Field Soils

Elizabeth L. King
Field Soils

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INTRODUCTION

For thousands of years and in various civilisations, people have cultivated plants and managed grazing animals for food, fibre and many other necesseties of life.

Soil degradation started slowly. So many parts of the world were relatively untouched that problems were only local, not global. As world population was low, people could simply cultivate another area when the soil become exhausted of nutrients. However, at the end of the Twentieth Century that option no longer exists, and the soils that remain must be managed and preserved. Those that are damaged need to be reclaimed as far as possible, though much of the world’s soil has been lost or degraded beyond the ability of our current technology to save.

This book is an introduction to field soils - those open ground soils in gardens, orchards, parks, farms, etc., around us. It is designed to give horticultural students, farmers and keen home gardeners some of the basis concepts of understanding soils without too much highly scientific detail that requires considerable prerequisite knowledge.

This book is also intended to raise people’s awareness of soil degradation, and the various topics related to this. The greater our understanding of the physical and chemical processes occurring in soil, then the greater are our chances of avoiding the things which destroy the soils around us.

Examples in various chapters apply in particular to the southwest of Western Australia, as this book is designed primarily for TAFE horticulture students in this state. However, the author hopes that this text will have a far wider usefulness.
CHAPTER ONE

SOIL AND PLANT GROWTH

1.1 INTRODUCTION

Soil may be defined as the thin veneer of unconsolidated material that covers most land surfaces and that provides the primary support for plant, animal and human life. Soil is a dynamic medium and is often fragile and prone to degradation.

In its natural condition, soil is the product of thousands (often tens or hundreds of thousands) of years of weathering and biological activity. Natural soils almost always occur under forest, woodland or grassland, and they are inherently stable.

Most of the soils on our planet have been cleared for agriculture, grazing, or one or more of the many human enterprises which impact on the soil. Those which have been cleared and managed in various ways are inherently unstable. The processes of land degradation and the measures to reduce and, hopefully, reverse these, will be emphasised in this book.

All terrestrial life depends on the soil: animal life depends on plants either directly or indirectly for food, while humans in turn depend on both plants and animals for food and clothing. For these reasons land degradation is a very serious business indeed.

1.2 SOIL/PLANT RELATIONSHIPS

Soil is a dynamic medium in which many processes combine to provide the requirements of the organisms which grow on and in the soil. Soil fertility is a measure of the suitability of a soil for plant growth. This reflects the extent to which the soil provides the requirements for plant growth, which are:

- light
- carbon dioxide
- oxygen
- water
- inorganic nutrients
- physical support.
Light

Plants arrange their leaves so that they are at the best angle to absorb sunlight. In order to do this they need to be firmly anchored to the soil by a healthy root system. Shallow soils will not support trees. Compacted layers in soils impede root growth and limit the support which a plant can obtain.

Carbon Dioxide

Carbon dioxide is absorbed from the air, through the stomates in plant leaves. Carbon dioxide and water are then converted by the energy of sunlight into sugars in the process of photosynthesis.

Oxygen

Plants need oxygen to produce energy in a process called respiration. Plants absorb some oxygen through the stomates and the lenticels, but most is absorbed by the roots from the air-filled pores in soil. Some plants that grow under waterlogged conditions, for example, mangroves and rice, have developed methods of transferring oxygen from the above-ground parts to their roots. This oxygen needs to be replenished from the atmosphere (which contains 21% oxygen) by diffusion through the soil pore spaces (that is, the spaces among the soil particles in a soil). For this to happen, soils need to have good aeration and drainage, both of which depend on the presence of many relatively large pores called macropores.

Plant roots grow into the soil pore spaces and do a lot of work in moving soil to make way for themselves. They need oxygen to do this work. In the process of exploring and penetrating the soil, plant roots create and help to stabilise soil aggregates called peds. (These are soil particles grouped together.) When the roots die, they leave channels through which air and water pass to support other plant growth.

Water

Plants are mostly water. It is needed for numerous cell processes, cooling, and for keeping soft growth turgid. Plants obtain water and inorganic nutrients from the soil solution which occupies some of the soil pore space. Soil water is taken up by plants and must be replenished by rainfall or irrigation. Soil porosity is therefore an important factor in allowing rainfall or irrigation to enter and be held in the soil rather than to run off or form puddles. This is particularly
important at the soil surface, and cultural practices which help keep the macropores of the topsoil open are vital to ensure that water soaks in rather than runs off.

**Inorganic Nutrients**

Plants need nutrients for cell processes and for building cells which form the structure of the plant. Inorganic nutrients are absorbed by plant roots as ions from the soil solution. The quantity of these nutrients in the soil solution at any time is only a small portion of the overall requirements of plants and so these need to be replaced as they are taken up.

As plant and animal remains are broken down to form humus, and nutrients are converted to an available form by micro-organisms, inorganic nutrients are released in an ionic form available to plants. The nutrient content of the soil solution may also be increased or replenished by the addition of fertilisers.

Nutrients are absorbed from the soil solution by soil *colloids* (that is, tiny particles of clay and humus) and are later released as needed by plants. This is very important in protecting nutrients (added as fertiliser) from loss by leaching.

**Physical Support**

Plant roots grow down into the soil. Plant shoots and leaves grow upwards toward the light. The soil provides the physical support that plants need for proper exposure to the light. As roots grow into the soil to obtain water and nutrients, they also anchor the plant, thereby protecting it from being damaged by the wind.

Barriers to root penetration such as those caused by compaction or hard-pan formation, inhibit or prevent root development and reduce aeration, water penetration, and physical support for plants. Soil compaction is a very serious form of land degradation, which will be dealt with in Chapter 2.

### 1.3 SUITABILITY OF SOILS FOR PLANT GROWTH

The suitability of soils for horticultural crops depends on several interacting factors, including:

- The *texture of the soil* - some plants prefer coarse-textured soils, while others prefer fine-textured soils.
Soil and Plant Growth

- **Structure of the soil** - the aggregation of the soil particles into peds, providing optimum porosity.

- **The depth of the soil** - some plants are shallow-rooted and do not require a deep soil, while some plants are deep-rooted and need a greater depth of soil to provide support and anchorage, and the volume of soil to provide sufficient water and nutrients.

- **Soil reaction (pH)** - some plants like a acid soil while other plants prefer a neutral or alkaline soil.

- **Moisture holding** - some plants cannot tolerate dry conditions, while other plants are adapted to drought conditions.

- **Drainage** - some plants are able to tolerate wet conditions while most cannot withstand waterlogging.

- **Fertility** - some plants are able to thrive with only low levels of plant nutrients, while others will only thrive under highly fertile conditions.

- **Disease organisms** - all soils contain micro-organisms, many of which cause disease. Some plants are able to tolerate these disease organisms while others have low resistance.

- **Beneficial micro-organisms** - some plants require micro-organisms in order to grow properly. For example, *Rhizobium* bacteria on the roots of legumes convert nitrogen from a gas to a form readily absorbed by the roots; pine trees need fungus in the soil to help them absorb nutrients from the soil.

### 1.4 SOIL COMPONENTS

Soil is made up of:

- mineral matter
- organic matter and organisms
- water-filled pore spaces
- air-filled pore spaces.

All of these components are important for plant growth and their nature and function will be described in this chapter.

The proportions of soil volume that are occupied by these components is of major importance in soil fertility and the suitability of a soil for plant growth.
A fertile soil may have half or more of its volume occupied by pore space. Soil organisms and plant roots live in this pore space and obtain water and air from it. The ease with which plant roots penetrate the soil is affected by soil porosity and this determines the physical support which plants obtain from the soil. Root penetration also determines the volume of soil from which the plant can obtain nutrients. Plants obtain nutrients from the soil solution which occupies water-filled pores. In order to grow, roots need the oxygen which they obtain from air-filled pores.

1.5 SOIL COMPOSITION BY VOLUME

The proportions by volume of the four major components in soils may be depicted using a pie chart. It will be seen that proportions of pore space occupied by air and water vary between a moist (Figure 1.1 (A)) and a dry (Figure 1.1 (B)) soil. The compacted soil (Figure 1.1 (C)) has less total pore volume and therefore less air space and available water.

![Soil Composition Diagrams]

(A) Moist Soil

(B) Dry Soil

(C) Compacted Soil

Fig. 1.1 Soil Composition
The water volume shown in Figure 2.1 is divided into available water and unavailable water. Soil water and its availability to plants will be treated in Chapter 6.

1.6 SOIL MINERAL MATTER

The mineral components of soils are mostly derived from weathering of rocks and/or alluvium. Some soil mineral matter blows in with the wind, some is added as animal or plant remains, and some is added by human intervention.

Some soils are developed by weathering of rocks (or parent material) with little transportation. These soils develop from the rocks over which they occur and the weathering rock is clearly associated with the soil. Such soils are relatively rare in Western Australia. Many Western Australian soils are very old. The original soils developed on the old granite rock have been weathered and eroded, and more recent soils have developed on the infertile remnants.

Other soils have been developed on transported material or alluvium. Alluvial soils may be highly fertile when they are developed on volcanic ash or river delta deposits. They may also be highly infertile when they are formed on old sand dunes which explains the low fertility of the Swan Coastal Plain.

As rocks or alluvium weather to form soil, the mineral components change, leaving coarse residual material and finer material which is often considerably altered by the weathering process. These coarse and fine components (soil texture) will be discussed further in Chapter 3. Soil mineral matter also consists of the inorganic residues of plants and animals and some deposited material from fertilisers and irrigation water.

1.7 SOIL ORGANIC MATTER

Soil organic matter constitutes a relatively small proportion of most soils but the small amount which is present is vital to soil fertility. Soil organic matter can be thought of under three categories:

- plant and animal remains
- organisms which live on (eat) these
- the relatively stable residue, which is called humus.

In the process of converting plant and animal remains to humus, soil organisms release nutrients to the soil solution and help to create and stabilise soil aggregates (or soil structure).
1.8 WATER-FILLED PORE SPACES

The pore space in soils may be arbitrarily divided into two sizes. The larger pores are mostly air-filled in well-drained soils. These are referred to as *macropores* and are important in soil drainage and aeration. The smaller pores, called *micropores*, are usually water-filled and retain this water against gravity by means of capillary action.

Soil water in micropores, and to a lesser extent in macropores, provides the water requirements of plants. It is also the medium from which plants obtain inorganic nutrients, because plants obtain nutrients from the soil solution.

1.9 AIR-FILLED PORE SPACES

Soil macropores contain some water but are largely air-filled in well drained soils. Macropores allow gases to diffuse through soils so that plant roots can obtain the oxygen for respiration to produce energy that is needed for metabolism and growth. Many soil organisms (the aerobic or oxygen-dependent organisms) need oxygen in order to dig, burrow and break down organic matter.

Even plants which are adapted to waterlogged soils need oxygen for their roots, and have developed mechanisms to provide this by bringing air down from the leaves, or developing respiratory roots.

1.10 SOIL DEPTH

The depth of soil, particularly the topsoil, is vital to plant growth because a plant derives most of its water and nutrients from the topsoil. Trees, which need deep roots for support and anchorage, and deep-rooted native shrubs which are adapted to search for water at depth, use the subsoils as well. Most plants, other than trees and large shrubs, live primarily in the first 30 centimetres of the soil. The depth of soil affects the size of the mass of roots that the plant produces and therefore its capacity to take up water and nutrients. Shallow soils heat up and cool down more quickly than deeper soils, affecting root growth.

Plants need support so that their stems and leaves are held up to the light and so that their flowers are in the best position for pollinators. Plants need to be firmly anchored into the soil to resist wind damage. Plants growing in thin soils will be much smaller and more prone to wind damage. This is apparent in plants on cliffs and exposed slopes. Moreover, shallow soils are not conducive to growing good quality horticultural crops that need to grow quickly and produce a high quality return.
1.11 FIELD SOIL TYPES

Field soils can be classified into several major groups with some common characteristics indicating their general advantages and disadvantages. Examples given here relate mainly to the Perth metropolitan area, though the general statements have a much wider application.

Sandy Soils

Examples of sandy soils are found on coastal sand plains such as those which occur on the Swan Coastal Plain around Perth.

Advantages:

- Good aeration
- Porous, so that there are no drainage problems.
- Light and easy to work.
- Can be worked all year round.
- Good root penetration.
- Not much compaction.

Disadvantages:

- Low nutrient levels, so that frequent fertilising is necessary.
- Have a low water holding capacity, so that regular reticulation is necessary.

Clay Soils

These are found scattered in most areas through Western Australia. In the Perth metropolitan area, clay soils are found along the foothills and along the rivers.

Advantages:

- Retain nutrients and so do not need heavy applications of fertiliser.
- Retain water.

Disadvantages:

- Sticky and difficult to work.
- Waterlog and need drainage.
- Compact easily, so that root penetration is reduced.
Loamy Soils

Have a blend of sand and clay and, at best, can combine the advantages of both.

These are scattered throughout many areas of Western Australia. In the Perth metropolitan area, they are found in the Hills and along the flats associated with rivers and creeks.

Calcicous Soils

Calcicous soils contain limestone and are found in many coastal areas. In the Perth metropolitan area they are found in the Spearwood-Cottesloe area and extend along the coastline.

Disadvantages:

- Often shallow.
- Alkaline.
- Lack organic matter and humus.

Peaty Soils

These are found in isolated swampy areas, particularly in coastal areas of the South-West. With careful management, they can be very productive.

Advantages:

- Good water-holding, especially in summer.
- Good nutrient holding.

Disadvantages:

- Prone to waterlogging in winter.
- Can be very acidic.
- Sometimes saline.
Gravelly Soils

These are found scattered throughout Western Australia but are commonly found locally in the Darling Range. Often the gravel is found with clay loam or clay. Gravel soils are used extensively for stone and pome fruit crops, pastures and ornamental gardens in the hills around Perth.

Advantages:

- Good aeration and drainage.
- Good support and anchorage for many trees.

Disadvantages:

- Deficient in many nutrients, especially P, Cu, Zn and Mn.
- Set hard when combined with clay-loam and need careful irrigation.
- Prone to erosion on slopes if cleared.

1.12 SOIL TYPES OF THE SWAN COASTAL PLAIN AND THE DARLING RANGE

The following information covers field soil types for the Swan Coastal Plain and the Perth Hills only. (Information regarding other areas can be obtained from other sources, such as the Department of Agriculture, CALM, and recommended texts such as Soils of South-western Australia.)

1.12.1 Swan Coastal Plain

There are six main soil types on the Swan Coastal Plain which extends from north of Perth to Bunbury.

From the coast to the Darling Scarp, these are:

- Quindalup Dune System
- Spearwood Dune System
- Bassendean Dune System
- Peaty Swamps
- Pinjarra Plain
- Ridge Hill Shelf
Quindalup Dune System

These are coastal sand dunes that usually extend less than a kilometre inland. They consist of deep white sands containing quartz grains, shell fragments and small amounts of heavy minerals. Sometimes there is organic matter darkening the surface. They are infertile and are alkaline due to shell fragments (calcium carbonate). These sands have very low water and nutrient retention capacity. They are subject to wind erosion because of their exposed location and lack of vegetation. Some of the dune areas have been badly degraded, but there are also some that have been successfully rehabilitated.

Vegetation: wattles, Rottnest cyrus, honey myrtles, paperbarks, Rottnest tea-tree, and many small shrubs.

Crops: little or no agricultural use. Ornamentals need to be chosen with care for tolerance to wind, salt and drought.

Spearwood Dune System

The Spearwood dunes consist of sand overlying limestone. They occur in a slightly elevated strip up to 10 kilometres wide to the east of the coastal Quindalup dunes. They are bounded on the east by the Bassendean dune system.

The surface soils are yellow to brown sands, depending on organic matter levels. Subsoils are orange-yellow sands made up of quartz grains coated with iron oxides. Soils are deficient in nutrients, but have better nutrient and water-retention capacities than either the Quindalup or Bassendean dunes. With fertilisers and irrigation, they support a range of crops. In exposed areas, they are subject to wind erosion.

Vegetation: tuart, bull banksia, sheoaks, with some jarrah and marri, and many small wildflower shrubs and herbaceous perennials.

Crops: market gardens, with a wide range of vegetables; ornamentals.

Bassendean Dune System

This is the oldest of the dune systems and consists of low sandy hills with poorly drained areas between. Soils are highly leached, acid, and almost devoid of nutrients. The Bassendean dunes occur in a strip up to 16 kilometres wide, east of the Spearwood dunes. Topsoils contain some organic matter and grade into grey sand subsoils while, deeper in the profile, layers of iron oxides accumulate
Soil and Plant Growth

near the watertable. The watertable lies between two to six metres beneath the surface and allows for easy irrigation of both market and domestic gardens. Deeper water in this area is also part of the source of the Perth water supply - the Gnangara and Jandakot mounds.

Vegetation: banksias, coastal blackbutt, sheoaks, blackboys, and a large range of small wildflower shrubs and herbaceous perennials. Swampy areas support paperbarks, rushes and sedges.

Crops: pine plantations, some market gardens, production nurseries, some grazing further south. Wide range of ornamentals. Much of the area is taken up with urban development in the Perth metropolitan area.

The Peaty Swamps

Throughout the dunes there are a series of north-south lakes and swamps corresponding to the old inlets and marshes behind the earlier beach dunes that gradually developed westwards to their present position. These areas are part of the system of coastal wetlands, much of which has been drained for urban development.

Vegetation: rushes, sedges and paperbarks.

Crops: market gardening around the peaty soil margins of the lakes and swamps. Some areas are waterlogged in winter, but retain water in summer. Very acidic and prone to salinity in places.

The Pinjarra Plain

The Pinjarra Plain is a complex of alluvial soils of different ages, washed down by numerous rivers and creeks from the Darling Plateau. Topsoils are generally sandy loams over sandy clay subsoils. In low-lying areas, the clay content is higher and waterlogging is common. Along the banks of rivers, soils are red loamy sands with clay content increasing with depth. These soils are well drained, as they occur on elevated banks.

The Pinjarra Plain varies in width up to 13 kilometres and is located between the Bassendean Dunes and the Ridge Hill Shelf at the foot of the Darling Scarp. It is widest to the south around Pinjarra and Harvey.

