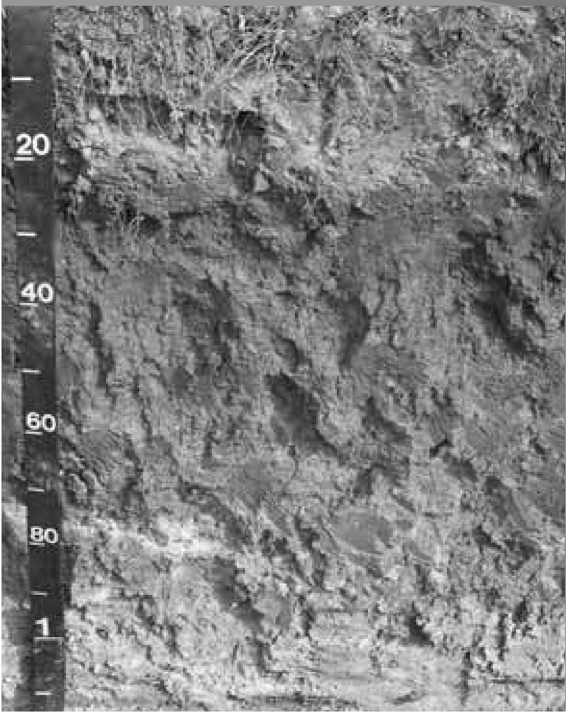
ute guide

Healthy soils for sustainable vegetable farms



Biology

Structure

Nutrients

Permeability

Drainage

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healthy soils for sustainable farms

Healthy Soils for Sustainable Vegetable Farms: Ute Guide

Project Leader

Helena Whitman, AUSVEG Environmental Manager

Editors

Dr Alison Anderson
Jim Kelly
Dr David McKenzie

healthy soils for sustainable farms
a natural heritage trust initiative

AUSVEG

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- The AUSVEG Environmental Committee

Ute Guide peer reviewers:

- Professor Mike McLaughlin, CSIRO Land and Water and The University of Adelaide
- Dr Cameron Grant, The University of Adelaide

Front cover:
Soil profile image courtesy Dr Stephen Cattle, The University of Sydney.

Preface

The management of soil is a key aspect of both economic and environmental sustainability of vegetable production. The vegetable industry has been at the forefront of innovation with projects such as Enviroveg and now the Healthy Soils for Sustainable Vegetable Farms: Ute Guide. The National Land & Water Resources Audit further recognises that improved soil health leads to better production performance including reduced input costs for herbicides, pesticides and fuel, less wear on machinery and more efficient use of water and nutrients.

The industry has been quick to recognise the value of soil and land management, not only to the ongoing sustainability of vegetable farms but also as a significant contributing factor to environmental management and the marketability of their produce when meeting the requirements of some of the most stringent quality assurance systems in the world.

The Australian vegetable industry has approximately 10,000 growers, producing crops valued at an estimated $3.2 billion annually. It could be argued that they manage Australia's highest value agricultural land and have the greatest intensity of production. Clearly, this project will not only add to the sustainability of vegetable production nationally through improved soil management; the increased value of production and higher rates of employment within the industry will also be beneficial to the Australian economy. Further, the social and community benefit from improved environmental practices adopted by growers implementing aspects of this project cannot be ignored.

The Ute Guide provides vegetable growers across Australia with a pictorial reference tool to assist them to measure, record, interpret, manage and monitor the health of their soil and to put in place practices that will maintain and restore soil health, sustainability, productivity and profitability. The Ute Guide is the foundation output of a three component project which includes: the Ute Guide; the *Healthy Soils for Sustainable Vegetable Farms: Resource Manual*; and the 'How To' DVD profiling growers experiences in adopting the outlined soil management practices.

This Ute Guide 'Healthy Soils for Sustainable Vegetable Farms' is a product of the Healthy Soils for Sustainable Farms Programme. The Healthy Soils for Sustainable Farms Programme is funded by the Department of Agriculture, Fisheries and Forestry through the Natural Heritage Trust in partnership with the GRDC and is managed by Land & Water Australia. The project has been managed through the AUSVEG Ltd Enviroveg project led by Helena Whitman and including Dr Alison Anderson (NSW Vegetable Industry Development Officer), Jim Kelly (Arris Pty Ltd) and Dr David McKenzie (E. A. Systems Pty Ltd).

The project team would like to thank the Healthy Soils for Sustainable Farms Programme for funding the project as well as those growers who actively participated in the development of the Ute Guide. We would like to make special mention of the contribution to the development of this project from growers Jeff McSpedden and Jason Huggins, and members of the AUSVEG Environmental Committee.

Helena Whitman
Project Leader AUSVEG Ltd, Environmental Manager

Contents

1 Questions to ask yourself about your soil

There is increasing awareness among producers about the importance of soil and land management to the economic sustainability of their farming enterprises.

As a vegetable grower there are questions you may want answers to, such as:

- Is the condition of my soil ideal for the vegetable crops I grow?
- If my soil is less than ideal, what can I do to improve it?
- When and how should I assess the condition of my soil and who can help me?
- What do my soil test results mean and how do I use these results to make appropriate management decisions?
- Am I maintaining my soil assets in a condition that allows easy sale of my farm?

Also, you may want to know if there is room for improvement with:

- crop yields (whole-farm average, sub-sections of management units)
- soil-related input costs (water, fertiliser, tillage)
- preparation for any future soil-related environmental Quality Assurance (QA) rules (nutrient/pesticide pollution, erosion losses, greenhouse gas emissions).

This manual has been designed to give you information that will enable you to meet the increasingly demanding challenges of landscape management while managing an economically sustainable enterprise.

2 How to use the UTE guide

This Ute Guide provides a practical reference for examining your soil:

- How to sample your soil in relation to the root systems of vegetable crops and your farm
- How to measure and describe soil properties
- How to interpret soil tests so that an effective soil management plan can be developed.

Regular inspection and analysis of soil with the information contained in this guide can help with early detection of soil problems, enabling timely implementation of remedial action.

This guide will allow you to identify areas on your farm with ideal soil conditions and help you to maintain them. It will also indicate areas where problems may occur and where improvements can be made.

Information about key soil properties is presented with photographs and diagrams.

