Chapter 1

THE AUSTRALIAN ENVIRONMENT

A.G. Brown, J.W. Turnbull and T.H. Booth

The purpose of this chapter is to provide an introduction to the main features of the Australian environment within which the trees and shrubs described have evolved. Other accounts of the Australian environment that provide more detail or have a different emphasis are given by Leeper (1970), Moore (1970), Alexander and Williams (1973), Jeans (1977), Beadle (1981), ABS (1988) and Groves (1994). Emphasis here is on those factors of the environment for which data are likely to be available in field situations in other countries where Australian trees and shrubs might be used, so facilitating the initial selection of species through the use of homoclimes. Because the natural distribution of trees and shrubs of interest may be limited by factors such as fire or competition, both of which can be manipulated under cultivation, and because information about the physical environment can give no indication of the adaptability and plasticity of potentially useful species, observations of natural occurrence are of limited worth for predicting performance under cultivation. Homoclimal information gained by testing a species as an exotic, however, has much more predictive value.

Moisture availability and temperature are very important influences on the survival and growth of plants, and thus the following account concentrates on these factors. Despite the value of integrating measures of moisture availability such as those of Thornthwaite and Mather (1957) and Penman (1963) only basic meteorological information is presented because of the ease with which such measures can be comprehended and because the indices do have limitations (Burley and Wood 1976).

GEOGRAPHY AND LANDFORMS

Australia, including the island of Tasmania, lies between latitudes 10°41'S (Cape York, Queensland) and 43°39'S (South Cape, Tasmania) and between longitudes 113°09'E and 153°39'E. It extends some 3700 km from north to south and about 4000 km from east to west. The land area, 768 million ha, represents about 5% of the world's land surface. It is almost as large as the United States of America (excluding Alaska) and about 50% larger than Europe (excluding the former USSR). It is considerably smaller than Africa or South America (Table 1.1), but if one compares only the areas south of 10° latitude (Torres Strait), Australia is in an intermediate position. More than one third of the land area of Australia is north of the Tropic of Capricorn (23°26'S), a factor which contributes to the comparatively frequent very high temperatures of inland areas.

The geologically very old Australian land mass is characterised by vast plains and plateaux. About 87% of the land lies at altitudes below 500 m and only 0.5% is above 1000 m. There are three major landform features, viz. the western plateau, the interior lowlands and the eastern uplands. The western half of the continent consists of a great ancient plateau of altitude mainly 300–600 m, although the low but often rugged mountains of the

Table 1.1. A comparison of the geographic features of Australia, Africa and South America.

	Australia	*Africa*	*South America*
Area ($10^6 \times km^2$)	7.7	29.8	17.8
Mean altitude (m)	330	660	650
Highest point (m)	2228	5895	6959
Land surface below 200 m (%)	39	10	38
Land surface above 1000 m (%)	0.5	23	13

MacDonnell, Musgrave and Hamersley ranges reach 1000–1500 m. The interior lowlands include the arid central basin of relatively young sedimentary rocks and gentle low topography. The eastern uplands are bounded by a well-watered coastal plain extending along the whole of the eastern seaboard; this is paralleled by the Great Dividing Range, 150–400 km wide, and consisting mostly of tablelands, ranges and low mountains. There are only limited mountain areas above 1000 m including the highest point on the continent, Mt Kosciusko (2228 m). A detailed physiographic map of Australia that subdivides the continent into major and minor regions in a hierarchy of increasing uniformity of relief types has been prepared by Jennings and Mabbutt (1977). Their nomenclature is followed in this book and a simplified version of the map appears as Figure 1.1.

The rivers of Australia have small flows by world standards; most streams in the interior flow intermittently while some flow rarely. About half of the western plateau has no coordinated drainage and over much of central and western Australia the river systems die out on the desert plains. The many salt lakes of arid Australia reflect the disintegration of surface drainage. A corollary of the failure of the river systems is the extent of aeolian sand surfaces — about one million km^2 of sand plain and about the same of sand-ridge desert. Remnants of ancient drainage systems may be present in the arid zone and the water-gathering nature of these and accumulated sand or gravel in old channels provide important ecological niches for trees, which may attain dimensions surprising in view of the low average precipitation. Elsewhere the microtopography of the plains may so greatly redistribute rainfall that tenfold variation in pasture production may be observed. Although well-established, deep-rooted plants may be less influenced by these effects, it is quite certain that even for these plants moisture redistribution can have a significant effect, as has been reported for mulga *(Acacia aneura)* groves in central Australia (Perry 1970; Winkworth 1983). In such circumstances, climatic data alone will not give a reliable indication of the moisture requirements of naturally occurring species.

Figure 1.1. Major landform provinces of Australia (adapted from Jennings and Mabbutt 1977).

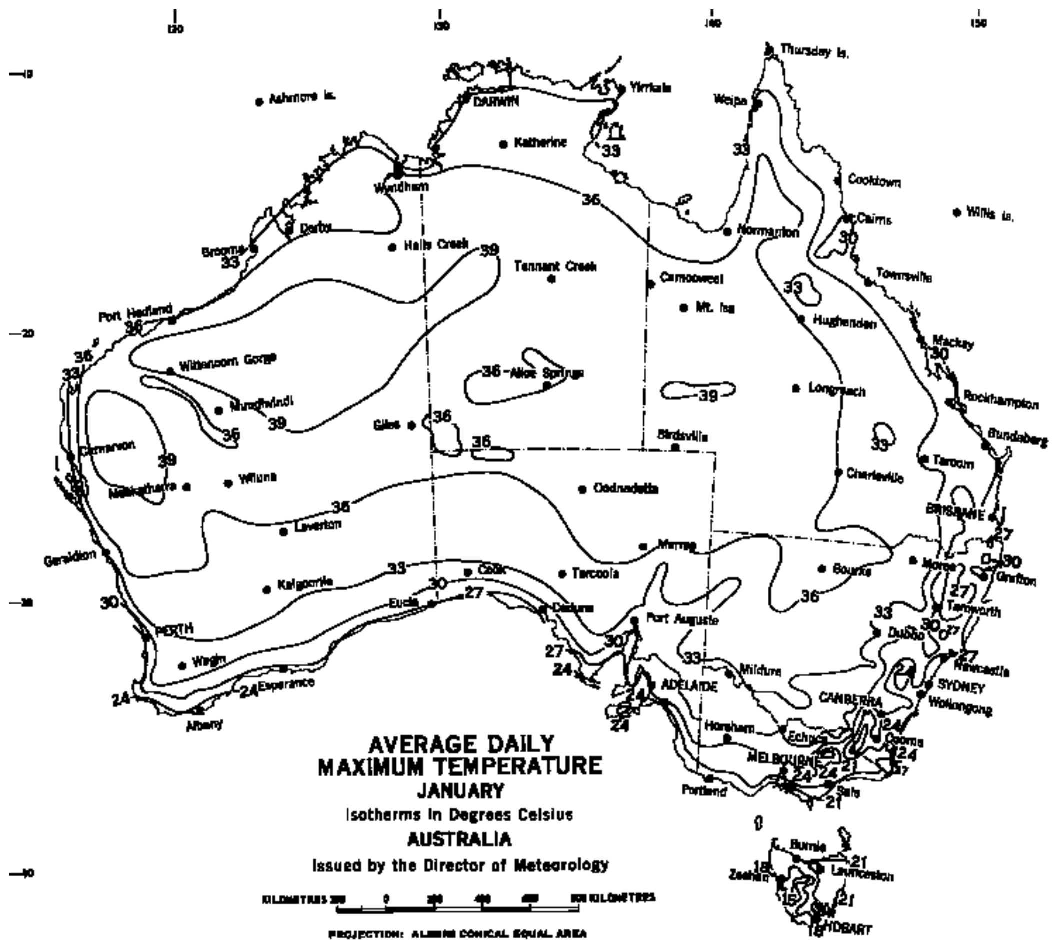
CLIMATE

The climate of Australia is predominantly continental with the weather conditions consistent with a relatively small land mass of modest altitude surrounded by extensive areas of water and situated in the low to mid-latitudes. Weather patterns are strongly influenced by the great anticyclones that travel from west to east in these latitudes. Over much of the continent the climate is characterised by low rainfall, high air temperatures and high levels of solar radiation. The wetter and cooler climates occur over relatively small areas, mainly in Tasmania and the southeast of the mainland within 100 km of the sea. The *Year Book of Australia* provides data on representative localities in Australia as well as periodically covering selected aspects of climate in special articles. Larger-scale maps are available in Parkinson (1986). Meteorological records of stations of forestry interest are given by Hall et al. (1981), while Australia (1988) is a comprehensive source.

