Contents


# Assessing Agricultural Land

## Agricultural land classification standards used in South Australia's land resource mapping program

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Government of South Australia
Department of Water, Land and Biodiversity Conservation

Natural Heritage Trust
*Helping Communities Helping Australia*

# Acknowledgments

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# 1 INTRODUCTION

All people with an interest in using and managing land apply some form of land assessment or classification when making decisions. Most properties for example include a range of soil types and topographic features, each with characteristic productive potential and management needs. Land managers when making decisions about paddock management, property layout and so on, need to use some sort of classification system which recognizes the differences between different types of land. Terms such as “hard red ground”, “gutless sand”, “Biscay soil”, “magnesia ground” and so on represent an informal classification system with implications for land use and management on the “farming by soil type” principle.

Across larger areas, systems of land assessment and classification need to be more formalized and objective to ensure consistency. During the 1980’s and 1990’s, the demand from State and Local Government, community groups, agricultural industry, researchers and private consultants for regional scale land assessment grew substantially. Because the nature of requested information varied from client to client, a common set of base-line data was needed from which to make customized interpretations. A program was established in 1990 to prepare soil landscape maps for the agricultural districts of South Australia, specifically to provide this base-line data.

This publication describes the land classification system and standards which were developed as the basis for interpreting the South Australian soil landscape mapping coverage.

### Aim

The aim of this publication is to set out the criteria which are used to classify land according to specific soil or landscape attributes. The classification criteria were developed specifically to enhance the description and mapping of land in the agricultural districts of South Australia (refer Figure 1). Application of these criteria and of the classification system elsewhere has not been investigated.

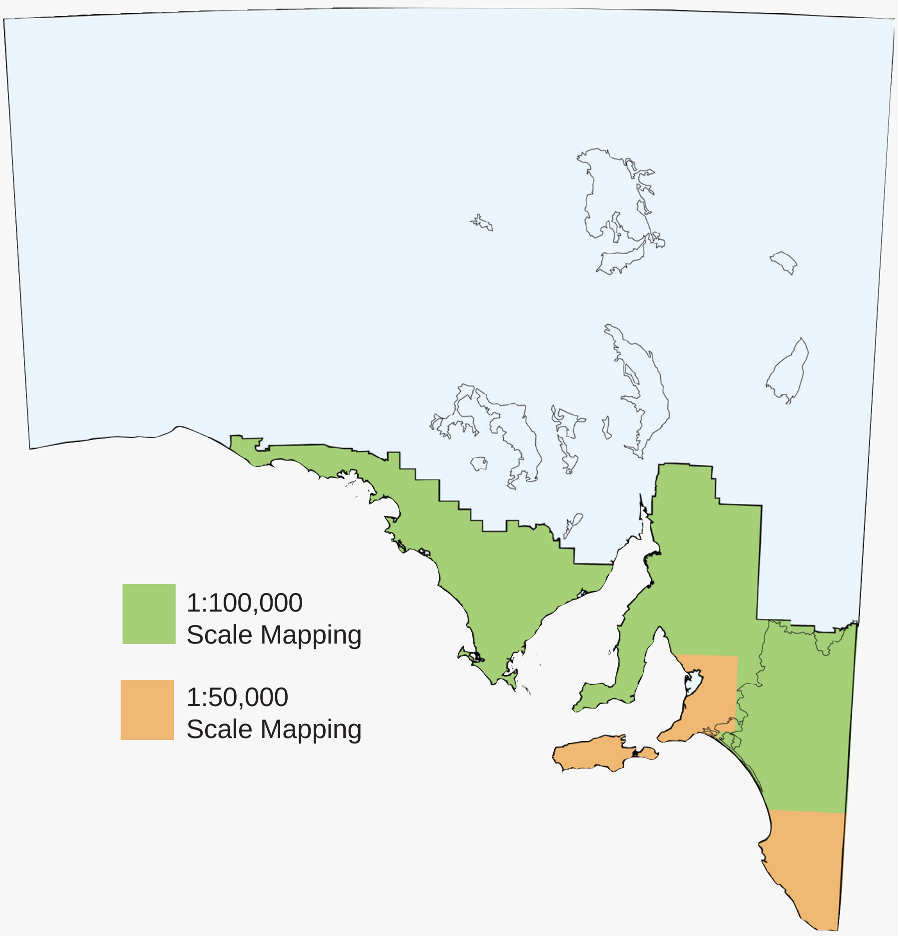



**Figure 1**. Extent of Soil Landscape Mapping Coverage.

## Background

In the mid 1980's, the then South Australian Department of Agriculture embarked on a program of mapping and land description across the agricultural districts of South Australia. The initial purpose of the program was to provide more concise information on the extent, distribution and nature of particular landscape features associated with land degradation. A pilot study concentrated on water and wind erosion potential, and salinity. This was done through a combination of aerial photograph interpretation and low intensity field assessments. Whilst the technique provided the information needed at the time, it had limited capacity for other uses.

The early 1980's saw the advent of geographic information system (GIS) technology, and the opportunities for using this technology to interpret and add value to land resource mapping soon became apparent. It was envisaged that over time, there would be interest in attributes other than simply erosion potential and salinity, and that these attributes might then be used to assess the potential for, or risks associated with, different land uses. Furthermore, during this period, there were rapid developments in the field of landscape process modelling as a tool for assessing the likely impacts on productivity and natural resources of various land use / land management scenarios. Land resource data was invariably a fundamental input to these models.

Traditional land resource assessments were based on mapping units accompanied by soil profile and landscape descriptors and analyses, with variable levels of interpretation. Despite the value of these products, it was generally difficult to determine with any degree of objectivity, values for the range of attributes which were required. For example, to reformat a traditional land resource map into a product showing six classes of *susceptibility to waterlogging*, would have involved a considerable degree of educated guesswork, because those types of interpretations rarely appeared in the reports accompanying older surveys. Yet by the simple expedient of ranking (or classifying) each mapping unit defined in the new survey work with respect to particular land attributes, the mapping data could be electronically analysed to meet the requirements of a range of potential users.

As the mapping and land description program progressed, so too did the range of data required to provide government, community groups, industry, researchers, consultants and individuals with the information they wanted. Some examples of the types of information provided during the mapping program are listed below:

- potential for viticulture irrigated by groundwater in the Mount Lofty Ranges.
- extent of inherently erosion-prone land protected by contour banks in the West Broughton Soil Conservation District.
- potential for onion weed infestation in the South East.
- extent of non arable land without perennial vegetation cover in the Northern Mallee.
- delineation of revegetation zones on Eyre Peninsula.
- extent of water repellent soils across the state in relation to supplies of clay suitable for amelioration

In order to service these types of requirements, the number of attributes assessed for each mapping unit expanded to 37. There was an obvious need for an objective basis on which to assign rankings for each attribute (ie a subjective high - medium - low system was clearly inappropriate). A numeric scale based on the conceptual framework outlined in Table 2 was adopted. Specific classification criteria for each attribute were then developed to ensure repeatability between operators. Descriptions of the classification system and the specific criteria are the basis of this report.

### Attributes

The attributes which are linked to the mapping data base, and which are discussed in the body of this report are listed in Table 1.

Table 1 Attributes linked to the Soil Landscape Mapping Coverage

| General category | Attributes |
|---|---|
| Soil moisture | Susceptibility to waterlogging<br>Depth to water table<br>Available water holding capacity<br>Recharge potential<br>Susceptibility to water repellence |
| Soil structure | Surface soil condidtion<br>Subsoil structure<br>Depth to hard rock<br>Depth to hardpan |
| Soil chemistry | Inherent fertility<br>Boron toxicity<br>Sodium toxicity<br>Aluminium toxicity<br>Susceptibility to acidity<br>Alkalinity<br>Acid sulfate potential<br>Surface carbonate<br>Subsoil carbonate |
| Salinity | Salinity (induced by water table)<br>Dry saline land<br>Scalding |
| Erosion | Water erosion potential<br>Wind erosion potential<br>Gully erosion<br>Mass movement (landslip) |
| Land surface | Surface rockiness<br>Exposure<br>Susceptibility to flooding |
| Irrigation (potential root zone depth) | Crop type A (citrus, avocado etc)<br>Crop type B (stone fruit, almond etc)<br>Crop type C (grape, olive etc)<br>Crop type D (root crops)<br>Crop type E (above ground annual crops) |
| Irrigation | Deep drainage |

### Conceptual framework

A simple approach would have been to define a set number of classes (eg low, moderate and high) and define arbitrary criteria for each attribute. For example, classifying land for rockiness could have been based on the criteria:

| | |
|---|---|
| Low | less than 5% rock outcrop |
| Moderate | 5-20% rock outcrop |
| High | more than 20% rock outcrop |

The USDA land capability classification (Klingebiel and Montgomery 1961) and an early South Australian system (Beare 1956) provided an alternative. Although these systems were going out of favour during the 1990's as being too generalist, not crop specific, and not applicable for irrigated land uses, they provided a very useful framework, not for land capability assessments, but for determining attribute class limits.

In the framework, a given class number imparts an immediate idea about the degree of limitation with respect to any attribute. For example, if Class 4 in the system is used to indicate a level of limitation which renders land semi arable for dryland field crops, an immediate mental image of land ranked Class 4 for water holding capacity is generated - the soil must be quite shallow with a water holding capacity so low that in some years crops are unproductive due to inadequate moisture availability. Similarly, land ranked Class 4 for salinity must be sufficiently saline that only a limited range of crops can be grown, and they are only productive under certain seasonal conditions. For some uses, these limitations may be irrelevant. For example, land which is Class 4 with respect to water holding capacity may not impose a limitation for irrigated grape vines. The soil still has a low water holding capacity, but irrigation systems make the limitation largely irrevelant. This low sensitivity to water holding capacity or any other attribute is accounted for in a set of interpretation rules developed specifically for grape vines.

The generalized land classification system uses eight classes. Each of these classes has broad implications in terms of dryland agricultural and grazing regimes. Class 1 land has no significant limitations, while Class 8 is useless from a primary production point of view. The generic class definitions are set out in Table 2.

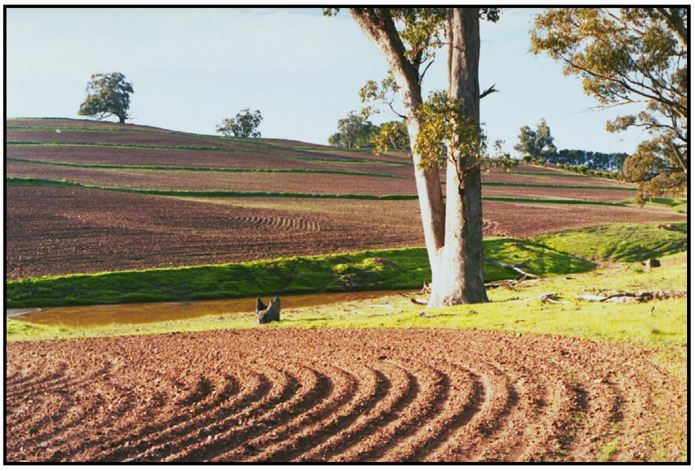
Table 2 Generalised Land Class Definitions

| Class | Description |
|---|---|
| 1 | Land with no significant limitations which can be used for all types of agricultural production on a permanent basis. |
| 2 | Land with slight limitations, which can be used for most types of agricultural production on a permanent basis provided that careful planning and simple modifications to standard practices are applied. Simple modifications do not include capital expenditure on works or machinery, nor do they require the use of specialized technology. Some examples of simple modifications are; contour working, reduced tillage, use of tolerant varieties, additional fertilizer applications and so on. Slight productivity reductions occur where limitations cannot be overcom. |
| 3 | Land with moderate limitations, which can be used for most types of agricultural production on a permanent basis, provided that very careful planning and intensive management practices are applied. Intensive practices involve capital expenditure on works or equipment, and/or the use of specialized technology, and/or practices requiring significant time and inconvenience. Moderate productivity reductions occur where limitations cannot be overcome. |
| 4 | Land with a sufficiently high level of limitation that the growing of annual crops requires a high level of management skill or is characterized by low productivity. This land is used for improved pastures or, depending on the type of limitation, for perennial or occasional annual crops. |
| 5 | Land which has such a high level of limitation that its low productive potential and/or extreme management requirements limit its use. Improved pastures, or perennial horticulture (where erosion potential is the main limitation), are the principal land uses. |
| 6 | Land not traversable with standard equipment due to steep slopes or excessive rockiness. The land is mostly used for grazing of native pastures. |
| 7 | Land with extreme limitations which requires protection by perennial vegetation. Some limited grazing is possible but the primary aim of management is protection rather than productivity. |
| 8 | Land with no productive potential, but not requiring any specialized management for its protection. This land includes exposed rock, bare salt pans and land permanently inundated. |

Although there are eight classes in the system, all are rarely used for any one attribute. For example, there is no Class 6 for salinity. This is because Class 6 is used for land which is not traversable due to steep slopes and / or rockiness. This is irrelevant to saline land, so Class 6 is not used. For most attributes, eight classification levels are unnecessary (eg eight classes of water repellence are meaningless in a broad scale mapping context). For some attributes, three or four classes are all that can be justified due to the level of precision of the mapping data.

### Examples of some Land Classes

Sloping land with a moderate potential for sheet and rill erosion (attribute “e”), can be used for cropping provided that appropriate surface management techniques are used and runoff control structures are built. This land is designated Class 3-e due to the nature of the principal limitation and the intensity of management required.



*Class 3-e land*

Very rocky land (attribute “r”) which is not traversable with standard machinery is limited to uses such as rough grazing, wildlife habitat and so on. This land is designated Class 6-r.

*Class 6-r land*

A very thick sand over an alkaline subsoil containing fine carbonates within a metre has a sub-optimal moisture holding capacity (attribute “m”). Slight productivity reductions in relation to the potential yield of such land can be expected. This land is designated Class 2-m.

*Class 2-m land*

The rest of this report focuses on describing each of the land attributes used in the mapping coverage, and showing how they are used to classify land. For each attribute, the causes and consequences of the particular conditions associated with that attribute are summarized, guidelines for assessing the attribute are given and criteria for classifying land according to that attribute are defined. General soil and land management guidelines for each class of land are also provided.

Scope of the Classification System

The classification criteria and management guidelines are flexible and subject to change. In particular the following points should be stressed:

- The criteria used to define the classes are based on observation and experience only, and not on experimental work. The classes provide a means of determining the nature and relative severity of limitations to agricultural land use.
- Under no circumstances should the criteria be used as rigid determinants of land class. They are guidelines only.
- The classification system is intended to be applicable throughout the agricultural districts of South Australia, so the management guidelines are deliberately generalized. It is recognized that each area of land, be it a paddock, property or district, has its own characteristics requiring specific management practices. Consideration of such detail is beyond the scope of this publication. More specific information should be sought from District Soil Conservation Boards or Officers from Primary Industries and Resources SA.
- As land management technology improves and our knowledge of the interactions between farming practices and the soil increases, there will be a need to modify the classification criteria and management guidelines. This publication will be revised to incorporate new information.
- The information in this publication applies to agricultural land in South Australia, with climate being used to define agricultural from pastoral districts. The lower rainfall limits for agricultural land in South Australia vary from 160 mm to 180 mm (median for April - October).

The classification system and the classification criteria described in this document deal only with soil and landscape parameters. Land assessments for particular crops or other types of land use involve two stages. Stage 1 entails analysing the land resource survey data to come up with a land classification. Stage 2 entails the formulation of rules (or models) in which the requirements of the particular crop type or land use are matched with land classification rankings and other relevant environmental and socio-economic data to predict the overall suitability of land for the use in question. The classification criteria outlined herein satisfy the requirements for stage 1. Draft rules which relate land class to specific crop potential are described in *Guidelines for Assessing Crop Potential,* (Maschmedt 2001).

## Explanation of terms

In discussing assessment techniques for the attributes, references are made to a number of basic soil profile characteristics. These are explained or illustrated in the Appendix.

## 2 WATERLOGGING AND DRAINAGE

Drainage refers to the speed and extent of removal of water from the soil. Sub-optimal drainage results in water-logging where some or all layers in the profile are saturated for periods ranging from a couple of hours to all of the time.

### Causes of waterlogging

The degree to which a soil becomes waterlogged depends on how much water enters the soil and how quickly it leaves it, either by deep percolation, lateral seepage or evapotranspiration. Clearly, low lying ground is more prone to waterlogging than higher ground, and, just as clearly, areas which get little rain or have heavy runoff are not affected.

Drainage is also influenced by the permeability of the soil, depth to water table and plant water use.

*Soil permeability*

Soils which are only slowly permeable because of high clay content, massive layers with low porosity or impervious hardpans, are unable to transmit water as rapidly as it enters, and it accumulates in the soil. Such soils can become waterlogged on sloping ground even though there is some opportunity for lateral movement downhill.

*Near-surface water table*

A water table near the surface will restrict percolation through the profile, regardless of the permeability of the soil.

*Evapotranspiration*

High evapotranspiration rates, mainly due to vigorous plant growth, can reduce waterlogging. However, only perennial plants with extensive root systems such as trees and shrubs, and others with deep tap roots such as lucerne have significant capacity to alter soil drainage conditions.

Soil drainage refers to wetness conditions under the existing climate and land use. The drainage status of a soil may alter significantly under irrigation for example, where water input can increase several fold. Permeability measurements, and not drainage estimates, must be used to assess a soil’s potential for irrigation.

*Waterlogging to the surface caused by slowly permeable clay layer at shallow depth*

### Consequences of waterlogging

Waterlogging causes oxygen deficiency in the rootzone. This retards root development and function, and may lead directly to death, or to poor growth and low productivity. Waterlogging also causes denitrification and can affect the availability of other nutrients. Toxins secreted by anaerobic bacteria, which flourish in waterlogged soils, can also damage plants.

Waterlogged soils are prone to compaction damage by livestock and vehicles, and on sloping ground are susceptible to erosion.

Access to waterlogged land is often difficult, and critical operations such as pesticide applications may be delayed with effects on productivity.

### Assessing drainage conditions

Observation of the soil after heavy rain and during late winter to late spring provides the best guide to soil drainage conditions. The most commonly waterlogged soils in South Australia are those with low permeability subsoil clay layers. Water accumulates in the coarser material above the clay, leading to waterlogging in the rootzone, often at depths as shallow as 20 cm. These soils can usually be recognised even when dry by their colours. The clay subsoil has dull yellow and grey mottled colours and the layer immediately above it is lighter coloured or bleached. Less severe waterlogging can occur in other texture contrast soils which do not have these colours.

Certain carbonate layers, especially classes I and IIIA (Wetherby and Oades 1975), are associated with restricted drainage. Most clay soils are also prone to waterlogging after the soil has wet up, and the cracks have closed.

*Restrictive subsoil clay causes water to perch*

*Class I carbonate layer restricts deep percolation*

*Well drained friable subsoil clay*

*Rapidly drained sandy soil*

### Classification of land susceptible to waterlogging

The susceptibility of land to waterlogging is classified by the length of time all or part of the soil profile remains saturated after prolonged or heavy rainfall or irrigation. Soil drainage categories based on those defined by McDonald et al (1990) are used in Table 3.

Table 3 Classification criteria for susceptibility to waterlogging

| Drainage Category | Classification Criteria | Land Class |
|---|---|---|
| Rapidly drained | Soil is never wet for more than several hours | 1-w |
| Well drained | Soil is never wet for more than several days | 1-w |
| Moderately well drained | Soil is wet for up to one week | 2-w |
| Imperfectly drained | Soil is wet for several weeks | 3-w |
| Imperfectly drained | As for 3-w, but prone to saturation very early in the growing season | 4-w |
| Poorly drained | Soil is wet for several months | 5-w |
| Very poorly drained | Soil is wet for most of the year | 7-w |
| Inundated | Land is permanently under water | 8-w |

**Productivity and management of waterlogged land**

Productivity potential generally declines with increasing duration of waterlogging although high soil moisture levels carrying through into late spring can provide useful greenfeed.

Management strategies include installation of drains (e.g. open ditches, sub surface agricultural drains, interceptor banks and bores), early working and seeding, use of waterlogging-tolerant varieties, excluding stock and careful irrigation.

Some management guidelines for agricultural land uses are summarised below:

Land classes 5-w, 7-w and 8-w are non arable and are too wet for virtually all annual and perennial horticultural crops.

Extensive Cropping Land

- Time operations carefully and sow early to avoid compaction and seed/seedling damage. On class 4-w land, crop establishment is only possible in seasons with a gentle and early break.
- Select species and varieties tolerant of waterlogging.
- On classes 3-w and 4-w land, install surface drains, interceptors or drainage bores where feasible.
- Control weeds which are tolerant of waterlogging.

Grazing Land

- Select species and varieties tolerant of waterlogging.
- Control grazing to avoid pugging.
- Fence off particularly wet areas where practicable.
- Drainage bores are effective in some areas.
- Stock should be excluded from class 7-w land except where land dries out sufficiently during summer.

Irigated Vegetables

- Select appropriate crops and varieties.
- Design and manage irrigation systems which prevent excess water accumulation.
- Install surface or sub-surface drains on land classes 3-w and 4-w.
- Plant on raised beds.

Perennial Horticulture

- As for Irrigated Vegetables.
- On land classes 3-w and 4-w, rows can be mounded, but subsoil should not be exposed. Mounds should be grassed.

*Surface drains*

*Mounding in orchard*

# 3 WATER TABLE DEPTH

Water tables are bodies of water, usually below ground level, contained within the pore spaces of rocks, sediments and soils. Water tables can only form where an impervious layer prevents downward movement. Although water tables can occur at any depth, only those occurring near the ground surface (ie within 2-3 metres) are relevant in the present context.

## Occurrence

Shallow water tables are naturally occurring features in some parts of South Australia, especially in the South East, parts of the Mount Lofty Ranges and Kangaroo island, and anywhere that salt lakes occur. European activity has caused a net increase in water table height, mainly through the effects of removal of deep rooted vegetation and its replacement with shallow rooted, often annual vegetation, using significantly less water. This change in equilibrium in the hydrologic cycle results in rises in water tables through increased accession.

## Consequences of shallow water table depth

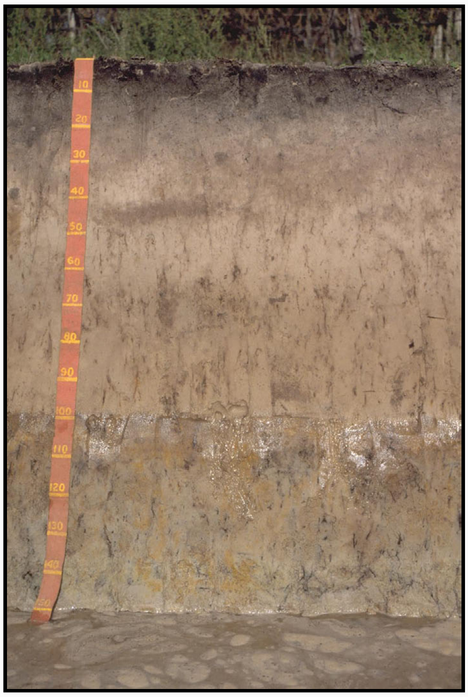
Water tables at shallow depth contribute to or cause waterlogging and / or salinity in soils. Where they occur at moderate depths (eg between 100 and 200 cm) and are salty, soil salinity is probably an existing or emerging problem. Marginally saline or fresh water tables at these depths may not affect dryland crops or pastures, but they have significant implications for irrigation. Addition of extra water inevitably raises water table levels, thus affecting not only the irrigated crops, but also plants on adjacent land underlain by the same water table.

Rising water tables are commonly the result of activity remote in time and space from the affected land. The effects of clearing at the top end of a catchment may not become apparent tens of kilometres away at the lower end, for many years.

## Assessing water table depth

Although there are electronic devices available which are capable of estimating water table depth as the operator traverses the land, test wells are the most common and simplest option. These must be installed correctly to prevent the perforations in the well liner from blocking up. But most importantly, the test well must not extend so deep as to break through an impervious layer and intersect a deeper water table which would not normally affect the land surface. Regular monitoring of depth will produce a record of within season and between season changes.


*Saline water table*



*Fresh water table*

## Classification of water table depth

Water table depth usually varies during the season and between seasons. Rankings are assigned according to the following rules:

- Maximum level of water table that is maintained for at least two weeks per year.
- Levels reached during exceptionally wet seasons are excluded if such seasons have a recurrence frequency of less than 10%.

Table 4 Classification criteria for depth to water table
(based on maximum level maintained for at least two weeks per year)

| Depth Category | Classification Criteria (depth below surface) | Land Class |
|---|---|---|
| Deep | More than 200 cm | 1-o |
| Moderate | 100-200 cm | 2-o |
| Moderately shallow | 50-100 cm | 3-o |
| Shallow | 0-50 cm | 4-o |
| Above surface | Above surface for up to 3 months | 5-o |
| Above surface | Above surface for 3-10 months | 7-o |
| Above surface | Above surface for more than 10 months | 8-o |

## Management of water tables

A major difficulty in dealing with shallow water tables is that they are commonly the result of someone else's activity, or are a long term natural feature of the landscape. Integrated catchment management approaches provide the most desirable solution. They rely heavily on increasing water use efficiency of crops and pastures, and introducing higher water use vegetation into the system.

In the absence of integrated management approaches, on site options come down to establishing tolerant plant species, or drainage where possible and appropriate.

# 4 SOIL WATER HOLDING CAPACITY

One of the main functions of soil is to store moisture and supply it to plants between rainfall or irrigations. Evaporation from the soil surface, transpiration by plants and deep percolation combine to reduce soil moisture between water additions. If the water content becomes too low plants become stressed. The plant-available-moisture storage of a soil provides a buffer which determines a plant's capacity to withstand dry spells.

However in some situations plants can suffer from moisture stress even though there is water in the soil. This is commonly caused by poor root growth and the consequent reduced capacity of the plant to take up adequate moisture. Excessive soil salinity which causes high osmotic pressure in the soil solution also causes moisture stress for plants in damp soils.

## Forms of soil water storage

Water is held in soil in various ways and not all of it is available to plants.

*Chemical water* is an integral part of the molecular structure of soil minerals and *hygroscopic water* is held tightly by electrostatic forces to the surfaces of clay crystals and other minerals. Both of these forms of soil water are unavailable to plants.

Other water in soil is held in the pores between the soil particles. The amount of moisture a soil can store and the amount it can supply to plants is dependent on the number, size and connectivity of its pores.

*Gravitational water* is held in large soil pores and rapidly drains out under the action of gravity within a day or so after rain or irrigation. Plants can make little use of gravitational water.

*Capillary water* is held in pores which are small enough to hold water against gravity, but not so tightly that roots cannot absorb it. This water occurs as a film around soil particles and in the pores between them, and is the main source of moisture for plants. As this water is withdrawn, the larger pores drain first. The finer the pores, the more resistant they are to removal of water. This capillary water can move in all directions in response to suction, and can move upwards as much as two metres through soil, the particles and pores of the soil acting like a wick. However unless root density is high, this movement may be too slow to keep pace with plant water requirements.

*Micro-pore water* is held in pores that are so small that the suction forces holding the water in them are too great for the roots of most plants to be able to extract it. Micro-pore water is unavailable to plants other than species specially adapted to very dry or very saline conditions.

When soil is saturated all the pores are full of water, but after a day or two (assuming that there are no impediments to free drainage) all gravitational water drains out leaving the soil at *field capacity*. This equates to a suction of about 8 kPa. Plants then draw water out of the capillary pores, readily at first and then at progressively slower rates, until the rate of movement from the soil to the root is so slow that the plant's water requirements can no longer be met. At this point the soil is said to be at *wilting point* and without water additions plants die. Wilting point equates to a suction of about 1500 kPa, although this varies between plant species. Some of the micro-pore water evaporates, but most can be removed only by heating.

The plant-available water is therefore the amount which can be extracted as the soil dries from field capacity to wilting point (ie between suctions of 8kPa and 1500 kPa). This value is expressed as millimetres of water per metre of soil (mm/m). The portion of the plant available water store which can easily be extracted by plants without their becoming stressed is termed *readily available water*. This is equivalent to the amount of water released between field capacity (8kPa) and a suction of about 60 kPa. Irrigators must have knowledge of the readily available water capacity so that water can be applied before productivity is affected. Rainfed crops can also suffer yield decline if the soil moisture content falls below the readily available level at critical growth stages.

## Factors affecting the water holding capacity of soil

The amount of soil water available to plants is governed by the volume of soil that roots explore (the rootzone), and the nature of the soil material. Because the total- and available-moisture storage capacities are linked to porosity, the particle sizes (texture) and the arrangement of particles (structure) are the critical factors. Organic matter, carbonate levels and stone content also affect water storage.

The rootzone

The depth to which roots can penetrate depends on the extent of the seasonal wetting front down the soil profile and the presence of restrictive layers. Restrictive layers include hard rock, tough clay subsoils, concentrations of fine earth carbonate (carbonate classes I and IIIA, as described by Wetherby and Oades 1975), and toxic levels of salt, sodicity, boron or aluminium.

The distribution of roots is as important as the depth of penetration. Sparse or uneven root distributions, frequently caused by unfavourable physical or chemical conditions or root diseases, affect the efficiency of water uptake. For example, root growth is usually poor through the large, dense clay aggregates which are common in many Southern Australian subsoils. Water stored in these aggregates is theoretically available, but plants suffer moisture stress because the rate of movement of water through the clay to the root tips can be less than the plant's required uptake rate.

Water availability is also restricted in soils which are prone to waterlogging, particularly where this is caused by impeding clay layers near the surface. In these soils, saturation of the subsurface layer on top of the clay prevents adequate vertical root growth during the winter. In spring time, these winter saturated layers rapidly dry out and often become very hard, imposing a physical barrier to roots. Consequently, although there is subsoil moisture, it is not available to the stunted surface root system.

