Chapter 14
Silviculture and Sustainability

Mead (2005) published a very thoughtful review where he attempted to identify the silvicultural practices that have proved to be most effective, generally around the world, in increasing plantation productivity (in biomass or wood volume growth rate). Table 14.1 summarises his conclusions and shows also his assessment of the relative costs incurred with various practices. On the basis of these results, he suggested that, in general, 'the priorities for improving productivity should be:

1. First, ensure that the correct species and provenance for the site are being used.
2. Treat major nutrient deficiencies and ensure that there is good rooting depth by draining the site, etc. These will lead to long-term improvements in [productivity] and the results can often be spectacular.
3. Use good planting stock, planting methods, weed control, and the optimum initial stocking level/rotation length. On droughty sites, weed control is critical.
4. A longer term option is tree breeding, while using [nitrogen] fertiliser on established stands produces rapid productivity gains.'

Irrigation is one silvicultural practice mentioned in Mead's table that has been considered little in this book. On drier sites, irrigation can lead to spectacular increases in productivity. However, the availability of water and the costs of large-scale irrigation generally preclude it as a silvicultural practice expect in specialised cases, such as plantations being used for disposal of sewage waste (Sect. 1.2). Baker et al. (2005) have discussed some examples of irrigated plantations in Australia. Mead did not include pest or disease control (Chaps. 10, 11) in his list of silvicultural treatments. Of course, these are protective measures to prevent loss of productivity, rather than to increase it; where they are necessary, failure to implement them can lead to disastrous losses. Nor did he include thinning or pruning (Chaps. 8, 9). Both of these are concerned principally with improvement of the quality of the wood produced, through increased sizes of logs or production of wood clear of knots. Nor did he consider in any detail the effects of silvicultural practices on the quality of the wood produced (Sect. 3.4), hence on its value.

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Table 14.1 A summary of the gains in wood production achieved, over a short (up to 12–15 years) or long (more than 15 years) rotation, through the application of various silvicultural practices in commercial plantation forests around the world, together with the relative cost of each practice

Silvicultural practice	Gains (%) in wood yields over a rotation		Relative cost
	Short rotation	Long rotation	
Selection of species or provenance	25 to > 75	25 to > 75	Low
Correction of major mineral nutrient deficiencies on-site	25–75	Up to > 75	Moderate to high
Provision of adequate rooting depth by drainage or breaking up compacted layers in soil	>75	25–50	Moderate to high
Site cultivation	>75	10–25	High
Quality of seedlings and care in planting	25–50	<10	Moderate
Stocking density at planting and choice of appropriate rotation length	10–75	10–25	Moderate
Weed control	25 to > 75	<10 to > 75	Moderate
Applying fertiliser at planting	10–25	<10 or 10–25	Low to moderate
Irrigation	Up to 75	Up to 50	High
Application of fertiliser after canopy closure	25–50	<10 or 10–25	High
Tree breeding	10–75	10–50	Very high

Adapted from Table 2 of Mead (2005)

In a practical example relating to Mead's conclusions, du Toit et al. (2010) reviewed the research in South Africa on eucalypt plantations being grown for pulpwood over a range of sites. They suggested that, of an average gain of 46 % in wood volume production by the plantations over the last few decades, 13 % could be attributed to choice of the most appropriate species, 13 % to choice of planting density, 11 % to choice of silvicultural practice and 9 % to improvements through tree breeding.

Ultimately, the decision as to what silvicultural practices are employed in any particular plantation will be determined by economic factors; these include not only financial but also environmental and social considerations (Mead and Pimentel 2006; Stewart et al. 2011; Gelo and Koch 2012; Obidzinski et al. 2012; May et al. 2012; Nahuelhual et al. 2012; Vihervaara et al. 2012; Witters et al. 2012). If the economic gains achieved through some silvicultural practices are insufficient to more than offset the costs involved, then obviously those practices will be avoided. Productivity, as reflected in tree growth, is often the most important factor determining at least the financial viability of a plantation enterprise; Mead's conclusions have given some useful guidelines as to what issues will generally be most important in determining productivity.

Of course, Mead's conclusions are generalisations. Any particular plantation will have to be considered on its merits to decide which factors are most crucial to ensure its viability. Various authors have emphasised that site-specific management is essential to ensure optimum plantation growth (Turner et al. 1999; Fox 2000; Burger 2009; Zhao et al. 2009; du Toit et al. 2010). That is, it will be necessary to have '…detailed knowledge of soils as they occur on the landscape and their physical, chemical and biological properties that affect productivity… Understanding the processes and properties of a specific soil will enable foresters to develop management regimes tailored to each soil' (Fox 2000). From the discussion in this book, it should be evident how complex the development of site-specific management practices for plantation forests can be.

Superimposed on consideration of the silvicultural technology that can be used today in plantation forestry must also be consideration of the sustainability of the plantation enterprise. From thousands of years of agricultural experience, it is well known that repeated cropping and manipulation of sites can lead to site degradation and, ultimately, crop failure. The book by Lindenmayer and Franklin (2003) gives much information on the developments in forestry that have occurred in recent times to promote sustainable management practices. Burger (2009) reviewed the developments in sustainable forestry practices that have occurred across North America over the last 100 years.

