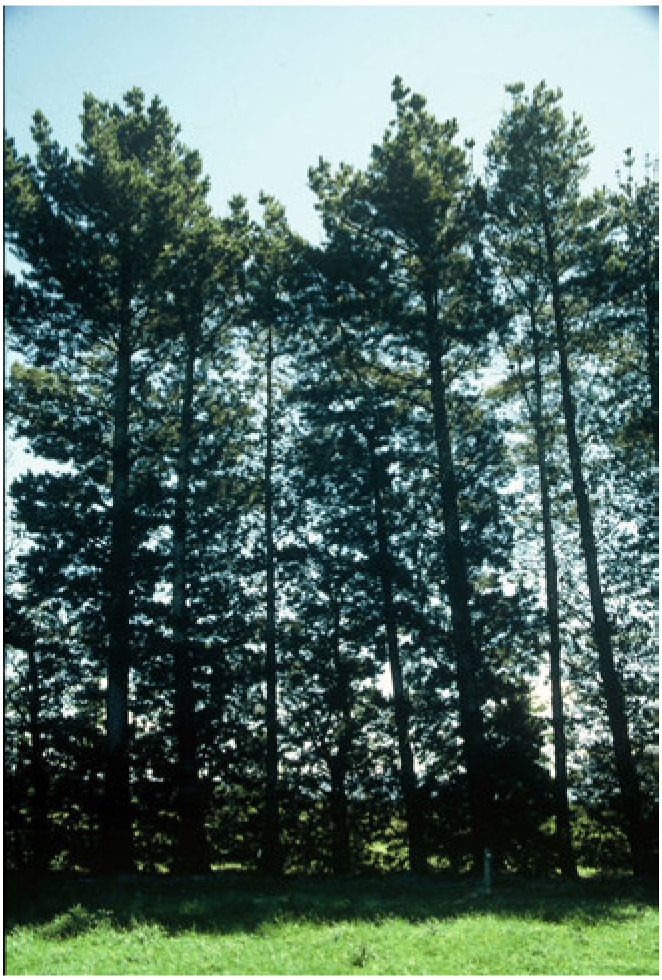


Note: In this example, every second radiata pine is high-pruned, but some growers prune them all.

fan-pruning, all branches, except those parallel to the tree row, are removed. The trees should not be topped.

High-quality establishment practices, including weed control and the correction of nutrient deficiencies, are essential for shelterbelt trees to ensure even growth and avoid gaps. It is advisable to use good genetic stock; with radiata pine, physiologically aged cuttings taken from 3-4-year-old trees are ideal. If animals are being grazed, good

FIGURE 11.6
A porous two-row radiata pine and deodar cedar shelterbelt that has been side-trimmed and in which every second radiata pine tree has been high-pruned



fencing is essential, and fences need to be at least 1.5 m from the trees. Thus, a single-row shelterbelt would remove a strip of 3–4 m from grazing and a double row of trees would be 4–7 m wide. Radiata pine is usually planted at 2.5 m spacing along the rows, and where there are two rows the two species would be planted so that they alternate (Figure 11.5).

It is possible to design shelterbelts that trap snow, leaving a snow-free area for animals in the lee. One design used in New Zealand is a multi-row radiata pine belt (4–6 rows) in which the leeward row has branches to their bases (trimmed or fan-pruned) and the windward rows are high-pruned. The snow accumulates under the high-pruned trees, leaving a snow-free area in the lee of the belt (Figure 11.7). Such belts can also provide income from wood. Other designs are used in North America (Brandle, Hodges and Zhou, 2004).Woodlots are another alternative to protect animals from snow (stock havens).

Shelterbelts can have adverse effects on highways. The shading of highways may increase the risk of road icing, while there can be reduced visibility at crossroads, and gaps may increase buffeting wind gusts. They can also create problems if they are close to telephone and power lines.

WIDELY SPACED TREES OVER PASTURE

Radiata pine use in this form of agroforestry has been studied in depth in Australasia and to a lesser extent in other countries (Hawke, 1997). The overall conclusion is that radiata pine is not easy to employ in this role because it is too competitive with pastures, the wide spacings result in reduced wood quality and quantity, and it increases the complexity of management. Due to decreased pasture productivity, grazing returns may not cover the increased costs of fencing and the provision of water to silvopastoral blocks (Hawke, 1997). Because of fluctuations in feed supply it is more difficult to match animal needs to feed supply. While radiata pine has seldom been accepted as an agroforestry species at a large scale (Bartle, 2009), there may be ways of improving its use in this role.