Soil texture and structure

The higher the clay content of a soil the higher the proportion of capillary and micro-pores. Clays therefore hold more water than sands, but much of this water is held in micro-pores and is unavailable. Provided there is sufficient rainfall to wet a clayey soil to field capacity throughout the rootzone, it has a larger (although slower) moisture supply capacity than a lighter textured soil. Consequently crops will persist longer particularly if spring rains do not fall.

In marginal rainfall areas, heavier soils may never reach field capacity, and only a fraction of stored water is available to plants, the bulk of it being held in micro-pores. In these situations sands are often more productive than heavier soils because they are able to release almost all of their stored water.

Plants on sandy soils are also able to respond quickly to light showers due to their low wilting points. More clayey soils must absorb considerable moisture before plants can have access to it.

Figure 2 illustrates the relative water retention of the three main soil texture categories.

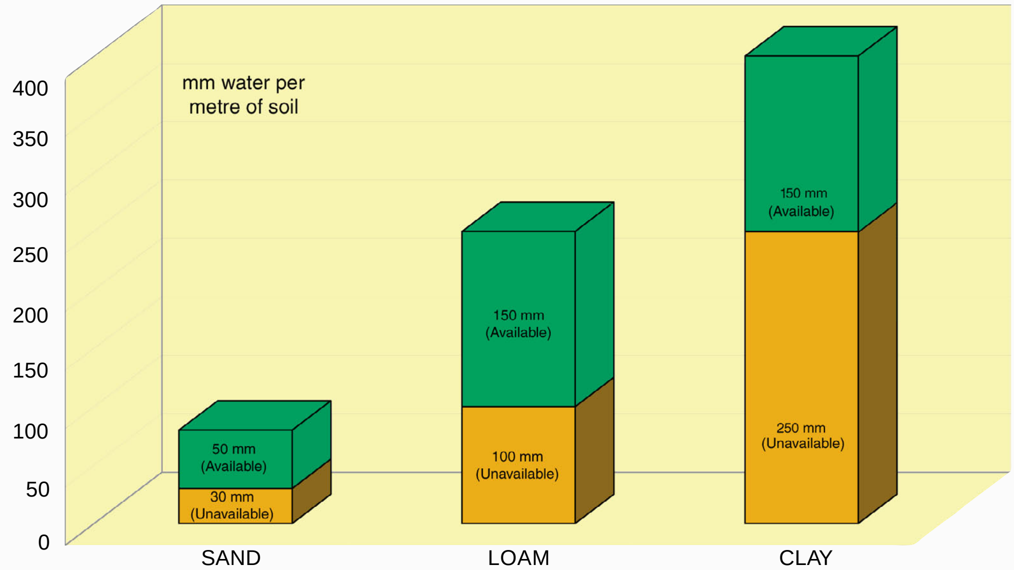



**Figure 2.** Relative water retention of sand, loam and clay.

### Consequences of low water holding capacity

The lower the available water storage capacity of a soil, the lower is its capacity to withstand dry periods and the more plants have to rely on frequent rainfall. In most of South Australia rainfall reliability during the critical spring growth period is low, so moisture storage capacity is crucial, and often the most important factor influencing potential yield. Soils with rootzone available water storage of less than 20 mm are generally not arable.

*Patchiness in crop due to variable soil water holding capacity*

### Assessing soil water holding capacity

The depth of the root zone must first be established, by observing the depth to which roots from the previous crop have extended, or by noting the depth of a restrictive layer. Roots of annual field crops and pastures rarely extend below 120 cm and are commonly restricted by adverse physical or chemical conditions to depths of less than 50 cm. Some perennial species, notably lucerne, may extend roots to 600 cm or more if soil conditions are ideal and moisture is present.

Estimates of available water holding capacities can be made in the laboratory by measuring the change in soil moisture content as samples are progressively dried from field capacity to wilting point. This is done by applying suctions ranging from 10 kPa to 1500 kPa to simulate plant water use. However these techniques are lengthy and expensive, and field estimates are needed for routine assessments.

Table 5 provides a range of readily available and total available water holding capacities for the various texture classes. Because organic matter and structure are significant modifying factors, the low end of the range should be used for dense, poorly structured or low organic matter materials, while the high end should be used for friable, open, well structured and high organic matter materials. Readily available water values are needed by irrigators in order to determine irrigation schedules.

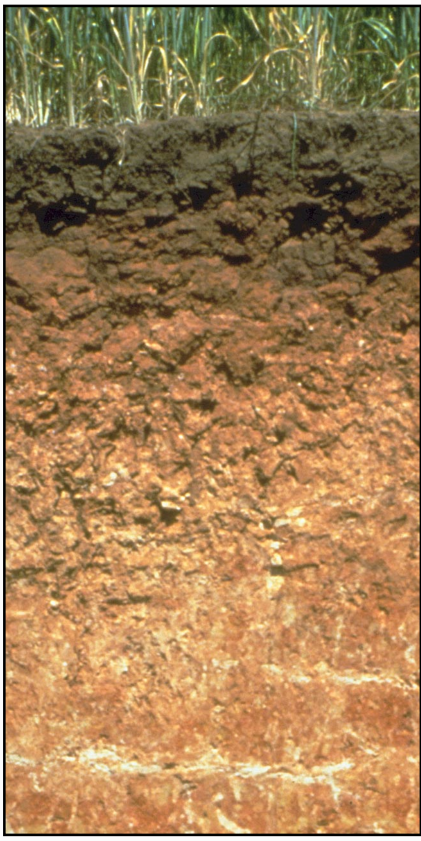
Table 5 Water holding capacities of texture groups

| Texture group | Water holding capacity (mm water/metre soil) | |
|---|---|---|
| | Readily available (8-60 kPa) | Total available (8-1500 kPa) |
| Medium to coarse sand | 30-50 | 40-80 |
| Fine sand | 40-60 | 60-100 |
| Loamy sand | 50-70 | 80-120 |
| Sandy loam | 40-70 | 100-140 |
| Light sandy clay loam | 60-90 | 110-170 |
| Loam | 80-100 | 140-200 |
| Sandy clay loam | 70-90 | 130-180 |
| Clay loam | 60-90 | 150-220 |
| Clay | 50-70 | 120-220 |

Figures should be reduced proportionally according to stone and gravel content.

Adapted from Wetherby (1992) and Dent and Young (1981)

The water holding capacity of a soil is calculated by adding the capacities of each layer in the rootzone. All layers in which root growth occurs should be included, even if root growth is poor. Reduced water holding capacity values are assigned to these layers to reflect their relative contributions to total available water storage.



0-15 cm
sandy loam

15-45cm
sandy clay

45-64 cm
alkaline clay

64 cm +
Sodic and saline clay

This soil has a root zone depth limited by sodic, saline clay from 64 cm. High alkalinity from 45 cm restricts root growth in the 45-64 cm layer.

Available water holding capacity in the root zone is:

| | | |
|---|---|---|
| 15 cm @ 140 mm / m | = | 21 mm |
| 30 cm @ 180 mm / m | = | 54 mm |
| 19 cm @ 130 mm / m | = | 25 mm |
| Total root zone | = | 100 mm |

**Figure 3.** Example of how to calculate profile water holding capacity

## Classification of land according to water holding capacity

This classification is intended to provide information relevant to non irrigated field crops, to indicate the total amount of moisture potentially available to the crop. The classes have little meaning for irrigated crops, where readily available water in the potential rootzone of a specific crop is of interest.

Land is classified with respect to water holding capacity on the basis that yield potential decreases with decreasing storage capacity, all other things being equal.

Classes are based on estimates of the total available water holding capacity of the root zone, as set out in Table 6. Potential root zone depth varies between species. Wheat is used as the benchmark in this classification.

Table 6 Classification criteria for available water holding capacity (AWHC)

| AWHC Category | Rootzone * AWHC | Land Class |
|---|---|---|
| High | >100 mm | 1-m |
| Moderate | 70-100 mm | 2-m |
| Moderately low | 40-70 mm | 3-m |
| Low | 20-40 mm | 4-m |
| Very low | <20 mm | 5-m |

* The potential rootzone of wheat is used as the benchmark.

Water storage capacity is not considered to be limiting if the available storage in the rootzone is more than 100 mm. Soils with less than 20 mm capacity are not generally arable under natural rainfall due to the poor capacity of the soil to supply sufficient water long enough for crops to mature.

*Profile with low water holding capacity*

*Profile with high water holding capacity*

### Management of soils with low water holding capacity

Lack of moisture storage capacity is a permanent limitation in many soils where there is no scope for alteration of the profile, as for example in shallow soils over hard rock. However where moisture can be stored and the problem is one of poor uptake, there is potential for improvement. Avenues which should be explored include:

- the use of deep rooted plants;
- deep ripping with added gypsum to open up the subsoil;
- the role of soil animals such as worms to improve soil structure;
- the use of surface supplied ameliorants such as gypsum and lime;
- selection of plant varieties which are more tolerant of chemically unfavourable subsoils.

# 5 RECHARGE POTENTIAL

When soil water content exceeds the water storage capacity of the profile, one of two things happens:

- Excess water will either pond on the surface, or run off across the surface or along the top of a slowly permeable subsurface layer; OR
- Excess water moves downwards into the material underlying the soil (substrate).

Where the latter situation applies, water is then out of reach of all but the deeper roots of perennial plants, and so most cannot be returned to the atmosphere by evapotranspiration. This deep drainage water is one of the main sources of water table and aquifer recharge.

Aquifer recharge is essential to maintain the viability of groundwater supplies for irrigation, stock or domestic use. However in some situations recharge creates problems. These are of two general types.

If recharge rates exceed the rates at which water is discharged or removed from the aquifer (eg by external drainage including outflows to the sea or deeper aquifers, by plant evapotranspiration or through artificial pumping such as irrigation), the elevation of the aquifer (the water table) rises. This is a widespread phenomenon in southern Australia following the clearance of deep rooted and relatively high water use native vegetation and its replacement by shallow rooted and relatively low water use annual plants. Commonly the near surface aquifers are saline, or the rising water table intersects saline rocks or sediments, with the result that saline water reaches the root zone or even the soil surface. This is known as secondary salinization, and is dealt with in Section 12. One of the main management approaches to stabilizing or reversing salinization is to reduce recharge to the groundwater table.

Another type of problem associated with recharge is the contamination of aquifers by substances in deep drainage water. Contaminants associated with agricultural land uses include fertilizers, pesticide residues, livestock excreta and carcasses, and soil colloids. In these cases, management to control contamination is a more sustainable option than recharge reduction.

### Factors affecting recharge

The inherent capacity for recharge is determined by more or less unchangeable or unmanageable environmental parameters including soil water holding capacity, topography, rainfall and the nature of the substrate. Actual recharge depends on the way in which the land is managed. In particular, the type and vigour of vegetation has a major bearing on the level of recharge.

<u>Soil water holding capacity</u>

As discussed in Section 4, the water storage capacity of the soil is determined by soil depth, texture, porosity, and stone content. However, from a recharge viewpoint, the total amount of soil water storage capacity, rather than the plant available fraction of this capacity is important. Deep, fine textured soils with high proportions of capillary and micro-porosity have the highest storage capacity, whereas shallow, very stony, sandy or high density soils have the lowest capacity. Clearly the greater the capacity of the soil to store water, the smaller the probability of deep drainage occurring.

<u>Topography</u>

On sloping land, some water will run off, either along the ground surface, or along a restrictive subsurface layer. Although this water may reach a water course, or access the groundwater table via another pathway, there is nevertheless a reduced amount of water available for recharge at the point where the rain fell.

<u>Rainfall</u>

All other things being equal, recharge rates are greater in higher rainfall districts. The Mediterranean climate of southern Australia favours recharge because most of the rain falls during the coldest months of the year when plant water use is low.

Nature of the substrate

Substrate is a general term used here to include those materials underlying the soil. Common substrates in South Australia include hard to highly weathered basement rocks, windblown deposits of sands, silts or clays which may be highly calcareous or siliceous, alluvial sands, silts or clays, calcrete, sedimentary limestones, and weakly consolidated sandstones and shales.

Impervious substrates prevent deep drainage water from accessing the water table directly, although it may enter elsewhere. On the other hand, highly permeable substrates such as loose sands or coarse sandstones allow water to move readily, facilitating recharge. The porosity and connectivity of the pores in the substrate are critical in determining whether water enters at all, how quickly it moves through the material, and how much can be stored in it. For example, a coarse grained, unaltered sandstone readily accepts water, conducts it rapidly and stores large amounts. A metamorphosed sandstone on the other hand has less recharge capacity. This is because recrystallization and new mineral growth which occurred during metamorphism have partially filled the original pores and reduced their connectivity.

Most basement rocks in the agricultural districts of South Australia are fractured and steeply dipping, as a result of crustal movements. Both of these features favour recharge, as cracks and bedding planes are open to the surface, as illustrated in the photograph.

*Steeply dipping rock strata which favour recharge*

Vegetation

High water use vegetation types result in less water lost to deep drainage. Natural vegetation communities have adapted to ambient rainfall, and generally use most of it, so losses to deep drainage are minimal. Most natural vegetation includes deep rooted species which are able to tap deep subsoil moisture reserves during the drier seasons. Annual plants which are predominant on most agricultural land, do not have extensive or deep root systems, so a proportion of deep subsoil moisture is unused. Water use is also increased if the vegetation growth is vigorous. Vigour is not only determined by the type of plant (eg some plants are more active during winter than others), but by the health of the plant, a function of nutrition and disease status.

### Consequences of changes in recharge rates

These are summarized as follows:

Increased recharge rates lead to:

- Rising water tables. If saline, these can contaminate surface waters (creeks and dams) and damage or kill plants (if within capillary range of the root zone). This may lead to further problems such as erosion of bare salinized ground. If rising water tables are non saline, there may be some benefits from a plant growth aspect, but when water tables approach the surface, waterlogging becomes a problem.

- Increased risk of groundwater pollution from a range of agricultural chemicals, animal waste and soil particles.

Decreased recharge leads to:

- Drawdown of irrigation aquifers resulting in increased pumping costs, reduced flow yields, and possibly decreased water quality where falling water tables allow contamination by more saline aquifers.

### Assessment of recharge potential

Actual recharge rates are highly dependent on vegetative cover. It is not the purpose of this assessment to estimate or measure actual rates, but rather to estimate recharge potential as a function of inherent landscape parameters. Recharge potential is assessed according to estimates of soil water holding capacity and porosity of substrate material, with a rainfall qualifier.

Soil water holding capacity

Although the total soil water storage capacity, rather than the plant available storage capacity influences recharge rates, in a relative ranking system it is convenient to use the available water holding capacities discussed in Section 4. Three categories of soil water holding capacity are used (Table 7), based on the classes defined in Table 6, Section 4.

Table 7 Soil water holding capacity categories

| Available Water Holding Capacity | | Amount of available water stored in soil |
|---|---|---|
| **Category** | **Class** | |
| High | 1-m | >100 mm |
| Mod - mod low | 2-m and 3-m | 40-100 mm |
| Low - very low | 4-m and 5-m | <40 mm |

Substrate porosity

Three categories of substrate porosity are used, according to substrate types commonly occurring in South Australia. They are defined in Table 8.

Table 8 Substrate porosity

| Substrate Type | Porosity Category |
|---|---|
| Siliceous sand, Class IV carbonate + | High |
| Calcareous (shell) sand | High |
| Clay, sandy clay, Class I carbonate + | Low |
| Silt loam, silty clay loam | Mod |
| Silty sand | High |
| Clayey sand | Mod |
| Class IIIB / IIIC carbonate + | High |
| Class IIIA carbonate + | Mod |
| Calcrete * | High (Mod)* |
| Basement rock # | |
| Massive and unfractured (eg granite) | Low |
| Metamorphosed sedimentary rock (eg schist, phyllite, metasandstone) | Mod |
| Non metamorphosed medium to coarse grained sedimentary rock (eg sandstone) | High |
| Non metamorphosed fine grained sedimentary rock (eg siltstone, mudstone) | Mod |
| Pallid zone material (kaolinized rock) | Low |
| Fossiliferous limestone | High |
| Non fossiliferous limestone | Mod |

* Calcrete is usually fractured, allowing water to pass through rapidly, so the underlying material determines the substrate porosity. If calcrete is unfractured, decrease Porosity Category to moderate.

\# Most basement rock in southern South Australia is fractured and steeply dipping. If not fractured or steeply dipping, reduce porosity category by one.

\+ Carbonate classes as defined by Wetherby and Oades (1975)

In order to account for the increased recharge potential in higher rainfall districts, an annual rainfall figure must be included in the assessment criteria. In hilly districts where a proportion of rainfall is lost to runoff, an arbitrary annual rainfall of 800mm is used. This figure is consistent with that used to define surface water pollution hazard zones (McMurray 1999) in the Mount Lofty Ranges watersheds. In non hilly districts such as the lower South East, this figure is tentatively set at 650 mm. Land where rainfall exceeds these figures is designated “high rainfall” in Table 9.

### Classification of recharge potential

Table 9 Classification criteria for recharge potential

| Soil Water Holding Capacity Category (from Table 7) | Substrate Porosity Category (from Table 8) | Recharge Potential Class | |
|---|---|---|---|
| | | Moderate to low rainfall | High rainfall |
| High (1-m) | Low | 1-q | 1-q |
| | Mod | 1-q | 1-q |
| | High | 1-q | 1-q |
| Mod - mod low (2,3-m) | Low | 1-q | 1-q |
| | Mod | 1-q | 2-q |
| | High | 2-q | 3-q |
| Low - very low (4,5-m) | Low | 1-q | 2-q |
| | Mod | 2-q | 3-q |
| | High | 3-q | 3-q |

### Management of recharge

Agronomic management

The principal means of reducing recharge is through increasing evapotranspiration. This involves maximizing the water use of existing vegetation, or by establishing higher water use vegetation systems. Maximizing water use of existing crops and pastures for example means maximizing productivity, through appropriate management of soil preparation, time of sowing, fertilizer use, pest control and grazing management. Practices such as fallowing to conserve soil moisture potentially contribute to recharge, but are usually only worthwhile on soils which have low recharge potential anyway.

Establishment of higher water use systems usually involves a shift from annual to perennial plants with deeper and more extensive root systems, and ideally with some degree of winter activity. Perennial vegetation systems commonly used in South Australia are lucerne pastures, fodder shrubs such as saltbush and tagasaste, agroforestry, plantation forestry and native vegetation.

It is critical to understand the hydrology of a particular area prior to changing land use. Restricted establishment of high water use vegetation (eg on a single property) will have minimal effect on rising regional groundwater tables, whereas the effect on localized water tables may be significant.

Irrigation management

Inefficient irrigation usually contributes to aquifer recharge. Drainage water from irrigated land can have the additional impact of increasing the salinity of groundwater by introducing salt flushed from the deep subsoil. Water applications must be tailored to the soil, crop type and soil water content to minimize the amount of water lost to deep drainage.

Well managed irrigation schemes can help to lower water tables through water withdrawal. However, by the same token, excessive irrigation will cause too much aquifer drawdown, so a balance must be found.

Engineering management

Drainage of waterlogged soils to remove surface or near surface water which would otherwise contribute to recharge may be effective in some situations. This can contribute to recharge reduction not only by preventing water accessing aquifers, but also by increasing evapotranspiration through waterlogging control and associated improved plant productivity. Groundwater pumping will lower water tables, but suitable disposal sites are needed if irrigation is not a feasible option for using the water (as is the case if it is too saline).

*Sandhills - usually high recharge zones*

*Deep clayey soil - a low recharge situation*

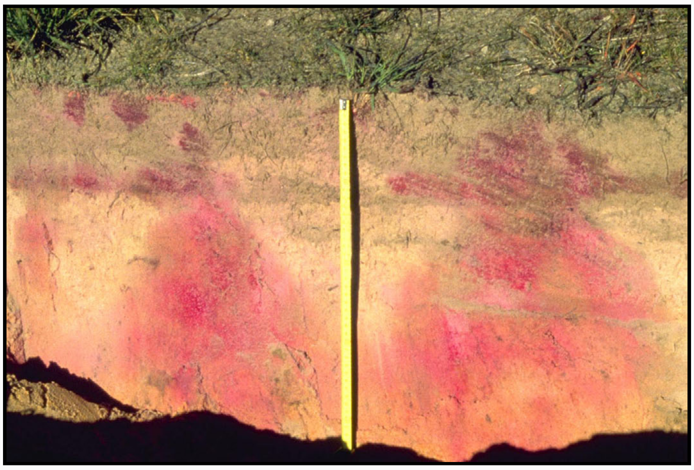
# 6 WATER REPELLENCE

Water repellence is a condition affecting some soils, whereby water is prevented from penetrating and wetting the soil.

## Causes of water repellence

Water repellence is caused by hydrophobic organic materials, mainly waxes, contained in plant remains in the soil. The waxes coat the soil particles causing water to bead on the surface. This causes uneven wetting of the upper part of the profile with large masses of soil remaining dry. Water repellence is most common on acid to neutral sands, although calcareous and more loamy soils can also be affected, although not as severely (King 1985).

Water repellence is usually low on virgin soils, but increases following development, particularly where the soil is infrequently cultivated, as under permanent pasture. Sands supporting old stands of lucerne and perennial veldt grass are commonly strongly repellent.



*Uneven wetting patterns in a water repellent sand*

## Consequences of water repellence

Water repellence can cause severe production losses through delays to sowing, patchy germination, increased weed competition and erratic herbicide performance. Water repellence also predisposes soils to erosion by both wind and water. However the sandy soils most likely to exhibit repellence also have low moisture holding and nutrient retention capacities and are highly susceptible to root pathogens. Low productivity on these soils cannot therefore be solely attributed to water repellence.

Repellence is not necessarily a problem every year. On Eastern Eyre Peninsula for example, repellence is considered a problem only when sufficient soaking rains do not occur in early winter, as happens about one year in three (Wetherby 1984).

In those years when water repellence is a problem, the soil takes longer to wet and more workings are required. As a result sowing is delayed. This is significant because early sowing is one of the key factors in improving productivity in these areas. Patchy germination and establishment are common because of the uneven distribution of water in the soil and this reduces grain yield and pasture production, through fewer plant numbers and sand blast damage. As well, there is reduced efficiency of herbicides because of their concentration in furrows by surface water runoff.

Poor plant establishment results in bare soil susceptible to erosion by wind and water. Water repellence can also indirectly contribute to salinity. Inefficient water use on repellent soils may lead to increased percolation and runoff and consequent additions to ground water tables, which may lead to salinization.

### Assessing water repellence

The severity of water repellence can vary significantly over short distances. A simple, quick test is needed so that many soil samples may be assessed. The "molarity of ethanol drop" (MED) test, described by King (1981), is a useful indicator of severity of repellence. This test ranks soils according to the concentration of ethanol needed to penetrate the sample within ten seconds.

Where a range of ethanol concentrations is unavailable, or only an approximate indication of severity is required, an abbreviated method using one ethanol concentration (2 molar) is satisfactory (McDonald et al 1990). Methylated spirits at a concentration of 24 mL per 200 mL of water can be substituted for 2 molar ethanol. Three categories are defined, as indicated in Table 10.

### Classification criteria for water repellence

Table 10 sets out classification criteria based on the abbreviated MED test using 2M ethanol, which is considered adequate for paddock assessments.

Table 10 Classification criteria for susceptibility to water repellence

| Repellence category | 2M Ethanol / water absorption | Land Class |
|---|---|---|
| Non repellent | Water is absorbed in less than 10 seconds. | 1-u |
| Repellent | Water takes longer than 10 seconds to be absorbed; ethanol is absorbed in less than 10 seconds. | 2-u |
| Strongly repellent | Ethanol takes longer than 10 seconds to be absorbed. | 3-u |

### Productivity and management of water repellent soils

The productivity of soils decreases as water repellence increases, usually because of lower germination and/or establishment percentages, greater susceptibility to sand blasting and reduced soil moisture.

Clay spreading is being increasingly used as a technique to overcome the problem. This relies on increasing the wettable surface area and the moisture retention capacity of the soil to ensure that a greater proportion of rainfall is held at or near the soil surface. Dispersive clays are more effective as they break down to produce a larger surface area and distribute through the soil quicker than well aggregated clays. Clay spreading at rates of between 50 t/ha and 250 t/ha (depending on depth of sand and degree of repellence) is expensive, so unless the clay is available on site (e.g. in swales between non wetting sandhills) or at least within a kilometre, this technique may be too costly. Incorporation to depths of 10-15 cm is essential.

Synthetic wetting agents or a range of industrial by-products can be applied in intensively used areas such as market and floriculture gardens, sports fields and home gardens with effects similar to those of clay spreading.


*Clay spreading to ameliorate water repellence*

Several tillage techniques may be used to control water repellence:

- weed control to minimize moisture losses, thereby improving the chances of seedbed wetting.
- cultivation and harrowing during rain to incorporate water into the soil.
- deep mixing to "dilute" the hydrophobic materials - this is not recommended on soils which are highly susceptible to erosion.
- sowing in furrows and using press wheels to take advantage of trapped moisture.

Water repellent soils on big sandhills, which are effectively non arable because of the risk of wind erosion, are best sown to permanent pastures such as lucerne, perennial veldt grass or evening primrose, or to shrubs and trees such as tagasaste. Although establishment may be difficult and the degree of repellence is likely to increase in the meantime, perennial vegetation is probably the most effective long term option on this class of land.

## Further reading

Anon. (1990). Non-wetting sands. The problem, causes, remedies and research. University of Adelaide.

Cann, M. (1999). Managing non-wetting sand with clay. Crop Harvest Report 1998/99. Primary Industries and Resources SA.

King, P.M. (1985). Water-repellent sands. Fact Sheet 12/85. Department of Agriculture, South Australia.

# 7 SOIL STRUCTURE, ROOT GROWTH AND SURFACE CONDITION

With the exception of loose sands, the individual clay, silt and sand particles of a soil are held together in larger lumps or “aggregates”. The nature of these aggregates and of the pore spaces between them determines the soil structure. Soil structure affects root penetration, water movement, aeration, soil stability, seedling emergence and workability. In a well structured soil roots can readily penetrate the aggregates, and water and air can move freely through the pores, so the soil is rarely saturated with water or starved of oxygen. A well structured soil resists the erosive forces of water and wind, allows germinating seedlings to emerge unimpeded, and can be worked over a wide range of moisture contents with minimal damage.

## Factors affecting soil structure

The way soil particles pack together is affected mainly by the amount and type of clay and the amount and size of sand grains. For surface soils, the amount of organic matter is crucial, as organic matter provides many of the materials necessary to “glue” particles together, and maintain pore spaces between them. Other bonding agents, such as calcium carbonate and compounds of iron, silicon and aluminium are important in some soils.

### Porosity

Soil structure influences plant growth through its effects on water and air movement, moisture storage and release, and impedance to root growth. These processes operate within the pore spaces of the soil. The total volume of pore space, the size distribution of the pores, and their connectivity determine the structural characteristics of a soil. These factors are discussed in detail by Cass et al (1993).

### Particle size distribution

Particle size distribution refers to the proportions of sand, silt and clay sized particles in the soil. The proportion of clay-sized particles in soil can vary from none to more than 80 per cent. The chemical properties of the clay fraction strongly influence the structural condition of the soil, but the non-clay fraction (sand- and silt- sized particles of mainly silica and feldspar composition) is also important. Many South Australian soils low in clay are hard and massive due to high proportions of very fine sand. These particles, when mixed with small amounts of clay pack together very tightly to form an impervious mass of soil. Other soils with low clay contents and smaller proportions of fine sand and silt have minimal coherence. The strength and pedality of more clayey soils is determined mainly by the nature of the clay minerals and the presence of chemicals such as calcium carbonate and gypsum which make soils more friable.

### Clays, exchangeable cations and sodicity

Clays are minerals consisting of minute silicate and oxide crystals bonded together into larger particles. The make-up of these crystals varies according to the type of clay mineral.

The surfaces of clay crystals are usually negatively charged and therefore attract positively charged particles called cations. Charged atoms of calcium, magnesium, sodium and potassium are the most common of these cations. Because they can be dislodged from the clay crystal surface by other cations from the soil solution, they are termed exchangeable cations. The number of “exchange sites” on the clay surface is expressed as the cation exchange capacity (CEC). In alkaline soils virtually all exchange sites are occupied by the four metal cations listed above. As pH decreases, hydrogen and aluminium occupy an increasing proportion of the exchange sites.

The proportions of each of the exchangeable cations, expressed as a percentage of the CEC, are important in determining the behaviour of clayey layers in the soil. For example, excessive exchangeable sodium (more than about 6% of the CEC) causes individual clay particles to separate or disperse when the soil wets. The suspended particles find their way into the soil pores and clog them, thereby forming a barrier to water and air movement, and root growth. When the soil dries it becomes very hard and dense. These soils are said to be “sodic”. This phenomenon is more pronounced in non calcareous soils. Relatively high levels of exchangeable sodium can occur in medium textured calcareous soils without any apparent effects on porosity, density and strength.

Sodicity is a natural feature of soils, and although it can increase (or apparently increase) as a consequence of salinization, erosion and acidification, it is otherwise unaffected by dryland farming practices. Irrigation on the other hand, generally causes increases in soil sodicity.

The dispersion test (Emerson 1967) is commonly used to provide an indication of sodicity. The relationships between dispersion and sodicity are inconclusive as some sodic soils do not disperse (if they are saline as well), and some dispersive soils are non-sodic. Excess exchangeable magnesium has a similar, but less marked effect to that of sodium. Soils in which the ratio of exchangeable calcium to exchangeable magnesium is less than 1:1 often have similar properties to sodic soils. Potassium may also contribute to dispersion. Whatever the cause, dispersion is a definite sign of a structural problem because it simulates what is happening in the soil. Although expensive, cation exchange data from the laboratory are desirable for representative soils in a district.