Vegetation: marri, wandoo, jarrah, bull banksia, and blackboys on the flats. Paperbark, swamp sheoak, swamp tea-tree in low lying areas. Flooded gums and swamp paperbark on the river banks.
Crops: grazing especially in the south, and some vegetable production on the flats. Vineyards, orchards, vegetables on the river levees.

Ridge Hill Shelf

The gravelly deposits at the foot of the Darling Scarp occur in a narrow band up to 1.5 kilometres wide. These have low fertility but are well drained and are used for a range of crops. To the west the gravels grade into yellow sands. The Ridge Hill shelf has formed on material carried from the Scarp by water, the gravels being deposited closest to the Scarp while the sands and clays were carried further out into the Pinjarra Plain.

Vegetation: marri, wandoo, jarrah, bull banksia, zamia, dryandras, blackboys on the gravels; and jarrah, marri, sheoak, Christmas tree, woody pear, banksias, and a big range of wildflower shrubs and herbaceous perennials on the sandier western edge.

Crops: some of the gravel and clay outwash areas are used for vineyards, especially along the Swan River.

1.12.2 The Darling Range

The Darling Range is an area of laterite caprock developed over ancient granite rocks, which rises abruptly to about 300 metres immediately to the east of the Swan Coastal Plain.

The Darling Scarp

These are thin, acidic clay soils on the steepest part of the Scarp, over granite outcrops. The soil is very dry in summer and often waterlogged in winter, with running springs. Much of the area is protected as reserves, with many wildflower species.

The Darling Plateau

On the plateau surface are clay soils with lateritic gravels over caprock. In the valleys are clay loams on the slopes, with heavy clays in the valley floors. Soils are acidic. They retain more moisture than the sands, but are lacking in nutrients because they are also derived from very old weathered materials.
Vegetation: jarrah and bull banksia on the lateritic soils, marri on the clay loams with wandoo in the areas of heavy clays. All areas have a substantial range of wildflowers in the understorey.

Crops: stone fruit (peaches, plums and nectarines) and pome fruit (apples and pears) are widely grown on the loamy soils, aided by the colder climate which assists fruit set.

1.13 SUMMARY

- Plants require:

<table>
<thead>
<tr>
<th>light, carbon dioxide</th>
<th>absorbed by the leaves</th>
</tr>
</thead>
<tbody>
<tr>
<td>oxygen, water, inorganic</td>
<td>absorbed by the roots</td>
</tr>
<tr>
<td>nutrients and physical support</td>
<td>provided by the soil</td>
</tr>
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- Soil must provide a balance between aeration, drainage and water-holding. Soils provide support and anchorage, and are the source of inorganic nutrients.

- Soil is made up of solid particles and spaces for air and water, called pore spaces.

- The four components of soil are mineral matter, organic matter and organisms, water-filled pore spaces and air-filled pore spaces.

- In a good soil, roughly half of the volume is mineral particles, and about half is pore space. The proportion of air and water varies between waterlogged soil and very dry soil. There should be a small percentage of organic matter.

- Mineral matter comes mainly from weathered rock or deposits of wind-blown or washed sands.

- Organic matter is made up of plant and animal remains, micro-organisms and humus.

- Water for plant growth is held in the smallest soil pores called micropores.
• Oxygen to produce energy for growth is absorbed by the roots from air held in the large pores called macropores.

• Plants grow better in deeper soil because there is more space for the root system to absorb water, nutrients and oxygen. Deeper soils provide better support and anchorage.

• The main field soils types in Western Australia are: sandy, clayey, loamy, calcareous, peaty and gravelly. All of these types are found around Perth and in many parts of the south-west of the State.
CHAPTER TWO

SOIL POROSITY AND COMPACTION

2.1 INTRODUCTION

The presence of air and water in soil is critical to plant growth. The balance among the four soil components (mineral solids, organic matter, air and water) will determine how useful a soil will be to grow a wide range of horticultural crops.

2.2 POROSITY

Porosity is the percentage of a soil sample which is not made up of solid mineral or organic particles.

Soils consist of mineral matter, organic matter, air-filled pores and water-filled pores. As already illustrated in Chapter One, the proportion by volume of the four major components in soils may be depicted using a pie chart. Proportions of the pore spaces vary between dry, moist and compacted soils as shown in Figure 1.1 earlier. The composition of a typical moist loam is shown below in Figure 2.1.

Fig. 2.1 Soil composition of a typical moist loam
Functions of Pore Space

- Rain and/or irrigation water enters the soil through larger pores, and soaks into micropores where some of it is retained, available for plant uptake.

- Gases diffuse into and out of soils, allowing plant roots and soil organisms to breathe.

- Soil organisms dig and burrow through pore spaces as they break down plant and animal remains, with a consequent release of nutrients for plant uptake.

- Nutrients diffuse through the water-filled pores, to be taken up by plants.

- Salts are leached into subsoils and to the water table.

- Plant roots grow into the soil through the pore spaces to provide anchorage for the plant and to obtain water and nutrients.

2.3 MACROPORES AND MICROPORES

Fertile soil may have over 50 percent pore space. Plant roots and soil organisms live in this pore space and obtain water and nutrients from it.

Both the amount of soil pore space and the pore size distribution are important. The macro pores exist between peds. Their roles include:

- Aeration - they are mostly air-filled.

- Infiltration - water enters soil through the macro pores and percolates through them, to be replaced by air in the balance between aeration and water holding.

- Living space - roots and larger organisms such as earthworms use the larger pore spaces.
These particles cannot be drawn to scale. The figure illustrates the concept of pore spaces.

Fig. 2.2 The effect of soil particle size on pore size

When soils are compacted, soil structure breaks down and the spaces between peds become filled with fine-textured material. The amount of pore space is reduced and the proportion of macropores is reduced even further. This is very bad for water infiltration, aeration and root growth.

Micropores exist within peds and are defined as pores smaller than 0.03 millimetres across. They are usually water-filled due to capillary action, and are associated with fine-textured particles. Their roles include:

• Water retention, but are less important for water infiltration.
• Nutrient transport from soil to plant roots.
Soil Porosity and Compaction

Note that:

- Soils contain a range of particle sizes which range from sand to silt to clay which in turn may form aggregates of different sizes.
- Soil pores range in size.

2.4 SOIL POROSITY AND WATER INFILTRATION

Movement of water into soils (that is, infiltration and percolation) depends on the amount of soil pore space, as well as on pore size distribution. Many large pores give good infiltration in that water enters the soil easily and penetrates deeply. Macropores form channels which allow water to percolate to a depth where it is available for plant use.

An impermeable layer at any level in the soil can result in waterlogging above the barrier and dry soil beneath. Water that does not soak in will either run off or form puddles and later evaporate. Run-off can cause erosion, while puddles can cause waterlogging.

When rain falls or irrigation is applied to a dry soil, infiltration is rapid at first as the dry surface soil, unless repellent, absorbs water. When the surface few centimetres become wet, further percolation is through the macropores down into deeper layers of the soil. Water is drawn into the soil by gravity and by capillary action. The depth to which it is drawn depends on the soil porosity and the rate of water addition. Too much water too quickly will result in run-off, which in Western Australia commonly occurs in storms, cyclones and powerful winter cold fronts.

Infiltration rates vary with:

- intensity and duration of rainfall
- porosity and structure of the soil
- time
- soil moisture content
- presence of impermeable subsoil layers
- ‘wettability’ of surface soil.

With dry soil, the initial rate will be rapid, slowing as the soil becomes wet. Wet soils will not show the rapid initial rate of infiltration.
Figure 2.3 shows graphically how infiltration rates vary with time of wetting, surface soil structure, and subsoil structure.

Fig. 2.3 Infiltration rates in three soil types
Infiltration rates of water into soils are increased by:

- Light cultivation to break surface crusts.
- Mulching to protect surface soil structure from rain drop impact. However, mulches of fine material that are slow to break down can develop into crusts and actually prevent free infiltration.
- Use of commercial wetting agents.
- Crop canopy to reduce surface crusting by rain drop impact.
- Addition of organic matter to improve structure and porosity.
- Reduced tillage to conserve soil organic matter and soil structure.
- Reduced stocking rates to increase surface cover and decrease damage to soil structure.
- Subsoil cultivation (deep ripping) to break hard pans.

Improved infiltration rates result in more water for the crop and less waterlogging, run-off and soil loss.

2.5 SOIL POROSITY AND WATER RETENTION

Water is retained in soils as surface films on the inside of macropores and in micropores. With micropores the surface films meet in the middle. A favourable balance between macropores and micropores is the basis of good soil structure. This is what is meant by good physical fertility or good soil physical condition.

Soils with many macropores but few micropores will accept water readily but will retain little of it. Sandy soils have these characteristics and require frequent irrigation because of their low water-holding capacity.

Non-wetting sands have many macropores but have waxy deposits from decomposing organic matter which repel water. These soils have low infiltration rates due to their water repellency and need to be treated with special products containing surfactants to overcome the waxy deposits.
2.6 ROOT PENETRATION

Porosity is important in allowing root growth to develop through the growing media. Roots use a lot of energy in moving soil to make way for themselves, and this requires oxygen. In the process of exploring and penetrating the soils, plant roots create and help stabilise soil aggregates. When the roots die, they leave channels through which air and water pass to support other plant growth. Plants require extra energy to develop new roots that have to push through compacted soils with poor porosity, so they will not grow so quickly as those in suitable media.

Crops that need to grow quickly (like vegetables and flowers) in order to get a quick, high quality return, must have soil with good porosity. Oxygen, water and nutrients in solution are all more readily available to the roots which are able to search further when the soil is well structured with good porosity. Plants need support for their stems and anchorage from their roots to prevent damage from wind, so they need to be able to develop the full root system appropriate to their species. Shallow soils and those with a compacted layer prevent adequate root penetration.

2.7 SOIL COMPACTION

As soil compaction is one of the major forms of soil degradation, it is mentioned frequently in texts such as this. Here, it is looked at in some detail.

'Compaction' refers to damage by machinery, pedestrians and stock, such that pressure concentrated in an area forces the air from the soil.

Compaction also occurs when clay particles from the topsoil wash into the subsoil which then loses its macropores and becomes compacted.

Compacted soils have less than half of their volume occupied by pore space. (See Figure 1.1(c)) In severely compacted soils the volume of pore space may be less than one third of the total soil volume.
Soil Porosity and Compaction

As pore space is reduced, so also is pore size. When soils are compacted, it is the large pores - the macropores - which collapse or are filled with fine textured material. Water cannot enter the soil as easily and, when the soil is wet, it does not drain freely. The soil wets slowly and then becomes waterlogged - fine for rice or mangroves but not for most other plants.

Roots need air to grow - compacted soils have little air-filled pore space, and may become waterlogged.

Roots need water to grow - compacted soils often have little water at depth, due to slow infiltration.

Roots need space to grow - compacted soils prevent root penetration, depriving plants of air, water and support.

Infiltration of water into compacted soils is slower and this results in water being lost as run-off. This run-off frequently carries soil material with it, and is a major cause of soil erosion. Water that does soak into compacted soils tends to remain near the surface where it may exclude air, leading to waterlogging. Water retained in waterlogged topsoils or puddles is not useful to plants and is readily lost by evaporation.

Soil compaction is a serious form of land degradation, leading to:

• Loss of porosity and structure.
• Loss of infiltration and water percolation.
• Reduced effective soil depth.
• Increased density.
• Poor aeration and drainage.
• Increased run-off and soil loss.
• Waterlogged topsoils over dry subsoils.
• Less available water for plant growth.
• Short, stunted roots, poor root penetration, poor support and anchorage.
• Poor plant growth.
Methods used to overcome compaction include:

- Avoiding using tracks, gateways and playing fields in wet weather.

- Confining traffic (be it machinery, pedestrian or stock) to well organised paths, to reduce the area damaged. Routes up and down slopes should be avoided to minimise the risk of erosion developing on the steep bare surface.

- Improving the structure of growing media by regularly adding organic matter. This improves the physical properties so that compaction is less likely and the media is capable of producing better plant growth.

- Techniques such as digging, spiking and ripping to break up the compacted layer and allow air and water to penetrate. Spiking and coring are used especially on turf areas subjected to heavy use.

- Improving drainage to reduce the chance of waterlogging and maintaining the balance between air and water.

**2.8 SUMMARY**

- Porosity is the proportion of a soil sample which is not made up of solid mineral or organic particles.

- Soil particles form peds, with pore space between and within the peds.

- The larger pore spaces are called macropores. The functions of macropores are: aeration, infiltration, drainage and space for roots and organisms.

- The smaller pore spaces are called micropores. Water is retained by capillary action. The functions of micropores are water retention, and nutrient retention in solution in the soil water.

- The process of water entering the soil is infiltration.

- Waterlogged soil does not drain properly. This will occur in low lying areas, but may also occur above hardpans layers and in compacted soil.

- Soils with poor wettability do not absorb water easily unless treated.

- Compaction occurs when air is forced from the soil by pressure (for example, from machinery) or when macropores are filled with dispersing clay.
Soil Porosity and Compaction

- Compacted soils have poor porosity. They lack adequate air and root space, and may be waterlogged or very dry due to poor drainage or poor infiltration.

- Compaction can be minimised by avoiding using soil when wet, installing drainage where appropriate, controlling access to susceptible areas, adding organic matter and by breaking up compacted layers.
CHAPTER THREE

SOIL TEXTURE

3.1 INTRODUCTION

Soil texture is defined in terms of particle size. Gritty, sandy soils are described as coarse-textured. Sticky, clayey soils are described as fine-textured. The grittiness or stickiness of soils is very important in deciding how to manage them, and which crops to grow on them. In this chapter, methods used to measure and define soil texture will be described. The significance of soil texture to land management will be considered, as well as a range of practices appropriate to soils of different texture.

Soil texture is the proportion of solid mineral particles of various sizes in a soil sample.

3.2 THE EFFECTS OF TEXTURE ON PLANT GROWTH

3.2.1 Coarse-Textured Soils

Sandy soils are mostly made up of large grains and are said to be coarse-textured. They are also referred to as 'light soils' or 'light land'. The term light land arises from the ease of cultivation of coarse-textured soils. Coarse-textured soils are often more dense or heavy than fine-textured or 'heavy land'. To avoid this confusion, the term 'coarse-textured' is used to refer to soils which consist mostly of sand.

Coarse-textured soils are easy to manage and are not prone to damage by careless treatment. Their productivity can be high, but only with frequent applications of nutrients and water to maintain plant growth.

3.2.2 Fine-Textured Soils

Soils which mostly contain very small particles are said to be fine-textured. These are the clays or loams. Clay soils are also referred to as heavy soils or
Soil Texture

heavy land, as they can be very difficult to dig or cultivate. ‘Fine-textured’ is a better term to describe these soils, as their properties are dominated by the very fine particles, or clay, which they contain.

Fine-textured soils are potentially very productive, but may become sticky and unmanageable if treated wrongly. Poorly structured fine-textured soils are sticky when wet and hard when dry. Root penetration is more difficult, though water and nutrients are better retained than in sandy soils. Poor aeration becomes a problem as the percentage of clay increases.

3.3 DETERMINING SOIL TEXTURE

Soil texture is defined in terms of particle size distribution by determining the content of sand, silt and clay in a sample of the soil. Soil texture does NOT include organic particles in a soil. We take a sample of soil which will pass through a 2 millimetre sieve.

- Larger particles (those which will not pass through a 2 millimetre sieve) are referred to as gravel, and are treated separately.

- Particles which will pass through a 2.0 millimetre sieve but not a 0.2 millimetre sieve are referred to as coarse sand.

- Particles ranging from 0.2 to 0.02 millimetre are termed fine sand.

- Particles from 0.02 to 0.002 millimetre are termed silt.

- Particles smaller than 0.002 millimetre are termed clay.

Sand dominates the properties of coarse-textured soils. Such soils are referred to as sands or sandy loams and their advantages and disadvantages are largely due to the high content of sand in them.

Clay dominates the properties of fine-textured soils. The clay content of any soil is arguably the most significant physical property of that soil. The fine-textured components are vital to the chemical and biological fertility of soils.

Silt content of any soil is of rather less importance. It makes up the rest of the soil. When soil is analysed for particle size:

\[
\text{% clay} + \text{% sand} + \text{% silt} = 100.
\]

Soils which have a high gravel content are referred to as gravel or as being gravelly; for example, gravelly sand, gravelly clay, gravelly clay loam, etc.
In textural terms, a loam is a mixture of sand and clay particles with some silt. In horticultural terms, a loam is much more than this. It is a soil with an organic matter content sufficient to develop good structure and fertility. Loams cannot be created by mixing sand and clay.

3.4 SOIL TEXTURE BY FEEL

Soil in nature consists of aggregates containing many (or sometimes relatively few) particles loosely bound into what soil scientists call *peds*. To determine particle size distribution, or soil texture, these aggregates are broken down into their component parts in a process called *dispersion*. In the field this is done by wetting the soil sample and then manipulating it, usually between finger and thumb.

If we wet a small sample of soil and squeeze it around until it loses its aggregates, we get a ‘mud pie’ which soil scientists call a *bolus*. In the process we get a good feel of the soil sample. For example:

- Sandy soils will feel *gritty*.
- Clays will feel *sticky*.
- Silty soils are neither gritty nor sticky. They feel *silky*.

The degree of stickiness and/or grittiness gives us an indication of the proportions of sand and clay in the sample. This method sounds a bit rough and ready, but it is the one that is used most often by most people who manage soils. It is quick, easy and free. With a bit of practice and experience it is also accurate enough for most purposes. We can add to its accuracy by pressing the mud pie into a ribbon.

3.5 SOIL TEXTURE BY RIBBON

We can manipulate our mud pie to form a ribbon. The mud pie should be as wet as it can be without sticking to the fingers, or just dry enough to not stick.

Coarse-textured soils (sands) will crumble and not form a ribbon, as shown in Figure 3.1.
Fine-textured soils will form ribbons of increasing length, depending on their clay content. See Figures 3.2 and 3.3.