Because of its long-term nature, only rather limited information is available to assess whether or not plantation forestry around the world is in fact being done in a sustainable fashion. Zhang et al. (2004) found that above-ground biomass growth of China-fir (*Cunninghamia lanceolata*) in central China declined appreciably in a second plantation rotation, apparently due to increases in soil bulk density and nutrient losses between rotations. However, later work in western central China (Tian et al. 2011) found that total biomass (above- plus below-ground) growth of China-fir was reduced only during the first decade of a second rotation, following a 21-year long first rotation. By 18 years of age there was no difference between the first and second rotation biomasses. Tian et al. attributed the early growth reduction in the second rotation to the use of establishment practices in the second rotation that reduced nutrient availability on the site more so than practices used in the first rotation. This favoured the development of a higher proportion of root biomass in the second rotation sites. In later years, this gave second rotation sites an advantage in accessing soil resources for growth, allowing them to grow more rapidly overall in later years and make up the earlier growth disadvantage.

A well-researched and longer term example of sustainability comes from the radiata pine (*Pinus radiata*) plantations of south-eastern South Australia. Their productivity (as assessed by stem wood volume growth) was found to have declined from their first rotation, established in the early 1900s, to their second rotation, established 30-40 years later (Keeves 1966). It was found that silvicultural practices applied in the second rotation were inferior to those used in the first, particularly with respect to weed control and heaping and burning of the debris left after harvesting the first rotation. These deficiencies were overcome in the third rotation that was established in the 1970s and, coupled with a breeding programme that provided faster growing trees, growth in the third rotation exceeded that of the first (O'Hehir and Nambiar 2010).

Study of plantation yields from the same sites over several rotations in other parts of the world have also found productivity increases in later rotations, apparently due to continued improvements in silvicultural practice (Evans 1999; Powers 1999; Everett and Palm-Leiss 2009). In the case of radiata pine (*Pinus radiata*) plantations in New Zealand, increased productivity in the second rotation was ascribed to chance improvements in weather conditions between the first and second rotations (Woollons 2000), whilst increased atmospheric deposition of nitrogen due to increased industrial activity in Europe (Spiecker et al. 1996a; Solberg et al. 2009) may have been a contributing factor to increased yields of second rotation Norway spruce (*Picea abies*) plantations in Sweden (Eriksson and Johansson 1993). Much further study will be needed to determine if these productivity increases, due to improved silvicultural practice, improved genetic material or other factors, are hiding much longer term, deleterious effects on sites. Carter et al. (2006) gave an example from loblolly pine (*Pinus taeda*) plantations in south-eastern USA where growth reductions in the second rotation, due to soil compaction from first rotation harvesting practices, were hidden by gains due to improved weed control in the second rotation.

Considerable effort is being made in forestry in general, not just plantation forestry, to develop criteria by which long-term sustainability of forestry practices might be judged together with indicators (that is, specific measurements) to assess whether or not those criteria are being met (Grayson 1995; Hickey et al. 2005). Powers (1999) was of the opinion that determination of the effects of plantation forestry on soil air porosity and the organic matter in the soil will be two of the most important indicators of any long-term deleterious effects of plantation forestry; air porosity determines the ability of roots to grow and develop (Sect. 5.1) and organic matter is associated intimately with the cycling of nutrients in the plantation and the availability of nutrients from the soil (Sects. 2.3.3, 6.1.2, 6.3, 8.1). Attempts have been made to consider various soil properties as indicators of sustainable forest management (Hopmans et al. 2005; Palmer et al. 2005; Powers et al. 2005; Gartzia-Bengoetxea et al. 2009).

Stupak et al. (2011) summarised the attempts that have been made around the world to develop such criteria and indicators. They presented a summary list of the issues that have been considered important by forest management and certification agencies in assessing the sustainability of forest management for fuel (firewood or bioenergy) production; the list has considerable relevance to all forms of forestry practice in both plantations and native forests. Quoting directly from Stupak et al. the issues to be considered were:

- 'Decreases in productivity and soil fertility because of increased removal of nutrients and organic matter, and impacts of fertilisation to compensate for increased nutrient removals or to increase productivity.
- Reductions in the amount of breeding and feeding material left on-site for dead-wood-living organisms because of increased removals of dead organic matter.

- Increased risk of insect pests and of trapping and removal of rare deadwood-living insects in biomass stored or seasoned on-site.
- Physical soil damage and reduced water quality because of intensive management methods, such as increased machine traffic, site preparation or stump harvesting.
- Loss of or undesirable change in biodiversity or soil and water quality due to over-utilisation, land-use change, or use of exotic species or [genetically modified organisms].
- Reduced emissions of greenhouse gases due to substitution of fossil fuels for forest fuels, increases in energy use efficiency, or carbon storage in the forest.
- Potential for increasing social and economic benefits for local people and society in general (e.g., access to fuelwood, increased employment and income possibilities), and the use of efficient and low-impact technologies in transport and production, such as fuelwood collection and charcoal production.
- Off-site impacts on, for example, biodiversity, soil and water, and land use.
- Efficient forest management and the existence of and adherence to relevant legislation, forest management recommendations or guidelines for sustainable forest fuel production and harvesting'.

In conclusion, it seems fair to say that plantation forestry is being hailed today as a potential saviour of the remaining native forests of the world, forests that have been cleared and exploited ruthlessly in the past. However, it is clear that much work remains to be done to ensure plantation forestry is a long-term, sustainable supplier of wood and other social and environmental benefits and does not become, ultimately, an environmental problem itself.