Temperature

The summer is warm to hot (Figure 1.2). The isotherms of summer maxima generally run parallel to the coast, the highest temperatures occurring in the arid northwest; in the southeast the broad pattern is modified by high elevations and strong sea breezes. (In comparing these isotherms with those from other countries, note that some maps depict not actual temperature, but what the temperature would be if the surface were reduced to sea level.) The north–south gradient is not as great as the latitudinal range might lead one to expect, probably because of the common occurrence of cloud in the north in the summer months.

Mid-winter is warm in northern Australia and cold in the south (Figure 1.3). The highlands of southeastern Australia are too cold for plant growth in the winter months, and snow may occasionally reach down to 600 m. The frequency and severity of frost depend



on latitude, altitude and nearness to the sea. The actual incidence of frost is highly variable from year to year; occasional early frosts in autumn or late frosts in spring may be of considerable ecological importance. Figure 1.4, based on Fitzpatrick and Nix (1970), shows areas delimited by dates that represent one standard deviation prior to the mean date of the first occurrence of a screen temperature below 0°C in autumn, and one standard deviation after the mean date of last occurrence in spring. The extreme minimum temperatures recorded in each State are shown in Table 1.2. The actual minimum temperatures experienced by young plants near the soil may be much lower than the screen temperatures, and will be greatly influenced by the degree of exposure to the sky, the soil characteristics of adjacent surfaces and microtopography (Turnbull and Eldridge 1983; Cremer and Leuning 1985). For these reasons small young seedlings in plantation situations may be exposed to significantly greater cold than when regenerating naturally in the presence of other plants, and thus records of screen minima from Australia may not be a good guide to frost hardiness of plants grown in cultivation.

Rainfall

Australia is the world's most extensively dry continent (excluding polar regions) with erratic rainfall and frequent droughts. The annual 10 and 50 percentile rainfall maps are shown in Figures 1.5 and 1.6. On average, in 1 year in 10 the total rainfall has been less than the 10 percentile value; in half the years rainfall has been lower, and in half the years rainfall has been higher, than the 50 percentile value. The 50 percentile value is generally close to the arithmetic mean. About half the country has a median (50 percentile) rainfall of less than 300 mm and almost one-third has less than 200 mm. The driest States are South Australia (88% of area has less than 300 mm), Western Australia (73%)

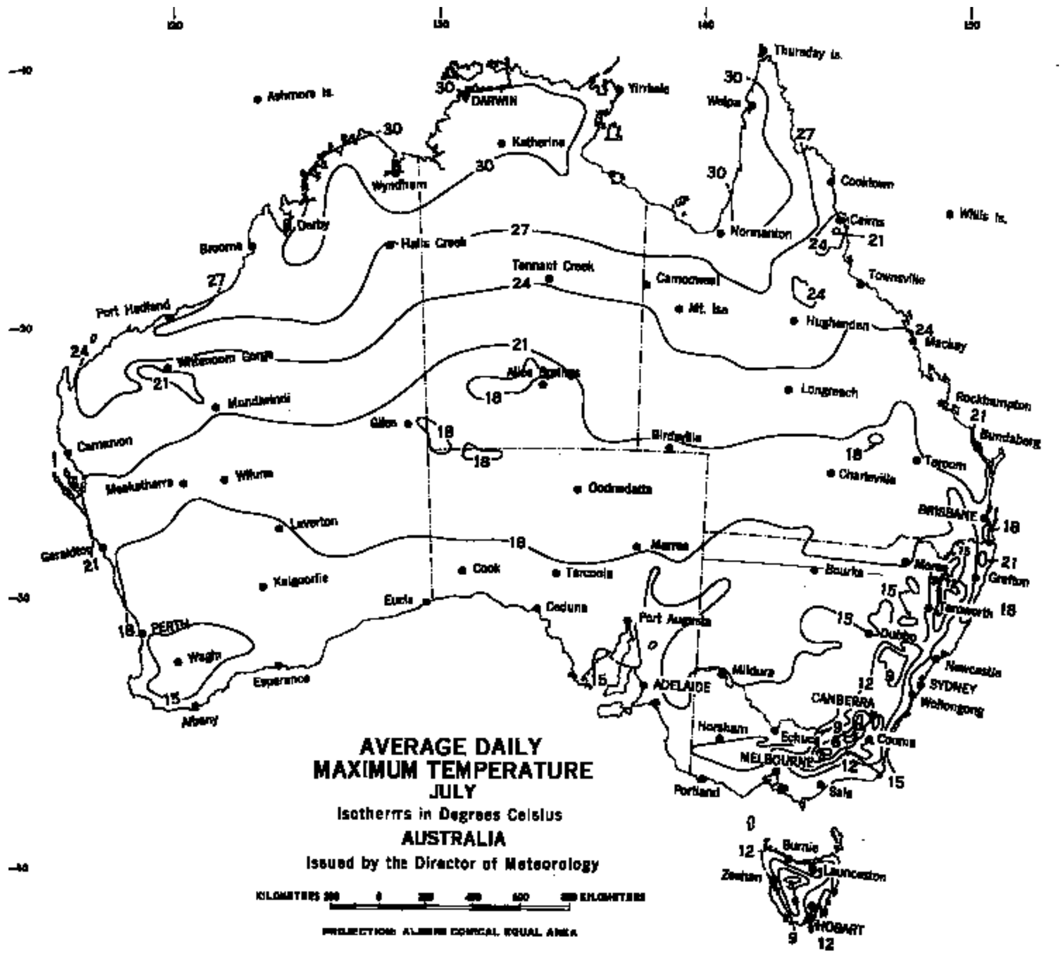


Figure 1.3. Average daily maximum temperature in July (winter) (ABS 1994).

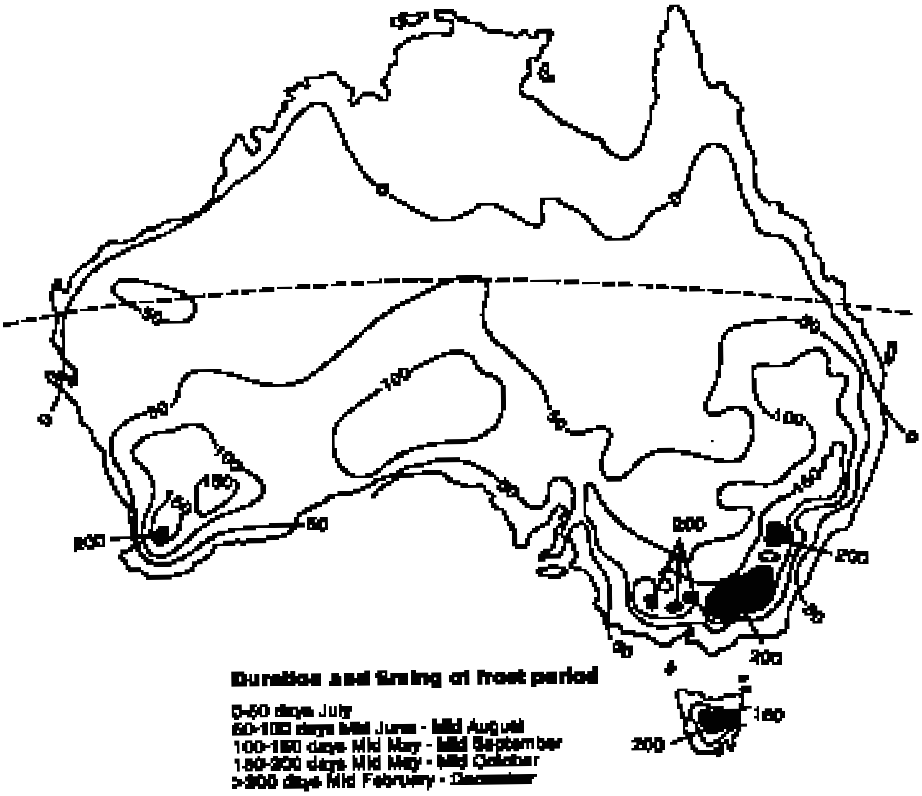


Figure 1.4. Duration and timing of frost periods (adapted from Fitzpatrick and Nix 1970).

and the Northern Territory (51%). Wetter areas are confined to coastal strips and to mountainous areas of the southeast and south of Australia.