This soil is coarse to touch and easily breaks up when touched. When rubbed between the thumb and forefinger it will not form a ribbon. Sandy soils have less than 5% of clay.

Fig. 3.1 Sand

This picture shows a ‘ribbon’ of about 2.5 cm. When attempts were made to make the ribbon longer, it broke off. Because sand grains could be felt, heard and seen in the soil, this soil was called a sandy clay loam. These soils have 30-40% clay.

Fig. 3.2 Sandy Clay loam
You can see that the soil is quite plastic, so that it could be moulded into different shapes. You can see also that the soil can be rolled into a ribbon longer than 7.5 cm. This clay soil feels smooth to touch.

Clay soils have more than 50% clay, but this particular soil, which is a cricket wicket soil, has a rather higher clay content.

Fig. 3.3 Clay
3.6 **SOIL TEXTURE CLASSES**

Soil texture classes are described in detail in Table 3.1 below. This table summarises information on ‘feel’, ribbon length, texture classes, and approximate percentage of clay.

<table>
<thead>
<tr>
<th>Texture Class</th>
<th>Description of Handling</th>
<th>Approximate % Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>Does not stick together. Gritty feel.</td>
<td>0 - 5</td>
</tr>
<tr>
<td>Silty Sand</td>
<td>Does not stick together. Silky feel to fine particles.</td>
<td>0 - 5</td>
</tr>
<tr>
<td>Loamy Sand</td>
<td>Just begins to stick together. Gritty feel. Ribbon length up to 5 mm</td>
<td>10 - 20</td>
</tr>
<tr>
<td>Sandy Loam</td>
<td>Sticks together but breaks easily. Gritty/slightly silky feel. Ribbon length 10 - 20 mm</td>
<td>20 - 30</td>
</tr>
<tr>
<td>Loam</td>
<td>Sticks together. Silky feel. Ribbon Length 20 - 30 mm</td>
<td>20 - 30</td>
</tr>
<tr>
<td>Silty Loam</td>
<td>Sticks together. Very smooth and silky. Ribbon length 20 - 30 mm</td>
<td>20 - 30</td>
</tr>
<tr>
<td>Clay Loam</td>
<td>Can be moulded into shapes. Sticky feel. Ribbon length 30 - 50 mm.</td>
<td>30 - 40</td>
</tr>
<tr>
<td>Sandy Clay Loam</td>
<td>As for clay loam but with a gritty feel.</td>
<td>30 - 40</td>
</tr>
<tr>
<td>Sandy Clay</td>
<td>Can be moulded into shapes. Gritty and sticky feel. Ribbon length 50 - 72 mm</td>
<td>40 - 50</td>
</tr>
<tr>
<td>Clay</td>
<td>Can be moulded into shapes. Sticky smooth feel. Ribbon length 50 - 75 mm, and longer for HEAVY CLAY.</td>
<td>40 - 99</td>
</tr>
</tbody>
</table>

*Table 3.1 Soil texture classes*
3.7 MODIFYING SOIL TEXTURE

In field soils, the task of moving and mixing soils at a site is not practical on a large scale. It may cause layering, compaction and destroy other physical and chemical properties. (Check the appendix for the lists of these.)

In many horticultural situations such as a golf course or a large scale landscaping project where the landforms are extensively regraded, soil can be completely replaced or top-dressed by using quantities of soil from another site or more suitable commercial soil mixes. However, this is not the same as trying to alter the texture of existing soil by mixing in mineral matter of a different texture.

Modifying soil texture is only feasible on very small areas for special purposes. Cricket pitches are prepared by importing clay soils and usually have 50 percent or more clay. The surrounding field should be of coarser textured soil to allow for free drainage. Bowling greens and putting greens are prepared from coarse-textured soils, to give good aeration and drainage.

Garden beds (for example, for a rose garden) may be improved by adding loam to increase water and nutrient retention, but:

- adding clay to sandy soil is expensive;
- if the clay disperses, it may lead to drainage problems;
- removing clay or loam is ecologically damaging on the site from which it is obtained.

Adding compost and/or mulch to coarse-textured soils is more effective and ecologically more acceptable. This will improve the soil for plant growth, but it should be noted that it does not alter the texture, for that concerns only the solid particles and does not include organic matter.

Adding sand to fine-textured soils to ‘lighten’ them is not beneficial, as the damage done to soil structure in incorporating the sand more than offsets any possible benefit. The result is likely to be a poorly structured loam with:

- poor drainage and aeration;
- problems of run-off and erosion, and
- compaction.
Fine-textured soils with structural problems need minimum cultivation techniques or are left uncultivated with a good cover of plant material and leaf litter. The soil macro-fauna will do a much better job of improving the soil than we can and they need to be left in peace to get on with the job. Cultivation is disastrous to ants, termites, earthworms, wood lice, millipedes, etc.

3.8 SUMMARY

- Texture is the proportion of solid mineral particles of various sizes - sand, silt and clay - in a soil sample. Texture never includes organic matter.

- The finest particles are clay, then silt, fine sand, then coarse sand. Gravel is treated separately.

- Sandy soils are also referred to as light soils or coarse-textured soils. They are easy to cultivate but nutrients are leached and water drains away quickly.

- Clay and loam soils are referred to as heavy soils or fine-textured soils. They are harder to work, can be poorly drained, but hold more water and nutrients.

- Texture can be judged by feeling moist soil. When moist:
  - sandy soils feel gritty
  - clay soils feel sticky
  - silty soils feel silky.

- As the percentage of clay increases, soil can be made into longer and longer ribbons.

- Texture types are based on the percentages of particles; for example, sand, loamy sand, sandy loam, clay loam, etc.

- Texture cannot be altered easily or practically over a large area. Mixing is difficult and damages existing soil properties. Most soil additives and improvers are designed to improve soil structure rather than texture.
CHAPTER FOUR

SOIL STRUCTURE

4.1 INTRODUCTION

The capacity of a soil to support plant growth, or soil fertility, depends on a number of factors. Great progress has been made in correcting chemical deficiencies in soils and our understanding of physical problems in soils has improved in recent years. This has involved consideration of chemical and biological factors as they affect the fabric of soil, that is Soil Structure. The study of soil structure is aimed at improving our understanding of the physical fertility of soils and the importance of this for plant growth. We will consider the properties of:

- aeration and drainage
- water infiltration rates
- porosity
- root penetration.

These properties are related and they affect plant growth. Land management practices also affect these properties.

4.2 SOIL STRUCTURE

Soil structure refers to the arrangement of mineral and organic particles as aggregates to allow for pore space within and between them.
Good soils consist of mineral and organic components with air-filled and water-filled pore space around and between them. The mineral components of soils vary in particle size - sand, silt, and clay which combine with organic matter to form clumps or aggregates. As previously stated, soil scientists refer to these aggregates as peds.

Peds are loosely arranged in fertile soils and the spaces or pores between them allow for infiltration of water and diffusion of gases. These are vital for maintaining aeration and drainage in soils. The loose arrangement of peds accounts for soil porosity and is the most important aspect of the physical fertility of soils.

Under natural forest, this loose arrangement is stable and is maintained by natural biological processes of digging, burrowing, moulding, etc. Forest soils are usually well drained and aerated. Unfortunately, the structure of soil is fairly fragile and can be damaged by unnatural interference. For this reason, almost all agricultural soils are structurally degraded or compacted to some extent. In extreme cases, soils have been compacted to the point where the pore space in them is not sufficient to allow air, water or plant roots to penetrate. Such soils are severely degraded and are said to have very low physical fertility. Crop yields are very much reduced.

We will now consider methods of describing aggregation in soils and describe practices which help to stabilise soil structure and those which damage it.

**Soil Aggregates**

Aggregates are classified by shape as:

- **Crumb** - porous peds that look like a collection of very small granules loosely bound together. There are many pores both within and between peds. This is the most desirable structure and is usually found only in fertile topsoils with high organic matter content.

- **Granular** - peds similar to those in crumb structure but relatively non-porous, with many pores between peds. They are commonly found in topsoils and well-drained subsoils.
Soil Structure

- Angular blocky - close-fitting blocks with flat sides and sharp edges. Commonly found in subsoils, particularly those with high clay content, but sometimes in the topsoil of very clayey soils.

- Sub-angular blocky - as for angular blocky, but with rounded edges.

- Platy - flat plates arranged horizontally. Found in both topsoils and subsoils; these usually result in inhibited drainage and are characteristic of soils that have been compacted.

- Prismatic - large close-fitting prisms with vertical cracks between.

- Columnar - similar to prismatic, but with rounded tops on the columns.

- Massive - massive soils lack obvious pore space and present severe problems of slow drainage and lack of aeration. Root penetration is inhibited and organic activity virtually absent. This is the least desirable soil structure for plant growth, and is also indicative of compaction.

Of these classes, crumb and granular aggregates in the topsoil are the most favourable for aeration, drainage and plant growth. Blocky, platy, prismatic and columnar are progressively less favourable, and massive is least favourable. These are subsoils.

Coarse-textured or very sandy soils are described as having single-grain structure, being structureless or having no aggregates. Structure only becomes a significant factor in soils with around 10 percent or more clay content to bind the particles into aggregates.

4.3 DAMAGE TO SOIL STRUCTURE BY LAND USE

Soil aggregates are formed by gentle processes of root growth and burrowing organisms. They are stabilised by fungal hyphae and bacterial slimes. It is not surprising that steel cultivation implements drawn by high-powered tractors can damage soil aggregates. Cultivation is damaging because of the forces involved and also because of the decrease in organic matter that follows.
Cultivation of wet soils causes smearing of aggregates and dispersion of clay; that is, clay is broken up into individual fine particles. The dispersed clay moves into soil pores and blocks them. Cultivation of dry soils causes fracture of aggregates which then slake (collapse) and disperse when rain falls, especially when high-intensity rain falls onto soil left bare after cultivation. These processes will be discussed further in the chapter on soil erosion.

The more vigorous and frequent the process of cultivation, the greater the potential damage to soil structure. Rotary hoes generally do most damage. Disc ploughs can be very destructive, particularly when drawn at high speeds or when soils are too wet or too dry. Tine cultivators are less damaging and have the added advantage of leaving some plant material on the soil surface to form a protective mulch against rain-drop impact. Main factors causing damage include the following:

- Cultivation of soils which are too wet causes smearing of peds and dispersion of clay.
- Cultivation of soils which are too dry gives rough, cloddy soils which slake and collapse on wetting.
- Cultivating too frequently leads to a decrease in organic matter and destruction of peds.
- Compaction of soils by the passage of vehicles, feet and hooves, leads to reduced infiltration rates, waterlogging, and further compaction and puddling of wet soils.
- Raindrop impact on soil surfaces which are not protected by leaf litter or foliage canopy causes surface crusting, reduced infiltration rates, run-off and soil loss.
- Use of irrigation water with high sodium content leads to unstable soil structure and dispersion of clay from peds.

4.4 FACTORS WHICH IMPROVE SOIL STRUCTURE

Any management practice which increases biological activity in soils and decreases physical disturbance will be beneficial to soil structure.
Adding to organic matter through the application of manures, composts or mulches will provide food for organisms and nutrients for plants. The nutrients will promote more vigorous plant growth, which will in turn increase the return of leaves and roots to the soil. Manufactured fertilisers, while not organic, help to increase soil organic matter levels by increasing plant growth in this way. However, an excessive use of chemicals can reduce the worm population and destroy soil structure.

Addition of composts, manures and mulches may be practical on small areas, but it is not over large areas. Compost, manure and mulch have to come from somewhere and it is ecologically more desirable to grow the organic matter on the site. Under natural conditions, organic matter comes from leaf fall from trees and the associated understorey, while nutrients come from deep in the soil, from weathering parent material with some from ground water and rainfall.

Unfortunately, population pressure has reduced the area of ‘natural soils’ to an insignificant amount. Natural forest will not support our burgeoning populations, so other possibilities need to be explored. Well fertilised pastures, properly managed and rotated with food crops, may provide the solution. This is probably the nearest we will ever get to viable ‘organic farming’. An increasing number of these mixed organic farms are being developed.

Sodium-affected clays and loams have unstable structures which can be improved by the addition of calcium, usually as gypsum.

The addition of organic matter provides:

- food for earthworms, insects, fungi, bacteria, etc;
- nutrients for plant growth, which increases root activity;
- humus to stabilise soil aggregates;
- mulch to protect soil surfaces from raindrop impact.

Minimum cultivation techniques, rotation and more pasture gives:

- less disruption of peds by tillage;
- reduced rates of organic matter breakdown and perhaps even increased organic matter levels;
- less compaction by vehicles and tractors.
Minimal use of chemical pesticides and fertilisers encourages:

- populations of earthworms and natural predators to increase.

Reduced stocking rates on pastures gives:

- less pugging by hooves;
- increased organic matter levels from pasture roots and manure.

Controlled access to wet crop land and playing fields gives:

- time for soil to dry out without compaction and destruction of aggregates.

Well designed layout of paths and roads in nurseries, parks and farms gives:

- the greatest amount of productive land.

The addition of gypsum to sodium-affected clays and loams:

- will reduce or prevent slaking and dispersion of aggregates on wetting.

4.5 **SOIL TILTH**

Good soil tilth is a general term which describes the properties of a soil which is easy to cultivate and is suitable for plant growth. The soil will be friable; that is, it will have crumb structure, which means that it will have good porosity and the right balance of aeration, drainage and water-holding for the plants to be grown. When cultivated, it breaks down into small crumbs which are particularly suitable for planting seeds, seedlings, and small plants from tubes, etc. Good tilth is much more necessary for vegetable seedlings in a market garden than for planting bottlebrushes in a park or reserve.

Soils with poor tilth are not friable - they are either hard and cloddy or structureless sands. Neither of these is suitable for seeds and small plants, as they collapse when watered. Cloddy soil is also difficult for workers to handle. The success rate of seed germination will be much greater in a soil of good tilth.

Good tilth can be best obtained by the following:

- The managed addition of organic matter. It must be composted down and not be coarse, undecomposed fragments in a seed bed, or the soil structure will be poor, with too many large pores. The organic matter may still be toxic to germinating plants.
Soils should not be over-cultivated, as this damages the structure.

Cultivation should be timed so that the soil is neither too wet nor too dry. If it is too wet, the soil may be left cloddy; if it is too dry, the seedbed will be too fine and dusty.

The goal is to achieve a fine crumb structure which supports the seedling without collapsing around it thereby depriving it of air and available water. Germinating seeds and young plants have very precise needs for air and available water, if they are to be grown at a success rate acceptable to industry.

4.6 SUMMARY

- Structure is the arrangement of soil particles to allow for pore space within and between the particles.

- Particles form into peds through the presence of organic matter and the activities of soil organisms.

- Aggregates are classified by the shape of the peds.

- The most desirable soil structure is crumb structure with various sized pore spaces within and between the particles.

- Granular structure is less porous than crumb structure.

- Sand is structureless because it does not form into peds without the presence of organic matter and some clay.

- Platy and massive structures indicate compaction.

- Blocky, prismatic and columnar structures are found in sub-soils.

- Structure is damaged by vigorous and frequent cultivation which breaks up the structures, damages the soil organisms, and reduces the amount of organic matter in the soil.

- Soil structure is protected and improved by reduced cultivation techniques, the managed applications of organic matter, and by minimisation of compaction.

- Gypsum added to clay soils will improve structure.

- Good tilth describes the condition of soil that has good structure, is easy to cultivate, and is suitable for growing seedlings and small plants.
Soil Structure

- Cultivation of soil containing more than a trace of clay should be timed so that the soil is neither too dry nor too wet.

- All horticulturists should aim to achieve the best possible structure in the soils in their care.
CHAPTER FIVE

SOIL TEMPERATURE

5.1 INTRODUCTION

Temperature is an important physical property of soil. It can affect the capacity of soils to produce crops over a fairly short distance, for example, plants in the Perth Hills differ from those on the Plain not only in selection but also in growth and timing. Soil temperature is one of the factors causing these differences. However, like all the factors affecting the suitability of soils for plant growth, there is an interaction, and no particular one is all important.

The temperature of soil is only variable for the top few centimetres. Below this, temperatures are much more stable, changing only slowly in winter and summer, without any of the extremes of the surface. Nevertheless, much of the plant's root growth is in the first few centimetres and the effects of temperature change can be quite severe on the roots of that plant.

5.2 THE EFFECTS OF SOIL TEMPERATURE ON PLANTS

Growth can take place in a fairly narrow range of soil temperatures. The best range for growth is between 15°C and 30°C. Below that range, growth is reduced and then stops as plants become dormant. Uptake of water and nutrients is reduced and the rates of translocation and photosynthesis slow down in low temperatures.

5.3 HOT SOILS

Temperatures over 40°C are common in heatwaves in Western Australia. Bare soils in full sun become hotter than the air temperatures in these conditions and can reach 50°C. Tolerance varies in individual plant species, and young plants are more susceptible. Roots are damaged in hot soils. Plants are also scorched by the heat reflected off the bare soil.

Above 30 - 35°C various processes are affected. Respiration is speeded up, thus wasting energy, and transpiration increases until the stomates close to reduce water loss. Evaporation also increases, especially from bare soils. Hot soils will damage germinating seeds so many native plants stay dormant until the cooler weather in the autumn.

5.1
Soil Temperature

High temperatures reduce the rate of decomposition of organic matter, and the number of organisms in the soils declines. For instance, in soils in the north of the state which are hot and dry most of the time, there is an absence of worms compared with soils in the southern part of the state.

Cold climate plants may need chilling of seeds in order to germinate (stratification) or chilling of bulbs to produce flowers (vernalisation).

5.4 FACTORS WHICH DETERMINE SOIL TEMPERATURES

The main factors that determine soil temperatures are as follows.

- **Latitude**

  The higher the latitude, the colder the temperatures become, particularly in winter. Near the equator, temperatures are more even throughout the year.

- **Altitude**

  Increasing height above sea level reduces air and soil temperatures, and hollows in valleys and basins can become very susceptible to frost.

- **Coastal Location**

  Areas near the coast have a much lower range of temperature daily and seasonally than inland areas of the same latitude.