Explanations are given about how soil management interacts with the wider environment.

This guide also gives you information about where to go to obtain professional help when dealing with difficult soil problems.

Information about a particular soil property will be found in more than one chapter. For example, Chapter 4 explains how a particular soil property is assessed, Chapter 5 explains how to interpret measurements of that soil property and Chapter 6 explains how to improve the condition of that soil property.

3 Vegetable crops — soil requirements

3.1 Root systems under ideal conditions

For successful growth the soil needs to provide plants with:

- water
- air
- nutrients
- physical support

It is rare to find a soil that is ideal with all of the features shown in Figure 3.1, as vegetable growers often have to deal with several problems simultaneously. However, you should aim to manage and improve your soil so that it can perform to its full potential. The techniques used will vary with soil type and location.

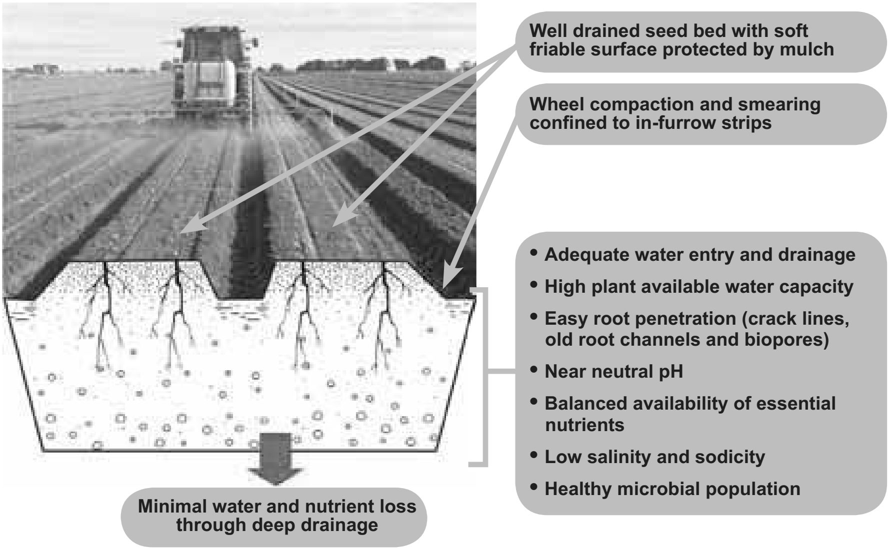


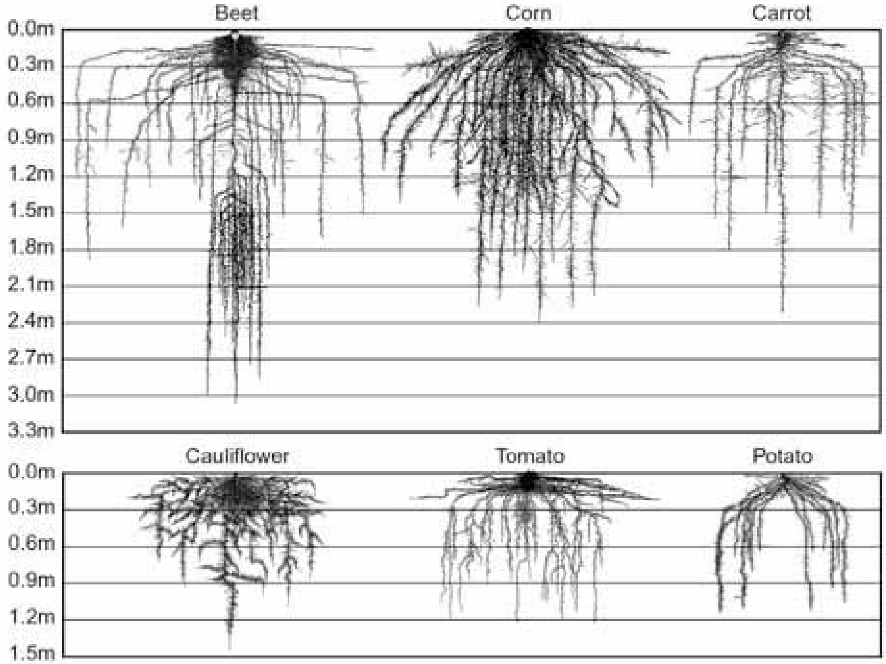
Figure 3.1 *Features of an 'ideal' soil for vegetable production*

Root shape and depth are affected by soil condition. The typical rooting depths for a range of vegetable crops given a good soil environment are shown in Table 3.1. The root distributions of several vegetables under ideal soil conditions are shown in Figure 3.2.

Table 3.1 *Typical rooting depths for a range of vegetable crops*

Crop	Rooting depth (m)
Tomato	0.5 – 1.5
Onion (green and dry)	0.3 – 0.6
Watermelon	0.8 – 1.5
Carrot	0.5 – 1.0
Lettuce	0.3 – 0.5
Broccoli	0.4 – 0.6
Cabbage	0.5 – 0.8

Source: Qassim & Ashcroft (2006)



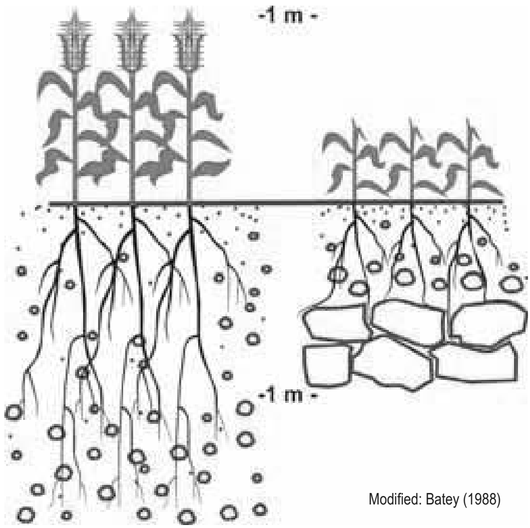
Modified: Hayward (1938) and Weaver & Bruner (1927)

Figure 3.2 *Root distributions of vegetables under ideal conditions*

3.2 Root systems where soil limitations occur

If any one feature of the soil is not ideal then plant growth is likely to be restricted. Observing the shape of roots and how deep they are growing can give you an indication of why plants may not be performing as well as expected.