The rainfall pattern is strongly seasonal in character with a winter rainfall regime in the south and a summer regime in the north (Figure 1.7). Uniform rainfall occurs in much of New South Wales, parts of eastern Victoria and southern Tasmania. The monsoonal rains of the extreme north fall between November and March; they are rather unreliable. In southwestern and southern Australia fairly reliable, mainly winter rains are associated with the fronts of atmospheric depressions moving across the continent. Tropical cyclones occur and move erratically in the summer or early autumn period in northern Australia, but they may bring rain to areas far to the south. Orographic rains are most important to a small part of the northeastern coastline of Queensland.

Table 1.2. The lowest mean temperatures recorded in the Australian States (based on Foley 1945 and Hall et al. 1981).

State	*Location*	*Latitude*	*Longitude*	*Elevation (m)*	*Temperature (°C)*
New South Wales	Charlotte Pass	36°20'S	148°20'E	1759	–22
Victoria	Mount Hotham	36°59'S	147°09'E	1861	–18
Tasmania	Oatlands	42°18'S	147°22'E	432	–13
Queensland	Stanthorpe	28°39'S	151°36'E	792	–11
South Australia	Kyancutt	33°08'S	135°34'E	58	–8
Western Australia	Booylgoo	27°45'S	119°55'E	610	–7
Northern Territory	Alice Springs	23°36'S	133°36'E	5	–7

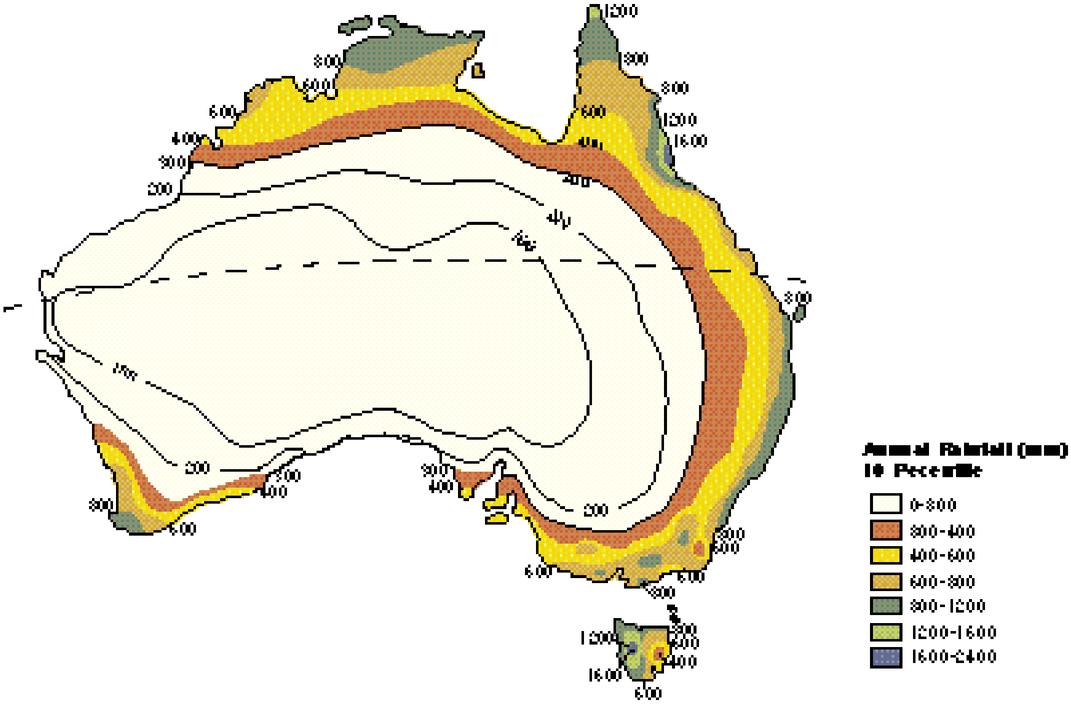


Figure 1.5. Annual 10 percentile rainfall (ABS 1983).

More than 80% of the continent has at least three months each year that are without effective precipitation. Erratic rainfall and drought, disastrous for the agricultural and pastoral industries, are recurring themes over most of Australia. Coasts facing west and southwest in the temperate zones receive exceptionally constant rainfall; the variability increases inland and northwards as storm rains replace winter showers as the main source of precipitation. The variability is greatest on the west coast near the Tropic, but in fact a very large area extending three-quarters of the way across the continent is essentially similar, and even the central coast of Queensland has a value of 28%. Only in the northernmost portions of the continent is rainfall as reliable as the agricultural south. Aridity or drought is a most conspicuous feature of the environment of mainland Australia.

Two further points may assist the reader in comparing the Australian position with that of other countries. First, as a rule of thumb, one can say that one-tenth of all years will have the rainfall shown in Figure 1.5, rather than falling closer to the median value shown in Figure 1.6. Second, the variability in Australia is mostly greater than the world mean of places of the same average rainfall (Leeper 1970).

Annual rainfall is a first approximation of the supply of water for plants but the effectiveness of rainfall is modified by seasonal distribution, intensity, evaporation, surface runoff, and seepage or subsurface flow, all of which have a direct bearing on the availability of soil moisture, which in turn depends on the water-holding capacity of the particular soil type. High-intensity rains fall at a rate that exceeds the infiltration capacity of the soil surface, and a large fraction of the rain may run off. Even gently sloping soil surfaces with a poor structure may absorb little moisture from rainfall of moderate intensity, and soils of poor structure are common in Australia.

The rate of evaporation of rain also influences its effectiveness; the annual evaporation from an open tank exceeds annual rainfall everywhere on the mainland except in the eastern highlands, and exceeds 2000 mm over 75% of the total area.

The two factors of high rainfall intensity and high evaporation combine to diminish effectiveness of

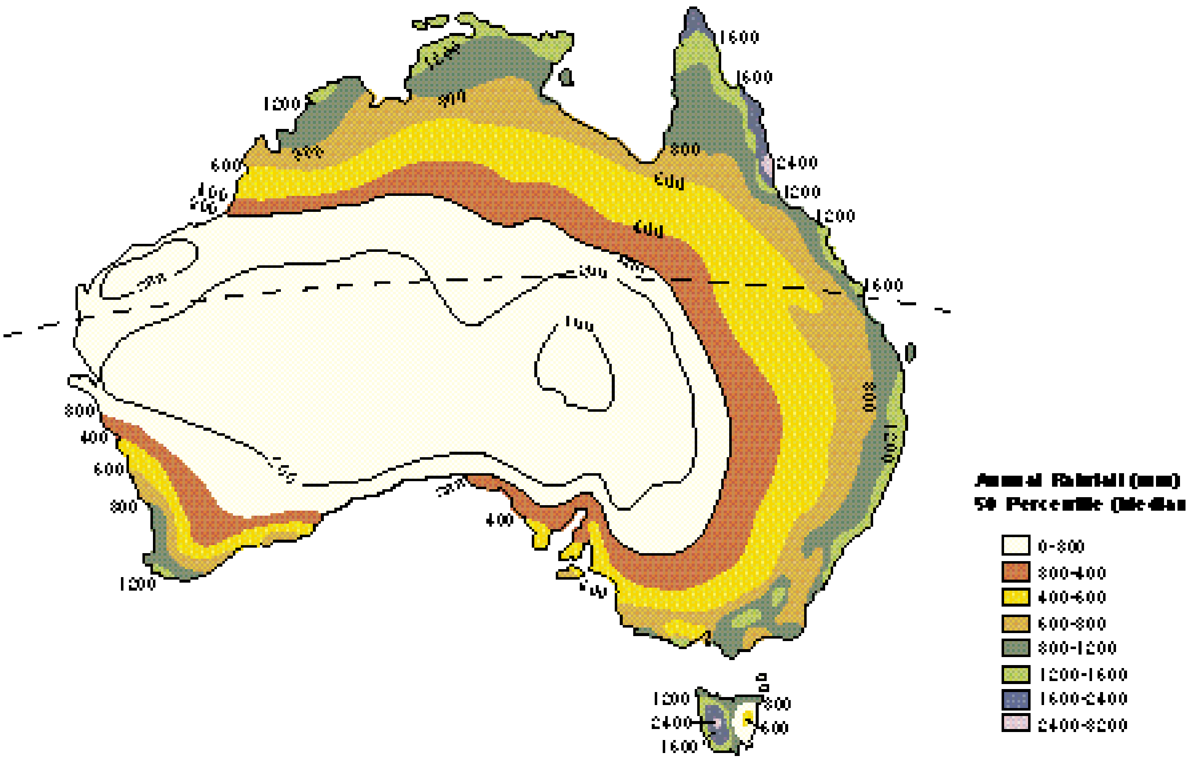


Figure 1.6. Annual 50 percentile (median) rainfall (ABS 1983).

rainfall in northern parts of the continent. At the same time, significant runoff may mean that in water-gaining areas much more moisture is available to plants than figures for average precipitation alone would suggest. The variable occurrence of reserves of soil moisture is undoubtedly a major factor in the development of indigenous vegetation; species from such localities may not thrive when planted in areas of corresponding climate but with different surface drainage characteristics. Rare groups of years of above average rainfall may have particular significance for the regeneration of trees and shrubs in normally arid or semi-arid areas. Thus records of mean or median rainfall may give a poor indication of the requirements for successful establishment in exotic situations.

