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A Commonwealth Government Initiative

# AUSTRALIAN AGRICULTURE ASSESSMENT 2001

**National Land & Water Resources Audit**

*A program of the Natural Heritage Trust*

VOLUME 2

## NATIONAL LAND AND WATER RESOURCES AUDIT

*Providing Australia-wide assessments*

The National Land and Water Resources Audit (Audit) is facilitating improved natural resource management decision making by:

**Providing a clear understanding** of the status of, and changes in, the nation's land, vegetation and water resources and implications for their sustainable use.

**Providing an interpretation of the costs and benefits** (economic, environmental and social) of land and water resource change and any remedial actions.

**Developing a national information system** of compatible and readily accessible land and water data.

**Producing national** land and water (surface and groundwater) **assessments** as integrated components of the Audit.

**Ensuring integration with**, and **collaboration between**, other relevant initiatives.

**Providing a framework for monitoring** Australia's land and water resources in an ongoing and structured way.

In partnership with Commonwealth, and State and Territory agencies, and through its theme activities—Water Availability; Dryland Salinity; Native Vegetation; Rangeland Monitoring; Agricultural Productivity and Sustainability; Australians and Natural Resource Management; Catchments, Rivers and Estuaries Condition; and Information Management—the Audit has prepared:

**Assessments** of the status of and, where possible, recent changes in the condition of Australia's land, vegetation and water resources to assist decision makers achieve ecological sustainability. These assessments set a baseline or benchmark for monitoring change.

**Integrated reports** on the economic, environmental and social dimensions of land and water resource management, including recommendations for management activities.

**Australian Natural Resources Atlas** to provide internet-based access to integrated national, State and regional data and information on key natural resource issues.

**Guidelines and protocols** for assessing and monitoring the condition and management of Australia's land, vegetation and water resources.

This report presents the key findings for the Audit's Agricultural Productivity and Sustainability theme as:

> *Australian Agriculture Assessment 2001* reports on landscape processes, soil, nutrient and water movement and serves as a key input towards improved land and water resources management.

Australian Agriculture Assessment 2001 was prepared in partnership with CSIRO Land and Water, Australia's States and Territories and major agricultural industries.

# AUSTRALIAN AGRICULTURE ASSESSMENT 2001 Volume 2

National Land & Water Resources Audit
*A program of the Natural Heritage Trust*

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**National Land & Water Resources Audit**
*A program of the Natural Heritage Trust*

Minister for Agriculture, Fisheries and Forestry
Parliament House
Canberra, ACT 2600

Minister for Environment and Heritage
Parliament House
Canberra, ACT 2600

Dear Ministers,

I have pleasure in presenting to you *Australian Agriculture Assessment 2001*—a report of the National Land and Water Resources Audit.

This assessment demonstrates first and foremost the role of partnerships in understanding and addressing natural resource management issues facing Australian agriculture. The assessment of soil acidity (for example) is based on the combined resources of the Australian fertiliser industry, soil scientists and government agencies. It includes data from the thousands of soil tests taken by farmers as part of their integrated farm management each year. Up to 24 million hectares of agricultural soils are highly acidic (some five times the area at risk from dryland salinity)—presenting significant on-farm productivity and management challenges.

To set the benchmark for improvements in agricultural practice this report:

- details the first comprehensive assessment of **water-borne erosion** and **sediment transport** for Australia's agricultural catchments and rivers, and highlights implications for soil, river and estuary management;
- details **river nutrient budgets** and changes in nutrients loads to our rivers;
- details changes to **landscape water and farm nutrient balances** and the implications for on-farm nutrient management;
- forecasts the extent and impact of **soil acidification** on agricultural soils and their productivity;
- details new soil information for **Australia's agricultural soils**;
- details **progress of agricultural industries** in meeting natural resource challenges; and
- details key components of **land condition monitoring** that could be used to report changes in the natural resource base and tracks progress in implementing improved practices.

This report highlights the long-term nature of natural resource processes such as soil acidity or nutrient and sediment movement down rivers. Meeting the twin goals of increased productivity and reduced off-farm impacts requires ongoing commitment to innovation and continuous improvement in farm practice. The assessment of industry natural resource management practice highlights agricultural industry ability to adapt, improve and innovate.

Australian Agriculture Assessment 2001 and the more detailed information in the Australian Natural Resources Atlas will prove invaluable to regional communities as they set priorities for activities under the National Action Plan for Salinity and Water Quality and the extension of the Natural Heritage Trust.

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The assessment also provides a framework and information for government, industry and science agencies to review programs and develop the policies required to deliver sustainable agricultural development in Australia. It identifies the monitoring activities that would provide information to track improvements in practice and resource condition, ensuring efficiencies in program delivery and maximising returns on investment.

The Audit Advisory Council commends this report and the *Australian Natural Resources Atlas* to you. It remains for Australian agriculture in partnership with industry groups, research and development agencies and government to keep this information up to date and use it for tracking progress and setting natural resource management priorities.

I am pleased to present this report to the Natural Heritage Trust Ministerial Board.

Yours sincerely,

Roy Green

Chair
National Land and Water Resources Audit Advisory Council
October 2001

# SUMMARY

## *Natural resource challenges facing agriculture*

Australian agriculture feeds the nation with a diverse range of produce, contributes $17.6 billion every year to export earnings as raw and processed products, and employs approximately 400 000 Australians—generating national and regional wealth.

Australia's natural resources underpin our agricultural industries. Climatic variability, largely infertile and highly erodible soils, the chemistry of those soils, their salt stores and pH are all key factors affecting sustained productivity.

Agricultural activities can be broadly grouped into:

- *produce quality*—covering issues of food safety, meeting market specifications, processing, marketing, selling and transport (not covered by the Audit);
- *production*—covering issues of rotations, enterprise mix, varieties and trends in yield performance; and
- *natural resource maintenance and protection*—covering issues of on-farm resource management and off-farm impacts.

On-farm practices link these activities and are crucial to delivering natural resource outcomes.

The Standing Committee of Agriculture in Australia defined sustainable agriculture as:

> '*the use of farming practices and systems which maintain or enhance the economic viability of agricultural production; the natural resource base; and other ecosystems, which are influenced by agricultural activities*'
>
> SCA 1991

The guiding principles for sustainable agriculture were stated as:

- farm productivity is sustained or enhanced over the long term;
- adverse impacts on the natural resource base of agricultural and associated ecosystems are ameliorated, minimised or avoided;
- residues resulting from the use of chemicals in agriculture are minimised;
- the net social benefit derived from agriculture is maximised; and
- farming systems are sufficiently flexible to manage risks associated with the vagaries of climate and markets.

These succinct definitions imply the need to manage agricultural systems to be both profitable and environmentally sound, through adoption of efficient and environmentally benign management practices.

### Australian Agriculture Assessment 2001 objectives

To provide information to:

- understand the links between natural resource condition and production—to maximise sustainable agricultural production;
- document the condition of natural resources used in agriculture—to maintain and protect the natural resource base on which agriculture depends; and
- determine off-farm exports and fluxes of sediments, carbon and nutrients—for quantifying the off-farm impacts of agriculture on public resources, rivers and estuaries.

Australian Agriculture Assessment 2001 assessed key factors related to natural resource sustainability, including:

- soil loss off-farm and through our rivers to estuaries and marine environments through water-borne soil erosion;
- nutrient balance, incorporating an assessment of all inputs and outputs in the production cycle;
- soil chemistry—particularly pH and soil nutrient status; and
- transport and delivery of nutrients through regional river networks.

To underpin this assessment, the Audit has compiled Australia's first integrated soil properties information system (the **Australian Soil Resources Information System**) for agricultural landscapes as a framework for assessing condition, change and trends of change in agricultural landscapes, and to assist in managing soils.

Australian Agriculture Assessment 2001 should be read in conjunction with other Audit assessments:

- water balance and the onset of dryland salinity are covered in *Australian Dryland Salinity Assessment 2000* (NLWRA 2001a);
- water use and water use efficiency are covered in *Australian Water Resources Assessment 2000* (NLWRA 2001b);
- Australia's Rangelands are covered in *Tracking changes: Australian Collaborative Rangeland Information System* (NLWRA 2001c).

Impacts of land use on native vegetation, and catchments, rivers and estuaries are covered in separate Audit reports. A related report—*Australians and Natural Resource Management 2001*—details the economic benefits that agriculture delivers to the Australian economy and the costs of resource use, particularly off-farm.

## Landscape nutrient balances

Agriculture has *doubled* the productive capacity of agricultural landscapes. This capacity is determined by changes in water and nutrient availability and was assessed by mapping modelled water, carbon and nutrients balances and distribution of the major stores and fluxes; and determining how stores and fluxes respond to changes in agricultural inputs.

Net primary productivity (a measure of plant biomass gain) is an integrated measure of the coupled water, carbon, nitrogen and phosphorus balances. Distribution broadly follows rainfall patterns and is also influenced by air dryness, light and agricultural inputs. Net primary productivity strongly controls carbon stores in plants, litter and soil. Net primary productivity averages 0.96 Gt of carbon each year for the Australian continent. Nearly 60 Gt of the total *continental* carbon is stored as plant biomass (45%) and soil carbon (55%).

Agricultural nutrient inputs have increased continental net primary productivity by 5%; the mineral nitrogen store by 13% and the mineral phosphorus store by 8%. These increases have occurred over less than a quarter of the continent (since more than 75% of Australia is rangelands, national parks, or other largely natural and intact vegetation). Addition of nutrients and the use of legumes and irrigation water has increased agricultural productivity, nearly doubling pre-European stores of carbon, organic nitrogen and organic phosphorus. Soil mineral nitrogen, plant-available phosphorus, and nitrogen and phosphorus concentrations in soil water have also increased by up to a factor of five. These increases are concentrated in southern agricultural regions of Australia.

Harvested product is relatively small component of the continental net primary productivity and landscape stores of carbon, nitrogen and phosphorus. Nutrients applied to agricultural landscapes can exceed those required to achieve optimum production levels and in some regions are approaching diminishing returns. Attention to nutrient balance on farm will lead to more cost-efficient agriculture and fewer off-farm impacts.

Nutrients leaking from farms can lead to enriched rivers, estuaries and nearshore marine zones. Priority needs to be given to managing farm nutrient inputs more efficiently to counter increasing associated environmental costs.

## Farm-gate nutrient balance

Nutrient management is a critically important issue for Australian agriculture. A balanced supply of all essential plant nutrients is required to sustain productivity and maintain soil fertility status on farm. Nutrient leakages off-site (especially nitrogen and phosphorus) can degrade the quality of water resources with enrichment of waterways leading to problems such as algal blooms.

In the higher rainfall, more intensively managed areas, Australia's surface soils have become more fertile following a long history of fertiliser application, but areas of soils with potentially low or marginal soil phosphorus, sulfur and potassium levels occur within the agricultural zone of all States. Australian soils are generally well endowed with calcium and magnesium.

A major shift in fertiliser consumption in Australia occurred during the 1990s, with a doubling of nitrogenous fertiliser use. The reasons for this upsurge is most likely associated with a range of factors including:

- higher nitrogen demands in more intensively cropped rotations;
- failure of pasture legumes to persist;
- varietal changes and adoption of minimum tillage practices;
- as a result of declining protein levels in wheat a growing awareness by farmers of the increased quality and yields obtainable from increased fertiliser applications; and
- the introduction of premium prices for higher protein wheat.

Farm-gate nutrient balances differ across Australia's regions. Balances for nitrogen, phosphorus, sulfur, and calcium are mainly neutral (inputs = exports) or moderately positive (inputs > exports) across much of the southern agricultural zone. At the gross regional farming scale, this suggests that levels of these nutrients are generally being maintained in soils. Potassium and magnesium balances are usually negative (inputs < exports) indicating that soil reserves are being progressively depleted.

In intensive industries with high nutrient use, such as sugar cane, dairying and horticulture, nitrogen and phosphorus balances were assessed as positive (inputs > exports). Highly positive (inputs > exports) nutrient balance indicate a likelihood that nutrients are moving off-farm to streams and groundwater.

Mainly negative nutrient balances were derived for the subtropical regions, suggesting nutrient depletion is occurring on these soils, many of which are naturally fertile. This implies that close attention to nutrient status needs to be maintained from a productivity perspective, so that soils retain their nutrient status.

Overall, attention needs to continue to be paid at a higher level in Australian agriculture to nutrient status, monitoring and tracking changes in all farming systems. This needs to be done with dual objectives—maximising yields on-farm and minimising export of nutrients off-farm, with the consequent impacts on the quality of water bodies.

## Soil acidity

Soil acidification looms as a major soil degradation issue in all Australian States. The Audit estimates that 50 million and 23 million hectares of Australia's agricultural zone are already experiencing impacts from soil acidity in surface and subsoil layers respectively and that these are probably markedly affecting yields. Large areas of acidic soils occur in New South Wales, Western Australia, Victoria, and Tasmania.

Farmer awareness of the insidious nature of this issue has been heightened by research and extension programs in some States. However, awareness is by no means universal. Soil acidification is a cost of productive agricultural systems—whether from nitrogen fixation by legumes in mixed pastures or crop rotations, or from the increased use of nitrogen fertilisers.

In the absence of remedial lime applications, (which neutralise acidity) it was estimated that from 29 to 60 million hectares will reach the limiting soil pH value of 4.8 within 10 years, and a further 14 to 39 million hectares will reach the pH value of 5.5, where growth of sensitive plant species is impaired.

Currently, approximately 2 million tonnes of lime are applied to agricultural land each year and use is generally increasing. It has been estimated that from 12 to 66 million tonnes of lime is required to adjust Australia's existing acidic soils to pH values of 4.8 and 5.5 respectively, with a further 3 to 12 million tonnes needed each year to maintain soil pH status in a satisfactory range. These estimates indicate the imperatives for coordinated extension activities across industry groups, agribusiness and government.

Land degradation problems arising from induced acidification are mostly reversible by applying lime. Other management solutions can be used where liming is not a viable option. In northern Queensland banana plantations, improvements in nitrogen and residue management reduced the need for lime.

Other opportunities include stock management and attention to the use of perennials in the pasture management cycle.

## Erosion

Water-borne soil erosion is a major and continuing issue for Australian agriculture and catchment management and impacts on river, estuary and marine resources. It causes unsustainable losses of soil for agriculture that in some areas far exceed (up to 50 times) rates of soil development.

*Hillslope erosion* (sheet and rill erosion) remains high in Australia's tropical northern regions, particularly at the onset of the wet season, and especially in the semi-arid woodlands and arid interior. Maintaining vegetative cover, minimising soil disturbance and building sediment-trapping wetlands and riparian areas remain imperatives.

*Gully erosion* while inactive in many previously formed gullies, persists as the major erosion process affecting river condition in southern and eastern Australia. Sediment from these previously active gullies has affected about 10 000 kilometres of stream length in the Murray–Darling Basin alone. These rivers, now with coarse sand accumulations in stream beds, exacerbating flooding and smothering habitat of Australia's native fish.

Active gully erosion is still occurring in northern Queensland and in south-western regions of Western Australia. Changes to agricultural practices that minimise gully erosion is an imperative, from both on- and off-farm perspectives.

*River bank erosion* is a major problem. Extensive lengths (120 000 kilometres) of riparian vegetation along eastern Australia's rivers and streams are degraded and require rehabilitation. Where these landscape resources are intact, they protect the integrity of banks against erosion. Priority areas include much of the Murray–Darling Basin, South Australia and south-western regions of Western Australia.

*Sediment delivery* to streams, rivers, estuaries and near shore marine zones is high in many catchments. Deposition of sand and suspended sediments in streams and rivers is worst in the Murray–Darling Basin, coastal regions of New South Wales, south-east Queensland and the south west of Victoria.

From a near shore marine and estuary perspective, approximately 90% of suspended sediment loads reaching marine and estuarine environments is derived from 20% of agricultural catchments particularly in coastal regions of Queensland and New South Wales.

For the Great Barrier Reef Lagoon, about 25% or 12 million tonnes of sediment delivered to streams is discharged each year on average across all contributing catchments. This is predicted to be approximately three times greater than natural loads, with consequent impacts on estuaries and marine fisheries, seagrasses and near shore coral reefs. However for catchments such as the Burdekin and Fitzroy, loads can be more than 20 times natural loads

National, State and regional priorities for natural resources management can now be re-appraised in the light of these findings (e.g. soil loss on farm is irreversible and impacts that occur off-farm which will continue for many generations). Catchment management and industry priorities, particularly in terms of implementing improved practice are essential. Total impacts are likely to be equal to, if not greater than, those of dryland salinity. It is imperative that soil management targets hillslope, gully and river bank erosion in the areas identified by this assessment.

## Nutrient loads to Australian rivers and estuaries

Nearly 19 000 tonnes of total phosphorus and 141 000 tonnes of total nitrogen are exported to Australia's coast each year from areas of intensive agriculture: highest exports are in northern Queensland, Moreton Bay and New South Wales.

Total nutrient loads from river basins are partly dictated by sediment load and therefore basin size—the bigger the basin, the bigger the load. Smaller basins can export large loads if they have high export rates due to high slopes and intense rainfall; increases in population, or changes in land use and management.

Efficiency of phosphorus delivery from Australia's rivers to the coast varies from as low as 3% in the Murray–Darling Basin to over 90% in Tasmania.

The major sink for phosphorus is floodplain sedimentation, but reservoir sedimentation (both nitrogen and phosphorus) and riverine denitrification (nitrogen only) can account for substantial proportions.

Priorities for reducing river and estuarine nutrient loads vary—large relative increases in river nutrient loads do not always coincide with large total exports, and estuaries differ in their sensitivity to increases in nutrient loading particularly because of differences in residence times and tidal flushing.

Targeted erosion control and soil management provides a significant contribution to managing the supply of nutrients with much of the nutrient accompanying increased sediment loads to most rivers.

Where a large part of the increase is caused by increases in either surface run-off loads or point source discharges, close attention needs to be paid to fertiliser application, animal waste retention on-farm, and sewage treatment plant and septic tank effluent management.

## Agricultural practice

Australian agricultural industries have continuously implemented new or innovative practices. In more recent years, farmers have adopted:

- improved crop rotations;
- reduced tillage and stubble retention/ incorporation by the grains industry (to reduce wind and water soil erosion and improve soil health);
- green trash blanketing by the sugar industry (to add flexibility to harvest and reduce soil erosion); and
- potassium fertiliser and lime use in agricultural systems of Western Australia (identified as significant nutritional limitations).

The Audit assessment of farming practices across all agricultural industries has demonstrated how 'best management practice' is an evolving part of agriculture. Industry has a commitment to development and adoption of best management practice. A key agent for change will be linking practices and environmental stewardship to improvements in farm business profitability.

## Ways forward

Australian agriculture has shown its capacity to adapt and innovate in response to environmental challenges. Australian farmers are conscious of the need to manage their natural resources sustainably, delivering a 'clean and green' product and working hard to manage their activities within the broader context of catchment management. Continuous improvement in practice is the framework to deliver sustainable outcomes.

Australia could enhance its capacity to deliver both productivity outcomes on-farm and environmental benefits off-farm with:

- continued definition and improvement of best practice and tracking of implementation;
- leadership in monitoring and reporting from industries and their research and development corporations;
- soil management including soil erosion control and revegetation of riparian lands; and
- increased attention to soil fertility, pH and nutrient balance.

All these issues are best addressed through partnerships between industry groups, agribusiness, research and development corporations and government. Australian Agriculture Assessment 2001 has provided the information basis to improve natural resource management by Australian agriculture.

It remains for Australian agriculture and its support groups to keep this information current as a basis for tracking progress and setting priorities.

## Australian Natural Resources Atlas

Access to information on natural resources provides opportunities for increased awareness and informed debate. This access has been improved through internet and database technology. The interactive web-based Australian Natural Resources Atlas (Atlas) presents Audit products at scales from local to regional to national.

The Atlas provides information to aid decision making across all aspects of natural resource management. It covers the broad topic of water, land, agriculture, people and ecosystems. The Atlas presents information by geographic region (national, State, regional) and by information topic. Users of the Atlas can prepare a map—using the 'make a map facility'—or search hundreds of reports in a matter of seconds.

The Australian Natural Resources Data Library supports the Atlas with links to Commonwealth, State and Territory data management systems.

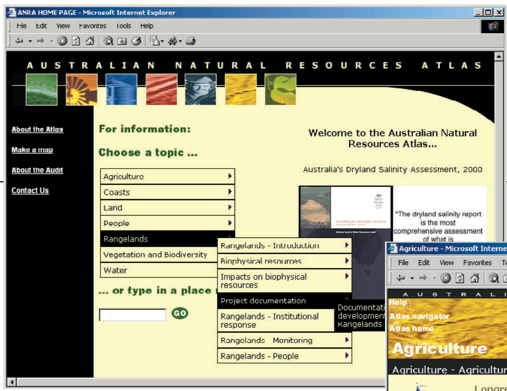
The outputs of Australian Agriculture Assessment 2001 have been reported in the *Agriculture* and *Land* topics of the Atlas.

## Audit reports

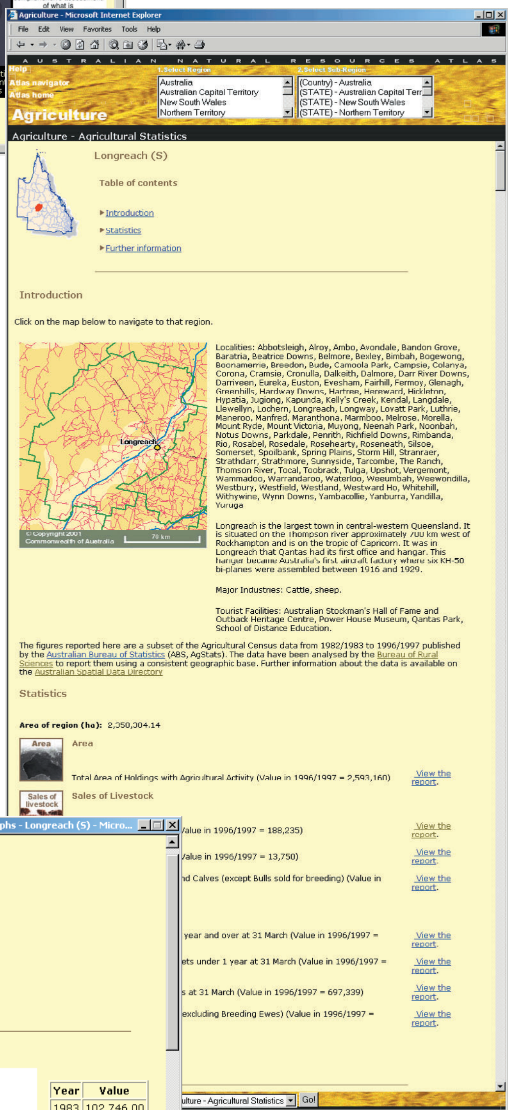
NLWRA 2001a, *Australian Dryland Salinity Assessment 2000*, a theme report for the National Land and Water Resources Audit, Canberra.

NLWRA 2001b, *Australian Water Resources Assessment 2000*, a theme report for the National Land and Water Resources Audit, Canberra.

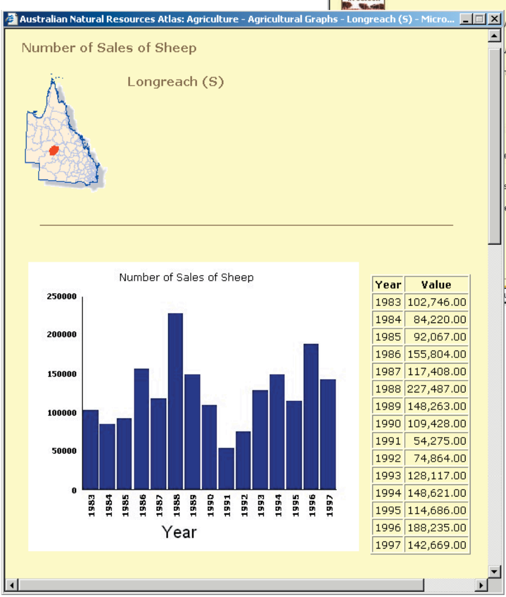
NLWRA 2001c, *Tracking Changes. Australian Collaborative Rangeland Information System*, a theme report for the National Land and Water Resources Audit, Canberra.




Australia-wide and regional information




Link to monitoring data




| Year | Value |
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| 1983 | 102,746.00 |
| 1984 | 84,220.00 |
| 1985 | 92,067.00 |
| 1986 | 155,804.00 |
| 1987 | 117,408.00 |
| 1988 | 227,487.00 |
| 1989 | 148,263.00 |
| 1990 | 109,428.00 |
| 1991 | 54,275.00 |
| 1992 | 74,864.00 |
| 1993 | 128,117.00 |
| 1994 | 148,621.00 |
| 1995 | 114,686.00 |
| 1996 | 188,235.00 |
| 1997 | 142,669.00 |

# CONTENTS

## Volume 2

# TABLES

## Volume 1

**6. Nutrient loads**



## Volume 2

**7. Changing face of Australian agriculture**



**8. Profile of Australian agriculture**

# APPENDIX TABLES

## Volume 2

Australian Soil Resources Information System

# FIGURES

## Volume 1

**3. Nutrient management**

## Volume 2

**8. Profile of Australian agriculture**

# APPENDIX FIGURES

## Volume 1



## Volume 2

# SUMMARY

- Land use and farming systems continue to evolve and diversify responding to commodity prices, market arrangements and natural resource conditions and opportunities.
- Livestock industries have reached a plateau. Areas under cotton, sugar cane, potato, rice and horticulture have all increased since 1983. Viticulture is also expanding in many regions.
- Farm numbers have decreased from 178 000 in 1982 to 145 000 agricultural holdings in 1996/97. Average property size has increased in the cropping and grazing industries.
- Between 1982 and 1997, cereal grain yields per hectare have improved in many regions, notably where crops are more diversified in regions of more reliable rainfall. Elsewhere, yield trends have been less spectacular. Improved nitrogen management was associated with strong productivity gains in several regions.
- Annual variations in yields of Australia's dominant crop—wheat—due to climate have reduced through development of drought-tolerant species and disease control.
- The area of irrigated agricultural land in Australia have increased by 26% in the last 20 years. Two-thirds of all irrigated land is in the Murray–Darling Basin; nearly half is used for pasture. Irrigated areas Australia-wide under cotton, sugar cane, pasture and fruit increased.

## INTRODUCTION

Demand from domestic and export food and fibre markets for high quality products is a continuing challenge facing modern farming systems:

- Market signals—linking processes from 'paddock to plate'—are beginning to influence international trade in agricultural goods.
- Accreditation for the use of ecologically sustainable production systems is also increasing.

Contemporary Australian agricultural industries are seeking new opportunities while attempting to minimise impacts on the natural resource base.

In this analysis, data from the annual Australian Bureau of Statistics agricultural census were assembled for the years 1982/83 through to 1996/97 and used to map and interpret regional changes in land use at statistical local area scale in Australia's agricultural zone. All data were adjusted to accord with the 1996/97 statistical local area boundaries.

## LAND USE CHANGE IN AUSTRALIAN AGRICULTURE

Australian agriculture has gone through phases of exploitation and expansion, adopted new technologies and dealt with issues such as pest invasions over the last century. The result has been steady growth in some land uses and productivity.

The decision to change land use is generally taken by an individual producer. Such a decision will have wide-ranging ramifications:

- increased capital expenditure;
- learning new farming skills and markets;
- reduced production for certain commodities and (if land remains in agriculture) increased production of other commodities for the region; and
- identifying new risks (e.g. income uncertainty).

At the regional or State scale, changes in land use reflect decisions by many individuals that, when added together, affect the patterns of agricultural activities, transport, food processing, employment and economics across a landscape.

Examples of land use change include:

- converting naturalised pasture to sown pasture;
- diversifying the range of crops grown;
- changing from grazing to viticulture;
- substituting wool production for beef or prime lamb production;
- sale of land for urban or hobby farm development;
- converting cleared land to farm and plantation forestry; and
- introducing irrigation where previously dryland enterprises existed.

## Driver for change

Fluctuating prices for commodities, particularly over extended periods, (Figures 7.1 and 7.2) may be a primary drivers to alter land use.

**Figure 7.1** Relative changes in the prices of animal-based commodities relative to that of wheat with a base year of 1981.

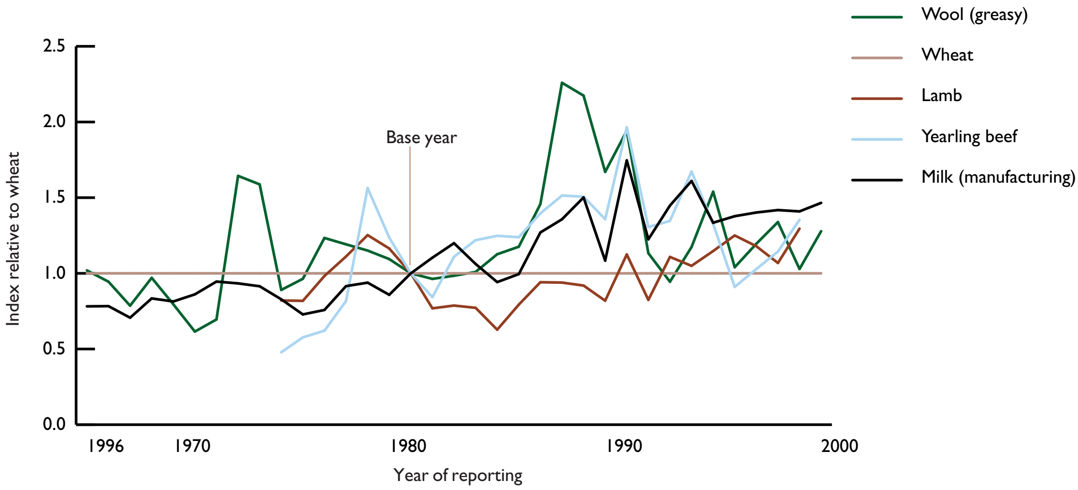
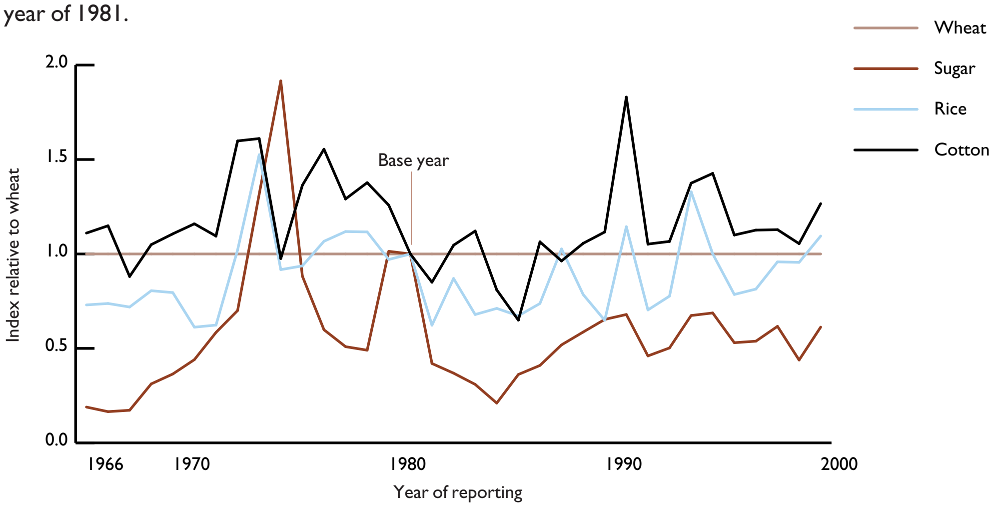



**Figure 7.2** Relative changes in the prices of plant-based commodities relative to that of wheat with a base year of 1981.

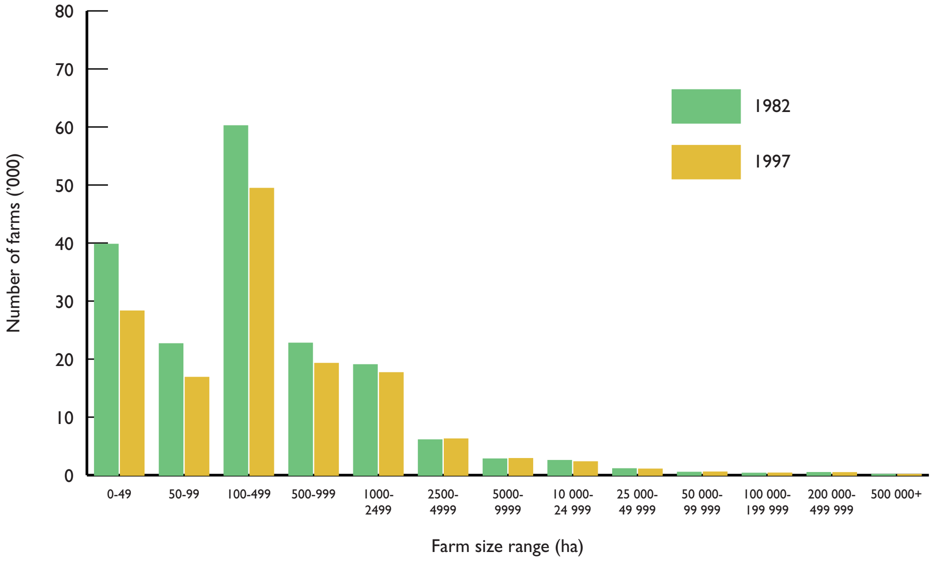



**Source:** Australian Bureau of Agricultural and Resource Economics.

## Change in farm size

Between 1982 and 1997, the total number of agricultural holdings in Australia decreased from around 178 000 to 145 000. The greatest reductions were in smaller holdings of less than 1000 ha, and especially <100 ha (Figure 7.3). As a consequence, the size of farm holdings in some agricultural sectors increased in some regions. For instance during these years, the number of sheep and beef cattle farms with areas between 100 and 5000 ha increased, as did grain cropping farms having areas between 1000 and 25 000 ha.

**Figure 7.3** Distribution of number of farms by farm size in 1982 and 1997.




**Source:** Australian Bureau of Statistics.

7

## Change in farming intensification

An index was developed to identify and summarise any changes in farming intensification that occurred between 1983/4 and 1996/97*. The index compared changes between groups of land use as a proportion of the total agricultural area. Groupings were based on resource requirements and extent of changes to the natural environment—as developed in the Australian Land Use and Management Classification and used in the Audit's National Land Use map (see Figure 1.2 *Setting the scene* section).

Intensity was based upon the average cost of production for 1991 to 1994 taken from the Australian Bureau of Statistics Farm Financial Survey. Intensity should not be interpreted as a measure of negative impacts on the natural resource base.

The greatest range of change in land use intensity occurred in a broad crescent that curves around inside the east coast, around the south coast to the southern part of the west coast of Australia and includes Tasmania (Table 7.1, Figure 7.4), reflecting change that occurred between cropping and pasture. Areas further inland appear to have changed less, possibly because of fewer viable land use options.

The areas of greatest change:

- surround large population centres;
- often occur near irrigation areas; and
- most likely reflect changes in semi-intensive cropping and horticulture.

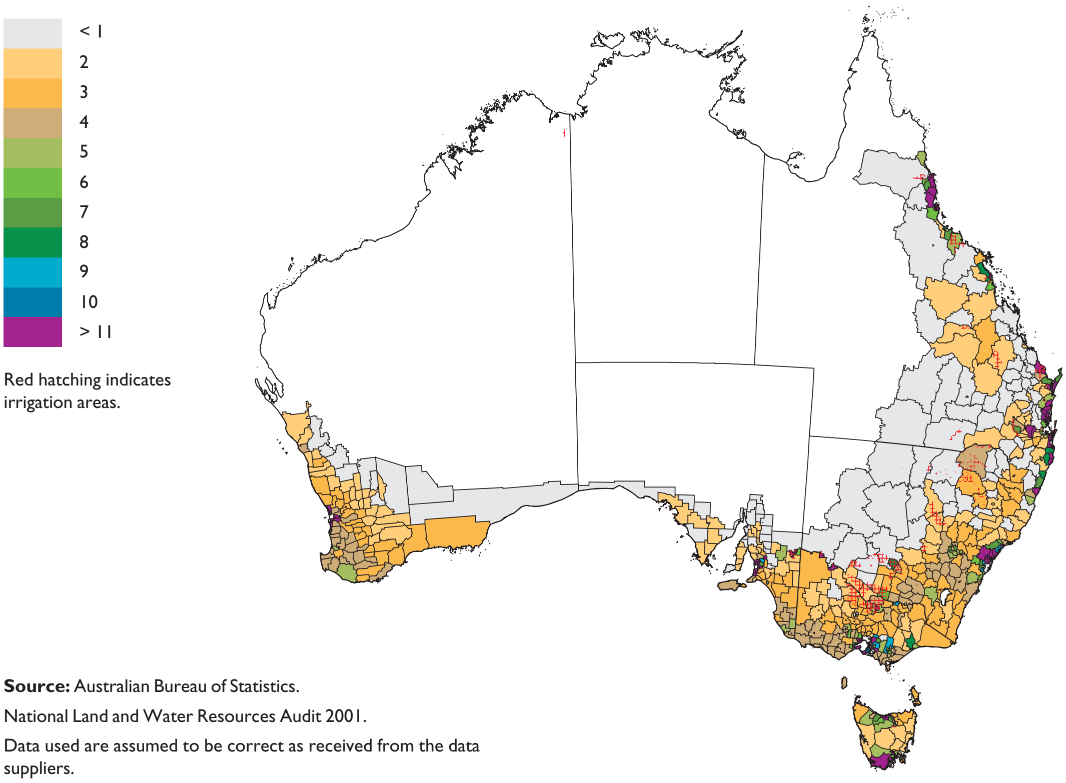
Some pockets also occur within these regions where little change in land use intensity appears to have occurred (e.g. in south-east Queensland extending into the northern tablelands of New South Wales, in eastern Victoria, the Eyre Peninsula of South Australia and eastern Western Australia).

**Table 7.1** Grouping of land uses into categories and the intensity factor applied to derive the agricultural Land Use Intensity Index (see Figure 7.4).

| Land use category | Major components | Intensity factor |
|---|---|---|
| Extensive grazing | Native pasture, residual | 0.5 |
| Sown pasture | Lucerne, grasses, legumes | 7.5 |
| Broadacre crop | Cereals, oilseeds, pulses | 7.5 |
| Semi-intensive crop | Cotton, rice, sugar cane, potatoes | 125 |
| Horticulture | Fruit, nuts, vegetables | 275 |

* Data from the 1995 agricultural census was omitted from calculations because a reduced range of items was collected in the Agricultural Census in this year.

**Figure 7.4** The range (maximum less minimum) in values of agricultural land use Intensity Index that occurred during 1982/83 to 1996/97.




**Source:** Australian Bureau of Statistics.

National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.



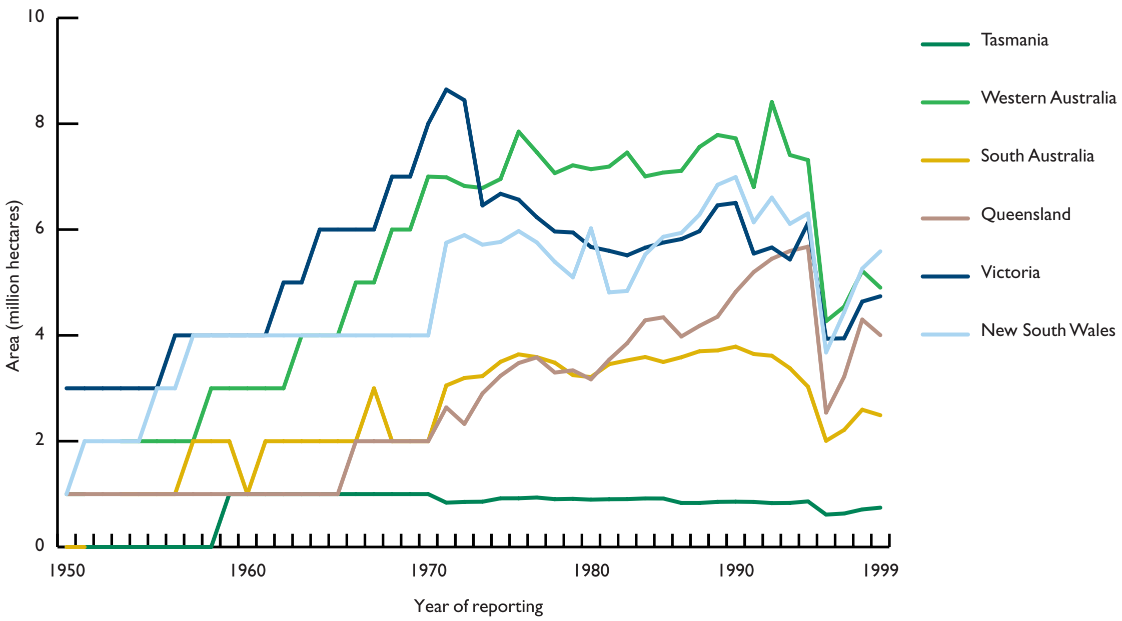
7

## Change in type of land use

### Pasture

Native and naturalised pastures and cleared scrub were steadily replaced with sown pasture in all States from 1960 until about 1970. In Queensland, this changing land use continued until 1994 (Figure 7.5). The sharp decline across Australia in 1996 and following years reflect the change in definition of the items collected by Australian Bureau of Statistics, not necessarily land use changes.

**Figure 7.5** Area of sown pasture across Australian States since 1950.



Intensive and semi- intensive commodities

- Horticulture (all vegetables except potatoes, fruit, nuts, vines, nurseries and turf) increased in all States. Collectively, these total areas are small and are concentrated around cities and within irrigation districts.
- Cotton in the growing areas between Moree Plains and Warren, in the Darling Downs and in the Central Highlands of Queensland, increased in area by at least 5%.
- Sugar cane along the tropical/subtropical eastern coast increased sometimes by more than 10%. However, within these regions small areas near Innisfail, Ayr – Home Hill and Bundaberg declined due to competition for land from horticulture (e.g. bananas, paw paw, melons, mangoes) and hobby farm development.
- Rice in the Murrumbidgee Irrigation Area (New South Wales) increased by about 5%.
- Potato increased in many regions by about 5%, with 10% increases occurring near Devonport in Tasmania, in southern Victoria and south-east Queensland.

Diversification is an important mechanism for managing risks in production, markets and income streams. It can also introduce biological resilience and productivity improvements within crop rotations and grazing systems.

A number of agricultural indices were assessed to evaluate temporal and spatial changes in the levels of farm diversification:

- Shannon's Index of Diversity;
- examination of crop type as the ratio of non-legume crops to total crop types;
- calculating the ratio of enterprise diversity and land use in five enterprise categories.

The last was explored using detailed data collected in the Australian Agricultural and Grazing Industry Survey by the Australian Bureau of Agricultural and Resource Economics.

## Ratio of non-legume crops to total crop types

The assessment examined crop type as the percentage ratio of non-legume crops (pulse and oilseed crops) to total crop types (Figure 7.6). This index showed the most diverse areas of winter cropping occur in:

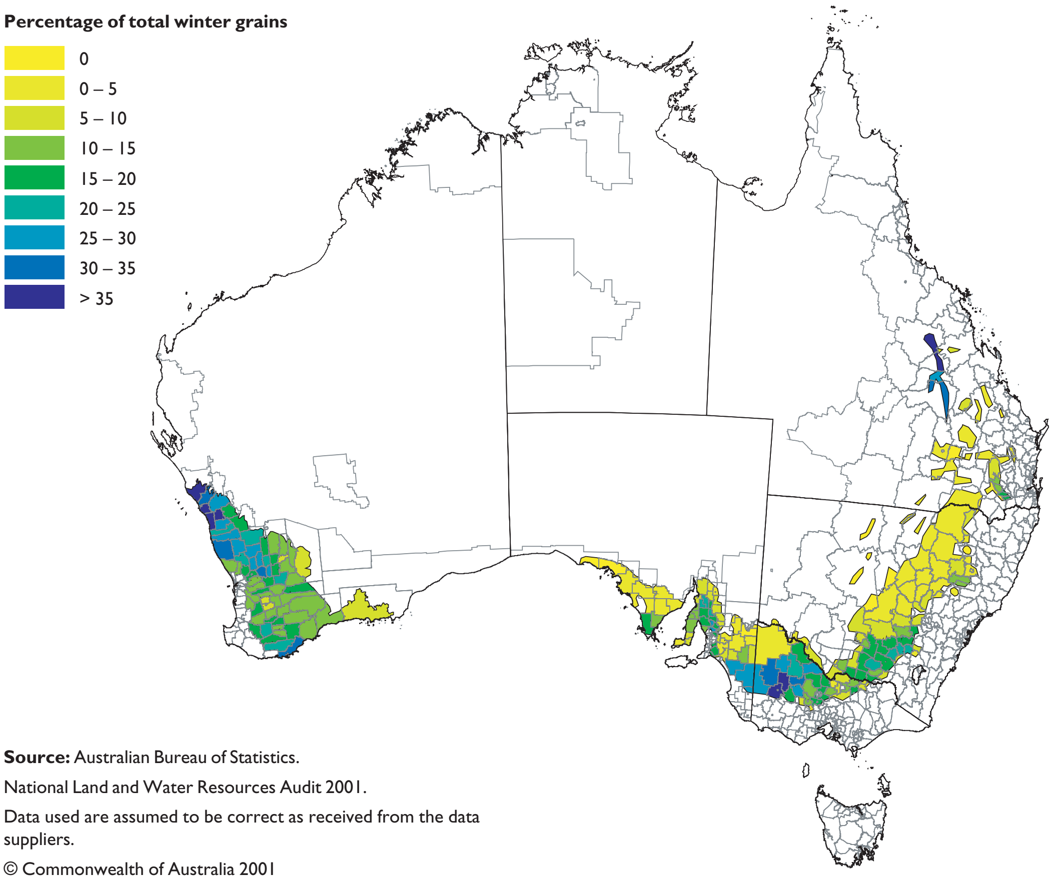
- northern parts of the Western Australian wheat belt, reflecting intensive use of lupins in crop rotations;
- the lower South East region of South Australia and the Wimmera of Victoria where pulse crops and canola are now grown with cereals; and
- in the Central Highlands of Queensland, where sunflowers have increased considerably, but also where areas under winter cereal are not large.

## Farm product diversity

The degree of farm product diversity was calculated as a diversity ratio using enterprise diversity and land use proportions of five enterprise categories. The index ranges from one to five depending on the number of on-farm enterprises. A value of one for a farm indicates a specialist farm (e.g. in the northern pastoral regions of the Northern Territory and Western Australia cattle production is typically the only broadacre activity undertaken); a higher diversity ratio value indicates farms with multiple or mixed enterprises. Mapping of broadacre crops as a proportion of total crop (Figure 7.6) shows:

- a moderately high product diversity for broadacre farms occurred in the cropping zone;
- higher farm product diversity areas occur in southern New South Wales, northern Victoria and southern Western Australia; and
- regions of highest farm product diversity within broadacre farms are consistently found in the traditional wheat–sheep belt of southern New South Wales and northern Victoria.

**Figure 7.6** An estimate of diversity in broadacre crops using proportion (%) of total crop that is non-cereal in the areas containing intensive agriculture during 1996/97.




**Source:** Australian Bureau of Statistics.

National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.

## Grain productivity

Trends in grain yields for 1982 to 1997 were calculated using the Stress Index model (Stephens 1997) that removes major effects of climate—important since two major droughts occurred during the study period. Trends were expressed as kilograms of grain per hectare per year.

**Wheat** showed the highest increasing trends in yield (Figure 7.7) when compared with other grains—barley (Figure 7.9), oats (Figure 7.10) and sorghum (Figure 7.11).

- The highest yield trends in **wheat** (Figure 7.7 ) occurred in the north-west and south-west cereal regions of Western Australia; south-eastern and north-eastern regions of New South Wales; more reliably yielding regions of South Australia; and the south-eastern edge of the Darling Downs in Queensland.

  With the exception of the north-eastern regions of New South Wales, all of these regions had high crop diversification (Figure 7.6), and in all regions new, advanced crop production practices and rotations have been adopted widely (e.g. in Western Australia, the use of high-yielding, short -season wheat varieties; early sowing; use of zero/minimum tillage; use of lupins and other pulses in rotations; and the use of nitrogenous fertiliser have combined, in the absence of droughts, to provide strong yield improvements through higher-input farming systems; in north-eastern New South Wales crop agronomy now uses increased nitrogenous fertilisers; better weed control during fallowing; and the use of sorghum as a break crop for disease.
- In South Australia, wheat yield trends were closely related to total seasonal rainfall: higher yield trends were observed in the more reliable rainfall regions (45 kg/ha/year) with only 30 kg/ha/year in the more arid cropping regions. More cropping options exist in the more reliable rainfall regions to control root diseases and increase supply of soil nitrogen.
- In the Wimmera region of Victoria, low yield trends in wheat were associated with high crop diversity (Figure 7.6). This has been partly attributed to the replacement of long fallows (for conserving soil moisture for the main wheat crop) with pulse and oilseed cash crops. This region also has negative phosphorus and nitrogen balance.
- Yield variability in wheat (Figure 7.8) was particularly high in Queensland regions with low yield trends following droughts in the early 1990s; the drier upper Eyre region (South Australia) and in central New South Wales. Low variations in wheat yields existed across Western Australia; the more reliable cropping regions of South Australia; and the slopes of southern New South Wales and north east Victoria.
- Trends in yield for **barley** (Figure 7.9) were similar to those for wheat, but generally lower due to lower nitrogenous fertilisers being applied to malting barley crops, that require low protein levels in the grain. When considered on a regional basis, some barley yields were higher than those for wheat (e.g. in southern regions of Victoria and Western Australia, where barley is better able to tolerate waterlogged or saline soils).

- Yield trends for **oats** were generally lower than for wheat or barley. Oats and other cereals (rye and triticale) do better in wetter, cooler environments, consequently yield trends are higher in southern Australia. The highest yielding regions were: south-west Western Australia, mid north and south-east regions of South Australia and south-east New South Wales. In these areas, farmers improved the management practices of oats and started applying more nitrogen as oats become more profitable.
- **Sorghum** is a summer crop and yields improved markedly in northern New South Wales, in conjunction with improved management of nitrogen (Figure 7.11). However, in Queensland, droughts in during the first half of the 1990s severely impacted on yields and the use of nitrogen fertiliser was less common.

**Figure 7.7** Trends in wheat yields (kg/ha/year) 1982 to 1997 for statistical local areas of Australia.

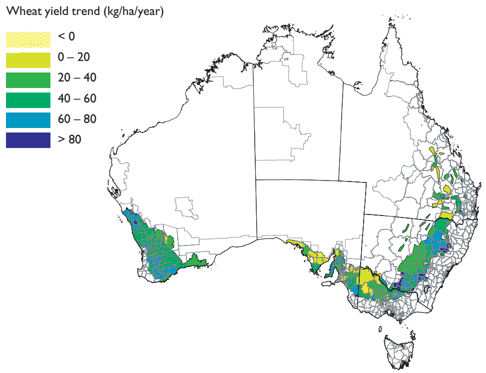



**Figure 7.8** Variability in wheat yields (expressed as coefficient of variation) 1982 to 1997 for statistical local areas of Australia.

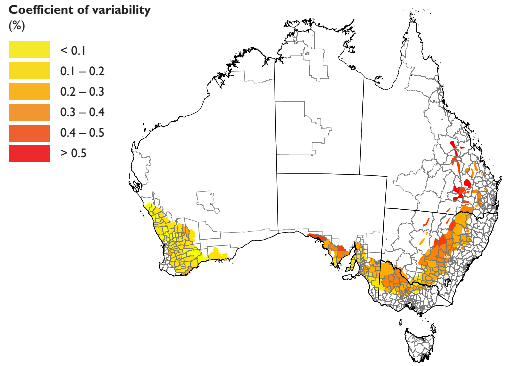



**Figure 7.9** Trends in barley yields (kg/ha/year) 1982 to 1997 for statistical local areas of Australia.

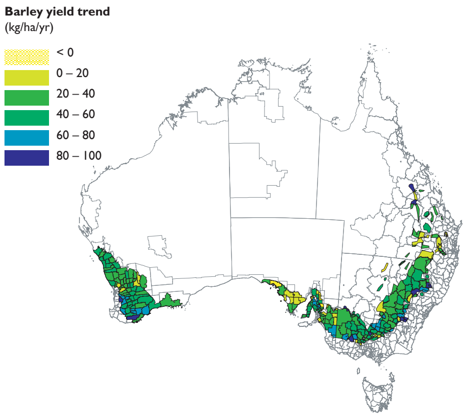



**Figure 7.10** Trends in oats yields (kg/ha/year) 1982 to 1997 for statistical local areas of Australia.

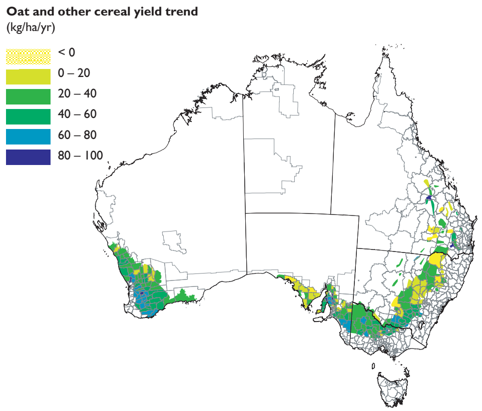
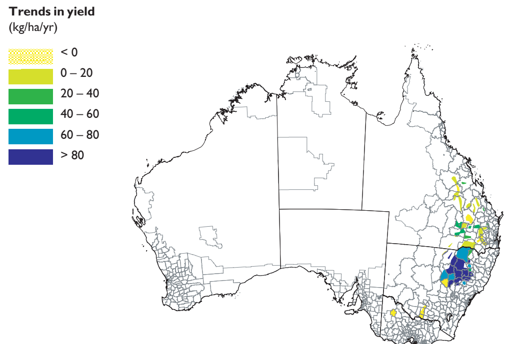



**Figure 7.11** Trends in sorghum yields (kg/ha/year) 1982 to 1997 for statistical local areas of Australia.




**Source:** Australian Bureau of Statistics and Agriculture WA.

National Land and Water Resources Audit 2001.

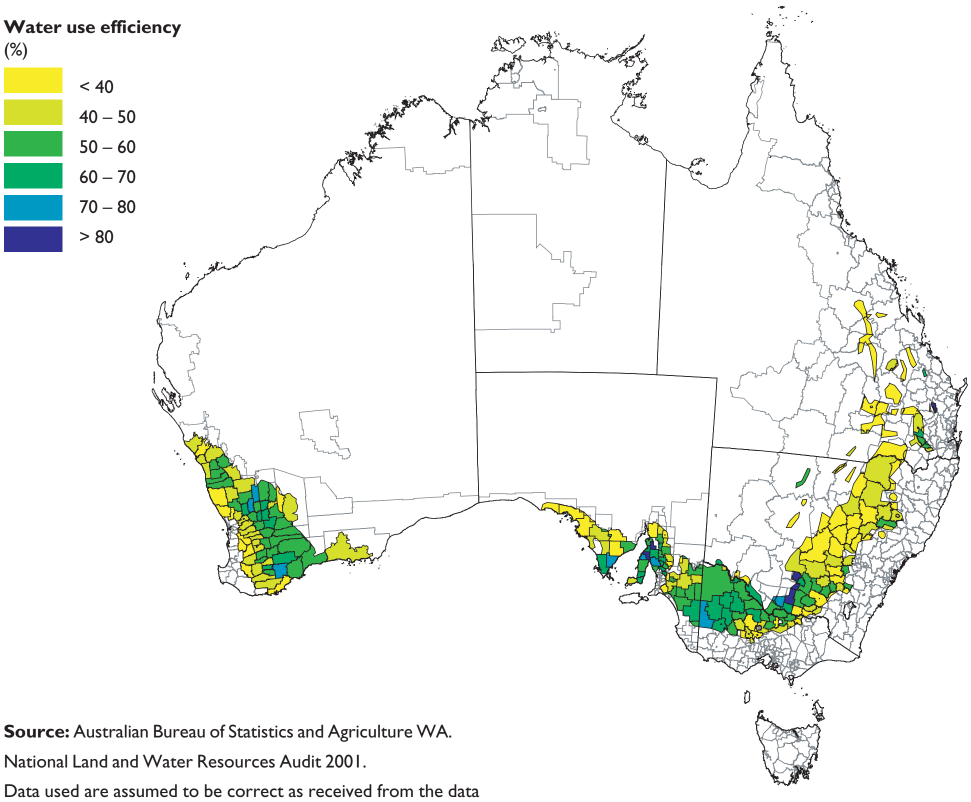
Data used are assumed to be correct as received from the data suppliers.

## Water use efficiency

Water use efficiency provides an index of how much water—from soil stores and rainfall—is used by the crops to produce grain. The unused remainder may run off, evaporate from the soil surface or drain beyond the depth of roots. Water use efficiency represents a possible unused resource for achieving higher productivity. Water use efficiency was calculated as the ratio of actual yield to potential yield (as estimated by the Stress Index model—Stephens 1997).

- The pattern for wheat (Figure 7.12) showed that areas receiving summer rainfall (i.e. northern New South Wales and Queensland) have low water use efficiencies (less than 50%). However, in many cases these areas have the option of growing summer crops to use rainfall more efficiently.
- Higher water use efficiencies (greater than 70%) occurred in the Riverina, on both sides of the Murray River, in the Wimmera, Yorke Peninsula and southern Eyre Peninsula, and in shires in the drier eastern part of the Western Australian wheatbelt.
- Many regions are still producing well below potential.

**Figure 7.12** Trends in the water use efficiency for wheat (% of total annual available water used by the crop) for different statistical local areas.




**Source:** Australian Bureau of Statistics and Agriculture WA.

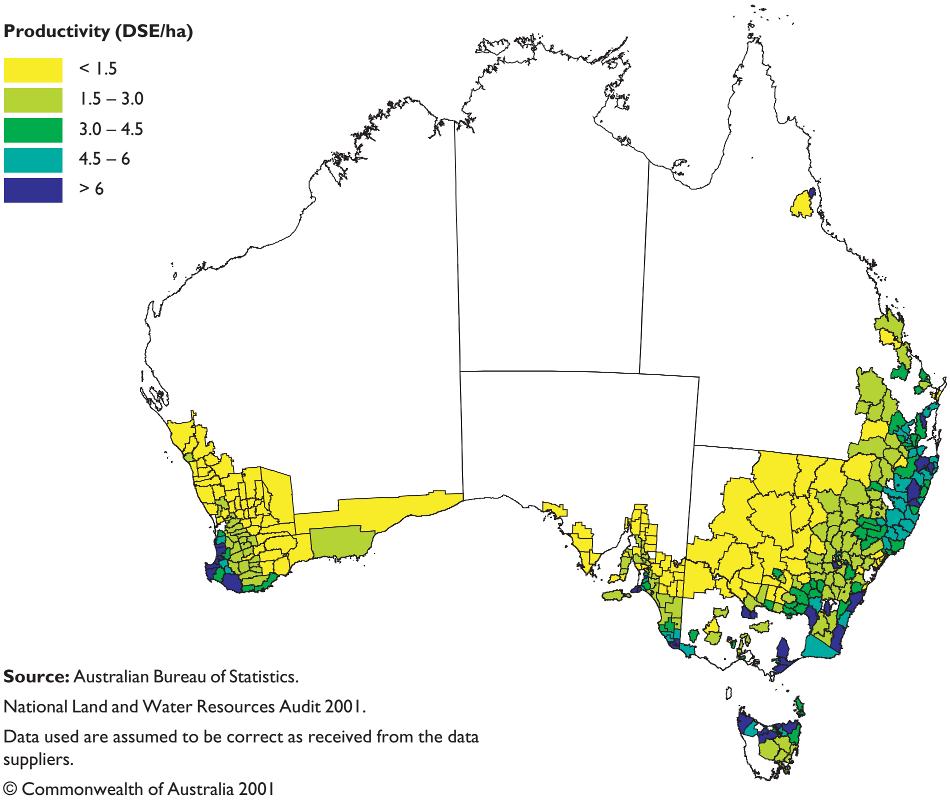
National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.

## Livestock productivity

National and regional statistics on the key grazing productive measure, livestock production/hectare, are not recorded. Broad estimates of stocking rate per hectare for agricultural regions (determined as dry sheep equivalents) were prepared as a first approximation, from estimates of annual pasture productivity and averaged for the years 1983 to 1997 (Figure 7.13).

**Figure 7.13** Mean productivity from pasture calculated as dry sheep equivalents from 1982/83 to 1996/97.




**Source:** Australian Bureau of Statistics.

National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.

## CONCLUDING COMMENTS

Australian agriculture, in the most general terms across all commodities, is best regarded as in a phase of consolidation. Key features include:

- contraction of agriculture away from marginal areas and consolidation of farm size and enterprises;
- incorporation of a mix of commodities on farm, seeking opportunities for more diverse and market responsive production;
- improvements in farming systems, integrating considerations of climate variability, soil type, soil fertility and water use efficiency;
- development of higher input – higher output systems, maximising gains from fertilisers, cultivation techniques, feedlots and irrigation;
- targeted and more integrated research, development and extension, delivering improved varieties, cultivation and breeding techniques within a farming systems context; and
- rationalisation of processing and marketing arrangements, moving away from localised cooperatives and single-desk selling arrangements to positioning commodities globally.

These shifts are all likely to continue and, fostered by a new generation of agriculture policies and partnerships, will deliver improvements in the profitability and productivity of Australian agriculture.

## REFERENCES

Stephens D.J. 1997, *Assessing and forecasting variability in wheat production in Western Australia*, final report to Agriculture WA.

# SUMMARY

- Irrigation has provided opportunities for developing higher-value, higher yielding industries: 75% of irrigation occurs in the Murray–Darling Basin.

- Irrigation produces about 26% of Australian agricultural products by value from less than 1% of land area dedicated to agriculture.

- Achieving high water use efficiency in dryland (rain fed) and irrigated agricultural systems is of paramount importance for both maximising production and protecting the resource base.

- Australian farmers and graziers are increasingly aware of and applying sustainable farming practices. Many farmers are also monitoring natural resource condition on-farm and managing to minimise impacts off-farm.

- There is much research, development and extension to be done in improving farming practices and developing industry databases that monitor and report on progression in environmental and economic performance.

- Resource degradation issues vary considerably with common issues including weeds, soil erosion, soil acidity, nutrient management and dryland salinity. Farmer management responses to these issues also vary with regions and commodities.

- Adoption of best management practices is gathering pace in most industries and is more rapid where outcomes are both profitable and environmentally sound. Recent industry surveys indicate that producers are well aware of natural resource issues and are adopting a range of practices relevant to their regions.

- Intensive industries such as rice, dairy, cotton and sugar, located in sensitive and land use-competitive environments, have developed environmental codes of practice for their industry. Management practices are continually improving. Guidelines such as the National Water Quality Management Strategy specify water quality thresholds for industries such as feedlots, piggeries and wool processing.