Poor soil structure will prevent roots from growing well and in extreme cases root growth may be limited to the very top layer of soil (Figure 3.3). The presence of taproots that grow at right angles (Figure 3.4) or fibrous root systems growing in a tight bundle are indicators of a very compacted layer. However, fibrous roots growing in a tight bundle may also indicate the presence of root nematodes.



Modified: Batey (1988)

Figure 3.3 *Fibrous root growth in well structured soil (left) and compacted soil (right)*

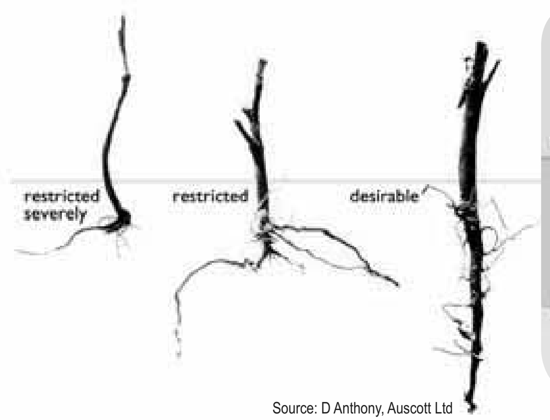


Figure 3.4 *Shapes of taprooted plants following compaction*

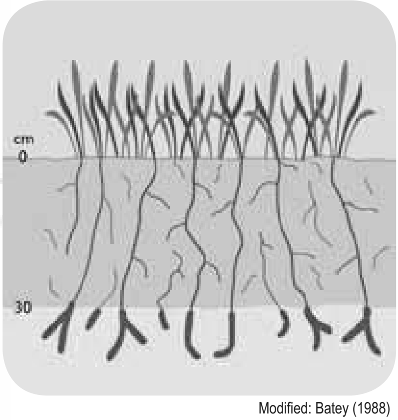


Figure 3.5 *Restricted growth of roots in sand*

Sandy and sandy loam soil types are highly susceptible to compaction. In sandy soil, a thickened stubby appearance in impeded roots (Figure 3.5) is associated with rigidly interlocked particles that cannot readily be moved apart. This compaction effect can occur even when the sand is porous and allows excess water to drain through it.

Poor nutrition, waterlogging or toxic conditions such as strongly acidic, alkaline or saline layers, and high aluminium or boron concentrations are some other reasons roots may not be growing as expected.

3.3 The main soil types used for vegetable production in Australia

The systems used to classify soil types vary from country to country. The main aim is to place soil with similar properties in a group. These properties include parent material, colour, texture, pH, drainage and how different soil layers (horizons) are formed.

The system used to classify soil in Australia is known as the ‘Australian Soil Classification’. Examples are Red Ferrosols and Brown Chromosols.

Soil classification can be very detailed. Instead, many people use broad descriptions of soil types, often based on soil texture and colour, e.g. a heavy black clay. There is much variation in the soil types used for growing vegetables in Australia, as shown in Figure 3.6. The soil type found at any particular site will depend on parent material (geology), slope, climate, weathering, erosion and time.

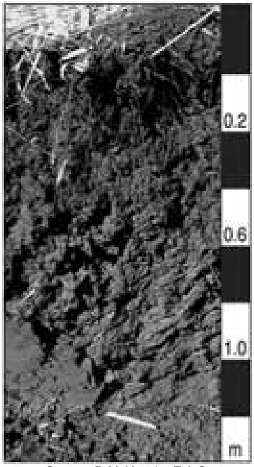
Key soil types used for vegetable production include:

- self-mulching clay (tends to crack when dry)
- duplex soil (a sandy or loamy topsoil with a clay subsoil)
- alluvial soil (associated with river plains)
- sandy soil.

Figure 3.6 *Photographs of a range of soil types used for vegetable production in Australia (Descriptions modified from McKenzie et al. (2004))*

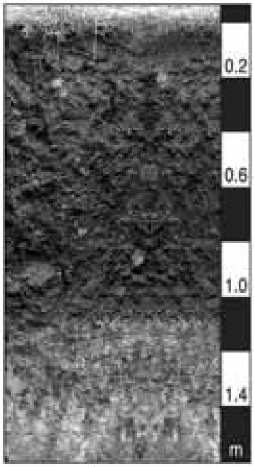
VERTOSOLS **(cracking clays)**

Black Vertosol
Kununurra, WA



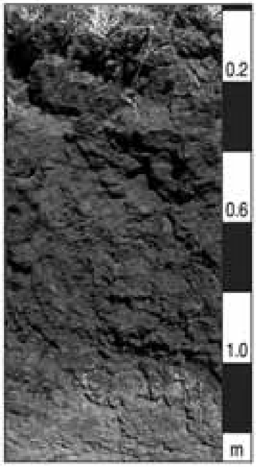
Source: D McKenzie, E.A.Systems

Black Vertosol
Lockyer Valley, Qld



Source: John Rasic Pty Ltd

Grey Vertosol
Hay, NSW

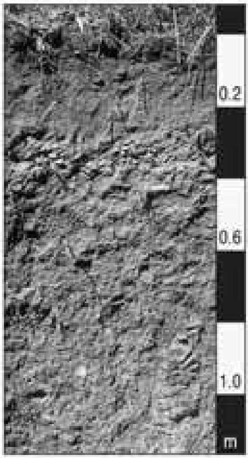


Source: M Hickey, NSW DPI

- Clay-rich throughout, often with a self-mulching surface which cracks when dry. Subsoil often sodic and sometimes saline.
- Occurs extensively throughout Qld and NSW.
- Used for vegetable growing in the Lockyer Valley (Qld), Kununurra (WA) and the Riverina (NSW).