- **Radiation**

  This is the heat absorbed by soil from the sun. Bare soil re-radiates heat to the atmosphere at night.

- **The Season**

  Soils will reflect the obvious differences between summer and winter temperatures. The hottest times are in mid and late summer when soil has had time for maximum heating. The coldest time will be after midwinter as the soils continue to cool down. In the southwest of Western Australia, most rain is in winter, and cold rain further chills the soil, while dry soil in summer is more likely to heat up.
• **Aspect**

The angle at which the sun's rays strike the soil on a slope is called the aspect. Hillsides which face the sun will be warmer in winter and the spring than those which face away from the sun, or to the south in Western Australia. This can be very important, particularly in the spring and autumn, as the growing season is much shorter than that on a north-facing slope. Warm slopes can be used for early crops before the very high temperatures of summer reduce any advantage.

![Aspect Diagram](image)

**Fig. 5.1 Aspect**

• **Texture and Porosity**

These affect the percentage of air in a soil. Air heats up and cools down faster than water so that the rate of temperature change on the surface of a dry soil is much faster than that in moist or very wet soils. However, moisture is a better conductor of heat than air, so warmth will penetrate deeper into a moist soil than into a dry soil. This is very significant in spring when the onset of plant growth is dependent upon soils warming up, so that nutrients can be absorbed by roots becoming active after winter.

• **Colour**

Dark colours absorb more heat than light colours which reflect heat. Consider, for example, the light and heat which are reflected off beach sand. Black plastic warms soil in winter and early spring, thus encouraging early growth of certain crops like strawberries.
Soil Temperature

- **Moisture**
  
  (See texture and porosity)

- **Vegetation Cover**
  
  Plant growth provides insulation for soils, especially in summer. This emphasises the importance of shade, ground covers and mulches to reduce summer temperatures. However, deep mulches can prevent soils warming up quickly in the spring. Organic matter such as mulch does not conduct heat to the soil below. This advantage in summer, but could be a disadvantage in winter depending upon whether crops are being grown or not.

- **Depth**
  
  Shallow soils are likely to heat up and cool down much faster than deep soils.

### 5.5 SOIL TYPES

In the southern part of Western Australia, the light coloured sandy soils are known by farmers and horticulturists to heat up faster in the spring and to retain their warmth longer into the winter than the clay soils. This is because they are better aerated. Heat is conducted quickly into the air-filled pore spaces as days warm up in the spring. Warm days in the autumn and winter are more effective at warming the better aerated sands than the wetter clay soils. Many of the clay soils in low lying areas become very wet and cold in the winter. Loamy clay soils in the Perth Hills are colder partly because of altitude and heavier rainfall, but also because the clays hold more water and stay cold for longer.

### 5.6 MODIFYING SOIL TEMPERATURE

It is more difficult to alter the temperatures of field soils than of media for containers and production nurseries. Only the top few centimetres can be affected, but there are some cultural practices that can take advantage of possible benefits.

#### 5.6.1 Improving Plant Growth

- Maintain good aeration and drainage so that the air in the soil can warm up quickly in the spring.
• Avoid waterlogging.

• Mulch with organic material such as shredded prunings and compost in summer to keep surface temperatures down so that roots are not stressed by high temperatures.

• Organic matter does not conduct heat to the soil beneath. Be aware that organic mulches in winter may keep temperatures lower because the sunlight does not directly reach the soil. However, the mulches also improve infiltration and protect the soil from raindrop impact and erosion.

• Irrigation will cool the soil in summer, and the moisture will help to reduce the extremes of temperature.

• Black plastic mulches in winter and spring will warm the soil as well as suppress the weeds. This technique is widely used by strawberry growers.

5.6.2 Reducing Frost Damage

Frost damage generally occurs in areas that are known to be susceptible in the southwest of Western Australia; for example, in frost hollows, basins and high ground in the Southwest and the Hills, as well as inland areas of the Great Southern. While frost is actually a result of very cold air at ground level, the soil is also very cold on the surface. In these areas it is unwise to grow crops or ornamentals that are very susceptible.

• Species selection is the obvious way to avoid damage, and other crops such as stone fruit and apples that need the cold conditions can be grown. Occasionally, frosts can be very severe or prolonged which does a great deal of damage to vegetable crops, and damage is much more widespread throughout the Southwest, even to the coast.

• Plant on slopes rather than in the frost hollows.

• Ensure that there are no barriers across slopes; that is, walls, shrubs, to trap cold air and prevent it draining to the lowest levels of a slope.

• Use shadecloth and taller plants to shelter ornamentals.

• Huge fans have been used, especially overseas, to stir the air to prevent frost which only forms when the air is very still. This is expensive, and is used only for very valuable crops.
Soil Temperature

- Frost sensors in open paddocks of crops like vegetables turn on the sprinklers automatically. Because the water will be above freezing point, this raises the temperature of the air around plants and prevents frost forming.

- In the past, it was believed that if soil in an area such as an orchard was compacted, frost damage could be minimised. This worked on the principle that soils containing at least some clay could be mechanically compacted. This soil would hold the heat longer and slowly release it during the night. This re-radiated heat would reduce the possibility of frost. However, in modern practice, compaction is recognised as a serious aspect of soil degradation. It causes poor porosity and aeration, poor water infiltration and percolation, and a greater risk of erosion on sloping land. It is doubtful that many modern growers would employ this technique.

5.6.3 Sterilisation of Soil by Solarisation

This is a very useful method of sterilising growing media and small areas of open ground. It does not require the use of dangerous chemicals and is quick to set up. Sterilisation kills pathogens which cause disease, and also kills many weed seeds, insect eggs and pupae.

To carry out sterilisation of soil by solarisation follow these procedures:

- Cultivate and level the surface, if the soil is bare. Remove any rough sticks or stones, and cut short any plant growth, if there is any.

- Make sure the soil is moist so that the heat will be moist.

- Cover the area with clear plastic film; ensure that the edges are held down with soil, bricks, etc., so that air cannot get under the sheeting and it cannot blow away or tear easily.

- The temperatures reached in summer will exceed 50°C and after a few weeks, the soil will be sterilised to several centimetres, and can be used for planting.

- The same method can be used to kill persistent weeds like couch grass which are cooked by the heat under the plastic.

In winter, this method takes longer to work and, depending on the winter temperatures, may not be so effective as in summer.
5.7 SUMMARY

• Temperature in the topsoil changes rapidly, but becomes more stable with depth.

• Roots are damaged in hot soil and cease to uptake nutrients in cold soil.

• The pattern of soil temperatures is largely determined by latitude, altitude and distance from the coast.

• Heat absorbed from the sun is called radiation.

• Heat is conducted through air faster than through water, so dry soils heat up and cool down faster than moist soils.

• Heat is conducted further through moist soils, so moist soils warm up to a greater depth than dry soils.

• In winter, wet soils will be colder than better-drained soils.

• Sandy soils heat up and cool down faster than clay soils. Clay soils retain moisture so are colder in winter than sandy soils.

• Organic matter is not a good conductor of heat, so mulch keeps the soil cooler in summer.

• Dark soils heat up faster than light coloured soils. Black plastic is used to warm soil in spring for strawberries.

• Slopes facing the sun heat up faster than flat areas or soil sloping away from the sun.

• Careful species selection is the best way to avoid frost damage in susceptible areas.

• Use shadecloth to shelter sensitive ornamentals from slight frost.

• Frost can be minimised by sensors which turn on sprinklers when temperatures fall to critical levels.

• Soils may be sterilised to kill pests, pathogens and weeds by solarisation. Moist soil is covered by clear plastic and left to heat up during very hot weather.
CHAPTER 6

WATER IN SOIL

6.1 INTRODUCTION

When water is added to dry soil, some of the water drains through as it is drawn downwards by the force of gravity. However, not all of the water passes through the soil under the influence of gravity; some is retained.

6.2 EFFECT OF PORE SIZE ON THE SOIL WATER CONTENT

The water that is retained in the soil against the force of gravity is held in the soil pores by capillary forces. The size of the capillary force depends on the size of the soil pores. Soils with large pores, that is, macropores, have small capillary forces and so can hold only small amounts of water. Sandy soils have large pores, so do not hold much water.

Water from a tank flows out of the tap under the influence of gravity. The same force of gravity pulls water down through the soil.

Capillary forces draw water up thin tubes against the force of gravity. Capillary forces also occur in soils where they stop some water from draining through.

Fig. 6.1 Principles of water retention in soils
Soils with small pores that is, micropores, have large capillary forces and so can retain large amounts of water. Clay soils have these small pores and so can hold a lot of water. When water is added to clay soils, a large amount is retained and only some drains through. Clay soils hold between three and six times the amount of water that the same volume of sandy soils holds.

![Diagram showing water retention in clay and sandy soils](image)

**Fig. 6.2 Effect of pore size on water-holding**

### 6.3 WATER-HOLDING CAPACITY OF SOIL

The amount of water that a soil can hold against the force of gravity is called the field capacity.

To understand the idea of field capacity, think about what happens when rain falls onto a dry soil. When the rain begins to fall, it soaks into the ground and begins to fill up the pores between the soil particles. If the rain continues to fall, the soil will become completely saturated, with all the pores being full of water.

Field capacity refers to the amount of water in a soil saturated by rainfall or irrigation then drained freely under gravity.
Saturated soils are waterlogged and are unsuitable for plant growth because there is no air in the soil. Without air the plant roots cannot get any oxygen for respiration which produces energy for growth. If the soil stays waterlogged for several days, the roots of many plants may be killed and the plants will wilt and die.

After the rain stops, some water will evaporate if temperatures are high, while more water will be drained away by gravity. This water which drains away will be replaced by air, bringing oxygen back to the roots.

Water drains from the large pores first because the capillary forces in large pores are small. The small pores hold the water because they have large capillary forces. At field capacity, the small pores hold water and the large pores contain air.

Although gravity is unable to drain the small pores, plant roots are able to suck the water out of many of the small pores. Much of the water in the small pores is available for plant use. As the plants begin to use the water in the soil at field capacity, the water remaining in the soil is left in smaller and smaller pores. As the plants keep taking water from the soil, a stage is reached when the plant is unable to extract any more water. At this stage the plant begins to wilt. At temporary wilting point, plants can still recover, but at permanent wilting point, water is held so tightly that plants become too stressed to extract the water. There is considerable species variation in the capacity to extract water under conditions of stress.

Figure 6.3 illustrates ‘Soil Saturation’, ‘Field Capacity’ and ‘Permanent Wilting Point’.

Soils differs in the amount of water that they hold at permanent wilting point. A clay soil at permanent wilting point may have an amount of water equal to 20% of its weight. This relatively large amount of water is held because the tiny pores in the clay hold the water too tightly for the plants to extract it.

Loamy soils retain between 10 and 15 percent of their weight of water at permanent wilting point. Because they have larger pores than clay soils, they do not hold on to the water as tightly as clay soils, so plants are able to extract more water from them.

In sandy soils there are only a few small pores, so plants can extract most of the water from them. Thus, at permanent wilting point, sands only contain about three percent of their weight of water.
Large and small pores filled with water. No air.

Water forms a film around large particles and fills micropores. Air in macropores.

Water is still in the soil but it is held tightly within and on particles.

SATURATED SOIL

In saturated soils all the pore space is filled with water.

There is no air present. Soils in this condition are unsuitable for plant growth.

SOIL AT FIELD CAPACITY

At field capacity the soil is holding all the water that it can against the force of gravity.

The larger particles are surrounded by a film of moisture. The small pores are still filled with water. Air is available for the roots from the large pore spaces.

SOIL AT WILTING POINT

At wilting point there is still water in the soil, but it is held too tightly to be available to plants.

Fig. 6.3 Water-holding in soils
Fig. 6.4 Water availability in soil at field capacity

Note: It should be remembered that a diagram such as this cannot be drawn to scale because humus and clay are microscopic compared with sand. The purpose of this diagram is to illustrate the processes.
6.4 EFFECTS OF LACK OF AVAILABLE WATER

Plants become stressed from lack of water. Most of a plant is actually water, carrying many nutrients, sugars, hormones, etc., in solution. Cells are kept fully extended or turgid by water, and the latter is essential to keep the plant cool. Lack of water causes serious harm to the plant’s processes. The tolerance of plants to lack of water varies enormously with genera and species. Consider the water needs of ferns, hydrangeas, roses, bottlebrushes and spinifex. In Western Australia, lack of available water may be short-term and temporary, or a permanent seasonal situation. Selection of plants in horticultural situations must take this into account.

Plants seasonally adapted to water stress have developed characteristics such as leathery grey leaves, needle leaves, leaves covered in fine hairs, etc., to reduce water loss in adverse conditions. Some plants die down to underground storage organs such as bulbs and tubers. Still others survive as seeds.

Plants faced with sudden water shortage close their stomates to prevent water loss through transpiration. If additional water is not made available quickly, the cells lose turgidity and the plant wilts. This is called the temporary wilting point. But, depending on its species and the age of the plant, watering will revive it. Some plants, which are particularly susceptible, will wilt during a hot day then revive at night, because their roots cannot take up sufficient water even though it may be present in the soil. Seedlings and recently transplanted plants are always more vulnerable to water stress, and special care must be taken. Once wilting occurs, growth processes slow down or cease, so it is important that production crops such as flowers and vegetables do not wilt, as their quality will be rapidly affected.

If water stress is prolonged then permanent damage to the plant will occur. This is permanent wilting point. Watering will not bring about recovery, though some perennial plants may shoot again from buds lower down the stems.

If plants are regularly stressed before reticulation takes place, then:

- growth will be reduced;
- yields of flowers and fruit will be smaller and of poorer quality;
- the foliage and display from amenity plants will be much poorer;
- some species will drop flowers and fruit to save moisture;
If water stress becomes severe and prolonged, then:

- shoot tips will die;
- buds, flowers and fruit will drop;
- the death of the plant will occur.

Therefore, it is important that only plants adapted to water shortage are planted in areas where irrigation will not be applied regularly in the summer. Many native plants in parks and gardens do not need water once established and they will not be stressed by heatwaves in summer. Plants that are sensitive to water loss need to be located together to save water and simplify reticulation. Careful siting and the use of mulches will also make the best use of the water applied.

6.5 PLANT CULTURAL PRACTICES TO ENSURE MOISTURE RETENTION

Water that is applied slowly and carefully is more likely to infiltrate and be retained than water that is applied carelessly or falls as very heavy rainfall. Soils with poor wettability need to be treated. Sloping land used for production horticulture and large landscaping schemes needs to be cultivated carefully and contour banks etc. installed to prevent rapid runoff and to encourage infiltration.

Different types of irrigation devices suit different soil types and produce different water movement patterns. Drippers concentrate water over a small surface area but it is able to percolate to some depth. In clayey soils, this water is absorbed and held by the clay particles so that the water moves out laterally as well, while sandy soils would allow a much more rapid percolation of water to a greater depth. Sprayers and sprinklers spread water over a much greater area but water infiltration can be patchy or lost as run-off if the soil is non-wettable. Distributing the water with sprayers prevents the water being directed rapidly to a much greater depth. The types of plants being irrigated also affect the choice of irrigation method, and it needs to be cost effective.

Soil needs to be kept free of weeds which take a lot of the available moisture in the top few centimetres of the soil. This water is lost to horticultural plants if the weeds are left.

To ensure moisture retention:

- Water may be applied to soils by dripper reticulation or by some type of sprinkler or sprayer device. Water applied by drippers soaks into the ground with less evaporation loss, but is not appropriate to all plants; for example, drippers are used on shrubs but not on annuals.
Water in Soil

- Water will be retained if the soil has good water-holding capacity, which sandy soils do not naturally have.

- Organic matter should be added to the soil to improve structure and porosity so that more water is retained as the number and variety of pore spaces are increased. The exception to this is in areas being prepared for high quality turf.

- Remove weeds.

- Treat soil if non-wettable.

- Install banks along the contours to slow down run-off, increase infiltration and prevent erosion.

- Mulch the soil to protect the surface from heat, reduce evaporation and keep the roots cooler. As it is broken down, it contributes slowly to the organic matter content of the soil. Mulches can, however, become caked hard and actually prevent infiltration, so they need to be checked and loosened when necessary.

6.6 EFFECTS OF WATERLOGGING

Water in soils may also be too much of a good thing. If there is poor drainage and a loss of aeration to the roots, plant growth will suffer.

Simply, waterlogged plants are deprived of oxygen at their roots. This oxygen is essential for the production of energy for growth in a process called respiration. Waterlogged plants grow slowly or stop growing, leaves turn yellow and fall prematurely, roots at depth will rot or become diseased and new roots may appear near to the surface of the media.

Problems related to excess moisture include the following.

- Waterlogging may occur in clay soils and in peaty soils in poorly drained swampy areas.

- Sandy soils over clay subsoils are also prone to waterlogging, as happens in many of the wheatbelt areas of Western Australia.

- Some of these soils may be able to be drained into lower lying areas, though often taking the nutrients previously applied to the soil into the wetland system.
Some of the peaty soils in Perth can only be cropped in the summer.

Waterlogged soils have a greater chance of becoming saline, because the salts are not leached out into the deeper subsoils.

6.7 PLANT CULTURAL PRACTICES TO PREVENT WATERLOGGING

If an area is very low lying, then it is probably not possible to drain it effectively and it will always be flood prone. However, some areas of waterlogging can be improved:

- Install drainage systems to drain the excess water to a larger drainage system. However, problems can result if other areas become more susceptible to flooding or the nutrients are leached into wetlands.

- Relieve compaction if waterlogging is caused by a hardpan layer. Subsoil hardpans can be ripped to allow better drainage.

- Choose crops carefully, and possibly only crop during the summer when the moisture will be an advantage.

- Choose amenity plants carefully for wet areas as there are many species suitable for bog and water gardens.

- In the Wheatbelt of Western Australia, waterlogging is often associated with a rise in salinity. River catchments need carefully designed management schemes.

- Plant tolerant trees (which are good pumps) to possibly lower the watertable.

6.8 SUMMARY

- The process of water soaking into the soil surface is called infiltration.

- Water is retained in micropores by capillary forces.

- Water drains through macropores by gravity.