### Australian agriculture at a glance (1989/90 to 1998/99)*

| | |
|---|---|
| • Gross domestic product | $ 621 billion |
| • Agriculture as a percentage of GDP | ~ 3% |
| • Gross value of farm production | $ 24.7 billion |
| • Irrigated agriculture (as a proportion of gross value of agriculture) | ~26% |
| • Export value | $ 17.6 billion |
| • Export value as a percentage of total exports | ~ 20% |
| • Net farm value | $ 3.2 billion |
| • Total farm costs | $ 21.6 billion |
| • Total farm debt | $ 17.2 billion |
| • Employment at 4.6% of national workforce | 370 000 |

* The data show trends averaged for 1989 to 1992 and for 1995 to 1998. They were all sourced from the Australian Bureau of Agricultural and Resource Economic Commodity Bulletins (1997–1999), where the data for 1998 are stated as 'provisional'.

## VALUE OF AGRICULTURE TO AUSTRALIA

Agriculture is Australia's primary way of using natural resources to produce food, drink and clothing. We also export a significant proportion of these goods (Table 8.1).

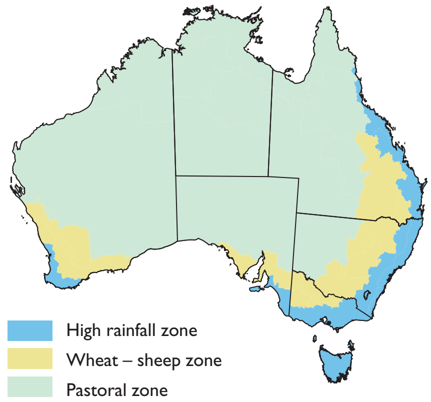
**Table 8.1** Value of major products from agricultural land uses in 1996/97.

| Commodity & group | Value (A$ m) | % of total agriculture | % exported | Distribution by State (%) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | NSW | Vic | Qld | SA | WA | Tas |
| **Horticulture** | 4 243 | 15.1 | 13 | 21 | 26 | 24 | 16 | 9 | 3 |
| Vegetables | 1 213 | 4.3 | 15 | 13 | 27 | 33 | 10 | 11 | 6 |
| Fruit | 2 389 | 8.5 | – | 24 | 26 | 19 | 22 | 6 | 3 |
| orchard | 1 668 | 5.9 | 22 | 25 | 24 | 26 | 14 | 7 | 4 |
| grapes | 721 | 2.6 | 17 | 22 | 30 | 2 | 41 | 4 | – |
| **Semi-intensive** | 3 289 | 11.7 | – | 41 | 4 | 47 | 4 | 1 | 2 |
| Sugar | 1 186 | 4.2 | 79 | 6 | – | 94 | – | – | – |
| Cotton | 1 342 | 4.8 | 80* | 70 | – | 30 | – | – | – |
| Rice | 310 | 1.1 | 57 | 99 | 1 | – | – | – | – |
| Potatoes | 449 | 1.6 | >1 | 11 | 27 | 12 | 26 | 8 | 16 |
| **Broadacre crops** | 8 383 | 29.8 | 76 | 32 | 14 | 10 | 15 | 29 | 1 |
| Cereals (includes wheat) | 7 177 | 25.5 | 76 | 36 | 11 | 10 | 14 | 28 | – |
| Wheat | 4 878 | 17.3 | 81 | 36 | 10 | 9 | 12 | 33 | – |
| Oilseeds | 325 | 1.2 | 45 | 51 | 17 | 13 | 7 | 13 | – |
| Pulses | 594 | 2.1 | 69 | 8 | 25 | 4 | 17 | 47 | – |
| Hay (includes pastures) | 596 | 2.1 | – | 20 | 35 | 9 | 16 | 5 | – |
| **Livestock products** | 5 754 | 20.4 | – | 28 | 37 | 10 | 8 | 13 | 4 |
| Wool | 2 621 | 9.3 | 83 | 38 | 20 | 7 | 11 | 22 | 3 |
| Milk | 2 809 | 10.0 | – | 18 | 55 | 12 | 6 | 6 | 5 |
| **Livestock slaughters** | 6 215 | 22.1 | 53 | 28 | 23 | 26 | 7 | 11 | 2 |
| Lamb & mutton | 1 039 | 3.7 | 70 | 24 | 33 | 5 | 13 | 23 | 2 |
| Beef & veal | 3 390 | 12.0 | 74 | 23 | 20 | 36 | 4 | 8 | 2 |
| **Total agriculture** | **28 156** | **100** | **–** | **29** | **22** | **20** | **10** | **15** | **2** |

* Over 90% in 2000/01.

**Source:** Australian Bureau of Statistics.

## SHEEP




Sheep and wool producing regions of Australia.

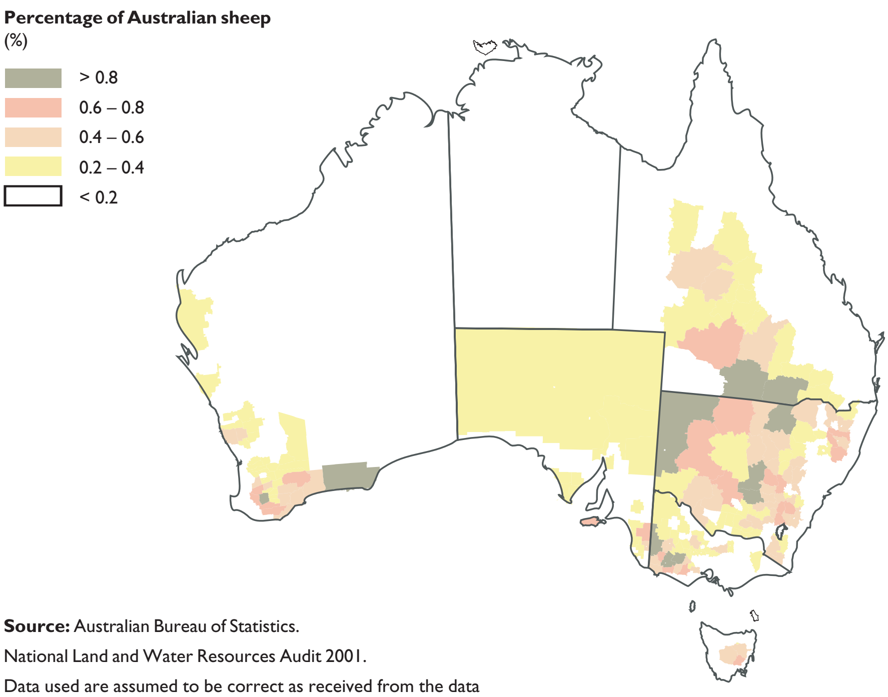
### National perspective

The sheep and wool industry produces sheep skins and a range of wool qualities that are used for fine garments, yarn, upholstery and carpets. Mutton and lamb are produced for domestic consumption and export markets. Live sheep are also exported.

Sheep farming occurs across much of Australia (Figures 8.1), including areas in the:

- high rainfall zone;
- wheat–sheep zone; and
- pastoral zone.

**Figure 8.1** Sheep distribution as a proportion of flock by statistical local area for 1996/97.




**Source:** Australian Bureau of Statistics.

National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.

Freehold land tenure for the higher rainfall and wheat–sheep zones average 73% and 69% respectively, while the pastoral zone is mainly under long- term crown lease (91%). In each of these zones, farm business profit in 1998 was negative, with an average loss of $31 000. Farm debt averaged $135 000, being less in the wheat–sheep zone.

Many innovations and market forces have contributed towards the development of Australia's modern sheep meat and wool industries (Figure 8.2) so that today, Australia is the world's largest producer of wool, and remains the main exporting country.

The wool and sheep industry began with herded flocks of sheep spread over the countryside, grazing native grasses, with the wool clipped by hand shears, loosely packed in open bullock-drawn drays and sent to uncertain markets in the United Kingdom. National sheep numbers peaked in 1970 at around 180 million, but have since declined to about 120 million. Another peak occurred in the late 1980s, mainly in response to higher wool prices. Annual wool production per sheep has remained reasonably static since 1980, at around 4.5 kg.

**Figure 8.2** Total sheep and lambs in Australia each year since 1860, with significant historical events.

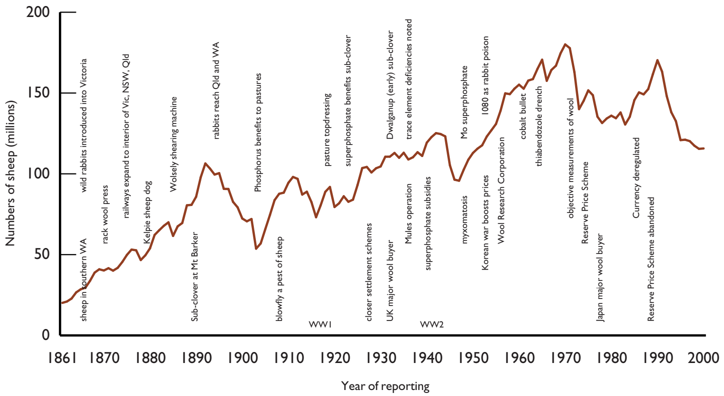
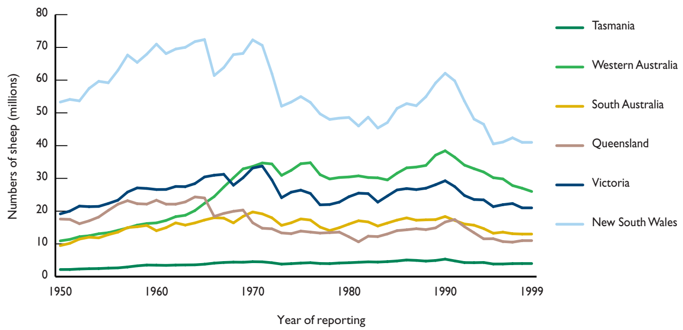



**Figure 8.3** Number of sheep in the different States of Australia from 1950.



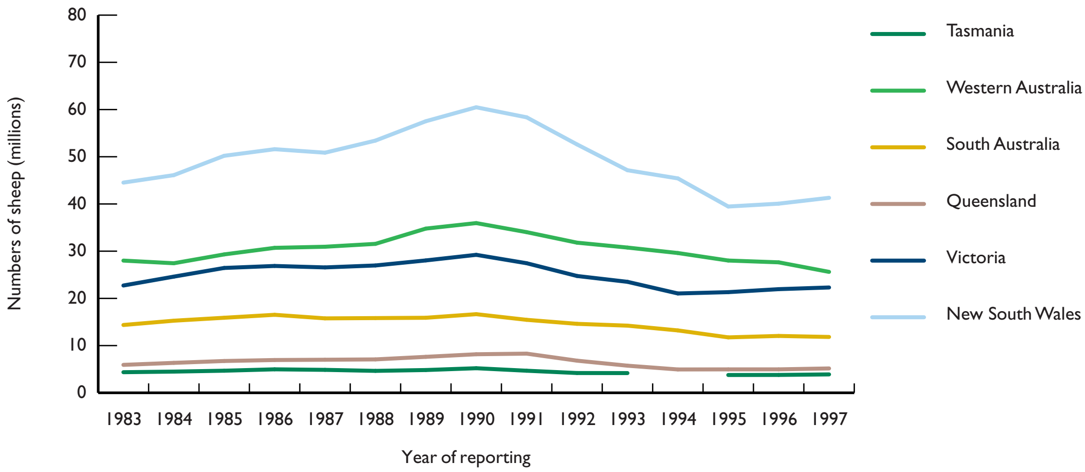

**Source:** Australian Bureau of Statistics.

At the State level, total sheep numbers over the last 50 years (Figure 8.3) have always been more numerous but more variable in New South Wales. In contrast to most States and Territories, where sheep numbers peaked during the 1960s, sheep populations in Western Australia continued to increase until 1990, partly caused by land clearing in the Great Southern region during the 1960s and 1970s. The general decline since 1990 in all States relates to lower wool prices from 1989.

## Regional perspective

Trends in sheep numbers located within the agricultural zones of each State and Territory between 1983 and 1997 tend to mirror total sheep populations in each State for this span of years (Figure 8.4).

**Figure 8.4** Recent changes in sheep numbers in the intensive agricultural areas of each State and Territory between 1982/83 and 1996/97.




**Source:** Australian Bureau of Statistics.

In 1999, 117 million sheep grazed over 86 million hectares, with much of this area being Australia's semi-arid rangelands or pastoral zone. Most of the sheep population and wool produced came from the relatively smaller high rainfall and temperate zones (Table 8.2).

The gross value of production for the industry in 1999 was $3772 m:

- $1 018 m in slaughtered meat products (0.62 million tonnes);
- $2754 m in wool products (0.64 million tonnes); and
- $175 m exported as live sheep.

About 25% of Australia's sheep meat production is exported each year, and between 4 and 6 million sheep are shipped live.

**Table 8.2** Regional sheep and wool production.

| Region | Flock size (millions) | Wool ('000 t) | Area grazed (million ha) | % of Australian sheep area |
|---|---|---|---|---|
| High rainfall zone | 18 | 82 | 5 | 5 |
| Temperate zone | 14 | 72 | 12 | 14 |
| Pastoral zone | 9 | 44 | 69 | 81 |

**Source:** Australian Bureau of Statistics.

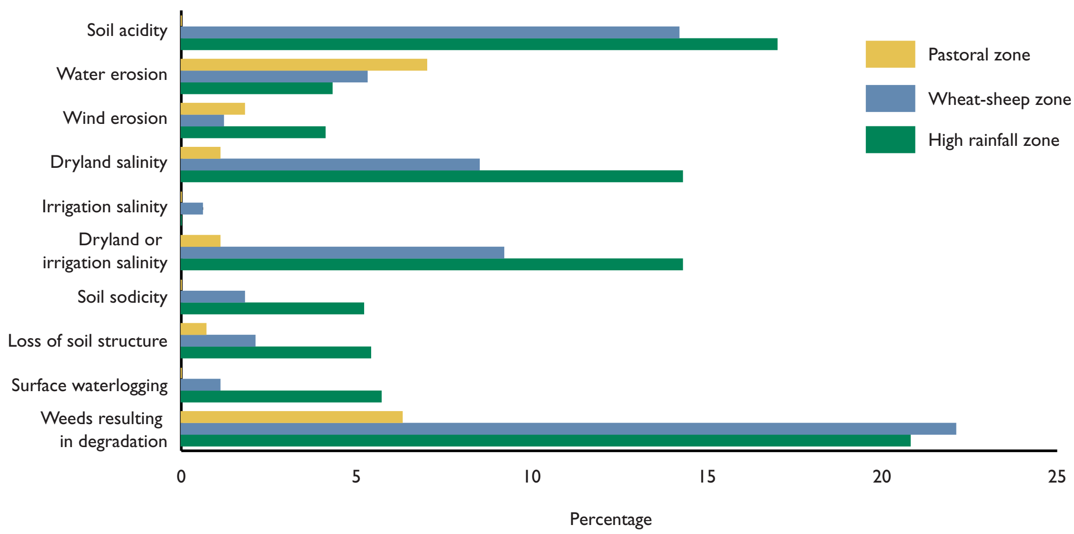
8

## Practice in the sheep/wool industry

Graziers in the three sheep/wool zones identified different resource degradation issues (Figures 8.5).

- Weeds, soil acidity and dryland salinity were identified as the most serious problems in the high rainfall and temperate zones.
- The main problems identified in the pastoral zone were water erosion and weed invasion. A smaller percentage of graziers noted loss of soil structure, surface waterlogging and wind erosion as issues.

**Figure 8.5** Proportion of sheep farms surveyed that reported significant degradation (1998/99).



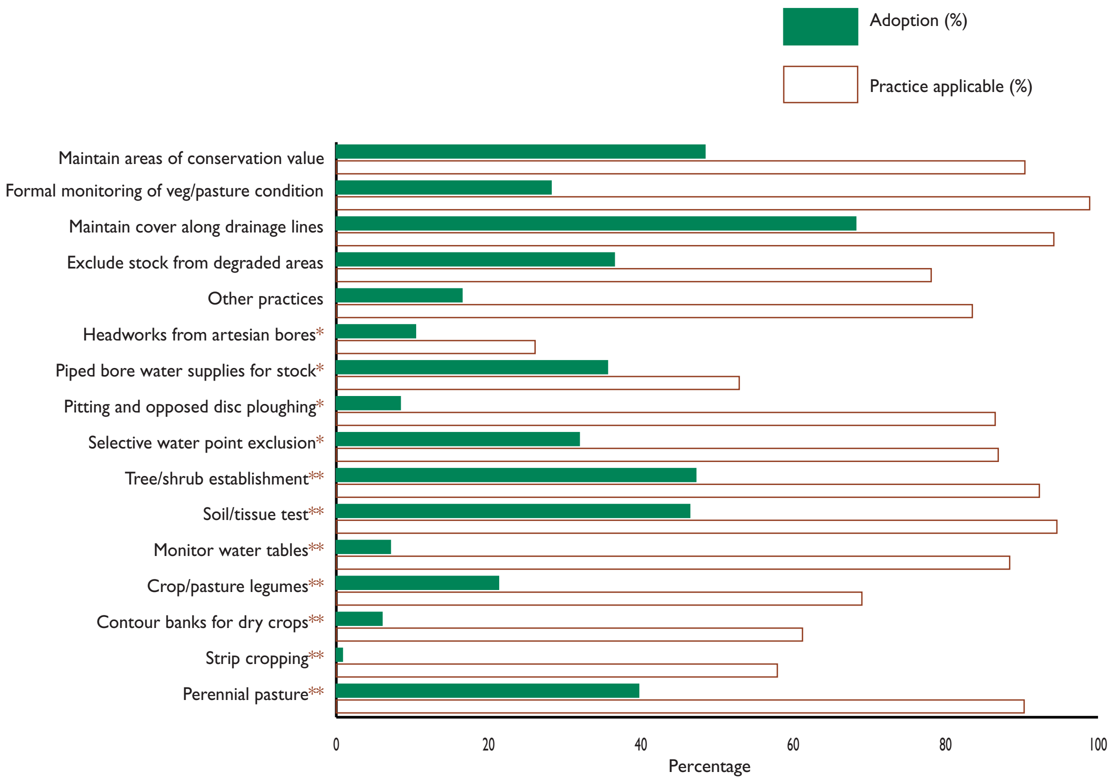

**Source:** Australian Bureau of Agricultural and Resource Economics.

Management practices also vary substantially between zones (Figures 8.6).

- Establishment of trees, shrubs, perennial pasture species, and legumes were ranked highly as key management practices in the high rainfall and temperate zones.
- Piping water to stock, formal monitoring of vegetation condition and stock exclusions at selected watering points were ranked highly as key management practices in the pastoral zone.
- Maintaining vegetative cover along drainage lines, maintaining conservation areas and exclusion of stock from degraded land were common across all zones.

Adoption of best management practice in the sheep/wool industry is being achieved through initiatives such as PROGRAZE (see case study).

**Figure 8.6** National sheep farm management and practice applicability (1998/99).




**Source:** Australian Bureau of Agricultural and Resource Economics.

* Pastoral zone farms only

** Temperate and high rainfall zones only

## SUSTAINABLE GRAZING SYSTEMS FOR SOUTHERN AUSTRALIA

### Meat & Livestock Australia in partnership with government

The Sustainable Grazing Systems program was set up to address the issues of declining pasture productivity and sustainability in the grazing systems of the higher rainfall zone of southern Australia (annual rainfall > 600 mm). Rather than the traditional approach where research works independently to develop and package information for producers, Sustainable Grazing Systems has pioneered an attempt to bring researchers, producers and extension agents into a partnership to collectively improve the productivity, profitability and sustainability of grazing systems in the high rainfall zone. There are three interacting elements within Sustainable Grazing Systems:

- PROGRAZE® to provide training and skills development for producers;
- a network of 11 regional producer committees to determine local issues and priorities for action, and then to manage local delivery; and
- a National Experiment to develop the principles, tools and indicators that are needed for assessing and improving the profitability and sustainability of grazing systems.

Sustainable Grazing Systems already has an excellent record of delivery to stakeholders, including the following key outcomes delivered by the end of June 2001:

- incorporation of key water management and sustainability messages into Prograze™, and its ongoing delivery to around 1000 producers per year;
- development of a new product (Prograze™ Update) with a strong emphasis on water management and sustainability, and its planned delivery to 5000 producers (Prograze™ graduates) over the next two years;
- establishment of an extended network of 11 committed regional committees throughout Southern Australia who have become champions for development and adoption of more sustainable grazing systems;
- 100 producer-driven regional sites, most of which focus on improving productivity and sustainability through improved use of perennial pastures, grazing management and improving ground cover—unlike many 'research' sites, these have strong credibility with producers;
- two Sustainable Grazing Systems National Farmwalks that attracted over 4000 producers to regional and national sites;
- quarterly publication and distribution of *Prograzier* to over 12 000 livestock producers in southern Australia. Recent editions include the successful *Water* and *Nutrients* editions, with *Pastures*, *Animals* and *Biodiversity* to come;
- distribution of a special series of Sustainable Grazing Systems *Tips and Tools* to 11 000 producers, focusing on establishment and management of perennial pastures in the high rainfall zone;
- two highly successful Sustainable Grazing Systems National Forums which have focused on the dual challenge of increased productivity and sustainability;
- three major benchmarking surveys across the high rainfall zone (1994 to 1998 to 2001) to monitor changes in producer adoption of more sustainable management practices (the most recent survey in June 2001 indicates that over 6500 producers in the high rainfall zone have participated in Sustainable Grazing Systems activities);
- detailed final research reports from the Sustainable Grazing Systems National Experiment, integrated across six national sites and five key themes. These reports will provide new data and information on interactions between pastures, water, nutrients, animal production and biodiversity across a wide range of production systems and environments;
- the Sustainable Grazing Systems Model, a dynamic and powerful predictive model incorporating the above elements being validated and tested against the outcomes of the national experiment;

- an economic analysis tool for use by researchers, that for the first time combines the financial assessment of the impact of experimental treatments, with an evaluation of the impact on the resource base to facilitate full reporting to producers;
- a Sustainable Grazing Systems final report, being written in triple bottom line format, to pull it all together. A survey of core Sustainable Grazing Systems participants has rated the effort and effectiveness of Sustainable Grazing Systems across productivity (67%) environmental (61%) and social (63%), indicating strong progress across each aspect of the triple bottom line.

### The Sustainable Grazing Systems harvest year

Sustainable Grazing Systems concluded on 30 June 2001, following five years of research, demonstration, extension and training. Instead of beginning a new program promptly on 1 July the harvest year will run for 12 months with a vision of producers working with researchers to extract and interpret the results and experiences from Sustainable Grazing Systems, and to derive maximum value from the investment in Sustainable Grazing Systems.

The key outcome of the Sustainable Grazing Systems harvest year will be the development and widespread adoption of more productive and sustainable grazing management practices for grazing (wool and meat) enterprises in the high rainfall zone of southern Australia.

The harvest year will build on the results achieved and seek to deliver the following outcomes:

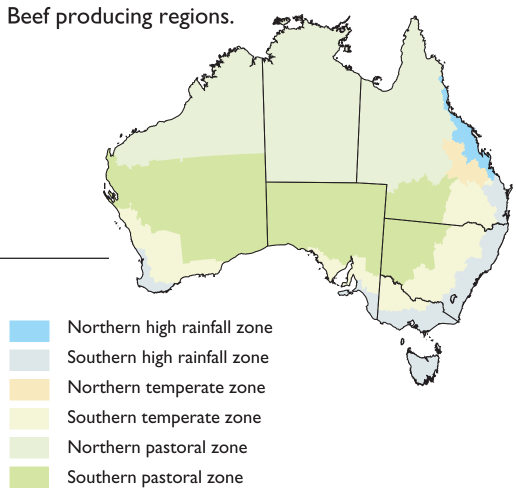
- continuation of a number of key elements of Sustainable Grazing Systems, including many of the sites in the Sustainable Grazing Systems national experiment;
- rapid development of the tools and products from the combination of proven scientific results and producer experience in Sustainable Grazing Systems;
- more rapid analysis of research results and delivery of scientific information and enhanced understanding of the interactions between grazing systems and their environment;
- clearly defined issues for demonstration to producers at local sites, through to key questions for new research and development in future research and development programs; and
- substantially improved program(s) to follow Sustainable Grazing Systems because of the pausing, reflecting, testing, and cross-site analyses during the harvest year.

To progress the development of tools and products for producers, four harvest teams are already operating. These are teams of producers and researchers working to rapidly draw together and interpret the results and experiences from Sustainable Grazing Systems. The harvest teams are:

- **water and nutrients** in grazing systems;
- **pasture and animal** management and performance;
- **biodiversity (including trees and shrubs)** in grazing systems; and
- **social and adoption** issues relating to profitable and sustainable grazing systems.

An integration team provides oversight and manages the trade-offs between teams.

## BEEF CATTLE



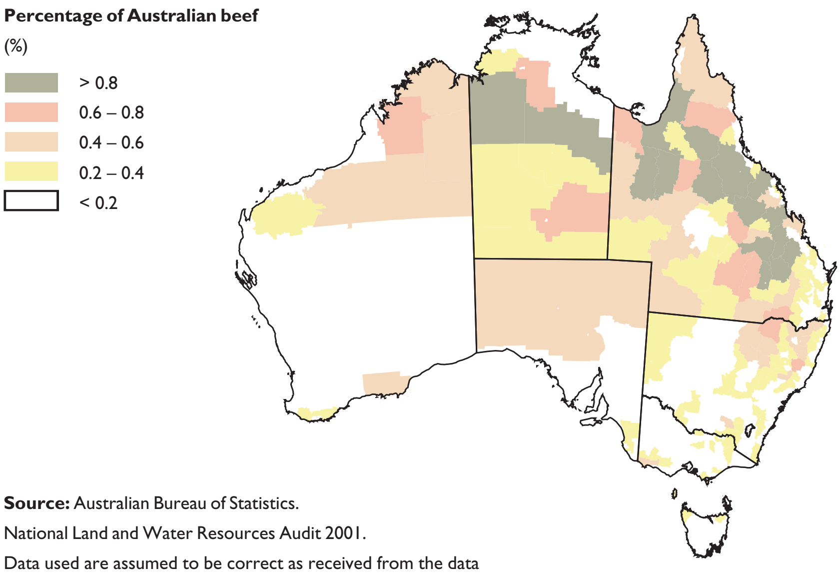

### National perspective

The beef cattle industry delivers quality meats and leather to Australian consumers, and exports chilled and frozen beef and veal and live cattle, earning a total annual export income of over $2.5 billion.

Beef production occurs across much of Australia (Figure 8.7), including:

- Northern Region (high rainfall 3% area, temperate 3% and pastoral zones 66%);
- Southern Region (high rainfall 4% area, temperate 4% and pastoral zones 20%).

**Figure 8.7** Beef distribution—percentage by statistical local area.




**Source:** Australian Bureau of Statistics.

National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.

The herd consists of 20 million beasts. Major breeds are:

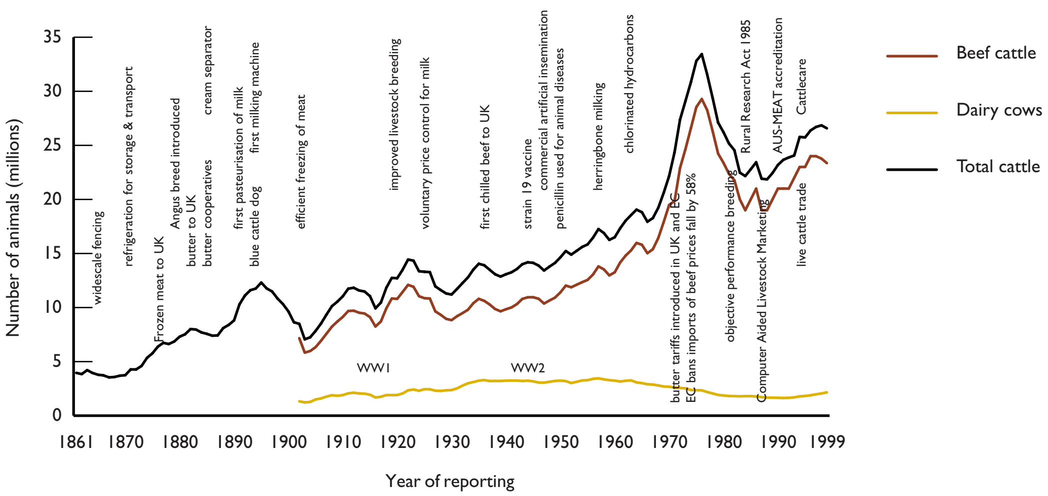
- Hereford (19.2%);
- Brahman (18.2%);
- Bos indicus x Bos taurus (14.7%);
- British cross breeds (10.7%); and
- Angus (8.4%).

In the pastoral areas of Australia, substantial proportions of the beef grazing lands are held under long-term crown lease tenure (85% of the land). In the higher rainfall and temperate areas, properties are mostly freehold (51% and 93% respectively).

The Australian beef cattle industry has expanded and responded to challenges during its history (Figure 8.8).

In recent times, the industry has sought to increase productivity to compensate for falling prices. In the early 1970s, a large increase in beef cattle numbers occurred as export markets in Europe, North America and Japan developed at the same time that wool prices fell and wheat quotas were introduced in Australia. In the mid-1970s the European Community and Japan restricted access to their markets, causing a collapse in cattle prices.

**Figure 8.8** Trend in numbers of beef and dairy cattle in Australian since 1860.



## Regional perspective

Beef cattle numbers reached their peak in the late 1970s in Queensland, a little later than the other States where changes in stock numbers were reasonably comparable (Figure 8.9). Restrictions to export markets caused numbers to decline after 1975 in all States. Since 1983, increases in exports of beef, veal and live exports have led to steadily increasing cattle numbers, while maintaining the relativities in total populations between States, with Queensland and New South Wales dominant producers.

**Figure 8.9** Numbers of beef cattle in each State from 1950.

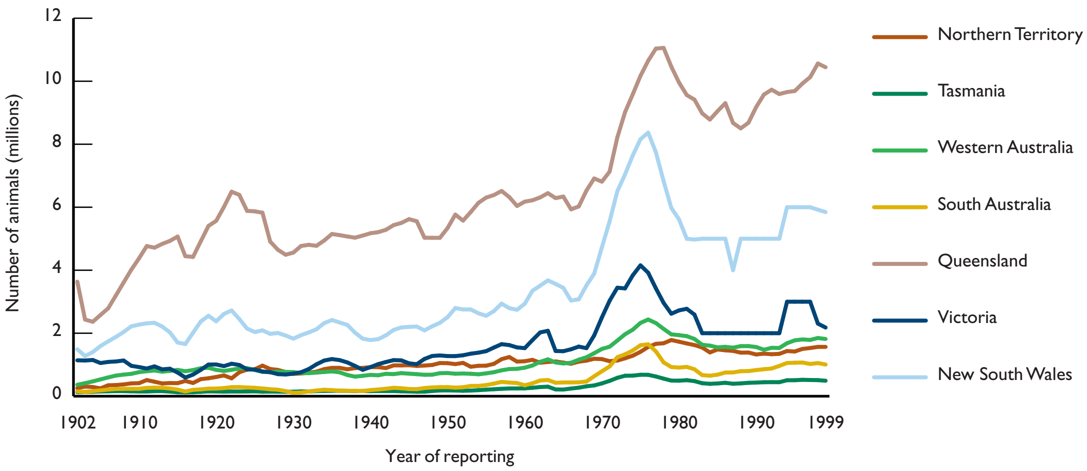
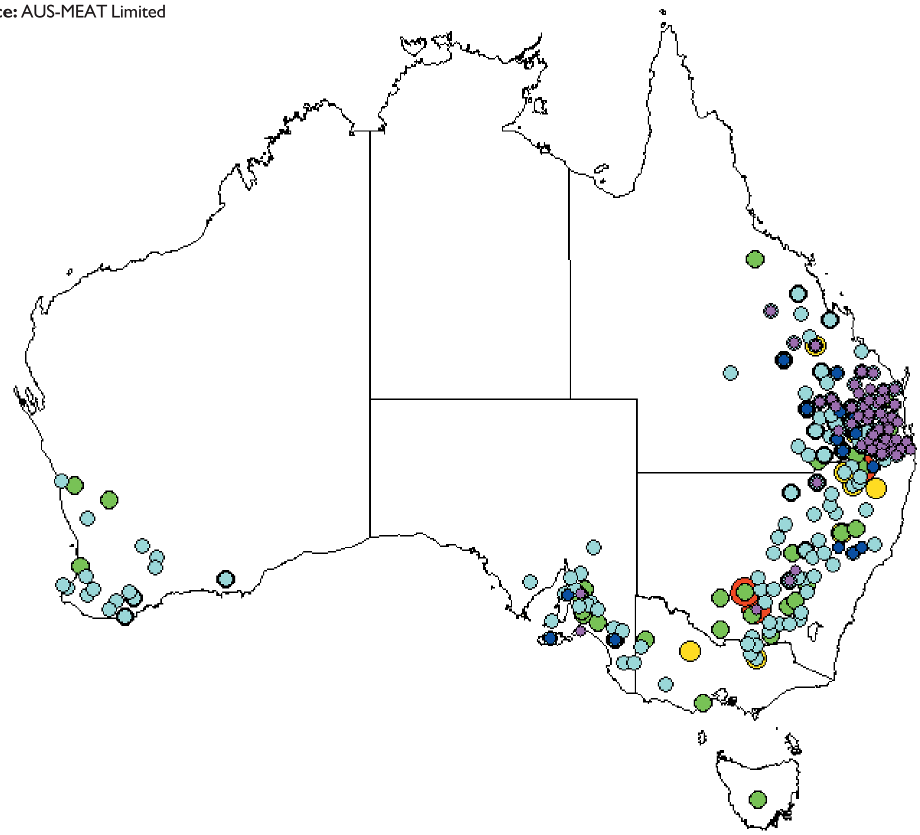


**Figure 8.10** Distribution of National Feedlot Accreditation Scheme accredited feedlots 2000.

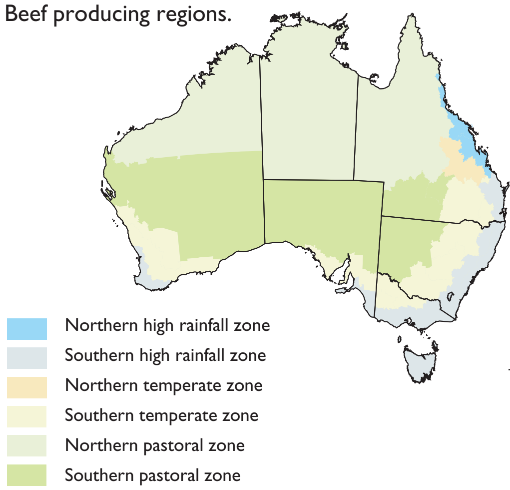
**Source:** AUS-MEAT Limited



Feedlots are increasingly being used to 'finish off' cattle before slaughter. Feedlots are located mainly along the western slopes of New South Wales and Queensland (Figure 8.10), partly to obtain year-round access to a wide range of cheaper grains as feedstuffs. In 1999, Australia's beef feedlot capacity was for more than 873 000 cattle and was used to 58% capacity. A large proportion (49%) of beef were held on just 14 very large feedlots (each holding >10 000 head). A further 14% were fed in the 700 smaller feedlots (holding <1000 head). In 1999, 349 000 lot-fed beasts were exported (63% of total beef exports).

In 1999, a total of 9.3 million cattle were slaughtered in Australia, producing 1.96 million tonnes of meat with a total value of $3763 m; 93 % of these were retained for the domestic meat markets.

Beef producing regions.




## Practice in the beef cattle industry

The beef cattle industry is spread over six zones in the northern and southern zones (making up high rainfall, temperate and pastoral zones).

The most consistently identified issues facing the beef cattle industry are:

- management of weeds (also identified as a priority by sheep/wool graziers); and
- water erosion (Figures 8.11, 8.12).

Other degradation problems identified include waterlogging (mainly in the southern zones), loss of soil structure, soil acidity and wind erosion (both zones) and salinity (southern zone).

Producers identified problems in pasture management requiring research in the 1994 Survey of Temperate Pasture Sustainability Key Program (Figure 8.13).

Graziers approach regional degradation problems in different ways (Figure 8.15) and management options in pastoral zones differ from those used in more intensive cattle enterprises.

- Highest priority was placed on maintaining cover along drainage lines (five of the six zones).
- High priority was also placed on monitoring vegetation condition (northern zone and the southern pastoral zone); maintaining areas of conservation; and soil and plant testing (high rainfall zones).

Best practice guidance is provided to graziers through codes of practice for general agriculture (e.g. developed by the Queensland Farmer's Federation) and through the industry's PROGRAZE (p. 244) and Northern Australia Program initiatives (see case study overleaf). These industries promote sustainability through self improvement approaches to water use, chemical and nutrient management and broadly building manager skills across the business enterprise.

**Figure 8.11** Proportion of northern Australian beef farms surveyed that reported significant resource degradation (1998/99).

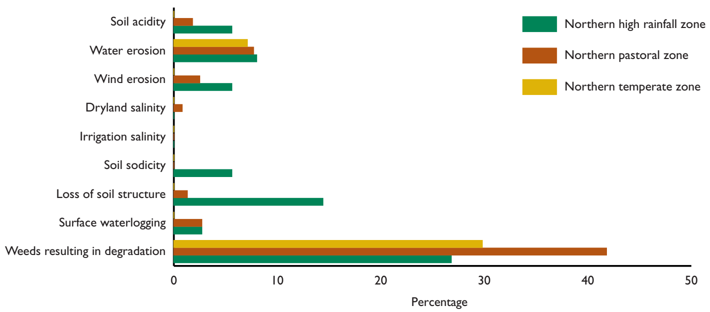



**Figure 8.12** Proportion of southern Australian beef farms surveyed that reported significant resource degradation (1998/99).

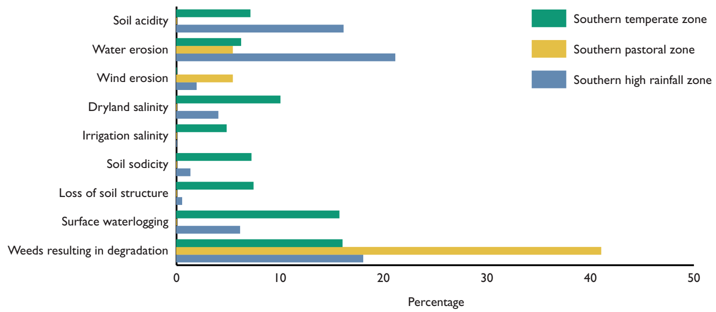



**Figure 8.13** National beef farm management and practice applicability (1998/99).

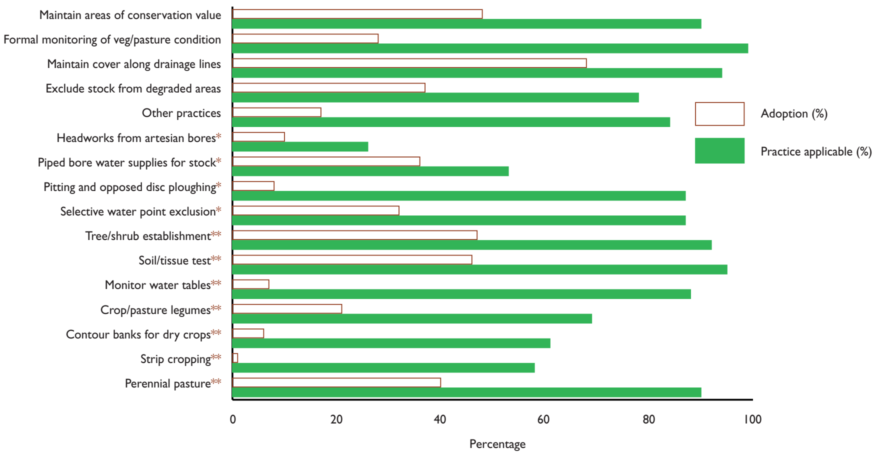
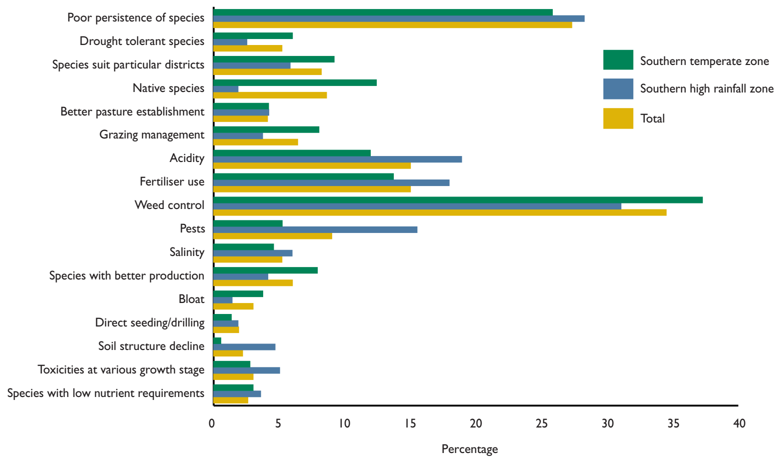



**Figure 8.14** Perceived pasture management problems requiring research.




* Pastoral zone farms only
** Temperate and high rainfall zones only

**Source:** Australian Bureau of Agricultural and Resource Economics.

## SUSTAINING THE BEEF INDUSTRY—NORTHERN AUSTRALIA

The North Australian Program was the main vehicle for Meat and Livestock Australia involvement in research and development in the beef industry from July 1996 to June 2001. The program included direct investment in projects related to natural resource sustainability and healthy landscapes and has spent $5 million of a $12.5 million five-year budget. A further $2 million will be invested in projects marrying beef productivity and sustainability aspects.

- A significant component of the research effort is directed at understanding environmental systems—a basis for practical management principles: a large-scale project in catchment hydrology and function has provided quantitative information on sediment transfers in the Burdekin river system, Queensland. This project provides a number of management principles to assist in effective soil conservation.
- Another project of similar scale has yielded another set of principles to aid in the conservation of biodiversity within grazing lands, contributing to the vitality and resilience of the Burdekin catchment.

The North Australian Program has also supported a number of focused projects to address specific issues:

- work to quantify the extent of soil acidification associated with stylo-dominant pastures (a tropical legume) and to develop appropriate management practices. Recommendations were produced and widely adopted within four years of the problem being recognised.

As well as understanding the typical Australian landscape system and the impact of grazing upon the landscape, the North Australian Program has initiated work to optimise the productivity of these grazed landscapes within a framework of sustainable land use. Large-scale grazing trials and observations in the Channel Country, Victoria River District, southern and northern spear grass and eucalypt/box woodland regions have expanded tools available to graziers for the use of fire, grazing tactics, infrastructure planning and cattle distribution.

Work has also been commissioned to deal with weed problems: notable success has been achieved in controlling rubber vine and parthenium and the search continues for control measures for other invasive weeds such as giant rats tail grass, chinee apple and African love grass.

The North Australian Program has placed a strong emphasis on integrating its funded research into a useable management framework and is in the final stages of producing a comprehensive training package in grazing land management. This package has been developed in response to producer demand and has been designed to deliver relevant, useful and practical outcomes.

The program has also initiated an evaluation of ISO 14000 and its application to beef enterprises. Adoption of a formal Environmental Management System takes environmental considerations into account within a management context (e.g. production, marketing, administration).

North Australian Program is also a key funder of Rangelands Australia, a joint initiative with the University of Queensland and others to develop a centre for rangeland science education and management with an emphasis on industry relevance and involvement. Rangelands Australia will form an essential link between science and application, providing formal training and qualifications for managers, advisors and administrators in Australia's rangelands.

The standout breakthrough North Australian Program project has been the Beef Plan project. This pilot project has reversed the normal Meat and Livestock Australia approach to technology transfer and adoption by empowering a limited number of groups of producers to work on their own issues, coming to Meat and Livestock Australia and other agencies for support if needed but always on their terms. Much of the activity within these groups has been directed towards resource management issues. The dynamic lessons learnt from the pilot have had a profound influence on shaping Meat and Livestock Australia successor to North Australian Program 3, the Northern Beef Program.

### Can North Australian Program claim success in its work in natural resource management?

Clearly, the research has been productive from a technical and scientific perspective.

It is also obvious that the program has:

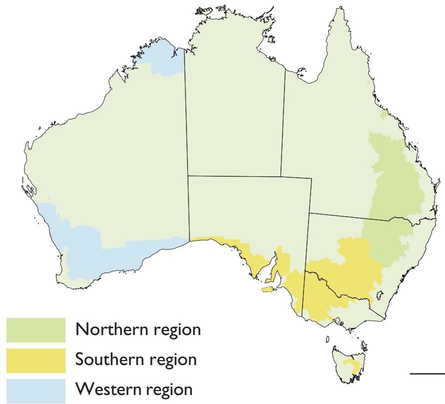
- listened attentively to producers;
- developed an understanding of their priorities; and
- established a good working relationship with the beef industry.

Without being able to attribute cause and effect, North Australian Program is pleased to note the importance of sustainability among producers with a recent survey of beef producers across Queensland, the Northern Territory and Western Australia ranking it equally as important as profitability.

In response to that awareness, the new Northern Beef Program has nominated 'Balancing business and environment' and 'Emerging environmental issues' as key themes for investigation and development over the next five years.

Meat and Livestock Australia acknowledges the integral support of Land and Water Australia, and Environment Australia in funding projects. It also recognises the immense contribution of collaborating agencies and individual producers. Meat and Livestock Australia will seek to strengthen that collaboration for the long-term betterment of the industry, rural communities and the environment.

## GRAINS




Grains regions of Australia.

### National perspective

Products from the grains industry provide raw ingredients for many familiar foods—bread, biscuits, cakes, noodles, spaghetti, pasta, baked beans, and breakfast cereals. They are used unrefined (rice and peanuts), have components extracted from them (vegetable oils and gluten), and contribute to value-added products (e.g. beer and some spirits). An increasing proportion is being used as feedstuffs for intensive animal production units.

Grain crops are grown in three main regions within the sheep–wheat zone of Australia:

- Northern Region (Atherton, Burdekin, Central, south-east and south-west regions of Queensland; and north-east and north-west regions of New South Wales
- Southern Region (Central and the slopes and plains of New South Wales; Victoria; Tasmania; and southern regions of South Australia).
- Western Region (Central, eastern and northern zones of Western Australia and the Ord River region).

The Australian grains industry produces a range of different crops (Table 8.3) including:

- cereals (wheat, barley, buckwheat, oats, triticale, maize, millet, panicum, sorghum and cereal rye);
- oilseeds (canola, soybeans, sunflower, safflower, linseed/linola, mustard seeds and sesame seeds);
- pulses or grain legumes (chickpeas, faba beans, field peas, lupins, lentils and mung beans); and
- rice (grown under full irrigation).

The grains industry is still dominated by wheat in terms of:

- area (57% of 19.2 million hectares in 1996/97);
- production (59% of 38.5 million tonnes);
- value of production (60% of $8.1 billion); and
- export income (68% of $6.36 billion).

**Table 8.3** Australian grain production in 1997/98.

| Grain | Volume Million tonnes | Value $ million |
|---|---|---|
| Cereals | 28.9 | 5145 |
| Oil seeds | 1.0 | 417 |
| Grain legumes | 2.2 | 602 |
| Rice* | 1.2 | 293 |

* In 1997/98, 0.38 million hectares of irrigated cereals were grown, of which 0.13 million hectares was rice. It used 1643 GL each year with an average return of $189 per megalitre of irrigation water.

## Exports

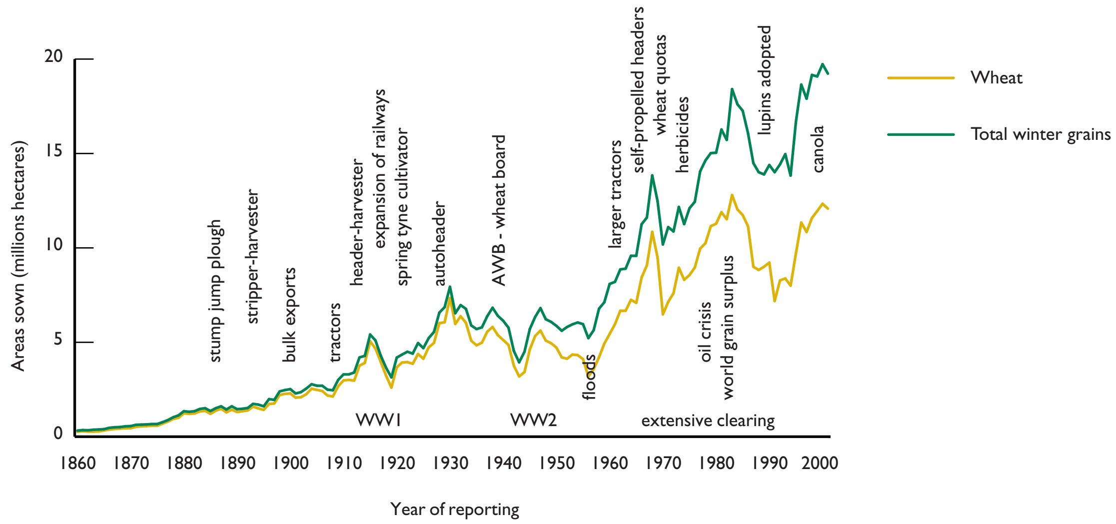
Approximately 75% of the grains produced in Australia are exported, earning about $6 billion a year. More than half of the exports are wheat and, although Australia produces only about 3% of total world production, national exports make up 15% of world trade.

Exports of canola have increased considerably since 1991, mostly to Japan and China. Australia's pulse crop exports make up between 10% and 20% of world trade.

## Wheat

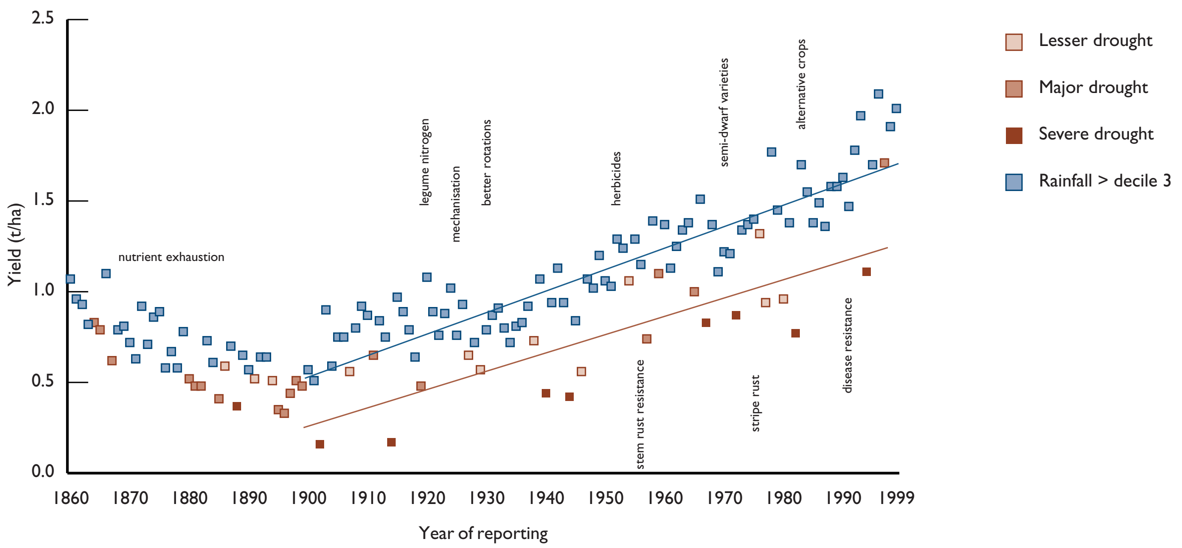
Wheat acreage expanded slowly in the late nineteenth century (Figure 8.15). Research since World War II has ensured that innovations have continually occurred such as improved wheat varieties and cropping techniques. Clearing of land and capacity to produce winter grain production means that wheat has continued to dominate total production.

**Figure 8.15** Area of wheat and total winter grains in Australia since 1860 with selected events.




**Source:** Australian Bureau of Statistics.

**Figure 8.16** Average grain yields of wheat in Australia since 1860 categorised according to incidence of drought.




**Source:** Australian Bureau of Statistics and Bureau of Meteorology.

During the 1980s, areas sown to wheat declined, mainly due to falling world prices. New crops (mainly lupins and canola) were introduced to diversify rotations and to improve control of weeds and diseases. With the collapse of wool prices in 1989, areas sown to winter grains (especially canola) increased, continuing a trend to increase the area sown to other crops relative to wheat.

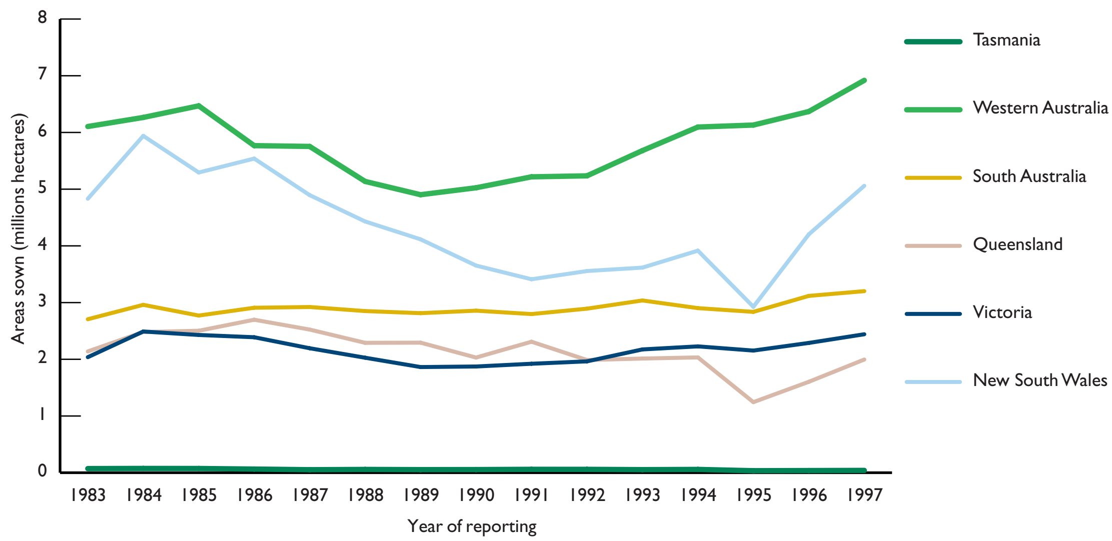
Paralleling the expansion in area sown to wheat, has been an almost continuous upward trend in yields achieved during the twentieth century (Figure 8.16) that followed the era of exploitation of the soil nutrient reserves at the end of the nineteenth century (Donald 1965, Angus 2001). Wheat yields over the past 100 years have quadrupled, approaching 2 tonnes per hectare, following the adoption of improved crop practices (e.g. stubble mulching, crop rotation and soil fertility management). Recent regional trends in wheat and other cereal yields are presented in *Changing face of Agriculture* section of this report.

## Regional perspective

Changes in the combined area sown to grain crops in each State (cereals, grain legumes and oilseeds, but excluding rice) show significant differences between States during the period 1982 to 1996 (Figures 8.17, 8.18).

- South Australia, in particular, shows little change in area over time.
- Western Australia, after an initial decline in area during the late 1980s has since shown continued expansion to new record areas.
- The pattern for Victoria, New South Wales, and Queensland are reasonably similar: a general downward trend until the early 1990s, with modest increases thereafter, except for the pronounced effect of the 1994 drought in New South Wales and Queensland.

**Figure 8.17** Changes in the area sown to grain crops within each State during 1982/83 to 1996/97.




**Source:** Australian Bureau of Statistics.

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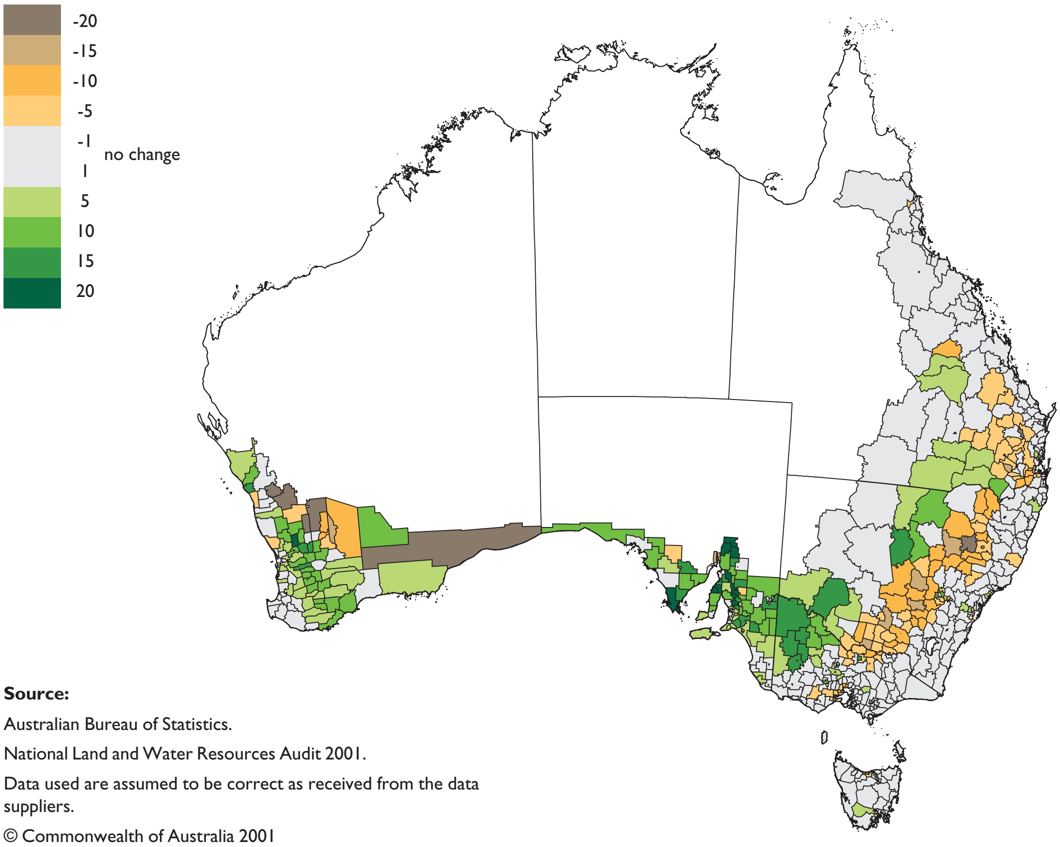
**Figure 8.18** Changes in the area sown to broadacre grain crops comparing the three years 1994, 1996 and 1997 on a statistical local area basis.




**Source:**

Australian Bureau of Statistics.

National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.



- Comparison of geographic changes in the areas sown to crops between the 1980s and the 1990s, show that in large areas of the agricultural zone no net change has taken place, because only minimal cropping is undertaken in these regions.
- Within the traditional cropping zone of Australia, major increases (greater than 5%) occurred throughout South Australia, western Victoria, south-west Western Australia, on the north-west slopes and plains of New South Wales, on the southern Darling Downs and parts of the central Highlands of Queensland.
- By contrast, fewer cropping areas (down by more than 5%) were recorded in the Darling Downs parts of the Central Highlands in Queensland, the slopes of New South Wales, and eastern parts of the Western Australian wheat belt.

The southern grains region produces about 46% of the total grain crop, while the western and northern regions produces about 30% and 25% respectively. Rice is produced entirely (1.2 million tonnes) in the southern region (Table 8.4).

**Table 8.4** Regional grain production (1998/99).

| Cropping region/location | Field grains ('000 t) | Oilseeds ('000 t) | Grain legumes ('000 t) | % of Australian grain production |
|---|---|---|---|---|
| **Northern region** | 8 863 | 177 | 117 | 24.5 |
| Qld central | 639 | 77 | 10 | 1.9 |
| NSW north-east, Qld south-east | 6 105 | 90 | 89 | 16.8 |
| NSW north-west, Qld south-west | 2 099 | 10 | 18 | 5.7 |
| **Southern region** | 14 514 | 529 | 1 027 | 46.2 |
| NSW central | 2 381 | 72 | 16 | 6.6 |
| NSW, Vic slopes | 3 373 | 262 | 94 | 10.0 |
| Vic high rainfall, Tas grain areas | 348 | 18 | 12 | 1.0 |
| SA, Vic Bordertown-Wimmera | 1 875 | 122 | 418 | 6.5 |
| SA, Vic mallee | 3 483 | 22 | 213 | 10.0 |
| SA mid north-Lower Yorke | 3 053 | 33 | 273 | 9.0 |
| **Western region** | 9 503 | 84 | 1 335 | 29.2 |
| WA central | 4 938 | 57 | 588 | 14.9 |
| WA eastern | 1 546 | 2 | 126 | 4.5 |
| WA northern | 1 967 | 4 | 564 | 6.8 |
| WA mallee and sandplain | 1 046 | 21 | 57 | 3.0 |
| **Australia** | **32 881** | **790** | **2 479** | **100** |

### Practice in the grains industry

The Australian grains industry conducted two benchmarking assessments of industry practices in 1994 and 1998. The assessments were aligned to the three major grain growing areas—northern, southern and western regions. Within these regions, the relative ranking of degradation issues varied, but in each region a proportion of grain growers recognised a range of issues of local importance (Figure 8.19).

- Water-borne soil erosion was by far the most recognised issue in the northern region.
- Dryland salinity was of greater significance in the southern region.
- A diverse range of degradation problems was identified in the western region including: soil acidity, dryland salinity, waterlogging, water erosion, weeds, and loss of soil structure (in that order of recognised importance).

The grain industry survey in 1998 indicated that:

- grain farmers were achieving a high level of better management practices compared to 1994 and the trend was towards more farmers using improved practices (Figure 8.20). Even so, the industry average for total adoption of nominated best management practices was still around 7%.
- 74% of farmers had changed their farming practices in the last five years directly due to research findings, and 57% had changed their farming practices in the last two years.
- the use of private consultants increased (up from 29% in 1994 to 49% in 1997) and there was a stronger inclination to experiment with new techniques.

Identified best management practices varied (Figure 8.21), but were mainly associated with:

- tillage (minimum tillage and stubble retention);
- rotations (use of crop and pasture legumes);
- soil fertility assessments;
- maintaining cover on drainage lines; and
- use of contour banks (high priorities in the northern and western regions).

Recent innovations in pasture-cropping techniques (regenerative agriculture) are highlighted in the Birriwa-Gulgong area in Central West New South Wales (see case study overleaf).

Avenues for advice on practice are provided to farmers through the industry programs such as TOPCROP program (Grains R&D Corporation) and through research agencies and agribusiness.