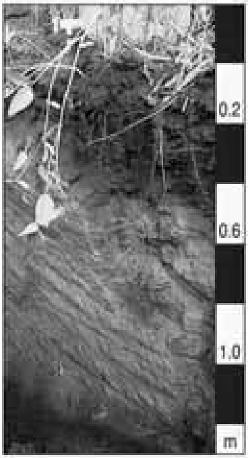
CHROMOSOLS **(neutral to alkaline soil with a sharp increase in texture)**

Brown Chromosol
Cranbourne, Vic



Source: M Imhof, DPI Vic

Red Chromosol
Hay, NSW

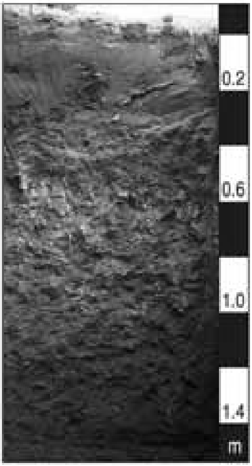


Source: M Hickey, NSW DPI

- Duplex non-sodic soil with abrupt texture contrast between the loamy topsoil and clay rich subsoil.
- Common in the wheat belt of southern NSW, northern Vic, south-western Australia and parts of SA.
- Used for vegetable growing at Cranbourne (Vic) and the Riverina (NSW).
- pH greater than 5.5 in the upper 20 cm of the B horizon.

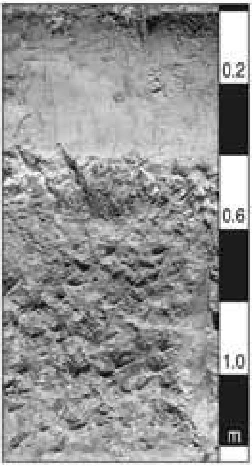
SODOSOLS (alkaline and sodic soil with a sharp increase in texture)

Red Sodosol
Nth Adelaide Plains, SA



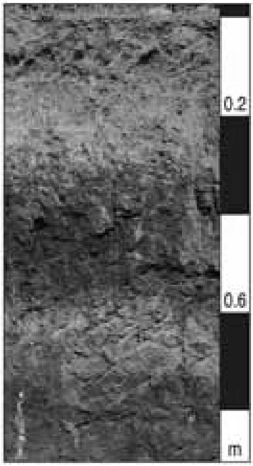
Source: D Maschmedt, PIRSA

Brown Sodosol
South East, SA



Source: D Maschmedt, PIRSA

Red Sodosol
Werribee, Vic

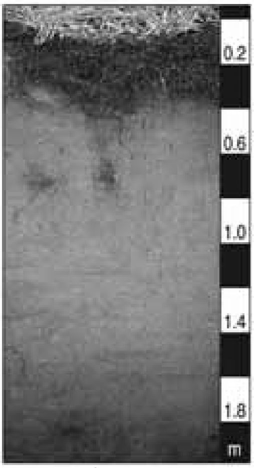


Source: M Imhof, DPI Vic

- Duplex soil which is most commonly brown and found in dry climates, where the upper subsoil is sodic and has a pH greater than 5.5.
- Variable structure — topsoil can be hard-setting, subsoil often is mottled with restricted drainage and root penetration.
- Widely distributed in the eastern half of Australia and the western part of WA.
- Used for vegetable growing on the Northern Adelaide Plains and south-east SA, Werribee (Vic) and central-north Vic and the Riverina (NSW).

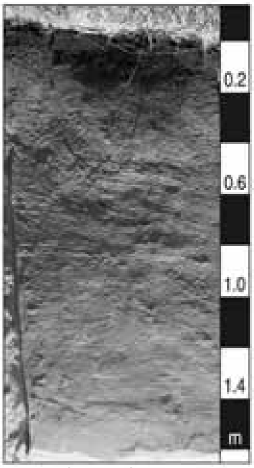
TENOSOLS (slightly developed soil)

Brown-Orthic Tenosol
North Midlands, Tas



Source: D Kidd, DPIW Tas

Yellow-Orthic Tenosol
Swan Coastal Plain, WA

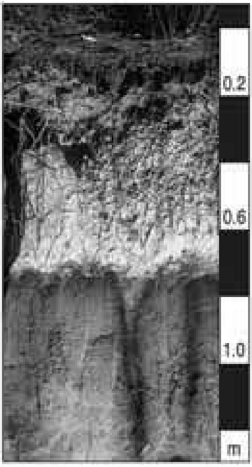


Source: N Schoknect, DAF WA

- Alluvial soil and earthy sands with low fertility and poor water storage — widespread in WA and the NT.
- Used for vegetable growing on the Swan Coastal Plain (WA) and the Tasmanian Northern Midlands.

PODOSOLS **(soil with accumulations of organic matter, iron and aluminium)**

Aeric Podosol
Cranbourne, Vic

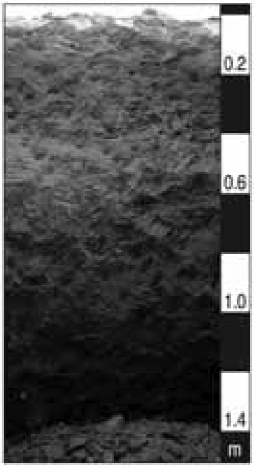


Source: M Imhof, DPI Vic

- Sandy coastal soils with low fertility and poor water storage.
- Subsoils dominated by organic matter and aluminium, with or without iron.
- Used for vegetable growing, following drainage works, at Cranbourne (Vic) and around Perth (WA).

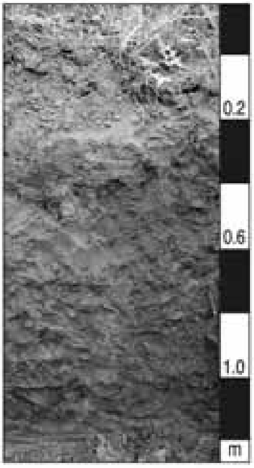
DERMOSOLS **(structured subsoil with minor changes in texture)**

Red Dermosol
Bundaberg, Qld



Source: M Ellis, NRW Qld

Red Dermosol
Camden, NSW

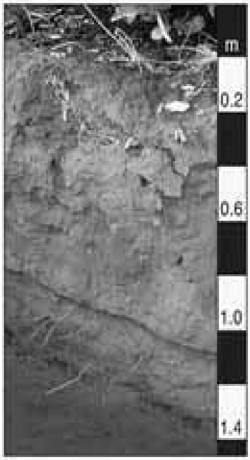


Source: S Cattle, The University of Sydney

- Minor changes in texture — gradual increase in clay content with depth.
- Subsoil usually well structured and well drained. May be acidic or alkaline. In drier areas, the lower subsoil may be sodic.
- Generally found in the wetter, east-Australian coastal and subcoastal zones on low, hilly to mountainous terrain.
- Used for vegetable growing in the Sydney Basin (NSW) and Bundaberg (Qld).