- Clay soils hold much more water than sandy soils, which are free-draining.

- Field capacity is the amount of water held in soil drained under gravity after rainfall or irrigation.
• Saturated or waterlogged soils are deprived of oxygen because they cannot drain freely.

• Water that can be absorbed by plants is called available water.

• Water in the soil that is held too tightly for plants to absorb is called unavailable water.

• Plants deprived of water close their stomates and wilt. The first stage of wilting is temporary wilting point, and the plants will recover at night or if watered.

• If plants are deprived of water long enough to damage tissue then permanent wilting point has been reached and the plant will be damaged and may die.

• Some plants, like Western Australian native plants, are adapted to water stress.

• Some sandy soils are non-wettable because of resins from organic material.

• Water soaks down quickly into sandy soil, but is more likely to spread out laterally in clay soil. Depending upon the crop, sandy soils are better watered with sprinklers to spread the water over the surface, while clay soils are better watered with drippers.

• Coarse-grained mulches reduce evaporation and improve infiltration, but some fine mulches can cause surface crusting and reduce infiltration.

• Waterlogging may occur in clay soils that are poorly drained, but also over hardpan layers and in compacted soils.

• If possible, waterlogged soils need to have the drainage improved to improve aeration.

• Waterlogging can be associated with increased salinity.
CHAPTER SEVEN

SOIL ACIDITY AND ALKALINITY

7.1  INTRODUCTION

Biological systems involve very complex chemical processes at the cell level. All of these chemical processes take place in water.

The chemistry of water is central to all life processes as we know them. All organisms are mostly made up of water and all biological processes involve water, either directly or indirectly.

The balance between acidity and alkalinity has a profound effect on many chemical and biological processes that take place in soils. Some organisms have preference for slightly acid conditions, while others prefer slightly alkaline conditions.

Acidity and alkalinity are two aspects of one important property of water, whereby molecules of water can split to form hydrogen ions and hydroxide ions.

If equal numbers (or concentration) of hydrogen ions and hydroxide ions are formed, then the aqueous solution is said to be neutral. If there are more hydrogen ions, then the solution is \textit{acidic}. If there are more hydroxide ions, then the solution is \textit{alkaline}.

As a solution becomes more acidic, it also become less alkaline - and vice versa. Soils are also described as being acidic or alkaline, depending on the hydrogen and hydroxide ion concentrations of the soil solution (the water in the soil). Rain in slightly acid due to the presence of dissolved carbon dioxide. Ground water is often slightly alkaline due to the presence of dissolved salts.

7.2  CAUSES OF SOIL ACIDITY

There are several causes of soil acidity:

- leaching of calcium, magnesium and sodium, which increase alkalinity;
Soil Acidity and Alkalinity

- crop uptake of nutrients;
- acid-forming fertilisers;
- acid rain;
- development of soils on acidic parent rock; for example, granite;
- adding organic matter, especially strongly acidic kinds such as pine needles and peat.

Soils tend to become acid as nutrients are removed from them by plant uptake or by leaching. Under natural forest, very few nutrients are removed in this way, and those that are lost are usually replaced by weathering of parent material. Clearing land for agriculture accelerates the depletion of nutrients by both leaching and crop removal. Agriculture causes soil acidity. There is no recycling when crops, including turf clippings, are removed.

Some fertilisers release acidity when they are broken down by soil organisms. The ammonium fertilisers, urea and sulphur, are very strongly acid forming. Great care should be taken if using sulphur to adjust soil pH, and it should not be used excessively as a fertiliser because it is acidifying. It occurs in many compound fertilisers; for example potassium sulphate, magnesium sulphate, and sulphate of ammonia. Intensive agriculture relies heavily on high applications of nitrogen fertilisers and this is probably the most potent cause of soil acidity.

Rain is slightly acid due to dissolved carbon dioxide and, to a lesser extent, sulphur dioxide and nitrogen oxides. Industrial pollution of the atmosphere has greatly increased the levels of these acid-forming gases, and consequently, the rate of soil acidification.

Soil acidity is a human problem in that it threatens our food supply. It is also a human problem in that it is largely caused by our agriculture and industry.

### 7.3 CORRECTION OF SOIL ACIDITY

Soils differ in the rate at which they become acid or alkaline. Coarse-textured soils (sandy soils) become acid much more quickly than do fine-textured soils. This is due to the much higher surface area of fine-textured soils and to the colloids in them, which resist rapid change of pH. Soils like this are referred to as having a high buffering capacity, while sandy coarse-textured soils have a low buffering capacity (that is, a low capacity to resist change in pH). This factor is significant both in the acidification of soil and in the correction of soil acidity.
Soil Acidity and Alkalinity

- Sandy soils become acidic more quickly than do clay soils.
- Sandy soils require less lime to correct acidity than do clay soils.

There are a number of liming materials used to correct acidity in soils. They all do the same thing and so the cheapest and safest should be used. Agricultural lime is usually a mixture of calcium and magnesium carbonate, and is obtained by crushing limestone. Limestone, with a mix of calcium and magnesium carbonates, is chosen, as this provides two essential nutrients (Ca and Mg) as well as neutralising soil acidity.

The limestone is crushed to a sandy consistency to provide a material which is convenient to handle and which will dissolve and act fairly promptly. If crushed too finely, the limestone is difficult to handle. If too coarse, it takes too long to react. Over-liming should avoided.

7.4 CAUSES OF SOIL ALKALINITY

There are several common causes of significantly high soil alkalinity:

- over-liming;
- use of alkaline irrigation water;
- alkaline material buried on domestic and commercial building sites;
- development of soils on alkaline parent rock, for example, coastal limestone;
- development of soils in arid and semi-arid areas (for example, the north west of Western Australia).

The first two should be avoided, as the correction of soil alkalinity is difficult and expensive. Caution in the use of lime has been mentioned above. Alkaline or saline water should not be used for irrigation except under very carefully controlled conditions. This requires expert management, with frequent testing of soil and water, and is not economic in most cases.

Soil alkalinity can result from the effects of saline and alkaline water from irrigation or rising ground water. The sodium associated with alkaline soils leads to structural instability and slow drainage.
7.5 CORRECTION OF SOIL ALKALINITY

Soils which have become alkaline by over-liming may be corrected by the addition of large quantities of organic matter which is naturally acidic, and by ensuring free drainage to leach the lime from the soil. Use of nitrogenous fertilisers will gradually lower the pH of over-limed soils.

Small quantities of soil may be treated with acid-forming agents such as sulfur. This is neither feasible nor desirable in field situations, but may be used in specialised horticultural situations.

Soils which have become alkaline from irrigation or rising ground water need to be drained and irrigated with good quality water. This is not always feasible, so reclamation of these soils often involves progressive re-forestation.

Naturally alkaline soil can be improved by the addition of organic matter. Careful selection of the right lime-tolerant species is very important.

7.6 DEFINITION OF pH

The pH scale is used to describe the presence of acidity or alkalinity in solutions. As one increases, the other decreases:

- acidity arises from the presence of hydrogen ions;
- alkalinity arises from the presence of hydroxide ions.

The concentrations of hydrogen and hydroxide ions in water in biological systems are extremely low, but still very important. The logarithmic pH scale is used as a simple and convenient way of describing the hydrogen concentration in a solution. This means that for each figure, the concentration is ten times stronger than the previous one; for example:

\[
\text{pH 5 is 10 times more acid than pH 6}
\]
\[
\text{pH 4 is 100 times more acid than pH 6}
\]

The pH Scale

pH is a measure of acidity or alkalinity. On a pH scale from zero to fourteen, seven is neutral. In other words, pH seven is neither acidic nor alkaline. A pH value of less than seven is acidic and the lower the value, the more acid the solution. A pH value of more than seven is alkaline and, the higher the value, the more alkaline is the solution.
Fig. 7.1 The pH scale in relation to horticultural crops

(Only the part of the scale that is relevant to the measurement of soil reaction is shown.)
7.7 EFFECT OF pH ON PLANTS

Plant roots can be damaged by pH below about 4.5, or above about pH 9. This is a direct effect, but there are more subtle effects of pH on plants. Low pH can decrease plant growth by:

- reduced availability of nutrients, particularly phosphate and molybdate;
- increased solubility of toxic elements in soils, particularly aluminium and manganese;
- inhibited release of nutrients from organic matter because the activity of micro-organisms is reduced.

High pH can decrease plant growth by:

- decreased availability of trace elements, particularly iron, manganese, zinc;
- decreased availability of phosphate;
- damage to soil structure.

The optimum pH range varies for plants. As a general rule, plants which come from wet, tropical climates do best in acidic to slightly acidic conditions (pH 5 - 6). Plants from temperate climates do best under weakly acidic to neutral conditions (pH 6 - 7). Plants from arid climates are usually adapted to slightly alkaline conditions (pH 7 - 8).

It should be remembered that pH alone does not determine whether plants grow successfully. Physical properties of soils such as structure, fertility and the presence of organic matter, are more important than adjusting pH unless the pH is extreme. Many garden plants grow in a wide tolerance of pH between 5.5 and 7.5, and our gardens would be much less varied if they did not.

However, there are certain plants where the effect of pH is critical. Hydrangeas have blue-toned flowers in acidic soil and pink-toned in alkaline soil, even when the plants are grown from the same stock plants. Well known acid-loving plants include gardenias, camellias, ericas, azaleas and rhododendrons, and special cultural practices must be followed to ensure their success if the soil is not naturally acidic. Carnations grow best in alkaline soils.

7.8 SOIL pH AND NUTRIENT AVAILABILITY

Plants obtain their nutrients from the soil solution, that is, water containing dissolved nutrients. Plant roots absorb nutrients as ions, and all fertilisers whether organic or inorganic must be broken down to their ionic form before they can be absorbed. Mineral salts used in fertilisers are electrically charged...
combinations of ions that separate when dissolved in water, and so then become available to plants. The solubility of different nutrients depends on a number of factors of which pH is one of the most important. The relationship between pH and nutrient availability is rather complex and differs for individual nutrients or groups of nutrients.

Figure 7.2 gives an indication of the availability of plant nutrients in soils as influenced by soil pH. The width of the bands gives an indication of the availability of each nutrient at that pH. The wider the band, the higher the availability.

![Nutrient availability diagram](image)

**Fig. 7.2** Nutrient availability in field soils in relation to pH

### 7.9 PLANT GROWTH AND NUTRIENT AVAILABILITY

The soil reaction affects plant growth in three ways:

1. Plants have different tolerances to soil reaction. Some plants like an acid soil when the pH level is low; others prefer a neutral soil, while still others prefer an alkaline soil where the pH level is high.
2. Soil reaction affects the activity of micro-organisms and hence the rate of organic matter decay.

3. Soil reaction affects the solubility of plant nutrients. Different nutrients are affected in different ways.

The list below summarises the way in which the availability of nutrients is affected by the pH of the soil. This list is for reference only.

- Nitrogen availability decreases when the soil pH falls below 6. This is because the activity of micro-organisms decreases when the pH falls below 6.

- Phosphorus availability is reduced at low pH levels (that is, in highly acid soils) because it forms insoluble compounds with aluminium, iron and manganese. The availability of phosphorus is also reduced at high pH levels because the phosphorus combines with calcium. The availability of phosphorus is greater when the pH is 6.5.

- Sulfur availability depends on microbe activity and so, under acid conditions, sulfur can become unavailable.

- Calcium and magnesium become unavailable under acid conditions because they are leached out of the soil. Under alkaline conditions, such as when the pH is greater than 8.5, calcium and magnesium can again become unavailable, because their places on the surface of the colloids are taken by sodium ions.

- Iron, manganese, zinc and copper all show their greatest availability in acid soils. When the pH of the soil is greater than 7 (that is, in alkaline soils), then these all form insoluble compounds and become unavailable. When the pH is less than 5 (that is, in acid soils), then these elements may become so soluble that they become toxic. This is especially so with manganese and also with the element aluminium.

- Molybdenum becomes unavailable under acid conditions.
On the whole, a pH of 6.5 provides the most favourable conditions for the supply of all plant nutrients so long as there is enough of the nutrient in the soil.

7.10 SOIL SAMPLING TECHNIQUES

It is not sufficient simply to grab a handful of soil from a garden bed or scratch it out from under some patch of turf and then test it. The final sample to be tested needs to be made up from a number of core samples taken through the depth of the topsoil in the area.

- Cores can be taken with a thin-walled tube, an auger, or with a spade or trowel, taking the sample from the depth of the topsoil; for example, 10 - 15 centimetres. At least 15 cores should be taken from an area the size of a golf green.

- Don’t include subsoil with topsoil.

- Remove the surface layer (1-2 centimetres) if it contains fertiliser granules or undecomposed organic matter.

- Soil at the top of a slope will be different from that at the bottom and should be tested separately. Keep the cores from each area separate.

- Combine the cores for an area by thorough mixing on a sheet of clean polythene. Take a sample to test. Depending on how many tests are to be done on each sample, a few hundred grams is usually enough. If it is to be sent away for testing, it will need to be dried. Follow the instructions of the laboratory.

Always make sure that all tools, containers, and your hands are clean - no traces of fertilisers, pesticides, etc. - which will alter the readings.

7.11 TESTING SOIL pH IN THE FIELD

An indication of the pH of a solution can be obtained by adding a dye to it which changes to different colours at different pH. There are a number of such dyes, called indicators, which tell whether the pH is above or below a certain value. Indicator solutions can be used to indicate soil pH by mixing a sample of
Soil Acidity and Alkalinity

soil with water and then dipping some indicator paper into the water. It is cheap and easy, but the colour of the soil extract can make comparison of the colours difficult.

The Colorimetric Method

A convenient field pH test kit has been developed and is commercially available. It uses a mixed indicator solution to develop a colour according to soil pH, and an inert white powder to provide a background against which this can be observed.

A small sample of the soil to be tested is mixed with a few drops of the indicator solution for a minute or so. The soil-indicator mix should be just wet enough for the surface to glisten. After waiting a few minutes for the colour to develop, the wet soil is sprinkled with the white powder. The coloured solution soaks into the powder, giving a clear indication of the pH by comparison with the colour chart provided. It is cheap, convenient, accurate and reliable. Table 7.1 illustrates the relationship between the pH level and the colour indicated by the test.

<table>
<thead>
<tr>
<th>pH</th>
<th>COLOUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.0</td>
<td>PURPLE</td>
</tr>
<tr>
<td>8.5</td>
<td>GREYISH-PURPLE</td>
</tr>
<tr>
<td>8.0</td>
<td>PURPLISH-GREY</td>
</tr>
<tr>
<td>7.5</td>
<td>GREENISH-GREY</td>
</tr>
<tr>
<td>7.0</td>
<td>GREYISH-GREEN</td>
</tr>
<tr>
<td>6.5</td>
<td>MID GREEN</td>
</tr>
<tr>
<td>6.0</td>
<td>LIGHT GREEN</td>
</tr>
<tr>
<td>5.5</td>
<td>YELLOWISH-GREEN</td>
</tr>
<tr>
<td>5.0</td>
<td>GREENISH-YELLOW</td>
</tr>
<tr>
<td>4.5</td>
<td>YELLOW</td>
</tr>
<tr>
<td>4.0</td>
<td>ORANGE-YELLOW</td>
</tr>
<tr>
<td>3.5</td>
<td>ORANGE</td>
</tr>
</tbody>
</table>

Fig. 7.1 pH kit colour chart
7.12 SUMMARY

- Soils may be made more acidic by the addition of organic matter and fertilisers, and by the leaching of calcium and magnesium. Soils formed on granite are naturally acidic.

- Acidic soil can be treated with lime to raise the pH.

- Soils may be made more alkaline by overliming and the use of alkaline irrigation water. Soils formed on limestone and in desert areas are naturally alkaline.

- Alkaline soils can be improved with organic matter or leached with non-alkaline water if available.

- It is easier to alter the pH of a sandy soil than a clay soil.

- pH is measured on a scale. Under 7 is acidic, 7 is neutral, and above 7 is alkaline. pH 5 is ten times more acidic than pH 6.

- Extremes of pH (below 5 and above 8) affect the availability of nutrients. Acidity particularly affects the macronutrients and molybdenum, while alkalinity particularly affects the micronutrients.

- The rate of decomposition of organic matter is reduced at extremes of pH.

- Many plants are tolerant of pH ranges from 5.5 to 7.5 so long as other growing conditions are met. Certain plants including azaleas need acidic soil and the colour of hydrangeas is determined by soil pH.

- Soil from an area to be sampled for testing should be taken from a number of core samples then a final representative sample taken from the combined samples.

- pH is most easily tested by the colorimetric method. Indicator dye on the soil stains white powder a distinctive colour which matches the colours on a pH chart.
CHAPTER EIGHT

SALINITY

8.1 INTRODUCTION

Salinity has become an increasingly serious problem throughout the soils and water resources of many parts of the south-west of Western Australia. It has a number of contributory causes, some of which are natural (given Western Australia's climate and physical features), and some of which are the result of past management practices on the part of farmers, government advisers and so on.

A salt is a compound which dissolves in water into its ionic form. Some salts are necessary for plant growth - these are the fertilisers dissolved in ionic form in the soil water which are ready to be taken up by the plants for growth. It is the excess salts that do the harm. Plants and animals have different tolerances to salinity, depending on the species.

In this context salinity describes the presence of sufficient dissolved salts in soil or water to cause harm to plant and animal life.

8.2 CAUSES OF SALINITY

8.2.1 Natural Factors

Every year in the south-west of Western Australia, tonnes of salt are blown inland from the sea by the prevailing southwesterly winds. In areas of high rainfall, the salt is leached out of the topsoil and away from the feeder roots of most plants. However, in dry areas inland this leaching does not take place because the rainfall is too low and too irregular to ensure proper leaching. Although less salt actually reaches inland areas, more of it accumulates in the surface soils.