The following summary of research is based largely on three major Australasian experiments involving radiata pine and, to a lesser extent, on a Chilean experiment. The Tikiteri experiment near Rotorua, New Zealand (rainfall 1 600 mm), studied final crop stockings ranging from 50 to 400 stems per ha for 25 years (Hawke and Knowles,

FIGURE 11.7
A radiata pine shelterbelt designed to catch snow

Note: The windward rows are pruned to allow snow to accumulate under the trees.

1997; Hawke, 2011). This good site had a site index of 33 m and a 300 index of 33 m^3 per ha per year. A similar experiment, but with lower rainfall (620 mm), performed at Carngham, Victoria, Australia, compared five planting systems over 25 years (Bird *et al.*, 2010). The site index was estimated to be 20 m and the 300 index was 16 m^3 per ha per year. The Lincoln University experiment at Canterbury, New Zealand (rainfall 660 mm), studied competition processes from different pasture understories, including nil understorey, over 16 years (Mead, 2010b). The experiment was established on arable soil and had an estimated site index of 26 m and a 300 index of 24 m^3 per ha per year. The Chilean experiment, in an area with 700 mm annual rainfall and a dry period of eight months, used natural and improved pasture (subterranean clover and phalaris) and compared silvopastoral treatments with a typical radiata pine plantation and non-tree treatments (Sotomayor and Cabrera, 2008). The estimated site index was 27 m and the 300 index was 23 m^3 per ha per year, similar to the Lincoln University experiment. All four experiments involved grazing by sheep.

Generally, pasture production under radiata pine is better than in the open for only 2–3 years in the early years of the stand (Figure 11.1; Hawke, 1997; Mead, 2010b). Animal management needs to be tightly controlled while the trees are small, so some managers prefer to cut the pastures for silage or hay in the first 2–3 years after planting (Hawke and Knowles, 1997; Maclaren, 1993). Animal damage to young trees varies widely, and caution is recommended when introducing sheep in the first few years; with cattle it is best to wait until the tree bark becomes corky (Reid, 2009). In these first few years, the lax grazing used to prevent tree damage works against maintaining good pasture quality. For large-scale operations, the use of individual tree protectors is too expensive and repellents are too labour-intensive, although they may be used on a small scale (more so with fruit and amenity trees). Slash from pruning or thinning and later from litter fall decreases the value of the pastures, as do other changes in pasture quality (Hawke, 1997; Hawke and Knowles, 1997; Mead, 2010b). Cattle forage among slash better than do sheep. Unless tree stockings are very low, grazing is generally restricted to less than half the normal rotation (Figure 11.1).

Individual tree diameter and crown growth is faster at low radiata pine tree stockings, but height growth can also be reduced (Box 9.1). In the Tikiteri experiment, log quality and grade outturns were poorest with the lower stockings because of the large branches and the high amount of low-density core wood; pruning was unable to offset these losses (Hawke, 2011). In this particular experiment, the low-density corewood was exacerbated by tree-breeding (see also Chapter 6).

In the Victorian experiment, where growth was much slower than at Tikiteri, only the trees at 60 stems per ha were large enough for logging at age 25, and only the pruned butt logs were suitable as sawlogs because the top logs were too heavily branched (Bird *et al.*, 2010). The higher stockings in this trial were suboptimal for sawlogs at age 25 and a longer rotation was necessary. Belts of trees had several advantages. Apart from greater pasture productivity (Figure 11.1), it is easier to exclude stock while young; the radiata pine trees also had similar growth characteristics to those grown in normal plantations. Belts of trees are probably better suited for cropping.

The Canterbury experiment had a uniform final crop stocking of 200 stems per ha and included comparisons of physiologically aged clones with seedlings (Mead, 2010b). Growth rates, tree taper, tree form and butt sweep, DOS of the pruned butt logs and branch index were all reduced by understorey competition during the first 10–12 years. Following suppression of the understorey, growth rates were similar; the most competitive understories would have increased rotations by two years to obtain the same volume at harvesting but the trees would have improved wood properties. There were distinct differences between radiata pine seedlings and clones. Seedlings were less affected than clones by competition and had higher taper, although differences between the two types were less at mid-rotation.

The clones were less susceptible than the seedlings to toppling (Gautam *et al.*, 1999).

A key lesson from the Canterbury experiment is that managers can control tree growth and form by their choice of understorey pasture. Lucerne under the radiata trees performed well in this summer-dry environment, but it would not be suitable where winter feed is important because it has lost its palatability by that time of year. Cocksfoot/clover pasture was a good compromise between growth rates, tree form and pasture production. A second important lesson is that clonal radiata pine has advantages. Now that highly improved clones with better corewood properties are becoming commercially available, these may overcome the problems associated with poor wood properties on farms (Carson and Carson, 2011; Figure 6.1).