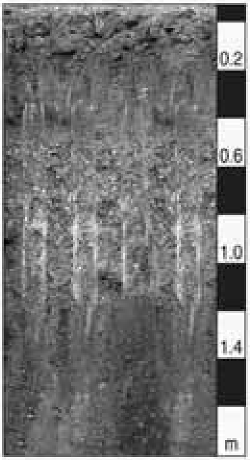
CALCAROSOLS (soil dominated by carbonate)

Calcarosol
Dareton, NSW



Source: Kelly & Giddings, NSW DPI

Calcarosol
Mildura, Vic

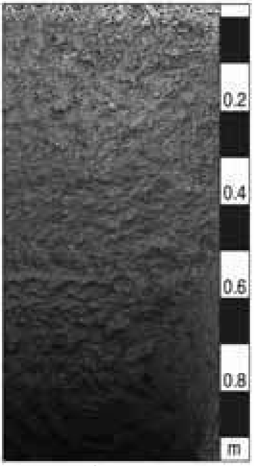


Source: John Rasic Pty Ltd

- Contains calcium carbonate with no strong texture contrast between the topsoil and subsoil.
- Predominantly found in low-rainfall southern parts of the mainland.
- Used for irrigated horticulture along the Murray River and for vegetable growing in the Sunraysia region of Vic, NSW and SA.

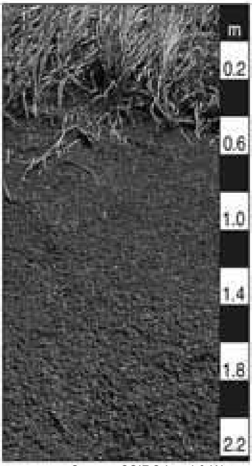
FERROSOLS (high iron concentrations and minor changes in texture)

Red Ferrosol
Scottsdale, Tas



Source: D Kidd, DPIW Tas

Red Ferrosol
Atherton Tablelands, Qld

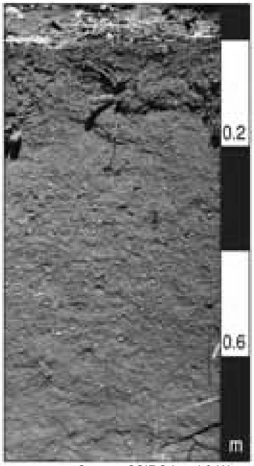


Source: CSIRO Land & Water

- Similar to Dermosols but with a free-iron oxide content greater than 5% in the subsoil — they are usually deep and acidic.
- Generally have stable aggregates in both the topsoil and subsoil.
- Used for vegetable growing on the Atherton Tablelands and Bundaberg (Qld), north-east NSW, and northern Tasmania.

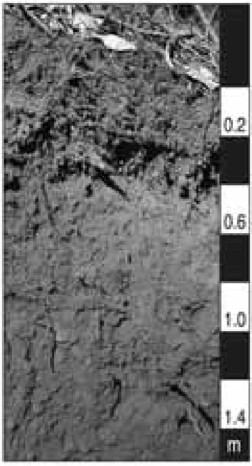
KANDOSOLS **(strongly weathered soil with minor changes in texture)**

Red Kandosol
Darwin, NT



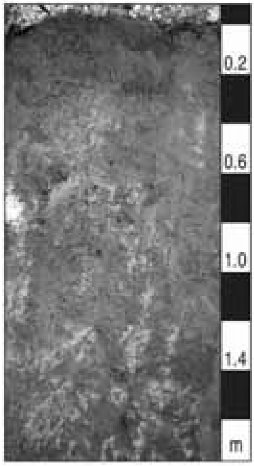
Source: CSIRO Land & Water

Red Kandosol
Manjimup/Pemberton, WA



Source: P Tille, DAF WA

Red Kandosol
Richmond, NSW



Source: S Cattle, The University of Sydney

- Mostly red, well-drained soils that can be up to 3 m deep. They lack a clear or abrupt change in texture between the topsoil and subsoil, which is massive or only weakly structured.
- Yellow and most Grey Kandosols have restricted subsoil drainage.
- Common in all states except Vic and Tas.
- Generally found on extensive, level to gently undulating plains.
- Used for vegetable growing near Darwin (NT), Manjimup and Pemberton (WA), the Sydney Basin (NSW) and central NSW.

All soil types have distinct characteristics that require specific management practices to ensure their sustainability. It is important to note that management practices will impact on soil nutritional and structural characteristics over time and will therefore require ongoing monitoring.

It is important to get to know the soil type/s on your farm and to discover how much variation there is across your property. For more information about soil types in the vegetable growing areas of Australia, refer to the ASRIS (Australian Soil Resource Information System) website: www.asris.csiro.au