**Figure 8.19** Proportion of grain farms surveyed that reported significant degradation (1998/99).

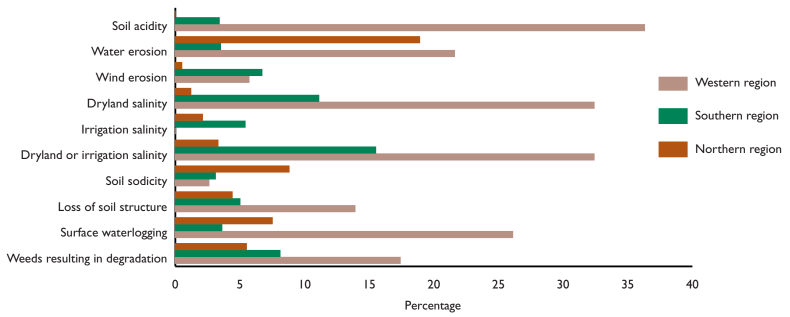



**Figure 8.20** National grain farm management and practice applicability (1998/99).

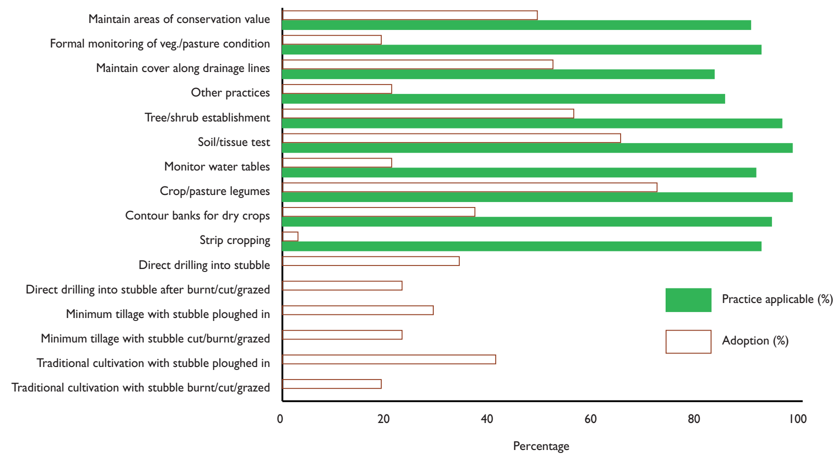
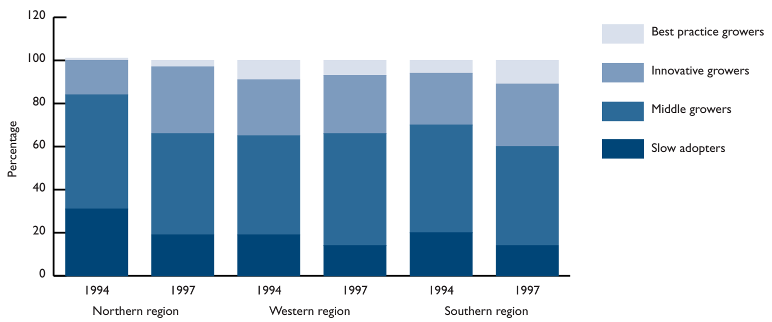



**Figure 8.21** Comparison of best practice adoption (1998/99).




**Source:** Australian Bureau of Agricultural and Resource Economics.

# REGENERATIVE AGRICULTURE

## New farming model: Oz farmers show the way

We hear a lot these days about the need to mimic natural ecosystems, increase biodiversity, improve soil structure, maintain year-round water-use, increase ground cover and soil organic matter levels, stabilise soil pH, stimulate nutrient cycles and enhance microbial antagonism to combat root-borne pathogens. There is little practical advice on how to incorporate these highly desirable features into the day-to-day reality of farming, let alone make a profit.

That was, until a handful of innovative Aussie farmers came up with the elegantly simple notion of 'pasture cropping'. Grain growers can now have all of the above, and more. They can graze their paddocks and crop them too. The pastures and the crops will improve with each passing year. How?

Darryl Cluff and Colin Seis from the Central West of New South Wales are two of Australia's leaders in pasture-cropping technology. The Cluff–Seis pasture-cropping technique involves the direct seeding of an annual crop into perennial native pasture. The remarkable success of the technique has hinged on the fact that the C3 winter cereals fit neatly into the growth cycle of C4 warm season native grasses, which are dormant during the cooler months.

They use natural ecological services to replenish and reactivate the resource base. With all agricultural practices, the true bottom line is whether soil is being formed or lost. If it is being lost, farming will eventually become both ecologically and economically unsustainable.

### The birth of pasture cropping

Traditional techniques, which involved the complete removal of all vegetation, resulted in vast tracts of bare ground both before and after the crops. These areas were recolonised by relatively unpalatable perennial grasses and naturalised annual weeds. Soil erosion on arable land was extensive, accompanied by soil structural problems and rapid nutrient decline. The use of subclover and superphosphate brought temporary relief, but the long-term trend in soil health continued to be down.

The average annual rainfall in the Birriwa–Gulgong district is around 600 mm with a slight summer dominance, although it is unpredictable and highly variable within and between years. In 1995, following an 18-month drought, Darryl Cluff direct-drilled an oat crop into a native redgrass (*Bothriochloa*) pasture in which subsoil moisture levels at sowing were zero, yet the crop performed well. The pasture-cropping technique was born. The technique is considered applicable across all rainfall zones.

The following year, Darryl Cluff began experimenting with wheat, and his Landcare colleague Col Seis tried pasture-cropping oats, some grown without herbicide application. Their crops were sown with an Australian-designed and constructed Agrowdrill direct-drill seeder, 30 cm row spacings, approx. 30–40 kg seed/ha and 85–135 kg/ha Granulock 15 fertiliser (N15:P12:S12), dropped into the rows with the seed.

Darryl Cluff intends to continuously crop some of his pasture paddocks to wheat to determine whether the microbial biomass and diversity associated with the living pasture base will be sufficient to prevent the proliferation of pathogens in the soil. In other paddocks, he is trying alternative crops such as lupins (which performed so well last year that follow-on summer pasture regrowth was inhibited), and experimenting with the re-sowing of native grasses such as *Themeda australis* (kangaroo grass) with the crop seed.

Col Seis has preferred to rotate the paddocks he pasture-crops each year, and reports significant improvement in the vigour and diversity of his native pastures. His principal focus is on livestock production and he uses pasture cropping as a pasture improvement technique.

### Improving crops and stock

Col Seis now pasture-crops 240 ha of his 809 ha property to oats, wheat and lupins. He has increased the cropped area every year without reducing his stocking rate; not only because the pasture health is continually improving, but also because the land doesn't have to be taken out of production and 'prepared' for cropping.

His 2000 wheat, **Whistler**, yielded 3.63 t/ha. The year before, **Janz** did not do as well and Col Seis puts it down to choosing the wrong variety for the acid soils on his property. Oats have yielded up to 4.4 t/ha since 1995.

Col Seis says the property is producing around 39 kg greasy wool per hectare at an average cost of $2.047 per kg. This compares with a regional benchmark of 35 kg wool per hectare at $3.07 per kg.

Livestock are important to the pasture-cropping method. Col Seis has improved the gross margins on his sheep enterprise by using sheep to heavily graze pastures prior to sowing, as an alternative to spending money on pre-sowing herbicides or cultivation. He also now does not have to re-establish pastures, which was the practice in the past, because they are rapidly improving.

Darryl Cluff says they use conventional harvesting techniques for their cereals; with the grasses below the crop level, there has been no problem. They have not noticed any significant compaction. In fact, the root systems of the pastures seem to have a 'de-compacting' effect which both counteracts the compaction effects of machinery and stock, and also seems to de-compact previously compacted soil after it's been established for a couple of years.

### Further adjustments

Both farmers learned that crop establishment is slower in the pasture base, and sow about two weeks earlier than the recommended date. They have observed an increase in red-legged earth mite but feel this will cease to be a problem once the biodiversity of plants and invertebrates increases.

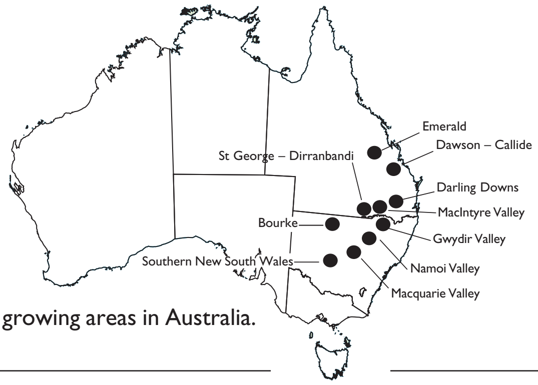
### Resowing natives

Col Seis is experimenting with the re-sowing of native *Paspalidium* and *Urochloa* (previously *Brachiaria*) species along with crops. The tools are the Scorpion brush seed harvester and Germinator seeder, enabling locally occurring native grass seed to be harvested and re-sown. This innovative equipment (with more to come) was developed by Darryl Cluff, Col Seis and other members of the Barneys Reef Landcare Group, and skilfully transformed into engineering masterpieces in the hands of Doug Seis, Col Seis' cousin.

As with the pasture-cropping model itself, the fine-tuning of the machinery capable of harvesting and re-sowing the often difficult seeds of native grasses and legumes has required much creative effort and testing, devotion to teamwork, countless late nights and the occasional beer.

The vision is to help develop a native grass seed industry which will enable regenerative practices such as the Cluff–Seis technique to be widely used. If native grasses are re-sown with crops, and nurtured via the pasture-cropping technique, millions of hectares of farmed land currently suffering severe soil degradation and dryland salinity problems could be rehabilitated.

Although the current pasture-cropping methodology has been developed for winter cereals, most annual crops would be healthier if sown into permanent, living, ground cover.




Cotton growing areas in Australia.

# COTTON

## National perspective

Cotton produces one of the world's premium fibres (lint) used for garments, sheeting and threads. It is also the second largest source of oilseed in Australia, second only to canola.

Australian cotton is grown in three regions:

- **Central Queensland Region** (Emerald and Dawson-Callide districts of Queensland, 7% of production);
- **Central Border Region** (Macintyre Valley, Darling Downs, St George-Dirranbandi, Namoi Valley and Gwydir Valley districts in Queensland and northern New South Wales, 79% of production);
- **Southern Inland Region** (Macquarie Valley, Bourke and Southern regions of New South Wales, 14% of production).

Cotton has been grown in Australia since the 1800s, although the modern cotton industry was not born until the 1960s, when the construction of large dams in northern New South Wales and southern Queensland made the development of irrigated production systems in these areas possible. A reliable supply of water, and the arrival of a small group of American cotton growers were the main driving forces behind the growth of irrigated cotton in Australia. Irrigated and dryland production expanded rapidly during the 1980s and 1990s. 1985 production totalled 1.1 million bales while 1998 production was 3 million bales (one bale = 227 kg of cotton lint). Average production for the last three years (1997–2000) is over 3 million bales per annum.

Australian cotton growers consistently achieve the highest yields of any of the world's large cotton producers. For example, in 1999 and 2000, the average yield on Australian farms was 1366 and 1574 kg/ha respectively. Corresponding figures for the United States of America were 725 and 696 kg/ha, and for China, 1064 and 1040 kg/ha. Most of the Australian crop (generally around 90%) is exported. The value of Australian raw cotton exports was $1.7 billion in 1999, and $1.6 billion in 2000.

Irrigation generally trebles the yield of lint and other cotton products.

The industry's major environmental issue relates to its use of pesticides for controlling budworms (*Helicoverpa* spp.). These pesticides collect in waterways affecting fish, birds and human health. Other issues relate to efficient use of water and fertilisers that may affect the volume and quality of water available downstream.

**Table 8.5** Areas of irrigated and dryland cotton production, 1999 and 2000*

| Production system | Area grown 1999 (ha) | Area grown 2000 (ha) |
|---|---|---|
| Irrigated | 403 300 | 402 400 |
| Dryland | 131 100 | 59 500 |
| **Total** | **534 400** | **461 900** |

***Source:** Australian Cotton Grower Yearbook

### Practice in the cotton industry

Recognition of key challenges—pesticide use, land use and water use—arose through an industry-wide environmental audit and appropriate best management practices were developed (Williams et al. 2000). Adoption of these practices across country is progressing very well. Research and extension are targeted to ensure comprehensive adoption. Direct expenditure on research and extension aimed at improving environmental sustainability, is almost $6 million each year from Cotton Research and Development Corporation funds.

The Australian cotton industry *Best Management Practices Manual* (Williams et al. 2000) was developed out of a joint research between the Cotton Research and Development Corporation, Land & Water Australia and the Murray-Darling Basin Commission.

The *Best Management Practices Manual* outlines the principles, purpose and benefits of best management practice and the need for 'due diligence'. The manual is in its second edition and incorporates extra information on pesticide storage and handling, farm hygiene, human safety, and dryland cotton production. It also contains extensive information updated from edition 1 of the manual on management strategies for :

- applying pesticides;
- integrated pest management; and
- farm design and management.

Each area covered in the *Best Management Practices Manual* contains:

- risk assessment—self assessment worksheets that help cotton growers identify and assess the risks relating to practices on their farm;
- best management practice booklets—these provide detailed information on best management practices for issues highlighted through self assessment; and
- action plans—cotton growers are required to develop action plans to address areas of identified risk; action plans focus on the implementation of best management practices recommended in the best management practice booklets.

The *Best Management Practices Manual* provides a flexible way for cotton growers to manage their farming operations so that they minimise environmental risks associated with pesticide use and is serving as the foundation for a comprehensive environmental management program. It provides a range of potential benefits, including:

- the ability to maintain a degree of industry control over the management of natural resources;
- ways to ensure access to markets in the event of increased demand for cotton produced in an 'environmentally responsible' manner; and
- reduction of on-farm costs.

## COTTON INITIATIVE—BEST MANAGEMENT PRACTICE IN ACTION

The Australian Cotton Industry Best Management Practices program has been developed to help cotton growers manage and improve their farming operations and minimise environmental impacts.

Rogate Farms is an irrigated cropping enterprise near Boggabilla in the Macintyre Valley of northern New South Wales. The farm has 1116 ha of irrigated cultivation and cotton is the principal crop. The farm manager and five other full-time workers have taken a proactive approach to innovation by applying research in practical ways.

The major farming and resource issues for Rogate Farms are the same as those facing most other cotton-growing enterprises:

- minimising use of chemicals in insect management programs;
- maintaining and improving soil health; and
- maximising water use efficiency.

Adoption of and ongoing commitment to the cotton industry voluntary Best Management Practices program is producing significant on-farm benefits to operations in these three resource areas.

Rogate Farms adopted the Best Management Practices program in 1998 and has successfully completed the first two audits (initial and compliance). A certification audit will take place in August 2001.

A key element of the Best Management Practices process is the identification and assessment of farm risks. Worksheets in the Best Management Practices manual assist growers to assess their farm operations and subsequently develop and implement action plans. For Rogate Farms, the risk identification and assessment process resulted in a number of capital improvements.

Enlarging the tail water return has increased irrigation system capacity and allows all water on the farm to be recycled. In conjunction with other farm-design initiatives this system also minimises the environmental impact of storm events by increasing control of run-off flows. In the field, water use is monitored throughout the season. Analysis of the data collected during the 2000/01 season revealed that Ingard® cotton (genetically modified varieties) grown on Rogate Farms produced 1.4 bales of cotton per megalitre of water, compared to 1.3 bales per megalitre for conventional cotton varieties—a productivity gain of around 7%. Conventional varieties took slightly longer to mature and needed one more irrigation than the Ingard crops.

The introduction of Ingard varieties has facilitated the widespread adoption of integrated pest management strategies in the cotton industry. This management philosophy suggests that effective control of insect pests can be facilitated by encouraging natural agents including predators, parasites and viruses. The practical implementation of this 'softer' approach to pest management by Rogate Farms includes placing Ingard cotton in sensitive areas (e.g. along property boundaries and near waterways). Some early season insect damage to the crops is tolerated as research has shown that cotton plants can compensate for early losses. Improved farm productivity has been a tangible benefit of the integrated pest management program with farm records showing significant reductions in pesticide use and therefore input costs achieved during the past five years.

Farm productivity can be significantly affected by soil health. On Rogate Farms beneficial elements within the soil are an important consideration for the overall disease management plan. One innovation has been trial of vetch as a rotation crop to cotton. Rather than being harvested, the vetch is worked into the soil as a green manure. This is based on research showing that vetch could fumigate the soil and help with disease control, particularly Black Root Rot. An added bonus is that vetch can fix a significant amount of nitrogen, reducing the need to apply nitrogen fertilisers. In last season's field trial, strips that had no additional nitrogen fertilisers produced a cotton crop of 7.2 bales per hectare, comparing favourably to other strips in the field which had 115 units of nitrogen applied to the soil and yielded 8.3 bales per hectare.

Farm hygiene plays an important role in maintaining soil health by preventing the spread of disease and is a key element of the Best Management Practices program. Central to the diseases management strategy on Rogate Farms has been the installation of an improved wash down facility and establishment of several disease management units. A number of soil-borne diseases can be transported from field to field and farm to farm in mud and dust on vehicles, equipment and footwear and thorough cleaning is required to prevent this.

The practical strategies and flexible guidelines outlined in the industry's Best Management Practices program have had a significant and beneficial impact on the operations of Rogate Farms and many other cotton properties. Improved resource management is occurring on a broad scale as a result of this program, with an even broader range of beneficiaries.

Cotton vetch

The best management practice program is successful because it is:

- industry led;
- voluntary;
- strongly supported by external organisations;
- flexible;
- simple to use, with clear and achievable objectives;
- focused on practical issues; and
- promoting gradual implementation.

The best management practice program includes an audit scheme for cotton growers (by independent assessors) on their adoption and compliance of the best management practice , as well as, implementation of specific best management practices. These independent auditors are required to have a background in cotton production and must complete an 'Environmental Systems' Auditing Course, specifically tailored to the *Best Management Practices Manual*.

By June 2001, 145 cotton growers had been audited on their compliance with the *Best Management Practices Manual*. Regional levels of adoption of the principles in the *Best Management Practices Manual* varies (Table 8.6).

Improved resource management is occurring on a broad scale as a result of this program (see case study example of the significant and beneficial impact of the industry guidelines).

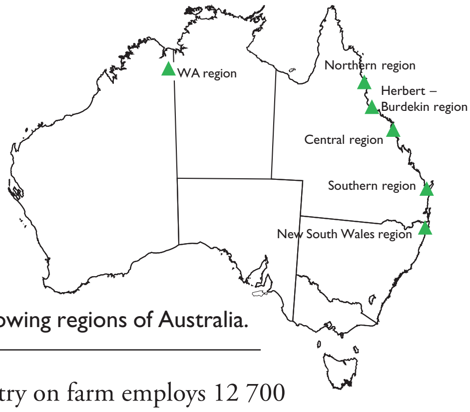
Future directions of best management practice will include management of:

- land and water;
- vegetation and biodiversity;
- waste; and
- noise.

The best management practice program also recommends that growers keep up to date with current Australian Cotton Cooperative Research Centre extension materials (e.g. SPRAYpak, ENTOpak, SOILpak, MACHINEpak, NUTRIpak).

**Table 8.6** Level of adoption (%) of the industry's best management practice manual by regional cotton growers.

| Audit stage | Australia total | Northern region | Central Border region | Southern Inland region |
|---|---|---|---|---|
| Number of growers | | 112 | 1006 | 162 |
| No progress / don't know (%) | 17 | 46 | 13 | 19 |
| Progressing (%) | 57 | 37 | 60 | 53 |
| Audit ready (%) | 12 | 12 | 11 | 16 |
| Audited (%) | 11 | 5 | 17 | 12 |
| 2nd *Best Management Practices Manual* (%) | 70 | 54 | 79 | 26 |




Cane growing regions of Australia.

# SUGAR CANE

## National perspective

The sugar industry produces sucrose—refined to give sugar—and some by-products such as molasses and fibre used for composite boards.

Australian sugar is grown mainly along the east coast of Australia in:

- **Northern Queensland Region** (Mossman, Tableland, Babinda, Mourilyan, Mulgrave, South Johnstone and Tully mill areas);
- **Herbert/Burdekin Region** (Inkerman, Invicta, Kalamia, Macknade, Pioneer and Victoria mill areas);
- **Central Queensland Region** (Farleigh, Marian, Plane Creek, Pleystowe, Proserpine and Racecourse mill areas);
- **Southern Queensland Region** (Bingera, Fairymead, Isis, Maryborough, Millaquin, Moreton and Rocky Point mill areas);
- **New South Wales Region** (Broadwater, Condong and Harwood mill areas);

A small area of production also exists in the northern **Western Australia Region** (Ord River mill area).

The sugar industry on farm employs 12 700 people across more than 5300 properties. The number of cane farmers increased steadily between 1989 and 1999 (from 5% to 22% in different regions of Queensland). The industry generates about $1.2 billion in value each year, with 70% of the refined sugar exported to a wide range of markets.

## Regional perspective

In 1998, nearly 60% of the sugar area and cane production were located in the Herbert/ Burdekin and Central regions of Queensland (Table 8.7). The Ord River Irrigation Area of Western Australia has the advantage of high radiation and plentiful irrigation water. Sugar yields are optimised and controlled in those areas where the cane is irrigated and where sunshine hours are highest.

Major environmental issues for the industry are water-borne soil erosion, chemicals and fertiliser to waterways, with special concern for impacts of outflows to the Great Barrier Reef Lagoon. The industry itself is also concerned about lack of yield increases in many areas. Gains in total productivity within the industry regions relate mostly to increased use of mechanisation and increased scale of operation.

**Table 8.7** Regional sugar production.

| Region/mill area | Cane (Mt) | Sugar (kt) | Cane yield (t/ha/year) |
|---|---|---|---|
| Northern Region | 7.7 | 862 | 87 |
| Herbert/Burdekin Region | 12.2 | 1 610 | 103 |
| Central Region | 11.4 | 1 412 | 105 |
| Southern Region | 6.0 | 781 | 85 |
| New South Wales Region | 2.5 | 294 | ~ 67* |
| Western Australia Region | 0.4 | 47 | 126 |
| **Australia** | **40.2** | **5 006** | |

**Source:** Canegrowers Annual Report 1998 and Australian Sugar Year Book 1999.

* New South Wales harvests are generally every two years as opposed to one year crops for other regions. The estimate of 67 t/ha/yr for New South Wales is likely to be an underestimate with some annual cropping in New South Wales.

8

## Practice in the sugar industry

The industry's intensive production areas are located in environmentally sensitive regions, where river systems discharge to the Great Barrier Reef. The areas also have high habitat value such as floodplains, wetlands and estuaries and increasing human populations.

The Queensland sugar industry audit in 1996, identified eight main environmental issues:

- irrigation and drainage;
- soil management for acid sulfate soils;
- the use of minimum tillage during periods of high erosion risk;
- storage of chemicals;
- fertiliser and nutrient management;
- herbicide management;
- waste management; and
- resource conservation.

More recently, extension officers identified a range of issues for each sugar- producing region (Table 8.8) including:

- soil erosion;
- weeds;
- water quality (nutrient exports to rivers);
- soil acidification; and
- salinity (salt wedge intrusion in coastal settings).

In response to the 1996 audit, the industry continues to develop environmental policies , codes and guidelines aimed at minimising environmental impacts. These guidelines are supported by extension and research, enabling informed adoption of technology. Codes of practice developed by the industry include: *Sustainable Cane farming in Queensland*, *Fish Habitat Code of Practice* and *Best Practice Guidelines for Acid Sulfate Soils*.

Adoption of recommended practices from these documents has increased, particularly for those practices that deliver positive environmental and economic outcomes (O'Grady & Christiansen 2000). Rapid adoption of green cane trash blanketing (to protect soil from eroding) is a good example and reflects the flexibility in harvest that green cane techniques provide. Other practices which are progressively improving are: waste disposal of chemicals, slashing techniques for headlands and grassed waterways, tail water drains, record keeping, trash management in ratoon crops and fallow, irrigation scheduling and chemical use and handling (O'Grady & Christiansen 2000). The development of sustainable production systems is highlighted by the research and adoption of surface drainage and nutrient management for canelands on floodplains in the Herbert (See Ripple Creek case study).

**Table 8.8** Environmental issues in the sugar industry as identified by regional industry extension officers.

| Issue | Northern | Herbert/Burdekin | Central | Southern | NSW | WA |
|---|---|---|---|---|---|---|
| Erosion in replanting | ✓ | ✓ | ✓ | | | |
| Erosion in ratoon | | | | | | |
| Rodents | ✓ | | | | ✓ | ✓ |
| Nutrient runoff | ✓ | ✓ | | ✓ | | ✓ |
| Weed control | ✓ | | | | ✓ | ✓ |
| Acid sulphate soils | ✓ | | | ✓ | ✓ | |
| Pest and disease control | | ✓ | | | ✓ | ✓ |
| Fish kills | | ✓ | ✓ | | | |
| Reduced oxygen in rivers | | ✓ | | | | |
| Riparian condition | | ✓ | ✓ | | ✓ | |
| Salted soils and groundwater | | ✓ | ✓ | ✓ | | |
| Pesticide runoff | | ✓ | | | ✓ | ✓ |
| Elevated groundwater levels | | | ✓ | | | ✓ |
| River health | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

# INTEGRATED SURFACE DRAINAGE, SEDIMENT AND NUTRIENT MANAGEMENT FOR FLOODPLAIN CANELANDS

## A sugar industry case study in the Ripple Creek catchment, Herbert floodplain

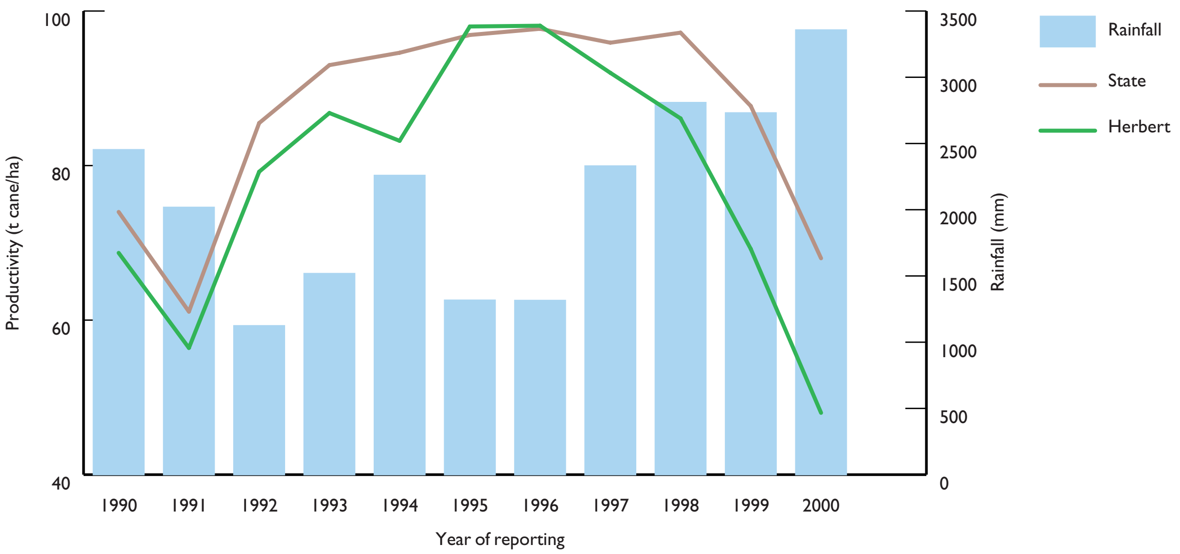
John Reghenzani, Bureau of Sugar Experimental Stations (Herbert) and Christian Roth, CSIRO Land and Water (Townsville)

A considerable acreage of sugar cane grown in North Queensland occurs in regions of high rainfall that need effective drainage. The sugar industry seeks to remove excess water within a multi-objective framework recognising the need to minimise any impacts on the high value ecological resources of Queensland (e.g. World Heritage Rainforest, Great Barrier Reef Marine Park, estuaries and fish habitats).

Industry need for integrated drainage and management plans has prompted the Sugar Research and Development Corporation, Bureau of Sugar Experiment Stations and CSIRO Land and Water to work with industry to provide both productivity and environmental outcomes.

The Herbert region has a pattern of less productivity in high rainfall years with delayed recovery (Figure 8.22). Productivity was further reduced after a succession of wet years. Gross sugar income in the Herbert was $141.9 million less in 2000 than in 1996. The cumulative effect of four recent successive wet years has placed a tremendous strain on farm profitability with flow-on effects to regional businesses and communities.

**Figure 8.22** Productivity (tonnes cane/ha) for the Herbert and for Queensland compared against Ingham rainfall (mm).



A series of key practices and activities has been confirmed as delivering the multi-objective production and environmental outcomes that the cane industry is seeking.

- Laser levelling is widely adopted and has an increasingly beneficial effect on yield (7, 11 and 13 t cane/ha over the past three wet years) and has resulted in more even and slower run-off bringing benefits of reduced erosion and less likelihood of low oxygen in discharge water.
- Laser levelling and mounded rows retain nutrients in low-lying areas, increased biomass production and maximised return on investment in fertilisers.
- Drainage design developed from monitoring, surveys and field experimentation specifically tailored to soil types, to minimise erosion on sloping lands and to improve drainage on floodplain lands while meeting key ecological criteria of minimal impact off farm.

**Figure 8.23** Thick growth of Pangola grass planted on the right bank by the property owner, acts as a filter strip for runoff from the field and protects the drain bank, while the unprotected left bank erodes.

- Risk mapping (priorities can be defined using GIS-coupled models, terrain and soil databases) allows targeted implementation of agronomic countermeasures to flooding risks and assists in design of efficient drainage systems that are more suitable as fish habitats.
- Integrated drainage plan and extension packages enable high levels of grower awareness and readiness to adopt improved on-farm drainage practices by providing guidelines that canegrowers can readily adopt to their particular farm, often as part of a local integrated floodplain management scheme.
- Practices to minimise soil loss. Key sources and sinks of sediments and nutrients have been identified using a sediment budget approach; the sediment budget for Ripple Creek has shown a net soil export of 5–6 t/ha, which is low in the context of the high rainfall in 1999/2000. Plant cane fields, water furrows and major drains with steep walls have been identified as key sources of sediments and nutrients leaving cane land. Important management practices increasingly being adopted include green cane harvesting, trash retained on ratoon fields and the use of shallow spoon type drains—trash management is now undertaken in about 90% of the cane area. In addition, trash retention recycles considerable nitrogen, allowing for reduced fertiliser application.
- Refining management practices to reduce sediment and nutrient export by targeting key sediment sources and sinks (e.g. enhancing the trapping efficiencies of headlands and filter strips along drains through improved grass species [Pangola grass, Figure 8.23], increasing ground cover in fallow cane blocks and improving drain design).

These activities are based on a strong partnership between industry and science. The key ingredient for success has been the willingness of cane farmers to link their concerns for increased productivity and reduced environmental impact. Farmers are adopting techniques identified through research, trials and monitoring, ensuring a productive and sustainable future for the cane industry and for the ecology of the Herbert floodplain.

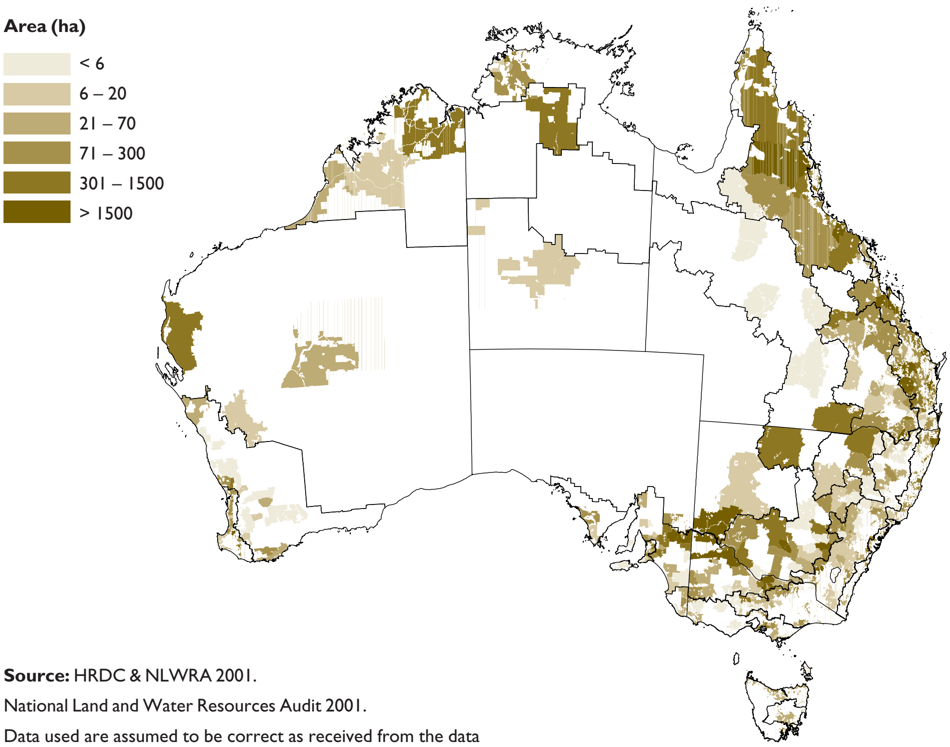
## HORTICULTURE

### National perspective

Australia produces a diverse range of annual and perennial horticultural crops, including vegetables, fruits and nuts, and has a well established and expanding viticultural industry. About 100 crop types are produced over more than 80 000 enterprises. The products are mostly used as fresh vegetables (e.g. beans and peas, onions, lettuce and carrots) and fresh fruit (e.g. bananas, apples, pears, peaches and oranges). Some are processed as frozen (peas, beans) or canned (pineapple, peaches), dried (sultanas, apricots) or made into beverages (e.g. wine and fruit juices).

The horticultural industry is distributed across a wide range of environments, but is primarily restricted by access to irrigation water, quality soils and topography. Major production areas are concentrated in fertile regions with high annual rainfall or abundant water for irrigation (Figures 8.24, 8.25). Vegetable production is highly concentrated close to major towns and cities, where domestic water supplies are used.

**Figure 8.24** Distribution and density of perennial horticultural crop production (excluding viticulture).

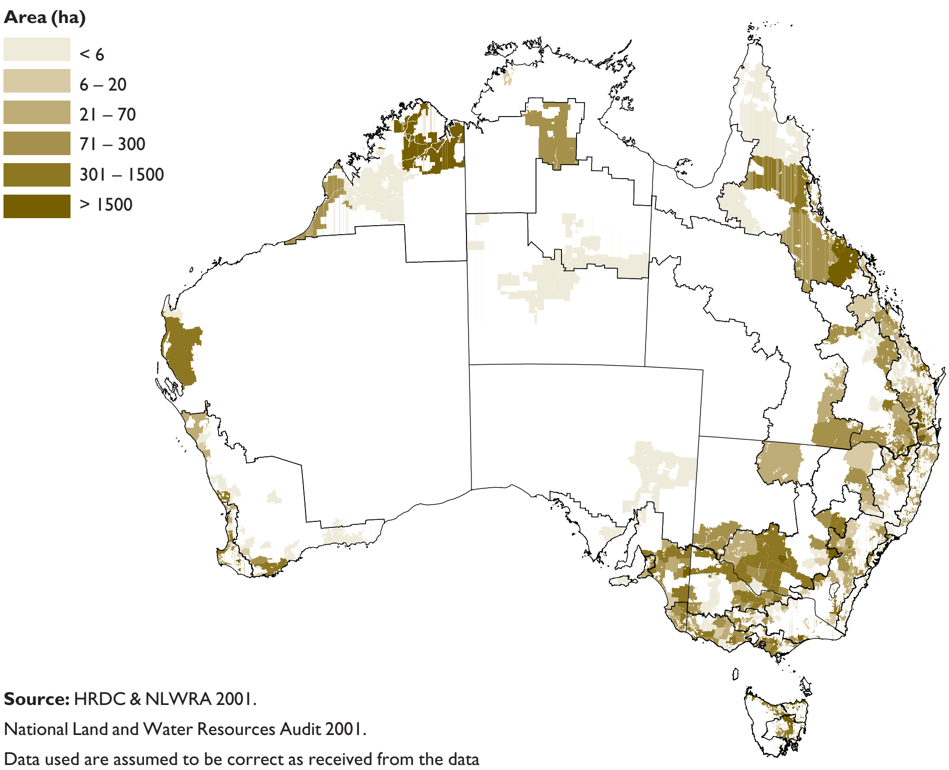



**Source:** HRDC & NLWRA 2001.

National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.

**Figure 8.25** Distribution and density of annual horticultural crop production.




**Source:** HRDC & NLWRA 2001.

National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.



In 1997, equal areas of annual (mostly vegetables) and perennial (mostly fruit) crops were grown (~136 000 hectares) with the major ones shown in Table 8.9. In 1997, these products were valued at $1905 million for the annual and $1719 million for the perennial crops. Much of this production was grown on 164 000 hectares of irrigated land, using 1640 GL of irrigation water and an average return of $590 per ML of irrigation water.

In 1998/99, Australian horticulture employed more than 93 000 people across 13 865 properties and generated an average farm income of $59 000 for fruit growers and $44 000 for vegetable growers.

**Table 8.9** Gross area, volume and value of production of horticultural crop groups.

| Crop group | Area (ha) | | Production (tonnes) | | Value ($m) | |
|---|---|---|---|---|---|---|
| | Annual | Perennial | Annual | Perennial | Annual | Perennial |
| Beans & peas | 18 040 | - | 83 260 | - | 74.6 | - |
| Brassicas | 13 910 | - | 181 730 | - | 152.6 | - |
| Cucurbits | 9 340 | - | 116 910 | - | 74.9 | - |
| Leaf vegetables | 6 040 | - | 160 120 | - | 115.8 | - |
| Melons | 7 710 | - | 163 370 | - | 91.2 | - |
| Nurseries | 4 670 | - | N/A | - | 378.2 | - |
| Onions & garlic | 5 630 | - | 205 070 | - | 107.7 | - |
| Peppers | 1 880 | - | 32 220 | - | 40.6 | - |
| Potatoes | 45 450 | - | 1 393 660 | - | 489.3 | - |
| Root vegetables | 9 880 | | 317 930 | - | 177.1 | - |
| Sweet corn | 5 430 | - | 64 790 | - | 26.5 | - |
| Tomatoes | 8 830 | - | 393 120 | - | 176.9 | - |
| Asparagus | - | 2 140 | - | 7 884 | - | 37.5 |
| Bananas | - | 11 610 | - | 199 580 | - | 216.6 |
| Berry fruit | - | 1 624 | - | 13 140 | - | 68.4 |
| Citrus | - | 30 400 | - | 645 260 | - | 391.8 |
| Nuts | - | 19 750 | - | 23 440 | - | 101.9 |
| Pome fruit | - | 18 690 | - | 940 470 | - | 513.0 |
| Pyrethrum | - | 740 | - | 590 | - | N/A |
| Stone fruit | - | 26 910 | - | 151 824 | - | 216.2 |
| Tropical fruit | - | 24 710 | - | 186 370 | - | 174.0 |
| **Total** | **136 810** | **136 574** | **3 112 180** | **2 168 558** | **1 905.4** | **1 719.4** |

N/A data not available

**Source:** Australian Bureau of Statistics 1997.

Most horticultural products are aimed towards the Australia's domestic markets, with less than 20% being exported. At least a third of the harvested asparagus, Chinese cabbage, strawberries and cauliflower are exported. In 1996/97, export earnings totalled $577 million and were dominated by citrus.

### Productivity and sustainability: key findings

The Audit in partnership with the Horticulture Research and Development Corporation commissioned and published an assessment of Australia's diverse horticultural industries (HRDC & NLWRA 2001).

Improved environmental performance is under way across all crop groups with industry changes being driven by:

- new and revised codes of practice ( best management practices and quality assurance standards);
- an increasing focus on integrated solutions to pest and disease management;
- improvements to the structure, management and planning of industry organisations;
- greater investment in environmental research and development projects on an enterprise and regional basis; and
- specific development of industry awareness programs.

Not all crop groups and regions are progressing at the same rate, with the larger professionally managed groups (e.g. Queensland Fruit and Vegetable Growers) being typically further advanced than others. However the process of cultural change and improved environmental performance is evolving. Strong signals for improved environmental management from the marketplace or from legislation are not common. As these signals strengthen, incentive for greater grower adoption will increase. Weakness in environmental performance relates to:

- poor linkages between programs (particularly research and development and codes of practice)
- poor and inadequate industry databases for monitoring environmental and economic performance and for preparing regional environmental plans; and
- the lack of resources and skills in some crop groups to adopt better practices.

Perennial crop groups are generally better prepared for improved environmental performance than annual crop groups.

# FARMCARE AND SUSTAINABLE FRUIT AND VEGETABLE PRODUCTION IN QUEENSLAND

Queensland's fruit and vegetable producers have taken a proactive approach to responsible environmental management and sustainable development. Through its Environment Program, Queensland Fruit & Vegetable Growers Ltd has played an important role facilitating industry activities.

Our achievements to date include the development of the *Farmcare Code of Practice for Sustainable Fruit and Vegetable Production in Queensland*. Our Code of Practice was launched in 1998 following two years of intensive work collecting ideas on environmental best practice from over 500 growers and a number of other horticultural and environmental specialists. Farmcare provides guidelines for the sound management of land and soils, water, biodiversity, air, noise and waste and integrated crop management. By following the Code of Practice, growers are able to demonstrate their due diligence under the Environmental Protection Act 1994 (Qld).

Farmcare has been distributed to all fruit and vegetable growers throughout Queensland and to many stakeholders in the horticulture industry as well. A total of 8000 copies have been distributed to date and Farmcare has recently been made available in CD-ROM format. To maximise awareness and adoption, the code of practice was launched by the Queensland Environment Minister and has been actively promoted at field days, workshops, commodity conferences and in industry journals. Farmcare training has also been incorporated into the natural resource management module of the Future*profit* in Horticulture integrated workshop series. Adoption of Farmcare practices is understood to be very high across all commodities.

The code of practice would be highly applicable and relevant to horticultural production systems across Australia and strong interest in Farmcare has been shown in other States, particularly in Victoria and New South Wales.

While the *Farmcare Code of Practice* provides valuable guidelines for fruit and vegetable growers, the Queensland horticulture industry still faces serious environmental challenges. Ongoing research, management innovation and commitment will be required to:

- refine integrated pest management techniques;
- balance production requirements with native vegetation retention needs;
- protect crops from damage by native wildlife;
- improve water use efficiency and maintain access to increasingly expensive and limited water resources;
- manage the good neighbour interface between the industry and protected or world heritage areas;
- protect downstream land and water ecosystems from impacts generated by fruit and vegetable production;
- develop meaningful links to regionally driven natural resource management planning; and
- respond to a tightening regulatory framework for property and natural resource management.

Optimising grower access to information about environmental issues and management options and establishing processes to monitor and report industry progress towards sustainability will also be important.

To address these needs and build on our successes with Farmcare, and to maintain momentum towards a more sustainable fruit and vegetable industry in Queensland, Queensland Fruit & Vegetable Growers Ltd conducted an Environment Forum in June 2000 with financial support from the Sustainable Industries Division of the Queensland Environmental Protection Agency.

Participants in the forum included representatives from most commodity groups in Queensland Fruit & Vegetable Growers Ltd and other stakeholders in the horticulture industry. The aim of the forum was to consider emerging opportunities for environmental management in Queensland's horticulture industry and to chart out future directions for Queensland Fruit & Vegetable Growers Ltd in facilitating the sustainable development of the industry. Queensland Fruit & Vegetable Growers Ltd then conducted meetings in growing regions across the state to seek feedback on, and support for, the action plan developed at the forum.

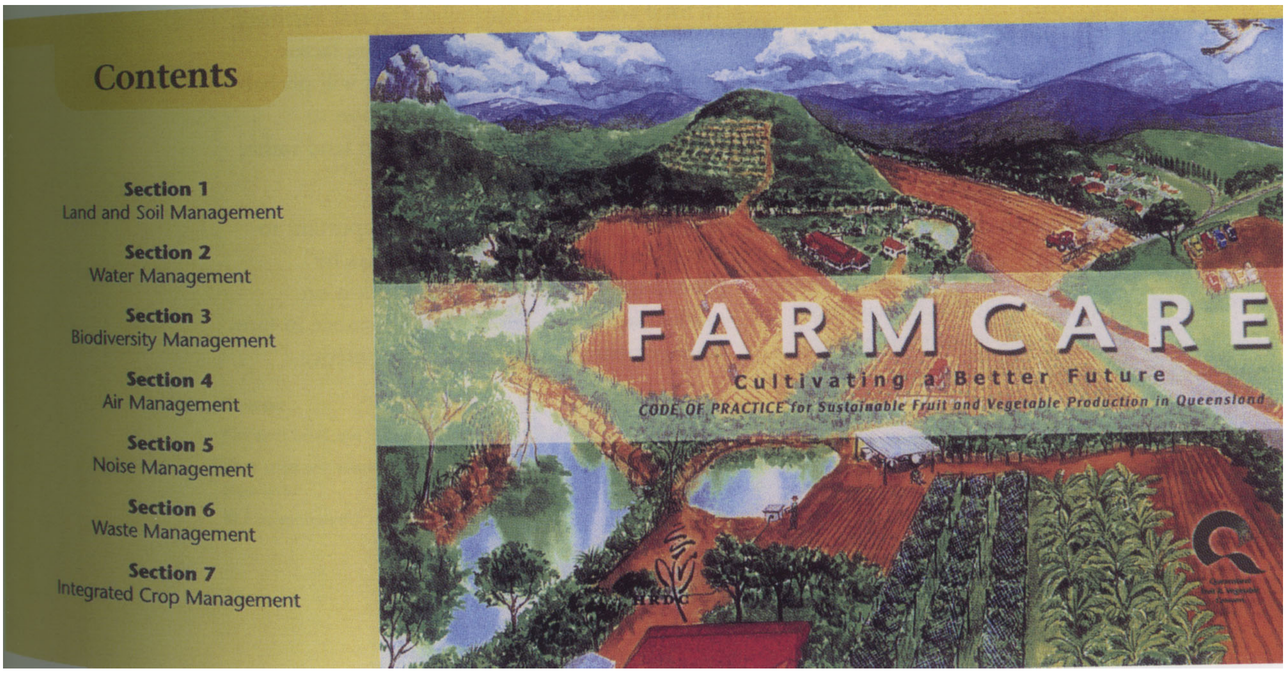
The 2000 Environment Forum and regional meetings were highly successful. Growers across Queensland demonstrated a strong interest in environmental issues and recognised the need for continual improvement in environmental management.

In response to this feedback, Queensland Fruit & Vegetable Growers Ltd now aims to expand its environment program. Investigating the application of Environmental Management Systems in horticulture was identified as a key priority. A case study has been established with banana growers in North Queensland to trial the use in horticultural operations of the AS/NZS ISO 14001 standard for Environmental Management Systems. Case studies in other growing regions and commodities are also proposed. Should the case studies show that Environmental Management Systems provides a useful framework for growers and delivers improved environmental performance, Queensland Fruit & Vegetable Growers Ltd will develop a program to support and facilitate widespread adoption of this approach.

Queensland Fruit & Vegetable Growers Ltd hopes to attract a number of co-investors to support other components of an expanded Environment Program, including:

- maintenance of a project to deliver improved pest management strategies for horticultural industries;
- an annual Environment Forum;
- development of industry-wide natural resource and environmental management strategies;
- development of a 'Sustainability Toolkit' of on-farm environmental management tools;
- investigation of property and industry-level environmental monitoring and reporting tools; and
- communication and promotion of environmental issues within the industry and to consumers and stakeholders.

Through its Environment Program, Queensland Fruit & Vegetable Growers Ltd aims to continue to support its members in their commitment to meet the challenges of a greener future. In our work, we will focus on developing a thorough understanding of the environmental impacts and risks of horticulture in Queensland; tools and strategies that assist growers to protect the environment; and methods for monitoring and reporting our progress towards sustainability.

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## Research

Much industry-sponsored research is directed at soil issues including:

- soil loss;
- chemical accumulations;
- organic matter and soil structural decline;
- nutrient levels; and
- acidity.

Integrated pest and disease management research is also in progress for the larger horticulture industries. Other areas of research include: spray management, waste disposal, and research of water, salt, salinity and riparian issues within horticultural catchments.

## Industry development and sustainability

The horticultural industry is generally ahead of other industries on quality assurance and equal with other industries for environmental management practice. However, its fragmented and multi-commodity nature creates barriers for introducing environmental initiatives. Variation between State legislative requirements inhibits a national approach to better environmental performance. This is not confined to horticulture and is a key issue across all commodities and their support agencies.

Implementing indicators to assess progress towards sustainable environmental management requires a substantial change among managers. Low grower membership of industry organisations is a limitation, creating difficulties for promoting industry-wide changes in practice.

Future industry expansion will be constrained by access to viable markets rather than by environmental limitations. Although accountability for food safety and environmental compliance will be increasingly important to future markets, the complexity of industry organisational structures inhibits close liaison and coordinated planning.

Access to resources (especially water) is considered the key industry risk. However the relatively high water use efficiency of many horticultural crops, compared with other irrigated agriculture, means that horticulture is well-placed to compete for increasingly expensive water entitlements.

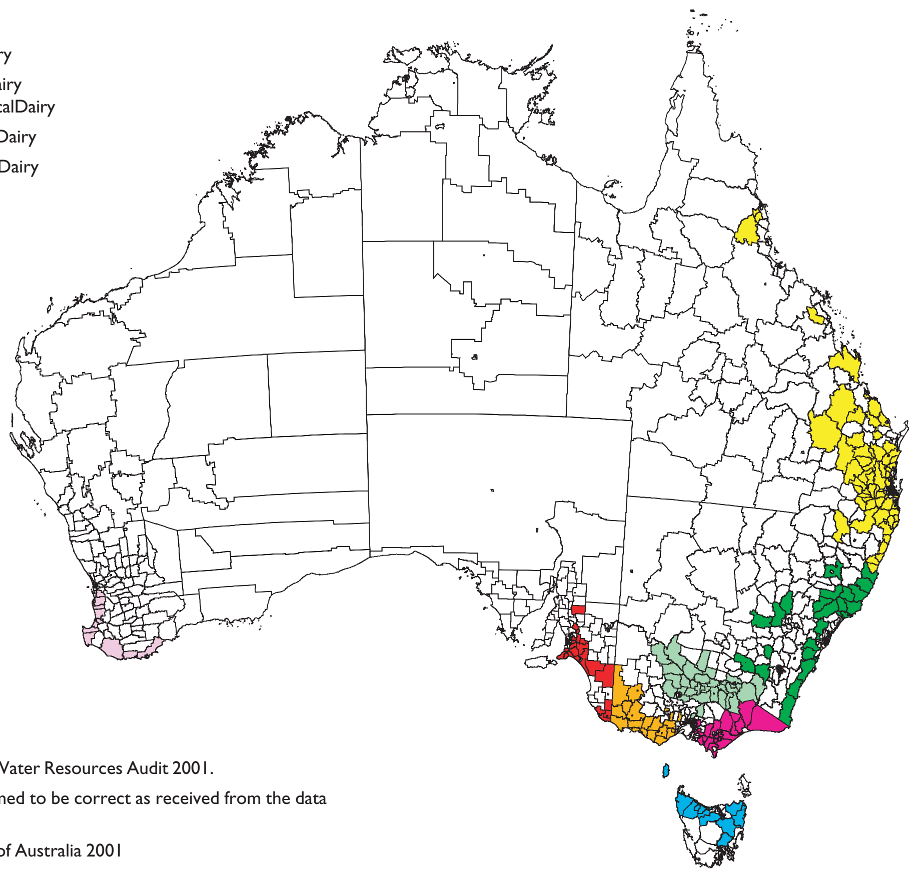
Future industry expansion will be based on market requirements and access to water resources. The scale of horticultural investments is likely to increase in the future, as technology and plant breeding become more integrated with consumer markets and supply chains serving domestic and export markets. Given that the existing horticultural industry is only equivalent in total area to the Australian Capital Territory, land is not expected to be a limiting factor. Wherever expansion does occur, it will probably be achieved through the re-allocation to horticulture of existing agricultural land rather than clearing of new land.

Technology will be increasingly important to expansion of horticultural industries by providing rapid access to information on markets and innovations, and assistance in farm management and environmental practice.

## National industry profile

Australian dairy production systems are dominated by pasture grazing with herds also receiving grain and fodder supplements. With the exception of inland irrigation schemes, dairy pastures depend heavily on natural rainfall, although in most regions at least some supplementary irrigation is now being used. Dryland dairying areas are mainly located in the high rainfall, coastal and adjacent areas (Figure 8.26).

**Figure 8.26** Dairy regions across Australia.



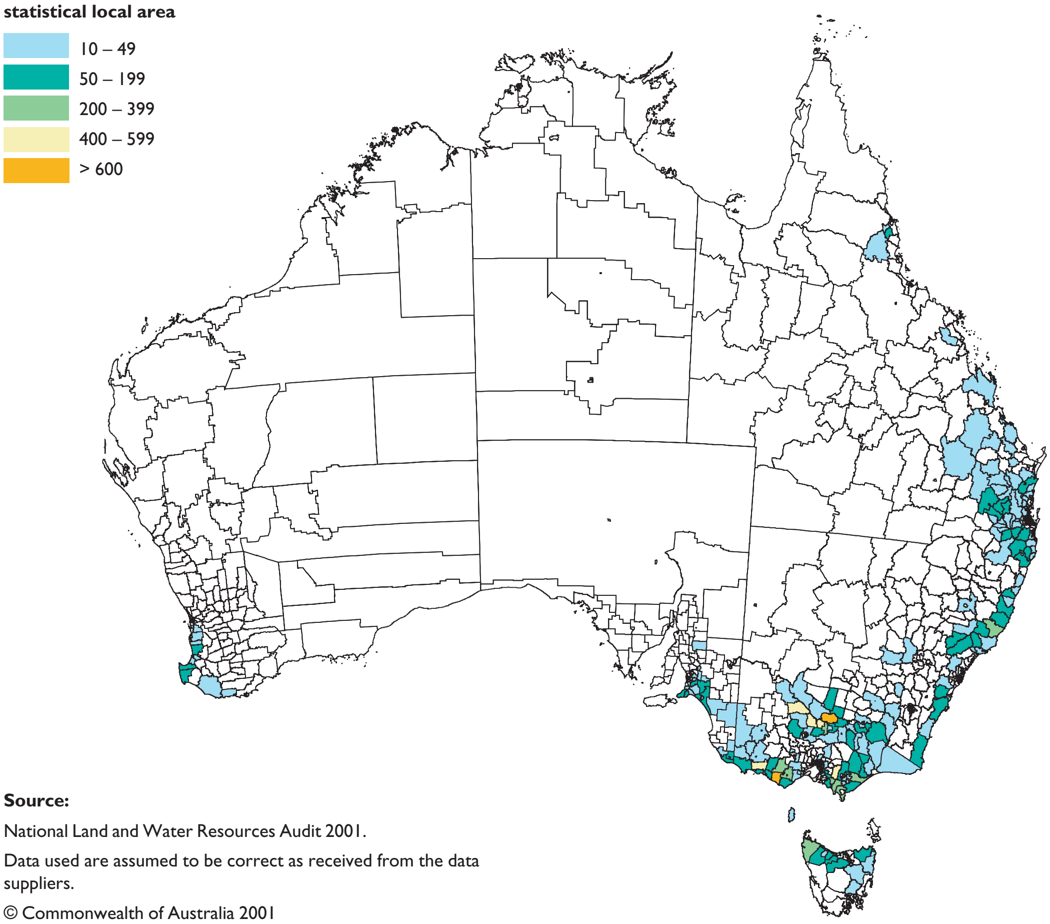

**Source:**

National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.

**Figure 8.27** Number of dairy farms per statistical local area in 1996/97.

**Number of dairy farms per statistical local area**




**Source:**

National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.

In 1998/99, over 60% of Australia's dairy farms (Figure 8.27), dairying herds and milk production were located in Victoria. Fourteen percent of the national dairy farms were located in New South Wales, 12% in Queensland, 6% in Tasmania, 5% in South Australia and 3% in Western Australia. Over 34 000 people are employed on 13 900 dairy properties.

During the last 25 years, the number of dairy farms has declined consistently (from around 30 630 in 1974/75 to 13 880 in 1999/2000); the size of the national dairy herd has remained reasonably constant. The volume of milk produced has increased strongly to over twice that produced in 1980/81 (Figure 8.28).

Milk is produced for direct human consumption (market milk) and for the production of dairy products (manufacturing milk). The increased production of milk in Australia (Figure 8.28) has led to strong growth in the manufacturing milk sector of the industry (Figure 8.29), fuelled by increasing domestic consumption of milk based products and increased export sales. Approximately 18% of total production is used for market milk and 82% for manufacturing (~8.9 billion litres). About two-thirds of the dairy products from manufacturing milk are now exported.

In 1999/2000, 10.8 billion litres of milk were produced, with a gross value of $2853 million, of which $1991 million was derived from the manufacturing milk sector (Figure 8.29).

In the period between 1979/80 and 1999/2000, the gross value for manufacturing milk more than doubled in constant dollars, but the value of market milk remained roughly constant in real terms.

**Figure 8.28** Trends in milk production, size of herd and number of dairy farms.

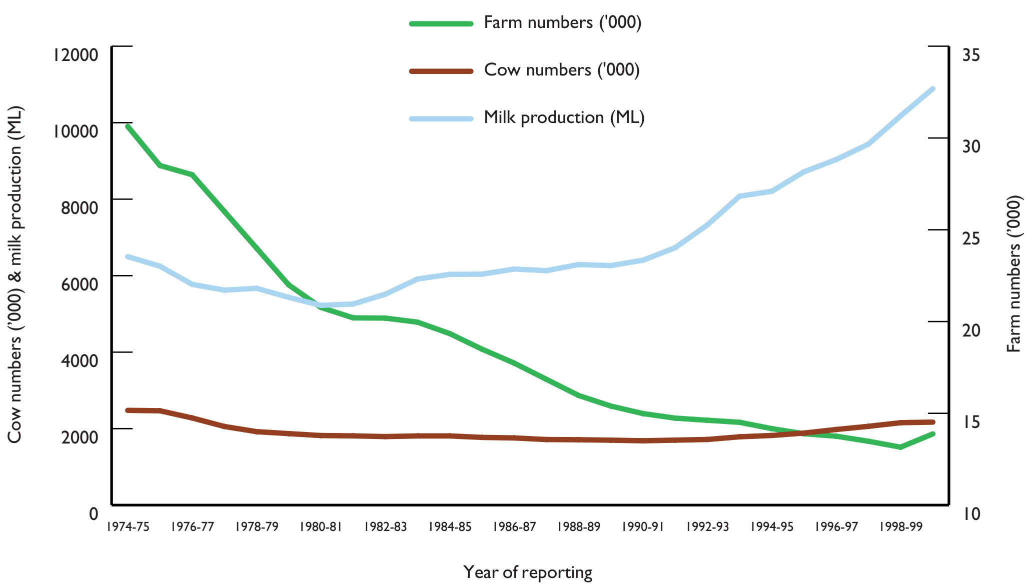



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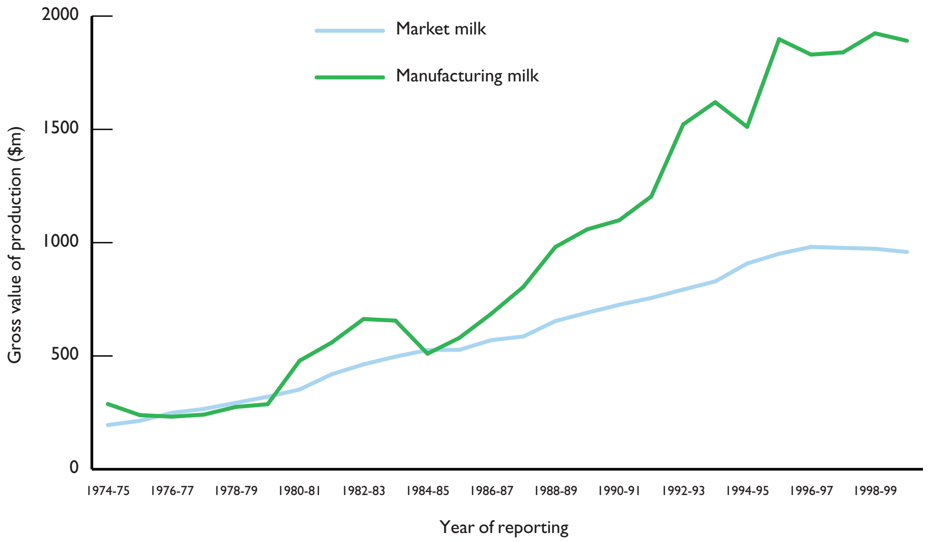
**Figure 8.29** Change in milk production in Australia.




## Industry deregulation

During the 1980s and 1990s, Commonwealth and State governments regulated milk production, fixing a price for a guaranteed amount of milk to be supplied for direct consumption of market milk. Manufacturing milk was sold at an unregulated price (generally well below that for market milk) and produced products such as cheeses and milk powders.

From 1 July 2000, the regulations in each State were removed, introducing a free market for the supply of all milk. Farmers relying on the sale of premium priced market milk, were faced with a severe and immediate challenge on farm profitability. To assist the industry during this transition, the Commonwealth government introduced the Dairy Industry Adjustment Package.

In the same way, Australian dairy manufacturing companies are now also restructuring, adapting their operations to remain internationally competitive.

## Australian dairy industry survey 2000

With the support of the Australian Dairy Farmers Federation, Australian Dairy Products Federation, Dairy Research and Development Corporation and the Audit, over 1800 of Australian dairy farmers (representing all dairying environments), were interviewed by phone to develop regional perspectives on:

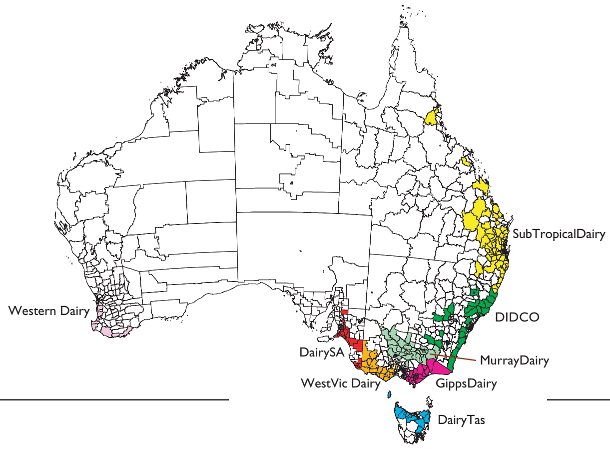
- profiles for the operations and productivity of dairy farming systems;
- current practices and attitudes for managing dairying environments; and
- best management practices needed for sustaining dairy farm income and natural resources.

From this survey, a picture of the 'average' dairy farm and farmer was developed (see box).

### The average Australian dairy farm

(assembled from across the eight dairy regions of Australia)

- The average dairy farm has 120 ha of milking area, 190 cows, produces 910 000 litres of milk each year, at 4600 L/cow. Production of milk per hectare averages 9400 L/year.
- The average dairy farmer is 49 years old and has been in the industry for 29 years.
- 70% of dairy farmers considered they would still be dairying in five years time; 55% indicated they intended to pass the farm over their children; 80% considered their farm would still be used for dairying in five years time.
- 57% of all dairy farms have at least some irrigation (especially those with higher stocking rates and larger herds).
- 90% of farms buy in feed (especially farms with high production levels) averaging 1.4 tonnes/cow/year.
- 97% of farms use fertilisers; 80% use soil tests as an aid to determining fertiliser needs and 43% adopt special measures to limit nutrient loss.
- 80% of farms have effluent management systems; 79% re-use effluent, with 57% via irrigation.
- 57% of farms with waterways have fenced off all or most of the streams.
- 40% of farmers attend farm discussion groups, 31% were in Landcare and 30% have a written farm plan.
- 47% of dairy farmers cited lack of money or finance as the main constraint to improving environmental management.