HOMOCLIMES

Australia's tropical region covers two separate zones with distinct climates. First, the monsoonal tropics characterised by well-defined wet and dry seasons are comparable to climates in eastern Indonesia, northern Thailand, parts of Myanmar, and southern and eastern India. Much of central and western Africa (south of the Sahel), northeastern Brazil and Venezuela have a similar climate (Figure 1.8). The second zone, the humid tropics, occupies a relatively small area along the northern coast of Queensland between latitudes 16°S and 19°S. It is comparable to much of Southeast Asia, the Congo Basin in central Africa and the Amazon Basin of South America.

Subtropical sub-humid and subtropical humid climates are confined principally to southeastern Queensland and northeastern New South Wales between latitudes 20°S and 32°S. Similar climatic conditions occur in southern China, parts of northern India, eastern areas of South Africa, Zimbabwe, southern Brazil, Paraguay and northern Argentina.

The basis of separating the arid and semi-arid regions from the rest of Australia lies not only in the low rainfall they receive but in that it is erratic, so the growing season for many agricultural plants can be as short as one month and rarely exceeds five months. In arid and semi-arid regions, the median is a more appropriate measure of rainfall than the mean because

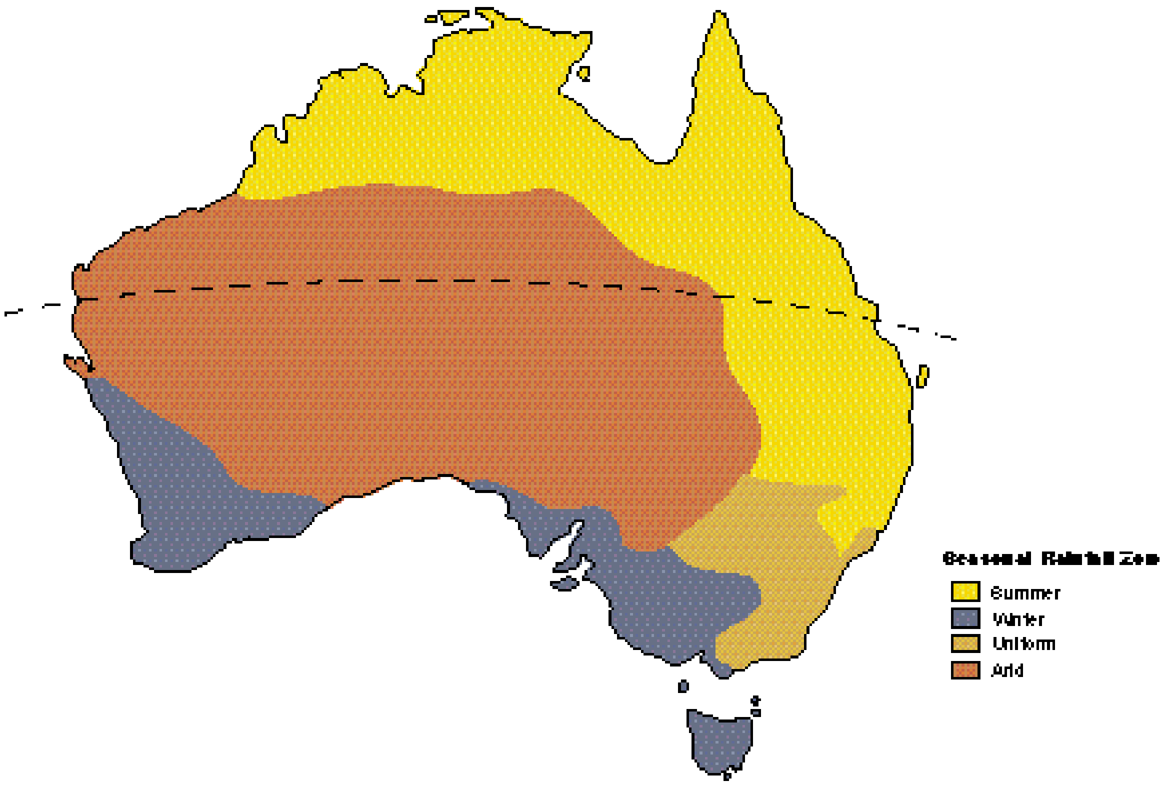


Figure 1.7. Seasonal rainfall zones (modified from Anon. 1983).

the combination of many small falls and few large falls exaggerates the influence of the few large falls, the mean in these circumstances being much higher than the median.

The northern arid and semi-arid zones extend across most of northern Australia between latitudes 16°S and 24°S. This climatic region corresponds with that of many developing countries, especially in the Sahel and Horn of Africa, southern Arabia, north-western India, Argentina and northeastern Brazil. The more temperate arid and semi-arid zones occur south of latitude 24°S and have low, erratic rainfall occurring mainly in winter. Similar climates are found in northern Africa, southwest Africa, the Middle East, Pakistan, southern Argentina, and northern Mexico.

The temperate humid and sub-humid climates of Australia occur in the extreme southwest, the south-east, and Tasmania. Comparable climates occur in southern Europe and countries fringing the Mediterranean Sea, in Chile, New Zealand, South Africa and parts of the United States of America. Species from these temperate zones often grow well in high altitude tropical areas. The success of *Eucalyptus globulus* in Ethiopia, the Nilgiri Hills of India and the Andes of Peru provides an example.

The climatic matchings produced using the zones shown in Figure 1.8 are very broad. For example, the temperate region includes both Kitimak in British Columbia (mean annual temperature 7°C, mean annual precipitation 2939 mm) and Tunis (mean annual temperature 18.5°C, mean annual precipitation 443 mm). Before computers were widely available, classifications were often used to show where particular species might grow. For example, maps were developed to show areas of Brazil and South Africa which were suitable for particular eucalypt species (Golfari et al. 1978; Poynton 1979). This work was highly successful, but it suffers from major disadvantages. Trying to describe a particular tree's climatic requirements in terms of an existing classification is like buying a ready-made suit; it may or may not be a good fit. The computing technology now available can provide a 'made-to-measure' description for each species or provenance, and in seconds generate a