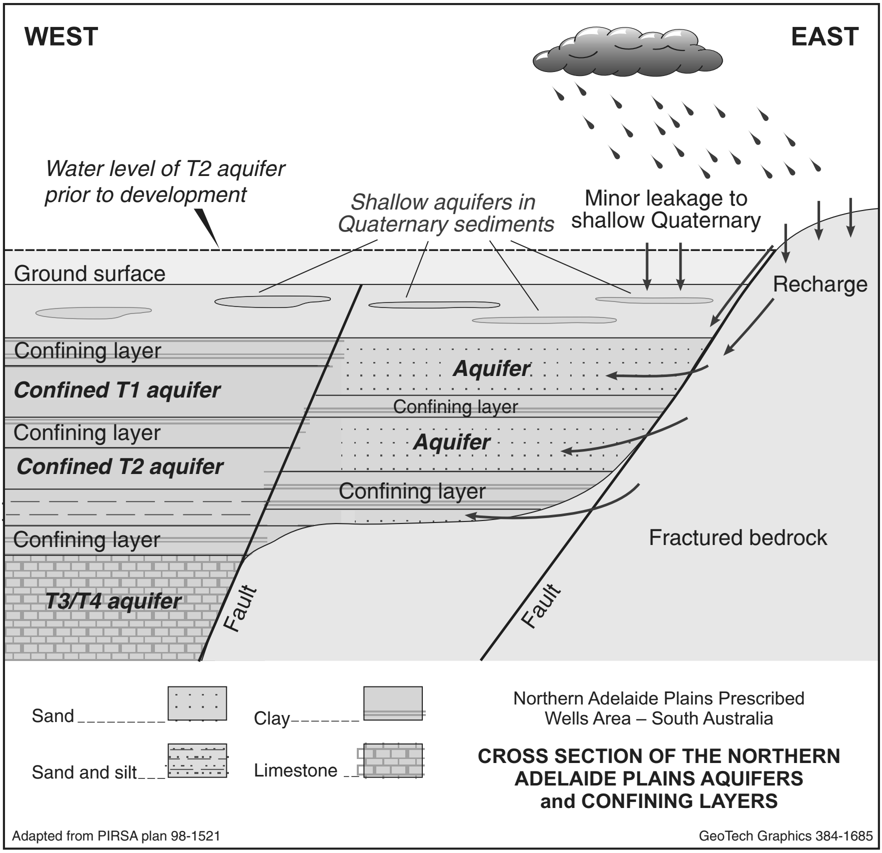
The book *Australian Soils and Landscapes* (McKenzie *et al.* 2004) provides an easy-to-read overview of soil distribution and formation processes.

3.4 Underlying geology and hydrogeology of vegetable farms

Most of the information required by vegetable farmers is related to the soil surface and the root zone of the crops produced on the farm.

However, it is also important to know about the features of underlying structures (Figure 3.7). This is because the deeper layers are where the drainage water from the root zone collects and will provide information about potential off-site impacts of intensive vegetable production. If the deeper layers contain large amounts of stored salt, or if they contain a watertable close to the soil surface (<2 m), farm management needs to be modified accordingly.

State Mineral Resources Departments and Catchment Management Authorities have bore log data that provide information about underlying structures, watertables and deep drainage that can be referred to without major expense.



Source: Adelaide and Mt Lofty NRM Board

Figure 3.7 *Aquifers of the Northern Adelaide Plains showing the system of recharge*

3.5 Cycles at the catchment and global scales relevant to vegetable producers

The practices used on one farm may impact on neighbouring farms and are also a part of what happens on a global scale (Figure 3.8). This is why soil management activities on a vegetable farm cannot be considered in isolation. They need to be viewed as part of ‘the bigger picture’, which includes whole of catchment issues such as salinity and river quality.

Of particular relevance to vegetable growers is the hydrological cycle which explains how water moves around their farms and the wider environment (Figures 3.9 and 3.10).

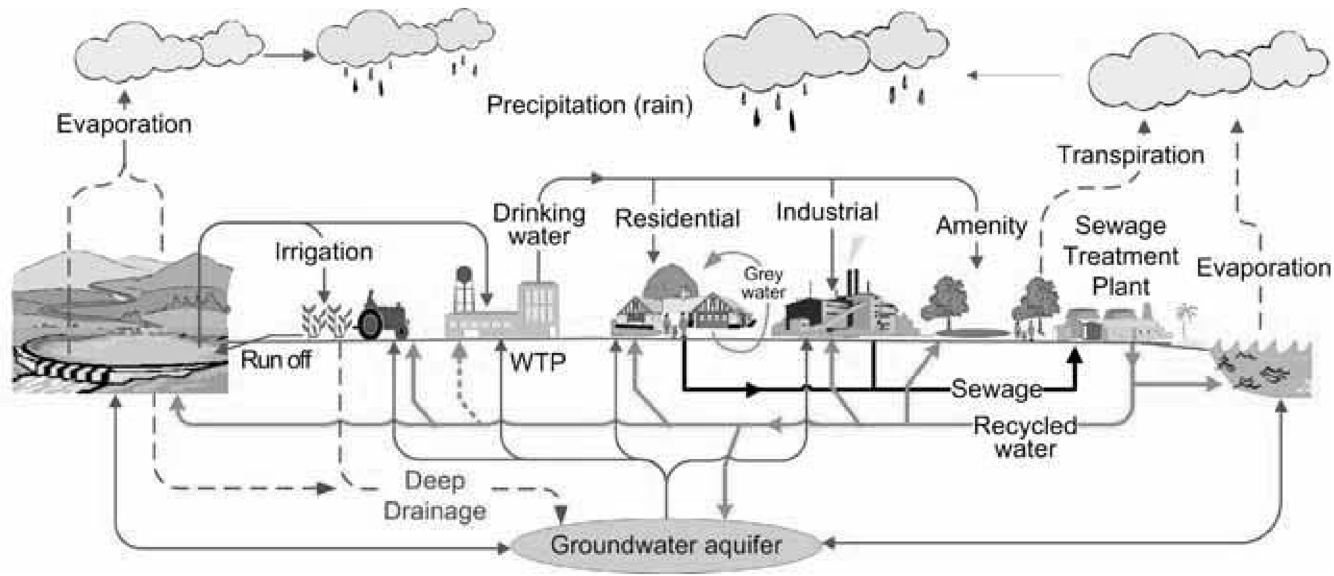
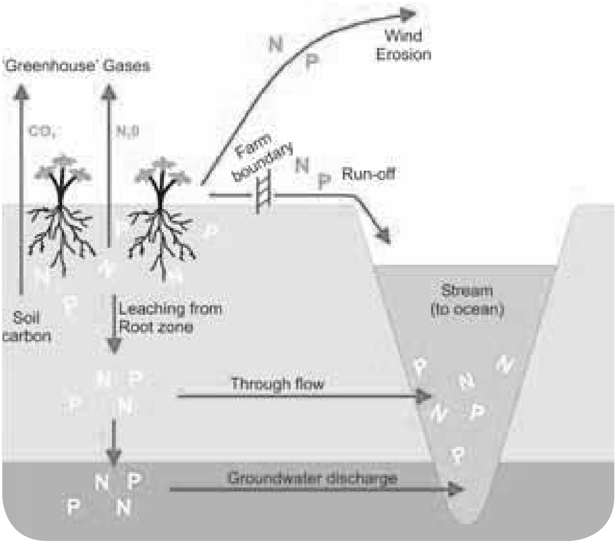
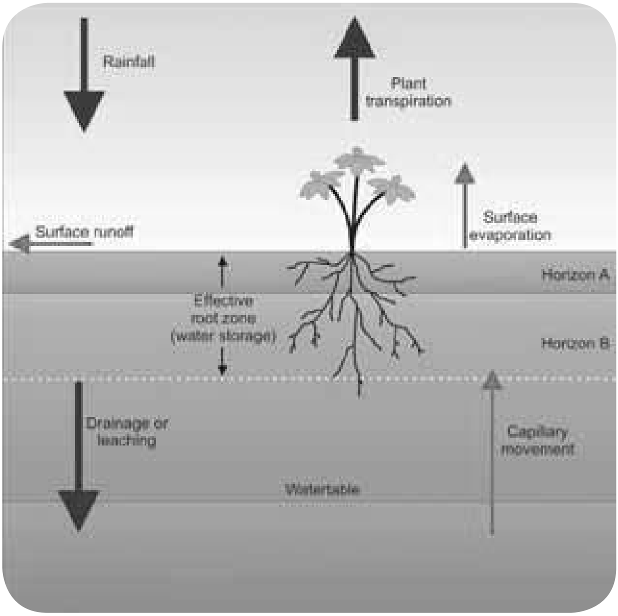