In the Chilean experiment, where the final crop stocking was 200 and 435 stems per ha for the silvopastoral and forest treatments, respectively, total volume at age 24 years was 20 percent lower in the silvopastoral treatments (Sotomayor and Cabrera, 2008). However, as the diameters in the silvopastoral treatments were over 50 cm, compared with 41 cm in the forest treatment, there was a considerably higher volume of more valuable pruned logs under the silvopastoral treatment. While this study did not include assessments of stem or log quality, animal productivity was included in the analysis. In economic terms, the silvopastoral treatments with natural pasture were slightly more profitable than the forest treatment, but the silvopastoral treatment with improved pasture was less profitable in this dryland situation. The traditional grazing of open pasture was reasonably profitable, but using improved pasture was not at all remunerative. IRRs of the better treatments, without land costs included, were between 9.7 and 11.5 percent.

In summary, the future use of widely spaced radiata pine (e.g. final crop stocking of 100 stems per ha) over pasture may be improved by planting specially selected clonal materials and choosing pastures other than ryegrass/clover to control tree growth and form. The correct combination could ensure that pasture is available for most of the rotation while at the same time producing large-diameter trees of acceptable quality timber. However, as this will not overcome the increased management difficulties with this type of system, there need to be additional benefits to justify this silvopastoral practice. Erosion control, the use of plantings as stock havens under adverse weather conditions or when animals are giving birth, fire control and other social advantages are all possible reasons that could tip the balance in favour of silvopastoral systems (Mead, Millner and Smail, 1999; Pasalodos-Tato *et al.*, 2009). In Chile, silvopastoral systems are favoured by over 90 percent of small farmers, who see it as a way of increasing income, improving their quality of life, reducing erosion and providing fuel (Sotomayor *et al.*, 2009).

WOODLOTS

Planting woodlots is a common practice on farms and small holdings. On farms, woodlots are often planted in areas that produce poor pasture or have other limitations that need to be addressed (Hawke, 1997; Mead, Millner and Smail, 1999; Nuberg, Reid and George, 2009). In Galicia, Spain, radiata pine woodlots have been supported by the European Union's agricultural policies (Rigueiro-Rodríguez, Mosquera-Losada and Fernández-Núñez, 2011). Plantations are frequently grazed, sometimes as an aid to weed control (see Chapter 8), and, particularly in Spain, as a fire protection measure (Pasalodos-Tato *et al.*, 2009).

The management of these woodlots usually follows normal management options for radiata pine (see Chapter 9). Thus, the recommended thinning and pruning schedules correspond to the typical schedules for radiata pine management (Maclaren, 1993; Sotomayor, Helmke and Garciá, 2002; Private Forests Tasmania, 2004). Many farmers, driven by profit and the wish to diversify income, may attempt to keep costs under control by doing the silviculture themselves. Environmental reasons are often also important in the establishment of woodlots on farms, but recreation and landscape aesthetics less so, at least in New Zealand (Rodenberg and Manley, 2011). However, the choice of site for woodlots is critical (Maclaren, 1993). Factors such as topography, roading, harvesting requirements and transport, a small woodlot size and lack of good markets can easily make a project unprofitable.

A radiata pine woodlot can play a major role as a stock haven, much like a block of widely spaced trees in pasture. For this role to be effective, the location of the woodlot needs to be planned (Mead, Millner and Smail, 1999). For example, if animals are to be kept under trees after shearing, the woodlot needs to be close to shearing sheds. Where protection is required during winter storms or at lambing, the location should allow ease of access from several paddocks. Woodlot stock havens should be located on warm sites. To minimize cold drafts, the outer row should not be pruned, although access to the interior should be sufficient to allow the distribution of feed.

FARM PLANNING

The integration of tree-based systems into farms is best achieved through whole-farm or catchment-based planning. In Spain, a common problem is the small size of landholdings; in this case, establishing some form of land management cooperative might be needed (Fernández and Sarmiento, 2004). For many catchments, the best outcomes will involve all farmers jointly planning their approaches.

The diagnosis and design process begins with defining the important roles for trees in the area, followed by design, priority setting and financial planning. The adopted design must be integrated into the owner's objectives. Planning may be assisted by experts, consultants or extension workers. A number of decision-making tools such as models have been developed, and in Australia the Master Tree Grower programme is available to assist farmers (Knowles, 1994; Nuberg, Reid and George, 2009). In Chile, the Instituto Forestal provides advice on agroforestry models (INFOR, 2008).