## Regional dairy industry profiles

### Production variation

Dairying farms are found in eight regions of Australia (see Figures 8.30), from subtropical areas in the north to cooler temperate regions of southern Australia. On-farm statistics differed between regions (Table 8.10 and Figure 8.30).

- The Gippsland region contained the smallest average dairy milking area (97 ha). The West Australian region averaged the largest farms (199 ha).
- Average stocking rates were highest in the Murray (2.2 cows/ha) and lowest in Western Australia (1.1 cows/ha).
- Farms in the Sub-Tropical region had the lowest herd size (138) and farms in Western Victoria the largest (226 cows).
- Average annual milk production per cow was highest in Western Australia (5489 litres/cow) and lowest in Tasmania (4013 litres/cow).
- Average milk produced annually (litres per hectare) varied from 6000 (Sub-Tropical region) to over 10 000 L/ha (Murray region).

**Figure 8.30** Milk production by dairy region.

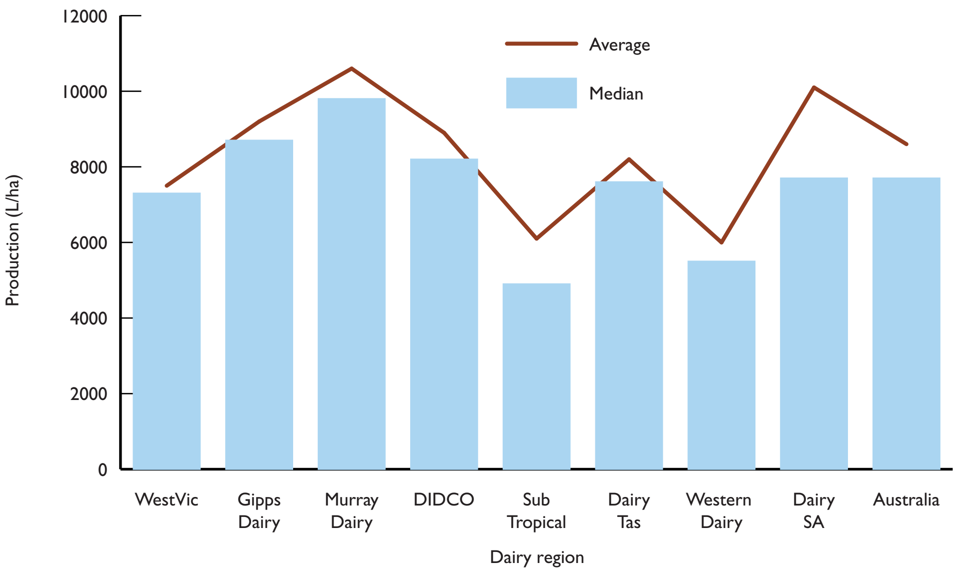


**Table 8.10** Dairy region production statistics.

| Region | Milk area (ha) | Stocking rate (cows/ha) | Stocking rate (cows/farm) | Production (L/cow) |
|---|---|---|---|---|
| West Victoria dairy | 143.4 | 1.6 | 226 | 4 323 |
| Gippsland dairy | 97.0 | 2.0 | 192 | 4 299 |
| Murray dairy | 112.5 | 2.2 | 207 | 4 702 |
| Dairy Industry Development Company | 110.8 | 1.7 | 159 | 4 886 |
| Subtropical dairy | 131.5 | 1.4 | 137 | 4 080 |
| Dairy Tasmania | 112.8 | 2.0 | 219 | 4 013 |
| Dairy Western Australia | 199.1 | 1.1 | 200 | 5 489 |
| Dairy South Australia | 143.8 | 1.8 | 188 | 5 398 |

## Irrigation practices

The dairy industry has a heavy industry reliance on irrigation to boost pasture and fodder production (Figure 8.31):

- 25% of farms flood irrigate;
- 29% use spray or sprinklers;
- 3% use both; and
- 43% use no irrigation.

Where flood irrigation is used, 75% of farm of the farm is irrigated, averaging 6.1 ML water per ha, and 2.6 ML/cow. On average, 80% of flood irrigated farms have a 'tail-water' re-use system and 95% have farms that are at least partly laser graded; 60% have laser graded more than half of the farm

Where spray irrigation is used, 16% of farm is irrigated, averaging 4.3 ML water use per ha, and 0.9 ML/cow.

Expenditure on feed supplements (Figure 8.32) and fertilisers (Figure 8.33) is on average high. The quantity of feed supplements fed per cow varies between regions. Expenditure on fertilisers varies substantially both within and between dairying regions.

**Table 8.11** Irrigation statistics for in dairy industry regions.

| Region | % of farms irrigating | Average area irrigated (ha) | % of irrigating farms using flood irrigation | % of irrigating farms using spray irrigation | Average irrigation water application rate (ML/ha) | Average irrigation water usage rate (ML/cow) |
|---|---|---|---|---|---|---|
| West Victoria dairy | 25 | 34 | 16 | 89 | 4.5 | 0.9 |
| Gippsland dairy | 29 | 60 | 58 | 53 | 4.1 | 1.3 |
| Murray dairy | 92 | 98 | 96 | 10 | 6.0 | 2.6 |
| Dairy Industry Development Company | 57 | 49 | 5 | 98 | 4.5 | 1.4 |
| Subtropical dairy | 62 | 29 | 2 | 100 | 4.5 | 0.9 |
| Dairy Tasmania | 62 | 45 | 2 | 99 | 2.7 | 0.5 |
| Dairy Western Australia | 42 | 41 | 92 | 13 | 9.5 | 2.1 |
| Dairy South Australia | 71 | 46 | 27 | 86 | 5.4 | 1.3 |
| **Australian average** | **57** | **64** | **49** | **56** | **5.3** | **1.9** |

**Figure 8.31** Irrigation on farm: area and use (%).

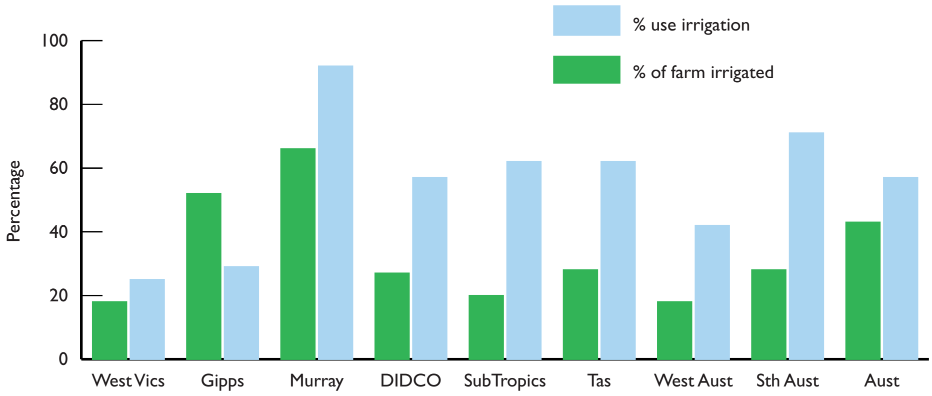



**Figure 8.32** Purchased feeds.

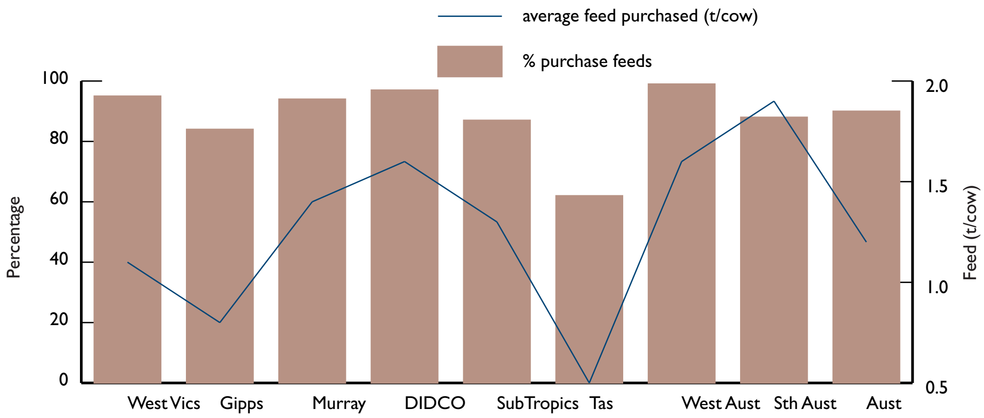
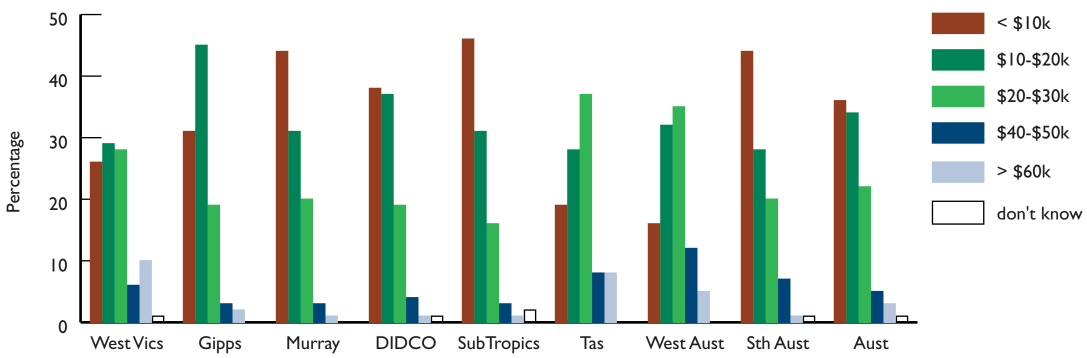



**Figure 8.33** Fertiliser expenditure.

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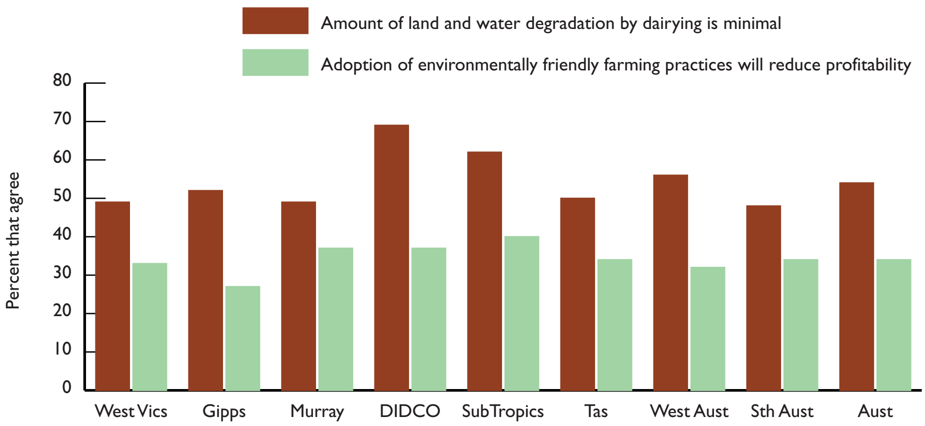
## Dairy industry's attitude to resource degradation

Nationally, around 50% of dairy farmers surveyed considered dairying in their regions was having minimal impact on land and water degradation. Over 30% considered 'environmentally friendly farming' in their regions would reduce farm profits. These were fairly consistent results across all regions (Figure 8.34).

**Figure 8.34** Environmental attitudes of a representative cross section of the dairy industry.

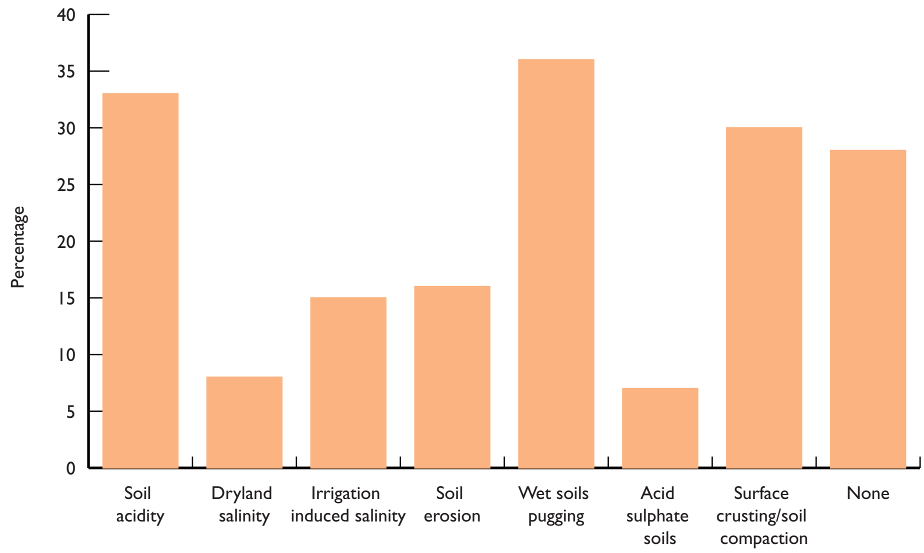


## Recognising and responding to resource challenges

### Soil management

The health and condition of dairy farm soils is vital for feed production and for minimising any off-farm impacts from farming activities. The national survey (Figure 8.35) indicated a strong awareness of soil health issues by farmers, and when recognised, they responded by adopting best management practices to contain or overcome them (see descriptions below). However, with 28% of farmers reporting no land management problems there is a question as to whether all soil health issues are recognised by farmers.

**Figure 8.35** Recognition of local soil loss as a degradation issue.

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- 28% of farmers reported no major land management problems affecting their property.
- 36% reported wet soils or pugging.

*78% of those with wet soils use 'on-off' grazing, 76% do not graze wet areas.*

- 33% reported soil acidity.

*90% of those with acidity problems soil test for soil pH; 83% apply lime.*

- 30% reported soil structure or compaction.

*73% of those with poor soil structure adopt conservation tillage; 72% deep rip and 73% changed their grazing management.*

- 16% reported erosion potential.

*91% of those with soil erosion risks have permanent pastures; 84% avoid cultivation at high-risk times; 69% adopt conservation tillage and revegetate.*

- 15% reported irrigation-induced salinity.

*80% of those with irrigation-induced salinity installed drainage; 70% adopted improved irrigation practices.*

Weeds invasion and their management were also given high priority by the industry, which supports concerns listed by the sheep/wool and beef cattle industries.

## Effluent management

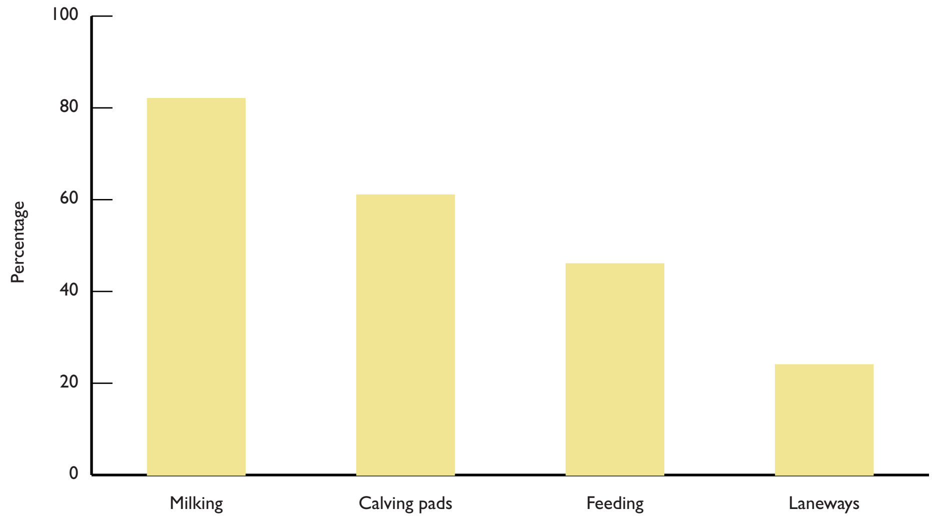
High concentrations of waste are generated where dairy cows congregate in high numbers (e.g. around milking sheds).

- 80% of dairy farms have an effluent management system (Figure 8.36).

Pond systems are the most common form of effluent management (54%), while 27% of farms use a sump and dispersal system.

- 79% re-use effluent, 57% of them via irrigation.
- More than 80% of dairy farmers have constructed a system to collect and manage effluent from dairy sheds. Farms without formal effluent systems tended to be less intensive and used lower stocking rates.
- The use of feed supplements has increased the use of feeding pads, with nearly 20% of all farms now using them. Of those farmers, more than 30% have an effluent management system.
- Calving pads were reported on 27% of farms, with nearly half (45%) managing the effluent by way of dry litter. Sump or pond management systems are used by a further 13%.
- Run-off from laneways is collected in 25% of farms, with a third directing it to a pond system for use in irrigation.
- Overall, nearly 80% of farms re-use their effluent, with more than half doing so by way of irrigation.

**Figure 8.36** Percent farms with effluent management systems.

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## Vegetation and waterway management

The ability of dairy farms to support native vegetation and wildlife varies between regional environments and with farming systems. However, the management of any remnant native vegetation, creeks and stream banks can enhance the property's contribution to biodiversity. Well-maintained waterways can also help minimise potential impacts off-farm.

- 64% of dairy farms have some remnant vegetation.
- Of those with remnant native vegetation, 36% have fenced off all or most of it.
- Of those with waterways, 57% have fenced off all or most of the stream.
- 56% have undertaken revegetation, (primarily for shade or shelter).

A number of these activities provide broad benefit to the community, possibly ahead of benefits to the individual who must invest time and money in the works and their maintenance.

Fencing remnant vegetation and waterways, and revegetating was associated with having a farm plan, being a member of a Landcare group, having a positive expectation for a future in dairying and being younger.

## Future options

The level of investment that farmers are prepared to make in their properties is influenced by a number of factors.

- 47% see the lack of money or finance as the main constraint to improved environmental management.
- 44% see the lack of money or finance as the main constraint to increased productivity (with a further 16% citing low milk prices).

To improve farm productivity, farmers nominated better pasture management, more use of fertilisers, enhanced irrigation and improved dairy milking sheds. Planting more trees was seen as the single most beneficial means to improve the environment.

## Dairy conclusions

The Australian dairy industry is vital to the national economy, providing domestic milk and dairy products and valuable export earnings. Dairying also generates considerable regional employment and economic activity. It is undergoing rapid restructuring through milk market deregulation, but the industry considers itself to be viable in the long term.

Dairying is an intensive grazing industry, centred mainly in higher rainfall catchments, and irrigation areas, which necessitates high levels of environmental management. Water is a key resource input and as a consequence, the industry will seek to increase their participation in the design and implementation of regional, catchment and waterway management to responsibly contribute to regional environmental needs.

The industry also seeks sustainable growth into the future. To achieve this it must simultaneously optimise production, profitability and environmental benefits and outcomes.

Australia's dairy industry is committed to adopting best management practices and modern decision support tools to recognise and resolve problems and to achieve the synergy required to build a greater industry capacity.

Through the Audit's partnership with the Australian dairy industry, greater awareness of industry and natural resource management issues and knowledge gaps were exposed. These new findings will now be used to frame and implement national and regional strategies and action plans including more targeted research, development and education. The strategies will resolve regional issues within the industry and deal with national natural resource management risks. It will focus on:

- improving productivity and profitability;
- protecting and enhancing on-farm resources; and
- minimising off-farm environmental impacts.

As the dairy industry intensifies to meet the challenges of deregulation, it is important that natural resource management issues are incorporated in on-farm development. Support to incorporate natural resources considerations at the design stage is imperative.

# WHOLE FARM PLAN PAYS DIVIDENDS

*Using farm plans to increase production*

- Paul & Nicole Clarke
- Eddie & Lillian Clarke
- Farming at Roelands, 15 km north-east of Bunbury, Western Australia
- 150 ha dairy farm plus 40 ha run-off block
- 53 ha flood irrigation
- Milking 200 cows in a 12 double-up dairy
- Developed a property plan to achieve increased production and a more sustainable management style.

Paul Clarke with wife Nicole and son Jack, of Roelands, Western Australia

Roelands Western Australian dairy farmer Paul Clarke has taken his dairy herd from 130 to 200 milkers in eight years without adding to his land holding and reckons he has 'another 100 cows to go' before he reaches maximum carrying capacity.

He singles out his decision in 1993 to develop a whole farm plan and acquire a detailed farm map that included contours and gradients, as the driver behind this dramatic growth in productivity.

Paul, who farms a 150 ha dairy farm and 40 ha run-off block in partnership with his wife Nicole and parents Eddie and Lillian, says the farm contour map made him 'look at his farm as he had never seen it before'.

'I just hadn't realised the levels in some of the paddocks, but the map showed us that we could create open drains to shift water that we previously had thought was impossible to shift without a huge amount of excavator work,' Paul says.

By referring to the contour map (Paul says there isn't a week that goes by, almost eight years later, when a family member does not refer to this map), they were able to make informed drainage decisions and approximately 1.5 km of open drains were installed.

'We were always going to address productivity by developing a better drainage system, but we estimate that we would have spent close to double the money using drainage pathways that we had incorrectly thought were the right ones, prior to the contour map showing us otherwise.'

The next phase in the farm's development was the establishment of a new dairy (more centrally located) and associated laneways, again taking into consideration the fall of the land and the associated soil types and the dirt excavated during the drainage program was put to good use in building up laneways.

But perhaps the most pronounced productivity gains came from the subsurface drainage program, introduced initially on a 10 ha plot in an area most prone to waterlogging.

At a cost of around $1800 per hectare, the rationale is that the process is still cheaper than purchasing new land and in this case, produced an immediate doubling in the carrying capacity of that paddock, which was previously unusable most winters and with comparatively poorer quality pastures during summer.

By 1999, the Clarkes had applied the same principles to a second plot and see an ongoing subsurface drainage program throughout their 53 ha of irrigation as the key to achieving carrying capacity targets.

The other strategy as it relates to achieving target stocking rates, is a complete review of the current flood irrigation practice (incorporating re-use of effluent at a 1:10 ratio), but with the intention to convert to centre pivot in order to use less water and grow more grass.

A centre pivot system should also reduce the amount of water draining off the property, which currently travels about 1 km and flows into the Collie River. Rate of flow varies considerably throughout the year and has been monitored for salt content, which was higher in the initial stages of the subsurface drainage program but has dropped to virtually negligible levels now.

And while salt by comparison is a 'lesser' issue, Paul admits to being surprised at discovering just how salty their irrigation water is and was quick to embrace a South West Irrigation initiative to survey the Collie River district using Electro Magnetic technology to identify saline areas and surface soil types.

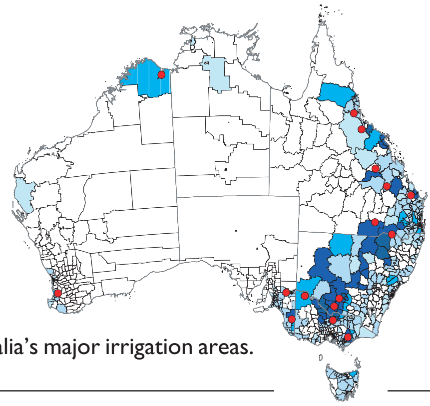
The resulting salinity farm maps have been an invaluable decision support tool to identify areas of salt build up and differentiate these from areas with deep water table levels that in most instances would not respond well to soil and drainage treatment.

'What we have been able to do with that information is make sure our dollars are spent wisely on renovating areas that have the capacity to improve and leave other potential trouble spots as areas for annual pastures.'

Buoyed by the success of the strategies employed so far as part of their whole farm plan, the Clarkes are now committed to introducing subsurface drains to all remaining irrigated areas on the property.

Paul believes once he has achieved this and made the conversion to centre pivot irrigation, he will be able to realise his ambition of milking 300 cows on the existing land holding.

Paul Clarke (right) with his father Eddie and son Jack, of Roelands, Western Australia



Australia's major irrigation areas.

## IRRIGATED AGRICULTURE

Irrigation offers opportunities for agricultural intensification, greatly enhanced yields and the substitution of low value crops with higher value enterprises. Without irrigation, a significant proportion of Australia's agricultural industries would either not exist or be greatly diminished

Irrigated agriculture occupies about 1% of Australia's agricultural land. Just under half of the water applied is used to irrigate pastures and fodder crops (~8000 GL), particularly in Victoria and New South Wales. About two thirds of Australia's agricultural production from irrigation is derived from the Murray–Darling Basin, producing rice, cotton, cereals, soybean, fruit and vegetable crops (see *Changing face of agriculture* section of this report). Outside the Basin, irrigation is used mainly for dairy pastures, seed, fodder, cereal and horticultural crops and sugar cane production.

The gross value returns from irrigated agriculture in 1996/97 were estimated to be $7.3 billion, or 26% of the total gross value of production derived from Australian agriculture (ABS 2000).

In the 40 years since 1955, the area of irrigated agricultural land in Australia has quadrupled to 2.06 million hectares. In 1996/97, a total of 18 000 GL of irrigation water were applied (NLWRA 2001a).

Irrigation water comes as either regulated or non-regulated diversions of water from rivers, dams and lakes, ground water reserves and from surface harvested water stored on farms.

Irrigation scheduling (the frequency and volumes of water applied at each irrigation event) attempts to match water application with plant water requirements. The amount of water that plants require is determined by interactions between the crop being irrigated, the soil type (particularly its water holding capacity) and local weather conditions experienced during the growing season.

Water can be applied by many different irrigation techniques including:

- gravity fed surface furrow and border check systems;
- overhead and under-tree sprinklers;
- micro-jets; and
- trickle irrigation systems.

At the farm scale, records of water volumes applied are either poorly documented or inaccessible. The box (p. 299) provides average data sourced from recent farm surveys, and indicates that in any irrigation region, water applications vary appreciably. Rice crops, because they pond water for significant times, use the most water per hectare.

A national framework of terms and definitions for water use efficiency in Australian irrigation has been determined (Barrett Purcell & Associates 1999). Further work on gaining acceptance of this framework is under way (Aquatech Consulting and Naturally Resourceful).

## SURVEYS REPORTING THE VOLUME OF IRRIGATION WATER

Recent farm surveys reporting the volume of irrigation water applied to different land uses in Australia

| Dominant land use | Irrigation region (State) | Year | Mean water applied (ML/ha) | Reference |
|---|---|---|---|---|
| Citrus | Riverland (South Australia) | 1996/97 | 11.5 | 1 |
| | Sunraysia (Victoria) | 1996/97 | 10.2 | 1 |
| | Murrumbidgee (New South Wales) | 1996/97 | 7.9 | 1 |
| | Queensland survey | 1997 | 7.6 | 2 |
| Wine grapes | Riverland (South Australia) | 1996/97 | 8.3 | 1 |
| | Sunraysia (Victoria) | 1996/97 | 7.2 | 1 |
| | Murrumbidgee (New South Wales) | 1996/97 | 7.1 | 1 |
| | Queensland survey | 1997 | 3.5 | 2 |
| Banana | Queensland survey | 1997 | 6.7 | 2 |
| Pineapple | Queensland survey | 1997 | 0.7 | 2 |
| Stone fruit | Queensland survey | 1997 | 5.2 | 2 |
| Avocado | Queensland survey | 1997 | 7.5 | 2 |
| Vegetables | Queensland survey | 1997 | 2.3 to 5.5 | 2 |
| Potato | Riverland / Sunraysia | 1996/98 | 3 to 5 | 3 |
| Beef/sheep | Kerang/Cohuna (Victoria) | 1995/96 | 4 | 4 |
| | Murray Catchment (New South Wales) | 1996/97 | 3 | 5 |
| | Murrumbidgee (New South Wales) | 1996/97 | 3 | 5 |
| | Central West (New South Wales) | 1996/97 | 3.9 | 5 |
| | Far West (New South Wales) | 1996/97 | 3.6 | 5 |
| | Barwon (New South Wales) | 1996/97 | 4.3 | 5 |
| Dairying | Shepparton/Central Goulburn (Victoria) | 1994/96 | 7.8 | 6 |
| | Murray Valley (Victoria) | 1994/96 | 9.1 | 6 |
| | Rochester/Campaspe (Victoria) | 1994/96 | 9.4 | 6 |
| | Torrumbarry/Pyramid Hill/Swan Hill (Victoria) | 1994/96 | 9 | 6 |
| | Southern Riverina (New South Wales) | 1994/96 | 7.8 | 6 |
| Mixed crops and pasture | Murrumbidgee (New South Wales) | 1995/96 | 7 | 4 |
| | Kerang/Cohuna (Victoria) | 1995/96 | 4.6 | 4 |
| Rice | Murrumbidgee (New South Wales) | 1995/96 | 13.7 | 4 |
| | Murray Catchment (New South Wales) | 1996/97 | 11.9 | 5 |
| | Murrumbidgee (New South Wales) | 1996/97 | 13.9 | 5 |
| | Murrumbidgee (New South Wales) | 1997/99 | 13.5 | 7 |
| Cotton | Central West (New South Wales) | 1996/97 | 7.3 | 8 |
| | Barwon (New South Wales) | 1996/97 | 4.9 | 8 |
| | Far West (New South Wales) | 1996/97 | 12.8 | 8 |
| | Namoi Valley (New South Wales) | 1998 | 3.5 to 6.2 | 9 |
| | Macquarie Valley (New South Wales) | 1998 | 6.9 to 7.8 | 9 |
| | Darling Downs (Queensland) | | 4.4 | 9 |
| | Lockyer Valley (Queensland) | | 4.4 | 9 |
| | Emerald (Queensland) | | 3.4 | 10 |
| | Industry survey (Queensland) | 1996/99 | 2.5 to 8.1 | 11 |
| Sugar cane | Atherton Tableland (Queensland) | | 11.5 | 12 |
| | Burdekin (Queensland) | | 10.7 | 12 |
| | Bundaberg (Queensland) | | 3 | 13 |
| | Eton (Queensland) | | 2.1 | 13 |
| | Industry survey (Queensland) | 1997 | 1 to 15 | 14 |
| Winter crops | Murray Catchment (New South Wales) | 1996/97 | 1.7 | 5 |
| | Murrumbidgee (New South Wales) | 1996/97 | 2.7 | 5 |
| | Central West (New South Wales) | 1996/97 | 3 | 5 |
| | Barwon (New South Wales) | 1996/97 | 1.7 | 5 |
| | Far West (New South Wales) | 1996/97 | 3.9 | 5 |

1. Topp & Danzi (1998)
2. Barraclough and Co. (1999)
3. Skewes & Meissner (1998)
4. McClintock (1997)
5. Mues & Opalinska-Mania (1998)
6. Armstrong et al. (1998)
7. Murrumbidgee Irrigation P/L (pers. comm.)
8. Chapman et al. (1998)
9. Zischle & Gordon (2000)
10. Goyne et al. (2000)
11. Tennakoon & Milroy (2000)
12. P. Moody (pers. comm.)
13. C. Mues (pers. comm.)
14. Tilley & Chapman (1999)

## Changes to areas under irrigation

About 45% of the total area irrigated in Australia is located in New South Wales, 27% in Victoria, nearly 20% in Queensland, 5% in South Australia, and less than 3% in Western Australia and Tasmania (Figure 8.37)

- Most of the increase in irrigated areas have occurred in New South Wales and Queensland (Figure 8.37).
- Regions where irrigation increased during this time frame by more than 10 000 hectares include Burdekin, (Queensland), Warren, Carrathool, Wakool and Hay in the Murrumbidgee Irrigation Area (New South Wales).
- Narrabri, Moree and Waggamba in northern New South Wales also had increases of 7000 or more hectares.
- The larger increases were usually associated with major rivers such as the Murrumbidgee, Lachlan, McIntyre, Barwon, Macquarie, Burdekin and the Daly.
- The most significant decreases occurred in the regions of Gippsland, Mildura and Gannawarra in Victoria, of Singleton/ Hawkesbury, Richmond, Copmanhurst and Lismore in New South Wales, and of Paroo in Queensland.

Between 1983/84 to 1996/97, the total area of irrigated commodity groups increased by 26% (Table 8.12). The largest increase in both actual and relative terms, was due mostly to cotton (314 956 ha in 1996/97) and sugar cane (201 000 ha in 1996/97).

**Table 8.12** Total area ('000 ha) of commodity groups in Australia that were irrigated in 1983/84 and 1996/97.

| Commodity group | 1983/84 | 1996/97 | Increase ('000 ha) | Increase (%) |
|---|---|---|---|---|
| Pastures | 871 | 935 | 64 | 7.3 |
| Cereals | 315 | 337 | 22 | 6.9 |
| Vegetables | 76 | 87 | 11 | 14.5 |
| Fruit | 97 | 151 | 54 | 55.7 |
| Other crops* | 260 | 544 | 284 | 109.2 |
| **Total** | **1625** | **2056** | **431** | **26.5** |

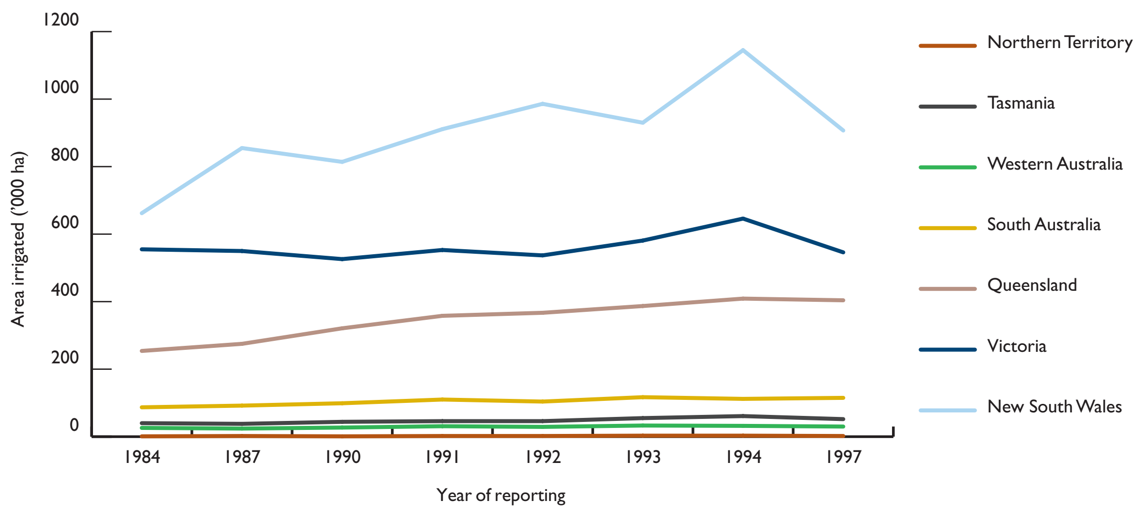
* 'Other crops' comprise mainly cotton, sugar cane and soybean.

**Source:** Australian Bureau of Statistics.

Other significant changes that occurred in the use of irrigated agricultural land between the 1980s and 1990s were:

- Irrigated pastures in southern New South Wales and Victoria, mostly used for dairying, still constituted the main irrigated land use in Australia; the largest increases occurred in south-east corner of the continent and in northern Tasmania.
- About 80% of irrigated cereals existed in New South Wales, with between one third to a half of the area being under rice. The largest increases in area were in the Murrumbidgee Irrigation Area. Areas of irrigated cereals, other than rice, have decreased.
- Irrigation of fruit increased in all States. Major regions of growth were in South East and Riverland regions (South Australia), Griffith (New South Wales), Huon Valley (Tasmania), Margaret River (Western Australia) and tropical regions in Queensland.
- Irrigated vegetables increased in area (Figure 8.38, Table 8.12), with large increases occurring in the Burdekin and Margaret River regions. Areas of decrease existed in New South Wales, and Tasmania.
- Collectively, the irrigated areas of cotton, sugar cane and soybean (plus other crops), mainly produced in Queensland and New South Wales, now make up the second largest area of irrigated agriculture (Figure 8.38, Table 8.12).

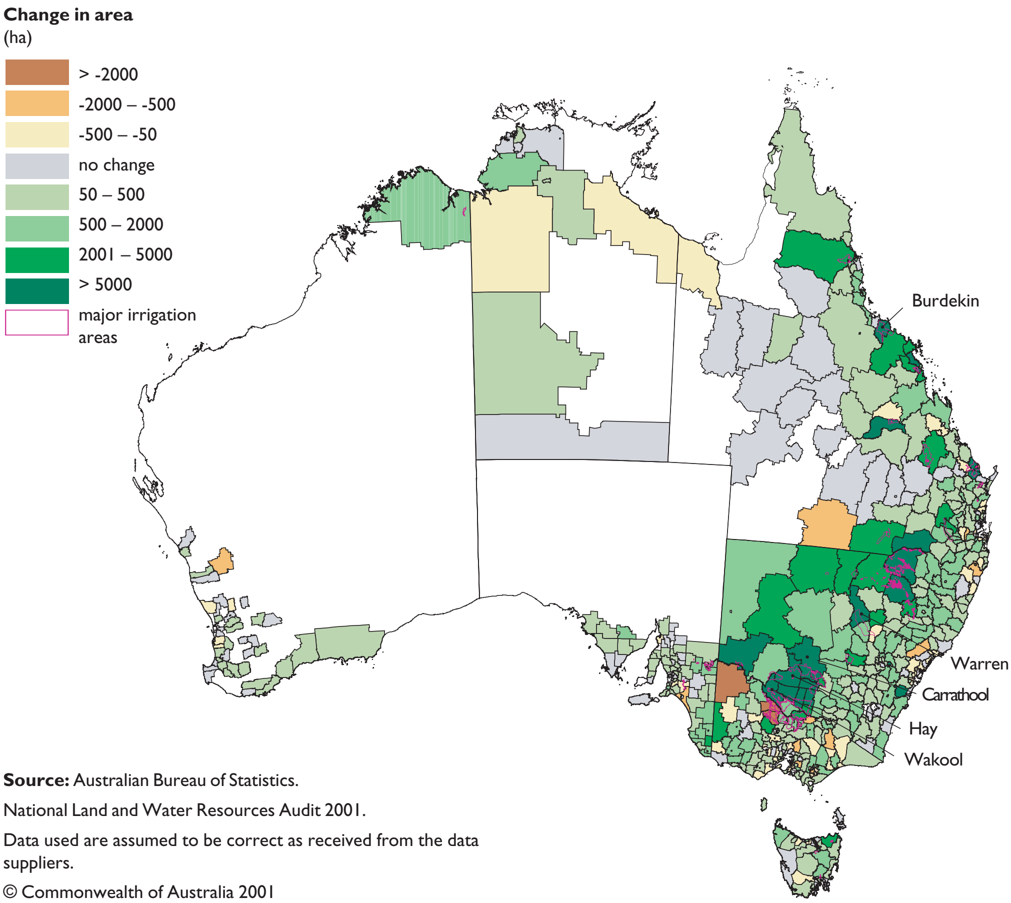
**Figure 8.37** Areas irrigated in the States and Territories between 1982/83 and 1996/97.




**Source:** Australian Bureau of Statistics.

8

**Figure 8.38** Changes in the areas irrigated between the 1980s (1984, 1987, 1990) and the 1990s (1991,1992, 1993, 1994, 1997).




**Source:** Australian Bureau of Statistics.

National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.

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# WAYS FORWARD FOR AGRICULTURE

Australian agriculture has well demonstrated its capacity to adapt and innovate in response to environmental challenges. Australian farmers are conscious of the need to manage natural resources sustainably and to deliver a 'clean and green' product. They are progressively improving their activities within the broader contexts of increased profitability and community demands for improved catchment management.

The resource assessment components of *Australian Agriculture Assessment 2001* focused on soils and nutrients—both on- and off-farm.

*Australian Agriculture Assessment 2001* improves our understanding of natural resource processes active in agricultural landscapes—providing pointers to priorities for management action and further investigation.

## Quantifying key management issues

- Nutrients have increased to five times their natural levels in agricultural landscapes—increasing the potential for leakage from land to rivers and estuaries and therefore closer attention to nutrient management on farm.
- Biomass productivity from agricultural landscapes has doubled from natural levels—reflecting the role of fertilisers and farm management systems in delivering profitable agriculture and buoyant rural communities.
- Almost 1200 million tonnes of soil potentially moves on agricultural hillslopes each year—demonstrating the need for close attention to in situ soil management.
- About 50 million tonnes of sediment from hillslopes each year enters the rivers with about 50 000 tonnes of phosphorus attached to the sediment—indicating the need for closer attention to sheet and rill erosion, especially maintenance of grass cover on our grazed landscapes.
- About 44 million tonnes of sediment each year enters the rivers from gullies, including about 11 000 tonnes of attached phosphorus—demonstrating that even following half a century of government and industry attention to this most obvious of soil erosion activities, much still remains to be done in improving land use practice.
- About 33 million tonnes of sediment each year enters the rivers from river banks, including about 9000 tonnes of attached phosphorus—clearly identifying that continued attention to riparian area management is essential.

- Nearly 19 000 tonnes of total phosphorus and 141 000 tonnes of total nitrogen are predicted to be exported down rivers to the coast each year—demonstrating the importance of minimising soil erosion and quantifying the extent of enrichment of estuarine and coastal waters and the likelihood of long term algal blooms affecting our fisheries and recreational areas.
- 44 million hectares or 50% of Australia's agricultural soils have soil pH values below optimal levels (< 5.5) for acid sensitive agricultural production systems—foreshadowing major reductions in the productivity of our soils and underlining the need for good fertiliser management.
- Amelioration of soil acidification by the current use of lime at a regional scale is less than adequate; projections suggest that liming needs to increase significantly—possibly up to 80 times present levels of use at appropriate rates of application.

Soil and nutrient management involves recognising inherent soil properties and maximising productivity with minimal degradation. Other soil properties that need to be part of management include soil organic matter, soil biota, soil compaction and structure, contaminants, salinity, waterlogging and soil sodicity. These were not able to be addressed by *Australian Agriculture Assessment 2001* within the time frame and resources available but nonetheless are important both on- and off-farm and as part of farm management planning.

## Soil management and regional climates

Agriculture productivity and maintenance of the natural resource base needs to be managed as a 'package'—understanding cause and consequence on farm and delivering to off-farm objectives set in a catchment context. *Australian Agriculture Assessment 2001* provides useful insights into natural resource processes and the 'footprint' of agriculture. Natural resource issues coincide and interact in the landscape—regional differences need to be understood and will help set priorities and shape decision making both on and off farm

Five associations between climatic regimes and natural resource attributes were observed:

- **Organic matter levels** in surface soils (estimated by soil organic carbon) were broadly related to regional rainfall and temperature regimes (Figures 3.6, 2.4). Thus, levels were usually higher in cooler and wetter environments and in irrigation regions than in more arid, dryland agricultural regions (e.g. the arid mallee soils of Victoria and South Australia and the northern wheat belt of Western Australia had very low levels). This pattern can be associated with substantial regional differences in the quantity of plant biomass generated annually (and hence gains in photosynthetic carbon), which in turn, affects carbon inputs into soils. Regional temperature mainly exerts its effect on the rate at which organic matter is decomposed in cultivated soils—rates being higher in tropical regions and warmer inland areas. Soil organic matter plays an essential role in nutrient supply, water holding capacity and structural stability. Practices to maintain

soil organic matter are important for all agriculture and imperative in the more arid regions. Examples of key practices include maintaining adequate plant residue cover; adopting minimum/zero tillage, stubble retention systems; avoiding cultivation in high erosion risk periods; no stubble burning or over grazing.

- **Soil pH** values in some agricultural regions tended to be lower as annual rainfall increased—therefore lower near the coast than further inland (Figure 4.5). This broad observation, particularly noticeable in transects inland from the eastern and southern coastlines, may be associated with soils in higher rainfall areas being naturally more acidic or, as in most cases, associated with the rate of induced acidification being more rapid in these higher rainfall environments. An integrated approach to fertiliser management will involve assessment of nutrient requirements and soil acidity hazard. While important for all of Australian agriculture, fertiliser management (Figure 3.3) is an imperative for the higher rainfall regions—from a soil acidity perspective and also recognising leakage of nutrients to groundwater and transport of nutrients by overland flow to waterways.
- **Soil erosion** and tropical Australian grazing systems provide a particular management challenge. Losses from hillslope erosion from grazing lands might be comparatively low per hectare when compared to cropping—of the order of 1–2 t/ha/yr for grazing compared to measured figures for the cane industry of up to 200 t/ha/yr before the implementation of green cane harvesting. The total volume of sediment from the larger catchments and extensive grazing lands such as the Queensland catchments of the Fitzroy and Burdekin is very substantial with impact in-river, through estuary to near shore marine zone of the Great Barrier Reef lagoon. Much of this is a feature of the interaction of land use and climate. Many tropical environments experience an 'annual drought' with reduced grass cover before the onset of the high intensity storms and then monsoonal rains from November onwards each year. Practices to manage grazing pressure and retain pasture cover, crash graze and spell, minimise impact on river frontage country and trap sediment leaving the paddock are essential.
- **Water use efficiency**, important for all Australian agriculture from a perspective of maximising productivity, becomes doubly important in those landscapes with a propensity to dryland salinity, particularly much of temperate Australia. Trends in wheat crop and other cereals **productivity** (Figure 7.7) were variable across the southern cropping regions of Australia, being generally greater and more consistent in the more reliable rainfall areas, where more intense and higher-input farming systems are practised and are more profitable. Broadly based, higher yield performances were particularly evident in Western Australia. Areas with consistently higher wheat yield gains, regardless of variation in rainfall, demonstrate the successful application of farming systems working with climate variability, are essential for maximising productivity in Australian agriculture.

Nevertheless, the **water use efficiency index,** defined for wheat-growing shires across southern Australia between 1983 and 1997, indicates that the level of water use by dryland wheat rarely exceeded 70%, with many shires below 50%, and some below 20% (Figure 7.3). Modelled estimates of deep drainage of soil water beyond the rooting zone (Figure 2.13) generally support low water use efficiency in many southern regions. This regional information can be associated partly with forecast risks of dryland salinity (NLWRA 2001) and secondly with soil acidification, where the leaching of soil nitrate is a major contributor to acidification (see *Soil acidification* section). Major risks exist on the sandier soils of Western Australia (Anderson et al. 1998) and in parts of New South Wales and Victoria.

In some regions, more diversified and intense systems of cropping with appropriate crop management will need to be adopted to minimise future risks of deep soil drainage of water and nitrate leaching. In others, the replacement of annual pastures with perennials maybe a more viable option to address acidity, water use efficiency and salinity hazard issues (Ridley et al. 2001, Heng et al. 2001).

- **managing nutrients on farm and in landscape** has climate and soil type components that needs to be recognised in best practise. The distribution of **acidic** land ($pH_{Ca}$ 4.3 – 5.5) extending from central New South Wales through Victoria into the south-eastern region of South Australia (Figures 4.5, 4.6) closely resembles the distribution of soils with **marginal soil phosphorus status** (20 – 30 mg P/kg; Figure 3.13)—with the exception of the irrigated areas in north-central Victoria. This association suggests that soil phosphorus availability in these regions may be limited by acidic soil conditions. **Dryland salinity risks** are also predicted to increase in these regions of southern Australia (NLWRA 2001) and this may be linked to **higher deep drainage losses** of soil water and phosphorus beyond the rooting zone in these winter dominated rainfall areas (Figure 2.13).

The largely **negative nutrient balances** (signifying nutrient depletion) estimated for major regions of Queensland and the Wimmera in Victoria are associated with relatively low applications of fertiliser on soils of naturally high soil fertility status. Soil fertility decline will need to be closely monitored in these regions so that fertiliser use can be increased as soil fertility decline starts to impact on productivity.

By contrast, the **highly positive nutrient balances** recorded for higher rainfall regions where dairy and horticultural industries often co-exist relate to the regular use of fertilisers and generally higher soil fertility status (see *Nutrient management* section). Attention to nutrient balance, minimising applications of fertiliser surplus to plant needs is essential in these regions and will contribute to minimising any off farm impact from these industries.

## Soil management—essential for integrated agricultural land and landscape management

Soil management decisions must also lead to:

- **optimising agricultural productivity** by identifying and alleviating soil constraints to yield;
- **countering longer-term degradation** to soils through current soil management practices that overcome insidious soil processes, including impacts on the physical, chemical and biological properties of the soil root zone; and
- **minimising off-site impacts in** catchments and downstream.

**A systems approach.** Agricultural research has repeatedly demonstrated that changes in soil use induce a myriad of complex changes to soil processes that affect soil health in both beneficial and detrimental ways.

- A change in tillage systems to minimise soil erosion can affect availability of soil nutrients (Robson & Taylor 1987).
- Applications of lime to arrest soil acidification increases availability of some soil nutrients (e.g. phosphorus and molybdenum) by altering soil chemical reactions, and may change the risk of disease or induce imbalances in the copper status of livestock (Brennan & Bruce 1999).

These 'cause and effect' relationships need to be carefully assessed in formulating 'site-specific' management practices. For example, the strongly positive yield trends observed recently in the Western Australian wheat belt have been attributed to farmers adopting an integrated package of new crop and soil management practices, which together produced synergistic impacts to increase crop yields.

**Recognising on farm variability.** Agricultural systems place varying demands on soil resources. Conversely, soils with widely varying properties *need* to be managed differently, irrespective of the land use practised, since some are more fragile, while others are more resilient.

We need to manage agricultural landscapes according to the known distribution and characteristics of soil types. For example, in the mallee regions of southern Australia, sandy dunes are often managed differently (including not being cleared for agriculture) to the loamy flats (e.g.. cereal rye is grown on the top of dunes, barley on the sides and wheat in the flats). Experience has shown that these particular land uses, with different soil and crop husbandry practices, better match land capability within the landscape and deliver higher productivity.

**Building off-farm needs into soil management.** Many of the problems encountered in achieving or maintaining sustainability in farming systems arise because agricultural management systems are not well matched to the landscape and its needs. Excessive leakage of nutrients and water is a widespread problem associated with many of the annual crops and pastures in southern Australia. Solutions include increased adoption of perennials—located to buffer rivers and watercourses—to maximise environmental returns, while minimising economic losses (perennials are normally less profitably than annuals). Placement of crops and pastures requires a good understanding of their environmental requirements, as well as, a good knowledge of how these requirements vary across a landscape. Regional soil information and an appreciation of interactions with the local landscape are critical.

Australian agriculture is progressively adopting and developing precision agriculture and site-specific management to meet the challenge of variable soils and landscapes.

## Underpinning soil management—building better knowledge and information to support integrated resource management

*Australian Agriculture Assessment 2001* has brought together the best available data and information on the condition of Australian landscapes used for agriculture. It has relied on major data collections by public agencies and private industry and interpreted these to provide management orientated information. The development of Australian Soil Resources Information System is a good example. This initiative has delivered soil properties information from national to regional scales. It is based on a diverse range of soil mapping activities across Australia over the past 20 years—many previously inaccessible to farmers and poorly presenting management orientated information.

### Better data to reduce risks in decision making

Information needs to be closely linked and driven by the decision making process whether at a paddock, enterprise, small catchment, region or nation scale.

**Agricultural industries** need better information to:

- match land use and practice with land suitability;
- gain market advantage by demonstrating the sustainable nature of production systems; and most importantly
- maximise productivity.

**Regional communities** need better information to:

- prepare or review regional development management plans and set realistic natural resources targets;
- prioritise works and then assess the efficiency of works in meeting their regional targets; and
- improve awareness among all land users of landscape processes and priorities for management.

**Government agencies** need better information to:

- develop policy frameworks to encourage sustainable and productive use of our natural resources;
- identify priority initiatives and then assess the effectiveness of natural resource management programs;
- implement trading schemes (e.g. for salt, water or carbon) to achieve better natural resource management outcomes; and
- set baselines and to monitor trends.

**Commodity research and development groups** need better information to:

- create improved management tools such as simulation models to assess the production opportunities of farming systems; and
- develop improved understanding of soil and landscape processes.

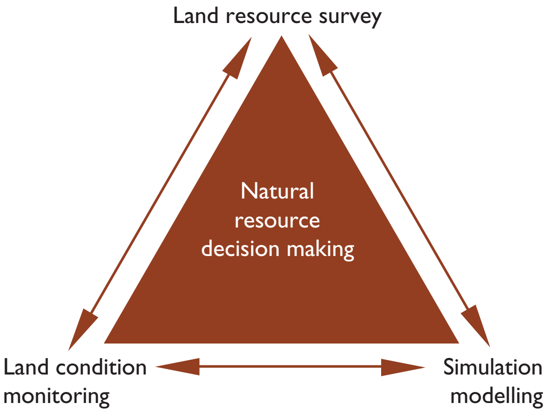
Trade-offs between the desired and practically feasible level of data and information provision are inevitable. The greater the detail, accuracy and precision, the greater the costs of gathering, interpreting and reporting.

## Information provision—mapping, monitoring and modelling: the tools

Mapping, monitoring and modelling land condition are complementary activities. In isolation, each fails to provide appropriate information for soil management and planning. Combined, they provide a powerful means for improving the quality of agricultural land management in Australia.

A major challenge facing those supporting agriculture—the public agencies, commodity research groups and industry bodies—is to achieve better integration and application of these activities.

**Figure 9.1** Mapping, monitoring and modelling are complementary activities for natural resource management.




## Land resource mapping—establishing a baseline

Land resource mapping provides a structured description of landscape attributes. Land resource mapping delineates repeating patterns of landscapes and associated soils. Key parameters of the landscape and soils that influence soil health and productivity are recorded including:

- terrain attributes of slope and relief;
- vegetation and land use descriptions of the major soil types and associated soil properties such as soil texture, structure, water-holding characteristics;
- pressure or absence of root limiting layers; and
- fundamental soil chemistry—pH interpretations are often linked to land resource mapping—suitability and versatility assessment or susceptibility to landscape issues such as waterlogging or erosion.

Land resource mapping provides a framework for extending our detailed knowledge of one location to other locations with similar characteristics. This is essential for planning and managing land at all scales. It provides the baseline for determining resource condition and input data required by models that predict likely response to changes in the landscape.

Good progress has been made over the past decade to improve the land resource information base—particularly through the National Landcare Program and Natural Heritage Trust. Australia is vast and a great deal remains to be done to meet the growing demand for high quality and resolution information. Resource constraints inevitably mean that information collected must be prioritised and targeted to areas of most significant need.

In the process of building the Audit's Australian Soil Resources Information System a number of significant deficiencies in the current land resource mapping coverage were identified:

- The coverage of land resource map in agricultural areas is incomplete and in most areas the scale is too broad to be useful for decisions at the farm level.
- Agencies have used incompatible methods for surveying land resources. This made compilation of an Australia-wide overview of land resource condition and provision of soil property information very difficult.
- Many key soil and land attributes controlling land degradation or productivity have not been measured in a rigorous manner, seriously limiting our capacity to make assessments linking land resource condition with practice.
- Lack of adequately geo-referenced, time-series data on critical soil properties.
- Soils have not been representatively sampled on the landscape nor on a statistical basis.

To support the information requirements of regional planning and evaluation—in the mid-term (10 to 15 years)—Australia should aim to have a land resource survey at nominal scales of 1:50 000 for intensive agricultural lands (irrigation, horticulture), 1:100 000 for dryland agricultural areas, both cropping and pasture, and 1:250 000 for the extensive pastoral regions.

Achieving these scale targets, even in priority areas, will require long-term investment in survey activities. The commitment requires permanent resource assessment groups in State and Territory agencies to ensure continual improvements to natural resource databases and better links with modelling and monitoring groups.

## Simulation modelling—building understanding and developing scenarios

The projects of *Australian Agriculture Assessment 2001* have demonstrated that computer simulation modelling of farming systems and landscape processes (e.g. erosion, soil acidification) can be used to improve understanding, set targets and prioritise management of Australia's land and water resources. To fully realise the potential benefit of simulation models we need to:

- ensure that survey and monitoring programs make data accessible through data libraries (e.g. Australian Natural Resources Data Library: adl.brs.gov.au) for running and validating models (with statements on accuracy and precision); and
- have an active research program to develop integrated simulation models useful for guiding land management decisions—at a range of scales, both on and off farm.

## Land condition monitoring—measuring progress

Many programs for land condition monitoring have been implemented during the last decade, generating significant benefits (e.g. community-based monitoring programs have provided basic data relating to weather and bird populations). Most programs for monitoring land condition have focused on improving land literacy rather than generating a technically sound monitoring network and accompanying database.

The focus on land literacy is most commendable, but there are few regions in Australia where comprehensive trends in land condition, and soil properties in particular, can be deduced from reliable time-series data.

Land condition monitoring programs must:

- have a **clear purpose** and be closely linked to a decision-making process at farm, catchment, State or national level. This link may be direct (e.g. a farmer monitoring nutrient levels and planning fertiliser applications accordingly) or more general (e.g. Birds Australia documenting the decline of particular bird species in agricultural areas). Such programs lead to increase community awareness, attract publicly funded programs and encourage landholder action.
- **include monitoring sites**—to establish reference point or reference condition. These sites should be located *after* land resource or ecological surveys have been undertaken so that sites represent well-defined landscape units and land use systems. Results can then be extrapolated with confidence.
- have **monitoring activities** closely aligned with modelling activities to assess whether change in land condition can be detected in a reasonable time and cost-effectively. Modelling can also be used to predict trends at locations beyond those used for direct monitoring by capitalising on the understanding gained from the field measurement program—the monitoring sites can be used to validate model predictions.
- focus monitoring in **areas where early change** in land condition is likely. This avoids wasting resources on measurement programs and ensures that it provides an early-warning system.

The proposed strategy for land condition monitoring for sustainable agriculture recognises that monitoring requires significant resources, cannot be undertaken everywhere and therefore must be clearly focused.

Land condition monitoring must provide multiple benefits by:

- assisting in site-specific decisions;
- being applicable and aggregated to regional scales; and
- providing inputs to predictive models—based on sound understanding of natural resource processes and interrelationships within the landscape and over time.

Key elements are:

- **Community programs** providing support for community land condition monitoring programs, where motivation is strong and technical capacity or support is sufficient. This should include the provision of protocols for measurement, training, database maintenance and feedback on trends and utility of the data.
- **Industry programs** providing support for soil monitoring (e.g. by fertiliser companies) by providing protocols to ensure data compatibility in sampling, site and profile characterisation, geo-referencing, laboratory measurement and database maintenance.
- **Setting a baseline** providing support for establishing a distributed set of reference sites within land resource survey programs. The properties of these sites would be thoroughly characterised to establish a baseline upon which future changes in properties can be assessed. Provisional protocols for these sites are being developed by the Audit and a scheme for soil carbon has been published (McKenzie et al. 2000).

- **Long-term sustainability issues** providing support for a number of substantial, long-term scientific studies on ecosystem and landscape processes in catchments that represent Australia's main agricultural regions. These long-term studies would measure and model water, sediment, nutrients, biological production and related processes and would be essential for developing an improved understanding of processes controlling agricultural sustainability.

Active partnerships between industry, government, research and community groups will be a key ingredient for the success of monitoring activities across Australia. It will be important to build on the achievements of, and draw support from, technical coordination activities such as the Australian Collaborative Land Evaluation Program. Participative structures that ensure the collaboration of farmers, community groups, policy makers and researchers are essential if the agricultural landscapes of Australia are to be well understood and managed in a sustainable manner.

## Conclusions

*Australian Agriculture Assessment 2001* has highlighted opportunities for continuous improvement in the information base to support Australian agriculture:

## Progress made by Australian Agriculture Assessment 2001

**Agribusiness, industry and government partnerships.** Building and improving agribusiness knowledge and information bases to support agricultural development, investment decisions and establishing environmental credentials to enhance market access. The *Sustaining Our Natural Resources—Dairying for Tomorrow* project provides an excellent example of an industry-led initiative where information was gathered to support sustainable development and to improve practice at regional and national planning scales.

**Best available information.** Information bases developed by the Audit such as the Australian Soil Resources Information System will need to be updated and information products developed, as new information and better understanding of soil processes becomes available. The full value of Australian Soil Resources Information System will only be realised if it is maintained and efforts coordinated Australia wide, probably through the Australian Collaborative Land Evaluation Program.

**Setting the context for soil management works and activities.** For the first time, Australia has a comprehensive assessment on the transport and fate of sediments and nutrients in agricultural landscapes. Sources and sinks for sediments and nutrients have been identified and the findings can be used to set priorities and to target actions.

**Defining monitoring needs.** Australia needs to establish a monitoring framework upon which progress and change in resource condition and the effectiveness of private and public investments can be assessed. Adoption of an integrated 'map–monitor–model' framework for land condition assessment will provide a basis for reporting and predicting change.

## Areas for improvement—filling the gaps

**Better links to on-ground activities.** A key input to *Australian Agriculture Assessment 2001* assessments was land use data. Improved geo-referencing of land use, productivity and practice information will provide the next upgrade path for these assessments (e.g. input of nutrients from point sources such as piggeries and feedlots were beyond the scope of this assessment because of a lack of geo-referenced data).

**Enhanced assessment.** Improved data on riparian vegetation (extent, type, condition and effectiveness in terms of buffering function) and river hydrology (degree and type of change from a reference condition) would increase accuracy of Audit assessments of sediment and nutrient transport from land to the river.

**Industry leadership in information provision.** Data and information are the currency of most organisations and industries. Structured approaches for their collection from industry sources would significantly enhance the capacity of industry and government to work in partnership towards sustainable resource and industry development. This could include improved understanding on the distribution and application of fertiliser and lime on agricultural landscapes, supported by routine soil, plant and water testing—as a budget approach to nutrient management. Partnerships between companies, industry peak bodies and government as demonstrated by the Audit nutrient management assessment through the member bodies of the Fertilizer Industry Federation of Australia are critical to achieving a coordinated approach.

The dairy industry has also clearly demonstrated (through *Sustaining Our Natural Resources—Dairying For Tomorrow*) that access to detailed regional data and information on the operational, socioeconomic and environmental activities and adoption of best management practice are fundamental to planning and implementing a sustainable future for the industry.

**Research and development.** The impact of agricultural land management and climate variations on soil and landscape processes and the inducement of changed soil properties requires continuing and accelerated research effort so that land, water and vegetation management targets can be realistically set and achieved. Off-site effects of soil acidification are at best surmised conceptually and based on anecdotal information.

## Where to from here?

Increased emphasis on integrated land management in Australia can deliver both productivity outcomes on-farm and natural resource benefits off-farm. Success of such initiatives needs:

- **leadership** in monitoring and reporting from within agricultural industries and their research and development corporations;
- **tracking progress** on the adoption of best management practices, and working to targets while continuing research, development and extension to refine management practices;
- **soil management** including soil erosion control and revegetation of riparian lands;
- **nutrient management**, increasing attention to soil fertility and nutrient balance on farm, based on a partnership with Australia's fertiliser industry, their extensive activities in soil testing, extension and farmer support;
- **green credentials**, developing consistent and Australia-wide accreditation systems, positioning Australian agriculture as the global leader in 'clean and green' commodities;

- **comparable data,** ensuring implementation of standards and protocols for the collection of land condition data and information—to support regional action planning, evaluation and monitoring activities—particularly for initiatives such as the National Action Plan on Salinity and Water Quality and Natural Heritage Trust programs; and
- **improved access** to data and information to *and from* community groups and land managers.