In Western Australia, summer temperatures are high, so evaporation rates are always high. Moisture is drawn to the surface by capillary action, and the salts accumulate. In a cooler climate, for example, Tasmania, salinity is not a problem because evaporation is so much lower and rainfall is much more regular. Salt which is blown in from the sea cannot accumulate on the surface.
Salinity

In much of inland Western Australia, including much of the Wheatbelt as well as the desert, rivers and creeks drain into inland lakes and wetlands. They do not reach the sea. The chains of lakes and wetlands in the Wheatbelt are part of old river systems when the rainfall in this State was much higher than it is now, and many of these systems reached the much shorter rivers which still flow to the sea. A brief study of a map which shows the State’s rivers reveals this inland drainage quite clearly. Salts in the soils which have been washed into these creeks then drain into salt lakes, so the salt accumulates rather than being flushed to the sea. Many lakes and wetlands in the lowest parts of these drainage basins have been saline since long before European settlement. The problems arise when these areas extend into significantly larger areas and salt contaminates wetlands that were fresh until the last twenty years or less.

Soils in this state are generally very old, so that the salts leached to the subsoils in the past are now at the surface exposed by weathering and erosion, and contribute to surface salinity of soils and run-off.

Salts are a natural part of soils which contain nutrients derived from decomposing organic matter and the weathering of nutrient elements in the soil. Because they are old or derived from old infertile materials, Western Australian soils are low in nutrients, and the dry climate over much of the state, except the southwestern forests, reduces the amount of organic matter available for decomposition. Therefore, the accumulation of salts from this source is not great.

Salts are leached through in ground water draining from higher areas to valleys, so valleys are always more prone to salinity unless there is a good fresh water flow to flush out the salt. If the quantity of salt coming in ground water increases, the valley will inevitably become more saline.

8.2.2. The Human Element

Salt has been present in the Western Australian landscape for thousands of years, but the changes were slow as the climate become drier. A balance was built up between the salt in soils, natural ground water and surface water flow, and the adaptability of specialised vegetation to the salt-affected areas. Aboriginal land management probably had little effect on salinity as land was not cleared, but European settlement led to large scale changes to the balances established.

The use of fertilisers increases the quantity of salts dissolved in the soil water. Many of these fertilisers are applied in excess because some of the salts are susceptible to leaching in sandy soils and are therefore lost before they can be
absorbed by plants. These salts accumulate in subsoils and are leached into ground water and into creeks and rivers, causing algal blooms and general loss of water quality.

Some aspects of domestic and commercial horticulture and agriculture require irrigation, if they are to be successful, for example, market gardens, floriculture, improved pasture and golf courses. When combined with fertiliser application, irrigation increases the leaching of salts into the water table.

The demand for irrigation water has reduced the overall quality of water available in some areas. Water in some dams originates in brackish and saline streams in the Wheatbelt and, if this salt is not sufficiently diluted by fresh water from the forested areas, the water becomes too salty for irrigation, domestic use and for stock. Rivers that rise in the Wheatbelt are becoming too salty for dam catchments and there are only limited rivers in the Darling Range and the Southwest which are suited to dam construction.

Irrigation from ground water gives better quality water in many places in the Southwest while in some areas the water is becoming brackish. In fact, the use of ground water is now part of the much wider issue of water resource management to ensure water quality for domestic, agricultural and commercial use.

Salinity caused by cultivation and overclearing has become the big issue in many areas of Western Australia, as salinity increases and the consequences are felt over a much greater area of the state. This is treated in detail at the end of this chapter.

### 8.3 SOIL SALINITY AND PLANT GROWTH

The effects of salinity on plant growth depend on two main factors:

- the concentration of salts in the soil water;
- the susceptibility of the plant to salinity.

Salinity affects plants by these processes:

- the structure of the soil; that is, the aeration and drainage properties of the soil, are destroyed and plant growth is limited;
the roots and tissues are damaged by salts;

water uptake is prevented by exosmosis, even when there is adequate water available.

Roots absorb water by osmosis, which means that water flows from an area of high concentration (the purer water in the soil) to an area of lower concentration (the less pure water in the cells where nutrients are concentrated by uptake by the roots). When salinity is high, the concentration of salts in the soil solution exceeds that in the roots, and water does not flow into the root cells. This is termed exosmosis. See Figure 8.1.

(a) Movement between soil water and a root hair cell

(b) Exosmosis in saline soil water conditions

Fig. 8.1 Water uptake
When exosmosis happens, the plant will quickly show stress symptoms such as these.

- Stomates close to prevent water loss.
- The plant wilts.
- When the salt concentration in the leaves rises, leaf scorching or burning occurs, especially around the margins of the leaves - which become chlorotic, then die.
- Roots are damaged and become vulnerable to disease.
- If the salinity continues, then there will be
  - slow growth,
  - stunting,
  - death of shoot tips, and finally
  - death of the plant.

In a salt scald situation, trees and shrubs are affected in the same way, as their roots are in a brackish or saline solution to which they are not adapted. Dead trees surround salt-scald areas and freshwater wetlands that have become saline.

**Salinity in Commercial Horticulture**

Sudden, excess salinity occurs if:

- fertilisers are not diluted or applied properly; or
- water used to dilute fertiliser already contains salts, so that the total solution is saline; or
- saline or brackish irrigation water is used, especially after fertiliser is applied.

This particularly applies to liquid feeds so that the roots are in a soil solution that is far too strong for them. Susceptible plants will be affected very quickly. Slow release fertilisers are far safer.
8.4 MEASURING SALINITY

Salinity is measured by an instrument called a conductivity meter. There is some difference among types, but in simple terms an electrode is placed into water or water extracted from a soil sample. The reading on the meter indicates salinity. Many nurseries, high schools and landcare groups have their own meters, but samples can be tested commercially or by the Department of Agriculture.

8.5 REDUCING SALINITY IN HORTICULTURAL SITUATIONS

To reduce salinity in horticultural situations, the following guidelines should be followed:

- Control the use of fertilisers so that they are not used to excess or used at the wrong dilution rates.

- If fertilisers have been applied in excess, leach immediately with water of low salinity to wash the fertiliser off the leaves and dissolve and/or dilute the solution.

- On plants that are sensitive, use only water that is not above a harmful level of salinity.

- Where water contains dissolved salts, use dripper rather than sprinkler reticulation because brackish or saline water will do more harm on leaves than it will on the soil under the plants, depending on the species.

- If the water has a tendency to salinity, mulch to keep the roots cool and reduce evaporation. This lessens the need for watering and reduces the accumulation of salts.

- In marginal areas of poor water quality, only salt-tolerant species can be grown. Lists are available of plants which are tolerant to increasing levels of salinity.

Remember that any salts leached from containers or soil must go into the subsoil, groundwater or drains. This is economically wasteful and environmentally unfriendly. Some Australian States are now beginning to monitor the leachates from nurseries into streams and drains.
8.6 SALT TOLERANCE IN HORTICULTURAL PLANTS

Tolerance to salinity among common horticultural plants can vary from those which are very sensitive to those which are adapted to salinity in their natural environment. Tolerance is not equal among members of the same species; thus, selected varieties and cultivars may show special tolerance and have great value in reclamation situations. Some species are tolerant of salt on their leaves as salt spray at the coast, if their roots are uptaking fresh water under the dunes. Others have adaptations in their roots so they can filter salts out and uptake only fresh water into the xylem. Others excrete salts through their leaves.

The following lists indicate some common plants that have varying degrees of sensitivity to salts in fertiliser application, irrigation water or in the media itself.

Sensitive to Very Sensitive

Avocado, African violet, asters, begonias, camellias, carrots, dahlias, fuchsias, lettuce, onions, pelargoniums, roses, strawberries, stone fruit.

Some Tolerance

Agapanthus, beetroot, bottlebrush, carnations, cabbages, citrus fruit, figs, grapes, junipers, oleanders, olives, Queen palms, pome fruit, potatoes, tomatoes.

Tolerant to Very Tolerant

Many widespread native genera have salt tolerant species, for example, in the Eucalyptus, Melaleuca, and Acacia genera.

Melaleuca cuticularis, M. nesophila, Acacia cyclops, as well as Norfolk Island Pine (which is tolerant of sea spray), date palm, pigface and iceplants, saltbush, spinifex.

(These lists have been adapted from a much more detailed appendix in Growing Media for Ornamental Plants and Turf, Handreck and Black, NSW University Press, 1991. Detailed information of species suitable for Western Australian country areas are available from the Department of Agriculture, CALM, and Greening Western Australia.)

8.7
8.7 SALINITY - A PROBLEM FOR THE STATE

The Effects of Overclearing

As salinity increases, more farm land becomes saline and useless. Many more areas become waterlogged, but fresh water supplies are reduced as streams and lakes become salty.

Increasing salinity is a complex process with several interacting factors, including time. Much of the damage was done 30 to 50 years ago when clearing for farming was widespread, but it has taken years for the salt and water balances to become so disturbed as to cause widespread salinity beyond the limits of the salt lakes established thousands of years ago.

Prior to Clearing

Variations occurred relating to total rainfall, slope angles and depth of soil, but there is a generalised progression. Taking a cross-section of a typical valley, there are three aspects to the water balance - input, output, and storage:

- Input rainfall
- Output evaporation and transpiration (or evapo-transpiration), and run-off into the stream
- Storage watertable

The surface water remained fresh and the salts were stored after leaching in the subsoils above the watertable.

In the situation shown in Figure 8.2 the balance between input, output and storage is maintained.
Fig. 8.2 Valley before clearing

After Clearing

Cropping was initially successful in the topsoil from the woodland and heath areas. However, annual transpiration rates drop dramatically when crop land is bare of living plants in summer. Moreover, evaporation increases because the soil is bare, and it leaves a dry surface that is susceptible to erosion by storms and strong winds.

Without the trees and shrubs that are adapted to survival, with their long roots down to the watertable and their high transpiration rates in the hot summers, the underground watertable rises and dissolves the salts previously stored or slowly leached to underground streams. After many years, the saline watertable rises to intersect the surface stream, turning it saline, particularly in summer when there is no surface run-off. As the quantity of saline water increases, the land on either side of the creek becomes contaminated with salt, and a salt scald develops.
Figure 8.3 shows that the balance between input, output and storage has been lost.

Fig. 8.3 Change in water balance after clearing and cropping
Once the balance between input, output and storage has been lost, it is very difficult to restore. Considerable costs may be involved in planting trees, erecting fences to protect them and establishing groundworks such as interceptor banks and drains. Each catchment area needs a management plan for individual problems, and the co-operation of all those affected is desirable.

8.8 SUGGESTED SOLUTIONS ON A LARGE SCALE

If trees are replanted, they will take up and transpire huge quantities of water as they mature. This is a long-term project and considerable research has been done to find the species best able to tolerate being planted close to salt scald areas. It is also desirable to find species that are able to transpire the greatest quantities of water.

The theory is that the new trees will take up and transpire huge quantities of water and will lower the watertable. The salts will then leach down into the subsoil above the watertable and be stored, or move down into deeper watertables below the lowest levels of the valley. Eventually, some streams higher in the catchment area will become fresh, and fresh water lakes can be saved before the environment is destroyed.

However, it will take a lot of trees and a lot of time for them to grow large enough to be effective. In difficult economic times, associated costs for items such as the trees themselves, fertiliser, fences or tree guards, watering and the construction of interceptor banks and drainage systems will all reduce the amount of work done in replanting.

Progressive lowering of the watertable by trees acting as pumps could, in time, reduce the salt land areas. See Figure 8.4.
8.9 SUMMARY

- Salts are compounds which dissolve and separate in water and become available for plants.

- Plant nutrients are available as salts dissolved in the soil water.

- Salinity occurs when there is such an excess of salts that plant or animal life is affected.

- Salinity is Western Australia is caused naturally by: salt blown in from the sea, high evaporation, inland drainage systems, exposure by erosion of old saline subsoils, and ground water drainage into low lying land. Human factors include: overclearing and cultivation, overgrazing, use of excess fertilisers, leaching of fertilisers, and the use of brackish irrigation water.

- Salinity causes damage to plant tissue - wilting, burning of leaf tissue around the margins, and root damage.

- There is a considerable range of tolerance to salinity among horticultural plants.
• Water uptake is prevented by exosmosis because the salt content of the soil water is too high.

• Salinity can be caused in a commercial situation by: fertilisers not diluted or applied correctly, use of slightly saline water to mix fertilisers, brackish or saline irrigation water.

• Dilute and apply fertilisers carefully to avoid waste and excessive leachates entering streams or the watertable.

• Salinity is measured by an instrument called a conductivity meter. An electrode is placed in water or water extracted from saturated soil to give a reading of the salts content.

• Overclearing destroys the balance between input, output and storage in the hydrological cycle of an area.

• In the Wheatbelt, clearing trees meant that transpiration rates fell and the water table rose, dissolving the salts previously stored in the subsoil. The rising water table becomes saline and eventually reaches the surface of the valley floor, causing saline streams, salt scalds and waterlogging.

• Replanting many trees adjacent to salt scalds goes some way towards lowering the water table again, but it is an expensive, long term process. Other techniques include constructing interceptor banks to divert saline water away from land which could be saved.
CHAPTER NINE

ORGANIC MATTER AND ORGANISMS

9.1 INTRODUCTION

The presence of organic matter is the key to turning mineral particles into true soil. Without organic matter and the organisms which feed on it, sand would remain simply sand. Only a small percentage of organic matter is present in most Australian soils, but it is very important.

9.2 ORIGINS OF ORGANIC MATTER

Soil organic matter is made up of all the plant and animal residues in various stages of decomposition, from fresh to the final stage in the soil - called humus. Much is lost through the processes involved in decomposition, and the quantity of organic matter decreases unless it is regularly renewed. In natural forests and grasslands, this happens. However, in cultivated soils, replenishment of organic matter has to be part of the management program for the soil.

Fresh Organic Matter

Fresh organic matter is added to soil through natural means and plant cultural practices.

Natural Means:

- Stems, leaves, flowers, fruit, seed cases, bark, twigs, branches and whole trees - though the latter two take very much longer to decompose.

- Plant roots which are broken or rubbed off in the soil, and the organic matter which is passed out of roots back into the soil. The roots from annual plants at the end of their life cycle, as well as herbaceous perennial plants at the beginning of seasonal dormancy, provide big quantities of organic matter.

- Excreta from animals, birds, insects and the numerous micro-organisms in the soil.
Organic Matter and Organisms

- Bodies of small animals and insects on and in the soil.
- The remains of bacteria and fungi.

Plant Cultural Practices

- Organic matter added as compost or mulch on the surface, or dug into the soil. This may be made up of many combinations of plant materials and manures. As well as the natural sources above, compost and mulch may include organic by-products of human activity, such as:
  - sawdust, bark fines and chips from sawmilling;
  - peat dug from swamps;
  - chippings and shreddings of tree and shrub prunings;
  - lawn clippings;
  - fruit and grape wastes from processing;
  - organic fertilisers such as blood and bone, and fish meal;
  - sewage sludge;
  - green manures - leafy crops grown to be dug in while still very leafy;
  - poultry manure, usually mixed with sawdust or newspaper from intensive deep litter production;
  - stable manure;
  - shredded recycled newspaper;
  - household peelings, tea leaves, etc.
  - commercially prepared ‘organic improvers’ made up of various combinations of the above.
9.3 BREAKDOWN OF ORGANIC MATTER

Soil micro-organisms break down most plant and animal remains in a matter of months. Harder pieces of plant material such as branches, thick bark and whole trees take much longer, sometimes many years, depending on moisture and temperature. As the micro-organisms decompose organic particles, the atoms are used as food and become part of their bodies. Micro-organisms consume other micro-organisms, so there is constant recycling. Hydrogen is converted into water and carbon is metabolised by the micro-organisms during respiration and released as carbon dioxide into the air, so the amount of organic matter from a specific application in the soil is always being reduced. Eventually, most of the organic matter is used up.

Humus

The remaining organic matter resists decomposition, and changes into *humus*. This is a very stable form of organic matter which can last for thousands of years. Humus is a very small, complex particle, which is dark in colour. Under a microscope, it resembles porous sponge. It is probably formed from the most resistant part of plant cell material, called *lignin*. Some clay present in the soil seems to be essential for its development. It is one of the most significant parts of the organic matter of soils as its influence on soil properties such as structure and nutrient-holding is more lasting than the less permanent organic matter which decomposes.

9.4 ROLE OF ORGANIC MATTER IN SOIL

As organic matter is decomposed, nutrients are released from the cells of former plants. The slow rate of decomposition ensures a supply of nutrients, which become gradually available for other plants to use. In an undisturbed forest or grassland, nutrients are constantly recycled in a natural progression. In a horticultural situation, a lot of the potential for natural recycling is lost because of crop harvesting, removal of amenity plants past their best, by pruning, mowing and removing clippings on turf, and the passion to have everything neat and tidy.

A steady supply of organic matter feeds the micro-organisms, ensuring that their populations remain present. Micro-organisms also help to make nutrients available, and their slimes and excreta bind particles into aggregates.
As it breaks down, organic matter combines with mineral particles to form aggregates. These crumbs are the basis of good soil, so organic matter ensures the best soil properties, for example, structure, aeration, drainage, infiltration, water holding, nutrient retention and root penetration. Figure 9.1 illustrates these points.

Fig. 9.1 Soil organic matter improves soil structure
Management of the application of organic matter is important. In a natural situation, leaves, etc., fall gradually or seasonally, and the micro-organisms are adapted to this. Very thick applications of organic matter as mulch in horticultural situations can lead to problems such as the following.

- Water infiltration can be reduced, as much is held in the mulch.

- Mulches, if not coarse enough (for example, lawn clippings, fine sawdust) can pack down, preventing diffusion of air to the soil. Mulches may need to be loosened to allow aeration and infiltration.

- Mulches can harbour pests and diseases (for example, fungi spores, and insect eggs and pupae). The risk of this for susceptible plants must be balanced with the obvious benefits of mulching.

- Too much organic matter dug into soil at once alters the structure too much so that the balance among the four components of soil (mineral matter, air, water and organic matter) is temporarily lost until the organic matter begins to decompose. There is also a high risk of nitrogen deficiency in plants grown in this situation. The micro-organisms feed on nitrogen so will take it from around plant roots to continue decomposing. This is called nitrogen drawdown. (Ref. 9.7)

9.5 COLLOIDS

Colloids are very finely divided particles. In soils, colloids are tiny particles of clay and humus. These particles have very large surface areas because of their small size, complex structure, and enormous numbers per gram of soil. The term ‘adsorb’ is used to describe the process by which matter attaches to solid surfaces. The term ‘absorb’ describes the ability of colloids to hold water within their structure. This is the main difference between sand and colloids, as sand cannot absorb water in the way that clay and humus can. The relative quantity of colloids in soils gives special properties of aeration, drainage, water retention and nutrient holding.