Figure 3.8 *Global hydrological cycles*



Source: Kelly *et al.* (2001)

Figure 3.9 *Environmental impacts of vegetable farming*



Source: Kelly *et al.* (2001)

Figure 3.10 *The paddock hydrological cycle*

At the global scale, issues such as carbon emissions and global warming need to be considered. Global warming is a direct result of increasing carbon dioxide and other greenhouse gas (such as nitrous oxide) concentrations in the atmosphere. The predictions of climate change indicate that farmers in all areas of agriculture are likely to find production much more difficult if global warming continues unabated. Efficient use of fertilisers and fuel are two critical aspects of vegetable farming which can help reduce the emission of greenhouse gases.

4 Examining and evaluating soil quality on vegetable farms

When developing a new field for vegetable production the first step should be to assess the condition of the soil.

A soil survey undertaken by a specialist is a great investment as it will highlight the soil type/s on your farm and provide important information about soil characteristics that will affect vegetable production. A soil survey will also reveal any areas that require special agronomic attention and will help you to select and design the most appropriate irrigation system and program.

However, you can undertake a basic soil assessment yourself and the information in this section will help you to do that.

Looking at local roadside cuttings is a useful method to give some insight to local soil profile characteristics.

Some soil features (e.g. soil structure, pH, nutrition) can change greatly over time so it is important to assess the condition of your soil regularly.

4.1 Choosing a location for soil inspection

Use clues from your experience such as yield differences, varying soil surface colour and aerial photographs as a basis for deciding on where to examine your soil for potential differences in soil and land management. Maps of crop yield, as well as during-season aerial scans of crops, are particularly valuable for this task.

For post-harvest soil assessments, aim to include the highest, average and lowest-yielding sections of a field in your soil sampling program. One sampling site might be enough if yields are uniform across the field.

When inspecting your soil, always avoid the compacted ends of a field where machinery turns.

If the main aim of the soil investigation is to assess salinity, or properties strongly correlated with salt content (e.g. deep drainage assessment in clay-rich soil), then electromagnetic induction (EM) survey maps can be used to define soil sampling sites.

Record where you take soil samples so that you can return to the site for follow-up inspections or ongoing monitoring. A Global Positioning System (GPS) instrument is a great tool for locating your position in a field to within a few metres.

4.2 Soil sampling tools

Once you have selected a site or sites, there are several tools you can use to prepare, inspect and sample a soil profile.

4.2.1 Excavators and backhoes

A soil pit (Figure 4.1) dug at right angles to the movement of field traffic provides a good overview of the whole root zone (soil profile) of a vegetable crop. It allows for easy sampling of both the topsoil and subsoil. Where important variation in soil condition is expected along the plant lines (e.g. soil acidity induced by drip irrigation), the pit wall should be oriented in that direction as well.

Figure 4.1 *Soil pit ready for inspection*

It is very important that you do not change the structure of the soil by driving an excavator or backhoe over the area where the soil pit will be. This equipment is very heavy and may compact the soil where you intend to dig. Having decided where you want your soil pit, reverse the backhoe up to the spot so that you can dig in undisturbed soil.

Depending on your crop you will need to dig to about 1.2 m to 1.5 m deep. Plant roots often extend well below 1 m (e.g. crops such as tomatoes and watermelons). A pit width of about 1 m is recommended although often it is more convenient to have a narrower pit (depending on bucket width).

Important warnings:

- Check on the location of underground telephone and electric cables and water pipes before digging a pit and keep the backhoe boom well clear of overhead power lines. Use the ‘Dial Before You Dig’ service as cutting telephone cables, particularly fibre optic cables, can be extremely costly (dial 1100 or visit website: www.dialbeforeyoudig.com.au).
- Make sure you know the maximum allowable depth for backhoe pits in your state without benching or special support. For example, in NSW it is 1.5 m.
- Be extremely careful that the sides of a soil pit are not likely to collapse while you are in the pit. It is recommended that you have someone with you while you are in a pit.
- Prevent the spread of soil-borne diseases and weeds by thoroughly cleaning excavating equipment. Sampling equipment and footwear should also be cleaned between farms and between fields if diseases are present.

Once a pit has been dug it needs to be prepared for inspection (Figure 4.2):

- Clear away any soil spilt on the soil surface above the area you wish to examine so that you can locate the original surface as a reference for the depth of features.
- Pick back an area on the face of the pit to remove soil compacted/smeared by the backhoe bucket so as to reveal the natural structure and colour of the soil. A long handled pick, chisel or asparagus cutting knife can be used.
- Work across the pit face beginning at the top and working down to the bottom, prising out the damaged exterior of the pit face. This systematic trimming will enable you to remove most of the marks left by your trimming tools.