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# MEETING AUDIT OBJECTIVES

*Australian Agriculture Assessment 2001* reports on productivity and practice in agriculture linking landscape scale processes, biomass estimates and fluxes to regional scale soil, nutrient and water movement and resource condition. The report serves as a key input towards more productive and sustainable land and water resource use.

**Audit objective 1. Providing a clear understanding of the status of, and changes in, the nation's land, vegetation and water resources and implications for their sustainable use by:**

- assessing how and the extent to which agriculture has **changed water and nutrient balances**;
- assessing **nutrient inputs and outputs from agriculture** and implications for nutrient management on farm;
- forecasting impacts of **soil acidification** on agricultural soils and productivity;
- describing key characteristics of **Australia's soils** that influence production, key soil and landscape processes and soil condition;
- presenting the most comprehensive assessment of **water-borne soil erosion** and **sediment transport** ever undertaken for Australia's agricultural catchments and rivers, and highlighting implications on farm and for soil, river and estuary management;
- presenting **river nutrient budgets** and changes for nitrogen and phosphorus; and
- summarising continuous improvement in Australia's **agricultural practices** as commodities strive for sustainable natural resource use.

**Audit objective 2. Providing an interpretation of the costs and benefits (economic, environmental, and social) of land and water resource change and any remedial actions by:**

- providing major **biophysical data inputs** to the integrated economic assessment of benefits and costs of resource use into the future. This is key information for the Audit's companion report *Australians and Natural Resource Management*. Together, the Audit reports and Australian Natural Resource Atlas deliver essential input to regional groups as they develop, implement and evaluate regional natural resources management strategies.

**Audit objective 3. Developing a national information system of compatible and readily accessible resource data by:**

- compiling Australia-wide data on soil resources, covering **key soil properties** and integrating a large number of separately mapped data sets on soil properties from State and Territory agencies;
- collating information on **acidification, nutrient fluxes, soil erosion and sediment and nutrient transport**—information products will be made available through the Australian Natural Resources Atlas; a summary of key information is listed in Appendix 1 covering basin level carbon and primary productivity, landscape nutrients, volume and types of water borne soil erosion, and nutrient export to rivers, floodplains, reservoirs and estuaries; and
- ensuring this information and underlying **data sets are readily available** with all data compiled in standardised databases and are made accessible through the Australian Natural Resources Data Library.

**Audit objective 4. Producing national land, vegetation and water—surface and groundwater—assessments as integrated components of the Audit by:**

- preparing linked **budgets** of carbon, water and nutrients at the landscape scale;
- **defining pathways and processes** for sediments and nutrients to be transported and deposited from diffuse and point sources, through waterways, onto floodplains and reservoirs and ultimately discharged to the coast (principally estuaries); and
- **linking these assessments to agricultural practice**, to provide an insight into priority management activities for Australia's agricultural industries.

**Audit objective 5. Ensuring integration with, and collaboration between, other relevant initiatives by:**

- working in **partnership** with Australia's leading research, industry and resource management agencies to deliver value-added outputs from the Audit's work plan; Audit outputs have exceeded expectations in terms of scope and quality and include innovative and risk-taking partnerships (notably with CSIRO Land & Water and the Australian fertiliser industry);
- providing an assessment of sediment and nutrient transport for Australia's river basins that contain intensive agriculture to serve as a key input to priority setting as part of the **National Action Plan on Salinity and Water Quality and the Natural Heritage Trust**;
- highlighting the **progress of all key agricultural industries** in meeting the natural resource challenges;
- working with the **Australian horticultural industry** to gain a better appreciation of natural resource issues for this industry; and
- piloting, with the **Australian Dairy Farmers Federation**, the development of industry-specific Natural Resource Management Strategies that build on continuous improvement in practice to meet priority issues.

**Audit objective 6. Providing a framework for monitoring Australia's land and water resources in an ongoing and structured way by:**

- providing a framework and direction for monitoring, assessment and reporting on Australia's soil resources—this calls for continued development and updating of the **Australian Soil Resources Information System**;
- demonstrating roles of agribusiness in information collation and assessment—especially **soil condition and trends in soil properties**; and
- building monitoring systems and techniques that commodity groups and research and development corporations can apply to measure improvement in industry practice.

*Australian Agriculture Assessment 2001* has highlighted major areas for investment as essential activities to improve the management of Australia's natural resources.

## APPENDIX 2. AUSTRALIAN SOIL RESOURCES INFORMATION SYSTEM

Australian Soil Resources Information System contains:

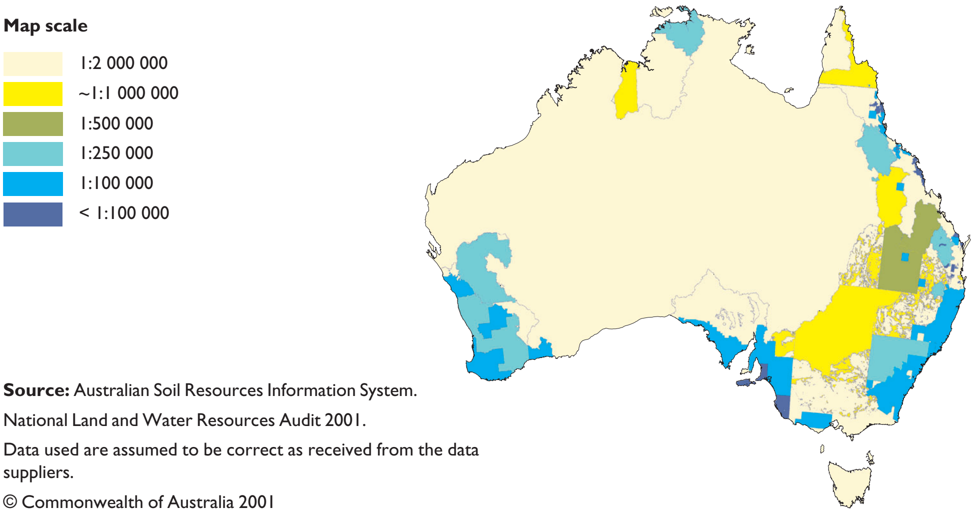
- A compilation (from data held by Commonwealth, State and Territory agencies) of soil profile data into a single database containing over 160 000 profiles in a standard format (SITES). These data are available from the Audit Data Library, subject to some licence conditions.
- A compilation (from data held by Commonwealth, State and Territory agencies) of soil and land resources maps at varying scales. These data were used in modelling, and descriptions of the data are available from the Audit Atlas and Data Library. The data can be obtained only from the original custodians.
- various ancillary data sets relevant to soils and used in modelling soil properties, including: 9 second DEM and derived terrain attributes, lithology (derived from geological mapping), climate surfaces, and Landsat MSS.
- a set of spatially distributed estimates of soil attributes and their data quality, in the form of gridded (raster) maps of soil properties for topsoil and subsoil. These maps were produced from collated data sets using several different modelling methods (below).

Soil attributes estimated are those most commonly required to characterise, model or predict land resource processes that drive plant productivity, measure resource sustainability or control rate of resource degradation.

The Australian Soil Resources Information System contains 27 soil attributes (see table below) for topsoil and (in some cases) the first subsoil layer. A full description of the methods and uncertainties involved (including distribution of points for modelling) is contained in the Australian Natural Resources Atlas.

The scale of the various soil maps used in deriving this map is shown in Figure A2. The distribution of point data used to construct point model maps used is shown in Figure A3.

**Figure A2** Mapping scale of land resource survey coverage in Australia.




**Source:** Australian Soil Resources Information System.

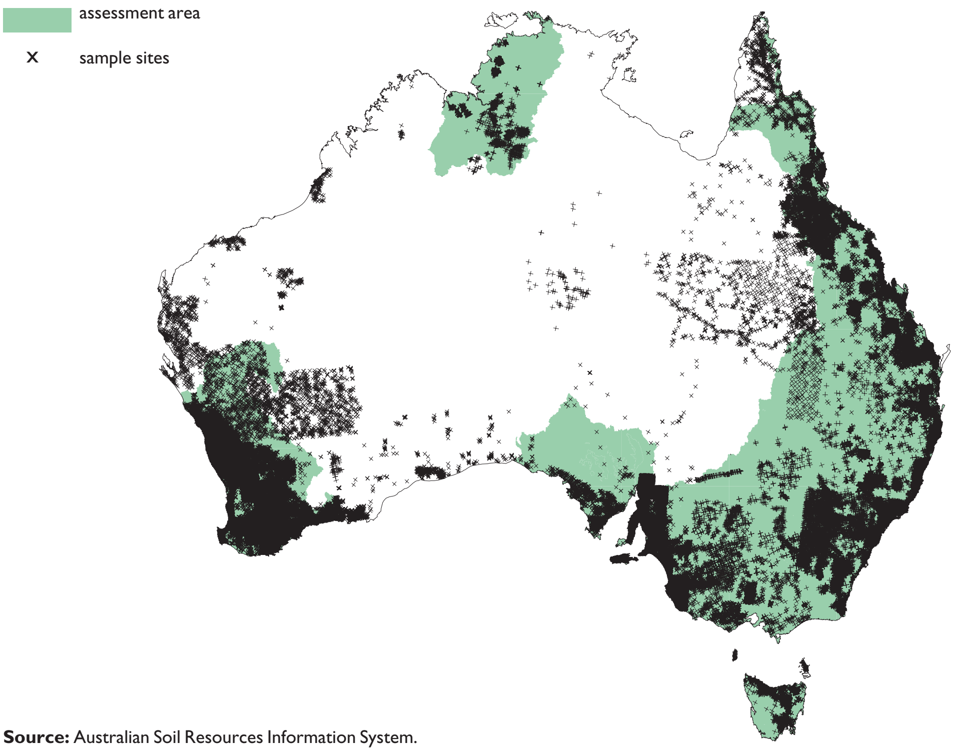
National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.

**Table A1** Australian Soil Resources Information System soil property data layers

| | | Map availability | |
|---|---|---|---|
| | Units | Topsoil (layer 1) | First Subsoil (layer 2) |
| **River basins containing intensive agriculture** | | | |
| **Point models** | | | |
| pH | pH scale 1 to 14 | ✓ | ✓ |
| Organic carbon | % | ✓ | ✓ |
| Total phosphorus | % | ✓ | |
| Extractable phosphorus (New South Wales and Victoria) | % | ✓ | |
| Total nitrogen (derived from carbon – nitrogen relationship) | % | ✓ | |
| Texture | texture class | ✓ | ✓ |
| Clay % (includes polygon model surface) | % fine earth fraction | ✓ | ✓ |
| **Australia-wide** | | | |
| **Polygon models** | | | |
| Clay % | % fine earth fraction | ✓ | ✓ |
| Silt % | % fine earth fraction | ✓ | ✓ |
| Sand % | % fine earth fraction | ✓ | ✓ |
| Thickness | metre | ✓ | ✓ |
| Solum depth | metre | ✓ | |
| Bulk density | $g/cm^3$ | ✓ | ✓ |
| Available water | mm | ✓ | ✓ |
| Saturated hydraulic conductivity | mm/hr | ✓ | ✓ |
| **Point-polygon models** | | | |
| Erodibility– pedotransfer, point & polygon model | t ha h / ha MJ mm | ✓ | |

**Figure A3** Distribution of all points used for soil attribute modelling.




**Source:** Australian Soil Resources Information System.

National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.

## Soil depth (topsoil, subsoil, total solum  thickness)

### What is it?

Solum depth refers to total depth of soil (A and B horizons). It does not include the unconsolidated or partially weathered material which underlie the soil, where soil forming processes are not obvious (carbon horizons). It is often difficult to determine the lower limit of soil, and for many purposes depth of soil is considered to be the rooting depth of plants.

**Topsoils (A horizons)** are defined as the surface soil layers in which organic matter accumulates, and may include dominantly organic surface layers (O and P horizons).

A horizons are usually darker than underlying layers but they may also be horizons that are lighter coloured or have a lower content of clay when compared to underlying horizons.

**Subsoils (B Horizons)** contain less organic matter than topsoils, and may often have a zone of accumulation of clays, carbonates or iron and aluminium oxides. The structure, colour or composition is significantly different to the overlying layer.

Some soils do not have a B horizon (e.g. young soils developing on alluvium). In this case, solum depth is the depth of the A horizon.

The depth of soil horizons is measured in metres.

### Why is it important?

Soil depth defines the zone available for growth of plant roots and determines the size of the soil water store. Available water capacity is a function of the depth of soil.

The depth of soil required varies for different crops, but in general shallow soils are less suitable for agriculture. Deep soils provide a much larger store of water.

The depth of topsoil is important because, with their higher organic matter content, topsoils generally have more suitable properties for agriculture, including higher permeability and higher levels of soil nutrients.

### How does it vary and what is it related to?

Soil depth depends on:

- type of parent material;
- rate of weathering (related to climate); and
- whether weathered material is being transport either into or out of the area.

In wet, humid areas, weathering of rocks to form soils is rapid, and soils tend to be deep. In arid zones, weathering proceeds very slowly, and soils are usually shallow.

Soil depth is usually strongly related to topography—soils on hillslopes (zones of erosion) tend to be shallow, those in valleys or depressions are deeper (zones of deposition). Wind, hillslope, gully and streambank erosion provide the source of sediments to these alluvial valleys. Deep soils are also associated with the volcanic landscapes, for example, the Ferrosols of the dairying region of the Atherton Tablelands and potato growing areas of northern Tasmania—these areas are well known for their deep red soils.

Soil depth classes used in the *Australian Soil Classification* are:

| Class | Soil depth (m) |
|---|---|
| Very shallow | < 0.25 |
| Shallow | 0.25 – < 0.5 |
| Moderate | 0.5 – < 1.0 |
| Deep | 1.0 – < 1.5 |
| Very deep | 1.5 – 5 |
| Giant | > 5 |

Depth of the topsoil (A horizon) is determined by the relative rates of accumulation and decomposition of organic matter. It is also related to the activity of soil fauna—earthworm and termite activity results in mixing of organic material to greater depths.

Topsoil ('A horizon') depth classes used in the Australian Soil Classification are:

| Class | Soil depth (m) |
|---|---|
| Thin | < 0.1 |
| Medium | 0.1 – < 0.3 |
| Thick | 0.3 – < 0.6 |
| Very thick | > 0.6 |

Subsoil depth is related to permeability, since this determine how easily water can penetrate and hence the depth of weathering and deposition.

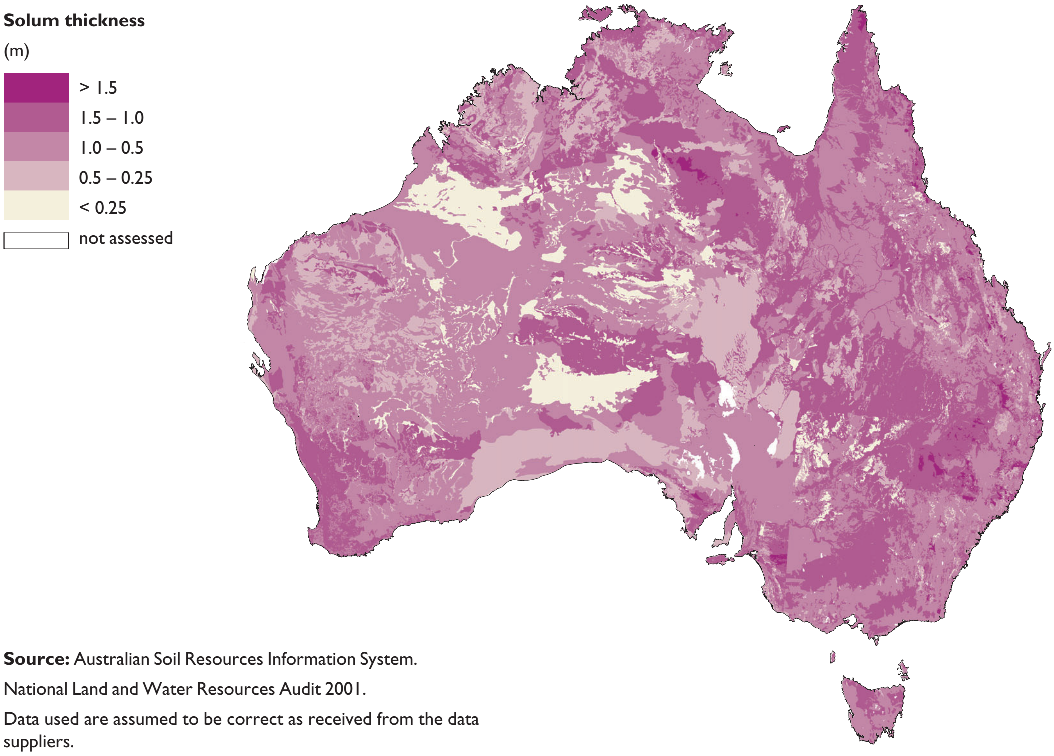
**Table A2** Percentage of land use categories at specified solum depths (m) across Australia.

| | Very shallow | Shallow | Moderate | Deep | Very deep | Total land use class area |
|---|---|---|---|---|---|---|
| | < 0.25 | 0.25 – < 0.5 | 0.5 – < 1.0 | 1.0 – < 1.5 | 1.5 – 5 | (ha) |
| Conservation and natural environments | 12 | 18 | 51 | 18 | 0 | 263 894 700 |
| Production from native environments | 3 | 14 | 47 | 35 | 1 | 443 032 600 |
| Cropping | 0 | 3 | 37 | 58 | 2 | 22 519 100 |
| Grazing modified pasture | 0 | 3 | 55 | 40 | 1 | 19 237 900 |
| Horticulture | 1 | 3 | 42 | 53 | 2 | 350 900 |
| Irrigated cropping | 0 | 1 | 24 | 70 | 5 | 949 000 |
| Irrigated modified pasture | 0 | 2 | 22 | 76 | 1 | 1 079 100 |
| **Total area** | | | | | | **751 063 300** |

**Table A3** Percentage of land use categories at specified topsoil thicknesses (m) across Australia.

| | Thin | Medium | Thick | Very thick | Total land use class area |
|---|---|---|---|---|---|
| | < 0.1 m | 0.1 – < 0.3 m | 0.3 – < 0.6 m | > 0.6 m | (ha) |
| Conservation and natural environments | 4 | 76 | 19 | 0 | 263 894 700 |
| Production from native environments | 9 | 75 | 15 | 0 | 443 031 100 |
| Cropping | 2 | 70 | 26 | 2 | 22 519 000 |
| Grazing modified pasture | 1 | 65 | 33 | 2 | 19 237 900 |
| Horticulture | 1 | 68 | 29 | 2 | 351 000 |
| Irrigated cropping | 4 | 89 | 7 | 0 | 949 000 |
| Irrigated modified pasture | 0 | 90 | 9 | 1 | 1 079 100 |
| **Total area** | | | | | **751 061 800** |

**Figure A4** Distribution of solum depth (m) across Australia.



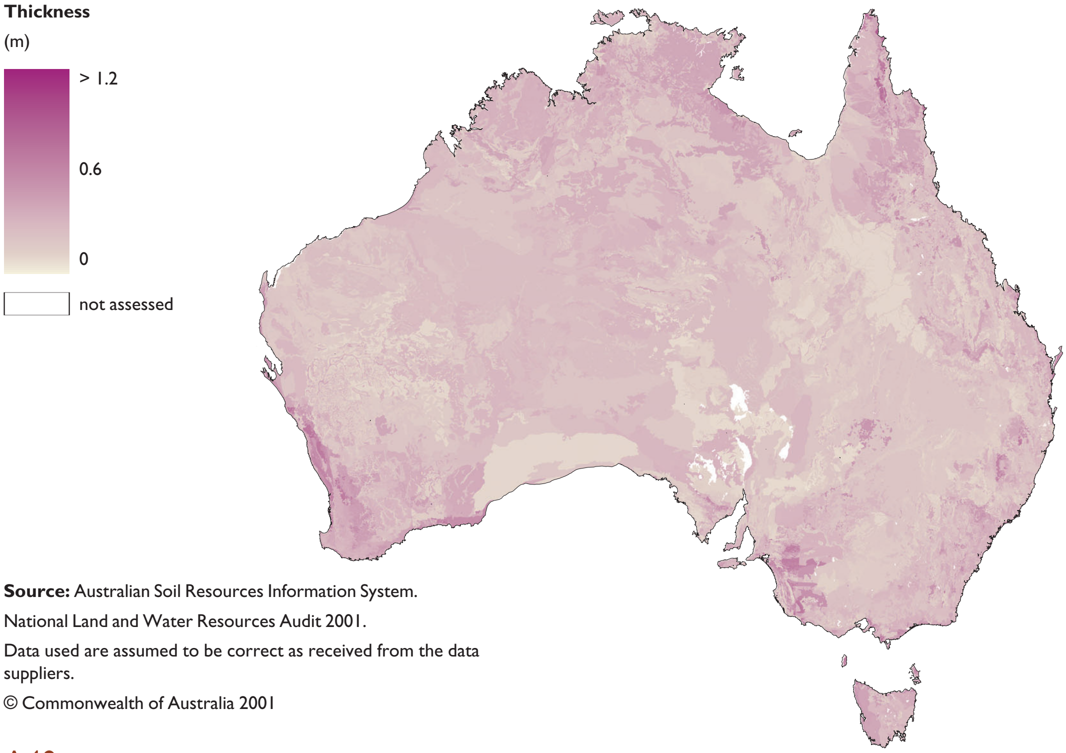

**Source:** Australian Soil Resources Information System.

National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.



**Figure A5** Distribution of depth of topsoils (m) across Australia.

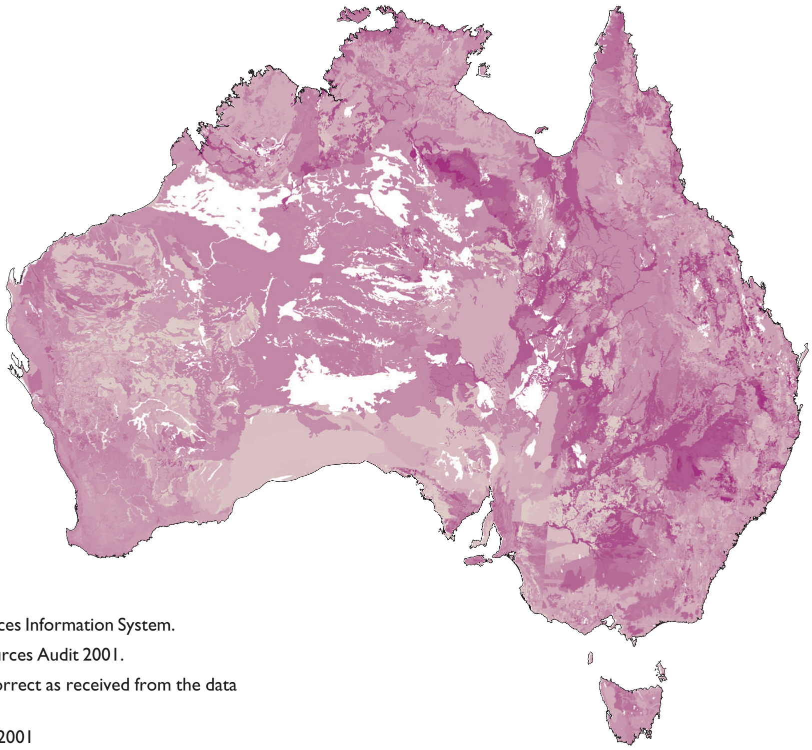



**Source:** Australian Soil Resources Information System.

National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.

**Figure A6** Distribution of depth of first subsoil (m) across Australia.




**Source:** Australian Soil Resources Information System.

National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.



## How can these maps be applied?

Estimates of soil thickness (Figure A4) are required to make calculations of soil volumes, for example, to assess total stores of soil carbon for greenhouse inventory or to assess total stores of nutrients.

Estimates of soil depths (figures A5, A6) are needed to calculate the amount of any soil constituent in either volume or mass terms (bulk density is also needed) (e.g. the volume of water stored in the rooting zone potentially available for plant use).

## What is the level of uncertainty?

The scale of the various soil maps used in deriving this map is shown in Figure A2.

Several sources of error are possible when estimating soil depth and thickness of horizons for the lookup tables:

- Because thickness is used sparingly in the Factual Key, estimations of thickness in the lookup tables were made using empirical correlations for particular soil types.
- The quality of data on soil depth in existing soil profile data sets is questionable—in many cases, the reported depth of the solum is limited by the method of observation (e.g. auger) or by the survey purpose.
- Thickness of soil horizons varies locally with topography, so values for map units are general averages.
- The definition of the depth of soil or regolith is imprecise and it can be difficult to determine the lower limit of soil.

**Percent clay, percent silt, percent sand, texture class (topsoil and subsoil)**

This description is relevant to three different sets of modelled surfaces:

- percent clay, percent silt, percent sand from polygon models;
- percent clay from point model; and
- texture class from point model.

### What is it?

Soil texture refers to the size distribution of soil particles or the relative proportions of mineral particles of various sizes (i.e. percent clay, percent silt and percent sand). Only particles of diameter < 2 mm are considered 'soil'.

- The sand fraction is made up of those particles that have a diameter between 2 and 0.02 mm.
- Silt-sized particles are those with diameters between 0.02 and 0.002 mm.
- Clay-sized particles are those with diameters < 0.002 mm.

Particle size distribution can be estimated from field texturing (see box), but reliable determination of the particle size distribution requires laboratory analysis. Descriptive names (e.g. loam, sandy clay) are assigned according to the percentages of sand, silt and clay using the Australian texture triangle (see below).

### Why is it important?

Soil texture is strongly related to many other soil physical (soil structure, bulk density, porosity, permeability) and chemical properties (cation exchange capacity). It is often used to estimate other soil properties (particularly soil water properties) if no direct measurements are available.

#### Field texture

Field texture is a measure of the behaviour of a small handful of soil when moistened, kneaded into a ball (the bolus) and then pressed out between the thumb and forefinger. It is mainly determined by proportions of sand, silt and clay. Clays cause the bolus to be more cohesive, sticky and plastic. Silts confer a silky smoothness. Organic matter can make the bolus more cohesive or greasy to feel, and the types of soil minerals present and cation composition also affect field texture.

Although field texture is closely related to the particle size distribution measured in the laboratory, texture classes assigned from field texture and particle size analysis are not always equivalent (e.g. soils with high levels of exchangeable sodium have a heavier field texture than suggested by the particle size analysis).

### How does it vary and what is it related to?

Particle size distribution is determined by the soil's parent rock, the rate at which rock breaks down into soil and whether this material is transported and sorted by size along the way. The rate at which rock breaks down into soil is a function of rainfall and temperature. Transport of soil material is affected by topography, rainfall, wind and vegetation cover.

### How and why does it vary across Australia?

Particle or soil texture varies in response to a range of factors:

- parent material – mineral composition, type (rock or sediment) and susceptibility to chemical and physical weathering (weathering status) (e.g. granite weathers to coarse sands).
- position in landscape and the method of soil formation or placement (e.g. alluvial soils have varying texture distributions depending on river – levee – floodplain position). Alluvial soils in the backplain position are often dominated by clay. Coast soils are often sandy.

## Comparing different models for %clay

Maps of percent clay in topsoil and subsoil were produced using respectively:

- polygon models, and
- combined point- and polygon-based models.

Spatial analysis of the maps compared the polygon model (in classes) against the combined point-polygon model (in classes) showing a 42% agreement between the two data layers. Some 82% of the estimations are covered within ±1 class or in value terms ±10% clay. Part of this discrepancy is due to differences between field texture (used in deriving the polygon models) and laboratory determinations of percent clay (used in the point-polygon model).

The map derived from the combined model is considered to be more accurate, and is the preferred choice for applications that require an estimate only of percent clay. Where clay, sand and silt are all required, the polygon-based maps should be used.

## How can these maps be applied?

Soil texture can be used, in conjunction with other information, to infer soil susceptibility to erosion (see soil erodibility attribute). It is also used to estimate soil permeability when no measurements of hydraulic conductivity are available. As a rule of thumb, sandy soils are highly permeable while clay soils are very slowly permeable.

**Table A4** Summary statistics—percent clay in topsoil by percent of land use type across Australia.

| | ≤10% | 10–20% | 20–30% | 30–40% | 40–50% | >50% | Total land use class area (ha) |
|---|---|---|---|---|---|---|---|
| Conservation and natural environments | 51 | 24 | 19 | 4 | 1 | 2 | 263 903 800 |
| Production from native environments | 16 | 25 | 30 | 9 | 4 | 15 | 443 051 500 |
| Cropping | 14 | 35 | 20 | 9 | 6 | 15 | 22 519 800 |
| Grazing modified pasture | 16 | 45 | 21 | 9 | 4 | 5 | 19 239 600 |
| Horticulture | 8 | 38 | 21 | 21 | 5 | 7 | 351 000 |
| Irrigated cropping | 2 | 11 | 18 | 24 | 9 | 36 | 949 100 |
| Irrigated modified pasture | 3 | 14 | 12 | 45 | 5 | 21 | 1 079 300 |
| **Total area** | | | | | | | **751 094 100** |

**Table A5** Summary statistics – percent clay in topsoil (from combined point – polygon model) by percent of land use type for river basins containing intensive agriculture*.

| | ≤10% | 10–20% | 20–30% | 30–40% | 40–50% | >50% | Total land use class area (ha) |
|---|---|---|---|---|---|---|---|
| Conservation and natural environments | 30 | 53 | 10 | 5 | 2 | 1 | 54 814 200 |
| Production from native environments | 16 | 48 | 18 | 10 | 4 | 3 | 184 376 300 |
| Cropping | 30 | 39 | 11 | 10 | 7 | 3 | 22 241 100 |
| Grazing modified pasture | 35 | 43 | 14 | 6 | 2 | 0 | 18 482 500 |
| Horticulture | 19 | 47 | 18 | 11 | 5 | 0 | 351 500 |
| Irrigated cropping | 3 | 26 | 20 | 25 | 17 | 9 | 948 800 |
| Irrigated modified pasture | 7 | 22 | 34 | 33 | 4 | 0 | 1 080 000 |
| **Total area*** | | | | | | | **282 293 800** |

**Table A6** Class difference between polygon and point models for topsoil clay classes.

| Class difference between polygon and point model | | Percentage of area* (%) |
|---|---|---|
| -5 | **Point model 'underestimating'** | 0 |
| -4 | | 0.1 |
| -3 | | 0.2 |
| -2 | | 0.8 |
| -1 | | 9.3 |
| 0 | **No difference** | 42.4 |
| 1 | | 34.0 |
| 2 | | 10.9 |
| 3 | | 2.0 |
| 4 | | 0.3 |
| 5 | **Point model 'overestimating'** | 0 |

* Only for overlap

**Figure A7** Distribution of percentage clay in the topsoil (polygon model).

**Percent clay in soil**

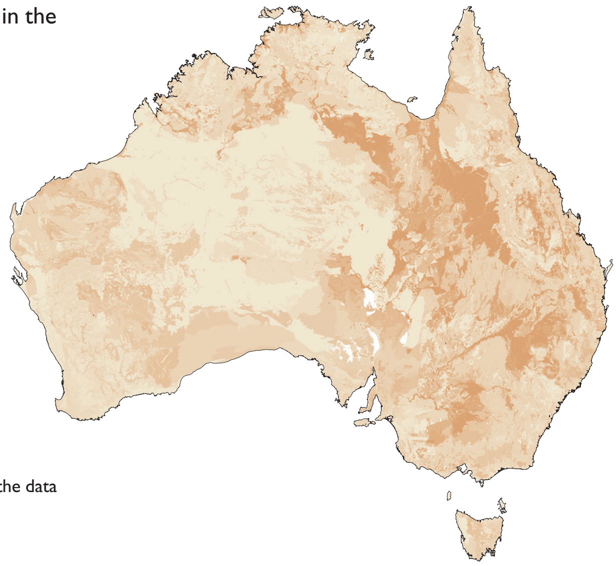
(% clay)

100

50

0

not assessed



**Source:** Australian Soil Resources Information System.

National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.



**Figure A8** Distribution of percentage clay in the topsoil within the river basins containing intensive agriculture (point model).

**Percent clay in soil**

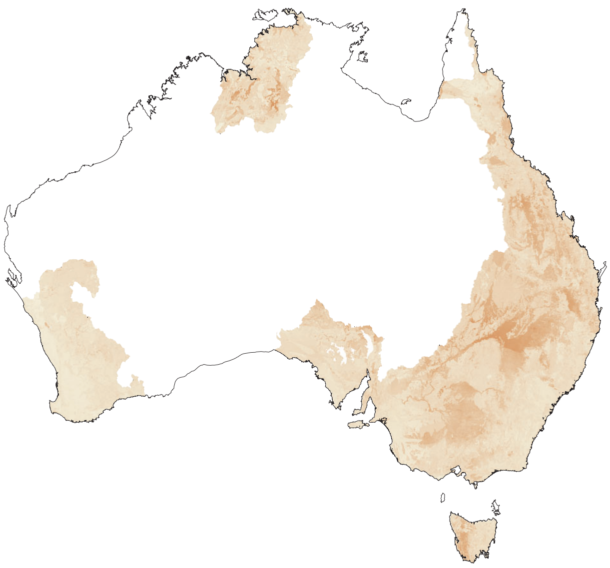
(% clay)

100

50

0

not assessed

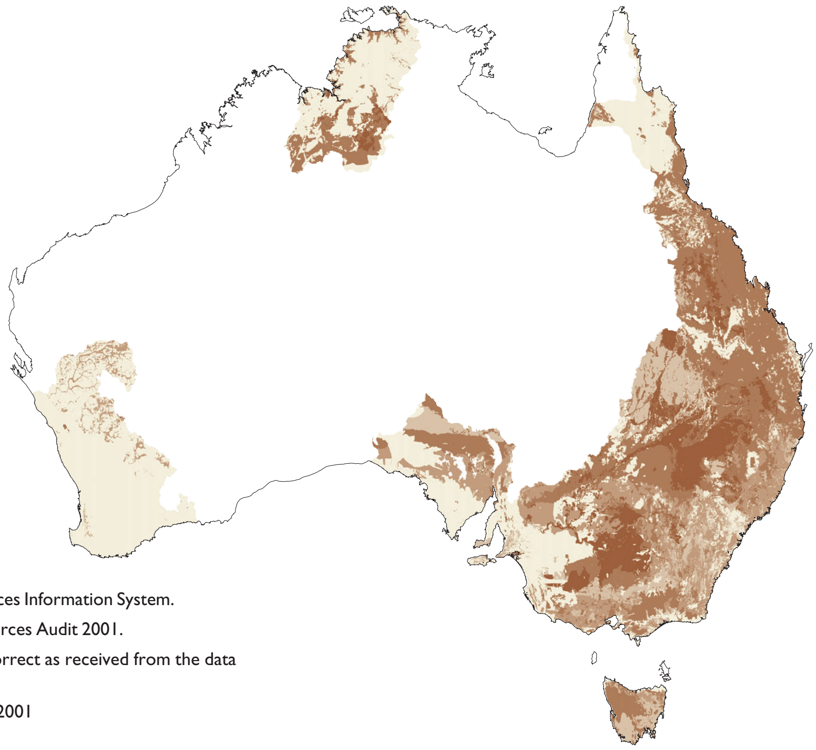


**Source:** Australian Soil Resources Information System.

National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.

**Figure A9** Distribution of soil texture of the topsoil within the river basins containing intensive agriculture.



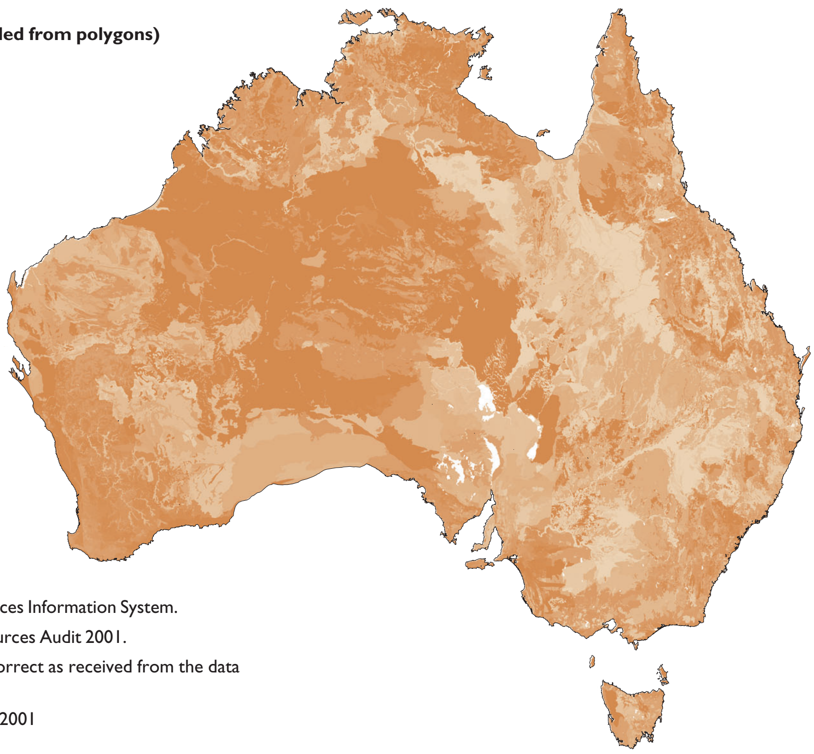

**Source:** Australian Soil Resources Information System.

National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.



**Figure A10** Distribution of percentage of sand in topsoil (m) across Australia.




**Source:** Australian Soil Resources Information System.

National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.

### What is the level of uncertainty: percent clay, point model (topsoil and subsoil)?

The model for percent clay in topsoil is generally good, although it is strongest in Queensland, Victoria and Tasmania and less reliable in southern New South Wales, Northern Territory and Western Australia. This is considered to be a more reliable estimate of percent clay than that produced by the polygon-based model.

The subsoil model is much less reliable, as indicated by the error diagnostics. It is weakest in New South Wales, Western Australia, South Australia and Northern Territory.

Error diagnostics

| Error diagnostic | Topsoil | Subsoil |
|---|---|---|
| Number of points used | 9750 | 7050 |
| $R^2$ | 0.538 | 0.319 |
| Relative error | 0.64 | 0.79 |

### What is the level of uncertainty: texture class, point model (topsoil and subsoil)

Despite the large number of available data points, models for texture class were not reliable. The topsoil model predicts classes A and D well, but has difficulty in distinguishing sandy loams and loams.

The subsoil model failed to distinguish the sand classes, and a three-class model was used. This model was more successful in distinguishing clays than other classes.

Error diagnostics

| Error diagnostic | Topsoil | Subsoil |
|---|---|---|
| Number of points used | 99316 | 73163 |
| Error (%) | 45.9 | 32.3 |

Topsoil model class-specific error rates:

| | | |
|---|---|---|
| A | sands | 0.15 |
| B | sandy loams | 0.83 |
| C | loams | 0.75 |
| D | clay loams/light clays | 0.28 |
| E | clays | 0.57 |

Subsoil model class-specific error rates:

| | | |
|---|---|---|
| K | sands/sandy loams/loams | 0.48 |
| M | clay loams/light clays | 0.51 |
| N | clay | 0.17 |

### What is the level of uncertainty: percent clay, percent silt, percent sand, polygon model (topsoil and subsoil)?

The scale of the various soil maps used in deriving this map is shown in Figures A2 and A3.

The Northcote Factual Key (a soil classification - Northcote 1979) uses soil texture as a differentiating characteristic. Estimation of texture for soils with a uniform primary profile form is straightforward, but it is more difficult to be definite about other soil types (e.g. duplex soils can have a range of surface textures).

The reliability of estimates of texture for Principal Profile Forms that do not have texture as a diagnostic varies. The main sources of uncertainty in deriving particle size distributions from texture are:

- is in the choice of representative values of percent clay, percent silt and percent sand for each texture class—use of Budiman's methods has improved these estimates significantly; and
- because field texture classes and particle size distribution are not completely equivalent (see McKenzie et al. [2000] for a discussion of the ways in which field texture may differ from particle size distribution, particularly for soils with high clay contents).

## Total phosphorus (topsoil)

Phosphorus is an element that is present in small amounts in some rocks (average total phosphorus content of rocks is 1.2%). As these rocks break down the phosphorus is released and becomes available for plants to take up and incorporate it into organic compounds. *Total phosphorus* measures the amount of phosphorus tied up in soil mineral particles (which come from the break down of rocks) and in organic matter. Total phosphorus is generally much higher than the amount of phosphorus actually available for plant uptake (see also Figure A12).

### Why is it important?

Phosphorus is essential for plant growth. The total phosphorus content of most Australian soils is low by world standards and many soils require phosphate fertilisers to maximise production.

Phosphorus can occur in many kinds of compounds in the soil—both organic and inorganic—and these are very sensitive to pH. If the pH is too low or too high, phosphorus is not available for plant uptake. Phosphorus is most available for plant uptake at pH ranging from 6 to 7.

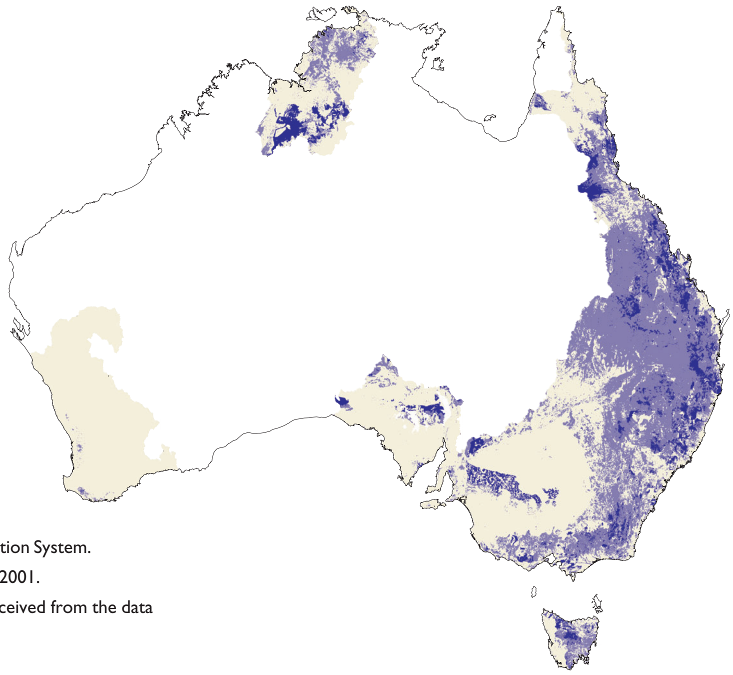
### How does phosphorus vary and what is it related to?

Most Australian soils contain less than 0.02% phosphorus (percent by weight or grams of phosphorus in 100 g of soil). Variations in total phosphorus are mainly due to different rock types. Soils with higher phosphorus levels are derived from basaltic rocks because these rocks are higher than average in phosphorus; phosphorus generally appears to be very low in areas where Calcarosols occur. Phosphorus content should also co-vary with organic carbon and nitrogen due to the phosphorus that is bound up in organic compounds.

**Figure A11** Distribution of total phosphorus (%) in the topsoil within the river basins containing intensive agriculture*.

**Total phosphorus (%)**

- > 0.05
- 0.02 – 0.05
- < 0.02
- not assessed



**Source:** Australian Soil Resources Information System.

National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.



* Australian Soil Resources Information System map estimates for total phosphorus appear anomalously high in portions of the Northern Territory.

### How and why does it vary across Australia?

Mapping of total phosphorus in topsoil can be used to identify areas where natural soil fertility is low and fertiliser inputs would be required for crop production. It can be combined with pH maps to:

- predict where and how much phosphorus is likely to be available to plants under natural conditions;
- identify the areas where fertiliser needs to be added; and
- estimate the amount of lime required to bring the pH to a level where the phosphorus will be available for plant uptake.

### Level of uncertainty

Very few measurements of total phosphorus were available for soils in New South Wales and Victoria with most measurements coming from Queensland and Western Australia. Modelled estimates are most reliable for Queensland and the Murray–Darling Basin, and least reliable for New South Wales, eastern Victoria, South Australia and Northern Territory.

Error diagnostics

| Error diagnostic | Topsoil |
|---|---|
| Number of points used | 7327 |
| $R^2$ | 0.684 |
| Relative error | 0.49 |

**Table A7** Total phosphorus (%).

| | < 0.02 % | 0.02 – 0.05% | > 0.05 % | Total land use class area (ha) |
|---|---|---|---|---|
| Conservation and natural environments | 63 | 28 | 10 | 54 814 200 |
| Production from native environments | 60 | 33 | 7 | 184 376 300 |
| Cropping | 71 | 24 | 5 | 22 240 900 |
| Grazing modified pasture | 65 | 28 | 7 | 18 482 500 |
| Horticulture | 60 | 24 | 16 | 351 500 |
| Irrigated cropping | 46 | 47 | 7 | 948 900 |
| Irrigated modified pasture | 84 | 12 | 4 | 1 079 900 |
| **Total area*** | | | | **282 294 200** |

* Area of river basins containing intensive agriculture

## Extractable phosphorus (topsoil – New South Wales and Victoria)

Total phosphorus measures the amount of phosphorus tied up in soil mineral particles and organic matter. Extractable phosphorus attempts to measure the amount of phosphorus that will be available for plants to use. Since phosphorus is essential for plant growth and most plants need more than 0.002% (the average natural level in Australian soils), addition of phosphate fertilisers is required to maximise production.

Many different methods have been used to extract phosphorus and they may give different estimates.

### How does it vary and what is it related to?

Most Australian soils contain < 0.002% extractable phosphorus (% by weight or g phosphorus per 100 g of soil). Extractable phosphorus is a function of complex interrelations between pH, soil minerals, organic matter and soil microbes.

Extractable phosphorus is highest in north-western New South Wales, in the Liverpool Plains, and in the Australian Alps across New South Wales and Victoria. It is almost non-existent in coastal New South Wales and in the Victorian mallee region. It is average for Australian soils over most of the remaining area.

Mapping of extractable phosphorus in topsoil can be used to identify areas where the natural fertility of soils is low, and how much fertiliser would be required for crop production.

**Table A8** Extractable phosphorus (%) – New South Wales and Victoria* by percent of land use type.

| | 0 – 0.002% | 0.003 – 0.005% | > 0.005% | Total land use class area (ha) |
|---|---|---|---|---|
| Conservation and natural environments | 92 | 7 | 1 | 14 300 700 |
| Production from native environments | 70 | 24 | 6 | 61 472 700 |
| Cropping | 91 | 8 | 0 | 8 812 300 |
| Grazing modified pasture | 97 | 3 | 1 | 7 836 500 |
| Horticulture | 97 | 2 | 0 | 151 100 |
| Irrigated cropping | 82 | 16 | 2 | 621 900 |
| Irrigated modified pasture | 99 | 1 | 0 | 931 100 |
| **Total area*** | | | | **94 126 300** |

* Area of river basins containing intensive agriculture within Victoria and New South Wales

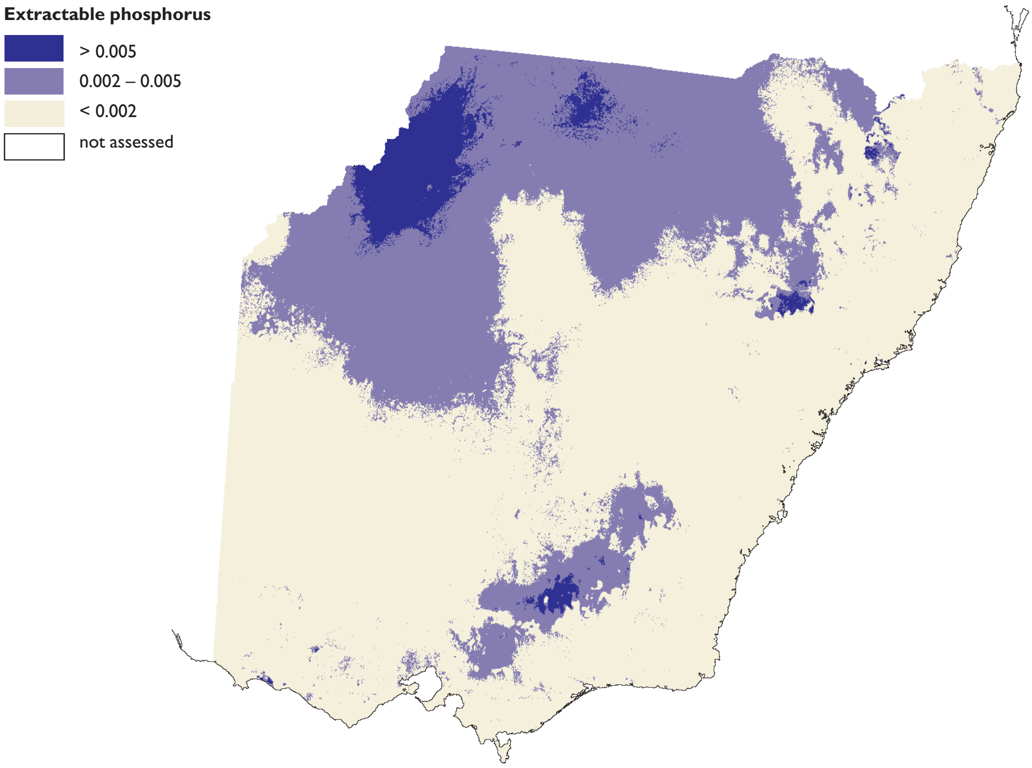
### Level of uncertainty

The model was derived only for Victoria and New South Wales. Estimates of extractable phosphorus are generally more reliable for Murray–Darling Basin and eastern Victoria than coastal New South Wales.

Error diagnostics

| Error diagnostic | Topsoil |
|---|---|
| Number of points used | 2124 |
| $R^2$ | 0.41 |
| Relative error | 0.73 |

**Figure A12** Distribution of extractable phosphorus in the topsoil within the river basins containing intensive agriculture of New South Wales and Victoria.




**Source:** Australian Soil Resources Information System.

National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.

## Total nitrogen

Nitrogen is a part of all living matter and is essential for plant growth. Nitrogen stimulates above-ground plant growth and is required to maintain high yields.

Most soil nitrogen is associated with organic compounds such as proteins or fertiliser inputs.

Soil nitrogen is presented here as weight percent.

### How does nitrogen vary and what is it related to?

Soil nitrogen varies with depth. Levels are highest in the topsoil and generally decrease exponentially with depth. Organic nitrogen commonly ranges between 0.2% and 0.5% (percent by weight or grams of nitrogen per 100 g of soil) in cultivated topsoils. It can reach > 2.5% in peats.

### How and why does nitrogen vary across Australia?

Total nitrogen varies mainly as a function of climate and land use. Highest levels (> 0.2%) are found on forest and cultivated soils; lowest levels (< 0.1 %) are found in rangelands.

Mapping of nitrogen can be used to identify areas where natural fertility of soils is low and fertiliser inputs would be required for crop production. Nitrogen measurements are difficult to interpret, without information on the types of nitrogen present and their relevance to crop nutrition.

### Level of uncertainty

The certainty in the nitrogen model depends on the strength of the organic carbon model (for topsoil) and the relationship between nitrogen and organic carbon. The uncertainty surface for nitrogen is calculated from that for organic carbon, downgraded to reflect the fact that nitrogen is not estimated directly but rather through this relationship. There is some suggestion that this carbon–nitrogen relationship may over-predict nitrogen at the low end.

Very few measurements of total nitrogen were available for soils in New South Wales and South Australia; most measurements were from Queensland and Western Australia. The modelled estimates are thus best for Queensland, Western Australia and Tasmania, and poorest for New South Wales, eastern Victoria and the Northern Territory.

Error diagnostics

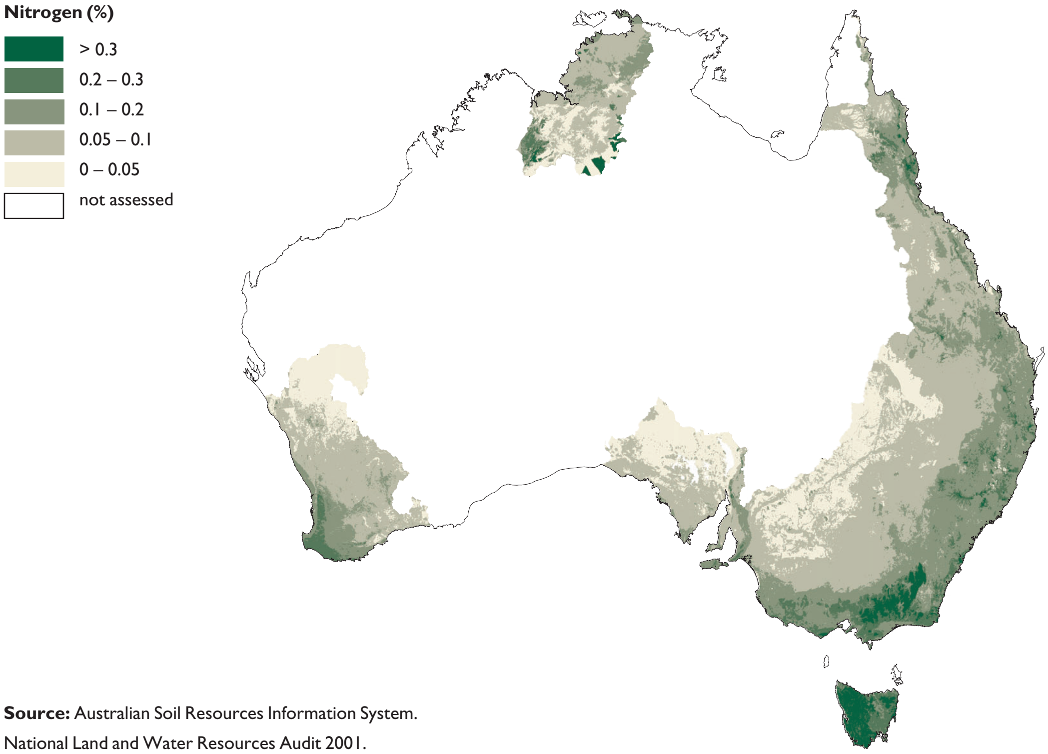
| Error diagnostic | Topsoil |
|---|---|
| Number of points used | 4746 |
| $R^2$ | 0.75 |

**Table A9** Nitrogen (%) in topsoil (derived from carbon–nitrogen relationship) by percent of land use type.

| | **Extremely low** 0 – .05 | **Very low** 0.05 – 0.1 | **Low** 0.1 – 0.2 | **Moderate** 0.2 – 0.3 | **Moderately high to high** > 0.3 | |
|---|---|---|---|---|---|---|
| Conservation and natural environments | 13 | 41 | 29 | 10 | 8 | 54 814 100 |
| Production from native environments | 26 | 47 | 20 | 5 | 2 | 184 376 200 |
| Cropping | 6 | 65 | 26 | 3 | 1 | 22 241 100 |
| Grazing modified pasture | 5 | 37 | 46 | 11 | 1 | 18 482 600 |
| Horticulture | 6 | 35 | 43 | 13 | 4 | 351 300 |
| Irrigated cropping | 2 | 73 | 23 | 2 | 0 | 948 800 |
| Irrigated modified pasture | 0 | 69 | 25 | 4 | 2 | 1 080 000 |
| **Total area*** | | | | | | **282 294 100** |

* Area of river basins containing intensive agriculture.

**Figure A13** Soil nitrogen (%) for river basins containing intensive agriculture (derived from site measurements of carbon/nitrogen ratio)




**Source:** Australian Soil Resources Information System.

National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.

## Percent organic carbon (topsoil and subsoil)

Organic carbon estimates the amount of organic matter in a soil as a percentage by weight. Soil organic matter content is an indication of natural soil fertility , and is a balance between input of surface litter (fallen leaves and dead organisms) and the rate at which microbes break down organic compounds.

Carbon is essential for plant growth. Organic matter is also important since it binds soil particles together into stable aggregates. It is also involved in adsorption of cations. Cations such as calcium, magnesium and sodium are important in plant nutrition.

### How does it vary and what is it related to?

Soil organic carbon varies with depth. Levels are highest in the topsoil and generally decrease exponentially with depth. Organic carbon commonly ranges between 0% and 15%. Most Australian soils contain less than 5%.

### Distribution of organic carbon across Australia?

Organic carbon does not appear to closely reflect soil types. Rather it varies as a function of climate and land use. It is highest in forested and cultivated areas, and generally follows continental rainfall and temperature patterns. Organic carbon is highest in the high rainfall, temperate regions of Tasmania, Victoria and Western Australia, along the coast of New South Wales and in the wet tropics of Queensland; and lowest in arid and semi-arid inland regions. The Australian Soil Resources Information System map estimates for organic carbon appear anomalously high in portions of the Northern Territory.

**Table A10** Organic carbon by land use categories for topsoil (weight %C) by percent of land use type.

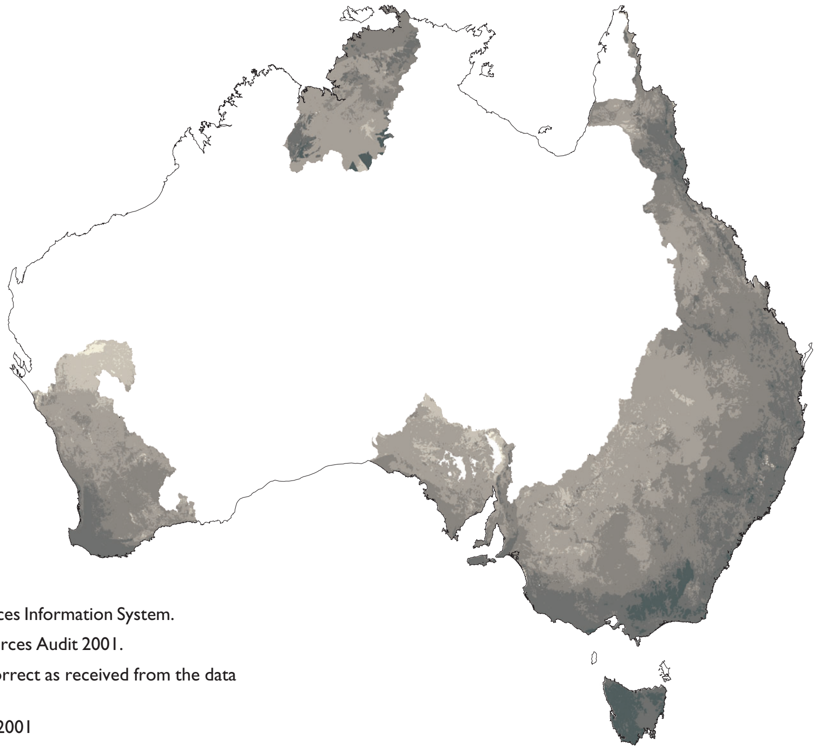
| | **< 0.3** | **0.3 – 0.5** | **0.5 – 1.0** | **1.0 – 2.0** | **2.0 - 5.0** | **> 5.0** | **Total land use class area (ha)** |
|---|---|---|---|---|---|---|---|
| Conservation and natural environments | 0 | 3 | 29 | 34 | 26 | 8 | 54 814 100 |
| Production from native environments | 0 | 7 | 42 | 33 | 15 | 2 | 184 376 100 |
| Cropping | 0 | 1 | 31 | 55 | 12 | 1 | 22 241 000 |
| Grazing modified pasture | 0 | 1 | 16 | 44 | 37 | 2 | 18 482 400 |
| Horticulture | 0 | 1 | 24 | 31 | 39 | 5 | 351 500 |
| Irrigated cropping | 0 | 0 | 23 | 68 | 8 | 0 | 948 700 |
| Irrigated modified pasture | 0 | 0 | 12 | 67 | 19 | 2 | 1 080 000 |
| **Total area*** | | | | | | | **282 293 800** |

**Table A11** Organic carbon by land use categories for subsoil (weight %C) by percent of land use type.

| | < 0.3 | 0.3 – 0.5 | 0.5 – 1.0 | 1.0 – 2.0 | 2.0 – 5.0 | > 5.0 | Total land use class area (ha) |
|---|---|---|---|---|---|---|---|
| Conservation and natural environments | 22 | 34 | 29 | 12 | 3 | 1 | 54 814 100 |
| Production from native environments | 20 | 43 | 29 | 7 | 0 | 0 | 184 376 100 |
| Cropping | 24 | 53 | 17 | 5 | 0 | 0 | 22 241 000 |
| Grazing modified pasture | 17 | 41 | 32 | 9 | 1 | 0 | 18 482 400 |
| Horticulture | 5 | 46 | 35 | 14 | 1 | 0 | 351 500 |
| Irrigated cropping | 20 | 56 | 17 | 8 | 0 | 0 | 948 700 |
| Irrigated modified pasture | 2 | 59 | 34 | 4 | 1 | 0 | 1 080 000 |
| **Total area*** | | | | | | | **282 293 800** |

* Area of river basins containing intensive agriculture

**Figure A14** Distribution of organic carbon (%) in the topsoil within the river basins containing intensive agriculture.



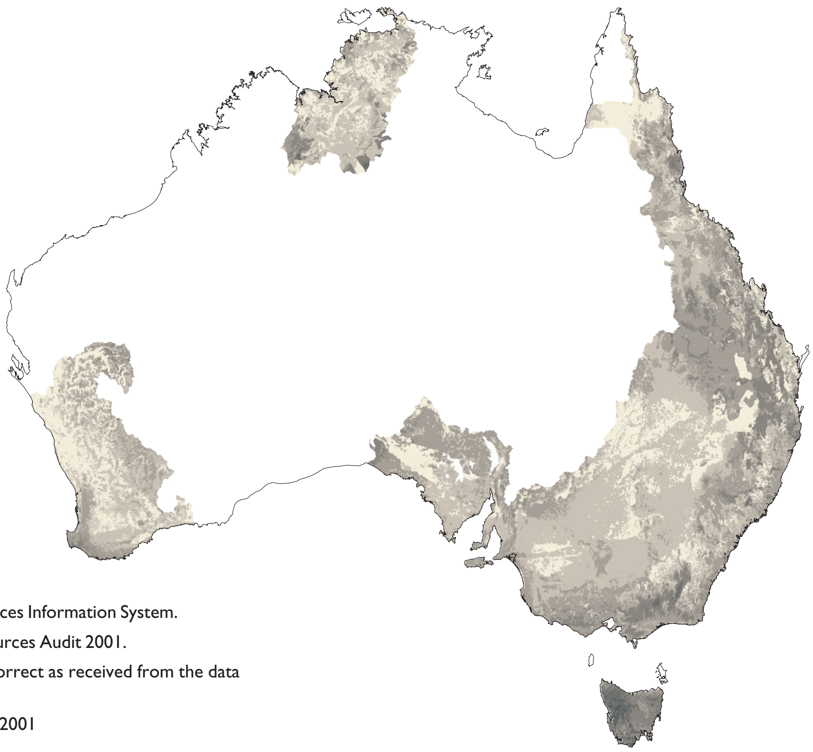

**Source:** Australian Soil Resources Information System.

National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.



**Figure A15** Distribution of organic carbon (%) in the subsoil within the river basins containing intensive agriculture.




**Source:** Australian Soil Resources Information System.

National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.

Soil organic matter content is an indication of natural soil fertility. The carbon:nitrogen ratio is an especially useful indicator of the source of organic matter, its state of decomposition and its potential contribution to soil fertility. Very high carbon:nitrogen ratios (> 25) indicate that organic matter accumulation is occurring faster than decomposition. These high ratios are observed in peats and forest litters. Carbon:nitrogen ratios between 12 and 16 suggest that organic matter is well broken down. Cultivated soils usually have a carbon:nitrogen ratio between 10 and 12. Carbon:nitrogen ratios below 10 usually occur only in the subsoil.