High percentages of exchangeable calcium have the opposite effect to that of sodium, causing the clay particles to hold together or “flocculate”. These soils are easily crushed into small crumbs and are said to be friable. The well known favourable structure of soils formed on limestone (eg terra rossa) is largely due to a high degree of calcium saturation (calcium may account for more than 90% of the exchange capacity).

Organic matter

Organic matter, particularly in surface soil, plays a key role in stabilizing clay particles and maintaining porosity between larger silt and sand particles. However, in most South Australian soils, organic matter from decomposing plant material occurs only in the top few centimetres. Subsurface organic matter is mainly associated with the linings of biopores (root channels, worm holes and other micro fauna burrows) and organic rich material which has fallen into them. These pores can often be important in opening up otherwise poorly structured subsoil.

Cations are attracted to organic matter which has a measurable cation exchange capacity. Calcium is usually the dominant exchangeable cation on the organic matter exchange complex.

Calcium and magnesium carbonates

Fine calcium carbonate, commonly but incorrectly called “lime”, and to a lesser extent dolomite (carbonate of calcium and magnesium) has a modifying effect on soil structure due to the large amounts of calcium it contributes to the cation exchange complex. Thus the highly calcareous “mallee soils”, which often have moderate levels of exchangeable sodium, are usually considered to have satisfactory structure. However, fine carbonates do not necessarily impart the favourable structural properties that might be expected, because in high pH soils, they are only very slightly soluble. The amount of calcium available for cation exchange is consequently low.

### Structure decline

All soils have an inherent structural condition developed over a long period. Farming practices can change some of the properties which contribute to the structural condition of a soil, but have little, if any, effect on others. On land used for dryland farming, the structural characteristics of the subsoil remain largely unaltered after development (except for the destruction of tree root channels), but management practices can change the surface condition. Table 11 summarizes the effects of dryland farming practices on soil structure.

Table 11 Effects on Soil Structure of Surface Management Practices (Dryland Farming)

| **Elements of soil structure which can be affected by surface management** | | **Elements of soil structure which are unlikely to be affected by surface management** | |
|---|---|---|---|
| Bulk density / micro-porosity | Compaction by implements, vehicles and livestock reduces micro-porosity and increases bulk density. | Particle size distribution | Apart from erosion losses, the proportions of sand, silt and clay are constant. |
| Macro-porosity | Destruction of macro-pores (tree root channels, animal burrows etc) generally follows clearing and development for annual crops and pastures. | Sodicity | Rising groundwater tables, erosion and acidification can potentially alter sodicity, but these are secondary effects of some other land degradation process. |
| Organic matter | Excessive cultivation, other activities which expose soil, and burning result in oxidation of organic matter. However, sound soil management practices can increase organic matter levels. | Clay mineralogy | The essential composition of the clay minerals in the soil is unaffected by agricultural practices |
| Aggregation | Soil disturbance by cultivation or trampling contributes to the breakdown of aggregates | Carbonate content | Acidification and increased leaching associated with agricultural practices contribute to gradual losses of soil carbonates. However, significant changes in the soils in which structural condition is most affected by carbonates (the calcareous soils) are unlikely. |

On irrigated land, the potential for structure decline is accentuated. Soils are wet for longer periods, so the risks of compaction are greater. Furthermore, prolonged applications of sodium salts in irrigation water alter the exchangeable cation ratios, with soils generally tending to become more sodic.

Structural condition can improve under both crops and pastures provided that they are carefully managed. However such practices as excessive cultivation, working the soil when it is too wet or too dry, working it too quickly, stubble burning and stock trampling and pulverising, all damage the structural condition of the surface layers. Sub-optimal fertility resulting in reduced biomass production will also lead to loss of condition. The main reasons for decline in soil structure are loss of organic matter, destruction of the small aggregates and their associated pores necessary to keep the soil open, and compaction of the soil mass which reduces porosity.

Soil compaction

Compaction occurs when pore spaces are filled by solid particles and the bulk density (ie the mass of soil per unit volume) increases. This usually results from:

- Compression by machinery. The pressure exerted by wheeled machinery or implements, wheel slippage or the compressive effects of implements being dragged through the soil causes reduction in pore volume. These effects are magnified when the soil is wet.
- Compression by hooves of livestock, particularly on wet soil. This is known as pugging.
- Pulverizing the soil. Working the soil when it is too dry creates dust (ie fine particles) which may subsequently wash into the soil pores.
- Dispersive clays. Any soil with dispersive clay is susceptible to compaction as the dispersed clay particles find their way into the pores. These materials usually have high bulk densities in their natural state.

### Consequences of Poor Soil Structure

Surface soil

Poorly structured surface soils which have high proportions of fine sand and silt, and/or sodic clays, and/or little organic matter, usually seal over after rain and set hard when dry.
This causes:

- patchy seedling emergence
- limited opportunities for efficient and non destructive cultivation
- ponding of water on the surface leading to waterlogging
- increased runoff leading to increased susceptibility to erosion
- increased runoff resulting in less water in the soil for plant uptake

Subsurface soil

Poor structure due to hard, massive layers immediately below the surface, and/or sodic or dispersive clay subsoils causes:

- poor root growth due to the mechanical resistance met by the growing root tips. Roots tend to be confined to the surfaces of large aggregates
- waterlogging and poor aeration caused by water tables forming on poorly structured layers
- reduced moisture storage capacity
- rapid saturation of surface layers, leading to water erosion on sloping land
- salt accumulation in irrigated soil

### Assessment of soil structure

There are several properties which can be assessed to gauge the structural condition of the soil. A key is then used to determine “soil structure categories” from these properties.

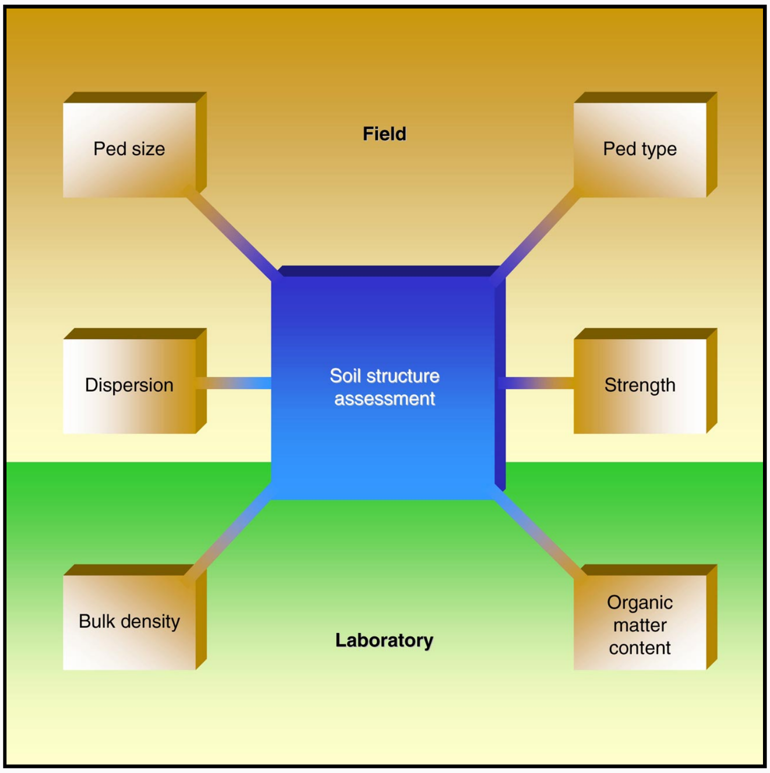



**Fig. 4** Soil structure assessment options

Pedality

Often the terms “structure” and “pedality” are used synonymously. This can be misleading. All soils have structure (ie a certain arrangement of particles and pores), but not all are “pedal”:

- In many soils the individual sand, silt and clay particles are aggregated into larger particles with well defined characteristic shapes called “peds”. Such soils are “pedal”.
- Soils without peds are “apedal”. There are two main types of apedal soils:
- Some soils (eg sands) have little or no cohesion between particles and their structure is termed “single grained”.
- Other soils are coherent and break into amorphous lumps with no regular shape. This type of structure is termed “massive”.

The type and size of the peds in a pedal soil usually provide a good indication of the physical condition of the soil. The common ped types are illustrated in the Appendix.

The most favourable ped types are granular (crumb), polyhedral and fine blocky. Large aggregates (more than 20 mm) which do not break down into smaller units are undesirable. Coarse blocky, prismatic, columnar and platy types are unfavourable with respect to root growth and permeability. Peds with rough porous faces (rough ped) are physically superior to those with smooth polished faces (smooth ped).

Consistence

The consistence (hardness or strength) of the aggregates and of the soil as a whole is also important. Consistence can be roughly gauged on dry lumps of soil about 20 mm in diameter. Aggregates which can be broken between thumb and forefinger are loose, soft, friable or firm, depending on the strength of the bonding between the particles. Aggregates which cannot be broken are described as “hard” and are often associated with adverse physical conditions.

High soil strength may be natural or may be due to compaction. Compaction may be identified in a soil pit by poking the surface with a wide blade screw driver, and gauging the relative strength of different layers. Massive layers in the 5-30 cm depth range are the most likely to be compacted. This assessment is best done when the soil is moist but not too wet (eg field capacity). A more objective technique is to use a penetrometer. This enables an assessment of changes in soil strength down the profile. The equipment and technique are described by Cass et al (1998). It should be borne in mind that changes in soil strength may simply be due to variations in moisture content down the profile, or the presence of subsurface stones and rocks.

Dispersion

In some soils, particularly those with excessive exchangeable sodium, aggregates disintegrate into discrete clay particles and sand grains when they get wet. The clay particles find their way into pore spaces, clogging them up and forming a barrier to root growth, air and water movement. This process is known as dispersion. The “Emerson Dispersion Test” (Emerson 1967) is used to assess the degree of dispersiveness and provides a valuable indication of soil behaviour. Refer to the Appendix for photographs of grades of dispersive soil.

Bulk density

Bulk density is a measure of the mass of soil per unit volume. It reflects both the nature of the soil particles (sand grains are denser than clay particles), and the percentage of pore space. Comparisons of bulk densities of different soil types indicate variations in inherent structural properties. Comparison of bulk densities of similar soil materials is a useful means of assessing changes in structural condition resulting from management practices. Compaction for example involves a reduction of porosity, and therefore an increase in bulk density.

Bulk density is measured by extracting an undisturbed core of soil in a metal cylinder of known volume, drying the soil and weighing the sample. Typical bulk density ranges for a selection of texture categories are presented in Table 12.

Table 12 Typical bulk density ranges

| Soil | Bulk density range |
|---|---|
| Siliceous sand | 1.3 - 1.8 |
| Shell sand | 1.0 - 1.2 |
| Sandy loam | 1.3 - 1.7 |
| Hard massive loam | 1.3 - 1.6 |
| Calcareous loam | 1.1 - 1.4 |
| Friable clay loam | 1.3 - 1.5 |
| Hard massive clay loam | 1.3 - 1.6 |
| Self - mulching clay | 1.2 - 1.3 |
| Friable subsoil clay | 1.3 - 1.5 |
| Poorly structured subsoil clay | 1.5 - 2.1 |

## Organic matter

Trends in organic matter content estimated from organic carbon analyses can be a useful indicator of surface soil condition over time. However it should be recognized that there is an upper limit to the amount of organic matter that can be accumulated, as determined by the soil's overall productive capacity and rainfall. Furthermore, depending on the soil biota, a point is usually reached where organic matter is broken down at the same rate as it is formed, so no net increase will be noted. So while falling organic carbon levels are commonly a sign of deteriorating structural condition, static but moderately low levels are not necessarily a bad sign.

In areas where annual rainfall exceeds 600 mm organic carbon values of more than 2% should be relatively easy to maintain. Conversely in areas receiving less than 350 mm annually, achieving levels of even 1% is difficult even under "best" management. Exceptions are highly calcareous soils where there is little biological activity to break organic matter down. Organic matter accumulates in these soils, so that organic carbon values of more than 2% are not uncommon, even under low rainfall. In sandy soils organic matter levels are inherently lower and more difficult to build up than they are on loams or clays. However, when assessing a range of soils under different management systems, large numbers of organic carbon analyses are impractical.

Structure assessments must be able to be made quickly, and in the field. The morphological parameters which influence structure are texture, pedality, strength, dispersion and carbonate content. Consideration of all the possible combinations of these is impractical, so the technique proposed relies on the identification of a limited number of soil material categories, as defined below.

For more information on practical soil structure assessment, refer to McGuinness (1991).

## Key for the identification of soil material categories

Various combinations of soil texture, pedality, strength, dispersiveness and carbonate type can be used to group soil layers into a limited number of categories with implications for root growth, workability and drainage. These categories are summarized in Table 13.

Table 13 Categories of Soil Material

| Description | Category | Permeability (water and air) | Root growth conditions |
|---|---|---|---|
| Single grained soil with loose consistence (eg sandhill soil) | Sandy (S1) | Very high * Drainage time: minutes | Good |
| Friable to firm apedal soil (includes calcareous sandy loam to sandy clay loam typical of "mallee" soil, but excludes Class III Carbonate - see below) | Friable SL-SCL (L1) | High to moderate Drainage time: hours | Good - even distribution patterns with high densities |
| Friable, pedal soil which crushes readily into aggregates of less than 5 mm. (eg non dispersive "crumbly" subsoil with polyhedral or fine blocky structure) | Friable CL-Clay (C1) | Moderate Drainage time: hours to days | Good - even distribution patterns with high densities |
| Hard massive non dispersive sandy loam to clay loam. May seal over at the surface after cultivation. | Hard SL-CL (L2) | Moderate to slow Drainage time: hours to days | Fair |
| Hard non dispersive coarse blocky clay (eg subsoil clay with smooth ped faces in many texture contrast soils) | Hard clay (C2) | Moderate to slow Drainage time: days to a week or so | Fair to good - root distribution concentrated between aggregates with restricted growth inside |
| Highly calcareous clay | Class I carbonate (K1) | Slow Drainage time: days to weeks | Poor |
| Boulder or sheet calcrete (sheet clacrete is hardpan and is not considered as subsoil for the purpose of structure classification) | Class II carbonate (K2) | Rapid (except where sheets are unfractured) Drainage time: hours to days | Fair to good (boulders) Poor (sheet) |
| Very highly calcareous sandy loam to sandy clay, <30% rubble | Class IIIA carbonate (K3A) | Moderate to slow Drainage time: hours to a day or so | Fair to poor |
| Very highly calcareous sandy loam to sandy clay, >30% rubble | Class IIIB/C carbonate (K3B/C) | High to moderate Drainage time: hours | Good |
| Hard sandy loam to clay loam with columnar, prismatic or platy pedality | Poorly structured SL-CL (L3) | Slow to moderate Drainage time: days to a week or so | Fair to poor - root growth is restricted and often forced along the surface of the layer or aggregate |
| Dispersive soil, usually hard with coarse blocky or prismatic structure (aggregates bigger than 20 mm), or apedal | Dispersive (D1) | Slow Drainage time: weeks | Fair to poor - very little root growth inside aggregates |
| Highly dispersive soil (usually hard sandy clay to clay with columnar structure which does not break down into smaller aggregates) | Highly dispersive (D2) | Very slow Drainage time: weeks to months | Poor - some root growth between aggregates, but little internal penetration |

### Classification of soil structure

The structure of the surface soil affects seedling emergence, near surface root growth, workability and water entry. The structure of the subsoil affects water movement (permeability), aeration, water holding capacity and deep root penetration. Classification of soil structure should account for these different factors.

Commonly the structure of the surface soil is different from that of the subsoil. These differences must be noted, as must the depth to a subsoil with structural problems. The thicker the surface soil overlying a "problem" subsoil, the better are the chances of successful management.

Surface soil is therefore classified separately from subsoil.

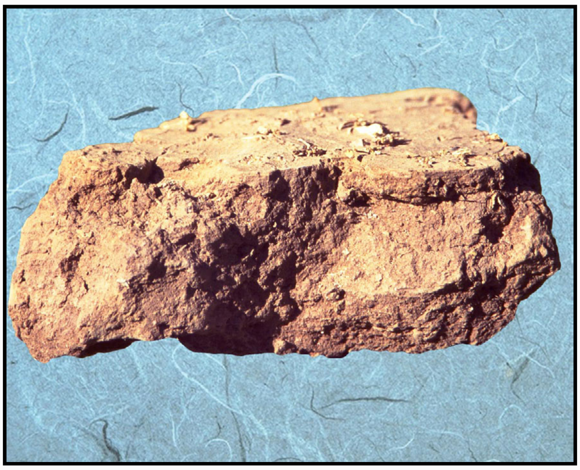
The criteria used in this classification system are based on morphological properties from Table 13 above, rather than laboratory analyses, as the latter are not generally available.

### Classification of surface soil condition

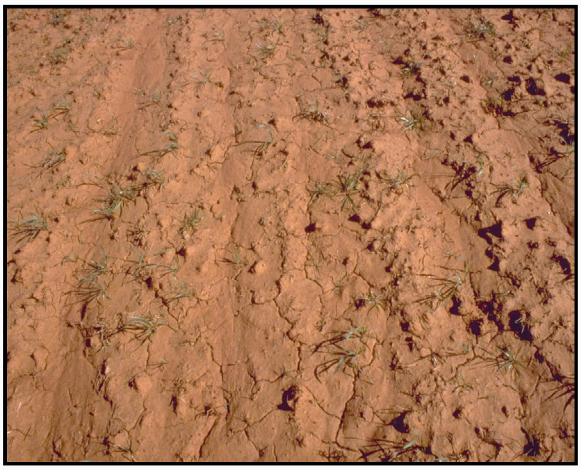
Surface condition classes may be used to categorise soils with respect to seedling emergence and workability (Table 14). Assessments of surface condition are best made on dry soil.

Table 14 Classification criteria for surface soil condition

| Surface soil material category | Seedling emergence and workability | Land Class |
|---|---|---|
| S1 Sandy<br>L1 Friable SL-SCL<br>C1 Friable CL - clay | Satisfactory | 1-c |
| L2 Hard SL-CL | Slight limitation | 2-c |
| D1 Dispersive<br>C2 Hard clay<br>L3 Poorly structured SL-CL | Moderate limitation | 3-c |
| D2 Highly dispersive | Severe limitation | 4-c |



*Hard setting soil with surface seal*



*Patchy emergence caused by poorly structured surface soil*

## Classification of subsoil structure

Subsoil structure classes are determined by identifying the subsoil structure category, and its depth below the surface.

Subsoils are considered as B horizons in texture contrast and gradational soils (ie Chromosols, Sodosols, Kurosols, Dermosols and Kandosols), carbonate layers in calcareous soils (Calcarosols), and the most limiting sub-surface layer in other Soil Orders. Ratings are made according to the criteria in Table 15.

Table 15 Classification criteria for subsoil structure

| Subsoil soil material category | Depth to subsoil | | | | |
|---|---|---|---|---|---|
| | > 60 cm | 30-60 cm | 20-30 cm | 10-20 cm | < 10 cm |
| S1 Sandy | 1-p | 1-p | 1-p | 1-p | 1-p |
| L1 Friable SL-CL | 1-p | 1-p | 1-p | 1-p | 2-p |
| C1 Friable CL - clay | 1-p | 1-p | 1-p | 1-p | 2-p |
| L2 Hard SL-SCL | 1-p | 1-p | 1-p | 2-p | 3-p |
| C2 Hard clay | 1-p | 1-p | 2-p | 3-p | 4-p |
| K1 Class 1 carbonate | 1-p | 1-p | 2-p | 3-p | 4-p |
| K3A Class 3A carbonate | 1-p | 1-p | 1-p | 1-p | 2-p |
| K3B Class 3B/C carbonate | 1-p | 1-p | 1-p | 1-p | 1-p |
| L3 Poorly struct. SL-CL | 1-p | 1-p | 2-p | 3-p | 3-p |
| D1 Dispersive | 1-p | 2-p | 3-p | 4-p | 5-p |
| D2 Highly dispersive | 2-p | 3-p | 4-p | 5-p | 5-p |

*Columnar subsoil structure of a Class 3-p soil*

**Management of poor soil structure**

Under normal conditions poor structure does not prevent land from being farmed, except where sodic subsoils have been exposed by erosion.

Management strategies should aim to increase surface organic matter levels, minimise the destruction of soil aggregates and porosity, promote the development of stable biopores, improve the calcium status of the cation exchange complex and break up hardpans.

Less frequent tillage, the use of less aggressive implements, and working the soil at optimum moisture content all help to preserve aggregation and porosity and reduce the breakdown of organic matter.

Increasing the productivity of crops and pastures and to some extent retaining residues will ensure a greater return of organic materials to the soil.

Establishment of perennial deep-rooted pastures and the encouragement of soil animals such as worms will promote better stability and moisture penetration through a system of pores and channels.

Deep cultivation is usually useful to break up long term compaction layers or hard clayey subsoils in non sodic soils (land class 2-p), but subsequent conservation surface management is essential.

On dispersive soils, gypsum (calcium sulphate) reduces the effect of sodicity by providing calcium ions to displace sodium from the cation exchange complex. Surface spreading (land classes 3-c and 4-c) will certainly improve soil condition. Although the incidence of sodic surface soils in dryland situations is very low, gypsum may still help improve soil condition (land class 2-c) due to an increase in calcium saturation, and the flocculating effect of gypsum in solution (the so-called electrolytic effect).

Subsoil sodicity, a far more widespread condition than surface sodicity, is not so easily treated. Dispersive clayey subsoils in land classes 3-p and 4-p (usually underlying sandy or loamy topsoils at depths of 10 to 50 cm) are not greatly affected by surface gypsum applications. Incorporation through ripping or slotting can have substantial benefits, but the answers to questions such as “how deep does the effect extend?”, “how long does it last?” and “how cost effective is it?” are generally not known with any certainty.

# 8 DEPTH TO HARD ROCK OR HARDPAN

Subsurface rock or pan is the solid material beneath soil which usually marks the extent of root and excavation depth.

## Nature and occurrence of rocks and hardpans

Rock here refers to basement or country rock, while hardpans refer to cemented layers in or below the soil which have generally developed as part of soil forming processes. Rocks either derive from sediments deposited by wind or water and which subsequently harden, or from molten volcanic materials erupting from the earth's surface. In South Australia, most basement rocks are associated with ancient mountain ranges (now substantially worn down by erosion). These rocks are therefore restricted to the Mount Lofty – Flinders Ranges chain, Lower and Eastern Eyre Peninsula and Kangaroo Island, with minor occurrences on Yorke Peninsula. Rock types include siltstones, sandstones, greywackes, granites and their metamorphosed equivalents, schists, phyllites, slates, gneisses and quartzites. These rocks are all more than 500 million years old. Granite outcrops (unrelated to the basement rock ranges) are scattered across Eyre Peninsula, Murray Plains, the southern Mallee and Upper South East.

Hardpans are usually very young (compared to rocks), and commonly result from near surface induration or cementation of soil or unconsolidated sediments. Three main types of hardpan occur in agricultural land in South Australia.

Calcrete is by far the most common type of hardpan in these areas, and dominates large tracts of country in the Murray Mallee, Eyre Peninsula, Yorke Peninsula and the Gulf Plains. It is also widespread in the South East where it forms thin caps over limestones or calcarenites of ancient coastal landscapes.

Calcrete is hardened windblown or soil material composed mainly of calcium and magnesium carbonates with variable amounts of sand grains. Calcrete forms when fine grained windblown carbonate, deposited in thick sheets over the landscape, hardens as a result of long term seasonal wetting and drying. Calcrete may also form as a cap on limestone through a process of dissolution and recrystallization. Calcrete pans vary from bands of hard carbonate nodules weakly cemented into a more or less continuous layer, to extremely hard dense sheets up to several metres in thickness. Sheets of calcrete often occur at shallow depth in mallee landscapes and in the dune - corridor landscapes of the South East. Because these sheets (or pans) are products of soil formation processes near the surface, they are usually underlain by softer sediments including highly calcareous materials and ancient clay and sand deposits.

Ferricrete is the second most common type of hardpan in southern South Australia. This occurs in iron-rich soils which have undergone prolonged deep weathering. Iron oxides, mobilized during the weathering process, recrystallize into nodules which in turn become cemented into discontinuous hard sheets in the subsoil. Ferricrete is typically yellow, brown or red in colour, with a "knobbly" appearance caused by its constituent nodules.

Silcrete is another type of hardpan which is formed from soil materials (sandy soils or other types high in silica). Silcrete forms when silica dissolves and recrystallizes to an extremely hard cap over soils, sediments or basement rock.

Red brown hardpans, common in arid environments, are not significant in agricultural lands.

Unlike hard rock, hardpans are generally underlain by softer material. As this is significant from an excavation and water movement point of view, the two types of material are classified separately.

## Significance of shallow rock and hardpan

The two main effects of shallow rock or hardpan are on plant root growth, and on ease of excavation.

Basement rocks generally become harder with depth, because they weather from the top down. Rocks with low silica content are easily weathered and may have weathering zones which are metres thick. More quartzitic rocks may be hard right to their boundary with overlying soil. Soft weathered rocks do not pose a physical barrier to root growth or excavation, but hard rock within the upper metre or two reduces rootzone depth and therefore water availability for many plants. Forest trees may suffer if hard rock is shallower than three to four metres, while some irrigated crops are not affected until depth is less than 20 cm. Annual field crops and pastures are likely to suffer moisture stress where hard rock is shallower than 50 cm. Similar comments apply to hardpans. The main difference is that fractures in hardpans allow roots to penetrate to underlying softer materials (provided these are not chemically hostile).

The effects of hard rock at shallow depth on excavation are obvious. However, hardpans can commonly be fractured or lifted by machinery, allowing excavation to continue into softer subsoil layers.

### Assessing depth to hard rock or hardpan

As a rule of thumb, rock is considered "hard" when a crowbar becomes ineffective – it bounces off rather than penetrates. This is roughly equivalent to the depth that a backhoe can excavate, although large sheets of calcrete, impenetrable with a crowbar, can be lifted by machinery, albeit with some difficulty, and with massive disturbance to the excavation.

### Classification of depth to hard rock or hardpan

The depth at which a crowbar can no longer be used to remove rock material defines the depth to rock or hardpan. Depth classes are specified in Tables 16 and 17.

Table 16 Classification criteria for depth to hard rock

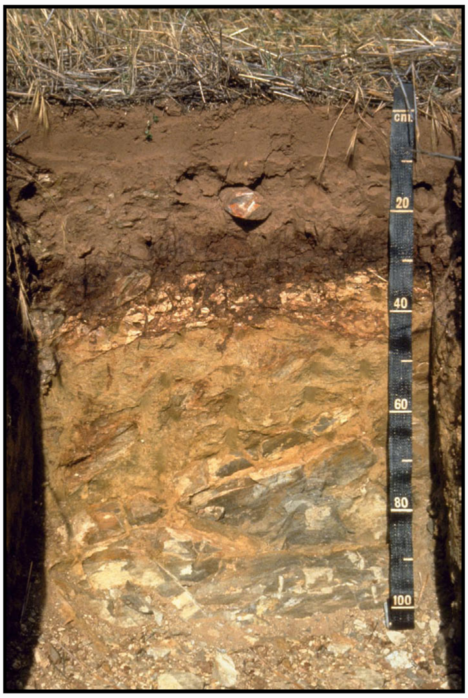
| Depth category | Classification criteria (depth to hard rock) | Land Class |
|---|---|---|
| Very deep | More than 150 cm | 1-xr |
| Deep | 100-150 cm | 2-xr |
| Moderate | 50-100 cm | 3-xr |
| Shallow | 25-50 cm | 4-xr |
| Very shallow | 10-25 cm | 5-xr |
| Extremely shallow | less than 10 cm | 6-xr |

Table 17 Classification criteria for depth to hardpan

| Depth category | Classification criteria (depth to hardpan) | Land Class |
|---|---|---|
| Very deep | More than 150 cm | 1-xp |
| Deep | 100-150 cm | 2-xp |
| Moderate | 50-100 cm | 3-xp |
| Shallow | 25-50 cm | 4-xp |
| Very shallow | 10-25 cm | 5-xp |
| Extremely shallow | less than 10 cm | 6-xp |

Soils less than 25 cm thick over hard rock or hardpan are only marginally arable. Soil thinner than 10 cm is non arable.

Note that these classes conform to those used in the Australian Soil Classification (Isbell 1996) for categorizing "soil depth", except that the "giant" class has been omitted, and the "extremely shallow" class has been added. The "very deep" and "deep" classes have been kept separate in this classification because the distinction may be relevant to tree crops, if not for field crops. As a result, the classes do not exactly correspond to the generic class definitions in Section 1. For example, Class 5-xr/xp could be considered semi arable, although by definition, Class 5 implies non arable.



*Profile over hard basement rock*

*Profile over calcrete*

### Managing shallow soils over rock or hardpan

Shallow rock imposes a permanent limitation on agricultural land use.

Shallow hardpans however, are manageable in some situations. For example, where calcrete overlies softer calcarenite and unconsolidated sands, it can be ripped prior to crop establishment, to allow roots to access the underlying materials. This is common practice in vineyard establishment in the South East where underlying materials are commonly sandy and low strength. However, it is less likely to be successful in mallee situations where substrates are usually sodic and strongly alkaline, high in boron and moderately saline.

# 9 SOIL CHEMISTRY

## The significance of soil chemical properties

The chemical characteristics of soil play a crucial role in plant growth and soil stability through their effects on nutrition, toxicity and soil physical condition. The obvious effect of nutrient deficiencies and toxicities is poorer plant performance. Unfavourable chemical conditions manifest themselves in many ways. A discussion of the physiological effects associated with deficiencies or excesses of each element is beyond the scope of this document.

The organic matter and the clay fraction hold virtually all plant nutrients and they also largely determine soil structure which in turn affects productivity. The implications of poor plant performance are not confined to reduced productivity. Reduced plant vigour also contributes to soil degradation.