Total surface area increases as particle size becomes smaller. Gravel and sand have a small surface area. Silt particles have a surface area up to 0.05 m²/g. Surface area increases rapidly as particle size decreases into clay.

In summary:

- The surface area of any material depends on the density of the material and the shape of the particles.

- The total surface area in a gram of soil increases as particle size decreases; that is, as the texture becomes finer.
Organic Matter and Organisms

sand

- rounded to slightly angular, smooth individual grains
- small combined surface area
- little adsorption, no absorption

colloids

- microscopic electrically charged particles
- large combined surface area
- high adsorption and absorption

clay

organic matter

- irregular fragments
- large combined surface area
- high adsorption and absorption

humus

- microscopic electrically charged, sponge-like particles
- very large combined surface area
- very high adsorption and absorption

Fig. 9.2 Surface area of types of particles
Some clay minerals have high internal surface area, as their structures can expand concertina-like. Others have structures that allow for diffusion between the layers.

Humus is very complex and may be considered as a porous, sponge-like material of small to very small particle size. It has a very large surface area.

The large surface area of soil colloids accounts for their important and distinct properties. They retain nutrients and water and account for the different properties of fine-textured soils compared with coarse-textured soils. The 0.002 millimetre size limit for the clay fraction was chosen because of the colloidal properties of particles smaller than this.
9.6 NUTRIENT-HOLDING CAPACITY

In fertile, well-structured soils with significant clay and humus content, the colloids are aggregated into stable peds. These peds are porous with macropores between them and within them. Water and air can enter and leave the ped through this maze of macropores.

The peds are also porous with numerous smaller pores or micropores. These have a large surface area due to their small size and they retain water very strongly by capillary forces. They interconnect with the smallest of soil pores - those within clay minerals and humus. The micropores and soil colloids are important in soil fertility. Nutrients are:

- stored and released;
- made available by micro-organisms;
- dissolved in water;
- moved from colloids to root hairs.

Soil colloids provide the micropores which provide the nutrient and water-holding capacity of fine-textured soils. The colloids are the reason why fine-textured soils are much more fertile than coarse-textured soils. They are also the reason why fine-textured soils are much more vulnerable to structural damage by incorrect management practices.

9.6.1 Clay

When rocks weather, the minerals in them soften and crumble. Nutrients are released, to be taken up by plants, recycled or leached from the soil, deposited by rivers or eventually washed to the sea. The clay minerals formed by the weathering of rocks are finely divided (small particle size), with high surface area. They are colloids. They adsorb water on to their surfaces. (Remember that the term adsorb is used to describe the process where matter attaches to the surface of solid particles.)
Clay minerals also develop electrical charges during the weathering process, causing them to attract nutrients to their surfaces. If there are some clay particles in soils, then there is less chance that the nutrients will be leached out of the topsoil and away from the plant roots.

9.6.2 Humus

Humus is a very complex material. It has a very large surface area and retains nutrients and water in large quantities. This results from its very small particle size, as well as from its porous nature. In coarse-textured soils, humus levels remain low, as clay minerals appear to be needed for its formation and stabilisation. Organic matter added to sandy soils tends to disappear unless added on a regular basis.

9.6.3 Sand and Silt

The interchange of nutrients and water between plant and soil colloids takes place in the micropores. Fine-textured soils have micropores; coarse-textured soils do not. That is the basic difference between coarse-textured and fine-textured soils. Sandy soils are mostly macropores, so they are well drained and aerated. However, nutrients and organic matter are easily leached out of the topsoil because of the absence of colloids. If clay is absent, then the processes that form humus are not so effective.

9.7 THE C:N RATIO

The term ‘C:N ratio’ refers to the proportion of carbon (C) and nitrogen (N) in organic matter. This ratio determines the rate of decomposition and therefore the rate at which nutrients become available for plants, as well as the rate at which soil structure can be improved. If organic matter breaks down too quickly, the benefits are lost, but if decomposition is too slow then the soil is not improved and toxins may build up.

Carbon is retained in the woody cells of plants. Its greatest concentration occurs in organic material such as sawdust, bark fines, shredded newspaper and dry leaves. Nitrogen is at its highest concentration in green, leafy material, in young plants, lawn clippings and poultry manure, etc.
Compost

To get good compost, the right balance of materials must be obtained. If there is too much carbon, the heap will be slow to decompose; too much nitrogen will mean that the heap decomposes too quickly and a lot of the nitrogen will be lost into the air.

If the organic matter dug into the soil is too high in carbon, then the decomposing organisms will take the nitrogen they need from the soil. This is called nitrogen drawdown and the plants in soil will show nitrogen deficiency; for example, older leaves turning pale-green to yellow, with stunted new growth. Nitrogen must be added as fertiliser to compensate so the plants do not suffer deficiency.

The desirable proportion of carbon to nitrogen is 30 to 1 (written as 30:1). While this can’t be worked out easily while making a compost heap, an awareness that too much sawdust or lawn clippings will lead to problems, gives the horticulturist a better opportunity to mix available ingredients to get a better ratio (and therefore a good quality compost in a reasonably short time.)

The C:N ratio is not so important for mulches, which are often of higher carbon materials that will be longer lasting; for example, shredded bark and branches, sawdust mixtures and fallen leaves.

Decomposition takes place mainly where the mulches are in contact with the soil, so the overall process is much slower than in a compost heap. Slow decomposition is desirable as the main purposes of mulches are to cool and protect the soil from evaporation while aiding infiltration. Figures 9.4 and 9.5 illustrate these points.

Fig. 9.4 Organic matter mulches improve the infiltration rate
Note that the figures given in Figures 9.4 and 9.5 are for example only. Infiltration and evaporation depend on the climate, the type of mulch and the type of soil.

Fig. 9.5 Organic matter mulches reduce evaporation

9.8 COMMON SOIL ORGANISMS

Good soil contains vast numbers of small to microscopic living organisms. Some are harmful to plants and damage plants or cause disease, but many are beneficial to plant growth because they are essential to the process of:

- converting organic matter to humus;
- converting nutrients to a form that is available to plants;
- improving soil structure, as the slime they excrete binds particles together to form aggregates.

9.8.1 Visible Organisms

Earthworms

Earthworms are the most readily visible of the organisms. By moving through the soil, they leave channels for aeration, water infiltration, drainage and root penetration. This improves the structure of the soil. They feed on organic matter
and recycle the soil through their worm casts. This increases the nutrients available to plants.

Earthworms need plenty of organic matter, especially compost and manures. The harder organic mulches like sawdust and bark fines are not such desirable food to them.

Earthworms need to be in cool, moist soil. Conditions in many parts of Australia for much of the year are not suitable for large earthworm populations, but the use of mulches to cool the surface will help them. Otherwise, in hot weather, they will go deep into the soil to survive.

Earthworms are discouraged by:

- acidic soils;
- excessive applications of fertiliser;
- excessive cultivation, which injures them and breaks up their channels.

Their numbers will be greatest in cool, moist soil with plenty of organic matter. Apart from managers of specialist turf areas such as bowling greens, all other horticulturists need to encourage earthworms for the good they do to soil structure and nutrient availability.

**Nematodes**

Nematodes are very small (just visible) creatures resembling tiny worms. While some live on other organisms and are beneficial, some are parasitic, extracting sap from the roots of plants which can have disastrous effects on plant growth. Some plants are more susceptible than others. The nematodes are more active in sandy soils, which makes them a serious problem in the sandy soils of the Swan Coastal Plain. They can be attacked with nematicides (pesticides), but crop rotation and growing deterrent plants such as marigolds (*Tagetes spp*) are methods used by organic growers.

**Insects**

Many small insects live in soil and on the soil surface. They may be pests to plants or predators on the pests. Some will have little effect on plants, but they burrow and disturb the soil, thus preventing crusting and adding to the overall organic matter content when they die.
9.8.2 Micro-Organisms

These are the organisms that are invisible to the naked eye. In good soils, they are estimated in millions per gram and they have a very great effect on the quality of soils as a growing media.

They contribute to weathering of rock and the breakdown and conversion of organic matter into humus and available nutrients. Some attack other organisms which would be harmful to plants. The main groups of interest to horticulturists are:

- Bacteria
- Fungi
- Mycorrhizae
- Actinomycetes

**Bacteria**

These:

- feed on and break down organic matter.
- destroy harmful organisms such as pathogenic fungi.
- break down pesticides and herbicides so that they do not accumulate in soils.
- convert nitrogen from a gas into a form that can be used by leguminous plants; for example, the pea family, acacias and cassias have root nodules containing *Rhizobium* bacteria.

This process is called *nitrogen fixation*. Native plants in these families absorb nitrogen through the nodules which is then recycled and made available to other plants after leaves fall. Clover can be inoculated with *Rhizobium* to ensure germination. In areas of regeneration, greater success can be achieved if the *Rhizobium* is added to the seed mix for direct seeding or to the potting mix for the seedlings to be transplanted later.

- can cause diseases such as crown gall and some wilts.
Organic Matter and Organisms

Fungi

Fungi are generally thought of as being harmful to plants, and many are. However they are also vital in the breakdown of organic matter, especially the harder woody parts which take the longest to decompose.

Mycorrhizae

Among the most interesting fungi are the mycorrhizae. These live in association with the roots of their particular host plant and assist in the absorption of nutrients. Both survive and prosper in each other’s presence, but die in their absence. The plants that have mycorrhizae include many native plants which are then able to utilise smaller amounts of nutrients and this enables them to survive in nutrient-deficient Australian soils. These plants are also more tolerant of drought, high temperatures and soil toxins, including excess fertilisers and pesticides.

In the cultivation of many native plants, much more successful results have been obtained by introducing the mycorrhizae to the growing media. In regeneration situations mycorrhizae have often disappeared from degraded soil for lack of a suitable host, and seeds of the host re-introduced by direct seeding need the mycorrhizae to survive the adverse conditions of a regeneration site. Mycorrhizae have been encapsulated into tiny granules which slowly break down in moist soil, on the same principle as Osmocote®. This has greatly increased the survival rate of planted and regenerated seedlings.

Actinomycetes

The main role of these organisms is the decomposition of the toughest part of plant material in compost. They are visible in compost heaps, especially very hot heaps, as a powdery white coating. They are also known to destroy harmful pathogens.

9.9 CROP ROTATION

Crop rotation is a plant cultural practice by which different annual crops are grown in the same piece of ground in successive seasons. Horticulturally, it applies mostly to vegetable growing, where there are a big numbers of different plants from several families, all of which have relatively short growth periods to picking.
Crop rotation was based originally on the knowledge that nutrient needs (especially for the micro-nutrients) vary among crops, and a range of different plants prevents the soil becoming exhausted. This may be less necessary in these days of fertiliser application, but there is more to crop rotation than just nutrient availability.

Pests and pathogens which introduce disease to a crop have life cycles which may depend on a certain crop being available. If that crop is not grown for a couple of years, the life cycle is interrupted and the population of the pest of pathogen may fall to such levels that the crop can be grown again for a season.

An area of land may be left fallow (bare of crops) but, better still, planted with a green manure crop to increase the organic matter content of the soil. Fallow soil leaves the micro-organisms without sufficient food, and can make the soil vulnerable to erosion.

Crop rotation has long been part of organic growing and permaculture. While these practices are sound in theory, they may be more difficult in intensive market gardening where crop selection is also market-driven to get the best return from the land available, while still trying to improve the existing soil. Reliance on pesticides and fertilisers is not the sole answer to maintaining the quality of the soil as well as getting good yields. Gradual changes in horticultural techniques are being made to find better answers.

9.10 ORGANIC MATTER AND TURF

In this chapter, the need to use and add regular amounts of organic matter to horticultural soils has been explained in detail. However, there is one situation in which the addition of organic matter is not desirable. Media for high quality turf does not contain organic matter.

Soils for turf should be thoroughly prepared before planting, as soil improvement once the grass plants are established is expensive and difficult. Topdressing does not adequately affect the main root zone or the drainage of the area. Spiking and coring are part of the turf maintenance to improve aeration and drainage and reduce compaction which develops from use, especially overuse.

Organic matter can cause several major problems. Even with mowing, the grass plants add sufficient organic matter to the surface to need careful management to avoid problems such as thatching.

- Resins from organic matter can make sand non-wettable. This results in a condition called dry patch. The turf is deprived of water even though there may be a well designed irrigation system delivering sufficient water. Water will run off the dry patch and adjacent areas may receive
too much water. The dry area will have only poor quality turf which will not look attractive, will be more susceptible to pests and disease, and will not be able to withstand normal use without damage.

- Organic matter may form a crust within the root zone. Unlike a mulch on the surface of an amenity garden, it cannot be cultivated or disturbed. For good turf, it is very important that infiltration and percolation of water through the turf and into the root zone take place quickly and evenly so that the turf surface does not remain wet and slippery. Otherwise, the turf is vulnerable to disease and not suitable for use.

- The presence of organic matter increases the population of earthworms. These are not desirable in good quality turf because the worm casts spoil the smooth finish of a high quality surface such as a bowling green.

- Any additional organic matter would further encourage fungal diseases and pests such as lawn beetles.

The establishment of good quality turf is very specialised, but soils for turf should be free-draining, non-compacting, and readily wettable sands. These soils allow for free movement of water, good aeration and easy root penetration for the plants.

9.11 SUMMARY

- Organic matter is derived from a variety of natural sources such as leaves, flowers, bark, roots, excreta and the remains of organisms on and in the soil.

- Horticulturists add organic matter such as compost, commercial organic improvers, organic fertilisers, mulch, sawdust and bark fines, green manure, sewage sludge, lawn clippings, and shredded tree prunings, etc.

- Organic matter is broken down by micro-organisms. Much is converted into carbon dioxide, but eventually only humus remains.

- Organic matter in soil must be replaced regularly as most of it is decomposed within two to three years.

- In the process of decomposition, organic matter improves aggregation of particles which improves soil structure, and improves aeration, drainage infiltration, water holding and root penetration by improving porosity (that is, the number and variety of sizes of pore spaces).
Compost is decomposed organic matter which breaks down best when the ratio of carbon to nitrogen is 30:1. Carbon is found in harder organic matter such as sawdust and bark fines, while nitrogen is found in poultry manure, lawn clippings, green weeds etc. When ready, compost can be dug in to the soil or used as a mulch.

Mulches are applied to the soil surface, and are not necessarily decomposed when applied. Fine mulches can cause crusting, which prevents infiltration. Mulches can harbour pests, but also prevent erosion.

Too much organic matter applied at once in soil can cause nitrogen drawdown.

Fine particles such as clay and humus are colloids (that is, they are able to retain nutrients in micropores against leaching in gravitational water).

Earthworms prefer cool, moist undisturbed soil. They improve aeration, drainage, infiltration and root penetration. There populations should be encouraged as they are a nuisance only in high quality turf. They are discouraged by acidity, inorganic fertilisers and cultivation.

Bacteria break down organic matter and some pesticides and herbicides. Rhizobium fix nitrogen in root nodules from the air in a form legumes can absorb and recycle.

Many fungi are harmful to plants but others are essential to break down organic matter.

Mycorrhizae live in association with the roots of certain plants especially some Australian native plants, and they assist in the absorption of nutrients in soils deficient in many nutrients.

Mycorrhizae need to be added to soil in many regeneration situations to assist plants to re-establish.

Actinomycetes assist in the breakdown of the toughest material in compost heaps.

Crop rotation means growing plants from different families in sequence in the same area of soil. It is particularly important in market gardens and helps to break the life cycles of pests and diseases, as well as avoiding the total depletion of some nutrients.

Fallowing means leaving the soil bare of crops, but it actually decreases the populations of micro-organisms and increases the risk of erosion.
Organic Matter and Organisms

- Organic matter should not be added to soil mixes for high quality turf.

- Organic matter is removed from turf areas to prevent thatching, dry patch and to reduce to number of earth worms.
CHAPTER 10

PRACTICES FOR SOIL IMPROVEMENT

10.1 INTRODUCTION

Soil texture is an important factor in land management. Techniques which are appropriate for coarse-textured soils may damage those that are fine textured. Fine-textured soils are more productive than the former, but they can be damaged by inappropriate management practices. Too much cultivation, lack of surface cover, depletion of organic matter, and an accumulation of salts can drastically reduce soil productivity.

Coarse-textured soils have problems of low water retention and low fertility, but they are much easier to manage and much less prone to damage.

10.2 MANAGING COARSE-TEXTURED SOILS (Sandy Soils)

Coarse-textured soils are those with high sand content. They have the following characteristics. They:

• have many macropores and few micropores;
• have high infiltration rates, except when the sand is water repellent;
• are usually well drained and may be highly leached in high rainfall areas;
• are easy to cultivate over a wide range of moisture content - hence the term 'light land';
• have low nutrient-retention capacities and low fertility, despite applications of fertiliser (because of the high leaching rate);
• have low moisture-retention capacities;
• usually have low organic matter content;
• have little or no aggregation (structureless);
• are highly alkaline in some sands in Western Australia.
These characteristics mean that coarse-textured soils are prone to:

- drought, if not irrigated at regular intervals;
- nutrient deficiencies;
- wind erosion, if the soil surface is left bare or exposed.

Coarse-textured soils need to be fertilised and irrigated frequently, using relatively low rates of fertiliser and water.

'Little and often' is the rule for such soils.

Irrigation should be by sprinklers or trickle. Furrow and flood irrigation are impractical due to rapid infiltration rates.

Slow-release fertilisers such as blood and bone, animal manures and composts have advantages on coarse-textured soils, as they have a sustained effect, reduce the risk of damage to plants, do not need to be applied so often and minimise leaching losses.

Slow-release fertilisers usually need to be supplemented with soluble fertilisers to provide for the peak requirements of annual crops at critical growth stages.