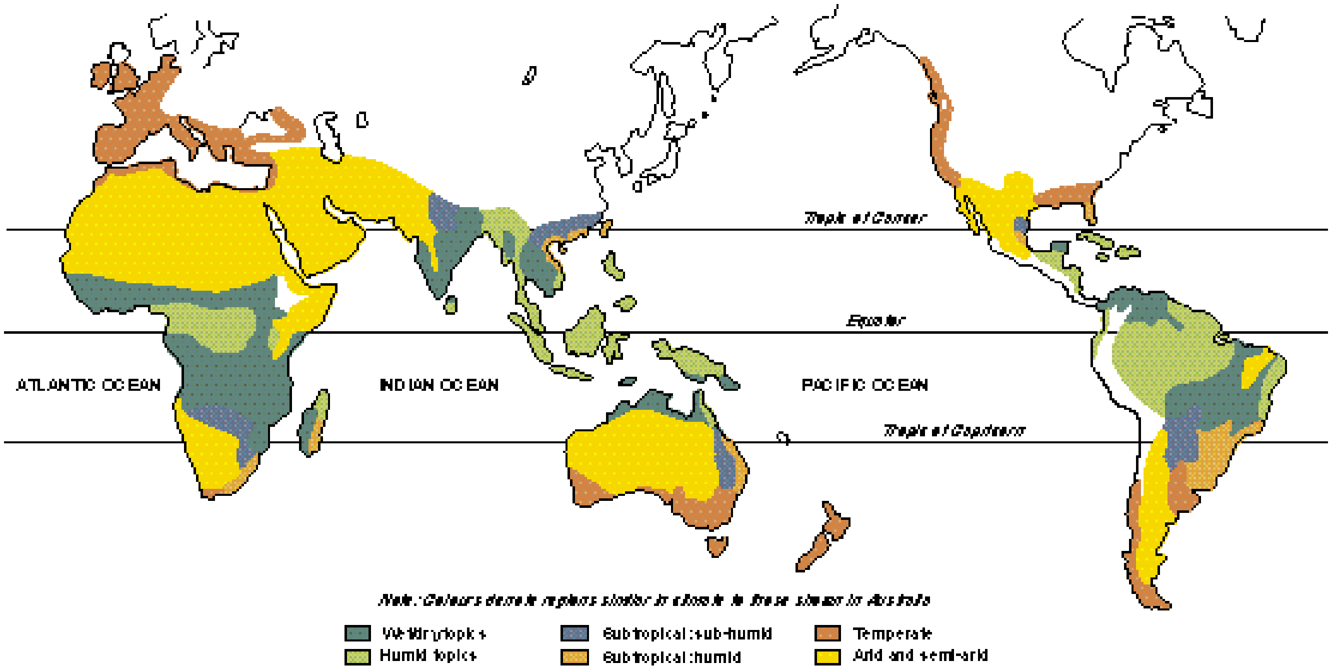


Figure 1.8. Climatic regions of the world (from Department of Trade and Resources 1982).

detailed map showing exactly where environments suitable for that tree exist (Booth 1996).

The key to this capability has been the development of methods of climatic interpolation. The map shown in Figure 1.9 was produced by a program which uses data interpolated for nearly 100 000 locations across China. Information for these locations was calculated from an analysis of data from over 2000 meteorological stations. Figure 1.9 shows areas of China which are climatically suitable for *Acacia mearnsii* according to the following description:

Mean annual temperature (°C)	14–22
Mean minimum temperature of coldest month (°C)	0–17
Absolute minimum temperature (°C)	> -5
Mean maximum temperature of hottest month (°C)	21–35
Mean annual precipitation (mm)	700–2300

This description has been developed from information on the species' natural distribution as well as its successful introduction into other areas (Booth and Yan 1991). Climatic mapping programs such as that used to produce Figure 1.9 have been developed for several countries including Australia, Zimbabwe, Indonesia and Vietnam, as well as regions such as Africa and Central/South America and the whole world. Many of these programs are described in a recent ACIAR proceedings entitled *Matching Trees and Sites* (Booth 1996). Descriptions of the climatic requirements of many well-known species have already been developed and tentative descriptions of requirements of lesser-known species in this book will be possible as information from successful trials becomes available. As more data are gathered from trials it will be possible also to describe the effects of soil conditions on growth. The ACIAR proceedings describes the use of the Plantgro model and simulation mapping programs, which use soils as well as climatic information to provide indications of the likely growth potential of particular trees on particular sites.

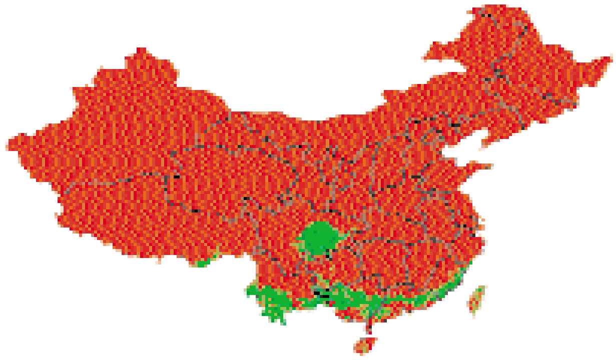


Figure 1.9. Green shaded areas are climatically suitable for *Acacia mearnsii* according to requirements described by Booth and Hong (1991).

SOILS

The soils of Australia have undoubtedly had a major influence on the evolution of the flora; the tolerance shown by many species to unfavourable conditions when grown in other countries is a reflection of their persistence under adverse conditions in their native habitat. Most of the major Australian soil groups have equivalents in other parts of the world, yet the soil cover of the continent presents a number of features that together give it some distinctive character (Hubble 1970):

- generally low nutrient status with widespread and severe deficiencies of phosphorus and nitrogen, and some deficiencies of trace elements, multiple deficiencies being common although accommodated by the indigenous flora;
- poor physical condition of surface soils, which over large areas have poor infiltration characteristics, set hard on drying and tend to surface sealing;
- large areas of soils with strongly-weathered or differentiated profiles; and
- the prominence and variety of soil micro–relief patterns of mounds and hollows (gilgai) with associated soil profile differences, which affect the distribution and growth of indigenous species.

A soil map of Australia of the size of this book would be either excessively complex or excessively generalised. Therefore for the present purpose reliance will be placed on the following rather general comment. Soil geography at the continental level is reasonably well covered at a scale of 1:2 000 000 by the *Atlas of Australian Soils* (Northcote et al. 1960–68; Northcote et al. 1975) and at a scale of 1:5 000 000 by Anon. (1980). Neither the U.S. Soil Taxonomy (Soil Survey Staff 1975) nor the FAO-UNESCO (FAO 1990) systems have been or will be used for soil survey in Australia, although features of Australian soils may be described by these systems for international audiences. A new classification system for Australian soils is described by Isbell (1996). Systems of soil classification in general have an agricultural bias, and are of less value for forests.

The soil classification used in descriptions of species ecology in this book is that of Stace et al. (1968), which recognises 43 groups of soils based on the degree of profile development and degree of leaching (Table 1.3). This system provides a better link to international systems than does that used by Northcote et al. (1960–68).

The native vegetation has not had an important influence on soil formation. The generally dry soil surface conditions, limited meso-fauna, woody nature of much of the litter, and efficiency of plants in withdrawing nutrients before abscission of plant components have tended to slow the incorporation of litter in the surface soil. For the most part reserves of organic matter in surface soils are only l–2%; perhaps more than 75% of the land has values less than 1% (Division of Soils, CSIRO 1983, p. 554). Since nitrogen levels (as well as other properties related to soil fertility) are correlated with those for organic matter, it is easy to understand the importance of nitrogen-fixing plants, including *Acacia* and *Casuarina*, in many Australian ecosystems.

Australia is geologically old with relatively minor geological events since the Tertiary (beginning 60 million years ago). There has been no recent mountain building or extensive vulcanism, and glaciation in the Pleistocene period affected only 0.5% of the continent, mainly in Tasmania. Consequently little new parent material has been exposed and there are many ancient land surfaces.

The most extensive example of the ill effects of old age is lateritic soil. This commonly occurs as a peneplain with ironstone or laterite on the surface or subsurface overlying kaolin up to a metre or more in thickness; the ironstone may be present as gravel or boulders. Sand may overlie the ironstone, constituting

Table 1.3. Australian Great Soil Groups in order of degree of profile development and degree of leaching, as defined and described by Stace et al. (1968) (based on Beadle 1981).

I. No profile differentiation. Nos 2–6 classed as Regosols, which are deeper soils formed from transported rock particles which may or may not have been weathered chemically.	1. LITHOSOLS. Stony and gravelly soils; texture varies from sand to clay loam; rock fragments usually present.	Elevated rocky or stony areas. Arid to humid. Many communities.
	2. SOLONCHAKS. Highly saline; sands to clays, the clays often granular and cracking on drying; surface sometimes salt-encrusted.	Near the sea, or in arid zone. Halophytic communities.
	3. ALLUVIAL SOILS. Formed on alluvium. Texture, stoniness, depth, colour and carbonate-content vary.	All parts of the continent, usually associated with rivers, fan-formations. Vegetation various.
	4. CALCAREOUS SANDS. Siliceous sands enriched with calcium carbonate.	Mainly littoral zone.
	5. SILICEOUS SANDS. Quartz sand without or with a coating of hydrated ferric hydroxide, hence white, yellow, yellow-brown to red. Acid throughout.	Coast, or inland as dunes.
	6. EARTHY SANDS. Sandy profiles, yellow or red. Some contain ironstone gravel. Acid.	Semi-arid areas with xeromorphic communities, or arid areas with hummock grassland.
II. Minimal profile development. Soils exhibit little or no evidence of leaching, either because they occur in drier climates, or the high clay content retards water movement through the profile.	7. GREY, BROWN AND RED CALCAREOUS SOILS. Shallow (to about 40 cm), weakly structured loams to light clays with fine carbonates throughout (pH about 9). Grey-brown or red. Organic matter very low.	Arid zone. Support halophytic shrubland.
	8. DESERT LOAMS. Moderate texture contrast. A horizon to 10 cm deep, neutral to alkaline, light brown to red-brown. B horizon with added clay, alkaline.	Arid zone; alluvial plains and associated stony uplands (gibber downs). Support halophytic shrublands.
	9. RED AND BROWN HARDPAN SOILS. Shallow to moderately deep. A horizon non-saline, acid to neutral. B horizon indurated with silica cementation and clay, massive, sometimes with gravel.	Arid zone; restricted to central WA and northeastern SA. Support *Acacia* shrublands.
	10. GREY, BROWN AND RED CLAYS. Deep clays, usually paler with depth. Surface soils granular, acid or alkaline, cracking, often with gilgais. Subsoil blocky, acid or alkaline.	Along watercourses and floodplains. Support grasslands in driest areas, woodlands of *Casuarina*, *Acacia* and *Eucalyptus* elsewhere.
III. Dark soils. Clayey soils with a relatively high organic content. Occur between 500 and 1000 mm isohyets.	11. BLACK EARTHS. Heavy clays with fairly uniform texture profile, dark grey to very dark brown to black. A horizon, neutral to alkaline. Lower horizons with secondary calcium carbonate. Crack deeply on drying.	Tas. to north Qld. High fertility. Support grassland or *Eucalyptus* woodland with a grassy understorey.
	12. RENDZINAS. Shallow alkaline soils developed on limestones or marls.	Small areas in eastern States. High fertility. Vegetation as No. 11.