- Stunted plants produce less surface biomass to protect the soil from the erosive effects of wind and water, and to contribute to the organic matter reserves.
- Poorly developed root systems result in fewer biopores which are necessary to ensure satisfactory soil stability, drainage and aeration.
- Sub-optimal productivity means lower water use efficiency, higher recharge and therefore potential for increases in water table levels and salinisation.

A useful background reference which summarizes many aspects of plant nutrition is the CSIRO Division of Soils booklet “Food for Plants” (Discovering Soils No.6).

## Assessing soil chemical status

Rule of thumb assessments of the inherent fertility of soils can be made from the nature of the original vegetation. Heath or low scrub usually indicates poor fertility. Woodlands often occur on more fertile soils. However, any objective assessment of a soil’s chemical status must rely on laboratory analyses.

A range of soil analyses is available:

- to diagnose soil chemical status as a guide to fertilizer use and rotation management.
- to monitor trends in the levels of chemical constituents of the soil.
- to detect the presence of naturally occurring chemicals which adversely affect plant health (eg soluble salt, boron and aluminium). Note that other potentially toxic chemicals in the soil (such as pesticide residues) are not dealt with in this publication.
- to characterize soils as part of land resource surveys and field experimental work. Characterizations assist in the extrapolation of results from one area to another on the basis of similarity of soil type.

Soil analyses are often expensive and not always conclusive. Because of the cost, only those analyses appropriate for particular situations should be done. However when characterizing representative soils in a district, all of the analyses cited below should be done on all layers.

It is beyond the scope of this document to discuss the sampling and analytical procedures necessary for each element. Soil sampling procedures and techniques for laboratory analysis are documented by Rayment and Higginson (1992). Nutrient analyses are most commonly carried out on surface samples bulked from approximately 30 subsamples of the same soil type and within the same management area. Judicious nutrient analyses of deeper layers should also be done.

The key components of soil chemistry and their assessment techniques are summarised here. Without additional information, soil test results should be used only as guides to nutrient status and to monitor trends, not to make fertilizer recommendations. Paddock history, rainfall, yield potential, cost and environmental consequences also need to be considered when determining fertilizer rates.

## The key components of soil chemistry

### Nitrogen and Organic Matter

Nitrogen deficiency is a widespread nutritional problem in South Australian agriculture. Most soil nitrogen occurs in the organic fraction but is available to plants only following mineralisation, which depends on seasonal and biological conditions. Achieving adequate levels of available soil nitrogen during the early stages of crop growth is always difficult.

Because nitrogen levels are usually linked to organic matter content which tends to increase with increasing clay content and rainfall, the soils with the lowest natural nitrogen status are sandy and/or occur in lower rainfall areas. However virtually all South Australian soils have low levels of nitrogen because of their inherently low organic matter status. Soil management and its effect on building up organic matter is critical in determining the total nitrogen reserve and the level of mineral nitrogen.

The total nitrogen test gives an indication of nitrogen status. The figure for total nitrogen is usually about 10% of that for organic carbon, so the latter can generally be used as an estimate for total nitrogen, provided that the soil sample is free of stubble and other plant debris. Although the total nitrogen test is often done, it is not useful for assessing fertilizer requirements without additional information on management history. Tissue testing and soil nitrate analyses are recommended to establish whether levels are low.

As well as being the main store of nitrogen in the soil, organic matter also holds and supplies other plant nutrients and plays a key role in developing stable soil structure. On sandy soils with little clay to retain nutrients, organic matter plays a key role in maintaining fertility.

The organic carbon test is a useful indicator of organic matter status and therefore of the overall fertility and structural stability of the surface soil. Because the levels of organic carbon which can be realistically achieved under dryland agriculture are dependent on rainfall and the clay content of the surface soil, desirable values vary considerably, as shown in Table 18.

Table 18 Desirable organic carbon percentage in surface soil in cereal districts

| Surface texture | Annual rainfall zone | | | |
|---|---|---|---|---|
| | <325 mm | 325-400 mm | 400-450 mm | >450 mm |
| Sand | 0.6 | 0.7 | 0.8 | 1.0 |
| Loamy sand | 0.8 | 1.0 | 1.2 | 1.4 |
| Loam | 1.0 | 1.1 | 1.4 | 1.6 |
| Clay loam | 1.1 | 1.3 | 1.5 | 1.8 |
| Clay | 1.3 | 1.5 | 1.8 | 2.0 |

(adapted from French et al 1968)

Except for sands and the lowest rainfall districts, 1.0% organic carbon is the accepted critical value below which fertility and stability are likely to suffer. Values of more than 2% are considered high for cropping soils.

### Phosphorus

Phosphorus is almost universally deficient in South Australian soils in their natural state. Most phosphorus occurs in the soil as phosphate which is only sparingly soluble in water and is readily attached (or “complexed”) to clay particles, organic matter and compounds of iron and aluminium. Therefore only a small fraction of the total soil phosphorus is available to plants. Phosphorus tends to be less available in soils with a pH higher than 8 and those with high levels of iron and aluminium. Fortunately, soil phosphorus is usually not subject to leaching. Only sandy soils in high rainfall areas are likely to suffer leaching losses of phosphorus.

Available phosphorus analysis, using the sodium bicarbonate extraction technique (Rayment and Higginson 1992) is commonly used to determine whether fertilizer rates should be increased, decreased or maintained. Critical values vary according to land use. Interpretations of the tests are set out in Table 19, for dryland cropping soils, pasture soils, and soils used for Brassica crops.

Table 19 Interpretation of sodium bicarbonate extractable phosphorus results (mg/kg)

| **Status** | **Dryland cropping soils** | | | **Vegetable crop soils #** | **Pasture soils** |
|---|---|---|---|---|---|
| | **Sands** | **Non calcareous** | **Calcareous** | | |
| Very low | <10 | <10 | <15 | <40 | <10 |
| Low | 10-20 | 10-20 | 15-25 | 40-80 | 10-18 |
| Marginal | 20-25 | 20-30 | 25-35 | 80-12 | 18-25 |
| Adequate | >25 | >30 | >35 | >120 | >25 |

Data from South Australian Soil and Plant Analysis Service (1996) and Elliot et al (1986)
# Excluding potatoes

Potassium

Except on very sandy soils in the higher rainfall districts, potassium deficiency in South Australia's agricultural soils is rare. This is because the rocks and sediments from which most soils are formed contain clay minerals which are naturally high in potassium. Deficiencies are most likely where large amounts of potassium have been removed in farm products, particularly hay and some annual horticultural crops such as potatoes.

Available potassium analysis, using the sodium bicarbonate extraction technique (Rayment and Higginson 1992) is commonly used to determine whether fertilizer rates should be increased, decreased or maintained. Critical values vary according to land use. Interpretations of the test are set out in Table 20, for soils used for pastures, potatoes and other vegetable crops.

Table 20 Interpretation of sodium bicarbonate extractable potassium results (mg/kg)

| **Status** | **Pasture soils** | **Potato soils** | **Other vegetable crop soils** |
|---|---|---|---|
| Very low | <50 | | |
| Low | 50-80 | <120 | <150 |
| Marginal | 80-120 | 120-250 | 150-250 |
| Adequate | >120 | >250 | >250 |

Data from South Australian Soil and Plant Analysis Service (1996)

Sulphur

Sulphur occurs in both organic matter and as sulphate in the soil. Sulphur deficiency used to be most likely in sandy soils in high rainfall areas and in soils low in organic matter. Sulphur removal by crops was commonly compensated by sulphur "impurities" in some fertilizers such as superphosphate, but prolonged use of high analysis fertilizers low in sulphur has led to more widespread deficiencies.

Sulphur is usually measured as sulphate. The results are difficult to interpret for management recommendations because sulphate levels fluctuate, and subsoil reserves of sulphur may more than compensate for surface deficiencies. However, early growth may be retarded by surface soil deficiency. The interpretation of the $KCl_{40}$ soil test is set out in Table 21.

Table 21 Interpretation of $KCl_{40}$ test for sulphate

| Status | Sulphate-S (mg/kg) |
|---|---|
| Low | <5 |
| Marginal | 5-10 |
| Adequate | >10 |

Data from South Australian Soil and Plant Analysis Service (1996)

Trace Elements

Trace elements are required by plants in very small amounts. The concentrations of available forms of trace elements in soils are usually very low. Deficiency symptoms may occur only sporadically and may be due to seasonal conditions; deficiencies may only show up in good seasons when plant demand is highest.

Table 22 Situations where the main trace element deficiencies are most likely to occur

| Trace element | Situation of likely deficiency |
|---|---|
| Copper | Mainly acid and calcareous sands.<br>Intermittently on a range of other soils types. |
| Manganese | Highly calcareous soils, particularly sands with more than 60% free carbonate.<br>Ironstone soils and some acid sands.<br>Soils which have been over-limed or irrigated with alkaline water. |
| Zinc | Calcareous soils of all texture ranges including clays.<br>Acid sands and acid to neutral sandy or loamy texture contrast soils. |
| Molybdenum | Sandy, acid or ironstone soils in high rainfall areas. |
| Iron | Calcareous or poorly drained soils. |
| Boron | Sandy acidic soils with low organic matter.<br>Boron levels of less than 0.5 mg/kg are thought to indicate deficiency.<br>Boron toxicity is more often a problem than boron deficiency. |

Soil tests for zinc, copper, manganese and iron are generally thought to have little interpretative value, and the situation is complicated by different analysis techniques. The DTPA test is used for alkaline soils, and the EDTA test is used for acid - neutral soils, but the interpretation standards are different. Tissue tests are recommended if soil test values are marginal or deficient according to Table 23.

Table 23 Critical limits for soil trace element results

| Element | DTPA * | EDTA (at pHCaCl2 =7) ^ | |
|---|---|---|---|
| | | Dryland crops / pastures | Horticulture |
| Cu (copper) | 0.2 mg/kg | 1-2 mg/kg | 4 mg/kg |
| Zn (zinc) | 0.5 mg/kg | 1-2 mg/kg | 4 mg/kg |
| Mn (manganese) # | 1.0 mg/kg | 10-20 mg/kg | 30 mg/kg |

# Estimated
^ EDTA data from South Australian Soil and Plant Analysis Service (1996)
* DTPA data – R.J.Hannam – pers. comm.

Tissue testing is recommended to determine the status of trace elements in the plant. Critical values vary and have not been determined for all crops.

A comprehensive review of trace elements in South Australian agriculture is presented in Technical Report No. 139 (Department of Agriculture, South Australia, 1988).

Calcium and Magnesium

Calcium occurs in limestone, dolomite, calcrete and fine carbonate (often called "lime"), which are all forms of calcium carbonate, a common constituent of South Australian soils. It also occurs in gypsum (calcium sulphate), and attached to clay minerals. Soils with high clay contents are unlikely to suffer calcium deficiency. Obviously calcareous soils won't. Sandy and sandy loam soils in high rainfall areas are most at risk of calcium deficiency, although in fact, absolute deficiencies of calcium in SA are rare.

Magnesium, like potassium and calcium is present in large amounts attached to the clay minerals of most soils. Leached sandy to sandy loam soils are the most prone to deficiencies, but like calcium, absolute deficiencies are rare.

Problems linked to these elements are more likely to do with imbalances in their ratios, as discussed below. Estimates of calcium and magnesium status and ratios can be made from exchangeable cation analysis. Historically the test has not been carried out for diagnostic purposes in South Australia as it was believed to be unnecessary, but during the 1990's, it gained acceptance as a means of providing a more comprehensive analysis for leached acidic soils in the higher rainfall districts.

### Cation exchange capacity and exchangeable cations

Clay particles and organic matter have large surface areas with negatively charged sites which can attract and hold positively charged atoms called cations. The main cations are calcium, potassium, magnesium and sodium; these are important in plant nutrition. The greater the number of charged sites (measured by the cation exchange capacity or CEC), the greater is the nutrient retention ability of the soil and the better is its capacity to supply the major nutrient elements to plant roots. Nutrient retention capacity can be used to estimate inherent fertility. Cation exchange capacities of more than 15 cmol(+)/kg indicate high inherent fertility; values of less than 5 cmol(+)/kg indicate very low inherent fertility.

For the vast majority of South Australian soils, the proportions of the various cations on the exchange complex are more important than the absolute amounts. In some situations the calcium to magnesium ratio needs to be maintained at about 3-4:1. Too much potassium relative to magnesium and calcium results in "hypomagnesia" causing grass tetany in cattle, and may have nutritional effects in some horticultural crops. Generally though, plants are able to maintain adequate balances through the absorption mechanisms of their roots.

As an approximate guide, the proportions set out in Table 24 are considered desirable (provided that the CEC is at least 10 cmol(+)/kg):

Table 24 Ideal proportions of exchangeable cations

| Exchangeable cation | Proportion |
|---|---|
| Calcium | 65-75% |
| Magnesium | 10-15% |
| Potassium | 3-8% |
| Sodium | Less than 6% |

Data from South Australian Soil and Plant Analysis Service (1996)

In acidic soils, many of the exchange sites are occupied by hydrogen and aluminium ions. In these soils, a better indication of the inherent fertility is gained from the base status (see below).

Measurements of cation exchange capacity and exchangeable cations are too expensive for routine assessments, particularly on neutral to alkaline soils in dryland farming situations. However, under higher return irrigated crops and pastures, and in higher rainfall areas where leaching and acidification are likely, these analyses are desirable to determine relative deficiencies of these elements, to determine the most effective product for ameliorating acidity, to identify the cause of soil structural problems, and to assess the overall nutrient retention capacity of the soil.

Exchangeable cation data for the upper subsoil, and in particular its base status is used in the Australian Soil Classification (Isbell 1996) to assess inherent nutrient retention capacity of soils, more or less independent of management. Base status is the sum of the exchangeable calcium, magnesium, sodium and potassium. In the classification, base status values of more than 15 cmol(+)/kg of clay in the upper subsoil are deemed to indicate an adequate nutrient retention capacity, more than 25 cmol(+)/kg being very high. Values of less than 5 cmol(+)/kg of clay indicate very low inherent fertility.

However, in soils with significant differences in base status between surface and subsoils (eg sand over clay soils), subsoil base status is a misleading indicator of inherent fertility. Surface soil CEC and base status are highly dependent on soil management, as in sandy and sandy loam soils most of the CEC is associated with the organic matter, so use of these is not appropriate in a generalized classification system. Consequently, although cation analyses are useful at the paddock / property level for estimating fertility status, they have limited application in broad scale land assessments, and should be used in conjunction with other parameters, as discussed below.

## Classification of land according to fertility

Classifying land according to the levels of individual elements is not appropriate in a generalised land assessment because management history and seasonal conditions vary so much.

Exchangeable cation data are useful as they provide a general indication of the likelihood of soil deficiencies, but these are not always readily available, and have limitations as described above.

The key soil groups of South Australia's agricultural lands (Hall et al 2000) can be categorised into one of six inherent fertility classes on the basis of texture, leaching capacity, exchangeable cation characteristics, susceptibility to acidification, carbonate and ironstone content and recorded fertilizer requirements. These categorizations are subjective and relative and should be treated as guidelines only.

Table 25 Estimated inherent fertility of South Australia's key agricultural soils
The soils categorized below are arranged into 14 Groups and 61 Subgroups, as defined by Hall et al (2000). Indicative Australian Soil Classifications (Isbell 1996) are included.

| Soil | Descriptive name | Typical Australian Soil Classification | Inherent fertility |
|---|---|---|---|
| **A** | **Calcareous soils** | | |
| **A1** | Highly calcareous sandy loam | Supravescent Calcarosol; loamy | Low |
| **A2** | Calcareous loam on rock | Paralithic Calcarosol; loamy | Moderate |
| **A3** | Deep moderately calcareous loam | Calcic Calcarosol; loamy | Moderate |
| **A4** | Deep (rubbly) calcareous loam | Hypercalcic - Lithocalcic Calcarosol; loamy/loamy | Mod. low |
| **A5** | Rubbly calcareous loam on clay | Supracalcic-Lithocalcic Calcarosol; loamy/loamy with clayey substrate | Mod. low |
| **A6** | Gradational calcareous clay loam | Hypercalcic Calcarosol; clay loamy/clayey | Moderate |
| **A7** | Calcareous clay loam on marl | Marly Calcarosol; clay loamy/clayey | High |
| **A8** | Gypseous calcareous loam | Gypsic Calcarosol | Low |

| Soil | Descriptive name | Typical Australian Soil Classification | Inherent fertility |
|---|---|---|---|
| **B** | **Shallow soils on calcrete or limestone** | | |
| **B1** | Shallow highly calcareous sandy loam on calcrete | Shelly - Supravescent, Petrocalcic Calcarosol | Low |
| **B2** | Shallow calcareous loam on calcrete | Petrocalcic Calcarosol | Mod. low |
| **B3** | Shallow sandy loam on calcrete | Petrocalcic Tenosol - Red Kandosol | Moderate |
| **B4** | Shallow red loam on limestone | Petrocalcic, Red Dermosol | High |
| **B5** | Shallow dark clay loam on limestone | Petrocalcic, Black Dermosol | Very high |
| **B6** | Shallow loam over red-brown clay on calcrete | Petrocalcic, Red Chromosol | Moderate |
| **B7** | Shallow sand over clay on calcrete | Petrocalcic, Brown Sodosol | Mod. low |
| **B8** | Shallow sand on calcrete | Petrocalcic, Bleached-Leptic Tenosol | Low |
| **B9** | Shallow clay loam over brown or dark clay on calcrete | Petrocalcic, Brown Sodosol | Moderate |
| **C** | **Gradational soils with highly calcareous lower subsoils** | | |
| **C1** | Gradational red-brown sandy loam | Hypercalcic, Red Kandosol; loamy | Moderate |
| **C2** | Gradational red-brown loam on rock | Hypercalcic, Red Dermosol; loamy | High |
| **C3** | Friable gradational red-brown clay loam | Hypercalcic, Red Dermosol; clay loamy | High |
| **C4** | Hard gradational red-brown clay loam | Sodic, Red Dermosol; clay loamy | High |
| **C5** | Gradational dark clay loam | Hypercalcic, Black Dermosol | High |
| **D** | **Hard red-brown texture contrast soils with highly calcareous lower subsoils** | | |
| **D1** | Loam over clay on rock | Hypercalcic, Red Chromosol; loamy | High |
| **D2** | Loam over red clay | Calcic, Red Chromosol; loamy | High |
| **D3** | Loam over poorly structured red clay | Calcic, Red Sodosol; loamy | Moderate |
| **D4** | Loam over pedaric red clay | Pedaric, Red Sodosol; loamy | High |
| **D5** | Hard loamy sand over red clay | Hypercalcic, Red Sodosol-Chromosol; sandy | Moderate |
| **D6** | Ironstone gravelly sandy loam over red clay | Ferric, Hypercalcic, Red Chromosol | Moderate |
| **D7** | Loam over poorly structured clay on rock | Hypercalcic, Red Sodosol; loamy | High |
| **E** | **Cracking clay soils** | | |
| **E1** | Black cracking clay | Black Vertosol | Very high |
| **E2** | Red cracking clay | Red Vertosol | Very high |
| **E3** | Brown or grey cracking clay | Brown - Grey Vertosol | High |
| **F** | **Deep loamy texture contrast soils with brown or dark subsoils** | | |
| **F1** | Loam over brown or dark clay | Brown Chromosol; loamy | Moderate |
| **F2** | Sandy loam over poorly structured brown or dark clay | Brown Sodosol; loamy | Moderate |

| Soil | Descriptive name | Typical Australian Soil Classification | Inherent fertility |
|---|---|---|---|
| **G** | **Sand over clay soils** | | |
| **G1** | Sand over sandy clay loam | Hypercalcic, Red Chromosol; sandy/clay loamy | Mod. low |
| **G2** | Bleached sand over sandy clay loam | Calcic, Brown Chromosol; sandy/clay loamy | Low |
| **G3** | Thick sand over clay | Eutrophic, Brown Chromosol; sandy/clayey | Mod. low |
| **G4** | Sand over poorly structured clay | Calcic, Brown Sodosol; sandy/clayey | Mod. low |
| **G5** | Sand over acidic clay | Mesotrophic, Brown Kurosol; sandy/clayey | Low |
| **H** | **Deep sands** | | |
| **H1** | Carbonate sand | Shelly Rudosol | Very low |
| **H2** | Siliceous sand | Calcareous, Orthic Tenosol | Low |
| **H3** | Bleached siliceous sand | Bleached-Orthic Tenosol | Very low |
| **I** | **Highly leached sands** | | |
| **I1** | Highly leached sand | Aeric or Semi-Aquic Podosol | Very low |
| **I2** | Wet highly leached sand | Aquic Podosol | Very low |
| **J** | **Ironstone soils** | | |
| **J1** | Ironstone soil with calcareous lower subsoil | Ferric, Calcic, Brown Chromosol | Mod. low |
| **J2** | Ironstone soil | Ferric, Brown Kurosol | Low |
| **J3** | Shallow ironstone soil on ferricrete | Petroferric Tenosol | Low |
| **K** | **Moderately deep acidic soils on basement rock or deeply weathered rock** | | |
| **K1** | Acidic gradational loam on rock | Brown Dermosol | Moderate |
| **K2** | Acidic loam over clay on rock | Brown - Red Kurosol | Moderate |
| **K3** | Acidic sandy loam over red clay on rock | Red Chromosol - Sodosol | Mod. low |
| **K4** | Acidic sandy loam over brown or grey clay on rock | Brown Kurosol | Mod. low |
| **K5** | Acidic gradational sandy loam on rock | Brown Kandosol | Mod. low |
| **L** | **Shallow soils on basement rock** | | |
| **L1** | Shallow soil on rock | Lithic Rudosol - Tenosol | Mod. low |
| **M** | **Deep uniform to gradational soils** | | |
| **M1** | Deep sandy loam | Brown - Red Kandosol or Orthic Tenosol; sandy | Moderate |
| **M2** | Deep friable gradational clay loam | Red - Black Dermosol; clay loamy | High |
| **M3** | Deep gravelly soil | Clastic Rudosol | Mod. low |
| **M4** | Deep hard gradational sandy loam | Sodic, Eutrophic, Brown Kandosol; loamy/clayey | Moderate |
| **N** | **Wet soils** | | |
| **N1** | Peat | Organosol | Moderate |
| **N2** | Saline soil | Salic Hydrosol | - |
| **N3** | Wet soil (non to moderately saline) | Redoxic Hydrosol | - |
| **O** | **Volcanic ash soils** | | |
| **O1** | Volcanic ash soil | Andic Tenosol | High |

Table 26 sets out criteria for classification of land according to estimated Inherent Fertility (Table 25)

Table 26 Classification criteria for inherent fertility

| Inherent fertility | Broad soil characteristics and management implications | Land Class |
|---|---|---|
| Very high | Clay loam to clay. Very high productive potential. Maintenance N & P needed. Other nutrients as required. | 1-n |
| High | Non leached, non acidic loam to clay loam. High productive potential. Maintenance N & P needed. Other nutrients as required. | 1-n |
| Moderate | Leached or acidic loam, calcareous loam. Nutrition should not limit productivity provided regular monitoring and fertilizer programs are maintained. | 2-n |
| Moderately low | Moderately leached sand over clay, highly calcareous sandy loam, acidic sandy loam. Annual applications of several nutrients needed for optimum productivity. | 3-n |
| Low | Moderately leached sand, highly leached sand over clay, sandy ironstone soil, very highly calcareous sandy loam. Arable, but low fertility limits productivity even under a rigorous fertilizer program. | 4-n |
| Very low | Sands - highly leached or very highly calcareous. Very low productive potential - semi arable at best | 5-n |

## Toxic elements

Common toxic elements in South Australian soils are boron, aluminium, manganese and sodium. Elevated levels of soluble salts are widespread in South Australian soils, and are considered separately in Section 12. Exchangeable sodium and its effects on soil structure are discussed in Section 7.

Aluminium and manganese toxicity

Aluminium is present in many soils, but its availability to plant roots is pH dependent. Problems of toxicity occur in soils which contain aluminium and are strongly acidic. Aluminium availability also increases at high pH, so toxicity is theoretically possible in strongly alkaline soils as well. Aluminium is most likely to be present in ironstone rich soils and those in which the dominant clay mineral is kaolinite. This is often recognisable as a pale clay with a “soapy” feel in the lower part of the soil profile.

The sensitivity of agricultural plants to aluminium is highly variable. Table 27 indicates the tolerance levels of a range of species.

Table 27 Interpretation of soil extractable aluminium levels *

| Plant sensitivity | Species | Extractable aluminium level above which yield declines |
|---|---|---|
| Very sensitive | Lucerne & canola | < 2 mg/kg |
| Sensitive | Barley, sensitive wheat & phalaris | 2-4 mg/kg |
| Tolerant | Sub. clover, cocksfoot, perennial rye, tolerant wheat & phalaris | 4-8 mg/kg |
| Very tolerant | Lupins, oats & triticale | > 8 mg/kg |

* 0.01M calcium chloride extractable

Manganese becomes toxic in the same way as aluminium, but susceptible soils are less common. Red loams and clay loams which have a tendency to acidify are the soils at greatest risk, but reports of manganese toxicity are rare (Department of Agriculture, South Australia, 1988).

Boron toxicity

Boron is an essential trace element deficient in some leached sandy soils. However, it is boron toxicity which is important in South Australia. Boron toxicity is commonly associated with calcareous soils, and appears to have a strong association with the Blanchetown Clay Formation, presumably because the clay has sufficiently low permeability that the boron has never been allowed to leach out. Classes IIIA and I carbonate layers which underlie much of the Murray Mallee, Eyre and Yorke Peninsulas and the Mid North of the state are also associated with high boron levels. In these soils, lack of leaching associated with low rainfall is the most likely reason for high boron levels.

Where boron toxicity is suspected samples should be taken from each layer down the profile. Symptoms of toxicity can be expected in cereals where test results exceed 15 mg/kg. For fruit trees this threshold may be as low as 2 - 3 mg/kg.

More details about boron toxicity are contained in Soils Brief No.15 (CSIRO Division of Soils 1991).

Sodium toxicity

Many soils in the drier parts of Southern Australia have very high levels of deep subsoil sodicity (ie exchangeable sodium percentage, or ESP more than 25), generally at depths of between 50 and 100 cm, sometimes shallower. These conditions are invariably associated with high pH, moderate salinity and often high boron concentrations, all of which are natural features of these soils. There is some evidence to suggest that these high levels of sodicity are toxic to some plants, particularly horticultural species. For example, Neja et al (1974) suggest that ESP of more than 25 is hazardous to grape vines, and that toxicity symptoms occur at levels of more than 13. Pearson (1960) found that ESP values of more than 10 contributed to 50% decline in productivity of citrus and deciduous fruit crops. By comparison, similar yield losses were recorded in wheat and barley at ESP levels of 30-50 and 50-60 respectively (Gupta and Abrol 1990).

If there are toxic effects, it is reasonable to assume that in some years at least, sodicity is preventing optimum water use efficiency, and could therefore be contributing to rising water tables.

Note that ESP is the exchangeable sodium value divided by the cation exchange capacity. If the CEC is less than 3, the ESP value becomes meaningless as the total amount of sodium is so small.

### Classification of land according to toxicity

Excessive boron, exchangeable sodium and aluminium levels are used to classify soils on the basis of their toxicity. High soluble salts which could be considered as toxic substances are considered separately (Section 12). Toxicity categories are defined in Table 28.

Table 28 Classification criteria for boron, sodium and aluminium toxicity

| Toxicity level | Classification Criteria | | | Land Class+ |
|---|---|---|---|---|
| | Depth to B > 15mg/kg # | Depth to ESP > 25 | Extractable Al* in rootzone | |
| Low | Below 100 cm | Below 100 cm | < 2 mg/kg | 1-t |
| Moderate | 50-100 cm | 50-100 cm | 2-4 mg/kg | 2-t |
| High | 25-50 cm | 25-50 cm | > 4 mg/kg | 3-t |
| Very high | 10-25 cm | 10-25 cm | - | 4-t |
| Extreme | Shallower than 10 cm | Shallower than 10 cm | - | 5-t |

\# Hot 0.01M $CaCl_2$ extractable
* 0.01M $CaCl_2$ extractable. These figures are arbitrary as species tolerance to aluminium is highly variable.
\+ The classification carries a subscript, B, Na or Al to indicate toxicity type, eg $2\text{-}t_B$, $3\text{-}t_{Al}$

### Productivity and management of fertility and toxicity classes

Management guidelines for the correction of various nutrient deficiencies are dependent on local conditions and cannot be dealt with here. Useful references include:

Bourne, J. and Elliott, D. (Eds.) (1992). Proceedings of the Soil and Plant Nutrition Training Course.
Eyre Region
Murray Bridge
Northern Agricultural Districts.
Department of Agriculture, South Australia. Internal Reports.

Holden, K. (1989). Fertilizer requirements for Eyre Peninsula. Department of Agriculture, South Australia. Unpublished internal report.

Taylor, G., Holden, K. and Yeatman, T. (1991). Winter Cereal Management Guide. Department of Agriculture, South Australia.

For general land assessments, the following broad statements apply:

Class 1-n land

Class 1-n soils are unlikely to be regularly deficient in any elements other than nitrogen and phosphorus. These soils have moderate to high clay contents in their surfaces (loams or heavier), are not highly calcareous, are not leached, and do not have phosphate fixing ironstone gravels. However, the high production usually associated with these soils means that nutrient depletions are generally higher than on lower class soils. Continuous intensive cropping without corresponding fertilizer inputs will inevitably lead to nutrient deficiencies, even on the most fertile soils, so a monitoring program is needed. For example, zinc and sulphur deficiencies due to changing fertilizer products are increasingly common on Class 1-n soils. Maintenance dressings of phosphorus are required regularly. Nitrogen levels are maintained through the use of vigorous legume based pastures in the rotation and/or the application of nitrogenous fertilizers.