A surface cover of mulch or vegetation helps protect coarse-textured soils from wind erosion and also helps conserve soil moisture.

10.3 MANAGING FINE-TEXTURED SOILS

Fine-textured soils have a high clay content. They have the following characteristics, which depend on the quality of the soil's structure.

- The higher the number of micropores and the fewer the macropores, the poorer the structure.
- If well structured, they are well drained; that is, they have good aeration.
- If unstructured, they are poorly drained and may become waterlogged, with poor aeration.
• They may be difficult to cultivate, being sticky when wet and hard and
  cloddy when dry.

• They have high water-holding capacity but may have low water
  availability.

• Usually they have higher organic matter and nutrient content than sandy
  soils.

• Their nutrient retention is good.

• Their anchorage is good, but their root penetration is poor.

• They have low infiltration rates and are prone to run-off and erosion by
  water, if poorly structured and compacted.

• They are prone to surface crusting and sealing by raindrop impact.

• They may be eroded by wind, if the surface is exposed and pulverised.

These characteristics mean that fine-textured soils are:

• highly productive if well managed;

• subject to structure collapse, compaction, waterlogging and erosion, if
  badly managed.

Fine-textured soils should be cultivated as little as possible as cultivation of such
soils when too wet will lead to smearing of aggregates and structure collapse.
This, in turn, will lead to compaction, waterlogging and erosion.

Cultivation of these soils when too dry requires large amounts of energy and
leads to structural damage and a rough, cloddy soil which is prone to slaking
(collapsing) when rain falls.

Raindrop impact causes crusting and surface sealing of fine-textured soils. They
should always be protected by crop canopy or mulch, and sprinkler irrigation
should be used carefully. Trickle, furrow or flood irrigation is best for clay soils.
10.4 MANAGING LOAMS

Loams (with five to forty percent clay) have similar characteristics to fine-textured soils, but are usually easier to cultivate. Their management depends largely upon the amount of clay present. They should be managed with the same care as clays (fine-textured soils), as they can become compacted and waterlogged if their structure is damaged, and their initial advantages lost.

Good loams provide the best balance of fine and coarse-textured soils, providing good aeration and drainage along with good water retention and nutrient holding. The surface of loams can be easily damaged in heavy rain if unprotected, as the fine particles block the macropores thus preventing infiltration and sealing the surface and leading to run-off and erosion.

Good quality loams have organic matter present in their aggregates. Constant cultivation without the replacement of organic matter leads to a deterioration of structure and degradation of the soil, if there is a high percent of clay present.

10.5 IMPROVEMENT TECHNIQUES

The main problems encountered in horticultural field soils are:

- Incorrect pH for specific crops, or extremes due to management or natural parent rock.
- Poor wettability and lack of moisture-holding capacity.
- Texture that has an excess of either sand or clay.
- Poor structure due to a lack of organic matter to develop aggregates.
- Lack of organic matter due to crop removal and a failure to incorporate extra organic matter into soils.
- Excess salinity due most probably to excessive fertilising or a rise in a saline water table.

The main improvement techniques in horticultural situations are:

- Addition of organic matter at regular intervals either dug in or applied as mulch.
- Application of lime to raise pH in acidic soils.
- Careful use of fertilisers and irrigation water.
CHAPTER ELEVEN

EROSION AND CONSERVATION

11.1 INTRODUCTION

The quantity and quality of our soils is an increasingly serious matter which concerns all those people with any interest in the environment, and all those who are involved in food production in areas of increasing degradation. For food production to continue into the foreseeable future, soils must be able to continue to produce at this level without the environmental disasters that have occurred in the past and into the present in many countries of the world. The pressures of increasing population, apparent climate change, and political unrest in Third World countries lead to additional neglect and mismanagement.

In Australia, much of our soil degradation is a result of the development of agriculture on models based on cool temperature climates. The vulnerability of our soils to degradation was not realised except by a few individuals until much of the damage had already been done, or set on a path that is very difficult to correct. Unfortunately, government policies encouraged clearing in the false belief that this would lead to increased food production and greater national income.

11.2 DEGRADATION

What is 'degradation'? It is a general term meaning that the soil is no longer capable of supporting the previous levels of plant growth. Its physical and chemical properties may all be changed for the worse, and the topsoil where most plant growth takes place may be destroyed by wind and water erosion.

Soil degradation has several aspects, some of which have already been covered in earlier chapters. The main aspects to be considered here are:

- acidification Chapter 7
- compaction Chapter 2
- salinity Chapter 8
- erosion Chapter 11
In general, large scale degradation is at its worst in areas with dry climates and a thinner cover of vegetation, particularly those with a marked seasonal rainfall often with episodic (or occasional) heavy falls. This characterises much of Australia, away from the wetter areas of the coastal strip, where cereal farming and grazing depend on rainfall that is seasonally and annually erratic. Western Australia has a very seasonal rainfall, often from cold fronts, cyclones and storms. It is also very windy, with vast flat areas with few hills or mountains to divert the wind flow. Once the vegetation cover is removed, it becomes very vulnerable to wind and water erosion.

11.3 EROSION

Erosion may be defined as follows.

Erosion is the loosening and removal of particles from an area by wind or water.

It is important to realise erosion is part of the normal four-stage cycle of what is called landform reduction. (For example, mountains are eroded down, gullies become rivers that cut gorges back into plateaus, and plains are formed by the deposition of eroded material). However, erosion is greatly accelerated in time by the clearing of vegetation.

For reference, the four stages of landform reduction are:

- **weathering** - the breaking up of rocks by chemical changes, and the effect of heat and cold;
- **erosion** - the loosening and removal of the particles by wind and water from their place of origin;
- **transport** - the moving of quantities of the eroded material by either wind or water to another area;
- **deposition** - the dropping or depositing of the eroded material on flatter land, in the sea or, in the case of wind, in another area as the force of the wind abates.
11.3.1 Water Erosion

When rain, even very heavy rain, falls on a well vegetated area, the force of the rain reaching the soil is reduced by leaves, branches, bark and layers of leaf mulch. The water has time to infiltrate the soil since large amounts are delayed on living and dead organic matter. Soil structure will allow infiltration of large quantities of water, but macropores will drain to field capacity before sustained waterlogging causes damage. Run-off will occur for days after, into streams on the surface and into underground water.

Different processes occur when an area is cleared or soil is seasonally bare due to cropping, excess grazing, weed control, tracks, firebreaks, clearfelling for timber production, clearing for urban development, etc.

Processes

A raindrop hits bare soil like a small explosion, breaking up the microscopic particles in crumb structure. Bonds between organic particles and mineral particles are lost. Micro-organisms are destroyed. As surface structure breaks down, small particles sink into the macropores below, preventing rapid infiltration. There is not enough time for infiltration, so run-off occurs very rapidly and a high percentage of water volume is lost. On slopes (particularly if rainfall is prolonged), the flow of water starts to carry the finest particles, then the larger ones as the volume and velocity of water increases. The materials carried in the water further dislodge the particles over which the water is passing, increasing the damage still more. Thus, erosion has started.

Sheet Erosion

The first stage of erosion occurs when layers of soil, perhaps only a few millimetres deep, are washed off large areas.

Fig. 11.1 Sheet erosion
Rill Erosion

As water concentrates into slight depressions, these deepen into noticeable drainage lines even though only centimetres deep. These may follow slight depressions in the ground, cultivation lines, walking tracks, etc.

Fig. 11.2 Rill Erosion

Gully Erosion

As more water becomes concentrated in one direction, the main rills begin to deepen and form into a gully.

As the concentration of runoff increases, the gully and its tributaries cut back into the slope. Soil may be exposed to the depth of several feet into the subsoil. If unchecked, large areas along tracks, creek banks and bare hillsides can be rapidly destroyed. See Figure 11.3.

Fig. 11.3 Gully Erosion
11.3.2 Wind Erosion

Cleared land in dry or seasonally dry areas is very prone to wind erosion. Western Australia has huge expanses of relatively flat land surfaces that are subjected to frequent strong winds as part of storms, cyclones, and high pressure cells and ridges. For example, summer easterlies can blow for days at a time across the Wheatbelt and the Southwest. Cyclones that influence the Southwest of this state carry clouds of red dust for hundreds of kilometres.

Strong wind on bare soil sorts the finest and lightest particles first (for example, clay, silt, fine organic matter and fine sand) and lifts them into the air, while the medium particles - mostly sand - bounce along the surface. Coarse particles, the gravels and stones, are left behind as shown in Figure 11.4. Sizes of particles and wind speed have known ratios. Fine particles are lifted by winds exceeding 28 km per hour, which is not particularly strong relative to the wind potential of storms and cyclones.

![Diagram of wind sorts material according to size](image)

**Fig. 11.4 Wind sorts material according to size**

During *duststorms*, soil is piled across obstacles like shrubs and fences. It drifts across roads. Visibility is cut by the tonnes of material in the air. Sparse existing vegetation is buried or the roots exposed. The best soil and organic matter are lost into the atmosphere, to fall hundreds, even thousands of kilometres away.

The power of strong wind to erode should not be underestimated, and even moderate gusts begin the process of disturbance. It is not necessarily a problem confined to the inland, as sand blows from building sites, bare roadsides, bare sand dunes, etc, in Perth when strong winds blow in summer.

Along many parts of the state's coast are sand dunes shaped by wind, but stabilised by vegetation. Once the sand is exposed by clearing, excessive track access, 'dune-bashing', etc., the surface layer of sand is disturbed and strong wind will shift the sand out from the dune, causing *dune blowout*. See Figure 11.5. Large areas of dunes can be destabilised in this way, and this explains why so many of the state's best beaches in populated areas now have fenced dunes with restricted access.
Fig. 11.5 Dune blow out
11.4 FACTORS CAUSING SOIL EROSION

Some of the causes of soil erosion present in the Western Australian environment are:

- seasonal, sometimes very heavy rainfall;
- long, hot dry seasons;
- flat surfaces prone to persistent strong winds;
- old, poorly structured soils that break up easily into particles and individual sand grains;
- possible climatic change due to the greenhouse effect, though this is not yet proven.

Other causes resulting from European settlement are:

- overclearing;
- overgrazing;
- excessive tillage;
- cultivation of annual crops that leave the soil bare for part of the year;
- failure to protect hillsides and creek banks;
- failure to locate tracks and roads across the slope as much as possible;
- failure to cultivate along contour lines, which applies as much to production horticulture as to broadacre farming;
- failure to protect bare soil on development sites.

11.5 PREVENTION OF EROSION

There are no easy answers to controlling and preventing erosion, as the causes may have originated in management practices years before. The various techniques may be divided into several categories:

- plant materials
- man-made structures
Erosion and Conservation

- soil treatments
- cultural practices.

Plant Materials

These can include living and dead plant material. (Dead material in included later in this chapter under ‘Mulches’.)

Trees and shrubs, either planted or naturally regenerated, help to control the force of wind and water. It is important to remember that an effective planting needs to contain shrubs as well as taller trees. Trees and shrubs also provide shade and shelter, and may be relevant to salinity control and protection of slopes, gullies, creek banks, etc., as well as being attractive and a refuge for wildlife.

Therefore:

- Plant windbreaks. These rows or areas of trees and shrubs break the force of the wind so that the soil is protected. This is just as applicable to domestic and commercial horticulture as to broadacre farming.

- Prevent overgrazing, so that some vegetation cover remains and plants can regenerate.

- Allow marginal land on steeper slopes to regenerate, or reseed with suitable species.

- Plant temporary green crops or ground covers to save the soil, for example, while landscaping/garden plans are completed and implemented so that soil is not lost in a new development.

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Wind break of trees and shrubs, filters the wind and reduces its force

Fig.11.6(a) A natural windbreak
Man-made Structures

![Diagram of wind and eddy affecting wall obstruction]

Fig. 11.6(b) A wall as a windbreak

These include retaining walls of various materials, including stone, bricks and concrete. Walls are not as effective at controlling wind erosion as trees and shrubs because the wind eddies on the lee side of the wall and can be even more damaging, as shown in Figure 11.6.

Other structures include biodegradable meshes, which are laid over the soil to prevent washing, but which do not inhibit plant growth.

Contour banks across slopes check the flow of water down the slope, minimising erosion and increasing infiltration rates.

Soil Treatments

These usually involve the use of some product sprayed on the soil to stabilise it until plant growth can establish itself. Oil-based sprays were trialled in the past on the Floreat dunes, but while the erosion was reduced, plant growth did not survive. In any treatment of the soil, it is essential to ensure that the requirements for plant growth (for example, water and oxygen) are not lost in the process.
Mulches

Mulches may be organic or inorganic. In both cases, their function is to prevent erosion by wind or water making direct contact with the soil. Rain soaks through mulches, to infiltrate gently into the soil. Organic mulches have the advantage of breaking down into the soil and improving it, but they do need renewing or the soil can be left vulnerable. Inorganic mulches last longer, but do not improve the soil in the same way.

Mulches, particularly those used to control erosion, may not be the same as those applied in gardens to improve the soil. Much coarser mulches can be used on a large scale, and these include the chipped and shredded material from tree pruning by Councils and SECSWA, which would otherwise the wasted. These can be spread over vulnerable areas.

Brushing is a technique of spreading branches of leafy plants over slopes (for example, on dunes) to stop the sand moving. Coarse mulches allow water and air to penetrate, and seedlings of desirable plants can become established if the mulch is not too thick.

Hydromulching is the technique of spraying seeds in a mixture of paper pulp (from recycled newspapers) on to slopes. The binding agents in the mulch hold it to the soil until the vegetation starts to establish (for example, on road cuttings).

11.6 EROSION IN HORTICULTURE

Much of what is written so far in this chapter may appear to apply more to broadacre farming than to horticulture. However, some sites for production horticulture are prone to erosion if rows of crops, vines or fruit trees are planted up and down the slope rather than across it. This can conflict with the need to plant rows in a north-south direction to maximise sunlight reaching the leaves. The best compromise must be selected.

Many crops are grown without any ground cover or mulch to protect the soil, so the exposed soil between rows is vulnerable. With the widespread use of herbicides, weeds are allowed to grow large enough to protect the soil; they are then sprayed so that the remains of the weeds’ leaves and roots resist erosion.
Many development sites in their early stages are likely to erode if the site is totally cleared. Partly finished landscaping projects can be ruined by heavy rainfall at the wrong time.

In horticultural situations, the use of mulches is probably the best and easiest way to minimise the risk of erosion except on steep slopes. Organic mulches have the advantage of improving the soil as well.

All opportunities to protect the soil should be taken, for once it is lost, we cannot bring it back.

11.7 SUMMARY

- Degraded soil is no longer capable of supporting the previous levels of plant growth.

- The main forms of degradation are: acidification, compaction, salinity and erosion.

- Erosion is the loosening and removal of particles from an area by wind or water.

- Soils covered by vegetation is protected from damage by heavy rain because the vegetation breaks the impact of the raindrops and prolongs the time for infiltration to take place.

- Heavy rain on bare soil breaks up the aggregates of the surface soil and loosens the surface layers.

- The first stage of erosion is sheet erosion. When small channels start to develop it is termed rill erosion, and when rills become larger, a gully forms. Eventually this gully could become a valley - this is a natural process but it is speeded up by the clearing of vegetation.

- Because of long, dry seasons, poorly-structured soils and strong winds over large flat expanses of land, Western Australia is very susceptible to wind erosion.
Erosion and Conservation

- Wind erosion is common along the coast, on bare development areas, and on cleared farmland, especially fallow paddocks and overgrazed range country inland.

- Roads and tracks should go along the slope as much as possible.

- Contour banks are constructed along the contours to improve infiltration and prevent runoff.

- Some of the measures to prevent erosion include: planting windbreaks, regenerating steep slopes (especially with shrubs and ground covers), preventing overgrazing, constructing contour banks, protecting creek and gully banks, using meshes and brushing on slopes, controlling access and traffic to certain areas, and the use of mulches and hydromulching.

- In horticultural situations, retaining walls on steep slopes and mulching are the main ways to prevent erosion.

- Soil lost by erosion cannot be replaced.
APPENDIX

The Physical and Chemical Properties of Soils.

The Physical Properties of Soils

- aeration and drainage
- water-holding capacity
- texture
- structure
- porosity
- root penetration
- infiltration and wettability
- colour
- warmth
- density

The Chemical Properties of Soils

- nutrient status
- nutrient holding
- soil reaction or pH
- nutrient fixation
- toxicities
Macronutrients and Micronutrients

The macro and micronutrients are necessary to produce good productive plant growth.

There are six macronutrients, six micronutrients and two micronutrients that are of significance only to some special crops.

All these are absorbed into the plant from the growing media by a process of active uptake in the roots.

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Macronutrients</em></td>
<td></td>
</tr>
<tr>
<td>nitrogen</td>
<td>N</td>
</tr>
<tr>
<td>phosphorus</td>
<td>P</td>
</tr>
<tr>
<td>potassium</td>
<td>K</td>
</tr>
<tr>
<td>sulphur</td>
<td>S</td>
</tr>
<tr>
<td>calcium</td>
<td>Ca</td>
</tr>
<tr>
<td>magnesium</td>
<td>Mg</td>
</tr>
<tr>
<td><em>Micronutrients</em></td>
<td></td>
</tr>
<tr>
<td>copper</td>
<td>Cu</td>
</tr>
<tr>
<td>iron</td>
<td>Fe</td>
</tr>
<tr>
<td>manganese</td>
<td>Mn</td>
</tr>
<tr>
<td>boron</td>
<td>B</td>
</tr>
<tr>
<td>zinc</td>
<td>Zn</td>
</tr>
<tr>
<td>molybdenum</td>
<td>Mo</td>
</tr>
<tr>
<td>chlorine</td>
<td>Cl</td>
</tr>
<tr>
<td>cobalt</td>
<td>Co</td>
</tr>
</tbody>
</table>

As well, there are three essential elements that are not absorbed in this way.

oxygen (O₂) absorbed through the roots by diffusion

carbon (C) split from carbon dioxide (CO₂) absorbed by leaves through the stomates from the air

hydrogen (H) split from water (H₂O) during photosynthesis