In an example in New Zealand (Box 11.1), the diagnosis and design process began with experts in science and policy and local Maori and farmer leaders reviewing farm characteristics and the problems being experienced in this high-country farming catchment and setting goals. The next step explored options to achieve increased profitability and sound environmental outcomes. This was supported by the use of a radiata pine agroforestry model that enabled various scenarios to be explored. Finally, the project was implemented and its outcomes monitored. In this case, radiata pine woodlots played a major role in stabilizing the steeper hills and providing for eventual timber income, while streams were protected by native trees and shrubs. Grazing was restricted to gentle slopes, fertile soils where animal management could easily be intensified.

TRENDS

Farm forestry involving radiata pine was popular with farmers and small investors in Australasia 15–25 years ago. It was supported by government extension workers, subsidies, strong farmer leaders, the prospect of good returns and the perceived need for income diversification. However, this supportive environment was followed by the dissolution or downsizing of state agencies and the sale of their forests and thus a loss of farmer confidence, first in New Zealand and later in many Australian states. Subsidies were withdrawn in New Zealand, except in special erosion-control situations, but advantageous tax treatments continued in Australia. However, in Australia there was also a switch towards growing short-rotation eucalypts for pulpwood. Coupled with this were decreased returns to growers and the realization that growing radiata pine at low stockings on improved grasslands was not as beneficial as previously assumed. More recently in New Zealand, dairy farms have been expanding on better land at the expense of sheep and beef farms. These and other factors have contributed to a decline

BOX 11.1

Catchment diagnosis and design planning in New Zealand hill country

An evaluation of this 296 ha hill farm catchment found that since the forest was felled in the 1920s, 11 percent of the area had been subjected to landslips and that up to 80 percent of the area was potentially prone to landslips. Further, sediments were high in unprotected streams compared with those coming from remnant forest areas, and 39 percent of the land area was covered with low-quality, difficult-to-manage pastures. Land managers, policy agencies and biophysical scientists worked together to identify the following main economic and environmental goals for the property:

- developing viable businesses;
- maintaining/restoring healthy ecosystems;
- protecting landscape values;
- improving environmental performance.

Various scenarios were explored using the agroforestry estate model (Knowles, 1994) and expert stakeholder knowledge. These scenarios included radiata pine plantations, riparian re-vegetation, native forest restoration, pastoral land stabilization, and livestock intensification. Time scale and economics were also considered. Priorities for action were determined, along with a timeline for implementation. The final plan called for radiata pine woodlots covering 153 ha in the upper catchment; 7 ha of native forest planting, primarily as riparian strips; and 131 ha in the lower catchment for improved sheep and beef farming. Planting 1 000 widely spaced poplar poles were also prescribed. About 20 km of steam fencing was undertaken. The pine were planted at 1 200 stems per ha and designed to have a final crop stocking of 400 stems per ha. Sheep grazing began under the trees at age 4 years.

Early assessments of the project found a large decline in stream sediments (76 percent), phosphorus (62 percent) and faecal coliform, while the native forest had started to recover. Lambs increased productivity by 87 percent per ha and beef cattle by 170 percent per ha. Overall, however, a big input of capital was needed to establish the forest, and this is causing cash-flow problems. It is expected that in the longer term the project will prove very profitable.

Sources: Dodd *et al.*, 2008a, 2008b, 2008c

in interest in planting radiata pine on farms in Australasia.

This trend away from radiata pine farm forestry in Australasia could change. A better understanding of the problems associated with growing radiata pine on improved grasslands has been discussed above but is yet to be translated into improved farm forestry confidence. Of greater importance, however, are the rapidly changing attitude on how markets and urban populations wish to see farming undertaken and the impacts of climate change and resource overuse. There is growing recognition that farming should follow a better ecological model, where the environment is protected and multiple objectives are emphasized. Whole-farm, catchment and landscape planning are part of this trend. Climate change mitigation, the need to move away from fossil fuels, and the implementation of greenhouse gas emission trading schemes are also raising the prospects of more large-scale tree planting, although it is unclear what role radiata pine will play compared with other species (see Chapter 3).

In Chile, small radiata pine plantation growers have been supported by various government programmes, including research, but they are also occasionally involved in contract growing for the timber industry (Morales, 2005). Subsidies are still available for small growers for woodlots, agroforestry systems and shelterbelts. For woodlots and widely-spaced trees in pasture, such subsidies can increase internal rates of return by 5–8 percent (Sotomayor, Helmke and García, 2002; Sotomayor and Cabrera, 2008). However, farmers are often keener on planting short-rotation eucalypts than pines.

In Spain, radiata pine forestry has taken place on abandoned agricultural land, often supported by European Union policies and with the help of local forestry associations (Michel, 2000; Rigueiro-Rodríguez, Mosquera-Losada and Fernández-Núñez, 2011). Grazing in silvopastoral systems is also seen as a way of reducing the risk of fire and increasing biodiversity. Research in agroforestry has been increasing in recent years and should assist with better implementation in years to come.