Table 1.3. *continued*

III. Dark soils. *continued*	13. CHERNOZEMS. Resemble No. 11, but differ in having only less clay in topsoil which is mildly acid.	Small areas in the eastern States, supporting *Eucalyptus* woodlands with a grass understorey.
	14. PRAIRIE SOILS. A horizon light clay or loam, dark grey-brown, brown or black, acid. B horizon more clayey; acid to mildly alkaline.	Coastal to sub-coastal areas from southern Qld to Tas. and SA. Support *Eucalyptus* forest or woodland.
	15. WIESENBODEN (Meadow Soils). Related to Nos 11 and 13, but they have gley formed under conditions of waterlogging, pH 6.0–8.0.	Same areas as No. 11. Support *Eucalyptus* spp. tolerant of waterlogging, e.g. *E. ovata*, *E. tereticornis*, or *Melaleuca* spp.
IV. Mildly leached soils. Texture-contrast soils, mostly with brown or grey-brown A horizons and darker brown B horizons.	16. SOLONETZ. Sandy or loamy A horizon abruptly differentiated from clayey B horizon. A horizon neutral to slightly alkaline. B horizon very compact resulting in poor drainage, pH high (to 9.0).	Semi-arid regions in southeast and southwest. Support *Eucalyptus* woodlands.
	17. SOLODIZED SOLONETZ AND SOLODIC SOILS. Resemble No. 16 but are more leached. A and B horizons abruptly differentiated. A horizon sandy, acid; B horizon columnar to blocky, very alkaline below.	Widespread in all States in areas with mean annual rainfall of 400–1000 mm. Support *Eucalyptus* and *Acacia* woodlands.
	18. SOLOTHS (Solods). Resemble No. 17 but are acid throughout the profile.	Occupy small areas. Vegetation as No. 17.
	19. SOLONISED BROWN SOILS. Contain abundant calcium carbonate. Profile sandy throughout. A horizon neutral or slightly alkaline, brown to red-brown. B horizon with much carbonate, alkaline.	Semi–arid and arid south in west and east. Support mallee, or woodlands (chiefly *Casuarina cristata*).
	20. RED–BROWN EARTHS. A horizon loamy. B horizon with added clay, calcium carbonate present. Usually with high base status.	Mainly south of the Tropic of Capricorn between 400 and 630 mm isohyets where they support *Eucalyptus* woodlands.
	21. NON-CALCIC BROWN SOILS. Similar to No. 20 but with no calcium carbonate in the B horizon. Profile slightly acid to slightly alkaline.	Semi–arid southeast and southwest. Support *Eucalyptus* woodlands.
	22. CHOCOLATE SOILS. Acid, friable clay loams; some leaching but high in bases. High fertility.	Mainly southeast, Qld to Vic. Support *Eucalyptus* woodlands and forests.
	23. BROWN EARTHS (Brown Forest Soils). Yellowish, reddish or dark brown throughout. Light loams to clays. Surface acid to neutral; pH and bases increase with depth.	Humid climates from SA to northern NSW. High fertility and support *Eucalyptus* forest or rainforests.
V. Soils with predominantly sesquioxidic clay minerals. Other than having uniform colour profile, the 7 Soil Groups have little in common.	24. CALCAREOUS RED EARTHS. Soil uniformly sandy, clay increasing slightly with depth; profile alkaline.	Arid zone. Support *Acacia* scrubs, *Casuarina cristata* woodlands, or *halophytic* shrublands.

continued over

Table 1.3. *continued*

V. Soils with predominantly sesquioxidic clay minerals. *continued*	25. RED EARTHS. Red throughout except for surface organic matter; contain some clay; structure weak crumby to blocky. Acid.	Widely distributed in northern arid zone to wetter tropics. Support *Acacia* woodlands (drier) to *Eucalyptus* forests (wetter).
	26. YELLOW EARTHS. Similar to No. 25 but yellow to yellow-brown. Acid.	Sub–humid to humid areas, NSW to Cape York; southwest and northwest WA. Low fertility and usually support xeromorphic communities.
	27. TERRA ROSSA SOILS. Shallow red or red-brown soils developed on highly calcareous materials. Neutral to slightly alkaline.	Uncommon; close to coast in southeast and Tas. Support *Eucalyptus* communities including some types of mallee.
	28. EUCHROZEMS. Red, clayey, strongly structured; derived from basalt. A horizon dark with organic matter, mildly leached, slightly acid. Clay increases with depth.	Small patches in the east and tropics between 630–750 mm. Support *Eucalyptus* woodlands.
	29. XANTHOZEMS. Yellow, clayey, friable, strongly structured, with moderate horizon differentiation, acid, high fertility.	Sub-humid regions in the east in summer rainfall zone. Support drier types of rain-forest or grassy *Eucalyptus* forests.
	30. KRAZNOZEMS (Red Loams). Deep, red or red-brown; high organic matter in surface. Acid (pH 4.5–5.5); base saturation about 50%.	Mainly east from north Qld to Tas. with mean annual rainfall 850–3700 mm. Support rainforests or tall *Eucalyptus* forests.
VI. Mildly to strongly acid and highly differentiated: Podzols and Podzolic Soils.	31. GREY–BROWN PODZOLIC SOILS. A horizon grey to grey-brown, medium textured; A2 distinct but not bleached. B horizon yellow to yellow brown, with blocky structure and high clay. Acid except neutral in lower B.	East and southeast from southern Qld to SA Mean annual rainfall 500–1000 mm. Support *Eucalyptus* forests and woodlands.
Characterised by strong eluviation of clay and sesquioxides from the A horizon and their deposition in the B horizon. The soils occur in wet climates.	32. RED PODZOLIC SOILS. A1 grey-brown; A2 light grey to yellowish; both sandy loam to clay loam. B horizon red brown to red, sandy clay to heavy clay. Profile acid; base saturation high to low.	Humid east and north. Support *Eucalyptus* forests and woodlands, rarely rainforests.
	33. YELLOW PODZOLIC SOILS. A horizon greyish or brownish sand to clay loam. B horizon yellow-brown, friable, clayey. Profile acid.	Mainly humid east. Support *Eucalyptus* forests and woodlands; *Nothofagus* forest in Tas.
	34. BROWN PODZOLIC SOILS. Profiles brownish to yellowish throughout. B horizon with some eluviated clay.	More humid areas of Tas., highlands of Vic., southwestern WA. Support tall *Eucalyptus* forests and woodlands or heaths.
	35. LATERITIC PODZOLIC SOILS. A horizon sandy; B horizon mottled yellow-brown to red clay. Ironstone present. Acid throughout.	Many parts of the continent with mean annual rainfall exceeding 500 mm. Support *Eucalyptus* forest or woodland.
	36. GLEYED PODZOLIC SOILS. Profile of the podzolic type with mottling from A2 downward which are the result of waterlogging. Acid throughout.	Areas subject to waterlogging, mainly humid southeast. Support species adapted to some waterlogging, e.g. *Eucalyptus ovata* and *Melaleuca* spp.