Class 2-n land

Class 2-n soils are generally loamy (ie moderate nutrient retention capacity), but have slight limitations due to leaching and acidification (higher rainfall areas), or calcareous surfaces (lower rainfall areas). Soils should be capable of retaining applied nutrients over at least one season, but nutrient levels must nevertheless be monitored. Comprehensive soil testing is required for the acidic soils in this class, because the range of possible deficiencies is greater than for Class 1-n soils. With careful management, these soils are as potentially productive as Class 1 soils.

Class 3-n land

Class 3-n soils are arable but have significant nutrient retention limitations. These are generally caused by sandy or leached sandy loam surfaces, but may also be attributable to high levels of fine carbonate in the surface soil. Leaching of nutrients is generally not a major problem, provided fertilizer is applied according to plant requirements (ie these soils have limited capacity to retain nutrients into the next season). Annual applications of a number of elements may be required for optimum productivity.

Class 4-n land

Class 4-n soils are usually sandy, but have more clayey or calcareous subsoils which help to reduce deep leaching losses of soluble nutrients. Very highly calcareous light sandy loams and ironstone soils are included in this category because of the combined effects of relatively low nutrient retention capacity, and high phosphate and trace element fixation (calcareous sandy loams) and phosphate fixation and high acidification potential (ironstone soils). Class 4-n soils are generally cropped (except on large sandhills), but poor nutrition is a principal reason for sub-optimal productivity.

Class 5-n land

Class 5-n soils are sandy with virtually no clay content. They are either very highly leached, or are very highly calcareous. Nutrient losses in the former category are high, as water movement through the soil (either vertically or laterally) is virtually unimpeded. The difficulty in maintaining adequate levels of nutrition is invariably their major limitation as agricultural soils. They are commonly uncleared. Where cleared, they are often non arable due to past wind erosion. Cropping, where practised, is intermittent. These are semi arable soils at best.

Classes 2-t and 3-t land

The productive potential of land affected by high boron and exchangeable sodium levels is permanently limited. Class 3-t land has a lower productive potential than Class 2-t land. The use of plants with boron and / or sodium tolerance is one solution. This implies specific cultivar selection, or the use of naturally occurring plants with tolerance to these elements. Neither gypsum nor any other ameliorant will have any significant effect on these soils.

Classes 2-t and 3-t soils where toxic aluminium is the limitation are invariably acidic. Lime applications should reduce or eliminate symptoms, except where subsoil aluminium is a problem. In these situations, deep placement of lime (where economically and technically feasible) is the only alternative to using tolerant plants. The latter option is generally undesirable as it does not address the cause of the problem, which will gradually worsen.

Classes 4-t and 5-t land

Toxic levels of boron and sodium this close to the surface present major problems for crop and pasture productivity. They are only likely to occur where impermeable or highly calcareous clays are close to the surface, or where the soil is saline. Consequently, there are likely to be other chemical and / or physical constraints to plant growth. Use of tolerant species or varieties is the only management option if the land is to be used for agriculture, but productivity is likely to be low.

# 10 SOIL pH

The pH of soil is a measure of its acidity or alkalinity and is important in determining the degree and likelihood of acidification, in estimating possible nutrient deficiencies and assessing suitability for particular crops.

Soils which are neither acidic nor alkaline have a pH 7.0 (neutral). Acid soils have lower pH values and alkaline soils have higher values.

Most agricultural plant species prefer approximately neutral pH levels. Soils which are excessively acidic or excessively alkaline suffer from reduced productivity.

## Factors affecting soil pH

Acidity

Some soils, particularly those with low clay and / or organic matter contents in high rainfall areas, are naturally acidic. These are restricted in South Australia. Induced acidification, caused by accelerated accumulation of hydrogen ions under certain land management practices, is a significant problem. Areas most affected are the higher rainfall districts such as the Mount Lofty Ranges, South East, Kangaroo Island and Lower Eyre Peninsula.

Acidification is caused by:

- accumulation of organic matter which produces organic acids;
- addition of nitrogen to the soil by fertilisers or fixation of atmospheric nitrogen by leguminous plants. Nitrate nitrogen in excess of plant requirements combines with base elements such as calcium and magnesium and is readily leached. Hydrogen replaces the bases on the cation exchange complex, increasing acidity.
- inappropriate fertilizer use. Fertilisers with ammonium or elemental sulphur directly acidify the soil, and all fertilisers can indirectly contribute to soil acidification because they increase productivity and hence organic matter levels.
- removal of alkaline farm products such as legume hay.

The susceptibility of a given soil to acidification is determined by its buffering capacity, or ability to resist pH change. Soils with high clay and/or organic matter have higher cation exchange capacities and generally higher buffering capacities. Soils with low buffering capacities acidify faster than high buffering capacity soils, under similar management systems and climate.

*Sorell infestation on acid soil*

Alkalinity

Alkalinity is usually an inherent characteristic of soils, although it can be increased by irrigation with alkaline or saline water. Soils made alkaline by calcium carbonate alone rarely have pH values above 8.3 (in water) and are termed "calcareous". Alkaline soils with pH values higher than 8.3 usually have significant exchangeable sodium (sodic soils) or carbonates and bicarbonates of sodium.

Alkaline soils are largely confined to areas with less than 400 mm annual rainfall.

### Consequences of soil acidity and alkalinity

Many of the adverse consequences of excessively high or low soil pH values are related to plant nutrient availability. In some cases the availability of essential nutrients is reduced while in others the availability of toxic elements is increased, as indicated in Figure 5.

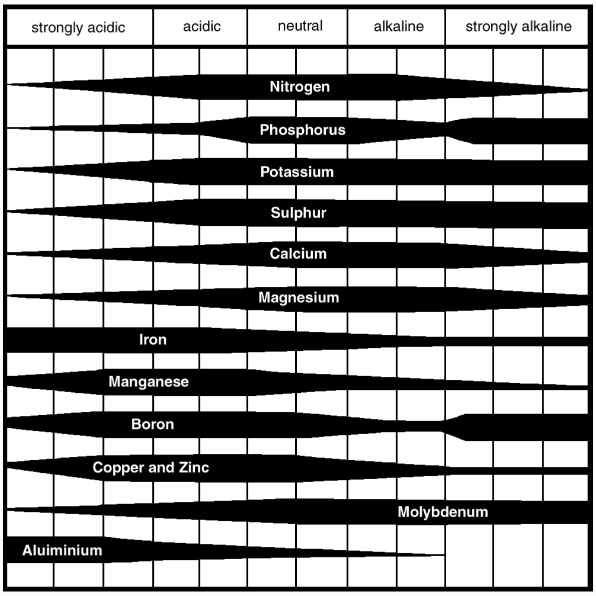



**Figure 5** Variations in nutrient element availability with pH change

Plants vary in their capacity to extract nutrients from the soil, or to tolerate low levels of availability, and for this reason some plants are able to perform better in acid soils, while others prefer a higher pH. Table 29 indicates the preferred pH range of selected species.

Table 29 pH tolerance of selected species (pH measured in 1:5 soil:water suspension)

| Species | $pH_{water}$ range | Species | $pH_{water}$ range |
|---|---|---|---|
| Wheat | 6.0 - 8.5 | Almond | 6.0 - 7.0 |
| Barley | 6.0 - 8.5 | Apple | 6.0 - 7.0 |
| Oats | 4.5 - 7.0 | Apricot | 5.5 - 6.5 |
| Canola | 6.0 - 7.5 | Citrus | 6.0 - 7.5 |
| Lupin | 5.0 - 7.0 | Grape | 5.5 - 6.5 |
| Lucerne | 6.0 - 8.0 | Peach | 6.0 - 7.5 |
| Medic | 6.6 - 8.5 | Potato | 4.5 - 7.0 |
| Phalaris | 6.0 - 8.0 | Tomato | 6.0 - 7.0 |
| Sub. clover | 5.5 - 7.0 | Onion | 6.0 - 7.0 |

Source: Inoculo Laboratories, Soil pH testing field kit.

Management flexibility is reduced at extreme pH values because intolerant species cannot be used in the rotation or pasture mixture.

There are also some specific consequences of acidity and alkalinity:

In acidic soils:

- nutrients are more readily leached due to a weakening of the cation exchange complex. For example, calcium deficiency may be associated with acid soils.
- the rhizobia bacteria, responsible for nitrogen fixation in legumes, are less active at low pH. Reduced vigour of leguminous plants is therefore a major consequence of soil acidification.
- aluminium and manganese become so readily available at low pH that toxicities may occur. Stunted growth and leaf necrosis can result.

In alkaline soils sodicity is often the cause of the high pH. As discussed in Sections 7 and 9, high levels of exchangeable sodium cause soil structural problems, and are toxic to some species.

## Assessing soil pH

Soil pH is easily estimated in the field but laboratory measurements are more reliable. Commercial field pH test kits and "pocket" meters are available and easy to use. If maintained properly, the meters can produce results comparable with those from a laboratory.

In the laboratory, soil pH is measured in solutions of either calcium chloride ($CaCl_2$) or water ($H_2O$). Solutions of one part soil to two parts 0.01M $CaCl_2$ are preferred, although the traditional method uses a 1:5 soil:water mix. The $CaCl_2$ method is more reliable: it better simulates the root environment and is less susceptible to seasonal variations. The two methods produce different results. Measurements in $CaCl_2$ are usually between 0.5 to 1.0 pH unit lower than in water. The method used must be known before results can be interpreted. Soil pH is categorized into one of five classes, as defined in Table 30.

Table 30 pH Categories

| Category | $pH_{CaCl2}$ | $pH_{H2O}$ |
|---|---|---|
| Strongly acid | < 4.5 | < 5.5 |
| Acid | 4.5 - 5.4 | 5.5 - 6.4 |
| Neutral | 5.5 - 6.9 | 6.5 - 7.9 |
| Alkaline | 7.0 - 8.5 | 8.0 - 9.2 |
| Strongly alkaline | > 8.5 | > 9.2 |

## Classification criteria for soil pH

Land is classified according to the pH of the upper 10 cm (topsoil), and the pH of the subsoil (nominally 30-80 cm). Classification of acidity also takes account of the surface soil's buffering capacity. Surface textures of sand, loamy sand or light sandy loam are considered to have low buffering capacities. Surface textures of sandy loam or finer are considered to have moderate to high buffering capacities.

Table 31 sets out a system for classifying soil according to acidity.
Table 32 sets out a system for classifying soil according to alkalinity.

Table 31 Classification criteria for susceptibility to acidity

| pH of topsoil (0-10 cm) # | pH of subsoil (30-80 cm) # | Land Class |
|---|---|---|
| Neutral or alkaline | Alkaline | 1>1-h |
| | Neutral | 1>2-h |
| Acid, moderate to high buffering capacity | Alkaline | 2>1-h |
| | Neutral | 2>2-h |
| | Acid | 2>3-h |
| | Strongly acid | 2>4-h |
| Acid, low buffering capacity | Alkaline | 3>1-h |
| | Neutral | 3>2-h |
| | Acid | 3>3-h |
| | Strongly acid | 3>4-h |
| Strongly acid, moderate to high buffering capacity | Acid | 4>3-h |
| | Strongly acid | 4>4-h |
| Strongly acid, low buffering capacity | Acid | 5>3-h |
| | Strongly acid | 5>4-h |

Table 32 Classification criteria for alkalinity

| pH of topsoil (0-10 cm) # | pH of subsoil (30-80 cm) # | Land Class |
|---|---|---|
| Neutral or acid | Neutral or acid | 1>1-i |
| | Alkaline | 1>2-i |
| | Strongly alkaline | 1>3-i |
| Alkaline | Alkaline | 2>2-i |
| | Strongly alkaline | 2>3-i |
| Strongly alkaline | Strongly alkaline | 4>3-i |
| Strongly alkaline in 10-30 cm | Strongly alkaline | 3>3-i |

# The most limiting pH value within the depth zone is used for classification purposes.

## Productivity and management of acid and alkaline soils

Acid Soils

Soil acidity can be managed by either using acid tolerant species and varieties, or raising the pH with applications of agricultural lime or dolomite. Lime is predominantly calcium carbonate (limestone); dolomite is a mixture of calcium and magnesium carbonates and is used where soil magnesium levels are low.

Reliance on plant tolerance alone is an unsatisfactory solution, as it fails to address the cause of the problem, which may continue to worsen.

The amount of lime or dolomite required depends on the soil's buffering capacity and the severity of the acidity. A sandy soil low in organic matter may require as little as one tonne per hectare to raise the pH by one unit. An acidic clay soil may require up to five tonnes for the same result (Kealey 1992). Actual tonnages will be influenced by the purity and particle size of the lime. Indicative application rates of lime needed to neutralize different acidity classes are shown in Table 33.

Table 33 Indicative application rates of lime * needed raise surface pH to about $6.5_{CaCl2}$

| Surface soil acidity class | Approximate range of lime application rates |
|---|---|
| 2-h | 2.5 - 5 t/ha |
| 3-h | 1 - 2.5 t/ha |
| 4-h | 5 - 10 t/ha |
| 5-h | 2.5 - 5 t/ha |

* Assume pure, fine lime, incorporated to 10 cm

High application rates carry the risk of inducing nutrient deficiencies (eg manganese) by dramatically altering the surface pH. Split applications and / or incorporation will alleviate this problem.

Subsoil acidity is more difficult to correct. Practical methods of subsurface lime application are being investigated. Some leaching of surface applied materials will occur, but movement is slow, especially on heavier soils in lower rainfall situations.

Alkaline soils

Correction of alkalinity is generally not practicable in agricultural situations. Addition of elemental sulphur will reduce pH, but the cost limits its use to home gardens or highly intensive, small area production. Gypsum, used to reduce sodicity, may lower pH, but large amounts of gypsum would generally be required. Where the soil is calcareous, gypsum will have no effect in lowering the $pH_{water}$ below 8.4.

There is a wide range of agricultural species which do well on alkaline soils provided that high pH-induced nutrient deficiencies are overcome. Species preferring acidic conditions should be avoided.

The lower productivity potential of strongly alkaline soils is a permanent limitation in most situations.

## Further reading

Kealey, L. (1992). Acid soils - their occurrence and management in South Australia. Bulletin 1/92. Department of Agriculture, South Australia.

## ACID SULFATE SOILS

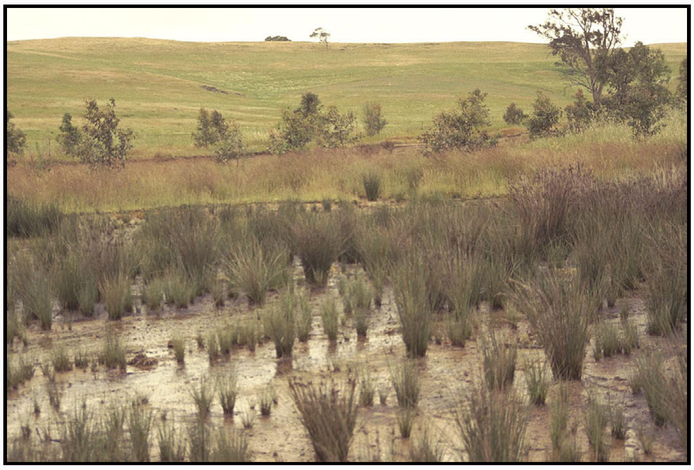
Acid sulfate materials are soils or sediments with accumulations of iron sulfides in the upper layers under waterlogged or highly reducing (anaerobic conditions). So long as these materials remain waterlogged or de-oxygenated, they are innocuous and do not cause any problems. Drainage or other disturbance which causes oxidation creates a chain of events resulting in the release of highly acidic leachates from the soil.

Three broad types of acid sulfate environments are recognized:

- coastal
- inland
- mine site

In South Australia, the largest area of land at potential risk is the coastline, or specifically those sections of coastline where tidal mud flats are prominent. These areas are scattered, but occur from the West Coast around both Eyre and Yorke Peninsulas to Adelaide, and from the Murray mouth, along the Coorong to the upper South East coast.

*Coastal samphire flat underlain by sulfidic sediments*



*Acidic leachates in an inland saline seepage*

There are sporadic inland areas at risk, on Eyre Peninsula, Kangaroo Island, Mount Lofty Ranges, Noora Basin and the upper South East. The low lying swampy land around Lakes Alexandrina and Albert is also possibly at risk.

Acid sulfate soils associated with mine sites are not considered in this context, where the focus is on agricultural land.

### Factors affecting the formation and development of acid sulfate conditions

Acid sulfate soils can occur wherever there are waterlogged soils or sediments, and pyrite (iron sulfide). Pyrites can occur naturally in some soils (where present in underlying rocks), or can form through the reduction of sulfates in sediments or soils containing iron and decomposed organic matter. Sulfates derive from two main sources, viz. saline water (sulfate salts, mainly of sodium), and gypsum (calcium sulfate). Iron is a relatively abundant constituent of most soils. Consequently, waterlogged saline land, areas with gypsum deposits (often associated with salt lake systems), and landscapes underlain by rocks rich in pyrite are at risk. Coastal land, in particular mangrove swamps, salt marshes and back swamps are particularly high risk because they usually accumulate large amounts of organic debris.

Waterlogged soils with iron sulfides are termed “sulfidic”, or potentially acid sulfate. Oxidation of the sulfidic material, which may be of neutral to alkaline pH, results in the formation of sulfuric acid, which can lower soil pH to less than 3.5. Oxidation usually occurs as a result of artificial drainage. Once this has occurred and acid is released, the soil or sediment is termed “sulfuric”.

### Consequences of the development of acid sulfate conditions

The overwhelming impact of the release of large quantities of acid from these materials is on water quality. There are several aspects:

- aquatic life can be severely affected. Breeding areas, often located in mangrove and other tidal areas are particularly susceptible. This can have catastrophic effects on fisheries and both marine and freshwater ecology.
- water potability is adversely affected.
- acidic waters corrode metal and concrete, thereby having a major impact on structures, a particularly important aspect of acid sulfate soils in and around coastal developments.
- heavy metals which may have accumulated in streams (by dumping or natural deposition) are mobilized at low pH.
- Flocs, which typically form in iron rich acid sulfate waters, can clog bores, aquifers and irrigation equipment.

Where the materials occur within the root zone, potential productivity of the soil is reduced. This occurs through direct physiological damage caused by the acid, induced mineral deficiencies (as caused by “normal” soil acidification), and through the toxic effects of a range of chemicals which are released simultaneously.

The generation of sulphur dioxide, and the dissolution of soil and sediment carbonates, both associated with acid sulfate soils, contribute to greenhouse gas emissions.

Acid induced acceleration of weathering can contribute to increased salinization.

### Assessing Acid Sulfate Soils

The aim is to identify sulfidic soils (ie those soils with potential to develop acid sulfate conditions). Whilst soil analysis to detect certain indicator minerals such as jarosite is an option and would be used in research applications, routine survey work needs to rely on observable site characteristics.

<u>Recognition of developed acid sulfate soils (sulfuric soils)</u>

Observation of an existing problem is a certain means of identifying a risk area. Red, yellow and smelly black iron-rich patches in soils are clear signs. Oily looking films occur on surface waters. Gelatinous substances develop on the soil surface during winter. In summer, surfaces dry and form an impermeable yellowish iron-rich crust.

<u>Identification of sulfidic soils</u>

The presence of the necessary conditions provides a first approximation of likely risk areas. Waterlogged soils and a source of sulphur and organic matter are essential:

Table 34 Indicators of sulfidic soils

| What to look for |
|---|
| At least the lower part of the soil profile must be saturated for most of the year |
| **AND** |
| Land lies within a geological formation containing pyrite bands **OR** |
| Near surface water tables are highly saline (more than 10,000 mg/kg dissolved salts) **OR** |
| There are gypsum deposits in the landscape (eg lunettes around salt lakes or salt pans, gypseous hummocks) **OR** |
| Gypsum segregations (crystals or soft flakes) occur in the soil profile |

Provided that these two conditions are met, the land is considered to have the potential to develop acid sulfate conditions.

### Classification of acid sulfate potential

In the absence of a more sophisticated approach, a simple three class system is proposed.

Table 35 Classification criteria for acid sulfate potential

| Acid sulfate potential | Land Class |
|---|---|
| No potential for development of acid sulfate conditions | 1-j |
| Potential for development of localized acid sulfate conditions | 4-j |
| Potential for development of acid sulfate conditions over more than 50% of the area | 5-j |

### Management of acid sulfate soils

Avoidance of sulfidic soils is the safest line of approach. Failing that, water table control is essential. Oxidation of deeper subsoil sulfide must be avoided. This may be achieved through surface or shallow drains, such as reverse interceptor banks, which reduce surface waterlogging but help maintain wet conditions at depth.

Increasing water use through better plant water use efficiency or altered vegetation regimes will help to lower water tables. This will result in a slow oxidation of sulfides and accompanying slow release of acid, so as to have minimal impact.

In small areas of affected soils, and on drain banks, lime applications to neutralize acidity will have some effect.

### Further reading

Fitzpatrick, R.W. (1999). Rising saline watertables and the development of acid sulfate soils. Research Project Information Sheet No.13. CSIRO Land and Water.

Fitzpatrick, R.W. Merry, R.H., Williams, J., White, I., Bowman, G.M. and Taylor, G. Acid Sulfate Soil Assessment: Coastal, Inland and Minesite Conditions. Unpublished paper prepared for the National Land and Water Resources Audit. CSIRO Land and Water.

White, I., Melville, M.D., Sammut, J., Wilson, B.P. and Bowman, G.M. (1996). Downstream Impacts from Acid Sulfate Soils. “Downstream Effects of Land Use”, pp 165-172. H.M.Hunter, A.G.Eyles, G.E.Rayment eds. Dept. of Natural Resources, Qld., Aust.

# 11 SOIL CARBONATES

Carbonates are predominant features of most soils in lower rainfall (less than 350 mm annually) districts, and are important in the subsoils of many soils receiving as much as 600 mm annual rainfall. Carbonates occur as finely divided sand, silt or clay sized particles in the fine earth fraction of the soil, as nodules of various sizes, or as sheet rock (calcrete). Calcium carbonate is most common, but varying proportions of magnesium carbonate may also occur.

## The Nature of Soil Carbonates

A range of theories has been proposed concerning the origins of the carbonate and the processes involved in the development of carbonate layers in and below modern soils. Milnes and Hutton (1983) summarize these aspects in “Calcretes in Australia”, Chapter 10 of “Soils: an Australian Viewpoint”. The nature and distribution of soil carbonates are the result of complex and long term processes of deposition by wind, leaching, precipitation, exposure and induration.

Fine carbonate

Fine carbonates are calcareous sand, silt and clay sized particles which are distributed through the soil matrix. The distribution may be uniform, or the carbonate may be concentrated in white, pale brown or pink blobs or “segregations”.

Nodular or rubbly carbonate

Wetting and drying cycles near the soil surface cause repeated dissolution and precipitation of calcium carbonate. This process commonly results in the formation of hard spherical to knobbly concretions or nodules, commonly called rubble. These vary in size from a couple of millimetres to 300 mm or more. They usually occur near the top of a highly calcareous layer and grade to softer calcareous material below. However, where there has been more than one period of rubble formation, alternating layers of rubbly and softer fine carbonates occur.

Calcrete

Prolonged near surface wetting and drying cycles of highly calcareous materials may result in the formation of a more or less continuous sheet, or pan, of indurated carbonate, called calcrete. This may be massive (ie composed of individual grains of carbonate or silica cemented by carbonate), or concretionary, where nodules or concretions (as above) are cemented together to form a carbonate pan. Calcrete pans vary in thickness from a few millimetres to many metres, and generally grade to softer calcareous materials below. In the Murray Basin, calcrete is commonly underlain by a heavy clay within a metre.

Wetherby and Oades (1975) proposed a classification system for the various types of carbonate layers, with emphasis on their land use and management implications. This system is briefly outlined and illustrated in the Appendix.

## Effects of soil carbonates on land use and management

Chemical effects

Calcareous soils are alkaline, but calcium carbonate alone will not raise soil $pH_{water}$ higher than 8.3. Higher pH values are usually caused by sodium carbonates or bicarbonates, or magnesium carbonates. Nevertheless, moderate to high levels (more than about 8%) of soil carbonates are sufficient to suppress the availability of several nutrient elements, notably phosphorus, zinc, manganese, copper and iron.

Many plants prefer neutral to acidic soils, usually because they suffer from nutrient deficiencies on calcareous or alkaline soils. These deficiencies can generally be corrected. Some species however are highly sensitive to calcareous soils. Lupins for example perform poorly on soils with high carbonate levels within 30 cm of the surface. This may be due to extreme sensitivity to iron deficiency (White 1990).

Poor root growth in many highly calcareous materials is not necessarily due to calcium carbonate as such, but most likely to the high levels of sodium carbonate, and/or sodium chloride and/or boron salts which often occur in highly calcareous subsoils. However, poor root growth is often observed in clayey subsoils with very high concentrations (eg more than 40%) of fine carbonates and relatively low levels of sodicity, boron, alkalinity and salinity. This suggests that combined high clay and carbonate contents may be impacting on root growth via induced trace element deficiencies or possibly waterlogging.

High levels of soil carbonates also appear to retard or inhibit the breakdown of some agricultural chemicals which on neutral to acidic soils are deactivated during the season of application. Some herbicides may persist in calcareous soils for several seasons, damaging subsequent crops and pastures. Some insecticides (eg some used for termite control) are relatively ineffective in calcareous soils. Knowledge of soil carbonates is essential in these situations to ensure effective and economic treatment.

Physical Effects

Depending on their form, soil carbonates affect drainage, water holding capacity and workability.

Fine carbonates in a sandy clay loam to clay matrix restrict drainage. Heavy clay substrate layers which often underlie calcareous clays exacerbate the problem. Sandy or rubbly carbonate layers are usually well drained.

Rubbly carbonate reduces water holding capacity in the root zone in the same way as any other rocks or gravels do, although some types of porous rubble have some capacity to store and release water.

Calcrete can have severe effects on plant growth, usually through the limitation it sets on root zone depth. Some sheet calcrete with few if any fractures also prevents free drainage.

High amounts of rubble in the topsoil or on the surface affect the workability of the soil. Surface stone sufficient to interfere with tillage must be picked up or rolled. Although relatively soft (compared to ironstone or quartzite), calcrete rubble nevertheless abrades implements.

## Assessing soil carbonates

Carbonates are easily detected by the effervescence caused by the application of hydrochloric acid of 1M concentration. The strength of the reaction gives a rough indication of the carbonate content. Carbonate layers should be described according to their reaction to acid, and their class (Wetherby and Oades 1975). This will enable assessment of their drainage and moisture holding characteristics, which are dealt with in the relevant preceding sections. The chemical effects of soil carbonates depend on the amount of surface carbonates and the depth to very highly calcareous layers. A surface carbonate classification provides useful information about potential nutritional problems, while a subsoil carbonate classification is useful for assessing land with regard to carbonate sensitive crops such as lupins, herbicide persistence, and efficacy of some pesticides.

## Classification criteria for soil carbonates

Two sets of criteria (surface soil and subsoil) are used.

Surface carbonates

Land is classified according to three levels of surface carbonates, as detected by acid reaction.

Table 36 Classification criteria for surface carbonate

| Category | Reaction to 1M HCl | Land Class |
|---|---|---|
| Non to slightly calcareous | Nil | 1-ka |
| Moderately to highly calcareous | Slight to moderate | 2-ka |
| Very highly calcareous | Strong | 3-ka |

Subsoil carbonates

Land is classified according to depth to a very highly calcareous layer (ie strong effervescence with 1M HCl).

Table 37 Classification criteria for subsoil carbonate

| Depth Category | Depth to Strong Reaction to 1M HCl | Land Class |
|---|---|---|
| Deep | >60 cm | 1-kb |
| Moderate | 30-60 cm | 2-kb |
| Shallow | <30 cm | 3-kb |

*Very highly calcareous surface soil (class 3-ka)*

*Soil with shallow carbonate layer (class 3-kb)*

**Productivity and management of calcareous soils**

Calcareous soils cannot be readily neutralized as acidic soils can, although most agricultural practices cause gradual acidification.

The effects of calcareous soils on nutrient availability must be recognized, and fertilizer programs adjusted accordingly. This involves closer attention to tissue testing for trace elements, and ensuring that soil phosphate reserves are satisfactory. On very highly calcareous soils, the degree of fixation of trace elements may be such that foliar application is the only effective means of ensuring satisfactory nutrition.

The potential for successfully growing carbonate sensitive crops such as lupins can be easily assessed. Subsoil investigations are essential. Until lime tolerant varieties are developed, sensitive crops should be avoided.

Careful attention to label warnings and advice related to pesticide behaviour in calcareous soils (or alkaline soils in general) is needed to avoid production losses or ineffective performance.

# 12 SALINITY

Saline soils are those which have sufficient soluble salts in the rootzone to adversely affect plant growth.

## Types and Causes of Salinity

Four broad groups of salt-affected land can be identified. Refer to Jolly (1988) for more details.

Salt Marshes and Pans

Salt marshes in coastal areas and salt pans in inland depressions are areas where salt has accumulated over long periods. Salt marshes are common around the northern margins of Spencer Gulf and St. Vincent Gulf, in the Coorong and parts of the west coast. Salt pans occur in most agricultural districts of South Australia and are common in the South East, Eyre and Yorke Peninsulas, Mid North, Kangaroo Island, north eastern Murray Mallee and the margins of Lakes Alexandrina and Albert.

Salt marshes and pans, where they are not bare, are characterized by samphire and/or tea-tree with mangroves along some coastal sections.

Dry Saline Land

Dry saline land is not influenced by a water table and is naturally saline in the subsoil or throughout the profile. Where surface vegetation is severely degraded or absent and salt crystals form, the land is commonly termed “magnesia ground”. Dry saline land is common around the northern fringes of Eyre Peninsula, throughout the West Coast agricultural district, and is scattered through the “Northern Marginal Lands”. Most soils of lower rainfall districts have elevated salt levels in their subsoils, but “magnesia ground” is rare outside of Eyre Peninsula.