Soil organic carbon is also important in determining soil erodibility and maps of organic carbon can be used in estimating erodibility by combining with maps of soil texture and permeability (see soil erodibility – Figure A25).

### Level of uncertainty

Models for organic carbon are reasonably robust.

Error diagnostics

| Error diagnostic | Topsoil | Subsoil |
|---|---|---|
| Number of points used | 11483 | 5100 |
| $R^2$ | 0.489 | 0.370 |
| Relative error | 0.65 | 0.77 |

Point distribution and other error diagnostics indicate that the topsoil model is considered to be good for South Australia, Western Australia, Murray–Darling Basin and central Queensland; but poor for the Northern Territory, Carpentaria and North Queensland, New South Wales (outside the Murray–Darling Basin), and Victoria. Similarly, the subsoil model is strongest for Western Australia, the Murray–Darling Basin, south and central Queensland, and Tasmania; and weakest for Northern Territory, western Victoria and northern New South Wales.

## Bulk density (topsoil and subsoil)

Bulk density is the weight of a dry soil in a unit of volume, and gives a measure of soil porosity.

Bulk density can indicate how the porosity (number of pore spaces) of soil samples helping to determine how much air or water can be stored and moved through the soil. Bulk density also indicates how tightly soil particles are packed and whether how difficult or easy the soil will be for roots (or shovels) to penetrate.

Soils with low bulk density are generally more suitable for agriculture, since the high pore space has a greater potential to store water and roots are able to grow more readily. As bulk density increases, resistance to roots increases and the amount of water available to crops decreases. Permeability of the soil also decreases so that crops are more susceptible to waterlogging. In sandy soils, bulk densities above 1.6 – 1.8 g/cm$^3$ may cause problems with root penetration. In silty and clay soils, problems may arise at bulk densities above 1.4 g/cm$^3$.

### How does it vary and what is it related to?

The density of  a soil sample is determined by the number of spaces (pores) in the sample, how tightly they are packed, and the composition of the solid material.

- Sandy soils have higher bulk densities (1.3 and 1.7 g/cm$^3$) than finer-grained soils, because they have larger, but fewer, pore spaces.
- Fine-grained soils (silts and clays) have bulk densities between 1.1 and 1.6 g/cm$^3$. In clay soils with good soil structure, there is a greater amount of pore space because the particles are very small, and many small pore spaces fit between them.
- Soils rich in organic matter generally have low bulk density.
- Surface soils usually have bulk densities in the range 1.1 – 1.4 g/cm$^3$, decreasing to 0.9 – 1.2 g/cm$^3$ after cultivation.
- Bulk density increases with compaction at depth, and very compact subsoils may have bulk densities above 2 g/cm$^3$.

**Table A12** Bulk density by land use categories for topsoil (g/cm$^3$) by percent of land use type across Australia.

| | < 1.2 (%) | 1.2 – 1.4 (%) | > 1.4 (%) | Total land use class area (ha) |
|---|---|---|---|---|
| Conservation and natural environments | 7 | 76 | 17 | 263 824 100 |
| Production from native environments | 15 | 63 | 23 | 442 984 600 |
| Cropping | 12 | 60 | 28 | 22 512 900 |
| Grazing modified pasture | 11 | 51 | 38 | 19 223 000 |
| Horticulture | 19 | 47 | 34 | 350 600 |
| Irrigated cropping | 21 | 47 | 32 | 949 000 |
| Irrigated modified pasture | 8 | 62 | 30 | 1 079 000 |
| **Total area** | | | | **750 923 200** |

**Table A13** Bulk density by land use categories for subsoil (g/cm$^3$) by percent of land use type across Australia*.

| | < 1.2 | 1.2 – 1.4 | > 1.4 | Total land use class area (ha) |
|---|---|---|---|---|
| Conservation and natural environments | 3 | 10 | 88 | 227 609 500 |
| Production from native environments | 3 | 24 | 73 | 426 254 500 |
| Cropping | 2 | 16 | 83 | 22 483 000 |
| Grazing modified pasture | 3 | 13 | 84 | 19 182 400 |
| Horticulture | 5 | 15 | 80 | 347 100 |
| Irrigated cropping | 2 | 26 | 72 | 947 400 |
| Irrigated modified pasture | 1 | 7 | 91 | 1 075 000 |
| **Total area*** | | | | **697 898 900** |

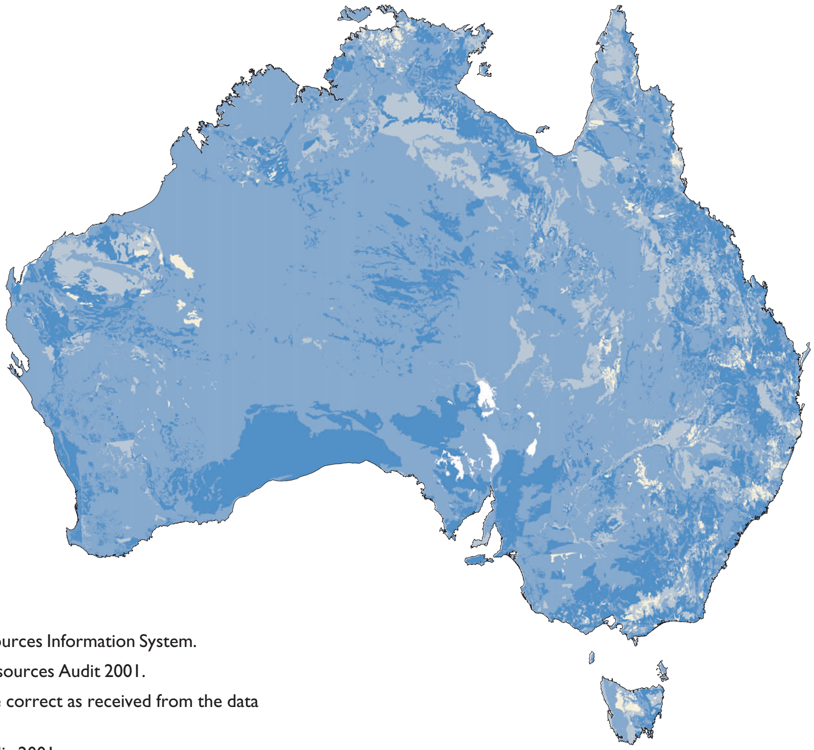
* Different area compared with topsoil results from large areas having no estimate for subsoil bulk density.

## How and why does it vary across Australia?

Areas with high organic matter (e.g. forests) generally have a low bulk density (< 1.1 g/cm$^3$) in topsoils that increases to 1.2–1.3 g/cm$^3$ in subsoils. These areas roughly correspond to Dermosols and Podosols. Vertosols have bulk densities less than 1.3 g/cm$^3$ in topsoil and subsoil. Calcarosols and Chromosols have bulk densities around 1.4 g/cm$^3$ throughout. Sodosols have bulk densities greater than 1.4 g/cm$^3$ in topsoils, increasing to > 1.6 g/cm$^3$ in subsoils.

The Australian Soil Resources Information System estimates for bulk density appear too low in the subsoil of Calcarosols and Sodosols across the wheatbelt of New South Wales and Victoria; actual bulk densities should be 1.6–1.7 g/cm$^3$.

**Figure A16** Distribution of bulk density (g/cm$^3$) of the topsoil.




**Source:** Australian Soil Resources Information System.

National Land and Water Resources Audit 2001.

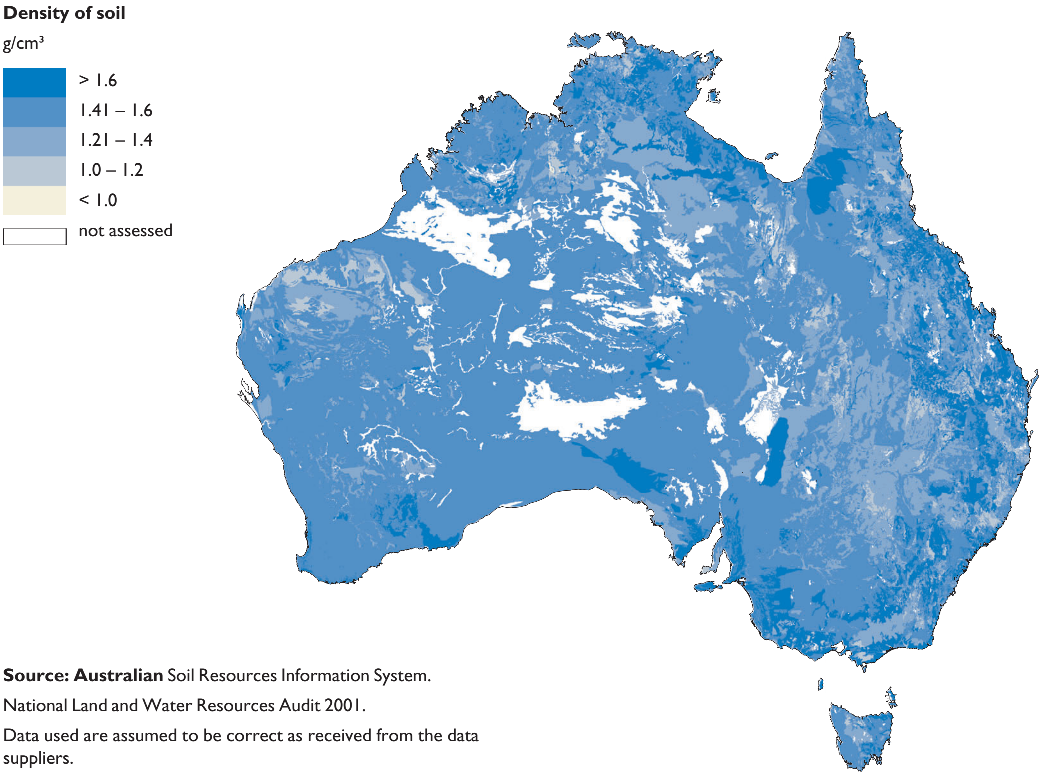
Data used are assumed to be correct as received from the data suppliers.

### Level of uncertainty

The scale of the various soil maps used in deriving this map is shown in Figure A2.

The quality of estimates of bulk density for different soil groups varies widely. Bulk density data have not been collected in routine soil surveys despite their importance. The CSIRO database used by McKenzie et al. (2000) to draw interpretations of soil properties contained had bulk density determinations for only 1755 soil layers, and these were biased to soils used for agriculture and the Bago–Maragle forest soil survey study. Bulk density data are not available for many groups of soils and there are many instances where bulk density will have little if any correlation with generalised soil types (e.g. where land management practices have led to increases in bulk density across a range of soil types). Uncertainty associated with bulk density estimates is very high.

**Figure A17** Distribution of bulk density (g/cm$^3$) of the subsoil.




**Source: Australian** Soil Resources Information System.

National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.

## Available water capacity (topsoil and subsoil)

Available water capacity is a measure of the store of water available for plants to use. It is presented as the estimated total for the horizon (topsoil or subsoil) and measured in millimetres.

This assessment provides an approximation of the water storage capacity of Australia's agricultural soils. It can be used in association with other soil (hydraulic conductivity, nutrient status, erodibility), climate and topographic characteristics to determine the suitability of land for either dryland or irrigated agriculture. An understanding of the soil–water regime is also important for moisture management in intensive agriculture (e.g. horticulture and viticulture) where optimising the supply of water to the plant at critical periods is important for plant growth and controlling ripening or perhaps optimising protein or sugar content.

### How does it vary and what is it related to?

The amount of water held by the soil varies with soil texture, organic matter content, bulk density and soil structure development. Available water is defined as the amount of water held in the soil between two critical thresholds:

- *field capacity* or the amount of water held in the soil after being saturated and allowed to drain to an equilibrium;
- *wilting point* or the point at which most plants cannot draw the water from the soil because it is bound too tightly to the soil particles.

Across Australia, available water capacity varies closely with thickness of the soil layers with favourable water holding properties.

Available water capacity is the amount of water in the soil horizon that can be extracted by plants. (Table A14) presents the estimated total for the solum (topsoil plus subsoil). Figures A18 and A19 depict the distribution of the topsoil and subsoil available water capacity respectively.

### Level of uncertainty

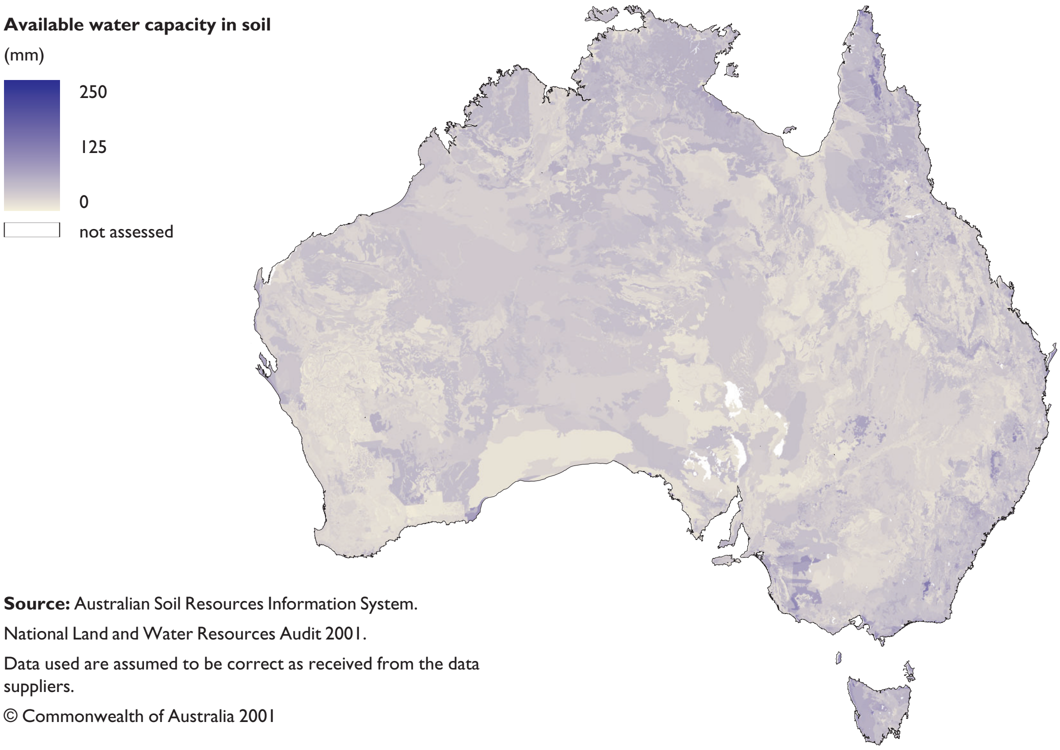
The scale of the soil maps used in deriving this map is shown in Figure A2.

Level of uncertainty associated with estimates of available water capacity are very high. McKenzie et al. (2000) note the many physical and practical reasons why such an estimate of available water capacity is only an approximate, and sometimes erroneous, estimate of the actual plant available water capacity (see Hillel 1980). Despite these limitations, it provides a reasonable first approximation of the water storage capacity of a soil.

**Table A14** Total profile available water capacity (topsoil plus subsoil) (mm of water) by percent of land use type across Australia.

| | 0 – 100 | 100 – 150 | > 150 | Total land use class area (ha) |
|---|---|---|---|---|
| Conservation and natural environments | 25 | 50 | 25 | 227 605 100 |
| Production from native environments | 40 | 39 | 22 | 426 286 100 |
| Cropping | 52 | 32 | 16 | 22 466 200 |
| Grazing modified pasture | 58 | 29 | 12 | 19 181 300 |
| Horticulture | 32 | 43 | 25 | 347 900 |
| Irrigated cropping | 21 | 46 | 33 | 948 000 |
| Irrigated modified pasture | 23 | 67 | 10 | 1 076 200 |
| **Total area** | | | | **697 910 800** |

**Figure A18** Distribution of available water capacity of the topsoil.



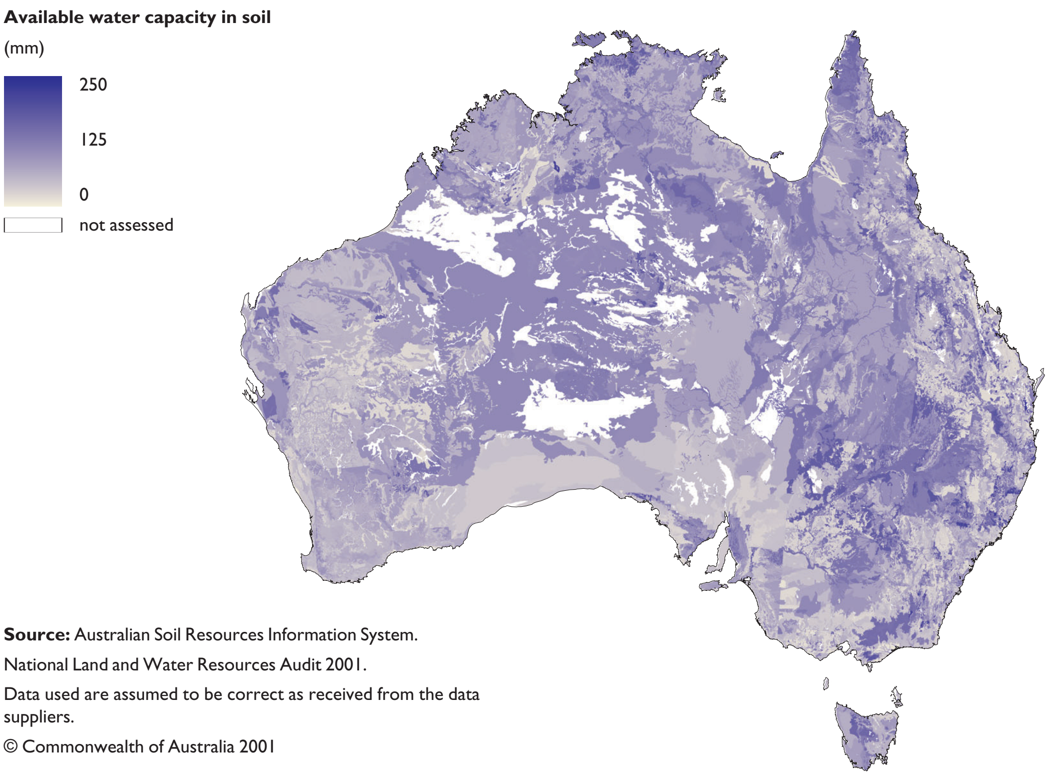

**Source:** Australian Soil Resources Information System.

National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.



**Figure A19** Distribution of available water capacity of the first subsoil layer.




**Source:** Australian Soil Resources Information System.

National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.

## Saturated hydraulic conductivity (topsoil and subsoil)

Saturated hydraulic conductivity is a measure of the permeability of a soil (or how quickly water can move through the soil when it is saturated). Soil permeability, in conjunction with water storage capacity, is fundamental to controlling the soil–water regime, that determines land suitability for a range of purposes.

Soils with a slow hydraulic conductivity at or near the soil surface (e.g. less than 30 mm/hr) cannot transmit water from heavy showers of rain and this can lead to excessive run-off and potentially to erosion. Run-off also represents a loss of water that could have otherwise been available to plants. Subsoil layers are nearly always less permeable than surface layers because of the lower rates of biological activity. Soils with a strong texture contrast between topsoil and subsoil (e.g. Kurosols and Sodosols) may have a sharp reduction in hydraulic conductivity with depth. In this case, drainage of water is impeded and waterlogging can be a problem.

### How does it vary and what is it related to?

Saturated hydraulic conductivity is controlled mainly by the texture, organic matter content and structure of the soil layer. Sandy soils are nearly always very permeable. Some clay soils can be more permeable than sands (e.g. Red Ferrosols) because of their strongly aggregated structure. Other clay soils (e.g. most Vertosols and the B horizons of Sodosols) are very impermeable.

The presence of worms, termites and other soil fauna increases soil permeability markedly. Earthworm burrows frequently make up a high proportion of the large pore space of soils, and soils with earthworms can drain two to ten times faster than soils without (Lee 1985).

Generally, heavy clay soils (Vertosols) have moderate permeability (Ksat < 50 mm/hr) in their topsoil, decreasing to very slow permeability (< 0.1 mm/hr) in their subsoil. Kandosols have rapid permeability in their topsoil (~500 mm/hr) which decreases to moderately slow in their subsoil. Sandy soils, Podosols, Chromosols and Tenosols in Western Australia and South Australia are very rapid permeable. Sodosols are rapidly permeable in their topsoil but only slowly permeable in their subsoil.

**Table A15** Permeability by percent of land use type for topsoil when saturated (saturated hydraulic conductivity mm/hr) across Australia.

| | ⩽0.3<br>very slow | 0.3 – 3<br>slow | 3 – 30<br>moderate | 30 – 300<br>high | >300<br>extreme | Total land use class area<br>(ha) |
|---|---|---|---|---|---|---|
| Conservation and natural environments | 2 | 0 | 7 | 90 | 0 | 263 893 800 |
| Production from native environments | 15 | 2 | 12 | 70 | 0 | 443 032 100 |
| Cropping | 5 | 5 | 13 | 72 | 5 | 22 519 000 |
| Grazing modified pasture | 2 | 2 | 15 | 76 | 5 | 19 237 500 |
| Horticulture | 4 | 1 | 15 | 79 | 1 | 350 900 |
| Irrigated cropping | 17 | 11 | 33 | 39 | 0 | 949 000 |
| Irrigated modified pasture | 15 | 2 | 50 | 33 | 1 | 1 079 100 |
| **Total area** | | | | | | **751 061 400** |

**Table A16** Permeability by percent of land use type for subsoil when saturated (saturated hydraulic conductivity mm/hr) across Australia.

| Land use class | ⩽0.3<br>very slow | 0.3 – 3<br>slow | 3 – 30<br>moderate | 30 – 300<br>high | >300<br>extreme | Total land use class area<br>(ha) |
|---|---|---|---|---|---|---|
| Conservation and natural environments | 2 | 6 | 17 | 74 | 0 | 227 606 400 |
| Production from native environments | 14 | 12 | 35 | 39 | 0 | 426 250 500 |
| Cropping | 10 | 13 | 44 | 30 | 2 | 22 482 300 |
| Grazing modified pasture | 4 | 14 | 39 | 40 | 2 | 19 182 100 |
| Horticulture | 5 | 8 | 40 | 46 | 1 | 347 300 |
| Irrigated cropping | 28 | 13 | 47 | 12 | 0 | 947 400 |
| Irrigated modified pasture | 16 | 10 | 60 | 13 | 1 | 1 075 100 |
| **Total area** | | | | | | **697 891 100** |

On average Australia applies about 18 000 000 ML of water onto agricultural soils every year.

Table A17 compares the permeability of saturated soil for topsoils and subsoils for irrigated lands. Of the 2 400 000 ha mapped as irrigated in the national land use map:

- 14% have topsoils and subsoils with very slow permeability;
- about 60% with similar top and subsoil permeability;
- 38 % have more highly permeable topsoil than subsoil;
- almost none have a subsoil more permeable than topsoil.

The most significant implication for irrigation operations are those lands (some 28%, see grey shading on table) that may be prone to waterlogging. These lands tend to have very slow or slow topsoil and subsoil permeability, or moderately permeable topsoils overlying slow or very slow permeability subsoils. Ripping and other farm tillage practices are commonly used to overcome these impediments for cropping.

### Application of map

Permeability is one controlling factor in determining how susceptible a soil is to erosion. This map of saturated hydraulic conductivity has been used as one input to estimate *erodibility*, by combining with maps of *%clay* and *organic carbon*.

### Level of uncertainty

Scale of soil maps used in deriving this map is shown in Figure A2.

Saturated hydraulic conductivity ($K_s$) typically exhibits substantial short-range variation and is relatively difficult to measure (there are few reliable sets of $K_s$ data for Australia). Estimates of $K_s$ on used by McKenzie et al. (2000) are based on experience gained in CSIRO Land and Water and published data sets. Estimates for Western Australia and South Australia soil groups are based on expert knowledge of $K_s$ for different horizons (based primarily on texture and structure), and on interpolation of McKenzie et al (2000). Attribution $K_s$ was estimated using the classes presented in Table A17, where the median values for each class are approximately equidistant on a logarithmic scale, since $K_s$ data are generally log-normally distributed.

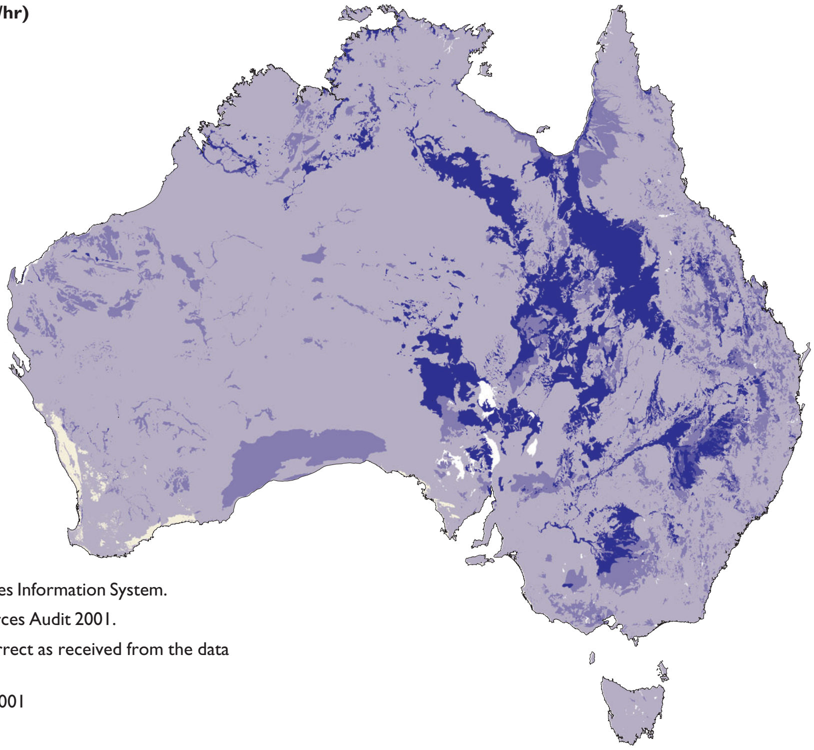
**Table A17** Comparison of saturated hydraulic conductivity (mm/hr) of topsoil and subsoil for irrigated areas (%) (includes all horticulture, irrigated crops, irrigated pastures).

| | **Topsoil** | **⩽0.3** | **0.3 – 3** | **3 – 30** | **30 – 300** | **>300** |
|---|---|---|---|---|---|---|
| Subsoil | | very slow | slow | moderate | high | extreme |
| ⩽0.3 | very slow | 14 | 4 | 1 | 0 | 0 |
| 0.3 – 3 | slow | 0 | 1 | 8 | 1 | 0 |
| 3 – 30 | moderate | 0 | 0 | 29 | 24 | 0 |
| 30 – 300 | high | 0 | 0 | 0 | 17 | 0 |
| 300 | extreme | 0 | 0 | 0 | 0 | 0 |

**Figure A20** Distribution of saturated hydraulic conductivity (mm/hr) of the topsoils across Australia.

**Hydraulic conductivity (mm/hr)**

- extreme (> 300)
- high (30 – 300)
- moderate (3 – 30)
- slow (0.3 – 3)
- very slow (< 0.3)
- not assessed



**Source:** Australian Soil Resources Information System.

National Land and Water Resources Audit 2001.

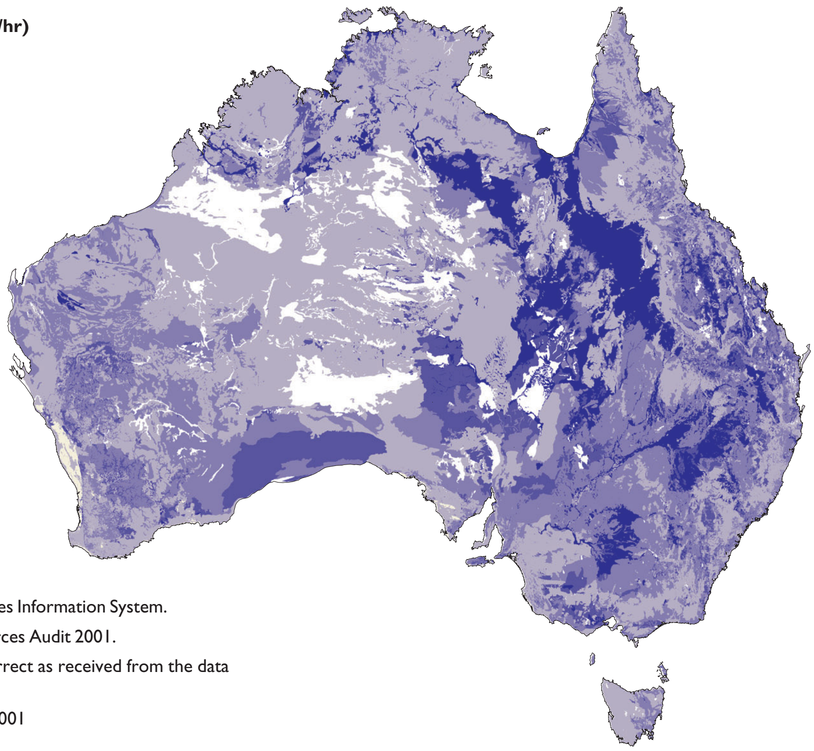
Data used are assumed to be correct as received from the data suppliers.



**Figure A21** Distribution of saturated hydraulic conductivity (mm/hr) of the subsoils across Australia.

**Hydraulic conductivity (mm/hr)**

- extreme (> 300)
- high (30 – 300)
- moderate (3 – 30)
- slow (0.3 – 3)
- very slow (< 0.3)
- not assessed



**Source:** Australian Soil Resources Information System.

National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.

## pH (topsoil, subsoil)

**Soil pH** is a measurement of the relative acidity or alkalinity of the soil and provide a guide to the overall chemical balance of the soil. The pH scale is divided into 14 points. Seven is the neutral point and each number below seven indicates ten times more acidic while each number above seven indicates ten times more alkalinity. On the pH scale:

- a pH of 7.0 is considered neutral
- a pH above 7.0 is considered alkaline
- a pH below 7.0 is considered acidic

Methods used to measure soil pH affect results with the main difference being between field kits (approximating pH as measured in water) and laboratory measurements (usually reporting pH in $CaCl_2$ solution).

Plants do not grow well outside the range of 4.5 – 8 since soil pH determines the availability of soil nutrients to plants:

- calcium and magnesium are much more readily available in alkaline soils;
- iron and manganese are much more readily available in acidic soils; and
- most nutrients are available in relatively neutral soils (pH 6 – 7.5).

Plant preference for certain types of soil means that they are often starved of important nutrients or damaged by unwanted minerals:

- acid-loving plants growing in alkaline soils may be starved of iron and manganese;
- alkaline-loving plants growing in acidic soil may not be able to access sufficient calcium and magnesium or be severely damaged by amounts of dissolved aluminium or manganese.

Strongly acid soils have pH in water below 5.5 or pH in $CaCl_2$ below 4.5. Agricultural problems associated with preventing legume nodules forming; release of toxic levels of aluminium reduced availability of phosphorus; and some trace element deficiencies.

Acid soils are commonly treated by the addition of lime to neutralise the acidity (see *Soil acidification* section of the Australian Agriculture Assessment 2001 report).

### How does it vary and what is it related to?

Soil pH is determined partly by the chemical composition of material from which the soil has developed, and partly by how much the soil has been leached. Soils derived from limestones or basalts are generally quite alkaline. Soils derived from quartz-rich rocks (sandstones, granites) may be acid. Acid soils develop in areas where rainfall is high, since water percolating through the soil washes away soluble bases such as calcium.

pH of the soil may also change as a result of farming practices. Cropping tends to increase the acidity of soils in the long term, since ploughed soils are more prone to leaching and nutrients are removed in crops. Prolonged use of fertilisers also increases soil acidity. Acidification of improved pastures due to fertiliser application is very common in Australia (see *Soil acidification* section)

Acid sulfate soils, with very low soil pH values, can develop in particular environments where pyrite occurs in the soil. Disturbance of the soil leads to oxidation and release of sulfuric acid. Acid sulfate soils occur in coastal marine environments, saline discharge areas and mine tailings.

| pH | |
|---|---|
| < 4.3 | extremely acid |
| 4.3 – 4.8 | highly acid |
| 4.8 – 5.5 | moderately acid |
| 5.5 – 7.0 | mildly acid |
| 7.0 – 7.7 | mildly alkaline |
| 7.7 – 8.5 | moderately alkaline |
| > 8.5 | highly alkaline |

## How and why does it vary across Australia?

The digital map of pH shows that, as expected in light of their carbonate content, Calcarosols in South Australia, Victoria and eastern West Australia have alkaline pH (> 7). Vertosols in the Murray and Darling alluvial plains and Queensland also have alkaline to neutral pH. Forested areas and coastal areas with high rainfall have the lowest pH.

Tables A18 and A19 show variation in topsoil and subsoil pH for different land use types. These show that:

- 20% of Australia's improved pastures have topsoil acidity in the 'very acid to acid' range;
- the proportion of cropping lands with acid to very acid topsoils is much lower (7%) but a total of 48% of cropping lands have topsoils which are marginally acidic or worse; and
- subsoil acidity is much less widespread.

**Table A18** pH of topsoil by percent of land use type.

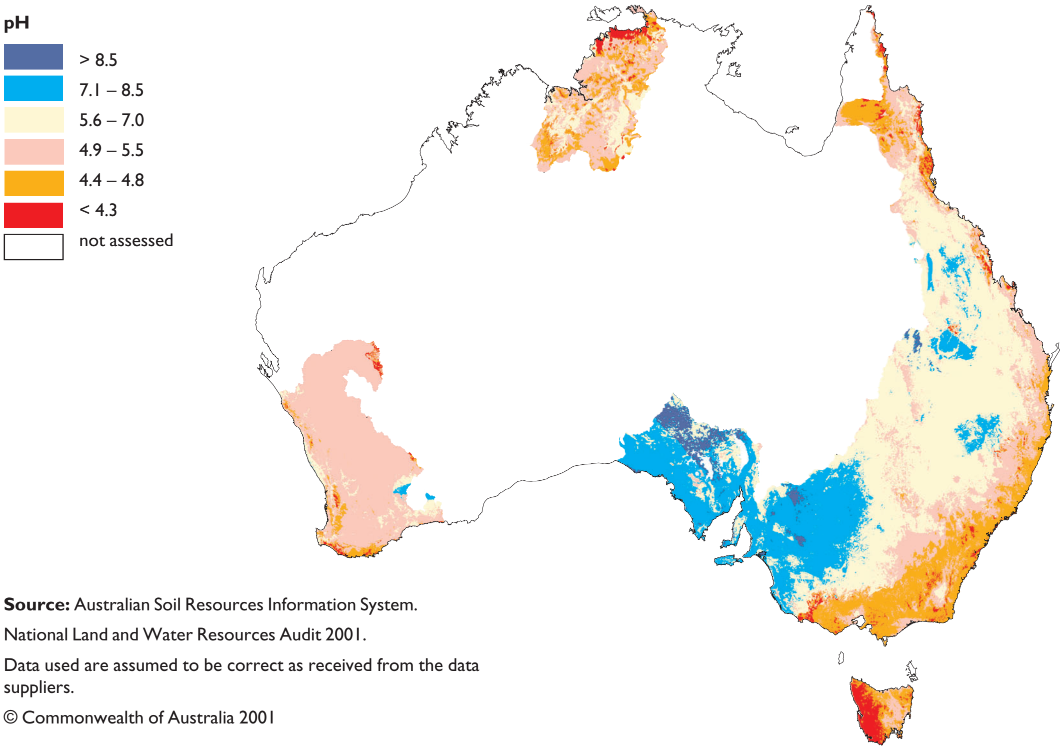
| | < 4.3 | 4.3 – 4.8 | 4.8 – 5.5 (% of land use class) | 5.5 – 7.0 | 7.0 – 8.5 | > 8.5 | Total land use class area (ha) |
|---|---|---|---|---|---|---|---|
| Conservation and natural environments | 8 | 23 | 35 | 17 | 16 | 1 | 54 814 300 |
| Production from native environments | 2 | 12 | 30 | 42 | 13 | 2 | 184 376 200 |
| Cropping | 1 | 6 | 41 | 33 | 19 | 0 | 22 241 000 |
| Grazing modified pasture | 1 | 19 | 39 | 29 | 11 | 0 | 18 482 600 |
| Horticulture | 2 | 27 | 23 | 22 | 26 | 0 | 351 500 |
| Irrigated cropping | 2 | 4 | 22 | 66 | 6 | 0 | 948 800 |
| Irrigated modified pasture | 0 | 9 | 19 | 65 | 7 | 0 | 1 079 900 |
| **Total area*** | | | | | | | **282 294 300** |

**Table A19** pH of subsoil by land use type.

| | < 4.3 | 4.3 – 4.8 | 4.8 – 5.5 (% of land use class) | 5.5 – 7.0 | 7.0 – 8.5 | > 8.5 | Total land use class area (ha) |
|---|---|---|---|---|---|---|---|
| Conservation and natural environments | 10 | 14 | 25 | 36 | 15 | 0 | 54 814 300 |
| Production from native environments | 2 | 4 | 15 | 52 | 27 | 0 | 184 376 200 |
| Cropping | 1 | 3 | 9 | 54 | 33 | 0 | 22 241 000 |
| Grazing modified pasture | 0 | 5 | 26 | 50 | 19 | 0 | 18 482 600 |
| Horticulture | 6 | 17 | 19 | 31 | 28 | 0 | 351 500 |
| Irrigated cropping | 0 | 2 | 12 | 42 | 44 | 0 | 948 800 |
| Irrigated modified pasture | 1 | 5 | 8 | 38 | 48 | 0 | 1 079 900 |
| **Total area*** | | | | | | | **282 294 300** |

* Area of river basins containing intensive agriculture

**Figure A22** Distribution of pH of the topsoil within the river basins containing intensive agriculture.



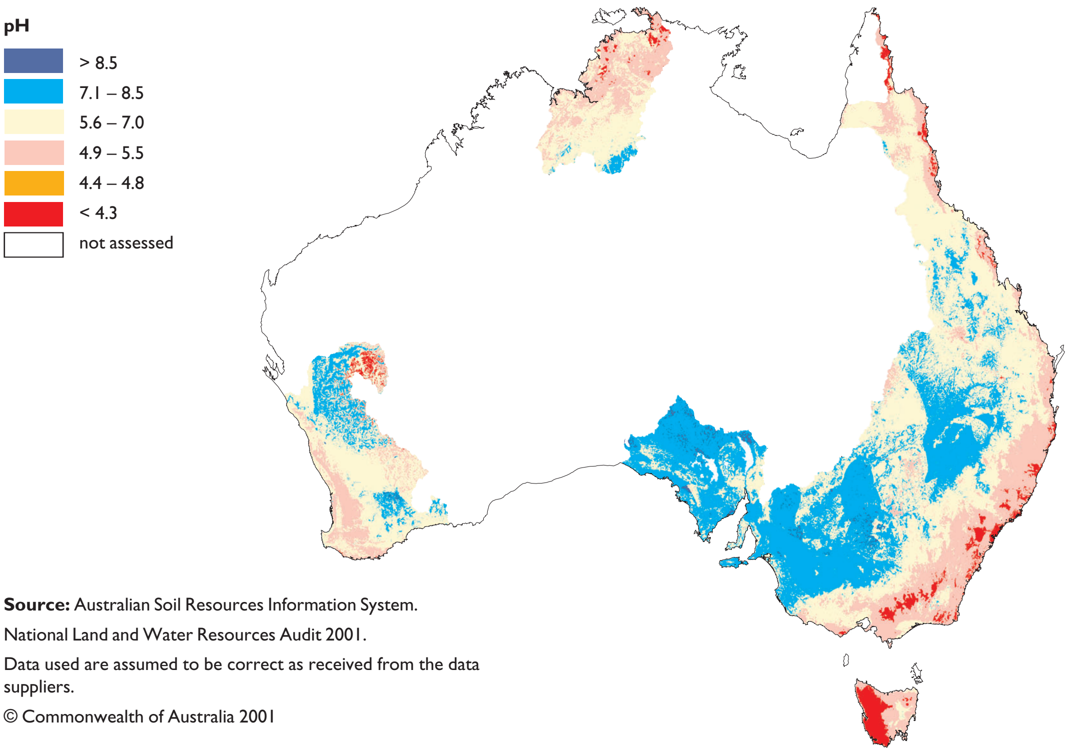

**Source:** Australian Soil Resources Information System.

National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.



**Figure A23** Distribution of pH of the subsoil within the river basins containing intensive agriculture.




**Source:** Australian Soil Resources Information System.

National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.

### How can this map be applied?

Distribution of soil pH can be used to assess **soil acidity** known as *surface acidity* when it is in the topsoil or ploughed layer (roughly 0 – 30 cm depth) – see Figure A22. *Subsurface acidity* (see Figure A23) occurs below the ploughed layer (30 – 60 cm). It can have as much effect on reducing yield as surface acidity but is much more difficult and costly to correct.

### Level of uncertainty

The models for pH are amongst the most reliable of the point-based models.

Error diagnostics

| Error diagnostic | Topsoil | Subsoil |
|---|---|---|
| Number of points used | 24319 | 12193 |
| $R^2$ | 0.677 | 0.605 |
| Relative error | 0.51 | 0.54 |

Soil points with pH measurement for topsoil are well distributed and the model is reliable in most areas. It performs best in the Murray–Darling Basin, Victoria and southern and central Queensland, and is weakest in South Australia, Northern Territory, Moreton (Queensland) and coastal New South Wales.

The subsoil model is less reliable (due to only half the number of points being available). It is most reliable in the Murray–Darling Basin, Tasmania and Queensland and is weakest in South Australia, northern New South Wales and the Northern Territory.

## Erodibility

Erodibility is a soil's inherent tendency to be transported by water or wind. One measure of erodibility (the resistance of a soil to sheet and rill erosion) is the K-factor (used in the Universal Soil Loss Equation – USLE) and is a function of:

- texture of the soil (specifically, soil fraction with grain size less than 0.125 mm);
- amount of organic matter in the soil; and
- permeability (how well water drains).

Only the topsoil is subject to erosion—except where gullying is extreme—so a map of estimated erodibility has been produced only for the topsoil.

Soil erosion—threatening both farmland productivity and water quality—is a consequence of erodibility.

Loss of topsoil implies a diminishing volume of soil for crop production. The transported soil particles carry with them adsorbed forms of calcium, nitrogen and phosphorus. With water-eroded topsoil these nutrients are lost for crop plants but can stimulate algal growth in surface water bodies. When the transported particles are deposited, they can build up behind dams or choke waterways.

### How does it vary and what is it related to?

Erodibility depends on the structural stability of the soil, and its capacity to transmit water downward. Structural stability is a function of soil particle size distribution (texture), mineralogy and organic matter content.

- Fine grained soils are more erodible than sands.
- Soils with high organic matter content are less erodible than those with low organic matter content.

The K factor has been estimated from field plot experiments, mainly in South Australia, because data for Australian soils are available only for a few sites. Typical values (from Rosewell 1997) are:

| Erodibility | K factor |
|---|---|
| Very low | < 0.02 |
| Low | 0.04 |
| Moderate | 0.06 |
| High | 0.08 |
| Very high | > 0.08 |

**Table A20** Soil loss—the K factor—by percent of land use type across Australia.

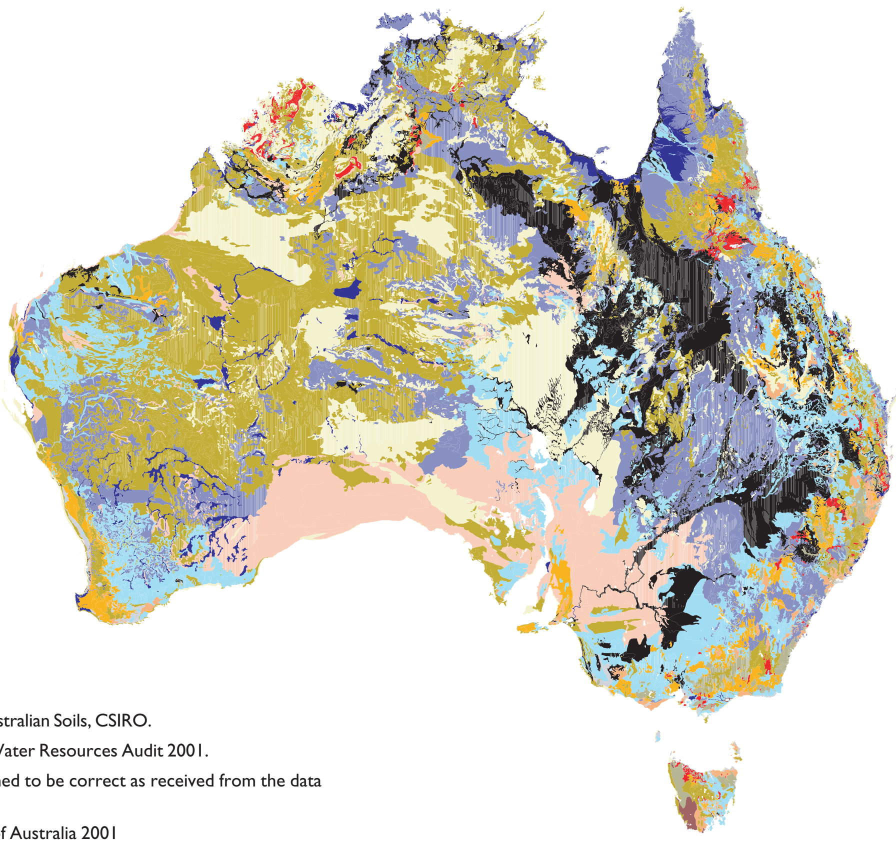
| | very low | low | moderate | High | very high | Total land use class area |
|---|---|---|---|---|---|---|
| | < 0.02 | 0.04 | 0.06 | 0.08 | > 0.08 | (ha) |
| Conservation and natural environments | 54 | 12 | 11 | 18 | 5 | 264 040 900 |
| Production from native environments | 18 | 8 | 12 | 38 | 25 | 443 296 900 |
| Cropping | 26 | 17 | 17 | 32 | 8 | 22 522 000 |
| Grazing modified pasture | 29 | 20 | 22 | 26 | 4 | 19 231 800 |
| Horticulture | 29 | 19 | 28 | 19 | 5 | 350 700 |
| Irrigated cropping | 3 | 3 | 13 | 60 | 21 | 949 100 |
| Irrigated modified pasture | 8 | 6 | 15 | 57 | 14 | 1 078 200 |
| **Total area** | | | | | | **751 469 600** |

## How and why does it vary across Australia?

Comparing erodibility with the soil map of Australia shows that heavy clay soils (Vertosols) are highly erodible as are structurally unstable, chemically dispersible sodic soils (Sodosols). Kandosols and Calcarosols with sandy topsoil are slightly less erodible. Rocky soils (Rudosols) and weakly developed soils (Tenosols) are least erodible.

The digital map of erodibility (Figure A24) shows that there is an obvious State boundary between South Australia and Victoria, partly due to land management differences and to original map sources of soil data.

**Figure A24** Distribution of soil orders in Australia.




**Source:** Atlas of Australian Soils, CSIRO.

National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.

## How can this map be applied?

Erosion can be modelled and thereby predicted by applying the Universal Soil Loss Equation relating erosion on agricultural land to rainfall intensity, soil, hillslope length and gradient, land cover, and management practices. Erodibility is only one input into this model.

For more information on soil erosion in Australia, see the *Water-borne erosion* section.

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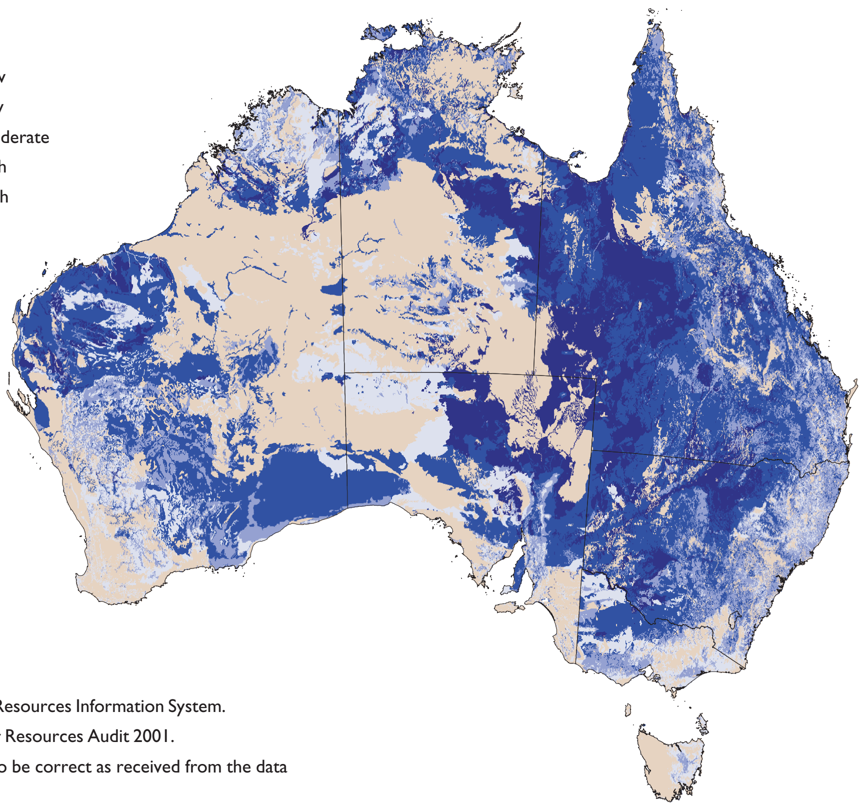
**Figure A25** Soil erodibility (K factor) across Australia.

**Soil erodibility**
(t ha h/ha MJ mm)

< 0.02 very low
0.02 – 0.04 low
0.04 – 0.06 moderate
0.06 – 0.08 high
> 0.08 very high



**Source:** Australian Soil Resources Information System.

National Land and Water Resources Audit 2001.

Data used are assumed to be correct as received from the data suppliers.

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# APPENDIX 3. MAJOR SOILS USED FOR AGRICULTURE IN AUSTRALIA*

Neil McKenzie, Ray Isbell, Katharine Brown and David Jacquier

CSIRO Land and Water

## Introduction

Soil test results are most useful when there is an appreciation of the general features of the complete soil profile. These features, together with climate, can have an overriding impact on plant growth. A great variety of soils are used for agriculture in Australia and this chapter provides a general account of 20 major types. The new Australian Soil Classification (Isbell 1996) is used as a frame of reference because of its practical focus. It is also the national standard for soil classification. However, there are many variants on the soil types described here and more detailed and local accounts should be consulted for specific guidance on land management.

## General features of Australian soils

In recent geologic times, there has been a general absence across the continent of major processes that renew soils, for example, mountain building, volcanic activity and glaciation. Land surfaces across many parts of Australia are ancient and as a consequence the associated soils are strongly weathered and infertile. However, the agricultural lands have significant areas with younger land surfaces and more fertile soils.

Australian soils have many distinctive features. The surface layers usually have low organic matter levels and are often poorly structured, a condition made worse by most agricultural practices. Subsurface layers with a sharp increase in clay content are widespread (Kurosols, Chromosols, and Sodosols) and they can restrict drainage and root growth. In these soils, bleached layers with very low nutrient levels are also common. Soils affected by salt, either now or in earlier geological times (e.g. Sodosols), cover large portions of the arable lands of the continent and have various nutrient and physical limitations.

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Soils lacking strong texture contrast generally pose fewer physical limitations to plant growth. Most notable are the deep red soils with high iron contents (Ferrosols) and closely related soild with structured B horizons (Dermosols). Australia is noted for the very large areas of cracking clays (Vertosols). These soils are relatively fertile but exhibit physical limitations. Soils formed in aeolian sands (Rudosols and Tenosols) fringe the southern cropping lands but are more extensive in the arid zone. A feature of the agricultural soils of parts of southern Australia is the widespread occurrence of highly calcareous soil types (Calcarosols). The remaining ancient land surfaces, particularly in northern Australia, have deep and strongly weathered soils (Kandosols) with very low levels of nutrients.

## Correlations between soil nutrition and major soil types

Many useful inferences can be drawn about particular aspects of the nutrient status of major soil types. However, caution is required because direct or universal correlations between nutrient status and soil type cannot always be assumed. Strong correlations should only be expected when the field criteria used for classifying profiles have a logical physical connection with the nutrient of interest. An advantage of the new Australian Soil Classification (Isbell 1996) over previous systems is the introduction of chemical criteria for classification. However, the large body of literature on soil variability demonstrates that many chemical properties are spatially variable and may exhibit only limited correlation with other chemical, physical and morphological properties. The impact of previous management practices (e.g. application of fertiliser and ameliorants, loss of organic matter.) will often further reduce the association between a given soil type and its nutrient status.

## *The Australian Soil Classification*

*The Australian Soil Classification* (Isbell 1996, Isbell et al. 1997) is a hierarchical, general purpose system that can be used at various levels of detail. In this appendix, soils are considered at the Order and Suborder level. A summary of the system at the Order level is presented in Figure 1. Most distinctions at the Suborder level are based on colour of the B horizon. The Organosol, Hydrosol, Rudosol and Anthroposol Orders are rarely used for extensive agriculture and are not represented here.

**Figure 1.** Schematic summary of the soil orders. Figures in parentheses refer to the number of soil profiles described in this chapter. The figure is not a key and readers are referred to Isbell (1996) if profile allocation is required.

**ALL SOILS**

- Human-made soils — **ANTHROPOSOLS** (0)
- Dominated by organic materials — **ORGANOSOLS** (0)
- Negligible pedological organisation — **RUDOSOLS** (0)
- Minimal pedological organisation — **TENOSOLS** (1)
- Bs, Bhs or Bh horizon — **PODOSOLS** (1)
- Clay ⩾ 35% in all horizons, cracks, slickensides — **VERTOSOLS** (3)
- Prolonged seasonal saturation — **HYDROSOLS** (0)
- Strong texture-contrast between A and B horizons
  - pH < 5.5 in upper B horizon — **KUROSOLS** (2)
  - Sodic in upper B horizon with pH ⩾ 5.5 — **SODOSOLS** (3)
  - Non-sodic B horizon with pH ⩾ 5.5 — **CHROMOSOLS** (2)
- Lacking strong texture-contrast between A and B horizons
  - Calcareous throughout profile or below A1 horizon — **CALCAROSOLS** (2)
  - High free iron B2 horizon — **FERROSOLS** (2)
  - Structured B2 horizon — **DERMOSOLS** (1)
  - Massive B2 horizon — **KANDOSOLS** (3)

## Selection of major soils and format

Twenty major soils used for agriculture were selected after consultation with State and Territory land resource assessment agencies. The information available on each soil varied substantially. The descriptions are based on the published literature and data held by CSIRO and the State agencies. A consistent format has been followed although some approximations were required and these are described in the following sections.

The various items covered in the format apply generally to the Suborders, whereas the soil profile descriptions and the laboratory data on which the graphs are based refer to specific example profiles shown by the images. In a few cases laboratory data were not available for the profile shown in the image. In these instances data from a similar soil was used and noted in the individual acknowledgments.

### Environment

A brief account is provided of distribution, climate, dominant parent material, landform and native vegetation. Terms defined by McDonald et al. (1990) are used where appropriate.

### Profile morphology

A simplified description of profile morphology is presented for a representative soil—in most instances it corresponds to the adjacent image. The description includes: horizon type and depth, colour (moist soil unless otherwise indicated), field texture, coarse fragments (if present), grade and type of structure, consistence, pedogenic segregations and sharpness of the horizon boundary. All terms are defined by McDonald et al. (1990).

There may be some small discrepancies between horizon boundaries on the image and in the profile description. This is usually caused by variation across the pit face, diffuse horizon boundaries or placement of the scale.

### Physical and chemical characteristics

Comprehensive soil physical data are lacking for many major groups. Particle size data for the fine earth fraction (< 2 mm) have been plotted wherever they were available. The percentage of clay, silt and sand gives an overall indication of the physical properties of a soil and sharp increases down the profile are often indicative of restrictions to root growth and water movement.

The total porosity of the soil and its capacity to store water are plotted on a profile basis. Soils with restrictions to plant growth often have a narrow range of available water (darker blue region in graphs on following pages) or aeration (pale brown region in graphs on following pages). The water retention data have in most instances been estimated using the predictive equations from Williams et al. (1992) or Cresswell and Paydar's (1996) two-point method.

The permeability of a soil profile is indicated by the saturated hydraulic conductivity in mm $hr^{-1}$. In general terms, soil layers with low hydraulic conductivity (e.g. less than the local rainfall intensities) will cause waterlogging and possibly generate runoff and erosion depending on the landscape setting.

Bulk density gives a general indication of limitations to root growth—bulk densities higher than 1.5 Mg $m^{-3}$ are often limiting while values less than 1.0 Mg $m^{-3}$ are very low and relatively uncommon. Further information on the interpretation of soil physical properties can be found in standard texts such as White (1997) or Hillel (1982). The source of data or estimation method used for each figure is denoted on the axis title using superscripts wherever direct measurements were not available.

- A Water retention data estimated using Williams et al. (1992)
- B Water retention data extrapolated from direct measurements using Cresswell and Paydar (1996)
- C Estimate based on direct measurements of similar soils
- D Estimate based on experience with similar soils

The values for soil properties at the immediate soil surface (i.e. 0.00 m depth) are rarely determined and they have been extrapolated manually using the near surface measurements (usually at 0.1 m).

Chemical characterization is restricted to the sum of exchangeable basic cations (Ca, Mg, K, Na) expressed as cmol(+) $kg^{-1}$, exchangeable sodium percentage (ESP), pH (1:5 soil:water) and electrical conductivity (1:5 soil:water dS $m^{-1}$). The ESP is not presented for soils with a very low sum of exchangeable basic cations because the interpretation of its effect on physical properties is unclear. In the remaining soils, an ESP of 6% or more is associated with dispersive clays and soil structure less suited to root growth.

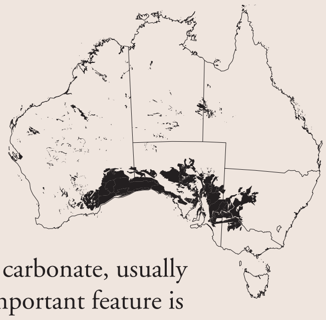
In most instances the analytical data are from the described profiles. Laboratory methods are generally consistent with those described in Rayment and Higginson (1992). More details can be obtained from the sources of the data listed in the individual acknowledgments.

### Related soils and common names

Many informal names are used for soils and these vary greatly between districts. Common names often perpetuate misunderstanding and prevent clear communication. However, some of the more useful common names are included along with superseded class names from previous classification systems.

### Soil qualities, occurrence and land use

Descriptive accounts of the main soil qualities relating to agriculture are presented. More specific rating systems for individual soils can be obtained from State and Territory land resource agencies. It should be appreciated that in a number of topics only broad generalisations are possible given the space constraints and the obvious difficulties in giving adequate brief accounts of, for example, the Australia wide occurrence and land use of widespread soils.



# CALCAROSOLS

The dominating feature of these soils is the presence of variable amounts of calcium carbonate, usually throughout the profile, or directly below a weakly developed A horizon. A further important feature is the absence of a clear or abrupt textural B horizon.

## Supracalcic Calcarosols

Soils with a calcareous horizon consisting of 20% to 50% of hard calcrete fragments, carbonate nodules or concretions, or carbonate coated gravel. An example of a *Endohypersodic, Regolithic, Supracalcic Calcarosol* is given below.

### Environment

*Distribution*: These Calcarosols occur widely in the Mallee region of South Australia, southern New South Wales, southern Western Australia and north-western Victoria.

*Climate*: Mean annual rainfall is approximately 300 mm to 350 mm and is winter-dominant.

*Parent materials or substrate*: Cainozoic sediments with variable calcareous aeolian accession.

*Landform*: Gently undulating plains, low rises and associated remnant calcrete rises.

*Native vegetation*: Sparse to mid-dense mallee shrubland or woodland on flats and rises.

### Land use

Mostly cropping (wheat and barley) and grazing of volunteer annual pastures.

### Common variants

The Supracalcic soils may vary in their substrate materials, amounts of soft carbonate, and the degree of B horizon sodicity.

### Nomenclature

Also known as Solonised Brown Soils and Mallee Soils.

### Soil qualities

*Water availability*: Low in the rootzone (50 mm).

*Drainage*: Well drained. Soil never stays saturated for more than a few days.

*Aeration*: Well aerated in the upper profile.

*Physical root limitations*: May be restricted by calcrete fragments.

*Erosion hazard*: Low to moderate when the soil surface is exposed. Sandier types are more susceptible to wind erosion.

*Nutrient availability*: Low nutrient status/availability in carbonate horizons.

Phosphorus fertiliser is essential.

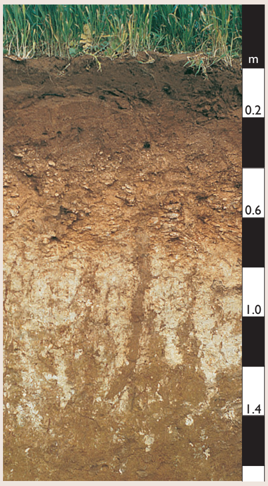
*Toxicities*: High subsoil boron and sodium will affect root growth.

*Workability*: Soft/firm surface. Good workability.

### Acknowledgment

Photo, soil description and laboratory data from Primary Industries and Resources, South Australia. Site MM009.

## Typical profile



Southern Murray Mallee, South Australia.