continued over

Table 1.3. *continued*

VI. Mildly to strongly acid and highly differentiated: Podzols and Podzolic Soils. *continued*	37. PODZOLS. Strongly differentiated sandy profiles. A1 dark, with organic matter; A2 white. B yellow to red to black with eluviated clay, sesquioxide and organic matter.	High rainfall areas, chiefly near coast. Low fertility soils, supporting xeromorphic woodlands, scrubs or heaths.
	38. HUMUS PODZOLS. Resemble No. 37, but have a dark coloured (sometimes black) B horizon formed as an accumulation at the level of watertable.	High rainfall areas, chiefly near the coast in areas subject to waterlogging. *Banksia* or *Melaleuca* dominant.
	39. PEATY PODZOLS. Profile surmounted by a thick layer of brown or black peat up to 25 cm deep. Very acid (pH 4–5).	Mainly southwest Tas. in perhumid cool–cold climates.
VII. Dominated by organic matter. Profile with much organic matter in the topsoil obscuring the effects of other components. Formed under wet conditions, some with waterlogging.	40. ALPINE HUMUS SOILS. Horizons merge. A horizon ca 25 cm deep, grey, brown to black, friable. Lower layers brown to yellow brown, merging to grey. High fertility.	Highlands of southeast. Support subalpine woodlands, heath, or grasslands.
	41. HUMIC GLEYS. Similar to No. 36 but with much organic matter intimately incorporated in the dark A horizon. Acid to neutral, some subsaline.	East coast behind littoral zone or valley plains along rivers. Support *Eucalyptus* swamp forests, or *Melaleuca* or *Casuarina* spp.
	42. NEUTRAL TO ALKALINE PEATS. Organic matter accumulated under influence of alkaline ground–water.	Coastal areas, southeast SA, northwest Tas.
	43. ACID PEATS. Dark–coloured to black; organic matter. Profiles up to ca 1 m deep, waterlogged permanently or regularly.	High mountains and plateaux, NSW, Vic. and Tas.
VIII. Fossil laterite residuals.	44. IRONSTONE GRAVEL SOILS. Gravelly soils sometimes with a sandy matrix; massive ferruginous laterite commonly present and sometimes part of the mottled zone below. See No. 35.	Extensive areas in southwest WA. and small areas in northwest WA. and NT., arid zone and the east. Vegetation various, but always xeromorphic.

sand plain. The laterite is a relic of warmer and wetter climates in earlier geological times, when weathering extended in some cases to a depth of 60 m. The durable ironstone capping may break away where the underlying clay is eroded, leading to the formation of a newer, lower land surface with more normal soils. Sands derived from weathered laterites are of low fertility and have been spread over wide areas, adding to the already poor sandy soils derived from older sandstone and granite formations.

Among the best soils are the undulating 'downs' of central western Queensland where, in the central basin, moderately fertile self-mulching clays have formed from underlying fresh sediments.

Between these two extremes a variety of soils has formed on various mixtures of the deeper weathered horizons of ancient profiles, accumulations or detritus on lower plains and fresh parent rock. The nature of the old materials, rather than current climate, has been the dominant influence on the soils now present. Even the more prominent hills generally have a mantle of soil, albeit often shallow. The balance in many cases appears to have been rather delicate, and consequently the disturbances that have accompanied European settlement over the last 200 years have tended to accelerate erosion. These changes are however of little significance in the present context.

Over large areas Australian soils are more acid than pH 6. Such soils are common in wetter climates, but contrary to what might be expected are not unusual in more arid areas. The extent of acid soils is such that only a relatively small number of indigenous species are adapted to alkaline conditions, and where soils in prospective planting areas have a high pH the range of candidate species from Australia is consequently rather limited.

High concentrations of salt (sodium chloride) are common in soils close to the coast; under drying conditions incrustations may form on the soil surface. It is not unusual to find species of *Casuarina* growing in such soils. High concentrations of salt (sodium chloride and sulfate) may also be found in inland soils, especially in and near shallow valleys of old river systems: the origin of this material is not always clear; although in some instances parent materials contain abundant salt. Certainly the limited opportunity for leaching, arising from low rainfall and high evaporation, contributes greatly to the salinity problem; the small runoff, unmatched in any other continent, is illustrated by the following figures (Australian Water Resources Council 1976):

Area (km^2)	7 690 000
Average rainfall (mm)	420
Evapotranspiration (% rainfall)	87
Runoff (% rainfall)	13

Saline soils, dominated by chlorides, occur over great areas of southern and central Australia (more than 5% of total area, Northcote and Skene 1972). Even greater expanses (25–30% of total area) of sodic soils occur over many parts of the continent.

The soils of other continents show some similarities but many differences with those of Australia. Parts of Africa come closest to the Australian scene, but the latter has a much greater occurrence of strongly differentiated soils with sodic clay B horizons. Such soils are also lacking in South America, while Australia has few deep, highly leached, strongly acid sesquioxide soils common in that continent, and on which some Australian trees have grown very well. Further contrasts between Australia and other continents are given by Sanchez and Isbell (1979).

FIRE

Much of the Australian flora is adapted to particular fire regimes (combinations of fire intensity, frequency, and season) (Gill et al. 1981). In addition to their direct effects on plants, fires have a less obvious and less well understood effect on nutrient status and cycling of the vegetation. The adaptive traits of trees and shrubs growing in fire-prone environments are discussed in Chapter 2.

In arid and semi-arid areas, extensive fires are rare because of the usually discontinuous nature of the fuels (Luke and McArthur 1978). In dry forests and woodlands, especially in northern Australia, annual fires are common. There is evidence that since Europeans arrived 200 years ago these fires have become more extensive, burning later in the dry season and with higher intensity than was the case when only Aboriginal people were present. At least some of the woody plants are adversely affected by present fire regimes, and relict communities of more fire-sensitive species are in retreat. In the tall moist forests of the southeast of the continent, fires are rare but when they do occur — perhaps at intervals of many decades — they are of high intensity due to the large accumulation of fuel and the extreme weather conditions (high temperatures, low fuel moisture content, low humidities and strong winds) associated with them (Pyne 1991). Between these two extremes are found a range of vegetation types in which fires of moderate intensity occur every few years.

PEOPLE

Studies of fossil pollen in eastern Australia show that eucalypts and other myrtaceous plants have become much more frequent, and casuarinas and other fire-sensitive flora less frequent, in the last 130 000 years. In the same period the amount of fine charcoal in the sediments markedly increased, and it has been suggested that this change in fire occurrence reflects the influence of Aboriginal people (Singh 1982). The hunting fires of the Aboriginal people would have favoured those species adapted or capable of adapting to fire.

When Europeans arrived 200 years ago, the influence of Aboriginal people lessened and was replaced by a variety of agricultural and industrial influences (Saunders et al. 1990). A large fraction of the rainforest was cleared, commonly for dairying; extensive areas of woodland in the southern half of the continent were cleared for cereals and improved pastures. Fire regimes were changed to new and variable patterns of burning to which in at least some cases the woody vegetation is not well-adapted. Watering-points were established in arid and semi-arid rangelands, so permitting population increases in native grazing animals (kangaroos) as well as providing for introduced hard-hoofed animals. The latter now include sheep, cattle, horses, buffalo, goats, pigs, donkeys, deer and camels. Hares and rabbits were established, the latter attaining plague numbers before the advent of myxomatosis in the 1950s reduced their population. A wide range of plants was introduced, some of which have become weeds, and now these frequently compete strongly with indigenous flora. Sometimes the new fire regimes have made regeneration a more precarious process than previously, when climatic factors presented the main difficulties (Adamson and Fox 1982).

It is both fortuitous and fortunate that the genetic resources of the trees of interest in the present context have probably not been greatly reduced by the changes described. Many of them have natural ranges in the north or more arid parts of the continent where the rates of change have been least, and their longevity has lessened the immediate effect of any problems with regeneration. Although arrangements in Australia for *in situ* conservation of indigenous flora are steadily improving, there is no assurance that existing provisions will be adequate for all species and provenances of value to other countries, and thus the conservation status of such species warrants examination on a case-by-case basis.

INSECTS

A large insect fauna has co-evolved with the Australian native flora. The insects associated with eucalypts have received most attention from forest entomologists because of the dominance of that genus; 'from germination, and throughout its life, every organ of a eucalypt provides food and shelter for numerous and diverse forms of insect life' (Carne and Taylor 1978). Remarkably few insect species have become recognised as pests; predators, parasites, diseases, competition and other agencies generally prevent more than very temporary expression of their capacity to increase to damaging levels.