Saline seepage

Saline seepage occurs where groundwater tables rise near to the surface following agricultural development. Deep-rooted, high-water-use plants are replaced by shallow-rooted annual plants using less water. The groundwater may be naturally saline or may mobilise salts stored at depth in the soil. Much of the salt is believed to be cyclic (blown in from the sea), and to have leached through the soil and accumulated at depth. The equilibrium between rainfall, plant water use and accession to the groundwater has been disturbed with widespread scrub clearance, and a new equilibrium with near-surface water tables is now being established. Saline seepage is widespread in the Upper South East, Eastern and Lower Eyre Peninsula, and Kangaroo Island and is locally significant on Yorke Peninsula, the northern agricultural districts and the Mount Lofty Ranges.

Scalding

Scalds occur where thin sandy to loamy topsoils have been eroded, exposing subsoil material which seals over. This material is sometimes sodic and/or saline. Scalding is widespread around the margins of the northern agricultural districts and into the pastoral country. Scalds are not associated with a water table.

Focus of assessments of agricultural land

Although salt marsh / salt pan salinity is naturally occuring and saline seepage is management induced, both forms are associated with water tables, so from a land assessment point of view are considered together. Information about the presence of near surface water tables is not always available, and so the differences between the other types of salinity are not always obvious. Nevertheless, seepage salinity, dry saline land and scalding are considered separately.

## Consequences of salinity

Plant productivity decreases as salt levels increase. Salt sensitive species become stressed and die at relatively low salt levels. More tolerant species withstand higher levels before productivity declines and death eventually occurs.

In naturally saline areas the native vegetation is adapted to saline conditions. Plants such as samphire, saltbush, bluebush and swamp tea-tree survive, although re-establishment after removal or over grazing is sometimes difficult if salinity has increased since European settlement.

On scalded land, few plants are able to survive, mainly because the sealed surface sheds water and provides little by way of footholds for seeds. Germination and establishment are severely restricted by lack of water, and the barrier of the surface seal. Scald surfaces are highly susceptible to further erosion, especially if disturbed by livestock or feral grazing animals. This problem is exacerbated on saline scalds due to the preference of livestock to camp on salty ground.

Where rising water tables are the cause of the problem, previously unaffected land becomes wetter with improved growth commonly occurring for a couple of seasons. Then the desirable species begin to die out and halophytic (salt tolerant) plants, particularly sea barley grass, take over. Eventually the soil becomes too salty for these plants and bare areas develop with water at the surface for much of the year. In hilly land and in drainage depressions, the unprotected soil is vulnerable to erosion.

A further consequence of saline seepage is the salinization of water supplies originating from the affected areas.

*Saline eroded valley floor*

### Assessing salinity

Salinity is assessed according to its type (using the categories described above), and its severity, assessed either by observing the vegetation or by measuring the soluble salt content of the soil.

The concentration of salt in the soil is easily measured and should be assessed for at least three layers in the top metre. Samples should be collected when the soil is dry, during late summer.

Total soluble salt content is estimated from the electrical conductivity (EC) of the soil solution. The quicker method involves shaking a 1:5 soil:water mixture and using a conductivity meter to obtain an EC (1:5) reading. When the results are more than 0.15 dS/m* (sands), 0.2 dS/m (loams) or 0.3 dS/m (clays), the saturation extract method should be used. This method is tedious but gives the only reliable assessment of soil salinity because it relates more closely to the impact of salinity on plant growth. The two methods are described by Rayment and Higginson (1992).

The conductivity of the saturation extract can be estimated from the E.C.(1:5) value, by multiplying it by a conversion factor which is dependent on soil texture, as shown in Table 38. Note however that while these conversions provide a guide, reliability is poor.

* dS/m = deciseimens per metre, a unit of electrical conductivity.

Table 38 Estimation of conductivity of saturation extract (ECe) from EC(1:5)

(after Wetherby 1992)

| Soil Texture | Conversion factor |
|---|---|
| Sand to clayey sand | 14 |
| Sandy loam to clay loam | 9.5 |
| Clay | 6.5 |

### Classification of land affected by water table induced salinity

Salt affected land is classified according to one or more observations. Soil salt concentration can be estimated from the electrical conductivity of the saturation extract of a soil sample. Ratings are made according to the highest levels of salinity in the upper 50 cm of the profile, and in the 50-100 cm zone. The type of vegetation growing on the site can also indicate the level of salinity. Depth to saline water table is a further indicator of the presence and severity of soil salinity. Table 39 defines salinity categories.

It is commonly difficult to determine whether or not a saline groundwater table is the cause of subsoil salinity. This may occur for instance where a water table is deeper than normal soil inspection depths. In these situations, a judgement must be made according to knowledge of the landscape. Where water tables may be present, although deeper than two metres, and could conceivably be having an influence on subsoil salinity, use the salinity classes below. If water tables are not affecting subsoil salinity, use the “Dry Saline Land” classification for ranking salinity.

If there is doubt about the cause of salinity, classify the land for both “Salinity induced by water table” (Table 39) and “Dry saline land” (Table 42).

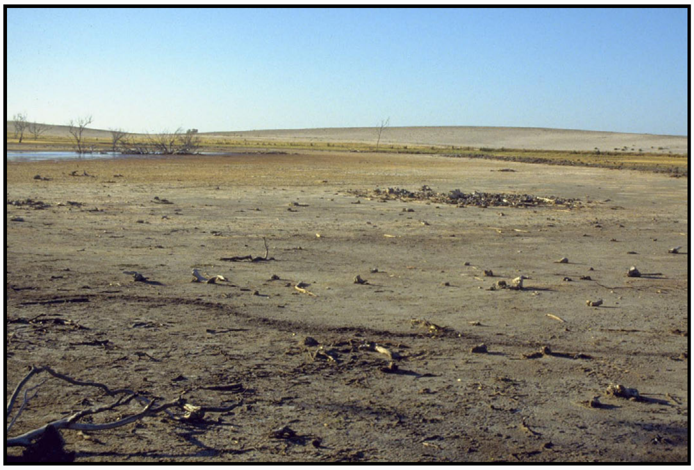
Table 39 Classification criteria for salinity (induced by water table)

| Salinity Category | Classification Criteria | | | Land Class |
|---|---|---|---|---|
| | Water table | Vegetation indicators | Indicative ECe (dS/m) * | |
| Low | None | No evidence of salt effects | <2 (surface)<br><4 (subsoil) | 1-s |
| Moderately low | Usually deeper than 2 m. | Subsoil salinity - deep rooted horticultural species and pasture legumes affected | <4 (surface)<br>4-8 (subsoil) | 2-s |
| Moderate | Shallower than 2 m, capillary effect reaches into rootzone | Many field crops and lucerne affected. Halophytic species such as sea barley grass are usually evident. | 4-8 (surface)<br>8-16 (subsoil) | 3-s |
| Moderately high | Seasonally within 1 m of the surface | Too salty for most field crops and lucerne. Halophytes are common (as above plus curly rye grass and salt water couch). Strawberry clover productivity is diminished. | 8-16 (surface)<br>16-32 (subsoil) | 4-s |
| High | Seasonally near surface | Land dominated by halophytes with bare areas. Samphire & ice plant evident. This land will support productive species such as Puccinellia, tall wheat grass etc. | 16-32 (surface)<br>>32 (subsoil) | 5-s |
| Very high | Near surface most of year | Land is too salty for any productive plants and supports only samphire, swamp tea-tree or similar halophytes. | >32 (surface) | 7-s |
| Extreme | Near or at surface most of year | Bare salt encrusted surface. | >32 (surface) | 8-s |

* Indicative only – soil salinity levels fluctuate too widely to be used as definitive criteria.

*Class 4-s landscape*

*Class 5-s landscape*



*Class 8-s landscape*

Land affected by patchy salinity

The effects of salinity are often not uniform across a landscape. It is common for isolated saline seepages to occur in land which is otherwise unaffected, or only moderately saline. This is the usual situation in undulating to hilly country, such as Kangaroo Island, Koppio Hills, Cleve Hills, Northern Agricultural Districts and Mount Lofty Ranges, and to some extent on flatter land. A qualifier symbol in the land classification caters for this situation.

*Typical valley floor salt patch*

Land with patchy salinity is defined as follows:

- Saline patches are at least Class 5-s severity
- Saline patches occupy less than 50% of the landscape
- Where patches occupy more than 50% of the landscape, the land as a whole is classified according to the severity of the patches.
- Where the landscape as a whole is Class 5-s or more saline, patchy salinity is not classified.

Three categories of patchy salinity are recorded, according to their proportion of the landscape. Classes of land affected by patchy salinity are defined according to Table 40.

Table 40 Classification criteria for land affected by patchy salinity

| Salinity Class of Majority of Landscape | Proportion of land affected by patchy salinity | | |
|---|---|---|---|
| | Up to 2% | 2-10% | 10-50% |
| 1-s | 1o - s | 1+ - s | 1x - s |
| 2-s | 2o - s | 2+ - s | 2x - s |
| 3-s | 3o - s | 3+ - s | 3x - s |
| 4-s | 4o - s | 4+ - s | 4x -s |
| 5-s | - | - | - |
| 7-s | - | - | - |
| 8-s | - | - | - |

**Productivity and management of land affected by saline seepage**

Management strategies depend on the topographic and hydrological situation, and on the severity of the salinisation. Both on-site and off-site management strategies have a role. Off-site management strategies offer the best options. These revolve around lowering water tables through the establishment of high water-use plants in the catchment generally, or at least in areas of high recharge potential. Options range from complete revegetation, to improving water use of conventional crops and pastures through modified rotations and optimum crop husbandry to increase productivity.

On-site strategies rely on improving productivity, conserving soil or simply improving appearances through establishment of appropriate plants. Selection of species and varieties which tolerate given levels of salinity is a fundamental on-site management strategy. Mounding to facilitate flushing of salts from the seed bed or planting line is used when establishing trees and row crops.

Salt marshes and pans (Classes 7-s and 8-s land) are commonly too salty to justify any ameliorative measures. Maintenance of vegetative cover by controlled grazing is the soundest approach.

Moderately to highly saline land (Classes 4-s and 5-s) is best managed through the use of salt tolerant species to maintain protective cover and achieve some productivity. On moderately saline land (Class 3-s), appropriate species and variety selection becomes important. Left untreated, land affected by saline seepage will become more degraded and productivity will decline until a new groundwater equilibrium is reached.

Groundwater pumping is a further option, but is only feasible on intensively used land. Subsurface or open drains are often effective in lowering water tables, although the risk of developing acid sulfate conditions must first be assessed.

The salinity tolerances of a range of agricultural plants are summarised in Table 41.

Table 41 Soil salinity tolerance of some crops (after Ayers, 1977)

| Crop | Soil ECe (dS/m) likely to cause yield reductions of: | | | |
|---|---|---|---|---|
| | **0%** | **10%** | **25%** | **50%** |
| Barley | 8.0 | 10 | 13 | 18 |
| Wheat | 6.0 | 7.4 | 9.5 | 13 |
| Field beans | 1.0 | 1.5 | 2.3 | 3.6 |
| Orange | 1.7 | 2.3 | 3.3 | 4.8 |
| Grape | 1.5 | 2.5 | 4.1 | 6.7 |
| Almond | 1.5 | 2.0 | 2.8 | 4.1 |
| Tomato | 2.5 | 3.5 | 5.0 | 7.6 |
| Potato | 1.7 | 2.5 | 3.8 | 5.9 |
| Lucerne | 2.0 | 3.4 | 5.4 | 8.8 |
| Perennial rye grass | 5.6 | 6.9 | 8.9 | 12 |
| Tall wheat grass | 7.5 | 9.9 | 13 | 19 |
| Strawberry clover | 1.5 | 2.3 | 3.6 | 5.7 |

On-site management strategies for salt affected broadacre cropping, horticultural and grazing land are summarized as follows.

Broadacre cropping land

Productivity declines with increasing salinity. On class 4-s land only the most salt tolerant crops such as barley can be grown. Heavy early rains may be needed to leach salt from the surface so that successful establishment is possible. This land is best used for grazing.

Maintenance of ground cover at all times will reduce surface evaporation, which concentrates salt. Salt tolerant varieties should always be used in both cropping and pasture phases of the rotation.

Vegetable growing land

Yield reductions for many vegetable crops of between 10% and 50% can be expected on land classes 2-s and 3-s depending on the species, soil drainage and irrigation management.

Salt tolerant crops and varieties must be used, and careful irrigation design and management are essential. Drainage is usually needed on Class 3-s land to ensure salts are leached below the rootzone.

Class 4-s land is too salty for most vegetable crops.

Perennial horticultural land

Significant yield reductions can be expected, even on class 2-s land. Salt tolerant root stocks are required and irrigation design and management are critical.

For many perennial crops land class 3-s is too salty for satisfactory production.

Grazing land

Many of the annual medics and subterranean clovers are salt sensitive and may even be affected on land class 2-s. Selection of the most salt tolerant varieties and cultivars is important. The choice of pasture legumes is severely restricted on land class 3-s. Specialised salt tolerant species may need to be introduced on class 3-s land.

On land classes 4-s and 5-s, satisfactory productivity is usually only possible with the establishment and careful management of salt tolerant species such as *Puccinellia* and tall wheat grass. Fencing is generally required because control of livestock to maintain cover and to allow regeneration is crucial to the persistence of these plants.

Water flow on to affected areas should be prevented as it can make the problem worse.

On class 7-s land, very light grazing or stock exclusion is necessary to protect the fragile vegetation. Damage may be irreversible.

*Puccinella*

## Further reading

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### Classification of dry saline land

Dry saline land is classified in much the same way as land affected by saline water tables, in that allowance is made for the level of soil salinity, and the proportion of land affected by highly saline "magnesia" patches.

This classification is generally only used in situations where water tables are not influencing soil salinity. As indicated previously, where there is doubt about the cause of salinity, classify the land for both "Salinity induced by water table" (Table 39) and "Dry saline land" (Table 42). Where saline water tables are known to be the main cause of salinity, classification for dry saline land usually becomes redundant. Refer to the note below Table 42 for classification guidelines in these situations.

Table 42 Classification criteria for dry saline land

| Salinity Category | Classification Criteria | | Land Class |
|---|---|---|---|
| | Indicative ECe (dS/m) | Vegetation indicators | |
| Low | Surface <2<br>Subsoil <4 | No apparent effects | 1-v |
| Moderately low | Surface 2-4<br>Subsoil 4-8 | Some wheat yield depression, but no vegetative indication | 2-v |
| Moderate | Surface 4-8<br>Subsoil 8-16 | Some barley yield depression<br>Halophytes usually evident | 3-v |
| Moderately high | Surface >8<br>Subsoil >16 | Halophytes predominant | 4-v |
| High | Any | >50% bare ground | 7-v |

Note Use the following guidelines for situations where water tables are known to be a cause of soil salinity (usually Class 4, 5, 7 or 8-s).

- Where a fluctuating water table is influencing salinity (commonly Class 4-s land), the land can be ranked for both types of salinity, (eg Class 4-s and Class 4-v).
- Where similar (but not water table affected) soils in the surrounding landscape have naturally elevated salinity, this can be reflected in the "dry saline land" ranking (eg Class 5-s and Class 3-v).
- In other situations of water induced salinity, a classification for dry saline land is redundant, and a ranking of 1-v is used.

Land affected by patchy dry saline areas

Patches of highly saline land ("magnesia" patches) may occur across landscapes affected by less severe dryland salinity. Three categories of patchy salinity are recorded, according to their proportion of the landscape, up to a maximum of 50%. If magnesia patches cover more than 50% of the land, it is rated 7-v. The proportion of magnesia ground is indicated by a symbol attached to the classification which applies to the majority of the land. For example, a landscape with soils which are moderately saline, and which has between 2% and 10% magnesia patches, is classified 3+ -v, according to Table 43.

Table 43 Classification criteria for dry saline land with highly saline magnesia patches

| Salinity Class of Majority of Landscape | Proportion of land affected by magnesia patches | | |
|---|---|---|---|
| | Up to 2% | 2-10% | 10-50% |
| 1-v | 1o - v | 1+ - v | 1x - v |
| 2-v | 2o - v | 2+ - v | 2x - v |
| 3-v | 3o - v | 3+ - v | 3x - v |
| 4-v | 4o - v | 4+ - v | 4x - v |
| 7-v | - | - | - |

## Management and Productivity of Dry Saline Land

There are no practicable methods of "desalinizing" dry saline land. On grazing properties, some productivity gains may be made through the establishment of salt tolerant plants such as salt bush.

Protecting the soil surface to prevent erosion is probably a more pressing management need. This inevitably involves exclusion of livestock during critical periods.

*"Magnesia" patch*

## Classification of scalded land

Classification of scalded land is based on the proportion of bare soil within the total area of land affected by scalding. Table 44 sets out the criteria (from McDonald et al 1990).

Table 44 Classification criteria for scalding

| Scalding Category | Description | Land Class |
|---|---|---|
| None | No scalding apparent. | 1-z |
| Minor | Up to 5% of area is scalded | 2-z |
| Moderate | Between 5% and 10% of area is scalded | 4-z |
| High | Between 10% and 50% of area is scalded | 5-z |
| Severe | More than 50% of area is scalded | 7-z |

*Scalded landscape*

## Management of scalded land

Land with minor scalding is only semi-arable because of its fragility and consequent need for conservative management.

Moderately to severely scalded land is non arable but has pastoral potential if well managed.

Management techniques for scalded land aim to encourage revegetation by controlling livestock and feral animal access, trapping seed in pits, furrows or rip lines and increasing water infiltration by water ponding or spreading techniques.

# 13 WATER EROSION POTENTIAL

This section deals with the susceptibility of land to erosion by overland flow of water. Removal of a more or less uniform thickness of soil is called sheet erosion. The formation of shallow gutters which can be obliterated by cultivation is rill erosion. Gully erosion caused by concentrated flow in unprotected watercourses, subsurface (or tunnel) erosion, landslip, mass movement and stream bank erosion are dealt with separately.

This discussion is also confined to the inherent potential of land in a clean cultivated condition to erode, as determined by soil properties, topography and rainfall. It does not deal with the susceptibility of land to erosion as a result of a particular land use or management practice. Thus a steep well grassed hill slope has a high erosion potential due to its slope, but a low erosion hazard because it is well protected by vegetation.

## Factors affecting water erosion potential

Topography

Three elements of topography influence erosion potential. Potential increases with:

- Slope steepness
- Slope length
- Proximity to rising ground (source of run-on water)

Soil

The inherent potential of a particular soil type to erode on a specified slope in a clean cultivated condition is called its erodibility. Erodibility is influenced by the capacity of soil to absorb the rain that falls on it and the resistance of the surface soil to raindrop impact and to being dragged along (entrained) by overland flow. The rate at which water enters the soil surface (infiltration), the rate at which it moves through the soil (permeability) and the stability of the soil surface are therefore the key soil properties. As discussed in Section 7, the stability of the surface is largely determined by its texture and organic matter content.

Rainfall

Rainfall affects erosion potential in three ways:

- If the infiltration of rainfall into the soil is impeded the surface soil becomes saturated, loses strength and is more likely to erode.
- Rainfall which is unable to infiltrate will run off, thereby providing a medium in which soil particles can move downhill.
- The impact of raindrops dislodges surface soil particles and thereby makes it easier for them to become entrained in overland flow. The kinetic energy of rainfall as it strikes the earth is defined as its erosivity.

The intensity and duration of rainfall events are key factors, modified by the moisture status of the soil before the rain.

## Consequences of water erosion

On-site effects

Sheet and rill erosion removes the most valuable layer of the soil profile, the surface. This is the zone of concentration of nutrients and organic matter. Loss of topsoil usually exposes soil of lower fertility and less organic matter with poorer structure and stability. Erosion therefore makes the soil even more erodible. Erosion also reduces the moisture holding capacity of the soil.

Rills and small gullies, which sometimes occur on inadequately protected land during heavy rain, can affect access across the land until they are removed by cultivation.

Soil formation rates are usually so slow that for practical purposes erosion represents a permanent loss of the resource.

*Rill erosion*

*Erosion rill exposing calcrete substrate*

*Silt deposit at bottom of slope*

Off-site effects

Eroded soil is often deposited on lower ground where it can damage or bury fences, block culverts, silt up dams and water courses and cover roads. These all involve public or private expense to rectify. Finer grained material, particularly clay, remains suspended in runoff water and can eventually pollute creeks and reservoirs. Nutrients, particularly nitrogen and phosphorus, attached to clay particles cause eutrophication of water supplies, pesticides adsorbed on clay colloids poison water and the clay particles themselves make the water turbid.

### Assessing water erosion potential

Rainfall erosivity

All districts in South Australia are subject to annual rainfall events of sufficient erosivity to warrant precautionary management practices for susceptible soils on all but the gentlest of slopes. Although there are differences in rainfall intensity across the state, they are not suffcently large to warrant the designation of rainfall erosivity zones for the purpose of land classification.

Slope

Slope length and run-on potential are not included in the classification of land with respect to water erosion potential, even though they must be taken into account when assessing land. In general, recommended practices for erosion control include agronomic or engineering techniques which effectively break slopes into smaller segments and divert water flow away from susceptible land.

Gradient is the major determinant of erosion potential. Erosion potential classes are based on slope categories, but the actual criteria used to define the categories vary depending on soil erodibility.

Soil erodibility

Six categories of erodibility are defined based on field observations. The categories are incomplete and represent a preliminary attempt to rank soil erodibility easily in the field. They should be treated only as a guide.

Draft erodibility categories for a range of soil profiles are defined in Table 45.

Table 45 Draft soil erodibility categories (water)

| Soil profile characteristics | Erodibility |
|---|---|
| Soils with sandy to loamy surfaces, shallower than 30 cm, overlying clayey subsoils. | |
| - Loose or soft surface | Very high |
| - Dispersive surface | Very high |
| - Hard setting loamy sand to loam surface | High |
| - Structured sandy loam to clay loam surface | Moderate |
| - Weakly structured, friable sandy loam to loam surface | Moderate |
| Note: - Increase erodibility by one category if subsoil is dispersive | |
| - Decrease erodibility by one category if depth to clay is more than 30 cm | |
| Calcareous soils | |
| - Loamy sand to sand over Class IV carbonate: | |
| Deeper than 50 cm | Negligible |
| Shallower than 50 cm | Very low |
| - Sandy loam to clay loam grading to : | |
| Class III B or III C carbonate | Very low |
| Class III A carbonate | Low |
| Class I carbonate shallower than 50 cm | Moderate |
| Class I carbonate deeper than 50 cm | Low |
| - Loamy sand to loam over Class II carbonate | Moderate |
| - Loam over calcareous weathering rock: | |
| Deeper than 50 cm | Low |
| Shallower than 50 cm | Moderate |
| Deep sands (more than 80 cm) | |
| Non water repellent | Negligible |
| Water repellent | Low |
| Strongly water repellent | Moderate |
| Deep (more than 80 cm) uniform sandy loams to clay loams | |
| Well structured | Very low |
| Massive | Low |
| Clay soils | |
| Well structured | Low |
| Massive | Moderate |
| Skeletal soils (shallow over bedrock) | |
| Gritty, stony sands on sandstone, quartzite | High |
| Stony loams on shale, siltstone | Moderate |

## Classification criteria for water erosion potential

Determine the Soil Erodibility Category from Table 45 and select the appropriate slope range to estimate erosion potential from Table 46.

Table 46 Classification criteria for water erosion potential

| Soil Erodibility | Slope Range (%) | Land Class |
|---|---|---|
| Negligible | Any | 1-e |
| Very Low | 0-3 | 1-e |
| | 3-6 | 2-e |
| | >6 | 3-e |
| Low | 0-2 | 1-e |
| | 2-4 | 2-e |
| | 4-12 | 3-e |
| | 12-20 | 4-e |
| | 20-30 | 5-e |
| | 30-100 | 6-e |
| | >100 | 7-e |
| Moderate | 0-1.5 | 1-e |
| | 1.5-3 | 2-e |
| | 3-10 | 3-e |
| | 10-18 | 4-e |
| | 18-30 | 5-e |
| | 30-100 | 6-e |
| | >100 | 7-e |
| High | 0-1 | 1-e |
| | 1-2.5 | 2-e |
| | 2.5-8 | 3-e |
| | 8-16 | 4-e |
| | 16-30 | 5-e |
| | 30-100 | 6-e |
| | >100 | 7-e |
| Very high | 0-0.5 | 1-e |
| | 0.5-2 | 2-e |
| | 2-6 | 3-e |
| | 6-12 | 4-e |
| | 12-30 | 5-e |
| | 30-100 | 6-e |
| | >100 | 7-e |

*Class 2-e land grading to Class 3-e slopes with Class 5-e in background*

*Class 3-e land with contour banks*

*Class 5-e slopes*

## Productivity and management of land prone to water erosion

Because land with potential for water erosion is prone to runoff, valuable rainfall can be lost. Apart from this indirect effect erosion potential does not significantly affect the productivity of arable land, although the cost of control measures may have effects on short term profitability. On steeper land where the potential for erosion is too great for safe cropping, agricultural land uses are restricted to pastures and perennial crops.

Management of arable land (Classes 1-e to 4-e)

A range of practices can control erosion on cropping land.

*Tillage techniques*

Contour cultivate to reduce velocity and volume of runoff.

Reduce tillage. Most soils, regardless of erosion potential, benefit from fewer and less aggressive workings. Reduction of tillage results in better retention of protective vegetative cover, less damage to soil aggregates and lower rates of organic matter breakdown, improving surface stability.

Retain residues by reduced tillage and controlled grazing. Burning should be eliminated or restricted to heavy stubbles. Protection of the soil surface by crop or pasture residues reduces the chances of erosion. As severe erosion can occur during summer thunderstorms, cover is critical at this time.

Reduce cultivated fallows. The longer bare soil is exposed and the more it is worked, the higher the risk of erosion. Long fallows should be avoided. If used, the number of workings should be minimized and the surface left rough.

Other techniques, not widely used in South Australia, include strip cropping (blocks of crop on the contour separated by strips of uncultivated land), and strip tillage in row crops (cultivating the planting lines only).

*Rotations*

Well managed pasture phases in the cropping rotation reduce the long term risk of erosion through reduction of soil exposure and structure improvement. Class 4-e land should not be continuously cropped.

*Timing of Operations*

The earlier a broadacre crop is sown, the sooner soil cover can be achieved and the less the chances of erosion. For summer growing vegetable crops, delayed working and planting in spring reduces erosion risk, but following harvest, the sooner the land is sown back to pasture the better.

*Structures*

On Class 3-e land earthworks are usually required to control erosion. On broadacre cropping land contour banks and waterway systems are recommended. On vegetable growing land grade furrows are used in conjunction with waterway systems.

Diversion banks to control run-on water from uphill are effective in protecting cropping land.

*Grading contour banks*

Management of land under perennial horticulture

On Land Classes 3-e to 5-e, a permanent sod should be maintained. On Classes 4-e and 5-e land, specialized establishment techniques are needed. These include the use of grade furrows, strip tillage and sowing of cover crops. Mounding is not recommended because of the extensive soil disturbance. On Class 5-e land, two-year replanting programs are desirable so that only a section of hillside is disturbed at any one time.

Management of grazing land

Maintenance of adequate ground cover through control of stocking rates and fertility levels is essential. Tillage for pasture establishment and renovation should be reduced on Class 3-e land, and direct drilling is recommended on land Classes 4-e and 5-e.

Fences, gates and watering points must be located so that the risk of erosion from stock camps and trails is minimized.

On Class 6-e land, grazing pressure should never be more than light if cover is to be maintained. Aerial seeding, spraying and fertiliser spreading may be possible. Grazing of Class 7-e land should be avoided as far as possible, as maintenance of perennial vegetative cover is essential.

# 14 WIND EROSION POTENTIAL

This section deals with the inherent potential of land to erode under the action of wind, as determined by the soil, topography and climate. It does not deal with the susceptibility of land to erosion as a result of particular land use or management practices.

## Processes of wind erosion

Land is susceptible to wind erosion when vegetative protection is low and when soil particles are light enough to be moved by the wind. Soil can be moved by wind in three ways.

| | |
|---|---|
| *Surface creep* | soil particles larger than 0.5 mm are too heavy to be lifted, and roll along the surface. |
| *Saltation* | particles of intermediate size (0.05 to 0.5 mm) are too heavy to be carried any great distance, but are lifted and bounce across the surface. |
| *Suspension* | fine particles (smaller than 0.05 mm) are light enough to be lifted and are carried significant distances as dust. |

Wind erosion takes two main forms: sweeping and active drift.

Sweeping drift involves the more or less uniform removal of topsoil with significant amounts of soil going into suspension.

Active drift involves substantial movement of both sand and clay size particles through a combination of all three processes, resulting in blowouts and drift banks.

## Factors affecting wind erosion potential

Topography

Erosion potential increases with increased wind velocity and greater turbulence. These wind characteristics are influenced by topography.

Sandhills are high points in a landscape of usually low relief and are especially vulnerable. Jumbled (irregular) and crescent shaped sandhills are geologically younger and less stable than linear sandhills and are more susceptible to erosion.

Turbulence or high velocity winds are often caused by topographic features which are difficult to identify without local knowledge. However other features such as high slopes facing the prevailing winds and broad plains without much tree cover or other windbreaks are usually vulnerable due to their exposure.

Soil

A soil's erodibility (susceptibility to erosion) by wind is determined mainly by the mass of the soil particles. Finer-grained soils are therefore the most vulnerable. However the individual particles in soils with more than 10 to 20% clay are usually aggregated into larger particles and so are more resistant. Similarly coarse sands and grit are resistant due to their particle mass. It is the low-clay-content fine-to-medium sands which have the highest erodibility because of their low particle masses and low potential for aggregation into larger particles.