### Soil description of a typical profile

A1 0 – 0.14 m Dark reddish brown (5YR 3/4) sandy loam; single grain structure; abrupt boundary to:

B21t 0.14 – 0.30 m Dark reddish brown (2.5YR 3/4) sandy clay loam; weak columnar structure; clear boundary to:

B21k 0.30 – 0.48 m Red (2.5YR 4/6) sandy clay loam; 20 – 50% hard carbonate fragments or nodules; massive structure; gradual boundary to:

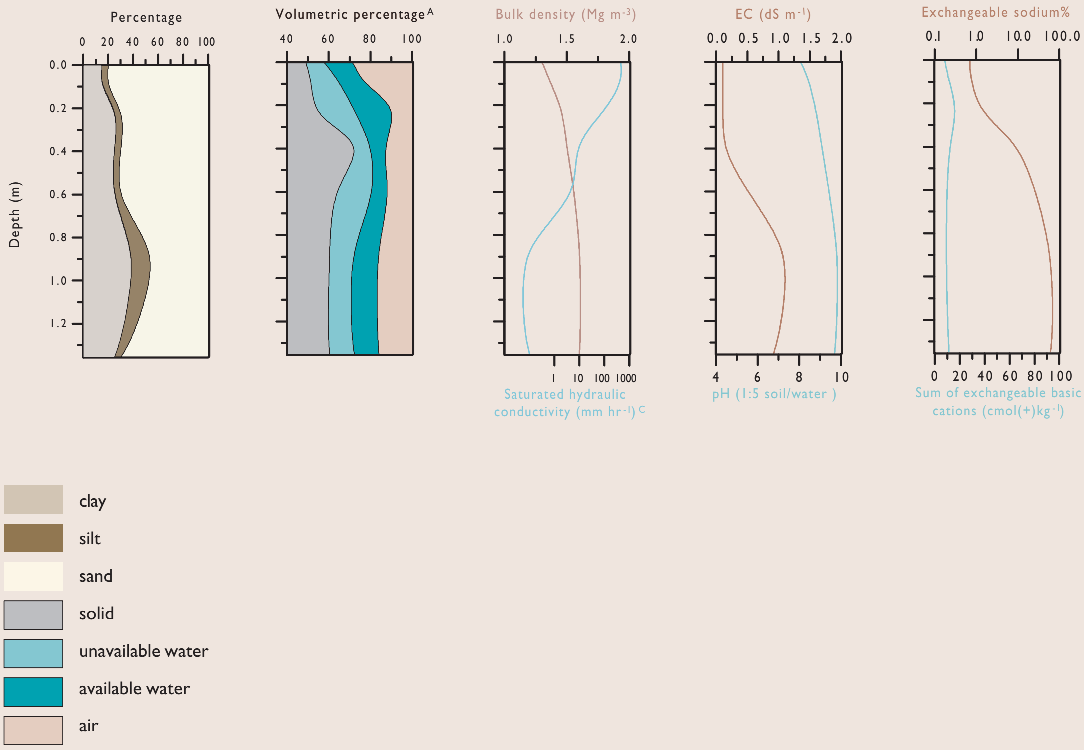
B22k 0.48 – 0.68 m Red (2.5YR 4/8) sandy clay loam; 20 – 50% hard carbonate fragments or nodules; massive structure; gradual boundary to:

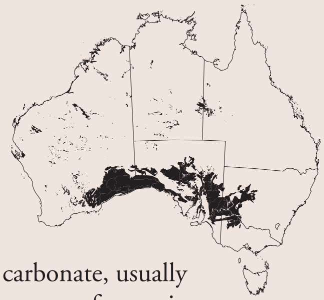
B23k 0.68 – 1.08 m Yellowish red (5YR 5/8) light clay; 20 – 50% soft carbonate; massive structure; diffuse boundary to:

C11 1.08 – 1.62 m Strong brown (7.5YR 5/8) sandy clay loam; 2 – 10% soft carbonate; massive structure; diffuse boundary to:

C12 1.62 – 2.00 m Reddish yellow (7.5YR 6/6) sandy clay loam; massive structure.

### Laboratory data for the typical profile





# CALCAROSOLS

The dominating feature of these soils is the presence of variable amounts of calcium carbonate, usually throughout the profile, or directly below a weakly developed A horizon. A further important feature is the absence of a clear or abrupt textural B horizon.

## Calcic Calcarosols

Calcic Calcarosols have a calcareous horizon consisting of less than 20% of hard calcrete fragments, carbonate nodules or concretions or carbonate coated gravel. An example of a *Epihypersodic, Petrocalcic, Calcic Calcarosol* (directly overlying a calcrete pan) is given below.

### Environment

*Distribution*: Calcic Calcarosols overlying calcrete are common across the Nullabor Plain, southern New South Wales, the Mallee region of South Australia and north-western Victoria.

*Climate*: Mean annual rainfall for the major occurrences ranges from 200 mm to 350 mm and is winter dominant.

*Parent materials or substrate*: Calcrete overlying sediments.

*Landform*: Level plains (Nullabor) and undulating dissected plains with stony calcrete flats and rises elsewhere.

*Native vegetation*: Sparse to mid-dense mallee vegetation on the flats and rises. Low open shrubland on the Nullabor Plain.

### Land use

Predominantly wheat and barley cropping (where rainfall is adequate) in rotation with annual volunteer pastures.

### Common variants

The depth to hard calcrete is variable and it may occur as a continuous pan. Many of the Calcic Calcarosols are Regolithic rather than Petrocalcic, similar to the previous soil.

### Nomenclature

Also known as Grey-Brown and Red Calcareous Soils, Solonised Brown Soils and Mallee Soils.

### Soil qualities

*Water availability*: Very low (30 mm) in the root zone. Crops are frequently stressed in spring.

*Drainage*: Well drained. Soil never remains saturated for more than a few days.

*Aeration*: Well aerated in the upper profile.

*Physical root limitations*: Restricted by stone and boulder calcrete.

*Erosion hazard*: Low.

*Nutrient availability*: Low phosphorus (fertiliser essential) and nitrogen (depends on pasture legume). Copper and zinc are marginal.

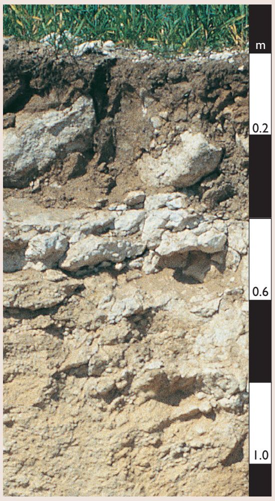
*Toxicities*: Possibly boron.

*Workability*: Firm surface. Good workability. Stoniness may affect farm equipment.

### Acknowledgment

Photo, soil description and laboratory data from Primary Industries and Resources, South Australia. Site MM011.

## Typical profile




Southern Murray Mallee,
South Australia.

### Soil description of a typical profile

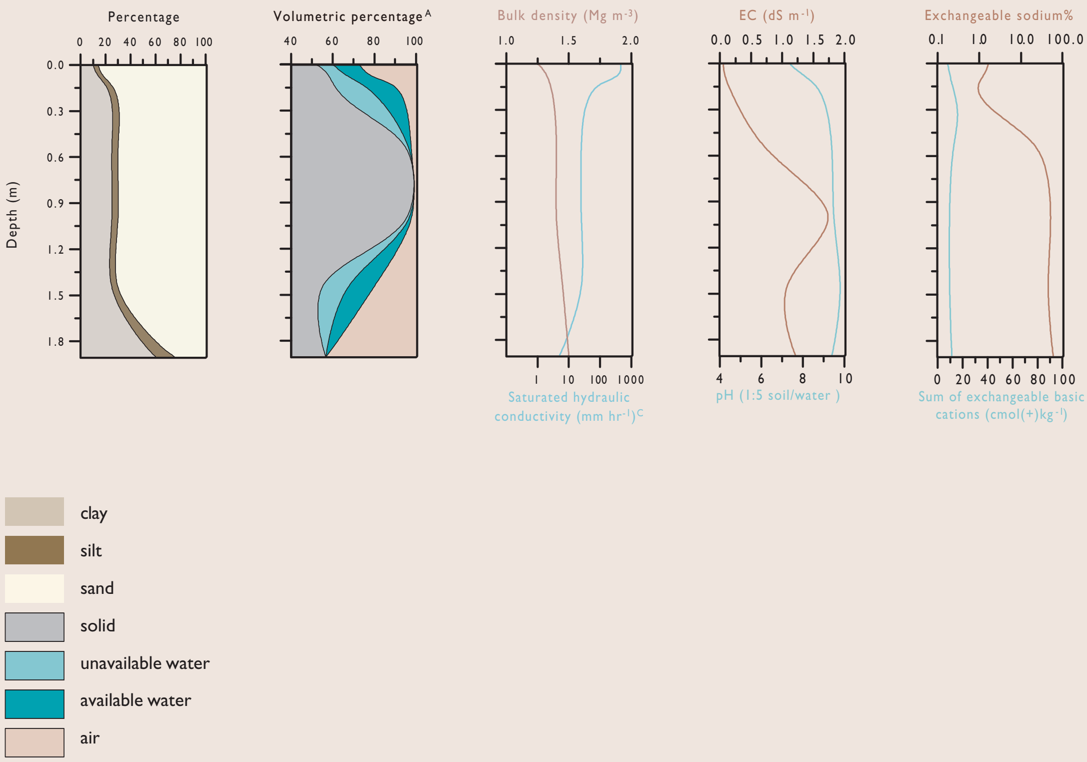
Ap 0 – 0.09 m Dark brown (7.5YR 3/2) sandy loam; single grain structure; abrupt boundary to:

Bk 0.09 – 0.18 m Brown (7.5YR 4/2) sandy clay loam; weak subangular blocky structure; abrupt boundary to:

2Bkm 0.18 – 0.81 m Brown (7.5YR 5/4) sandy clay loam; massive calcrete fragments (> 90%); massive structure; clear boundary to:

C 0.81 – 1.70 m Light brown (7.5YR 7/4) sandy clay loam; massive structure.

### Laboratory data for the typical profile



## CHROMOSOLS

The essential feature of Chromosols is the strong texture contrast between the A and B horizons. They are distinguished from other texture contrast soils by not being strongly acidic (cf Kurosols) or sodic (cf Sodosols) in their upper B horizons. In their natural condition, these soils may have favourable physical and chemical properties but many now have hardsetting surface layers with structural degradation caused by long-term cultivation.

### Red Chromosols

Although these soils have clayey B horizons they tend to be well drained. A typical example of a *Haplic, Calcic, Red Chromosol* is given below.

#### Environment

*Distribution*: A widespread soil in the cropping lands of eastern and southern Australia and to a lesser extent south-west Western Australia.

*Climate*: Broad mean annual rainfall range, approximately 300 mm to 1200 mm.

*Parent materials or substrate*: These vary widely from alluvial to aeolian sediment and less basic metamorphic and igneous rocks.

*Landform*: Undulating plains to rolling hills.

*Native vegetation*: Eucalypt woodland and sclerophyll forests.

#### Land use

Red Chromosols are prominent in the wheat belt of southern New South Wales, northern Victoria and the mid-north of South Australia where they are widely used for cereal and oil seed growing. In southern Queensland they are used for mixed farming but in the tropics mainly for cattle grazing of native pastures.

#### Common variants

Red Chromosols commonly lack an accumulation of carbonate in higher rainfall regions although base status is usually moderate to high. Bleached A2 horizons may occur indicating restricted drainage. Such variants are often sodic at depth and grade into Sodosols.

#### Nomenclature

Also known as Red – Brown Earths, Non-Calcic Brown Soils, Red Podzolic Soils or Red Duplex Soils.

#### Soil qualities

*Water availability*: Storage varies greatly but usually adequate and between 100 – 200 mm.

*Drainage*: Imperfectly to well drained but the B horizons can be an impediment.

*Aeration*: Generally adequate although temporary saturation can occur in bleached A2 horizons if present.

*Physical root limitations*: Main restrictions are caused by strong and dense B horizons and structurally degraded surface layers

*Erosion hazard*: Low to moderate depending on slope but increasing with degradation of the A horizons. Susceptible to surface slaking upon rapid wetting, resulting in hardsetting if organic matter is low.

*Nutrient availability*: Low contents of phosphorus and nitrogen with good responses to fertilizer.

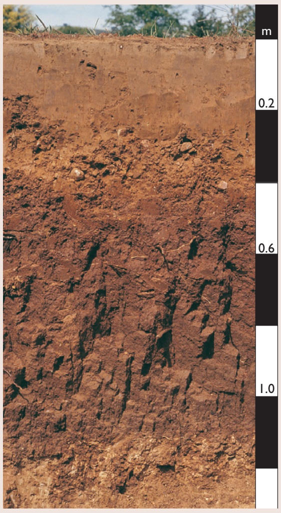
*Toxicities*: Boron in areas of Western Australia, South Australia and Victoria. Less commonly, aluminium associated with induced acidification.

*Workability*: Degraded, hardsetting surfaces have poor workability but this can usually be overcome with increased organic matter.

#### Acknowledgment

Photo from CSIRO Land and Water. Soil description and laboratory data from CSIRO Land and Water and Oades et al. (1981). Urrbrae Loam.

## Typical profile




Waite Institute, Adelaide, South Australia.

### Soil description of a typical profile

A1 0 – 0.15 m Dark reddish brown (5YR3/4) fine sandy loam; moderate subangular blocky structure; soft consistence; diffuse boundary to:

A2 0.15 – 0.26 m Red (2.5YR 5/8) sandy clay loam; moderate subangular blocky structure; soft consistence; sharp boundary to:

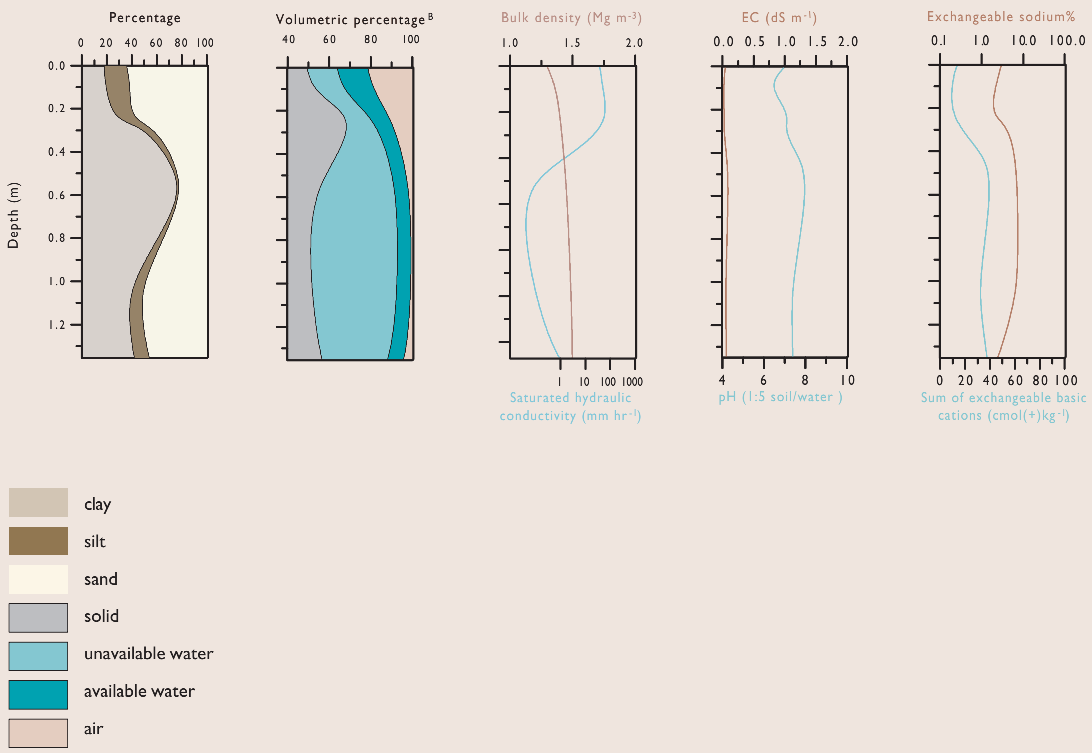
B1 0.26 – 0.30 m Dark red (2.5 YR 3/6) light medium clay; moderate subangular blocky structure; soft consistence; clear boundary to:

B22 0.30 – 0.80 m Dark red (2.5 YR 3/6) heavy clay; subangular blocky parting to strong subangular blocky structure; firm consistence; clear boundary to:

B2k 0.80 – 1.10 m Yellowish red (5YR 4/6) medium clay; weak subangular blocky structure; 2 – 10% carbonate nodules; very hard consistence; diffuse boundary to:

BCk 1.10+ Yellowish brown (10YR 5/6) medium clay; moderate subangular blocky structure; firm consistence; 10 – 20% soft carbonate segregations.

### Laboratory data for the typical profile



# CHROMOSOLS

The essential feature of Chromosols is the strong texture contrast between the A and B horizons. They are distinguished from other texture contrast soils by not being strongly acidic (cf Kurosols) or sodic (cf Sodosols) in their upper B horizons. In their natural condition, these soils may have favourable physical and chemical properties but many now have hardsetting surface layers with structural degradation caused by long-term cultivation.

## Brown Chromosols

These soils are characterised by brown clay loam or clay B horizons. An example of a *Bleached-Mottled, Mesotrophic, Brown Chromosol* with a conspicuously bleached A2 horizon is described below.

### Environment

*Distribution*: A common soil of eastern, southern and south-western Australia but is less extensive than those with a dominantly red colour class.

*Climate*: Broad mean annual rainfall range, approximately 300 mm to 1200 mm.

*Parent materials or substrate*: Wide range of rocks and sediments other than more basic materials.

*Landform*: Level to undulating plains, some hilly to high, hilly lands.

*Native vegetation*: Eucalypt woodland and open forest.

### Land use

The largest areas of Brown Chromosols used for agriculture are in the western part of the Western Australian wheatbelt where they are used for cereals and some lupins. In south-eastern Australia the soils are used mainly for improved pastures with some cropping (usually where the surface soil has a suitable depth, texture and workability).

### Common variants

Although an A2 horizon is commonly present it may not always be bleached. This usually implies better internal drainage. Base status varies widely and subsoil pH is more commonly neutral to slightly acid. Some profiles become sodic in the lower B horizons and thus grade to Sodosols. Ironstone nodule horizons (> 20% nodules) may also occur, usually below the A1 horizon.

### Nomenclature

Otherwise known as Brown Duplex Soils, Brown Podzolic Soils or Lateritic Podzolic Soils.

### Soil qualities

*Water availability*: Low to moderate in the rootzone.

*Drainage*: The bleached A2 horizon and mottled B horizon suggests the soil is imperfectly drained.

*Aeration*: Moderate. Temporary saturation may occur in the A2 horizon.

*Physical root limitations*: Slight restriction by some clay subsoils.

*Erosion hazard*: Moderate water erosion potential.

*Nutrient availability*: Needs organic matter and lime to maintain moderate fertility. Phosphorus content is usually low.

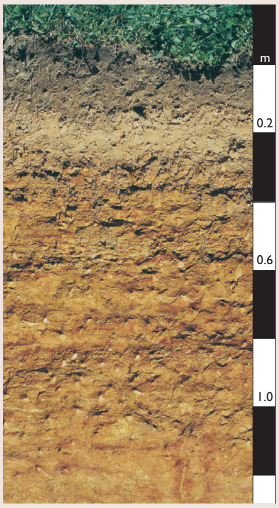
*Toxicities*: Low pH in deep subsoil – probable aluminium toxicity.

*Workability*: Good due to lack of stone and a relatively well structured surface.

### Acknowledgment

Photo, soil description and laboratory data from Primary Industries and Resources, South Australia. Site CH 013.

## Typical profile




Adelaide Hills, South Australia.

### Soil description of a typical profile

A1 0 – 0.15 m Very dark greyish brown (10YR 3/2 d) sandy loam; weak granular structure; moderately moist, very soft consistence; 10% ironstone and sandstone gravel; clear boundary to:

A2 0.15 – 0.33 m Pink (7.5YR 8/3 d) sandy clay loam; massive structure; moderately moist, very soft consistence; 10% sandstone and ironstone gravel; clear boundary to:

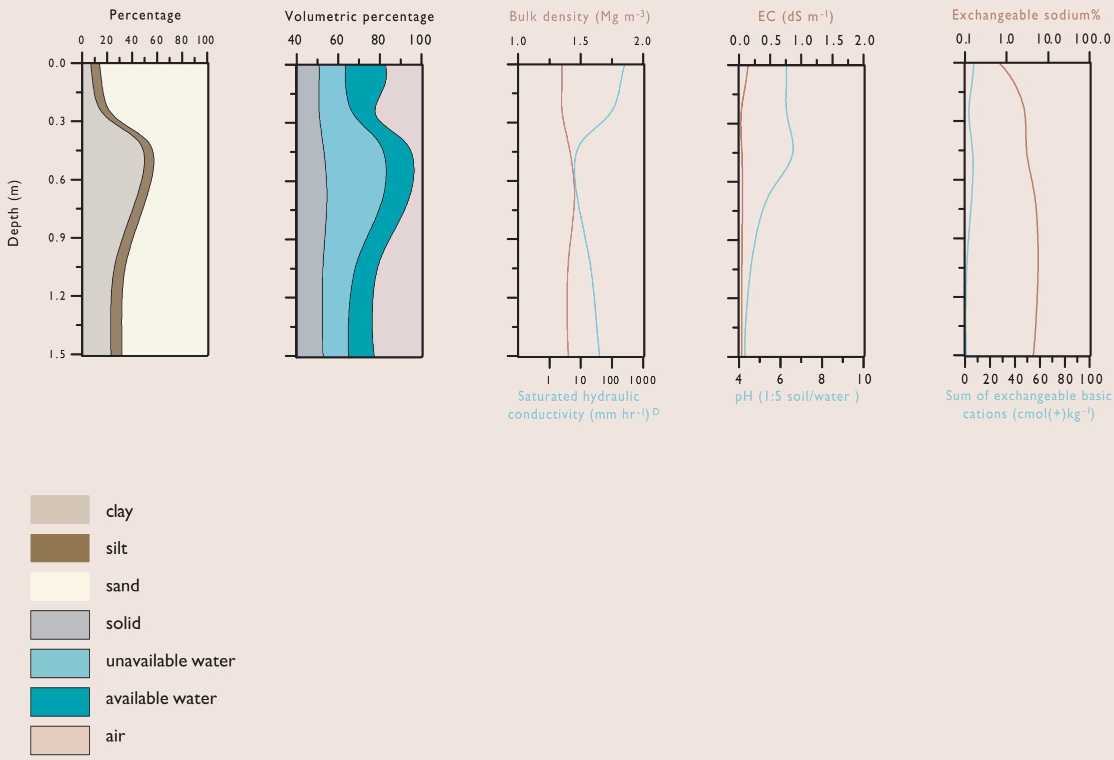
B21 0.33 – 0.48 m Strong brown (7.5YR 5/8) sandy light clay with red mottles; strong polyhedral structure; moderately moist, soft consistence; gradual boundary to:

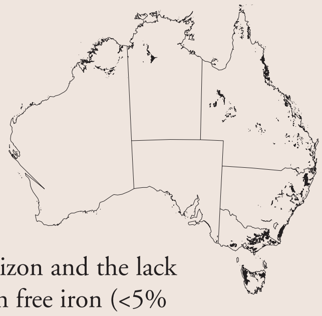
B22 0.48 – 0.85 m Brownish yellow (10YR 6/8) light clay; moderate polyhedral structure; moderately moist, firm consistence; diffuse boundary to:

B3 0.85 – 1.20 m Brownish yellow (10YR 6/8) fine sandy clay loam; massive structure; moderately moist, firm consistence; diffuse boundary to:

Cr 1.20 – 1.80 m Yellow (10YR 8/6) sandy clay loam; moderately moist, firm consistence; highly weathered kaolinitic sandstone.

### Laboratory data for the typical profile





# DERMOSOLS

Dermosols are distinguished by their moderate to strong structured B2 (subsoil) horizon and the lack of a strong texture contrast between the A and B horizons. These soils are not high in free iron (<5% Fe), nor are they calcareous throughout the profile. Dermosols are a diverse Order, bringing together a wide range of soils with some common important properties.

## Red Dermosols

Red and Brown Dermosols are the most common of the Suborders. A description of a *Haplic, Eutrophic, Red Dermosol* is given below.

### Environment

*Distribution*: Red Dermosols are most common in the east Australian coastal and subcoastal zones and northern Tasmania. The eutrophic and calcareous forms are uncommon in the higher rainfall areas and dominate the arid and semi-arid occurrences.

*Climate*: Very broad mean annual rainfall range, 300 mm to 4000 mm in the wetter east coastal zones.

*Parent materials or substrate*: Acid to intermediate igneous and metamorphic rocks and derived alluvium.

*Landform*: Undulating plains to high, hilly or mountainous lands with terraced stream valleys.

*Native vegetation*: Eucalypt forest, rainforest and open woodland.

### Land use

The Eutrophic, Red Dermosols are closely associated with Red Chromosols in the wheatbelt of New South Wales and are also common in north-east Victoria and Gippsland where they generally occur on lower river terraces and are widely used for improved pastures. Small areas of Acidic, Dystrophic forms are used for sugar cane in north Queensland where landform is suitable.

### Common variants

As would be expected from their wide rainfall range, Red Dermosols vary greatly in base status from very low (dystrophic) and acidic, to forms with calcareous subsoils. Some soils are sodic in their deep subsoils, particularly those low rainfall forms that grade to Vertosols.

### Nomenclature

Also known as gradational Red Podzolic soils and erroneously as Krasnozems.

### Soil qualities

*Water availability*: Plant available water capacity is usually greater than 100 mm and may exceed 200 mm in deeper soils.

*Drainage*: Relatively well drained due to well developed soil structure.

*Aeration*: No restriction.

*Physical root limitations*: Effective rooting depths are commonly 1.0 m.

*Erosion hazard*: Susceptible to surface slaking upon rapid wetting, resulting in hardsetting if organic matter is low.

*Nutrient availability*: Highly variable. Organic matter declines on cultivation.

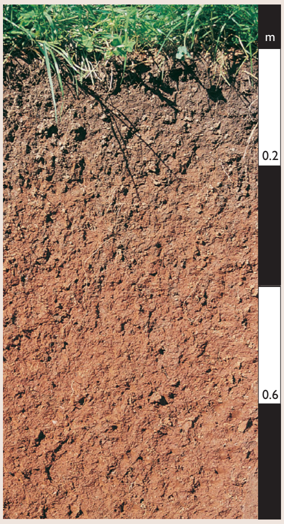
*Toxicities*: Aluminium toxicity may become a problem if pH levels decline to below 5.5.

*Workability*: Good, however a hardsetting surface will restrict workability in degraded soils.


### Acknowledgment

Photo, soil description and laboratory data from Department of Natural Resources and Environment, Victoria. Site NE 25.

## Typical profile




Tallangatta Valley, north-east Victoria.

### Soil description of a typical profile

A1 0 – 0.15 m Very dark greyish brown (10YR 3/2) light fine sandy clay loam; moderate medium blocky parting to moderate fine blocky structure; moist, firm consistence; clear boundary to:

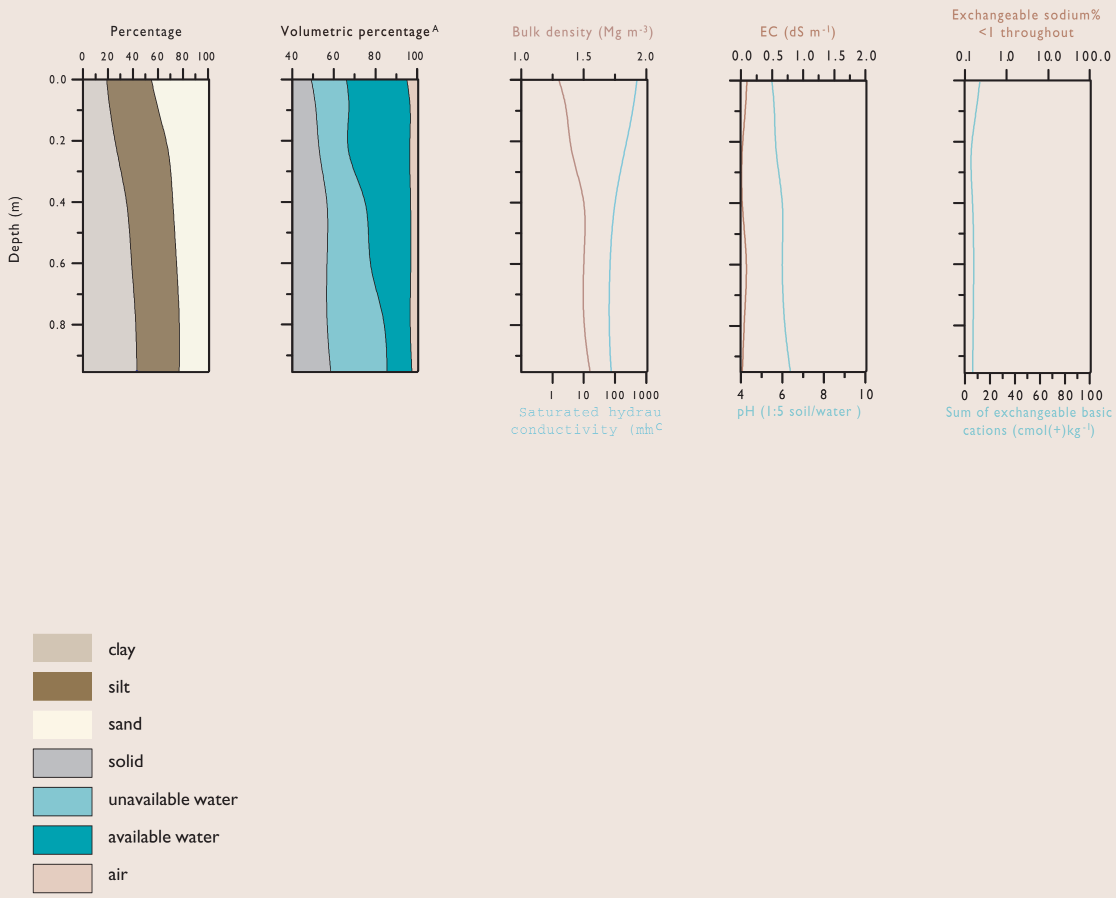
A2 0.15 – 0.30 m Strong brown (7.5YR 4/6) fine sandy clay loam with brown worm casts; moderate coarse blocky parting to fine blocky structure; moist, firm consistence; clear boundary to:

B21 0.30 – 0.50 m Yellowish red (5YR 4/6) clay loam; moderate medium blocky parting to strong fine blocky structure; moist, firm consistence; gradual boundary to:

B22 0.50 – 0.70 m Yellowish red (5YR 4/6) fine sandy light clay; moderate medium blocky parting to strong fine blocky structure; moist, firm consistence; gradual boundary to:

B23 0.70 – 0.85 m Yellowish red (5YR 5/8) light clay; moderate medium blocky parting to medium fine blocky structure; moist, soft consistence. At 1.5 m depth a coarse river gravel layer occurs.

### Laboratory data for the typical profile



## FERROSOLS

These very permeable clayey soils have relatively high contents of free iron oxide (>5%Fe) and no strong texture contrast between the A and B horizons. The most common forms have strong polyhedral or blocky compound structure resulting in very favourable physical properties. The majority of Ferrosols are red in colour, with fewer brown forms, and usually exhibit subplastic properties.

### Red Ferrosols

Although Red Ferrosols have a relatively restricted range in morphological features, they may differ widely in their chemistry. The first typical example given below is that of a *Haplic, Mesotrophic, Red Ferrosol.* These soils have a moderate base status (see below), pH in the B horizon is greater than 5.5 and the soils lack dark or humose A1 horizons.

#### Environment

*Distribution*: Widespread but relatively small occurrences of Haplic, Red Ferrosols occur mainly in subcoastal eastern Australia from north Queensland to Tasmania and in the Kimberley region of north-west Australia.

*Climate*: Mean annual rainfall ranges from 500 mm to over 1000 mm. Mesotrophic forms are less common at the extreme ends of this range.

*Parent materials or substrate*: Almost universally derived from basic igneous rocks such as basalt and dolerite, less extensively on ultrabasics such as serpentinite, and from derived alluvium.

*Landform*: Undulating plains and plateaux and some high, hilly lands.

*Native vegetation*: Rainfall dependent, ranging from open woodland to eucalypt forest and rainforests. Most areas are now cleared.

#### Land use

Haplic, Red Ferrosols are used for a wide variety of crops including sugar cane and tropical tree crops in south-central Queensland, grain crops (maize and peanuts) in north and south Queensland, vegetables (particularly potatoes) from north Queensland to Tasmania, improved pastures for dairying and horticultural crops over a wide latitude range. Cattle grazing of native pastures is the sole form of land use in the drier regions of north Queensland and the Kimberley region.

#### Common variants

Haplic, Red Ferrosols vary widely in base status with occasional soils calcareous in lower B or BC horizons. Dark A1 horizons tend to be masked by the high iron contents and hence are uncommon.

#### Nomenclature

Also known as Krasnozems and Euchrozems.

#### Soil qualities

*Water availability*: High to very high (250 mm).

*Drainage*: Well drained soils. Runoff may occur under high intensity rainfall.

*Aeration*: Short term saturation may occur under prolonged, heavy rainfall on compacted soil.

*Physical root limitations*: No serious limitation to root growth unless the soil is compacted.

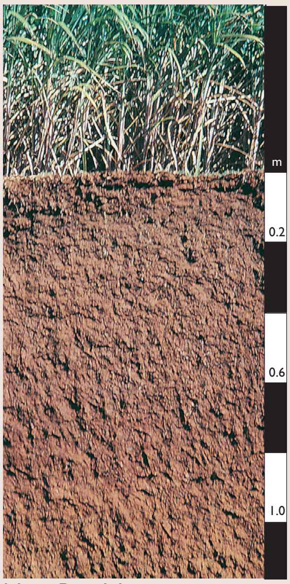
*Erosion hazard*: Often serious on slopes where compaction of surface soil layers leads to low infiltration.

*Nutrient availability*: Cultivated or eroded forms show deficiencies in nitrogen and phosphorus, most show high phosphorus sorption due to high free iron oxide.

*Toxicities*: Aluminium toxicity may be induced by high nitrogen fertiliser application causing strong acidity.

*Workability*: Compaction caused by heavy machinery on wet soils will lead to poor workability.

## Typical profile




Near Bundaberg,
Queensland.

### Soil description of a typical profile

A1 0 – 0.20 m Dark reddish brown (5YR 3/3) light clay; moderate polyhedral structure; dry, firm consistence; diffuse boundary to:

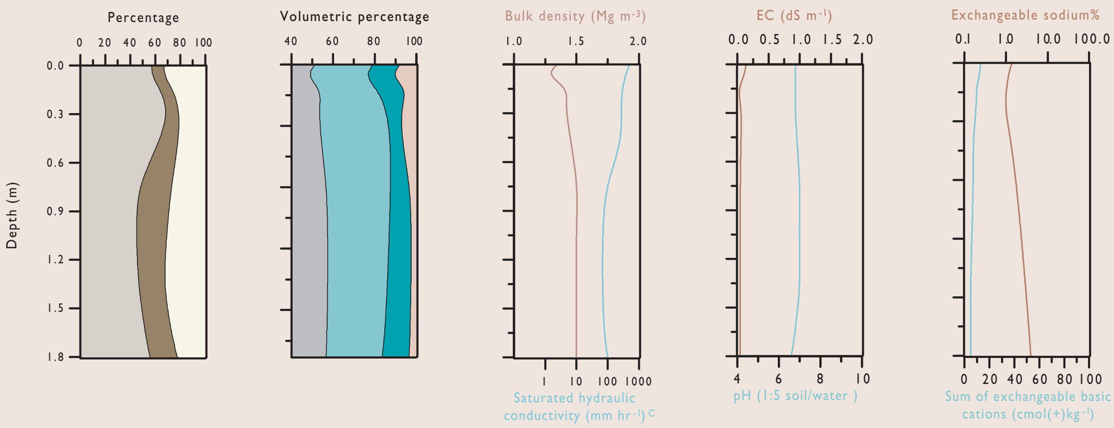
B21 0.20 – 0.90 m Reddish brown (2.5YR 3/4) light clay; strong polyhedral structure; moist, soft consistence; diffuse boundary to:

B22 0.90 – 1.80 m Reddish brown (2.5YR 3/5) light clay; moderate blocky structure; moist, soft consistence; diffuse boundary to:

B23 1.80 – 2.10 m Yellowish red (5YR 4/6) light clay with faint brownish mottles; slight amount of basalt gravel; moist, very soft consistence.

BC 2.10 m+ Mottled light clay with increasing weathered basalt.

### Laboratory data for the typical profile




clay
silt
sand
solid
unavailable water
available water
air

### Acknowledgment

Photo from CSIRO Land and Water. Soil description and laboratory data from Stace et al. (1968), p. 305, Profile B.

# FERROSOLS

## Red Ferrosols (continued)

The soil described and discussed below is a *Acidic, Mesotrophic, Red Ferrosol* of moderate base status but is strongly acid (pH <5.5) in the B2 horizon and lacks a dark or humose A1 horizon.

### Environment

*Distribution*: Almost entirely determined by the occurrence of basalt and high rainfall. The acidic soils occur mainly on the wetter east coastal areas of Australia and northern Tasmania.

*Climate*: Mean annual rainfall range approximately 1000 mm to over 3000 mm in near coastal north Queensland.

*Parent materials or substrate*: Basic igneous rocks (particularly basalt) and derived alluvium.

*Landform*: General range from near level plains to undulating tablelands and mountainous areas.

*Native vegetation*: Tropical/ temperate rainforest in high rainfall areas. Eucalypt forest elsewhere.

### Land use

Sugar cane is grown on these acidic soils in coastal north Queensland together with bananas and improved pastures for dairy and beef cattle. In the Lismore district of New South Wales intensive horticulture (mainly tree crops) is a feature. In the temperate subcoastal regions of south-east Australia and Tasmania vegetables (particularly potatoes) and improved pastures for dairying are grown.

### Common variants

Dystrophic forms with very low base status generally occur in higher rainfall areas and may have a humose A1 horizon.

### Nomenclature

Also known as Krasnozems.

### Soil qualities

*Water availability*: Generally high to very high (> 250 mm).

*Drainage*: Very well drained with a high infiltration rate due to their strongly developed and stable structure.

*Aeration*: These structured soils are generally well aerated in profiles not affected by compaction.

*Physical root limitations*: No serious limitation to root growth unless the soil is compacted.

*Erosion hazard*: High under high intensity rainfall. Compaction may lead to greater runoff and erosion particularly when vegetation cover is minimal.

*Nutrient availability*: The nutrient status of these strongly leached soils is usually low below the surface horizon. Strong phosphorus sorption due to high free iron oxide and high pH buffering capacity are a feature.

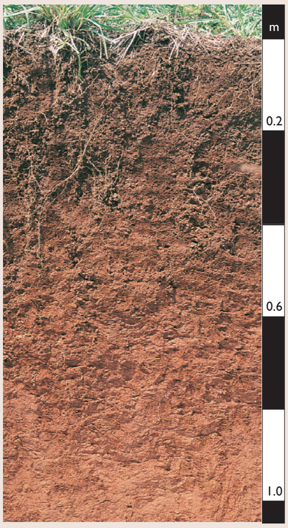
*Toxicities*: May suffer from acidification induced by high nitrogen fertilizer application.

*Workability*: Compaction occurs if over cultivated or tilled when the soil is wetter than its plastic limit.

### Acknowledgment

Photo, soil description and laboratory data from Department of Natural Resources and Environment, Victoria. Site GP 15.

## Typical profile




Ellinbank district, West Gippsland, Victoria.

### Soil description of a typical profile

A1 0 – 0.30 m Dark brown (7YR 3/4) fine sandy clay loam (subplastic); weak coarse blocky parting to very fine polyhedral structure; moist, soft consistence; gradual boundary to:

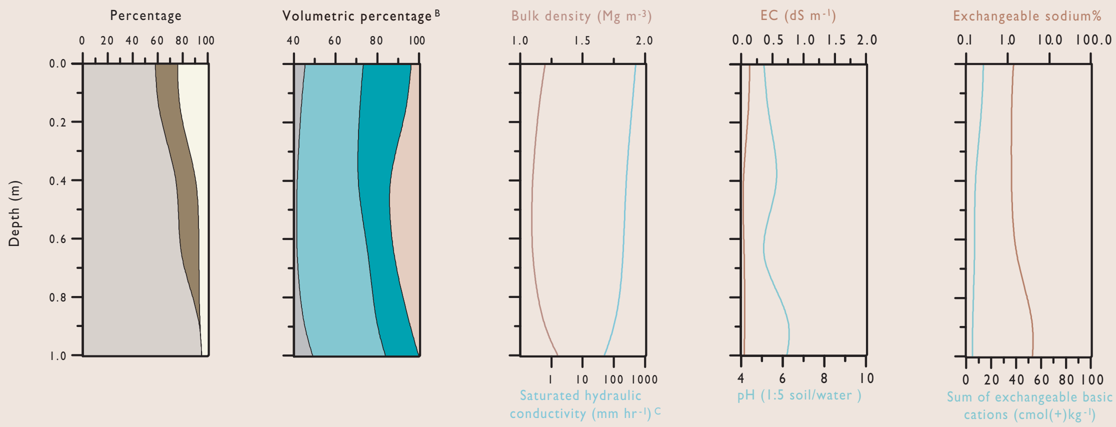
B21 0.30 – 0.50 m Yellowish red (5YR 4/6) clay loam (subplastic); moderate medium blocky parting to strong fine blocky structure; moist, soft consistence; gradual boundary to:

B22 0.50 – 0.80 m Red (2.5YR 5/8) light clay (subplastic); moderate medium blocky parting to strong fine blocky structure; gradual boundary to:

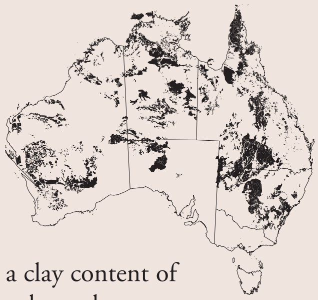
B23 0.80 – 1.00 m Yellowish red (5YR 5/8) light clay (subplastic); weak coarse blocky parting to strong fine polyhedral structure; clear boundary to:

B24 1.00 m+ Yellowish red (5YR 5/8) light clay (subplastic); moderate coarse polyhedral structure; 30% clay/ iron oxide nodules (10 – 20 mm in size).

### Laboratory data for the typical profile




clay
silt
sand
solid
unavailable water
available water
air



# KANDOSOLS

The Kandosol soil order accommodates soils with weak or massive subsoil structure, a clay content of greater than 15% in the B horizon, no strong texture contrast and no carbonate throughout the profile. The soils are often very deep (3.0 m or more). Kandosols may often grade to Dermosols depending on structure grade.

## Red Kandosols

Red Kandosols are the most commonly occurring soils of the Kandosol Order. Many are relict in low rainfall regions. A description of a typical *Haplic, Eutrophic, Red Kandosol* profile is given below.

### Environment

*Distribution*: Red Kandosols are widely distributed throughout Australia except for Victoria and Tasmania and are largely independent of present rainfall.

*Climate*: Mean annual rainfall generally ranges from 200 mm to 4000 mm.

*Parent materials or substrate*: A wide range of more acidic igneous and sedimentary rocks and sediments.

*Landform*: Wide range from extensive level plains to low hills, plateaux and mountains.

*Native vegetation*: Eucalypt woodlands and open forest are most common.

### Land use

Cereal and oilseed cropping in south-east Australia, sugar cane in coastal Queensland and extensive beef cattle grazing of native pasture in monsoonal Australia. Sparse sheep and cattle grazing on the arid lands of the interior.

### Common variants

Red Kandosols vary widely in base status and strongly acid dystrophic forms are common across parts of the arid zone where it is assumed that they are relict soils. Soils with a subsoil accumulation of carbonate are also common in arid regions of the continent. In some soils ferromanganiferous nodules may occupy 50% or more of the soil volume by visual estimate.

### Nomenclature

Commonly known as Red Earths.

### Soil qualities

*Water availability*: Moderate to high (150 – 350 mm) but generally less in shallower (< 1.5 m) soils.

*Drainage*: Most are well drained.

*Aeration*: Well aerated.

*Physical root limitations*: There are few restrictions to root growth.

*Erosion hazard*: Severe on slopes in high intensity rainfall areas.

*Nutrient availability*: Usually low in nitrogen and phosphorus.

*Toxicities*: Uncommon.

*Workability*: Surface soil subject to crusting and hardsetting.

### Acknowledgment

Photo, soil description and laboratory data from CSIRO Land and Water. Site CP 307.

## Typical profile


Wagga district, New South Wales.

### Soil description of a typical profile

A11 0-0.08 m Dark reddish brown (5YR 3/2) loam; weak subangular blocky structure; soft consistence; abrupt boundary to:

A12 0.08 – 0.15 m Dark reddish brown (5YR 3/3) sandy clay loam; massive structure; abrupt boundary to:

B21 0.15 – 0.40 m Dark red (2.5YR 3/6) light clay; massive structure; gradual boundary to:

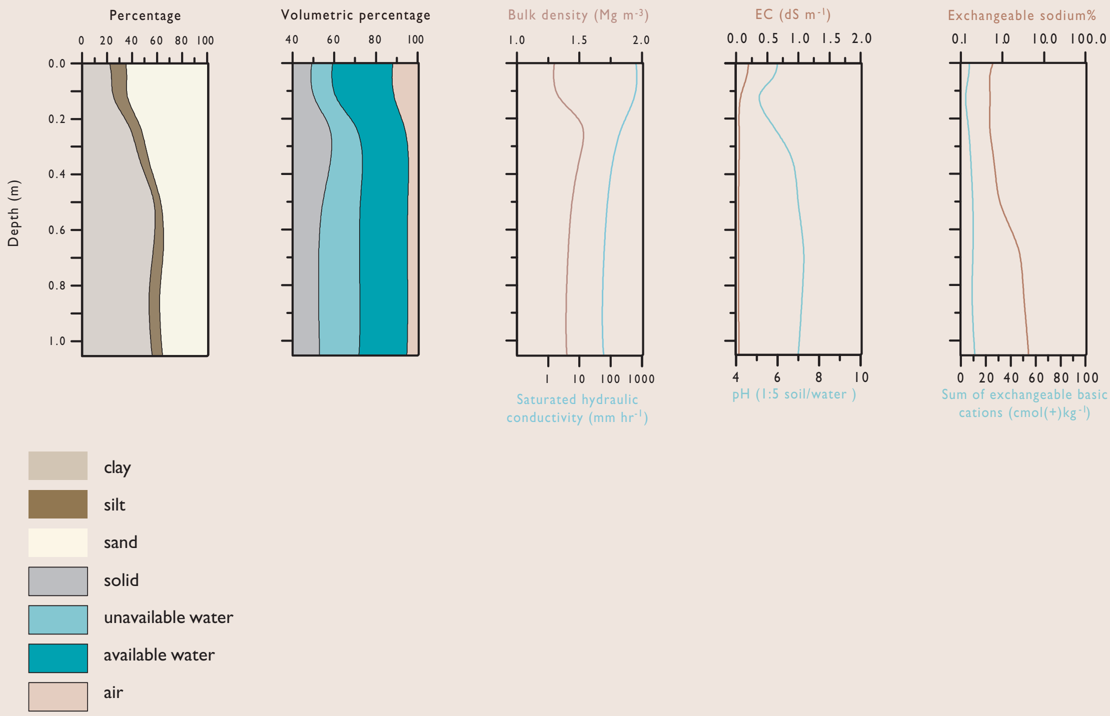
B22 0.40 – 0.60 m Red (2.5YR 4/6) light medium clay; weak polyhedral structure; gradual boundary to:

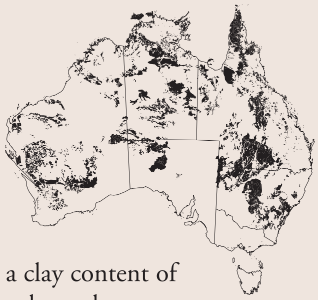
B31 0.60 – 0.75 m Yellowish red (5YR 4/6) medium clay; weak polyhedral structure; gradual boundary to:

B32 0.75 – 0.90 m Strong brown (7.5YR 5/6) medium clay; weak polyhedral structure; 2 – 10% ferromanganiferous nodules and veins; clear boundary to:

2B2 0.90 – 1.20 m+ Yellowish brown (10YR 5/4) weak polyhedral structure; 10 – 20% ferromanganiferous nodules and veins.

### Laboratory data for the typical profile





## KANDOSOLS

The Kandosol soil order accommodates soils with weak or massive subsoil structure, a clay content of greater than 15% in the B horizon, no strong texture contrast and no carbonate throughout the profile. The soils are often very deep (3.0 m or more). Kandosols may often grade to Dermosols depending on structure grade.

### Yellow Kandosols

The Yellow Kandosols are common soils almost Australia-wide. They grade into the brown and grey forms, sometimes in a catenary-type sequence on gentle slopes. A description of a typical *Acidic, Mesotrophic, Yellow Kandosol* is given below.

#### Environment

*Distribution*: The Yellow Kandosols occupy large areas in eastern, northern and south-west Australia.

*Climate*: Broad mean annual rainfall range, approximately 300 mm to 1500 mm.

*Parent materials or substrate*: Siliceous sedimentary rocks and sandy alluvial-colluvial deposits are most common.

*Landform*: A wide range from gently undulating plains to sandstone plateaux.

*Native vegetation*: Rainfall dependent and ranging from shrub woodland through open woodland to eucalypt open forest.

#### Land use

The Yellow Kandosols are used widely for winter cereals and lupins in south-western Australia. Elsewhere they are predominantly used for sparse grazing of native pastures, mainly by beef cattle.

#### Common variants

The Yellow Kandosols can vary widely in base status and soil reaction. They grade to Tenosols when there is little or no texture increase with depth. Many are mottled and contain high amounts of ferruginous nodules.

#### Nomenclature

Commonly known as Yellow Earths and Earthy Sands.

#### Soil qualities

*Water availability*: Generally moderate to high, less in shallower soils.

*Drainage*: Range from highly permeable and rapidly drained to soils with impeded drainage due to impermeable underlying layers.

*Aeration*: Usually well aerated unless impeding layers are present.

*Physical root limitations*: Excessive nodule content may restrict rooting depth.

*Erosion hazard*: Risk following clearing and cultivation.

*Nutrient availability:* Mostly deficient in major and often minor elements.

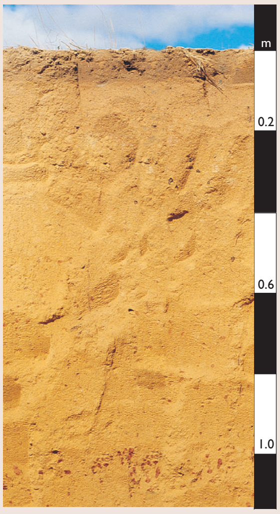
*Toxicities*: Mainly aluminium induced by strong acidity.

*Workability*: Good.

#### Acknowledgment

Photo and soil description from Agriculture Western Australia. Laboratory data for a typical profile from Grealish and Wagnon (1995), p. 77.

## Typical profile




Merredin district, south-west Western Australia.

### Soil description of a typical profile

A1 0 – 0.10 m Light brownish grey (10YR 6/2) loamy sand; single grain structure; loose consistence; clear boundary to:

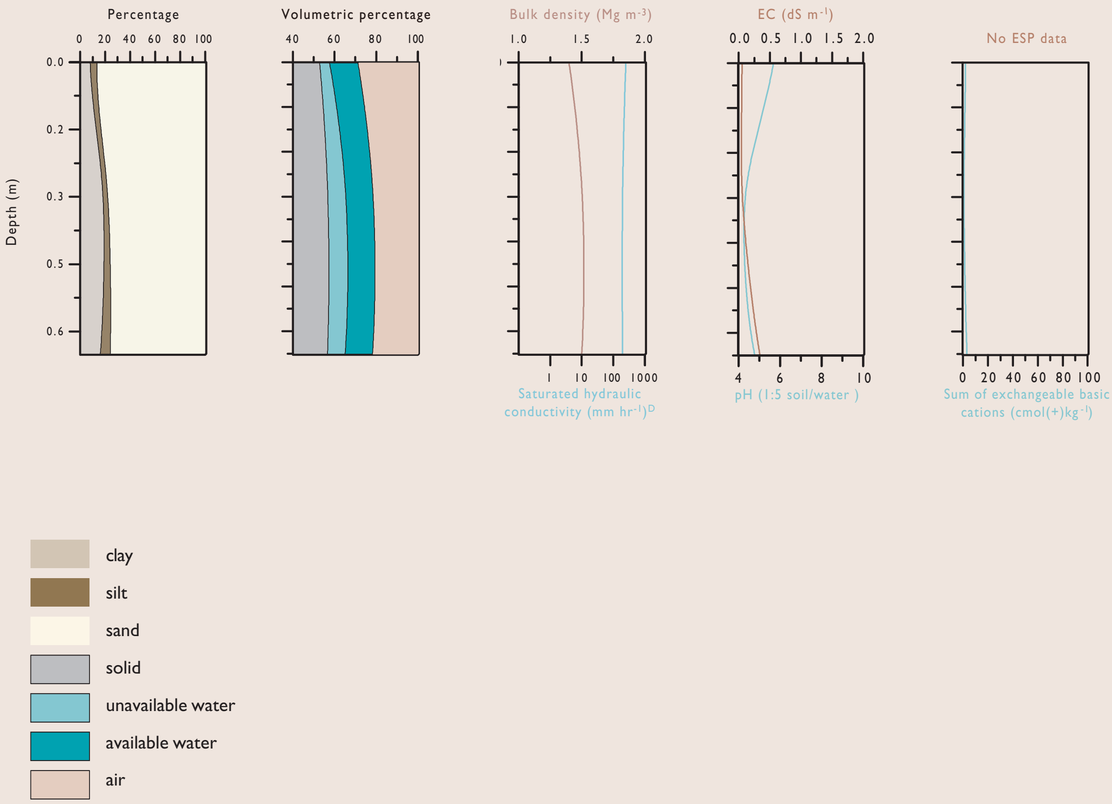
B1 0.10 – 0.45 m Yellow (10YR 7/6) sandy loam; massive structure; earthy fabric; diffuse boundary to:

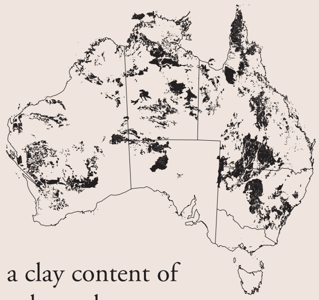
B21 0.45 – 1.05 m Yellow (10YR 7/6) sandy loam; massive structure; earthy fabric; 2 – 10% soft ferruginous nodules; very soft consistence; diffuse boundary to:

B22 1.05 – 1.20 m Yellow (10YR 7/6) light sandy clay loam; massive structure; earthy fabric; 10 – 20% soft ferruginous nodules; very soft consistence; diffuse boundary to:

B23 1.20 – 1.70 m+ Yellow (10YR 7/6) light sandy clay loam; massive structure; earthy fabric; very few soft ferruginous nodules.

### Laboratory data for a typical profile





# KANDOSOLS

The Kandosol soil order accommodates soils with weak or massive subsoil structure, a clay content of greater than 15% in the B horizon, no strong texture contrast and no carbonate throughout the profile. The soils are often very deep (3.0 m or more). Kandosols may often grade to Dermosols depending on structure grade.

## Brown Kandosols

Brown Kandosols are the second most commonly occurring of the Kandosol Suborders and very deep forms are much less common than in the Red Kandosols Suborder. A description of a typical *Acidic, Dystrophic, Brown Kandosol* is given below.

### Environment

*Distribution*: The Brown Kandosols mainly occur in Cape York Peninsula, the Top End of the Northern Territory, inland north-east Queensland, parts of the Sydney region and south-west Western Australia.

*Climate*: Mean annual rainfall range approximately 400 mm to 2000 mm.

*Parent materials or substrate*: Brown Kandosols commonly form on altered siliceous sedimentary rocks and derived alluvium.

*Landform*: Generally occur on extensive, level to undulating plains.

*Native vegetation*: Tall eucalypt forest to low open woodland depending on rainfall.

### Land use

Subcoastal, central New South Wales soils are used intensively for horticulture. Elsewhere beef cattle grazing is the most common land use, although some cereals and lupins are grown in south-west Western Australia.

### Common variants

The Brown Kandosols can vary widely in base status and soil reaction but this may not necessarily relate to present rainfall. B horizon mottling is a feature of some forms, as is the variable presence of ferromanganiferous nodules, which may exceed 50% by visual estimate.

### Nomenclature

Some examples of such soils are known as Yellow Earths.

### Soil qualities

*Water availability*: Generally moderate to high, less in shallower soils.

*Drainage*: Highly permeable and rapidly drained. Mottled and nodular forms have impeded drainage.

*Aeration*: Well aerated unless drainage is impeded.

*Physical root limitations*: Excessive ironstone nodule content may restrict rooting depth.

*Erosion hazard*: Erosion risk depends on vegetation cover, slope and rainfall intensity and may be severe in the tropics when cultivated.

*Nutrient availability*: Mostly very deficient in nitrogen and phosphorus.

*Toxicities*: None known.

*Workability*: Loamy surface soils subject to crusting and hardsetting.

### Acknowledgment

Photo, soil description and laboratory data from CSIRO Land and Water. Site CP 315.

## Typical profile


Kulnura district, Sydney Basin, New South Wales.

### Soil description of a typical profile

A1 0 – 0.10 m Brown (10YR 4/3) sandy loam; weak subangular blocky structure; very soft consistence; clear boundary to:

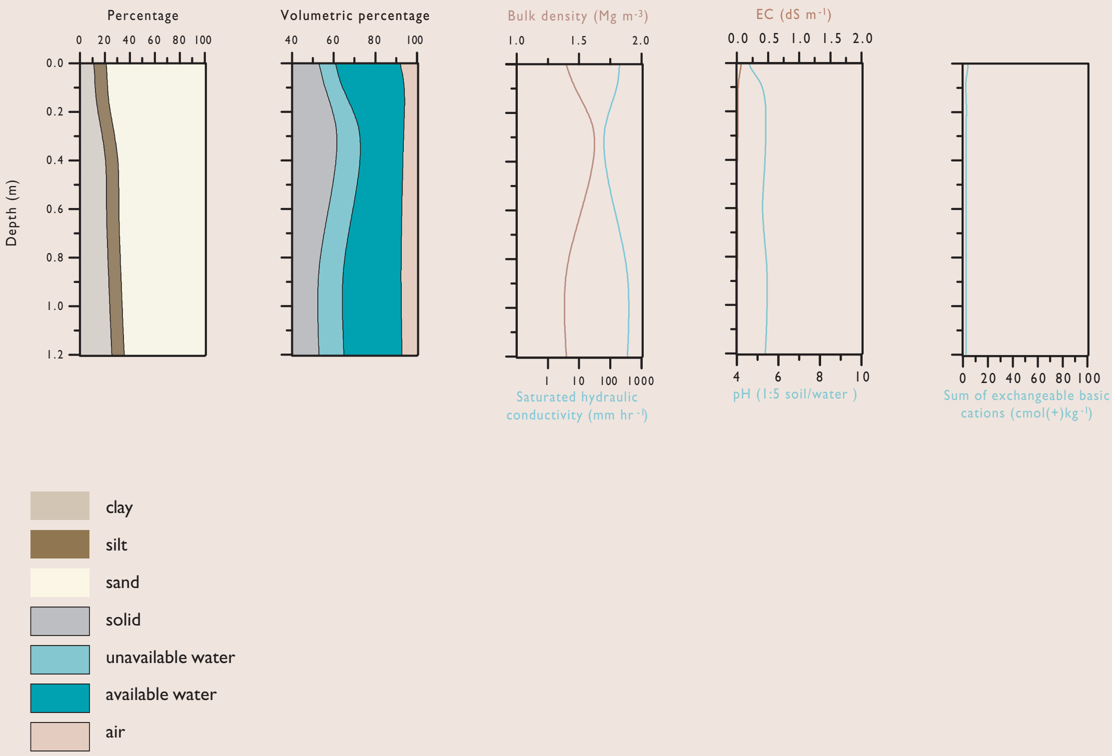
A3 0.10 – 0.20 m Brown (10YR 4/3) sandy loam; weak subangular blocky structure; soft consistence; gradual boundary to:

B1 0.20 – 0.30 m Strong brown (7.5YR 5/8) sandy clay loam; massive structure; soft consistence; diffuse boundary to:

B22 0.30 – 1.00 m Strong brown (7.5YR 5/8) sandy clay loam; massive structure; very soft consistence; diffuse boundary to:

B3 1.00 – 1.40 m Reddish yellow (7.5YR 6/8) sandy clay loam; massive structure; very soft consistence.

### Laboratory data for the typical profile



# KUROSOLS

Kurosols are distinguished by a clear or abrupt texture contrast between the A and B horizons. The upper part of the B horizon is strongly acid. Many of these soils have unusual subsoil chemical features such as high exchangeable magnesium, sodium and aluminium and very low calcium.

## Red Kurosols

The Red and Brown Suborders are the most widespread Kurosols in Australia but are not extensive. The *Bleached-Mottled, Natric, Red Kurosol* described below is a typical example of a Kurosol with a sodic clay B horizon.

### Environment

*Distribution*: Eastern coastal and subcoastal regions of southern Queensland, New South Wales, southern Victoria and Tasmania. Mt Lofty and Eyre Peninsula regions of South Australia and the south-west of Western Australia.

*Climate*: Mean annual rainfall ranges from 600 mm to 1200 mm.

*Parent materials or substrate*: Parent materials are mostly siliceous, in particular sandstones, metasediments and granitic rocks are common.

*Landform*: Occurs on a very wide range of landforms.

*Native vegetation*: Largely dependent on rainfall and ranging from eucalypt woodland to open forest.

### Land use

Improved perennial pastures and grazing of native pastures. Native hardwood forests.

### Common variants

The Red Kurosols vary widely in morphology and subsoil chemistry. The soils may have unbleached A2 horizons, B horizons may be whole coloured and lack columnar structure. They may be non-sodic, have high exchangeable magnesium, very low calcium and high extractable aluminium.

### Nomenclature

Also known as Red Podzolic soils and Soloths.

### Soil qualities

*Water availability*: Moderate water holding capacity in the root zone, depending on the depth of surface horizons. Storage capacity of the B horizon may vary greatly.

*Drainage*: Moderate. Surface soil may be water repellent.

*Aeration*: May be restricted by impermeable B horizons.

*Physical root limitations*: Tough clay subsoil.

*Erosion hazard*: Moderate to high wind and water erosion potential due to deep, loose, sandy surface.

*Nutrient availability*: Low nutrient retention. Phosphorus and organic matter deficient.

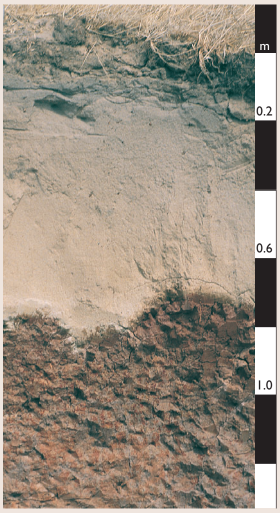
*Toxicities*: Acidity may limit root growth.

*Workability*: Good.

### Acknowledgment

Photo, soil description and laboratory data from Primary Industries and Resources, South Australia. Site CH006.

## Typical profile




Torrens Vale area, South Australia.