If these same species are transferred to other countries where Australian trees may be growing, the likelihood of their causing damage is increased because the full range of factors controlling population levels in Australia is likely to be lacking. There have already been examples of insects, inconspicuous in Australia, causing significant losses among exotic eucalypts. Because of these examples, and the attention accorded to quarantine measures by the Australian agricultural and pastoral industries, foresters involved in the testing and use of Australian flora in other countries make every effort to prevent insects accompanying exported seed or other plant material. It is realistic to expect that from time to time trouble will be experienced in exotic plantings through the establishment of insects indigenous to Australia. In such cases biological control by natural parasites or predators would be desirable, and if successful would reduce the troublesome insects to an inconsequential level.

In their review of the interaction of eucalypts and insects in Australia, Carne and Taylor (1978) drew attention to the importance of stress in rendering trees susceptible to insect attack. Although some factors such as unseasonal weather are beyond the control of the grower, others such as off-site planting or severe competition due to weeds or dense stands can and should be avoided.

REFERENCES

ABS. 1983, 1988, 1994. *Year Book Australia.* Canberra: Australian Bureau of Statistics.

Anon. 1980. *Atlas of Australian resources.* Third series. Volume I. *Soils and land use.* Canberra: Division of National Mapping.

—— 1990. *Atlas of Australian resources.* Third series. Volume VI. *Vegetation.* Canberra: AUSLIG.

Adamson, D.A. and Fox, M.D. 1982. Changes in Australasian vegetation. Pages 109–146 in *A history of Australian vegetation.* Smith, J.M.B. ed. Sydney: McGraw Hill.

Alexander, G. and Williams, O.B. ed. 1973. *The pastoral industries of Australia.* Sydney: Sydney University Press.

Australia. 1988. *Climatic averages Australia*. Canberra. Australian Government Publishing Service.

Australian Water Resources Council. 1976. *Review of Australia's water resources.* Canberra: Australian Government Publishing Service.

Beadle, N.C.W. 1981. *The vegetation of Australia.* Cambridge: Cambridge University Press. 699 p.

Booth, T.H. ed. 1996. *Matching trees and sites*. ACIAR Proceedings No. 63.

Booth, T.H. and Hong, Y. 1991. Identifying climatic areas in China suitable for *Acacia mearnsii* and *A. mangium.* Pages 52–56 in *Advances in tropical acacia research.* Turnbull J.W. ed. ACIAR Proceedings No. 35.

Burley, J. and Wood, P.J. 1976. A manual on species and provenance research with particular reference to the tropics. Tropical Forestry Paper 10, Department of Forestry, Oxford.

Carne, P.B. and Taylor, K.L. 1978. Insect pests. Pages 155–168 in *Eucalypts for wood production.* Hillis, W.E. and Brown, A.G. ed. Melbourne: CSIRO.

Cremer, K.W. and Leuning, R. 1985. Effects of moisture and soil temperature during radiation frost. *Australian Forest Research* 15: 33–42.

Department of Trade and Resources. 1982. *Australian farming systems. An introduction.* Canberra: Australian Government Publishing Service.

Division of Soils, CSIRO. 1983. *Soils: an Australian viewpoint.* Melbourne: CSIRO, and London: Academic Press.

FAO, 1990. *FAO-UNESCO Soil map of the world. Revised legend*. World Soil Resources Report 60. Rome: FAO.

Fitzpatrick, E.A. and Nix, H.W. 1970. The climatic factor in Australian grassland ecology. Pages 3–26 in *Australian grasslands.* Moore, R.M. ed. Canberra: Australian National University Press.

Foley, J.C. 1945. Frost in the Australian region. Australian Bureau of Meteorology, Bulletin No. 32.

Gill, A.M., Groves, R.H., and Noble, I.R. ed. 1981. *Fire in the Australian biota.* Canberra: Australian Academy of Science.

Golfari, L., Caser, R.L. and Moura, V.P.G. 1978. Zoneamento ecologico esquematico para reflorestamento no Brasil (Schematic ecological zoning for replanting in Brazil). UNDP/FAO/IBDF/BRA-45, Serie Tecnica No. 11 Belo Horizonte, Brazil, Centro Pesquisa Florestal da Regiao do Cerrado. Rome: FAO.

Groves, R.H. ed. 1994. *Australian vegetation.* 2nd edn. Melbourne: Cambridge University Press.

Hall, N., Wainwright, R.W. and Wolf, L.J. 1981. Summary of meteorological data in Australia. Division of Forest Research CSIRO, Australia Divisional Report 6.

Hubble, G.D. 1970. Soils. Pages 44–58 in *Australian grasslands.* Moore, R.M. ed. Canberra: Australian National University Press.

Isbell, R.F. 1996. *The Australian soil classification*. Melbourne: CSIRO.

Jeans, D.N. ed. 1977. *Australia — a geography.* Sydney: Sydney University Press.

Jennings, J.N. and Mabbutt, J.A. 1977. Physiographic outlines and regions. Pages 38–52 in *Australia — a geography.* Jeans, D.N. ed. Sydney: Sydney University Press.

Leeper, G.W. ed. 1970. *The Australian environment.* 4th edn. Melbourne: CSIRO and Melbourne University Press.

Luke R.H. and McArthur, A.G. 1978. *Bushfires in Australia*. Canberra: Australian Government Publishing Service.

Moore, R.M. ed. 1970. *Australian grasslands.* Canberra: Australian National University Press.

Northcote, K.H. and Skene, J.K.M. 1972. Australian soils with saline and sodic properties. CSIRO Australia Soil Publication 27.

Northcote, K.H. et al. 1960–68. *Atlas of Australian soils.* Sheets 1–10 with explanatory booklets. Melbourne: CSIRO and Melbourne University Press.

Northcote, K.H., Hubble, G.D., Isbell, R.F., Thompson, C.H. and Bettenay, E. 1975. *A description of Australian soils.* Melbourne: CSIRO.

Parkinson, G. ed. 1986. *Atlas of Australian resources.* Third series. Volume IV. *Climate.* Canberra. Division of National Mapping.

Penman, H.L. 1963. Vegetation and hydrology. Technical Communication, Bureau of Soils, Harpenden 53.

Perry, R.A. 1970. The effects on grass and browse production of various treatments on a mulga community in central Australia. Page 63 in Proceedings, Xl International Grassland Congress, Norman, M.J.T. ed. Queensland University Press.

Poynton, R.J. 1979. *Tree planting in southern Africa*. Vol. 2. *The Eucalypts*. Johannesburg: Department of Forestry.

Pyne, S.J. 1991. *Burning bush: a fire history of Australia.* New York: Henry Holt.

Sanchez, P.A. and Isbell, R.F. 1979. A comparison of the soils of tropical Latin America and tropical Australia. Pages 25–52 in *Pasture production in acid soils of the tropics*. Sanchez, P.A. and Terges, L.E. ed. Proceedings,

Seminar at CIAT, Cali, Colombia.
Saunders, D.A., Hopkins, A.J.M. and How, R.A. ed. 1990. *Australian ecosystems: 200 years of utilisation, degradation and reconstruction.* Proceeedings Ecological Society of Australia Vol. 16.
Singh, G. 1982. Environment upheaval. Pages 90–108 in *A history of Australian vegetation.* Smith, J.M.B. ed. Sydney: McGraw-Hill.
Soil Survey Staff 1975. *Soil taxonomy: a basic system of soil classification for making and interpreting soil surveys*. USDA Agriculture Handbook No 136. Washington: Government Printer.
Stace, H.T.C., Hubble, G.D., Brewer, R.G., Northcote, K.H., Sleeman, J.R., Mulcahy, M.J. and Hallsworth, E.G. 1968. *A handbook of Australian soils.* Glenside, South Australia: Rellim Publications.
Thornthwaite, C.W. and Mather, J.R. 1957. Instructions and tables for computing potential evapotranspiration and the water balance. *Climatology* 10: 185–311.
Turnbull, J.W. and Eldridge, K.G. 1983. The natural environment of *Eucalyptus* as the basis for selecting frost resistant species. Pages 43–62 in Proceedings of IUFRO/AFOCEL Symposium on Frost Resistant *Eucalyptus.* 26–30 September 1983, Bordeaux, France.
Winkworth, R.E. 1983. Plants and water. Pages 85–102 in *Man in the centre.* Crook, G. ed. Melbourne: CSIRO.