The stability of aggregated particles is crucial, and farming practices, such as excessive cultivation, fast working speeds and over-grazing, which destroy aggregation, increase susceptibility to wind erosion. A calcareous soil is less aggregated and has lower strength than a similarly textured non calcareous soil, and has a higher erodibility.

Water repellent sands generally have higher erodibility than non-repellent sands because of the lack of clay or carbonate bonding between the grains. Very infertile soils also have increased erodibility because they are less likely to have organically stabilised surfaces than more fertile soils (a result of their low productive potential).

Degraded soils, such as those with depleted organic matter or which have been affected by drift are more prone to wind erosion.

Surface stones reduce wind velocity and trap moving particles. They assist in reducing erosion.

Rainfall

The lower the annual rainfall the higher is the potential for wind erosion because there is less chance of adequate protective vegetative cover, either as crop stubbles or pasture residues. The most serious wind erosion occurs during droughts, common in South Australia's marginal agricultural areas.

Wind

Wind velocity, direction, duration and seasonal occurrences contribute to its capacity to cause erosion, or its "erosivity". Strong winds during the sensitive early autumn to early winter period have the potential to cause most damage.

### Consequences of wind erosion

On-site effects

Sweeping drift causes enormous losses of the nutrients and organic matter concentrated in the top few centimetres of soil. Loss of this most valuable part of the soil makes the land less productive and therefore even more susceptible to erosion.

Sand blasting by sweeping drift can severely damage young plants as airborne sand particles abrade tender emerging leaves.

During active drift, soil is eroded (often from sandhills and sand spreads), and redeposited nearby. This can cause serious gouging of sandhills, and burial of adjacent crops and fences. Rehabilitation is difficult and expensive.

*Severe crop damage resulting from active drift*

Off-site effects

Active drift often results in sand banks along fence lines and across roads and railways. Sand removal and refencing are expensive.

Dust storms commonly occur during droughts and in the summer and autumn when there is maximum bare soil exposure. Suspended soil particles can travel for hundreds, even thousands of kilometres. Duststorms cause widespread inconvenience, and pose a danger to traffic. Airborne dust may also be responsible for excessive machinery wear.

### Assessing wind erosion potential

Rainfall

To assess the climatic component of wind erosion potential, the agricultural districts are divided into four zones, according to average annual rainfall. The zones are:

- Low rainfall — Less than 350 mm
- Moderately low rainfall — 350 mm to 450 mm
- Medium rainfall — 450 mm to 600 mm
- High rainfall — More than 600 mm

For a given soil and topographic situation, the wind erosion potential increases as rainfall decreases.

Wind characteristics

There is insufficient wind data across South Australia to identify wind erosivity zones. Strong winds are likely in all districts and none are immune from wind erosion. Precautionary management practices are necessary on all susceptible land throughout the state.

Soil

Three categories of soil erodibility are defined, based on surface texture and coherence. For sandhill soils the depth of sand over a more clayey subsoil or carbonate layer is important when determining erosion potential. These criteria are specified in Table 47.

Table 47 Soil erodibility categories (wind)

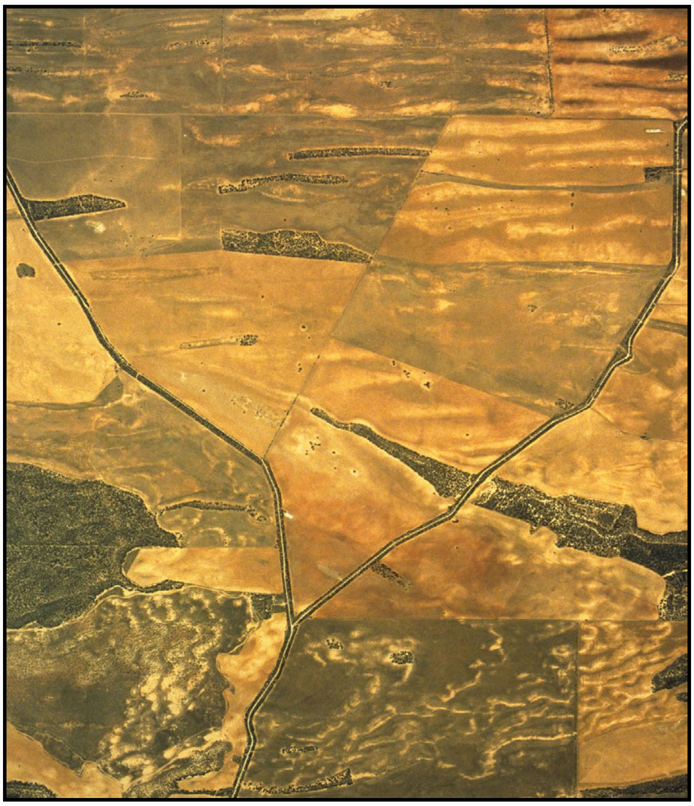
| Surface texture | Dry coherence | Erodibility |
|---|---|---|
| Sand to loamy sand | Loose | High |
| Loamy sand, sandy loam, light sandy clay loam | Weakly coherent | Moderate |
| Sandy loam, light sandy clay loam | Firm to hard | Low |
| Loam and finer | Any | Low |

## Topography

Topographic features in landscapes prone to wind erosion are flats, rises and sandhills, with subdivision of sandhills according to shape and height.

Table 48 Topographic categories in landscapes prone to wind erosion

| Feature | Height | Category |
|---|---|---|
| Flats | - | Flats |
| Rises | - | Rises |
| Linear sandhills | Less than 5 m<br>5-10 m<br>>10 m | Low linear sandhills<br>Moderate linear sandhills<br>High linear sandhills |
| Irregular (jumbled or parabolic) sandhills | Less than 5 m<br>5-10 m<br>>10 m | Low irregular sandhills<br>Moderate irregular sandhills<br>High irregular sandhills |



*Aerial view of linear (top) and jumbled (bottom) sandhills*

## Classification of land according to wind erosion potential

Land is classified with respect to wind erosion potential according to rainfall zone, soil erodibility, depth of sand over a more clayey or carbonate layer, and sandhill height and shape. Several other features, not included in the classification table, must be considered. Land which is infertile, has calcareous soils, is water repellent or has a high exposure to wind is more prone to erosion, and surface stones reduce the potential. These features should be noted when making assessments.

The classification criteria are set out in Table 49. This is a preliminary attempt to develop an objective assessment of wind erosion potential and should be treated only as a guide.

Table 49 Classification criteria for wind erosion potential

| *Rainfall Zone: 250-350 mm annual average* | | | |
|---|---|---|---|
| **Soil erodibility** | **Depth of sand** | **Topography** | **Land Class** |
| Low | - | Flats, rises | 1-a |
| Moderate | - | Flats, rises | 2-a |
| High | < 30 cm | Flats, rises | 3-a |
| High | 30 - 80 cm | Flats, rises | 4-a |
| High | > 80 cm | Low sandhills | 4-a |
| High | Any | Moderate sandhills | 5-a |
| High | Any | High sandhills | 7-a |
| *Rainfall Zone: 350-450 mm annual average* | | | |
| **Soil erodibility** | **Depth of sand** | **Topography** | **Land Class** |
| Low, moderate | - | Flats, rises | 1-a |
| High | < 30 cm | Flats, rises | 2-a |
| High | 30 - 80 cm | Flats, rises | 3-a |
| High | >80 cm | Flats, rises | 4-a |
| High | Any | Low sandhills | 4-a |
| High | Any | Low linear sandhills | 5-a |
| High | Any | Irregular sandhills | 7-a |
| *Rainfall Zone: 450-600 mm annual average* | | | |
| **Soil erodibility** | **Depth of sand** | **Topography** | **Land Class** |
| Low, moderate | - | Flats, rises | 1-a |
| High | < 80 cm | Flats, rises | 2-a |
| High | >80 cm | Flats, rises | 3-a |
| High | Any | Low, moderate sandhills | 4-a |
| High | Any | High linear sandhills | 5-a |
| High | Any | Irregular sandhills | 7-a |
| *Rainfall Zone: More than 600 mm annual average* | | | |
| **Soil erodibility** | **Depth of sand** | **Topography** | **Land Class** |
| Low, moderate | - | Flats, rises | 1-a |
| High | < 80 cm | Flats, rises | 2-a |
| High | >80 cm | Flats, rises | 3-a |
| High | Any | Linear sandhills | 4-a |
| High | Any | Irregular sandhills | 5-a |

*Class 2-a sandy flats with Class 5-a sandhill in the background*

*Cropping paddock with Class 4-a sandhill in the foreground, Class 2-a flat in the middle ground, and Class 3-a sandhill in the background*

**Management of land prone to wind erosion**

Management practices to control wind erosion aim to maintain adequate vegetative cover throughout the season. Some management guidelines for the broad land use categories are:

Broadacre cropping

For Land Classes 2-a and 3-a, erosion is controlled by modifications to tillage practices, more careful soil management and more appropriate rotations. Class 3-a land needs more intensive management than Class 2-a land. Recommended practices include:

- reduction in tillage and retention of residues.
- inclusion of improved pasture leys into rotations.
- use of break crops to control root diseases.
- early sowing.
- judicious use of grain legumes.
- reduction of cultivated fallows.

For Land Class 4-a:

> The early establishment of specialized crops such as cereal rye, with close attention to nutrition and to disease control and subsequent oversowing with appropriate pasture species is recommended.

Land class 5-a should not be cropped.

*Actively eroding Class 4-a sandhill*

*Stabilised sandhill*

Irrigated vegetables

For Land Classes 2-a to 4-a, these techniques are useful in controlling erosion, with more intensive management needed on Land Classes 3-a and 4-a:

- reduction in tillage and retention of residues.
- use of inter crops and nurse crops for cover and sand blast control.
- frequent irrigation.
- reduction in cropping frequency.
- quick establishment of a pasture or crop following harvest.

Land Class 5-a should not be cropped.

Perennial horticulture

Maintenance of vegetative cover between rows is sufficient for erosion control on all classes of land up to 7-a, which has a very low capability for horticulture.

Grazing

Control of stocking pressure to avoid baring off, maintenance of pasture vigour and control of rabbits are the main erosion control strategies on grazing land. This may require some fencing of highly susceptible areas such as the tops of sandhills where stock tend to camp. The land around gates and watering points is also susceptible to baring off because of livestock pressure so these should be put where the potential for erosion is least.

Direct drilling for pasture establishment and renovation is desirable on Land Classes 3-a to 5-a.

Much Class 5-a land in the lower rainfall districts is fragile with low productive potential. Consideration should be given to revegetating these areas if rabbits can be controlled.

Class 7-a land is extremely vulnerable to erosion and existing vegetation should be protected by the exclusion of stock. Where cleared only very light grazing is possible. Rabbit control is crucial. Revegetation programs should be undertaken.

### Further reading

Leys, J.F. and Heinjus, D.R. (1991). Simulated wind erosion in the South Australian Murray Mallee. Soil Conservation Service of New South Wales.

McCord, A.K. (1975). Wind erosion. Its causes and control. Leaflet No. 4039. Department of Agriculture, South Australia.

McGufficke, A.W. (Ed.) (1989). Wind erosion and its control on the aeolian soils of south eastern Australia. Proceedings of the Inter-State Wind Erosion Workshop and Research Update, Mildura, 23-24 Sept. 1987.

# 15 MASS EROSION

Mass erosion is a term used to describe gullies, landslips, tunnels and stream-bank erosion where large-scale but localized soil loss and damage has occurred. Not only does this indicate the need for intensive and specialized management, it also indicates which types of country are susceptible and therefore need preventative management strategies.

## Factors influencing mass erosion

Gullies

A gully is a recent erosion channel more than 30 cm deep that transmits intermittent water flow. Gullies may have their origins in natural watercourses or in artificial channels. Artificial depressions as small as wheel tracks or cultivation furrows have the potential to develop into gullies if sufficient water is concentrated into them.

Unchecked scouring of rills can rapidly lead to small gullies which extend higher up the slope by waterfall action. The obstruction of a watercourse, for example by a road, can exacerbate this by increasing flow energy and turbulence. This leads to greater damage downstream. As lateral watercourses enter gullies from upslope, branching gullies develop and the process repeats for each branch.

*Erosion gully*

Watercourses subject to gullying commonly consist of three sections:

- the headwaters section, usually in hilly country with slopes steeper than 10%, where a number of small drainage channels converge to form a larger creek.
- the midstream section, where the watercourse, contained in a well defined channel, crosses a gently sloping (2-10%) outwash fan.
- the downstream section, where the flow dissipates and silt deposition occurs.

All headwaters and midstream sections of watercourses should be considered susceptible to gullying, the potential being greatest where soils are unstable and catchment areas large.

Gullies eventually stabilize naturally when:

- the area of contributing catchment becomes too small; or
- resistant strata such as bedrock are reached; or
- the sides and floor have sufficient time to develop a protective vegetative cover; or
- the gradient of the gully floor flattens to a point where stream flow is no longer erosive.

The extent and severity of gullies depend on the area of catchment feeding them, the slope, soil characteristics and rainfall intensity. Soils with low strength are most susceptible. Surface rills are most likely to occur in soils with high erodibilities (refer to Section 13, Water Erosion Potential). As the rill deepens, the subsoil has a greater effect on gully development. Low coherence sands and silts, and highly aggregated and therefore easily detachable clays are most susceptible. Sodic or dispersive soils disintegrate rapidly under the action of water; gullies in these materials are highly unstable and characterized by fluting of their sidewalls. Massive, non dispersive clayey soils are less susceptible to entrainment by flowing water.

Stream bank erosion

Stream bank erosion is the accelerated collapse of stream banks resulting from loss of stabilising vegetation, damage by livestock and feral animals or increased water flow. The process usually involves the undercutting of destabilised banks and their subsequent collapse into the stream bed.

All watercourses are prone to bank erosion if the banks are inadequately protected. The factors which influence severity are similar to those which encourage gullying.

*Stream bank erosion*

Tunnelling

Tunnelling is a form of underground erosion which occurs on soils with unstable subsurface layers prone to wetness. Saturation causes dispersion of sodic or other unstable clay in the subsoil. Movement of this dispersed clay downhill through cracks or channels leaves voids which eventually join up forming a tunnel. Slopes with animal burrows or old tree stumps are especially susceptible, as they have a series of large subsurface cavities to assist underground flow and tunnel development. Other weakly consolidated subsurface material is also prone to tunnelling if on top of an impermeable layer. The tunnels may eventually collapse to form a system of gullies.

*Collapsed erosion tunnels*

Hillside mass movement

Hillside mass movement (landslip or earthflow) occurs when sufficient saturation of hill slope soil occurs that large slabs of earth, unable to support their own weight, slide downhill. Deep rooted natural vegetation usually provides sufficient anchoring and water use to prevent mass movement. A wet winter after clearing may provide the trigger for slippage on a susceptible slope. An accumulation of subsurface water, often associated with a spring, creates or exacerbates a zone of weakness in the soil or rock and that is usually where slumping begins.

*Landslip*

Slope is clearly a critical factor influencing mass movement, but some landscapes are more susceptible than others. Three geological/soil associations appear to be prone to damage in the agricultural districts of South Australia:

- soils on unconsolidated and slowly permeable substrate materials. The clays of the old glacial valleys of Fleurieu Peninsula are in this category. Susceptible soils include deep clays and sand to sandy loam over clay types on slopes as low as 12%.

- soils on sodic shales and quartzites. The Tapley Hill, Brachina and ABC Range Formations appear to be most susceptible. Mass movement of loam over clay soils on these formations is common in the Barunga Range and the Willunga Escarpment.

- soils on strongly laminated shaly bedrock. On slopes where the laminations in the rock are parallel to the ground surface, lubrication of these planes of weakness by water can cause slippage of the overlying soil. Occurrences are widely distributed, although not common, on slopes steeper than 20% in the Mount Lofty Ranges.

### Consequences of mass erosion.

Land affected by mass erosion is very fragile, has little if any productive value, and stabilisation often requires substantial time, money and effort. Once stabilised, these features affect paddock shape and access, and need protection to prevent renewed erosion.

Fences, tracks, bridges and other utilities can be damaged by mass erosion, and silting and water pollution often occur downstream. In addition, the problem areas are unsightly and lower land values.

### Assessment and classification of mass erosion

There are two levels of classification dependent on the scale of assessment.

For broad scale assessments, classification of eroded landscapes, rather than individual features, is the only option. This is because the small scale of assessment does not allow identification of individual gullies, landslips and so on. Usually there is a large percentage of unaffected land within an eroded landscape, the damaged areas being narrow watercourses and small sections of slopes. This land should be classified by its other attributes, noting the nature of the erosion and the proportion of affected land.

At the local or property level, classification is easier because of the larger scale of assessment. Individual gullies, mass movements, tunnelled areas and eroding stream banks can be delineated.

Assessment can relate to existing and to potential erosion. Except for recently developed areas much susceptible land has already been conspicuously affected by mass erosion, and this is the most reliable indicator of the susceptibility of similar land. However the likelihood of mass erosion on previously unaffected land should be assessed, particularly if a change in land use is anticipated.

Gullying

Individual gullies are assessed according to their degree of development, and degree of stabilization, as set out in Tables 50a and 50b (after McDonald et al 1990).

Table 50a Gully development categories

| | |
|---|---|
| None | Water courses are either absent or uneroded |
| Minor | Gullies are isolated, linear and discontinuous |
| Moderate | Gullies are linear and continuous. |
| Severe | Gullies are continuous or discontinuous and either tend to branch away from primary drainage lines and on to footslopes, or have multiple branches within primary drainage lines. |

Table 50b Gully stabilisation categories

| | |
|---|---|
| Stable | No evidence of recent erosion, sides are at a stable angle of repose and the floor and sides are vegetated. |
| Semi stable | Up to 10% of the gully is subject to erosion because of inadequate vegetative cover. |
| Unstable | More than 10% of the gully is subject to erosion because steep walls are likely to slump and/or because of inadequate vegetative cover. |

At the broadscale level where individual gullies cannot usually be assessed, land is classified according to the proportion affected by eroded water courses. For larger scale assessments, individual water courses can be classified - Table 51.

Table 51 Classification criteria for land affected by gully erosion

| **Landscapes - Extent of erosion** | **Land Class** |
|---|---|
| Nil | 1-g |
| <5% of land affected | 2-g |
| 5-10% of land affected | 3-g |
| 10-20% of land affected (semi-arable) | 4-g |
| >20% of land affected | 7-g |
| **Individual water courses - gully stability** | **Land Class** |
| Stable | 5x - g |
| Unstable / eroding | 7x - g |

*Class 7-g land*

Stream bank erosion

The simplest way to assess stream bank erosion is to record the length and location of collapsing or eroding banks. Eroding stream banks are classified 7x - g and stable stream banks are classified 5x - g (as indicated in table 51).

Tunnelling

There is little information on prediction of tunnel erosion. Soils with dispersive or sodic subsoils are highly susceptible. Tunnels are more likely to develop on steeper slopes, so the classification criteria (Table 52) are based on dispersiveness and slope gradient.

Table 52 Classification criteria for tunnel erosion susceptibility

| Soil | Slope | Land Class |
|---|---|---|
| Non dispersive | Any | 1-gt |
| Dispersive | 0-2% | 1-gt |
| Dispersive | 2-5% | 2-gt |
| Dispersive | 5-10% | 3-gt |
| Dispersive | 10-20% | 4-gt |
| Dispersive | > 20% | 5-gt |
| Existing tunnel erosion | | 7-gt |

Hillside mass movement

Observations of land affected by hillside mass movement can give an indication of the susceptibility of unaffected land. The following land types should be considered susceptible:

- Slopes steeper than 12%, where substrate has low strength, is prone to waterlogging, and extends below 200 cm. Typical materials are unconsolidated sedimentary clays and poorly drained sands. Weathering rock and saprolite are generally not included in this category.
- Slopes steeper than 20% with shaley or quartzitic rocks giving rise to dispersive soils.
- Slopes steeper than 20% where strongly laminated rocks dip parallel to the ground surface. This category includes partly weathered rock and saprolite.
- All slopes steeper than 30%.

Table 53 Classification criteria for land affected or potentially affected by mass movement (landslip)

| Extent or potential | Land Class |
|---|---|
| Nil, and no potential | 1-l |
| Nil, but with potential | 4-l |
| Up to 5% of land affected | 5-l |
| >5% of land affected | 7-l |

*Class 5-l land*

**Management of land affected by mass erosion**

Stabilisation, principally through the maintenance of vigorous vegetative cover and the establishment of perennial vegetation is necessary for land affected by, or subject to, mass erosion. This generally requires fencing to exclude livestock and feral animals.

Stable banks of watercourses must be protected by permanent cover, and cultivation should be avoided. In the headwaters sections of drainage systems grazing management and protection of watercourses is crucial to minimize the impact on lower sections of the system. Absorption banks can be installed to help control water flow in these areas.

Other engineering options are often useful. Gully head control dams, water diversion banks, fabricated chutes, weirs, gabions, bank battering and stabilization mats can all be used to help gully control, and can sometimes also be used on eroding banks.

Drains on and/or below the surface can also give some control of existing or possible mass movement.

## 16 ROCKINESS

There are two components to rockiness as a landscape feature.

Surface rocks and stones include loose fragments on the surface varying in size from a few centimetres to more than a metre.

Rock outcrops which are above ground extensions of the subsurface rock mass.

In hilly districts surface stones are usually from the underlying basement rock and represent fragments or strata which have resisted weathering and are exposed on the surface. Common rock types are quartzites, sandstones, siltstones, schists and granites - the main materials of basement rock formations. Hilly land with surface stone generally has hard rock within a few metres (often less than one metre) of the surface. Where rocks are highly resistant, outcrops are common. Ironstone, which is usually associated with old, deeply weathered soils, is widespread in high rainfall hilly country, plateaux and the surrounding plains. Silcrete is another type of rock which is formed from soil materials (sandy soils or other types high in silica). Silcrete forms when silica dissolves and recrystallizes to an extremely hard cap over soils, sediments or basement rock.

Surface fragments of basement rock on plains have usually been transported by water from surrounding hills. Only on plains in the more arid areas does hard rock commonly underlie the soil and contribute to surface stone.

*Outcropping basement rock and surface stone*

*Silcrete*

In the mallee districts calcrete is the dominant rock type. This is hardened soil material composed mainly of calcium and magnesium carbonates with variable amounts of sand grains. Calcrete forms when fine grained windblown carbonates, deposited in thick sheets over the landscape, harden - a result of long term seasonal wetting and drying. This process can result in the formation of discrete nodules or concretions, or in sheet rock which can subsequently break up to produce calcrete fragments. Calcrete may also form as a cap on limestone through a process of dissolution and recrystallisation.

*Calcrete*

### Effects of rocks and stones

Surface rocks and stones can interfere with cultivation, damage machinery, abrade tines, spark fires and in extreme cases can reduce the area of soil for plant growth and endanger livestock.

The amount, distribution and hardness of rocks and stones are important. Small (less than 100 mm) and relatively soft stones (such as calcrete) are less of a problem for cultivation and abrasion than larger or harder ones. In South Australia ironstone and quartz are probably the most abrasive of the commonly occurring stone types.

Some land uses are more affected by stoniness than others. Even small amounts of stone make land unsuitable for root crops, and for land uses which involve mowing, stones can cause equipment damage, fire and injury.

Rocks and stones in the soil profile decrease the effective water holding capacity of the soil.

Rock outcrops which are clustered in reefs or on knolls are easier to work around than those which are uniformly distributed across the land. Where rock outcrops become too dense, the land is effectively non arable. The cut-off point between arable and non arable rocky land is a matter of practicality with regard to machinery access and wear and tear.

### Assessing rockiness and stoniness

- record the amount as a percentage of ground surface coverage.
- record the average diameter of the one or two most prevalent size categories.
- note whether the stones can be easily broken with a hammer - if so, crushing these with a roller may be feasible.
- describe the proportion and evenness of distribution of rock outcrop.
- record the abundance and size of rocks in the soil profile.

The assessment should help decide whether or not:

- the land is potentially arable;
- stone picking is required to allow vehicle access and cultivation and minimise interference and / or damage to machinery;
- rolling is sufficient; or
- no special management is required.

## Classification and management of rocky or stony land

Because of the many combinations of ground coverage and rock sizes, distribution and types of surface stone and rock outcrop, it is impractical to classify land on such a basis. All these factors must be considered to judge the land use potential and management requirements. Criteria for classifying land according to rockiness are set out in Table 54.

Table 54 Classification criteria for surface rockiness

| Degree of Rockiness or Stoniness | Land Class |
|---|---|
| No outcrop. Nil to minor surface stone. | 1-r |
| Sufficient stones or rocks to interfere with tillage, but picking or rolling is not necessary for most uses. | 2-r |
| Sufficient stones to necessitate picking or rolling for cultivation. Less than 10% rock outcrop, concentrated in reefs. | 3-r |
| Between 10% to 50% rock outcrop concentrated in reefs, allowing cultivation in between. | 4-r |
| Too stony or rocky for cropping, but some pasture improvement possible, using standard equipment. | 5-r |
| Too rocky for machinery access. | 6-r |
| Rock pavements and rock faces. | 8-r |

Some rocky land (Class 6-r) is inaccessible to machinery and has a low productive potential, while some (Class 5-r) is non arable but has potential for pasture improvement. Cropping on Class 4-r land involves a significant proportion of the land being unused at the time and poses problems for installation of erosion control structures in sloping paddocks.

Class 3-r land is arable but stone picking and/or rolling is required. Some costs associated with implement damage and inconvenience may have to be borne on all land other than Class 1-r.

*Class 3-r land*

*Class 4-r land*

*Class 5-r land*

*Class 6-r land*

# 17 EXPOSURE

Exposure of land to wind and to some extent to the sun on west facing slopes can significantly reduce productivity. Assessment of exposure is highly subjective, and is designed to do no more than signal that it is a factor to consider in certain situations.

## Factors affecting exposure

For the purposes of this classification, only topographic position and proximity to the coast are used to categorize exposure. Exposure is very much governed by local topography and direction of prevailing winds. The distance of uninterrupted wind flow, and wind run (combination of velocity and duration) are the key factors. Elevated land, unprotected by nearby higher land, is at greatest risk, all other factors being equal.

## Consequences of exposure

Exposure to wind can retard growth through desiccation, growing tip bruising or removal, bud damage or loss, reduced grain or fruit set and disturbance of near surface roots. In coastal areas, these problems are exacerbated because the wind carries salt picked up from the ocean surface. Exposure to excessive sun causes desiccation and leaf and fruit scorch.

Exposed land is at greater risk of erosion, both due to the higher incident wind energy, and the greater chance of soil exposure due to reduced productivity.

## Assessment of exposure

Exposure is simply assessed for the purposes of this classification by judging whether or not the land is unprotected by nearby high ground. This land includes the following exposure types:

High exposure

- Land within 5km of the coast and with direct line of sight to the sea.

Moderate exposure

- Plateaux or summit surfaces of higher elevation than the surrounding terrain.
- Hillslopes adjacent to extensive lower lying land (eg escarpments bordering plains).
- Upper slopes projecting above neighbouring hills.
- Moderate to high sandhills.

Low exposure

- Land other than above.

## Classification of exposure

Land is classified into three categories which distinguish highly exposed inland and coastal land from land with low levels of exposure.

Table 55 Classification criteria for exposure

| Exposure type | Land Class |
|---|---|
| Low | 1-y |
| Moderate (plateaux, escarpments, upper slopes, moderate to high sandhills) | 2-y |
| High (coastal) | 3-y |

## Management of exposed land

There is little that can be done to protect crops and pastures from the effects of exposure other than to avoid the worst areas. Windbreaks may provide some protection, but effects are usually localized. More elaborate structures and plantings can be used to protect high value crops, but avoidance is preferable.

Protection of livestock is a more important issue. Wind breaks can play an important role, as can removal of stock from exposed areas during extreme weather conditions, such as very hot or very cold winds, sleet and so on.

*Class 2-y land*

*Class 3-y land*

# 18 FLOODING

Susceptibility to flooding imposes a serious limitation on land where structures are required. However, for some uses, floods can be beneficial, provided that energy and duration are low. Assessment of susceptibility to flooding is subjective in that generally flooding will not be observed during routine field investigations. A positive rating for flooding susceptibility simply signals that there is a potential risk.

## Factors affecting flooding

Flooding occurs on relatively flat land where water collects on the ground surface at a greater rate than that at which it is either absorbed or runs off. Flooding can also occur on sloping land, usually drainage depressions, as a result of over-bank flow. Although this form of flooding can be damaging to both the stream environment and adjacent structures and crops, it is generally short-lived in South Australia.

Inundation type flooding is more common. Usually, but not always, water concentrates by overland flow or sub-surface flow in depressions or on plains. The size of the catchment, the runoff coefficient of the catchment and the absorption characteristics of the soil of the low lying land are all important contributing factors. The amount and intensity of rainfall, and the antecedent moisture content of the soil affect the degree and duration of flooding. Frequency of flooding is a function of all of the above, as well as long term weather patterns.

*Flooded land*

## Consequences of flooding

Apart from the obvious damage to buildings and other infra-structure, and the danger to livestock, flooding has some specific impacts on soils, crops and pastures. Flash flooding with high energy is potentially disastrous from a soil erosion and plant damage point of view. Steam bank erosion and sheet, rill and gully erosion adjacent to streams can occur. Plants can be uprooted, buried or suffer foliar damage.

Inundation flooding is less of a soil erosion problem, although if inundation originates from high energy water movement, sediment carried by the incoming waters will settle out, and siltation is a potential problem. Inundation is unlikely to cause physical damage to plants, apart from siltation effects. However, plants sensitive to waterlogging will be affected, so the degree of damage is related to the duration of inundation. Weed seed dispersal is a further problem commonly associated with flooding.

Positive aspects of flooding include boosting the water reserves of the soil profile, laying sediment (often nutrient rich) on the surface, and flushing salts from the soil.