### Soil description of a typical profile

A11 0 – 0.10 m Very dark greyish brown (10YR 3/2) sand; single grain structure; dry, very soft consistence; clear boundary to:

A12 0.10 – 0.22 m Brown (10YR 4/3) loamy sand; single grain structure; dry, very soft consistence; gradual boundary to:

A2e 0.22 – 0.75 m Light yellowish brown (10YR 6/4) sand; single grain structure; dry, very soft consistence; sharp boundary to:

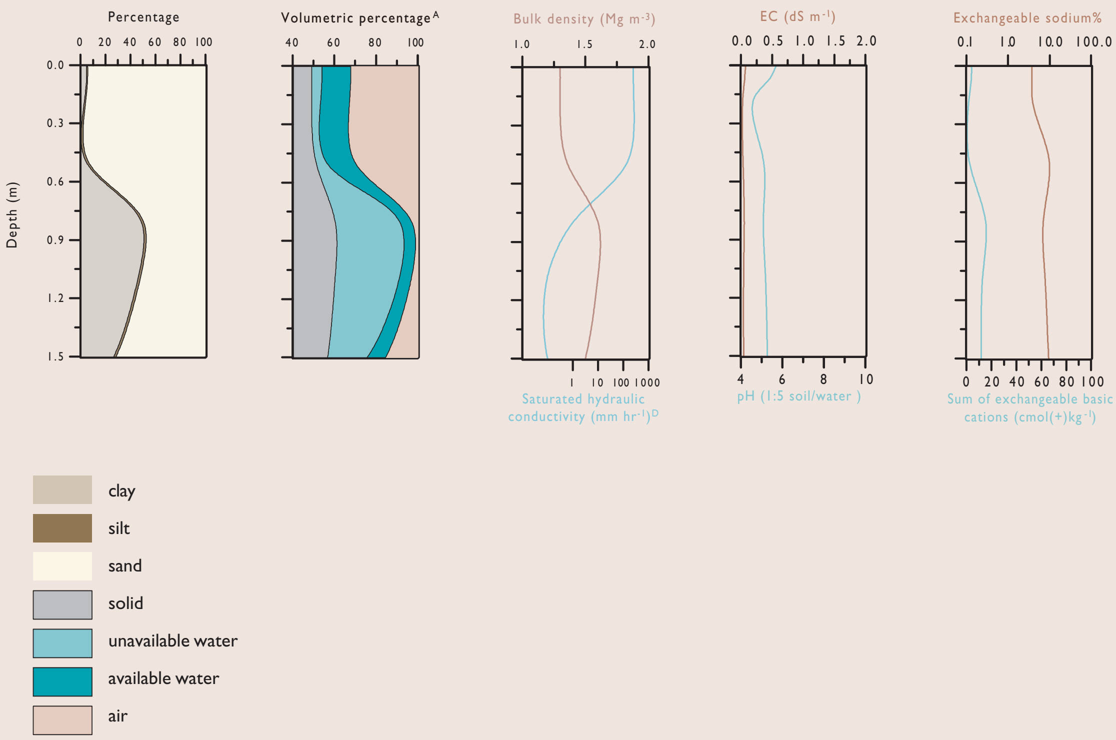
B21 0.75 – 0.85 m Red (2.5YR 4/6) medium heavy clay with yellowish red mottling; strong columnar structure; moderately moist, very hard consistence; gradual boundary to:

B22 0.85 – 1.30 m Greyish brown (2.5Y 5/2) medium heavy clay with yellow and red mottling; weak prismatic structure; moderately moist, very hard consistence; diffuse boundary to:

B3 1.30 – 1.70 m Light yellowish brown (2.5Y 6/4) sandy medium clay with yellow and red mottling; massive structure; moderately moist, very hard consistence; gradual boundary to:

B3/C 1.70 – 2.00 m Pale yellow (2.5Y 7/4) sandy light clay with yellow mottling; massive structure; moderately moist, firm consistence.

### Laboratory data for the typical profile



# KUROSOLS

Kurosols are distinguished by a clear or abrupt texture contrast between the A and B horizons. The upper part of the B horizon is strongly acid. Many of these soils have unusual subsoil chemical features such as high exchangeable magnesium, sodium and aluminium and very low calcium.

## Brown Kurosols

The Red and Brown Suborders are the most widespread in Australia but are not extensive. The clay subsoil of the *Bleached-Vertic, Eutrophic, Brown Kurosol* described below may shrink and swell on wetting and drying. The clay subsoil is non-sodic but high in exchangeable magnesium.

### Environment

*Distribution*: Eastern coastal and subcoastal regions of southern Queensland and New South Wales, southern Victoria and Tasmania, Mt Lofty and Eyre Peninsula regions of South Australia and the south-west of Western Australia.

*Climate*: Mean annual rainfall range approximately 600 mm to 1200 mm.

*Parent materials or substrate*: Mostly siliceous rocks and sediments.

*Landform*: The soils occur on a very wide range of landforms.

*Native vegetation*: Eucalypt woodland and open forest are most common.

### Land use

Improved pasture grazing for dairying, fat lambs and beef cattle. Otherwise beef cattle grazing of native pastures and timber from native hardwood forests.

### Common variants

The Brown Kurosols may vary in both morphology and subsoil chemistry. A2 horizons may be absent and the B2 horizon may be whole coloured. The latter may also be sodic and have high exchangeable magnesium and very low calcium, but is not likely to disperse due to strong acidity.

### Nomenclature

Also known as Soloths and Grey-brown Podzolic soils.

### Soil qualities

*Water availability*: Moderate unless restricted by impenetrable B horizons.

*Drainage*: Often imperfectly drained due to restrictive heavy clay subsoils.

*Aeration*: Saturation may occur above the B horizon.

*Physical root limitations*: The dense clay subsoil may restrict rooting depth.

*Erosion hazard*: Moderate to low erosion risk.

*Nutrient availability*: Phosphorus deficient.

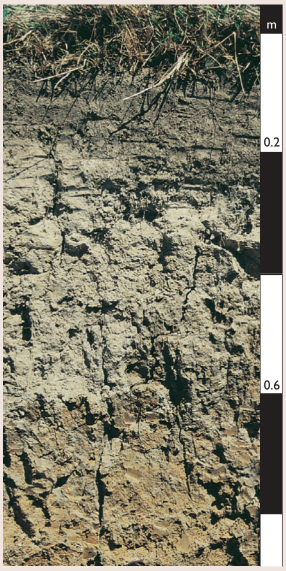
*Toxicities*: High extractable aluminium levels may affect sensitive species.

*Workability*: Good.

### Acknowledgment

Photo, soil description and laboratory data from Department of Natural Resources and Environment, Victoria. Site 2 SW Gippsland.

## Typical profile




South-west Gippsland, Victoria.

### Soil description of a typical profile

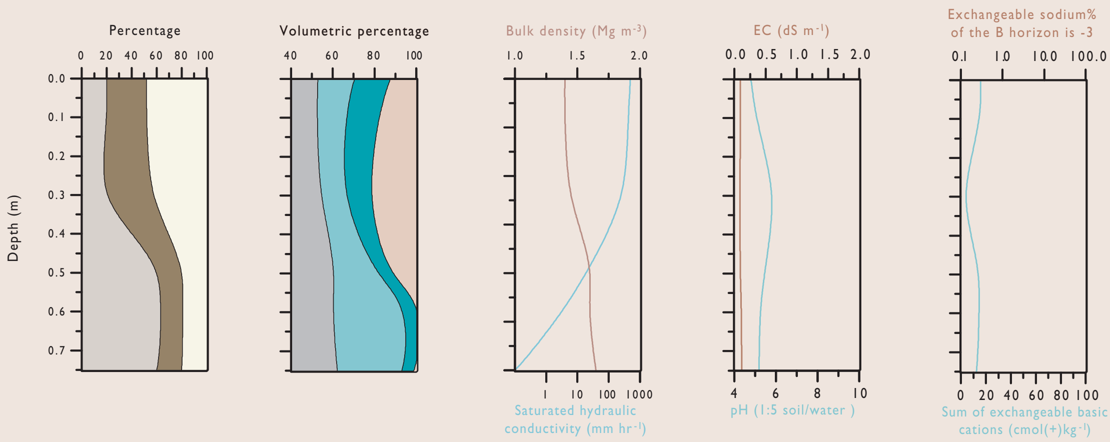
A1 0 – 0.15 m Dark greyish brown (10YR 4/2) fine sandy clay loam; hardsetting surface condition; strong polyhedral structure; dry, very hard consistence; abrupt wavy boundary to:

A2e 0.15 – 0.45 m Light brownish grey (10YR 6/2) fine sandy clay loam; root channel mottling; dry, firm consistence; clear wavy boundary to:

B21 0.45 – 0.70 m Brown (10YR 5/3) medium heavy clay with brownish yellow (10YR 6/8) mottling; strong coarse prismatic parting to strong coarse blocky structure; dry, very hard consistence; gradual boundary to:

B22 0.70 m+ Light brownish grey (10YR 6/2) medium clay with brownish yellow (10YR 6/8) mottles; strong coarse prismatic parting to strong coarse blocky structure; moist, firm consistence; slickensides present.

### Laboratory data for the typical profile




clay
silt
sand
solid
unavailable water
available water
air

# PODOSOLS

In Australia the majority of these soils are distinguished by a bleached A2 horizon and a coloured B horizon caused by the accumulation of organic compounds, aluminium and/ or iron compounds. These diagnostic horizons may occur singly or in combination.

## Semiaquic Podosols

The Suborders of Podosols are separated on soil and site drainage conditions. Semiaquic Podosols have few restrictions to drainage in the B horizon or substrate and experience only short term saturation. The *Parapanic, Humosesquic, Semiaquic Podosol* described below has a strongly coherent B horizon with consolidated tongues of 'coffee rock' in the subsoil.

### Environment

*Distribution*: Virtually confined to coastal and subcoastal zones of Queensland, New South Wales, southern Victoria and South Australia, northern Tasmania and south-west Western Australia. Occurrences elsewhere are of small extent.

*Climate*: Mean annual rainfall range is very broad, approximately 300 mm to over 3000 mm.

*Parent materials or substrate*: Coastal soils occur on Quaternary deposits of quartz sands. Less common forms are found on acidic parent rocks such as quartzite, sandstone, granites and gneisses, or within the A horizons of older soil profiles.

*Landform*: Sand plains and low beach ridges, swales and large dune systems.

*Native vegetation*: Extremely wide range from shrub heath and mallee shrublands to tall, open eucalypt forests and rainforests.

### Land use

Grazing on improved pastures. Other uses include sugar cane in Queensland, irrigated vegetables in Victoria, *Pinus* plantations and mining for heavy minerals.

### Common variants

Weakly coherent B horizons and absence of any restrictive layer of consolidated materials such as 'coffee rock'.

### Nomenclature

Otherwise known as a Humus Podzol.

### Soil qualities

*Water availability*: Low to high depending on soil depth.

*Drainage*: Very well drained sandy surface horizons and subsoil horizons where pans are not a feature.

*Aeration*: Well aerated.

*Physical root limitations*: 'Coffee rock' or siliceous pans may restrict rooting depth.

*Erosion hazard*: The surface soil is prone to wind erosion if vegetation cover is removed.

*Nutrient availability*: Very low fertility, naturally deficient in nitrogen, phosphorus, sulphur, potassium, calcium and trace elements.

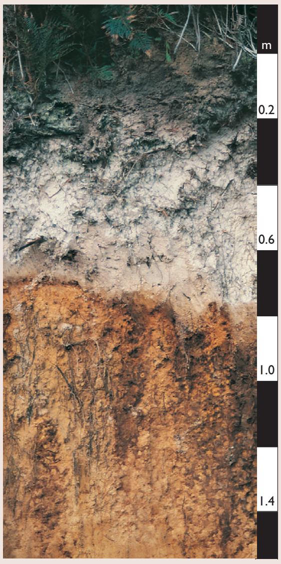
*Toxicities*: None apparent.

*Workability*: Good. Can be cultivated throughout most of the year.

### Acknowledgment

Photo, soil description and laboratory data from Department of Natural Resources and Environment, Victoria. Site 7 SW Gippsland.

## Typical profile




Bald Hills district, south-west Gippsland, Victoria.

### Soil description of a typical profile

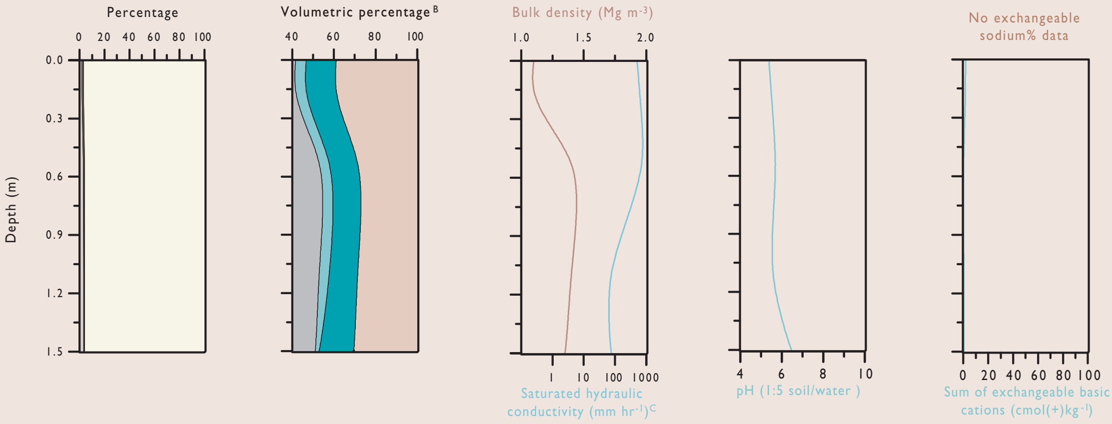
A1 0 – 0.30 m Dark grey (10YR 4/1) loamy sand; loose surface condition; clear boundary to:

A2e 0.30 – 0.75m Light grey (10YR 7/2) sand; single grain structure; clear wavy boundary to:

Bhs 0.75m – 1.40 m Strong brown (7.5 YR 5/8) and dark reddish brown (5YR 3/3) sand with tongues of variably cemented 'coffee rock'; massive structure; firm consistence; diffuse boundary to:

C 1.40 m+ Brownish yellow (10YR 6/6) sand; single grain structure.

### Laboratory data for the typical profile




- clay
- silt
- sand
- solid
- unavailable water
- available water
- air

# SODOSOLS

Sodosols are a specific kind of sodic soil with a clear or abrupt textural B horizon, which is not strongly acid and has an exchangeable sodium percentage (ESP) of 6 or greater in its upper part. The B horizons are usually clayey with restricted hydraulic conductivity caused essentially by the dispersive nature of the sodic clay. An ESP of 6 is the critical limit for the sodicity to have an adverse affect on productivity of the soil.

## Red Sodosols

The Red Suborder is the second most common of the colour classes next to the Brown Suborder. The *Hypercalcic, Mottled-Hypernatric, Red Sodosol* described below has an ESP greater than 25 and has more than 20% soft carbonate in the B horizon and up to 20% hard calcrete fragments/ nodules/ concretions or coated gravel.

### Environment

*Distribution*: Red Sodosols are widely distributed in the arid and semi-arid regions, particularly in Western and South Australia, western New South Wales and Queensland.

*Climate*: Broad mean annual rainfall range, approximately 250 mm to 1200 mm.

*Parent materials or substrate*: Most commonly occur on alluvial/ colluvial deposits, also on aeolian accessions and acidic to intermediate igneous, metamorphic and sedimentary rocks.

*Landform*: Gently undulating plains to some low, hilly areas.

*Native vegetation*: Depending on rainfall, ranges from arid low open shrublands to mallee shrublands and open woodlands. Open forest is rare.

### Land use

Sparse sheep and beef cattle grazing in arid regions. In the Mediterranean climatic zone wheat and barley are grown in conjunction with sheep grazing. Small areas are irrigated for pastures in Victoria and New South Wales.

### Common variants

Red Sodosols may vary widely in both morphology and chemistry. A horizons range from sand to clay loam with most soils having bleached A2 horizons. B horizons may be whole coloured and their structure may be blocky rather than columnar or prismatic. Carbonate content can vary in kind and amount and B horizon sodicity can range from ESP 6 to greater than 40.

### Nomenclature

Also known as Solodized Solonetz and Solodic soils.

### Soil qualities

*Water availability*: Moderate to very low depending on the thickness of the A horizon.

*Drainage*: Imperfectly drained. Soil may remain saturated for several weeks. Sandy surface soils are commonly water repellent.

*Aeration*: Poor aeration in the A2 horizon.

*Physical root limitations*: Dense clay subsoil may restrict roots.

*Erosion hazard*: High when exposed by cultivation or over grazing.

*Nutrient availability*: Low organic matter. Most likely to be deficient in phosphorus, nitrogen, copper and zinc.

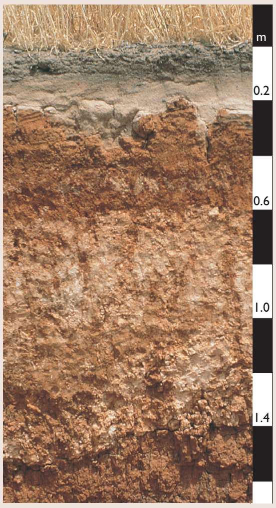
*Toxicities*: Moderate salinity in the lower subsoil horizons and possible boron toxicity.

*Workability*: Wide variation but good for loose, soft surfaces ranging to poor for hardsetting surfaces.

### Acknowledgment

Photo, soil description and laboratory data from Primary Industries and Resources, South Australia. Site MM 035.

## Typical profile




Southern Murray Mallee, South Australia.

### Soil description of a typical profile

Ap 0 – 0.09 m Very dark greyish brown (10YR 3/2) loamy sand; single grain structure; abrupt boundary to:

A1 0.09 – 0.18 m Brown (10YR 4/3) loamy sand; single grain structure; clear boundary to:

A2e 0.18 – 0.23 m Light yellowish brown (10YR 6/4) sand; single grain structure; sharp boundary to:

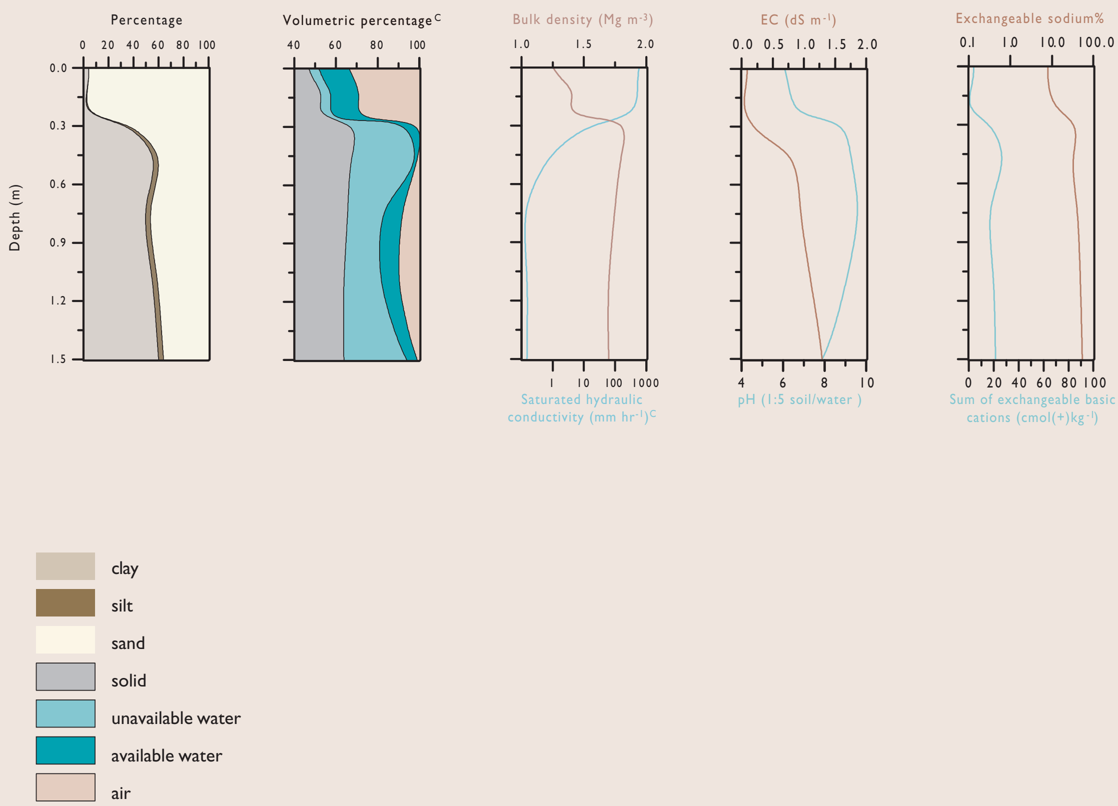
B1t 0.23 – 0.38 m Yellowish red (5YR 4/8) sandy light clay with yellowish brown (10YR 5/8) mottles; strong columnar structure; gradual boundary to:

B2tk 0.38 – 0.54 m Red (2.5YR 4/6) medium clay with yellowish brown (10YR 5/8) mottles; 5% carbonate; moderate granular structure; gradual boundary to:

B3k 0.54 – 1.34 m Yellowish red (5YR 5/8) sandy clay with brownish yellow (10YR 6/6) mottles; highly calcareous 10 – 20% calcareous nodules; massive structure; diffuse boundary to:

C 1.34 – 1.90 m Red (2.5YR 4/6) heavy clay with pale brown (10YR 6/3) mottles; strong prismatic structure.

### Laboratory data for the typical profile



# SODOSOLS

Sodosols are a specific kind of sodic soil with a clear or abrupt textural B horizon, which is not strongly acid and has an exchangeable sodium percentage (ESP) of 6 or greater in its upper part. The B horizons are usually clayey with restricted hydraulic conductivity caused essentially by the dispersive nature of the sodic clay. An ESP of 6 is the critical limit for the sodicity to have an adverse affect on productivity of the soil.

## Grey Sodosols

The Grey Sodosols are one of the most common and widespread of the Suborders. A description of a typical *Calcic, Mottled-Mesonatric, Grey Sodosol* is given below.

### Environment

*Distribution*: The Grey Sodosols are widely distributed in eastern, southern and south-western Australia.

*Climate*: Seasonal rainfall ranging from 300 mm to 1200 mm.

*Parent materials or substrate*: Wide range of rocks (other than more basic forms) and derived alluvial and colluvial deposits.

*Landform*: Plains, undulating and rolling landscapes and hilly slopes.

*Native vegetation*: Woodland and open woodland, some mallee shrublands in regions of southern Australia experiencing a Mediterranean climate.

### Land use

The largest areas of Grey Sodosols in eastern Australia are used for the grazing of native pastures, mainly by beef cattle. In southern Australia they are used for winter cropping of cereals and some grain legumes.

### Common variants

A horizon thickness may range up to 0.25 m and the degree of A2 bleaching may also vary. Some upper B2 horizons may be whole coloured. The degree of sodicity and amount of carbonate may differ in individual profiles.

### Nomenclature

Commonly known as Solodized Solonetz and Solodic Soils.

### Soil qualities

*Water availability*: Low to very low (< 50 mm) and controlled primarily by the depth of the A horizon.

*Drainage*: Poorly drained, slowly permeable. Shallow, saline watertables may develop.

*Aeration*: Restricted aeration in the A2 and B horizons.

*Physical root limitations*: Dense, sodic clay subsoils may inhibit root development.

*Erosion hazard*: Sandy surface soils are subject to wind erosion and dispersive subsoils are prone to gully erosion.

*Nutrient availability*: Poor due to shallow, sandy surface soil.

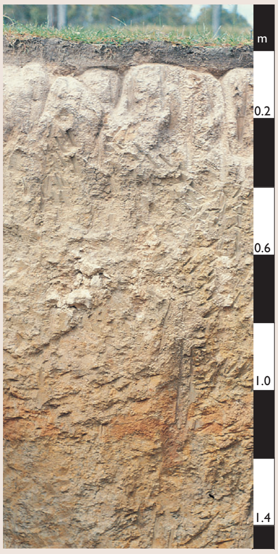
*Toxicities*: Surface soil may develop strong acidity.

*Workability*: Good, providing clay subsoil is below the depth of cultivation.

### Acknowledgment

Photo and soil description from Agriculture Western Australia. Laboratory data from McArthur (1991), p. 173.

## Typical profile




Narrogin district, south-west Western Australia.

### Soil description of a typical profile

A1 0 – 0.03 m Dark greyish brown (10YR 4/2) sand; single grain; dry, soft consistence; abrupt boundary to:

A2e 0.03 – 0.05 m Light brownish grey (10YR 6/2) clayey sand; massive structure; dry, soft consistence; sharp boundary to:

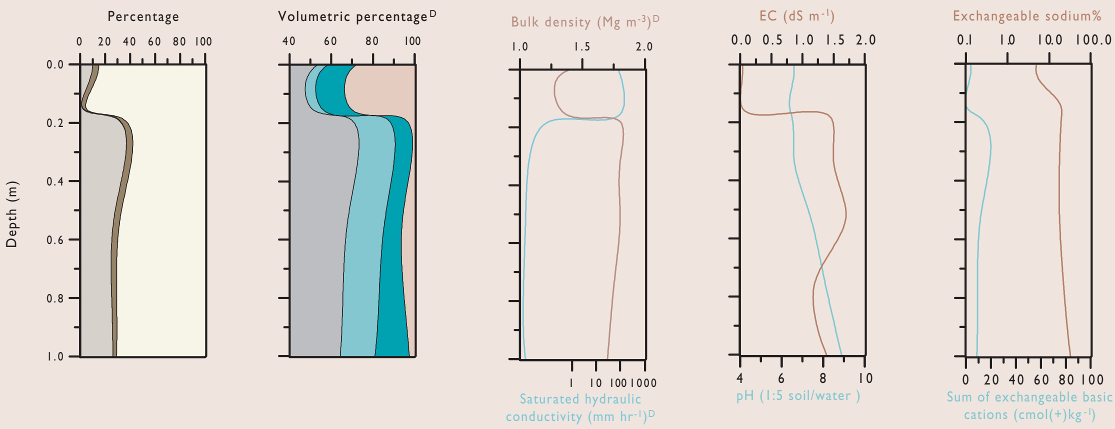
B21 0.05 – 0.30 m Light brownish grey (10YR 6/2) sandy light clay with many distinct brown mottles; columnar structure coated with white, bleached, clayey sand; moist, very hard consistence; gradual boundary to:

B22 0.30 – 0.60 m Light grey (10YR 6/1) sandy light clay; moist, firm consistence; gradual boundary to:

B23 0.60 – 0.90 m Yellow light medium clay with (20 – 50%) distinct grey mottles; (2 – 10%) carbonate nodules; clear boundary to:

BC 0.90 – 1.25 m Yellowish brown light medium clay with common grey mottles.

### Laboratory data for a typical profile (similar to the illustrated profile above)




# SODOSOLS

Sodosols are a specific kind of sodic soil with a clear or abrupt textural B horizon, which is not strongly acid and has an exchangeable sodium percentage (ESP) of 6 or greater in its upper part. The B horizons are usually clayey with restricted hydraulic conductivity caused essentially by the dispersive nature of the sodic clay. An ESP of 6 is the critical limit for the sodicity to have an adverse affect on productivity of the soil.

## Black Sodosols

The Black Suborder is less common than most of the other colour classes. The *Vertic (and Calcic), Mottled-Mesonatric, Black Sodosol* described below has an ESP between 15 and 25, displays vertic properties and has a calcareous lower B horizon.

### Environment

*Distribution*: Mainly occurring in the subhumid to semi-arid regions of eastern Australia, often associated with Vertosols.

*Climate*: Mean annual rainfall ranges from 400 mm to 800 mm, is summer dominant in Queensland and winter dominant in the south.

*Parent materials or substrate*: Most commonly occur on alluvial clayey deposits on flood plains, also on intermediate igneous, metamorphic and sedimentary rocks.

*Landform*: Plains and undulating or rolling landscapes but may also occur on hilly slopes up to 30%.

*Native vegetation*: Mainly eucalypt woodlands and some *Acacia* open forests.

### Land use

The eastern Australian Black Sodosols are used for both summer and winter cereals with small areas of irrigated pastures and cotton. Elsewhere they are used mainly for beef cattle grazing of native pastures.

### Common variants

A bleached A2 horizon is present in many Black Sodosols. B horizons are often whole coloured and columnar or prismatic structure is common. High amounts of carbonate are uncommon but B horizon sodicity is often high (ESP >25).

### Nomenclature

Also known as Solodized Solonetz and Solodic soils.

### Soil qualities

*Water availability*: Low to very low depending on A horizon thickness.

*Drainage*: Moderately to imperfectly drained.

*Aeration*: Restricted aeration in the A2 and B horizons.

*Physical root limitations*: Effective rooting depth approximately 0.50 m, restricted by the strongly sodic and dispersive subsoil.

*Erosion hazard*: Low, provided vegetation cover is adequate.

*Nutrient availability*: Molybdenum, calcium, magnesium and potassium deficiencies in strongly acid surface horizons.

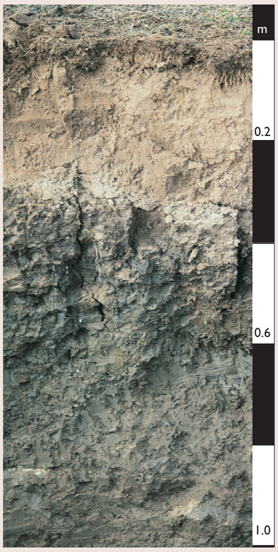
*Toxicities*: Aluminium problems may occur in the strongly acid surface soils.

*Workability*: Excessive cultivation may lead to surface sealing and hardsetting.

### Acknowledgment

Photo, soil description and laboratory data from Department of Natural Resources and Environment, Victoria. Site LP 65.

## Typical profile




Lexton district, south-west Victoria.

### Soil description of a typical profile

A11 0 – 0.25 m Dark brown (10YR 3/3) fine sandy clay loam; hard setting surface; weakly structured; 5% ferromanganiferous nodules; rusty root channel mottling; dry, firm consistence; abrupt and wavy boundary to:

A2 0.25 – 0.30 m Brown (10YR 4/3) fine sandy clay loam; weakly structured; 5% ferromanganiferous nodules; rusty root channel mottling; moist, firm consistence; sharp boundary to:

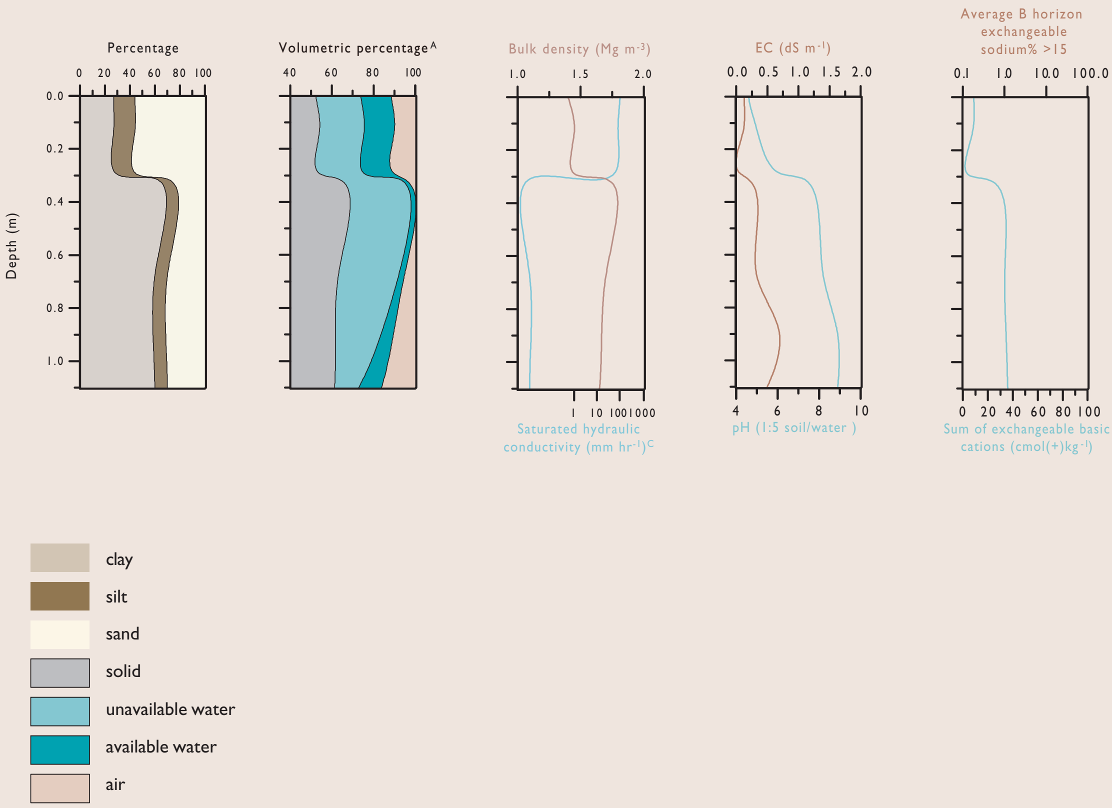
B21 0.30 – 0.55 m Dark grey (10YR 3/1) heavy clay with yellowish brown (10YR 5/8) mottles; moderate coarse blocky structure; moist, firm consistence; clear boundary to:

B22 0.55 – 0.80 m Greyish brown (10YR 5/2) medium heavy clay with a yellowish (10YR 7/6) diffuse mottle; moist, very hard consistence; clear boundary to:

B23k 0.80 – 1.00 m Greyish brown (10YR 5/2) medium heavy clay; 2 – 5% soft carbonate and trace (2%) hard carbonate; slickensides below 0.70 m; moist, very hard consistence; abrupt boundary to:

BC 1.00 m+ Dark greyish brown (10YR 4/2) sandy clay loam; moist, very hard consistence; 5% manganese flecks.

### Laboratory data for the typical profile



## TENOSOLS

Tenosols may be considered as intermediate between Rudosols (characterised by having only a minimal development of soil features such as horizons) and Kandosols in which B horizon development is clearly expressed with more than 15% of clay. Tenosols thus encompass a fairly wide range of soils which, apart from some A horizons, do not have a strong degree of horizon development.

### Orthic Tenosols

These soils are characterised by a weakly developed B horizon, usually in terms of colour, texture or structure or a combination of these. A description of a *Basic, Arenic, Orthic Tenosol* is given below.

#### Environment

*Distribution*: The most extensive areas of Orthic Tenosols are in the semi-arid to arid regions of Western Australia and the Northern Territory, with much smaller occurrences in eastern Australia.

*Climate*: These soils span a large mean annual rainfall range, approximately 200 mm to over 2000 mm, and a similarly wide latitudinal range from tropical to temperate.

*Parent materials or substrate*: A diverse range of siliceous alluvial and aeolian deposits with lesser occurrences derived from acidic rocks.

*Landform*: Vast, gently undulating plains are characteristic but hilly to mountainous topography is common, particularly in eastern Australia.

*Native vegetation*: Very diverse and dependent on rainfall, ranging from spinifex hummock grassland in the arid regions to tall open forests in the high rainfall eastern occurrences.

#### Land use

Because of their general acidity or unfavourable topography, many Orthic Tenosols are used only for sparse grazing. Important exceptions are the sand plains of southern Western Australia which support winter cereal cropping and lupins where rainfall is adequate.

#### Common variants

Red forms (mainly in the arid zones) occupy the greatest area of Orthic Tenosols. The yellow soils vary in texture and the presence of ferruginous nodules. Arenic Tenosols (sandy textured throughout) are common.

#### Nomenclature

Commonly known as Earthy Sands.

#### Soil qualities

*Water availability*: Moderate to high, varying with soil depth.

*Drainage*: Highly permeable and well drained.

*Aeration*: No restriction.

*Physical root limitations*: Few in general.

*Erosion hazard*: Susceptible to wind erosion on bare surface soils.

*Nutrient availability*: Very low inherent fertility.

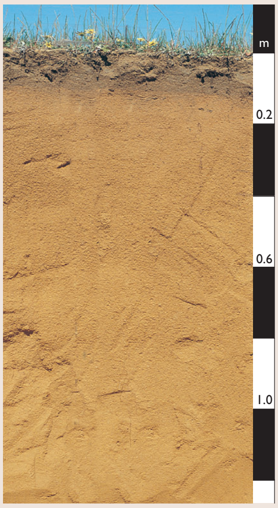
*Toxicities*: Acidification can lead to aluminium toxicity.

*Workability*: Good.

#### Acknowledgment

Photo and soil description from Agriculture Western Australia. Laboratory data for a typical profile from McArthur (1991), p. 138.

## Typical profile




South-east of Geraldton,
Western Australia.

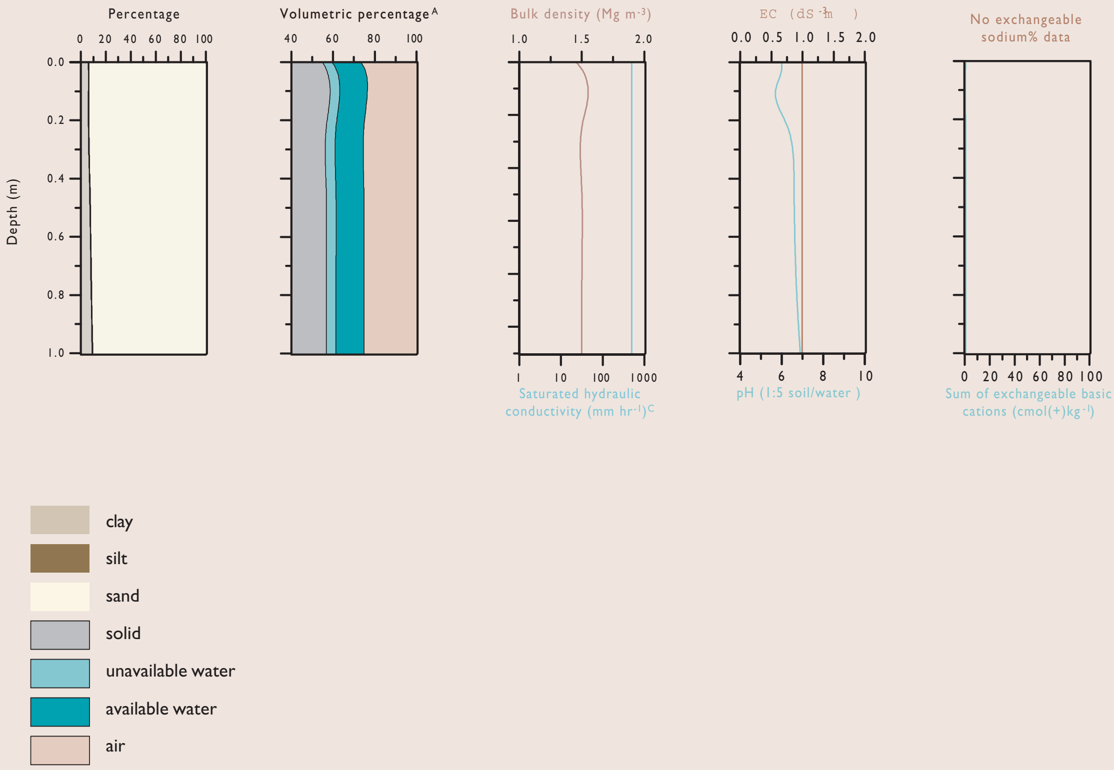
### Soil description of a typical profile

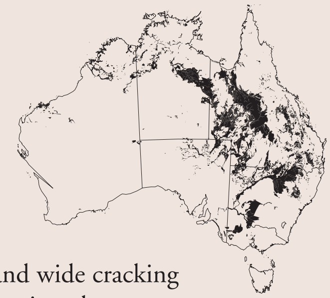
A1 0 – 0.10 m Brown (10YR 5/3) loamy sand; single grain structure; loose consistence; gradual boundary to:

B1w 0.10 – 0.75 m Brownish yellow (10YR 6/6) clayey sand; massive structure; loose consistence; diffuse boundary to:

B2w 0.75 – 1.50 m Yellow (10 YR 7/8) clayey sand; massive structure; loose consistence.

### Laboratory data for a typical profile





## VERTOSOLS

Vertosols are clay soils (>35% clay) with shrink-swell properties which cause deep and wide cracking on drying. Lenticular structure and slickensides are diagnostic features. The soils vary in colour – black, brown, grey and red with every gradation in between – and range from strongly acid to highly calcareous. Australia has a greater area and diversity of Vertosols than any other country.

### Black Vertosols

Black Vertosols are one of the most highly productive soils for agriculture in Australia. A typical example of a *Haplic, Self-mulching, Black Vertosol* with a self-mulching surface (strongly pedal loose surface mulch) is described below.

#### Environment

*Distribution*: Occur discontinuously from Tasmania to the Kimberleys. The most important agricultural areas are in subhumid eastern New South Wales and subtropical Queensland. Strikingly uncommon in virtually all of Western Australia except the far north.

*Climate*: Mean annual rainfall ranges from 500 mm to 1000 mm, is summer dominant in the north and winter dominant in the south.

*Parent materials or substrate*: Most common on basic igneous rocks such as basalt and dolerite, lithic and felspathic sandstones and shales, and derived alluvial and colluvial sediments.

*Landform*: Level to undulating plains, hillslopes and undulating rises.

*Native vegetation*: Grassland, open eucalypt woodland and *Acacia* open forest.

#### Land use

Winter grain and oilseed crops (often with bare fallowing) dryland cereals, sunflower and irrigated cotton in the summer. Grazed native pasture in regions of unreliable rainfall and steep slopes.

#### Common variants

Black Vertosols may range in depth from 0.30 to 2.00 m. Calcareous segregations may occur higher in the profile (Endocalcareous or Epicalcareous) in association with gilgai microrelief. Massive or coarsely structured soils and profiles with a pedal soil surface condition may also occur. Aquic types occur in the backswamps and depressions of some northern coastal plains.

#### Nomenclature

Also known as Black Earths and Black Cracking Clays.

#### Soil qualities

*Water availability*: Moderate (150 – 200 mm).

*Drainage*: Initial rapid infiltration via cracks but imperfectly drained when wet.

*Aeration*: Generally adequate but compacted layers may be restrictive, particularly when irrigated.

*Physical root limitations*: Plough pan development will limit root growth.

*Erosion hazard*: Serious on slopes in high intensity rainfall regions (tropics and subtropics).

*Nutrient availability*: Nitrogen levels decline under cropping. Commonly deficient in sulphur and zinc.

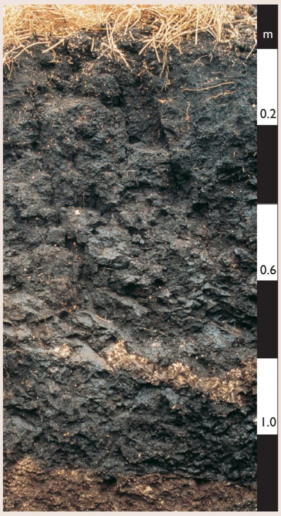
*Toxicities*: Secondary salinity may be a problem.

*Workability*: Self-mulching properties enhance soil surface condition. Plough pan due to compaction of wet soil will reduce workability.

#### Acknowledgment

Photo, soil description and laboratory data from Queensland Department of Natural Resources.

## Typical profile




Eastern Darling Downs, Queensland.

### Soil description of a typical profile

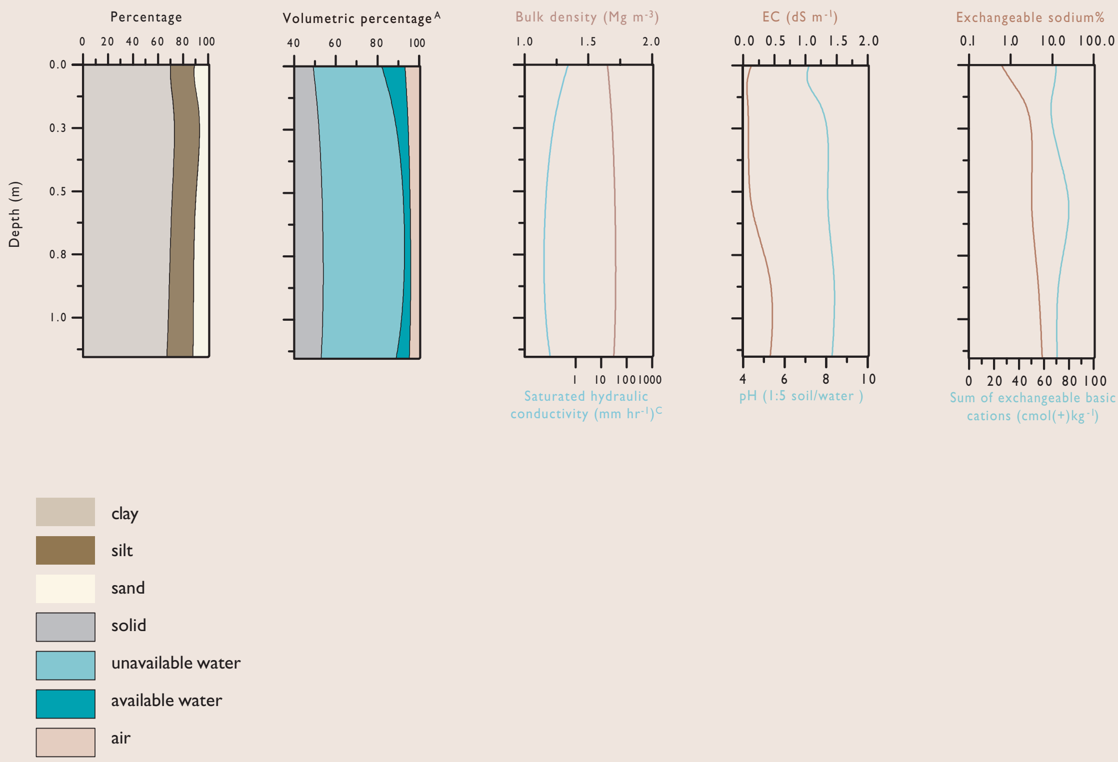
A1 0 – 0.03 m Black (10YR 2/1) medium clay; strong fine granular structure; self-mulching; moderately moist, firm consistence; abrupt boundary to:

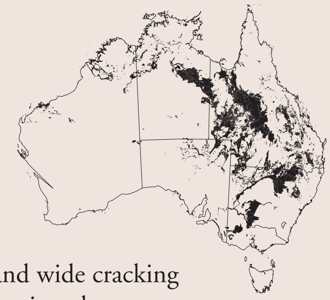
B21 0.03 – 0.20 m Black (10YR 2/1) medium heavy clay; strong subangular blocky parting to fine granular structure; moderately moist, firm consistence; clear boundary to:

B22 0.20 – 1.10 m Black (10YR 2/1) medium heavy clay; strong blocky parting to moderate lenticular structure; some slickensides; tongue of brown clay with carbonate at 0.90 m; moist, firm consistence; abrupt boundary to:

B23 1.10 – 1.75 m Brown (7.5YR 3/4) medium heavy clay; strong blocky parting to moderate lenticular structure; moist, firm consistence; 2 – 10% soft, calcareous segregations.

### Laboratory data for the typical profile





## VERTOSOLS

Vertosols are clay soils (>35% clay) with shrink-swell properties which cause deep and wide cracking on drying. Lenticular structure and slickensides are diagnostic features. The soils vary in colour – black, brown, grey and red with every gradation in between – and range from strongly acid to highly calcareous. Australia has a greater area and diversity of Vertosols than any other country.

### Grey Vertosols

These are probably the most widespread and diverse of all Australian Vertosols. Many are extremely deep (up to 6.0 m) and have a very pronounced gilgai microrelief. The *Epicalcareous-Endohypersodic, Self-mulching, Grey Vertosol* described below has a surface horizon that is self-mulching (strongly pedal loose surface mulch) and a calcareous and strongly sodic subsoil.

#### Environment

*Distribution*: Largely confined to the eastern States (except Tasmania) and the Northern Territory, occupying large continuous areas in western Queensland.

*Climate*: Essentially soils of the arid and semi-arid regions. Mean annual rainfall is 600 mm or less.

*Parent materials or substrate*: Most extensively derived from lithic sandstones, mudstones, shales and alluvial and colluvial sediments derived from these and more basic igneous rocks.

*Landform*: Level to undulating plains and vast inland floodplains subject to sporadic major flooding.

*Native vegetation*: Grasslands and sparse, low shrublands in arid regions. Open woodland and originally extensive *Acacia* open forests in more humid areas.

#### Land use

Climate is a major influence. Irrigated cotton, rice and pastures in New South Wales and Queensland. Grazing in the arid zones. Dryland cereals and grain legumes in most eastern States. Bare fallowing to allow winter crops in areas of unreliable rainfall.

#### Common variants

Other soils may have a thin, crusty surface (< 0.03 m); massive structure; coarse blocky or pedal non self-mulching A horizon. Various forms and amounts of subsoil carbonate occur with gypsum in the more arid varieties. In eastern Queensland and northern New South Wales strongly acidic subsoils are a distinctive feature. Aquic types occur on some high rainfall coastal plains.

#### Nomenclature

Commonly known as Grey Clays.

#### Soil qualities

*Water availability*: Low to moderate (75 – 150 mm) depending on depth of chemical or physical impeding layers. Low infiltration can restrict filling of soil water storage.

*Drainage*: Initial rapid infiltration via cracks but imperfectly drained when wet.

*Aeration*: Can be restrictive, particularly when irrigated, compacted or both.

*Physical root limitations*: A plough pan and a strongly dispersive subsoil may restrict water and root movements.

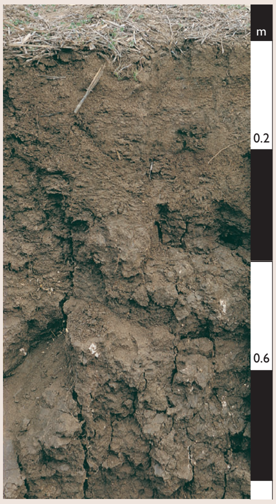
*Erosion hazard*: Serious on slopes in high intensity rainfall regions (tropics and subtropics).

*Nutrient availability*: Nitrogen and phosphorus decline with cultivation. Possible zinc deficiency in strongly alkaline soils.

*Toxicities*: Subsoils may be strongly saline.

*Workability*: Self-mulching properties enhance surface condition. Sodic, crusty or massive surface soils may cause workability problems

## Typical profile




Horsham district, north-west Victoria.

### Soil description of a typical profile

A1 0 – 0.05 m Dark greyish brown (10YR 4/2) light clay; moderate granular structure; self-mulching; <2% hard carbonate nodules; dry, soft consistence; sharp boundary to:

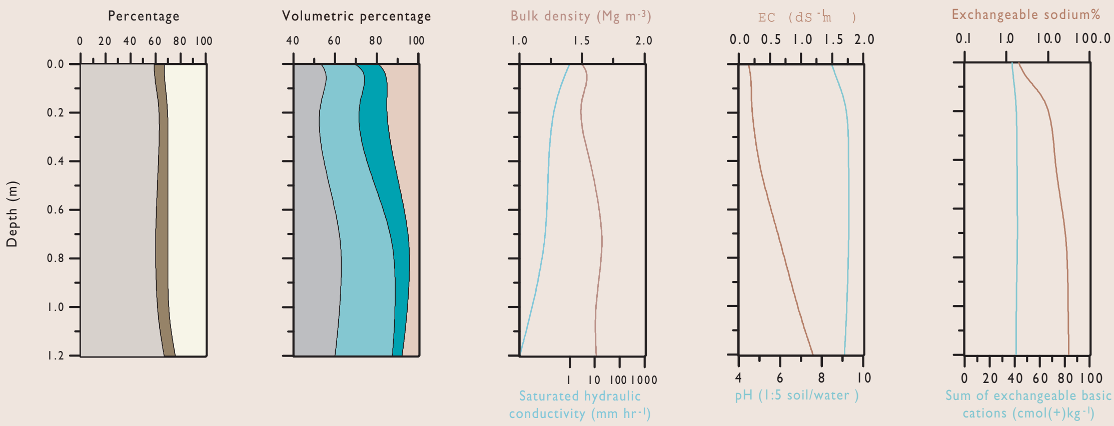
B21 0.05 – 0.25 m Dark greyish brown (10YR 4/2) light medium clay; moderate very coarse prismatic structure; dry, firm consistence; moist, slightly sticky consistence; <2% hard carbonate nodules; gradual boundary to:

B22 0.25 – 0.60 m Dark greyish brown (10YR 4/2) heavy clay; moderate very coarse prismatic structure; dry, firm consistence; moist, slightly sticky consistence; <2% hard carbonate nodules; gradual boundary to:

B23 0.60 – 1.20 m Greyish brown (10YR 5/2) heavy clay; weak coarse blocky structure; dry, firm consistence; moist, slightly sticky consistence; slickensides; <2% hard carbonate nodules; sharp boundary to:

B3 1.20 – 1.75 m Brown (7.5YR5/4) changing to yellowish red (5YR 5/6) medium clay; dry, firm consistence; moist, slightly sticky consistence; slickensides; <2% hard and soft carbonate nodules.

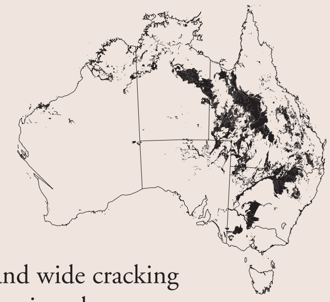
### Laboratory data for the typical profile




- clay
- silt
- sand
- solid
- unavailable water
- available water
- air

### Acknowledgment

Photo, soil description and laboratory data from Department of Natural Resources and Environment, Victoria. Site 8 Wimmera.



# VERTOSOLS

Vertosols are clay soils (>35% clay) with shrink-swell properties which cause deep and wide cracking on drying. Lenticular structure and slickensides are diagnostic features. The soils vary in colour – black, brown, grey and red with every gradation in between – and range from strongly acid to highly calcareous. Australia has a greater area and diversity of Vertosols than any other country.

## Brown Vertosols

Brown Vertosols are very similar in their properties to the grey forms, into which they commonly grade. Many are deep but gilgai microrelief is less strongly developed and less extensive. A typical example of a *Haplic, Epipedal, Brown Vertosol* is given below.

### Environment

*Distribution*: Major areas are in the arid zone where they are commonly associated with Red Vertosols.

*Climate*: The largest areas occur in the arid zone with less than 500 mm mean annual rainfall.

*Parent materials or substrate*: Most extensively derived from lithic sandstones, mudstones and shales and alluvial and colluvial sediments derived from these rocks.

*Landform*: Level to gently undulating plains are most common.

*Native vegetation*: Tussock grasslands and sparse low shrublands. Some more humid regions in eastern Australia originally carried *Acacia* open forest.

### Land Use

Cattle and sheep grazing of native pastures. In humid regions practices are similar to Grey Vertosols.

### Common variants

Otherwise similar soils may be self-mulching or have a thin crusty surface soil. Carbonate may occur throughout and subsoils may be strongly saline and sodic. Soils in the arid zone usually contain variable amounts of gypsum.

### Nomenclature

Also known as Brown Clays.

### Soil qualities

*Water availability*: Moderate (100 – 150 mm) depending on depth of chemical or physical impeding layers. Low infiltration may restrict filling of soil water storage.

*Drainage*: Initially rapid via cracks. Low to moderate when wet and if surface soil is dispersive.

*Aeration*: Can be restrictive, particularly when irrigated, compacted or both.

*Physical root limitations*: Restricted by sodic and strongly alkaline subsoil if present.

*Erosion hazard*: Serious on slopes in high intensity rainfall regions and dispersive surface soils.

*Nutrient availability*: Nitrogen and phosphorus decline with cultivation. Possible zinc deficiency in strongly alkaline soils.

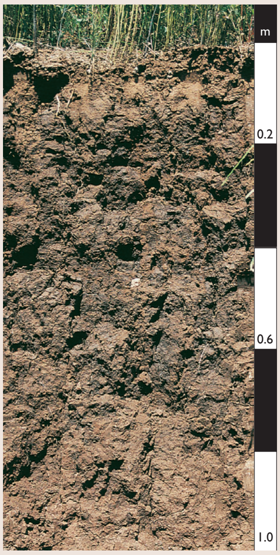
*Toxicities*: Some arid soils may be strongly saline.

*Workability*: Good, providing the soil is not overworked, compacted when wet or strongly dispersive. Self mulching properties will improve workability.


### Acknowledgment

Photo, soil description and laboratory data from Department of Natural Resources and Environment, Victoria. Site LP 95.

## Typical profile




Charlton district,
northern Victoria.

### Soil description of a typical profile

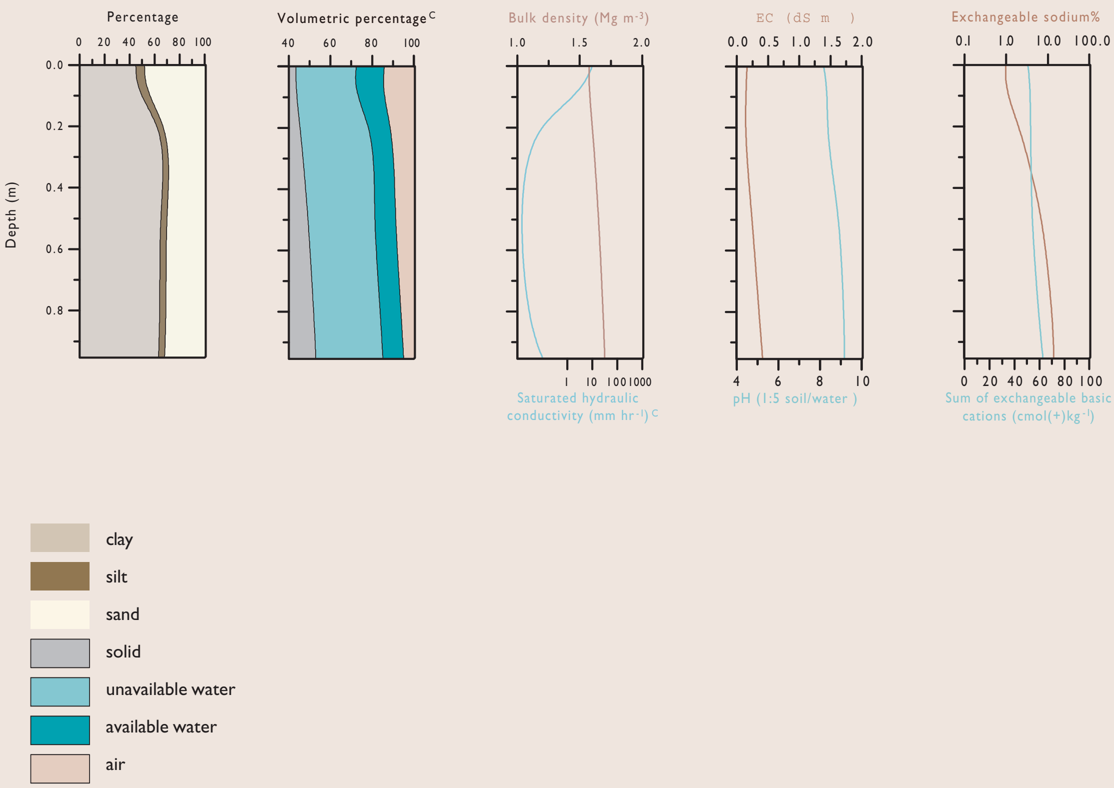
A1 0 – 0.10 m Dark brown (7.5YR 3.5/4) light medium clay; moderate coarse blocky structure; dry, firm consistence; abrupt boundary to:

B21 0.10 – 0.70 m Dark brown (10YR 3/3) medium heavy clay; coarse prismatic parting to strong coarse blocky structure; dry, very hard consistence; clear boundary to:

B22 0.70 – 1.20 m Brown (10YR 4/3) medium heavy clay with strong brown (7.5YR 5/6) diffuse mottles; moderate coarse prismatic parting to moderate coarse blocky structure; dry, firm consistence; abrupt boundary to:

C 1.20 m+ High amounts of soft carbonate.

### Laboratory data for the typical profile



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Dr Bill Young, CSIRO Land and Water .......... River nutrient budgets

Dr Doug Reuter, formerly CSIRO Land and Water .......... Farm nutrient management

Dr Adam Hood, Victoria Department of Natural Resources & Environment .......... Signposts for agriculture

Bob Noble, Queensland Department of Natural Resources and Mines .......... Fitzroy study

Dr Neil McKenzie, CSIRO Land and Water .......... Land condition monitoring

Dr Elisabeth Bui, CSIRO Land and Water .......... Australian Soil Resources Information System

Dr Robyn Johnston, Bureau of Rural Sciences .......... Australian Soil Resources Information System

Also to the numerous industry groups and research and development corporations who contributed data and information and case studies.

## Special note of thanks

To the ‘unsung heroes’ of all projects—the project teams—without your dedication and commitment this work could not have been completed. Please accept our sincere thanks and gratitude.

## PHOTO ACKNOWLEDGMENTS


| | |
|---|---|
| Baden Williams | pages 29, 31, 310 |
| CSIRO | pages xiii, xvii |
| Horticultural Research and Development Corporation | pages 114, 220, 274 |
| Murray Darling Basin Commission | front cover, pages v, viii, xxiv, 1, 23, 26, 40, 81, 90, 188, 193, 216, 307, 313, 314, 317 |
| Themeda | pages xx, 151, 227 |

# NATIONAL LAND AND WATER RESOURCES AUDIT

## Who is the Audit responsible to?

The Minister for Agriculture, Fisheries and Forestry – Australia has overall responsibility for the Audit as a program of the Natural Heritage Trust. The Audit reports through the Minister for Agriculture, Fisheries and Forestry to the Natural Heritage Board which also includes the Minister for the Environment and Heritage.

## How is the Audit managed?

An Advisory Council manages the implementation of the Audit. Dr Roy Green, with a background in research, science policy and management chairs the Advisory Council. Members of the Advisory Council and the organisations they represent in October 2001 are: Warwick Watkins (L&WA), Geoff Gorrie (AFFA), Stephen Hunter (EA), John Radcliffe (CSIRO), Peter Sutherland (SCARM), Jon Womersley (SCC), Roger Wickes (SCARM) and Colin Creighton (Audit).

## What is the role of the Audit Management Unit?

The Audit Management Unit's role has evolved over its five-year life. Phases of activity include:

> **Phase 1. Strategic planning and work plan formulation—**specifying (in partnership with Commonwealth, States and Territories, industry and community) the activities and outputs of the Audit—completed in 1998–99.
>
> **Phase 2. Project management—**letting contracts, negotiating partnerships and then managing all the component projects and consultancies that will deliver Audit outputs—a major component of Unit activities from 1998–99 onwards.
>
> **Phase 3. Reporting—**combining outputs from projects in each theme to detail Audit findings and formulate recommendations—an increasingly important task in 2000–2001 and the early part of 2001–02.
>
> **Phase 4. Integration and implementation—**combining theme outputs in a final report, working towards the implementation of recommendations across government, industry and community, and the application of information products as tools to improve natural resource management—the major focus for 2001–2002.
>
> **Phase 5. Developing long term arrangements for continuing Audit-type activities—**developing and advocating a strategic approach for the continuation of Audit-type activities—complete in 2001–2002.

The Audit Management Unit has been maintained over the Audit's period of operations as an eight-person multidisciplinary team. This team as at October 2001 comprises Colin Creighton, Warwick McDonald, Stewart Noble, Maria Cofinas, Jim Tait, Rochelle Lawson, Sylvia Graham and Drusilla Patkin.

## How are Audit activities undertaken?

As work plans were agreed by clients and approved by the Advisory Council, component projects in these work plans were contracted out. Contracting involves negotiation by the Audit to develop partnerships with key clients or a competitive tender process.

## Facts and figures

| | |
|---|---|
| • Total Audit worth, including all partnerships | in excess of $52 m |
| • Audit allocation from Natural Heritage Trust | $34.19 m |
| • % funds allocated to contracts | ~ 92% |
| • Total number of contracts | 149 |

Natural
Heritage
Trust

*Helping Communities*
*Helping Australia*

A Commonwealth Government Initiative

**National Land & Water Resources Audit**

*A program of the Natural Heritage Trust*

**www.nlwra.gov.au/atlas**