## Assessment of flooding susceptibility

Ideally, flooding susceptibility should be assessed in terms of type (ie flash flood or inundation), frequency (ie how many floods per year, decade etc), and duration. In broadscale mapping, collecting this data through observation and landholder / local government surveys would represent an enormous task, and for many areas, the information would be unreliable. Alternatively, a modelling approach could be used. This is feasible using digital elevation models, climatic records and soils data, but is beyond the scope of this assessment procedure.

The most appropriate compromise is to rank land as either susceptible to flooding or not, based on a combination of observation and inference.

Observation includes evidence of past flooding such as debris, silt deposits and water marks, as well as verbal or written evidence from landholders local government staff or media reports.

Inference entails a judgement about the likelihood of flooding as indicated by the nature of the terrain and soils, proximity to and size of water courses, and to some extent, knowledge of the rainfall patterns of the district. As this approach is highly subjective, conclusions drawn should only be used to indicate flooding risk in general terms; decisions involving some specific action on the ground should under no circumstances be based on data collected in this way.

### Classification of flooding susceptibility

Land is classified into two categories, as discussed above.

Table 56 Classification criteria for susceptibility to flooding

Land is classified according to whether or not there is a risk of flooding. No frequency, duration, type or severity rankings are attempted.

| Susceptibility to flooding | Land Class |
|---|---|
| No | 1-f |
| Yes | 2-f |

### Management of land susceptible to flooding

Flooding in South Australia is very much an episodic event, and may only occur once every hundred years or so. Runoff control in catchments is the fundamental management approach, but even the best practices will not be able to control major events. Improving soil infiltration, maintaining high levels of plant and residue cover on the surface, slowing water flow with engineered structures all contribute to reducing the risk of downstream flooding.

Flood mitigation measures are also used, usually to protect structures. These include flood control dams, diversions, levees and other major engineered works.

Where these protective measures are not feasible (technically or economically), damage minimization is the fall-back management tool. Installation and erection of structures, and establishment of crops which could be damaged by floods should be avoided on susceptible land.

# 19 POTENTIAL ROOT ZONE DEPTH
**(with emphasis on irrigated crops)**

In a soil with no physical or chemical limitations, the potential root zone depth corresponds to the depth of wetting of the soil by rainfall, irrigation or groundwater. In reality, most soils have a barrier of some sort which restricts optimal root growth. These barriers are particularly important in irrigated soils, as they determine the amount and frequency of irrigation water applications. In dryland situations, roots of healthy crop and pasture plants will proliferate to the extent necessary to supply their water requirements. Depending on the type of plant and seasonal conditions, the zone of exploitation may include the entire wetted profile, or at least that part unaffected by physical or chemical barriers. Commonly, some root growth occurs in unfavourable conditions, especially in dry seasons when plants become moisture stressed. However, the aim of irrigation is to maintain the plant in a stress-free condition by ensuring that the potential root zone of the particular crop contains readily available moisture. Knowledge of the potential root zone of specific crops is crucial to ensure that a) sufficient water is applied to enable the crop to achieve optimum potential, and b) excessive water is not applied which may cause water tables to develop, salt to accumulate, or which may simply be wasted to deep drainage or seepage.

## Factors affecting the depth of the potential root zone

There is a range of physical and chemical factors which restrict potential root zone depth. Critical values for each factor vary between crop types (eg grape vines are more tolerant of a range of adverse physical and chemical conditions than citrus). The following discussion is generalized; detailed discussion of the particular tolerances of individual crop types is beyond the scope of this document.

Poor subsoil structure

Except for shallow soils, most soils in South Australia have subsoils which are substantially different from their surfaces. Some subsoils (eg loose sands or crumbly clay loams) do not limit root growth, while others (eg hard dispersive clays) are highly restrictive. A characteristic feature of many South Australian agricultural soils is “texture contrast”. This is where there is a clear break between a sandy or loamy surface soil layer and a significantly more clayey subsoil. The depth to this break is usually between 10 and 50 cm. The structure of the subsoil affects water movement and root growth.

*Restrictive clay layer*

*Non restrictive clay layer*

Poorly structured subsoils have high bulk density, low porosity and are often dispersive. This causes water to “perch” on top of the clay for extended periods, resulting in waterlogging. Where the clay layer is within 20 to 40 cm of the soil surface (depending on the crop type), the root zone depth is insufficient to sustain irrigated horticulture. Waterlogging can also affect plant growth in non-irrigated soils, especially in higher rainfall areas where the problem may persist for a week or so to several months in extreme cases. Low root densities in restrictive clays are commonplace. During the warmer spring months, water cannot move quickly enough through the clay to meet the demands of the plant, so productivity suffers, and unused water often remains in the subsoil at the end of the growing season.

Hard basement rock and calcrete

In the hilly districts of South Australia, soils are formed on underlying basement rocks. Some rock types such as siltstones, shales and phyllites are often significantly weathered and soft, so plant roots can find their way between plates or lumps of rock to access moisture. In fact in some shallow soils forming in weathering rock, there is more water stored in the decomposing rock than in the soil itself. However, harder rocks such as quartzite, sandstone, granite and ironstone do not allow much root penetration. Hard rock within 50cm affects productivity and management of perennial crops, and for deeper rooted species, hard rock as deep as 100cm has an effect.

Calcrete is another type of hard rock common in South Australia. Unlike basement rock, calcrete is a cap rock, usually overlying softer sediments. This is particularly significant for native vegetation, the roots of which can access deep subsoil moisture if they can find their way through cracks in the calcrete. However, as the underlying sediments are often either sodic and highly calcareous materials, or tight heavy clays, there are limited opportunities for agricultural plants to take advantage of the deeper subsoil moisture reserves. Consequently, the calcrete layer marks the extent of the root zone. Where the calcrete is shallower than 20 cm, irrigation is not a practical proposition. However, in the South East and near coastal areas elsewhere in South Australia, especially on rises, the calcrete overlies softer calcareous sands of old coastal dunes. These sands are not chemically hostile, so some root growth can occur. Ripping to break up the calcrete is common practice prior to establishment of vines and other high value crops or pastures.

Apart from plant growth considerations, shallow hard rock causes significant problems for erection of trellises and other structures and installation of underground services (eg pipelines and drains).

*Weathering basement rock in potential root zone*

*Calcrete restricting root zone*

Salt and boron

Excessive levels of soluble salt and boron in the soil retard or prevent plant growth. Soluble salts may occur naturally in the soil, may be brought in by rising saline ground water tables or may accumulate under irrigation with saline water. The effects of salinity and the tolerances of various species are discussed in Section 12. Boron toxicity is discussed in Section 9. Horticultural crops in general are far more sensitive to both soluble salts and to boron than field crops. Rootzone depths of most horticultural crops are restricted by soil ECe levels in excess of 4 dS/m, and by $CaCl_2$ extractable boron levels of more than 3-5 mg/kg (or less for some crops).

pH

Root growth of most agricultural plants is severely restricted by high pH ($pH_{water}$ >9.2). This is due at least in part to the very low availability of some nutrient elements at extreme pH levels. Subsoil pH levels in many soils of the lower rainfall districts of South Australia commonly exceed this value. These subsoils are typically very highly calcareous, strongly sodic and have high concentrations of bicarbonates and carbonates of sodium. It is the latter which cause very high pH levels. Horticultural plants generally have a lower tolerance of high pH than field crops. $pH_{water}$ values as low as 8.5 affect many horticultural crops. However, as field determined pH values (only accurate to 0.5 pH unit) are often the only available data, $pH_{water}$ >9 is used as the critical high pH for assessment of potential rootzone depth.

Low pH adversely affects plant growth through cation leaching and associated loss of fertility, inhibition of Rhizobial activity in leguminous plants and higher availability of aluminium and manganese. The effective rootzone is determined in acidic soils by the depth at which aluminium and / or manganese reach toxic levels. Refer to Section 9. As a rule of thumb, $pH_{CaCl2}$ <5 is used as the critical low pH value for determining potential rootzone depth.

Sodicity

Sodic soils are those with high levels of sodium attached to the exchange complex of the clay particles. Excessive sodium is usually associated with poor soil structure, but there is evidence that high sodicity may have adverse chemical effects as well. Toxic levels of sodicity will determine effective root zone depth, although, like boron and salinity, critical values are crop specific. For example, Neja et al (1974) suggest that exchangeable sodium percentage (ESP) of more than 25 is hazardous to grape vines, and that toxicity symptoms occur at levels of more than 13. Pearson (1960) found that ESP values of more than 10 contributed to 50% decline in productivity of citrus and deciduous fruit crops. By comparison, similar yield losses were recorded in wheat and barley at ESP levels of 30-50 and 50-60 respectively (Gupta and Abrol 1990).

Typical or indicative critical limits of the factors discussed above are summarized in Table 57.

*Class I carbonate with high pH, high boron, high ESP and moderate salinity*

*Non restrictive deep subsoil*

Table 57 Summary of factors limiting potential rootzone depth of irrigated horticultural crops

| Factor | Typical or indicative limiting condition |
|---|---|
| Poor subsoil structure | Hard clay<br>Platy sandy loam to sandy clay<br>Dispersive or highly dispersive clay<br>(refer to Section 7 for details of these categories) |
| Hard basement rock or calcrete | Can only broken by blow with a hammer |
| Soluble salt<br>(soil with no leaching capacity) | ECe > 4 dS/m |
| Boron | > 3 mg/kg (CaCl2 extractable) |
| Alkalinity | pHwater > 9 |
| Acidity | pHCaCl2 < 5 |
| Sodicity | ESP > 15 |

### Consequences of restricted potential root zone depth

The immediate effect of restricted root zone depth is on irrigation scheduling. In general, shallow root zones should have smaller but more frequent water applications, to avoid either water table development, excessive runoff, or excessive deep drainage, depending on what is restricting the root zone. Without adequate soil survey to identify shallow root zones, or if heed is not taken of recommendations from the survey, plants may suffer either from periodic moisture stress, or from alternating moisture stress and waterlogging.

The longer term effects depend on the nature of the restriction. Where hard rock is the problem, there should be no long term deterioration in soil condition or productivity, provided that drainage is adequate.

However, where poorly structured clays are restricting root zone depth, there is a risk of salt accumulation and increased sodicity in the soil with continued application of saline water. Soils which are saline prior to irrigation development may become more or less saline over time, depending on their leaching capacity. Naturally occurring dissolved salts and boron in soils which are permeable to depths of more than 2 m are generally leached out by irrigation water. However soils with root zones restricted by water table salinity, irrigation induced salinity or which are not freely draining are likely to become more saline and sodic. Effective root zone depths will reduce accordingly.

### Assessment of potential rootzone depth

Most of the factors listed above are closely linked to commonly occurring soil materials or layers (eg coarsely structured dispersive B horizons, carbonate layers etc). Because soil profile descriptions are much more widely available than laboratory analyses, it is more practical to base assessment of potential rootzone depth on specific soil materials, rather than estimates of a range of individual factors. The method used here is adapted from Wetherby (1998).

Five categories of horticultural crop are considered, as there is significant variation between species in their ability to tolerate adverse soil conditions. The categories are:

| | |
|---|---|
| A | Sensitive crops such as citrus and avocadoes |
| B | Intermediate crops such as stone fruits, pome fruits and almonds |
| C | Hardy crops such as grape vines and olives |
| D | Root crops such as potatoes, carrots and onions |
| E | Above ground annual crops such as brassicas |

Table 58 Potential root penetration depth in a range of soil materials

| Soil material * | Category * | Crop type A | Crop type B | Crop type C | Crop type D | Crop type E |
|---|---|---|---|---|---|---|
| Topsoil | S1, L1, L2, C1, | All | All | All | All | All |
| Sandy subsoil | S1 | All | All | All | All | All |
| Stony soil (>10% coarse fraction) # | - | All | All | All | 0cm | All |
| B horizon clay with moderate to strong polyhedral, angular or subangular blocky pedality | C1,C2 | 20cm | 50cm | 50cm | 20cm | 20cm |
| B horizon clay with moderate to strong columnar, prismatic or lenticular pedality (usually dispersive) | D1,D2 | 0cm | 0cm | 20cm | 0cm | 0cm |
| B horizon sandy loam to clay loam with any pedality other than columnar, prismatic, lenticular or platy | L1,L2 | All | All | All | 20cm | 20cm |
| B horizon sandy loam to clay loam with columnar, prismatic, lenticular or platy pedality | L3 | ND | ND | 70cm | 0cm | 0cm |
| Carbonate Class I | K1 | 0cm | 0cm | 20cm | 0cm | 0cm |
| Class II | K2 | 0cm | 50cm | 50cm | 0cm | 0cm |
| Class IIIA | K3A | 0cm | 0-30cm | 30-50cm | 0cm | 0cm |
| Class IIIB | K3B | 0cm | 30cm | 30+cm | 0cm | 10-20cm |
| Class IIIC | K3C | 0cm | 50cm | 50+cm | 0cm | 10-20cm |
| Weathered rock | - | ND | ND | 70cm | 0cm | 0cm |

* Soil materials and categories as summarized in Table 13.

\# Stone does not prevent root growth but is used here to account for the adverse effects of stones on the harvesting of root crops.

Potential rootzone depth is calculated for each of the five crop types using the criteria from Table 58. This depth is then allocated to a Class according to the limits set out in Table 59. Because different crop types have different root zone depth requirements, eight depth classes are defined. Note that these do not correspond with the eight generic land classes defined in Table 2 (Section 1).

Table 59 Classification criteria for potential rootzone depth

| Depth to limiting condition | Land Class * |
|---|---|
| >100 cm | 1-d |
| 80-100 cm | 2-d |
| 60-80 cm | 3-d |
| 50-60 cm | 4-d |
| 40-50 cm | 5-d |
| 30-40 cm | 6-d |
| 20-30 cm | 7-d |
| <20 cm | 8-d |

* Note that this classification is specific to irrigated crops so the eight generic land classes defined in Table 2 (Section 1) are irrelevant and do not correspond.

**Management of irrigated land with restricted rootzone depth**

Ripping of hard basement rock or calcrete may be an option prior to development in some situations. Generally however, rock which restricts root zone depth is unrippable. Where practised, there is a strong likelihood of unfavourable subsoil material being brought to the surface (note exception on calcreted calcareous sands mentioned previously).

Amelioration techniques such as ripping and deep gypsum placement to improve poorly structured subsoil clays and deep placement of lime to rectify subsoil acidity which have dubious economic benefits in dryland situations, are often feasible for high value horticultural plantings.

Choice of tolerant varieties or rootstocks is an option in some situations. Depending on the problem, plant material which has been bred to tolerate waterlogging, salinity, acidity, alkalinity, sodicity or high boron may be available.

In established plantings, the essential element is to control irrigation water applications according to the limited soil depth. This may require more complicated than usual irrigation systems to enable different watering regimes across the planting. Soil moisture monitoring is required to ensure that roots are getting sufficient, but not excessive, water. Shallow root zones reduce irrigation flexibility and greatly decrease margins for error.

Where salt build up is of concern, there may be the opportunity to supplement bore water with fresher mains or dam water to dilute salt concentrations.

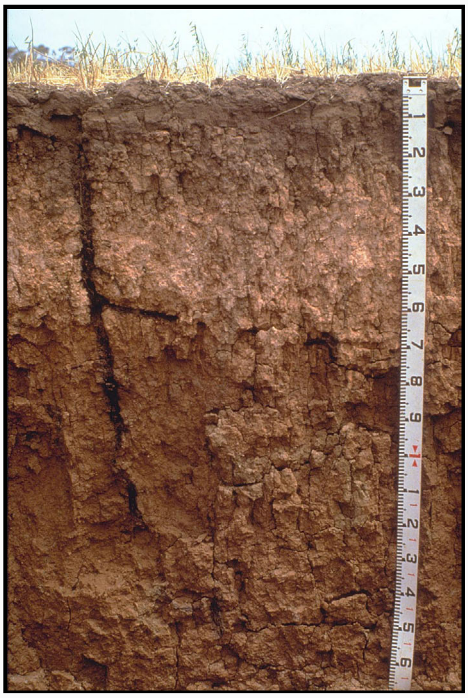
# 20 DEEP DRAINAGE

The capacity of soil and its underlying material to allow excess water to move downwards into deep sediments or fractured rock is critical on irrigated land to prevent the development of saline water tables below or in the soil.

## Impediments to deep drainage

Most soils with poorly structured subsoils within 10-50 cm of the surface have waterlogging problems at least in wet seasons. However, many South Australian soils show no signs of waterlogging or impeded water movement under rainfed conditions. This is despite a large proportion of soils in the Mallee, Northern Agricultural Districts (NAD), Eyre and Yorke Peninsulas having slowly permeable layers at depth. The simple reason that problems are not apparent, is that natural rainfall rarely penetrates deep enough to saturate them.

These layers include clayey Class I carbonate and clayey sediments underlying the carbonate. Large areas of agricultural land in the medium to low rainfall areas (excluding Central and Western Eyre Peninsula and hilly land in the NAD) are underlain by a thick layer of heavy clay locally known as Blanchetown Clay (in the Murray Basin), or Hindmarsh Clay (west of the ranges). This clay is believed to have been laid down in lake beds about a million years ago, but other theories (eg Ward 1966) suggest that it was windblown. Similar clay also occurs on rising ground where it is apparently forming from the decomposition of quartzitic basement rocks. Regardless of its origin, it is widespread and easily recognizable.



*Blanchetown clay restricting deep drainage*

Its strength and characteristic structure make identification easy. It is very hard, and invariably has a coarse angular blocky or lenticular structure comprising parallelepiped shaped aggregates with sides of 10-20 mm. Slickensides (shiny faces with striations) are usual. It is typically red in colour, but commonly has greenish grey mottles. In situations where it has been waterlogged, it is uniformly greenish grey.

Hydraulic conductivity tests indicate that once wet (ie all cracks have closed up), permeability may be as low as 5 mm / year. Hence it is an effective barrier to downward percolation of water.

Other types of deep clay layers also impede deep drainage, but not to the same degree. Unfractured basement rock or calcrete also hold water up, but generally large expanses of rock without any fissures are rare. On rises or hills where most basement rock occurs, at least some water drains away laterally downslope.

## Consequences of impeded deep drainage

The purpose of assessing deep drainage is to provide an indication of a potential problem on irrigated land.

Irrigation not only changes the hydrological equilibrium of the soil; in South Australia, it usually affects the salinity of the root zone as well, as many soils are moderately saline at depth, and most irrigation water is saline to some degree. An impeding layer at depth has the potential to:

- prevent subsoil salts from being leached
- promote the development of a water table immediately under or in the root zone
- cause salt from both the deep subsoil and from the irrigation water to accumulate in the root zone.

In a well drained soil without a deep impeding layer, subsoil salt is leached relatively soon after irrigation commences, and salt in the irrigation water is flushed through the soil at more or less the same rate at which it is added. This process is helped in areas of high winter rainfall. In a soil with impeded deep drainage, salt accumulates, and depending on the depth to the impeding layer, and the quantity of salt applied, will sooner or later affect the root zone.

This is a particularly serious threat to perennial horticulture, where productivity must be sustained for many years, even decades.

### Assessing deep drainage

As Blanchetown Clay or equivalent clay is the most significant impediment to deep drainage, assessment is simply a matter of determining its depth below the ground surface. Typically, it underlies a carbonate layer – the change in colour from off white to red is very obvious. Usually, blotches of red clay appear within the carbonate layer. The depth at which the clay first appears is used in this assessment. Where there is little or no carbonate, the depth at which the characteristic structure first appears is used.

### Classification of land with respect to deep drainage

The classification is simply based on the depth to the impeding clay layer, using the criteria set out in Table 60.

Table 60 Classification criteria for deep drainage

| Depth to impeding layer | Land Class |
|---|---|
| >150 cm | 1-b |
| 100-150 cm | 2-b |
| 50-100 cm | 3-b |
| 25-50 cm | 4-b |
| 0-25 cm | 5-b |


*Deep sand with unrestricted deep drainage*

### Management of deep drainage problems

Irrigation developments on land with impeded deep drainage should be avoided. Although irrigation may be successful in the short to medium term, salt will accumulate over time. This is potentially disastrous for perennial horticultural crops, and even though annual crops can be moved away from affected areas, the damage to the soil has been done.

The traditional technique for dealing with the problem has been to install agricultural drains. However, the saline drainage water must be discharged into a suitable site. Historically, severe salinization of groundwater or surface water has occurred due to indiscriminate discharge. Suitable sites are basins or underground storages which are isolated from surface water bodies and groundwater which is or could be used for irrigation.

# Appendix

The soil profile characteristics used in defining classification criteria are outlined below. For a comprehensive account of soil and landscape description standards, refer to McDonald at el (1990).

Carbonate classes

Calcium and magnesium carbonates are common and important constituents of most soils where the annual rainfall is less than 500 mm. They take several forms:

- fine whitish particles, commonly called “lime”, but more correctly “fine earth carbonate” in the soil matrix
- hard nodules or rubble
- sheet rock

Wetherby and Oades (1975) define six classes of carbonate. Classification is based on the form and amount of carbonate, texture and the nature of boundaries with overlying layers. The classes are given Roman numerals from I to IV based on decreasing age of the geologic materials in which the carbonate has accumulated, Class I being the oldest.

Table A1 Carbonate Layer Classes (after Wetherby and Oades 1975)

| Class | Description |
|---|---|
| I | Fine soil carbonate in clay, few if any calcrete fragments present. Boundary with topsoil is diffuse. Usually associated with Blanchetown Clay, Pooraka Formation or Parilla Sand. |
| II | Sheet or boulder calcrete. Very hard and usually banded with pinkish colour. Concretions common in layer just above the calcrete. Usually associated with Crocker’s Loess, Upper and Lower Bridgewater Formations. |
| IIIA | Compact mixture of finely divided carbonate, sand and clay. Contains less than 30% calcrete fragments. Texture may be sandy loam through to light clay. Usually associated with Woorinen or Wiabuna Formations. |
| IIIB | As for Class 3A except that calcrete fragments account for 30-60% of the layer. |
| IIIC | As for Class 3A except that calcrete fragments account for greater than 60% of the layer. |
| IV | Weak accumulation of fine carbonate in a sand to sandy loam matrix. The carbonate is present as a coating on sand grains and is visible as a whitening in exposed profiles. Usually associated with Bunyip, Molineaux, Moornaba and Lowan Sands. |

The differences between the carbonate classes are highlighted in the photographs below.

Class I

Class II

Class III A

Class III B

Class III C

Class IV

Soil colour

Colour is a valuable descriptive characteristic of soil and provides an indication of soil drainage, degree of leaching and organic matter content.

Colour is assessed objectively by comparing the colour of a freshly broken surface of moist soil with the standard Munsell Soil Colour Charts. The colour can be expressed as a code representing the hue (relation to red and yellow), value (lightness), and chroma (strength). The code (e.g. 10YR5/6) can also be expressed as a colour name (e.g. yellowish brown).

Consistence

Soil consistence (or strength) is assessed on 20 mm cubes of material. Consistence assessments are only objective if soils are at a set moisture content. Dry soils are usually harder than wet ones and soil consistence is best assessed on dry samples. Moisture status, either moderately moist, moist or wet should be noted if the soil is not dry.

Table A2 Consistence (strength) categories (adapted from McDonald et al 1990)

| Category | Feel of sample |
|---|---|
| Loose to very weak (soft) | Sample has little or no coherence |
| Weak (friable) to firm | Sample is coherent but easily crushed between thumb and forefinger |
| Very firm (hard) | Sample is barely crushable between thumb and forefinger |
| Strong (very hard) | Sample cannot be crushed between thumb and forefinger |

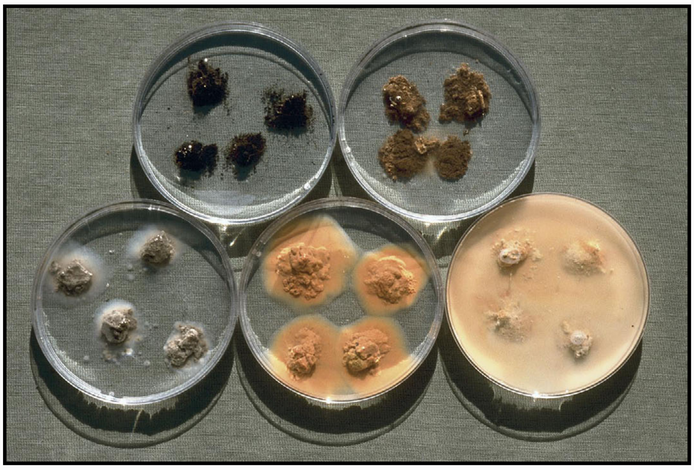
Dispersion

The dispersion test (adapted from Emerson 1967) involves placing several pea sized pieces of air dry soil into a jar of distilled (or rain) water and noting any disintegration or development of a milky cloud after two hours. Samples which disintegrate but do not disperse are said to have "slaked".

Table A3 Dispersion / slaking categories

| Appearance of sample | Category |
|---|---|
| Stable | Non slaking or dispersive |
| Disintegrates but no milkiness is visible | Slaking |
| Slight milkiness visible (halo around sample) | Slightly dispersive |
| Moderate milkiness (clouds in water) | Dispersive |
| Complete disintergration (sand grains in a cloud of clay) | Strongly dispersive |

These categories are illustrated below.



Pedality

Soils are “pedal” when individual clay, silt and sand particles are grouped together into well defined aggregates which separate easily from one another. The aggregates, or peds, have characteristic shapes, illustrated in Figure A1.

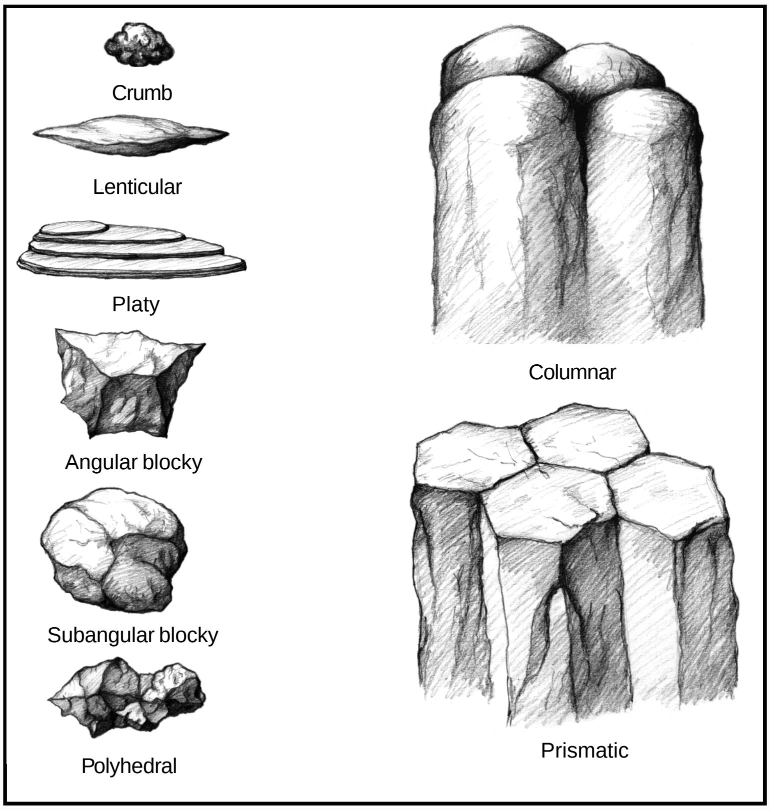



**Figure A1** Ped Type (after Schoknecht in Moore 1998)

Pedal soil material is described in terms of the size and type of ped. Size categories are:

| | |
|---|---|
| Fine | less than 5 mm |
| Medium | 5 mm to 20 mm |
| Coarse | more than 20 mm |

Texture

Texture refers to the relative proportions of sand, silt and clay sized particles, which make up the mineral fraction of the soil. The size ranges of these particles are:

| | |
|---|---|
| Coarse sand | 2 - 0.2 mm |
| Fine sand | 0.2 - 0.02 mm |
| Silt | 0.02 - 0.002 mm |
| Clay | Less than 0.002 mm |

The proportions of these particle sizes influence the amount of water that can be stored in the soil, the rate of movement of water and air through the soil, the soil’s nutrient supply, ease of root growth and its workability and resistance to erosion.

Table A4 Common field texture grades

| Symbol | Description of Soil Ball |
|---|---|
| S | Sand (less than 5% clay). Coherence nil to very slight, cannot be moulded; single grains adhere to fingers. |
| LS | Loamy sand (about 5% clay). Slight coherence; will form ribbon about 5 mm long. |
| CS | Clayey sand (5-10% clay). Slight coherence; sticky when wet; many sand grains stick to fingers; discolours fingers with clay stain; will form ribbon 5-15 mm. |
| SL | Sandy loam (10-20% clay). Coherent but very sandy to touch; sand grains readily visible; will form ribbon 15-25 mm. |
| L | Loam (about 25% clay). Coherent and spongy; smooth feel with no obvious sandiness; greasy feel if high in organic matter; will form ribbon about 25 mm long. |
| SCL | Sandy clay loam (20-30% clay). Strongly coherent; sandy to touch; sand grains are visible; will form ribbon 25-40 mm. |
| CL | Clay loam (30-35% clay). Coherent and plastic; smooth to manipulate; will form ribbon 40-50 mm. |
| LC,MC,HC | Light, medium and heavy clay (35-45%, 45-55%, more than 55% clay respectively). Smooth and plastic; resistant to shearing; will mould into rods; will form ribbons 50-75 mm (LC) and more than 75 mm (MC and HC); HC very difficult to ribbon. |

Each of these grades may have coarse sandy, fine sandy and silty variations. Soils with silt fractions greater than 25% are uncommon in South Australia, and textures of silty loam, silty clay loam and silty clay are usually found only on recent alluvial deposits.

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**R**



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