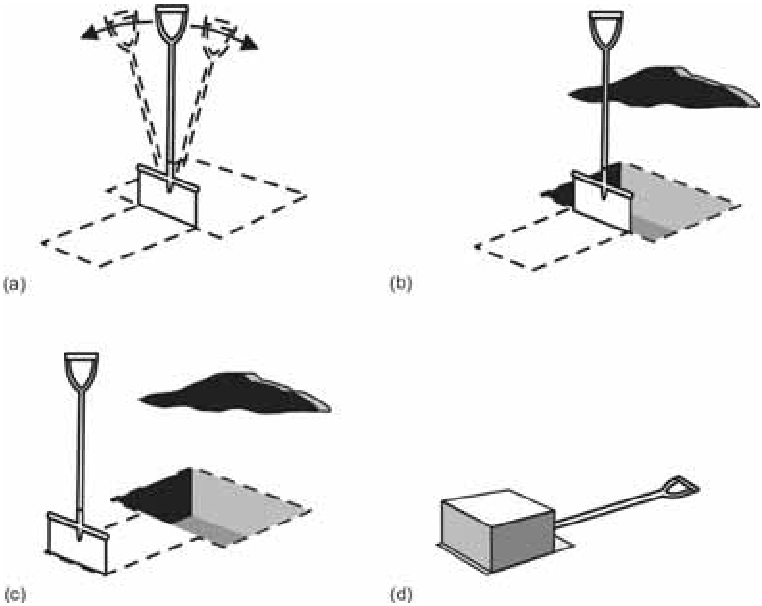
NOTE: If you don’t have experience in examining soil pits it will be advantageous to use an accredited advisor to gain necessary experience.

Figure 4.2 *Trimmed clay soil pit, ready for description and sampling*

As soon as possible after inspection, fill in pits with a slight mound to allow the soil to settle before planting the next crop. Subsided pits may be a hazard to light, fast-moving traffic so mark them clearly with visible and flexible plastic pegs. If the pit is to be left open, make sure it is well marked and roped off.

4.2.2 Spade inspections

A spade is very useful for the rapid inspection of soil to a depth of about 30 cm. To ensure that the lower part of the mini-profile is not compressed, it is recommended that you dig a hole with the spade first and then take a slice of soil from the side of the hole for examination of root health, and of soil factors such as structure, pH and biological activity (Figure 4.3).



Modified: Munkholm (2000)

Figure 4.3 *Outline of how to take out a sample for spade analysis, steps (a) to (d)*

4.2.3 Corers

Hydraulically driven or hammered coring tubes can be useful in non-stony soil when it is not possible to dig a soil pit but sampling is required to depths greater than that readily accessible using a spade.

However, when the soil core has a diameter less than 75 mm, disturbance of soil structure inside the core during the insertion process limits soil analysis to the assessment of chemical properties. Besides this, the core itself may be compacted when removed from the corer and it may be difficult to determine how positions in the core relate to the natural soil profile.

4.3 Inspection zones

There are three main inspection zones in the root zone that need to be considered by vegetable growers:

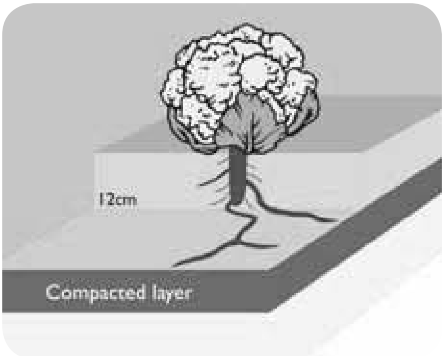
1. **Surface (0–10 cm)** (Figure 4.4): This is the soil zone that strongly influences seedling establishment and the infiltration of water.

2. **Sub-surface (10–30 cm)** (Figure 4.5): This layer is usually the zone of maximum water uptake and nutrient extraction by plant roots.

Figure 4.4 *Surface soil inspection (0–10 cm)*

3. **Subsoil (30–120 cm):** These deeper layers contain valuable reserves of water and nutrients but can severely retard plant growth if problems such as waterlogging and salinity are present.

   It is also desirable to have knowledge of conditions deeper than 120 cm, to answer questions such as watertable behaviour and salt movement.



Modified: Batey (1988)

Figure 4.5 *Sub-surface inspection (10–30 cm)*

4.4 Collecting soil samples for laboratory testing

When using soil pits to inspect your soil it is easy to collect soil samples from the different inspection zones for laboratory testing. Collect 500 g of soil from each inspection zone in a sealed plastic bag (snap lock lunch bags are useful) to ensure that the sample does not dry out. Send samples to the laboratory as soon as possible after collection and make sure that each bag is carefully labelled (e.g. pit number, farm or paddock name, depth and date of sample).

If you have soil pits in the highest, average and lowest-yielding parts of your paddock take soil samples for each of these pits and do not mix them. If you do you will lose valuable information and may not be able to determine what is causing the differences in yield. Keeping samples separate allows the information to be mapped in a way that allows variable rate input of soil improving materials such as lime, gypsum and nutrients.

Topsoil sampling (0–10 cm) for soil nutrient testing (prior to adding fertiliser) is likely to be carried out every 1–2 years whereas soil pits are usually dug prior to a new development or to assess soil condition to determine reasons for yield variability. Topsoil sampling is easily done using a spade. Ensure you do not include plant material from the soil surface.

Many laboratories will recommend that you collect a minimum of 20 samples from across a paddock and mix them in a bucket. A 500 g sample is then taken from the bucket for analysis. However, mixing soil samples for laboratory testing is only appropriate if the soil is from the same depth (inspection zone) and from a uniform area (same soil type, has been managed uniformly and yields uniformly). Always use clean equipment for sampling soil and do not sample from unusual sites such as:

- gateways
- the end of a field where machinery turns
- old fertiliser stockpiles
- an area where the soil has previously been disturbed (e.g. an old soil pit site).

If you are unsure about sampling methods and tests to carry out, discuss your situation with a soil consultant, state agricultural department personnel or a soil laboratory. The information you require for management will impact on the methods you use for collecting and analysing the soil samples.

4.5 Soil evaluation

4.5.1 Checklist

For each of the inspection zones discussed in Section 4.3 there are tests that can be done in the field and laboratory to diagnose the condition of your soil. Table 4.1 is a checklist of soil properties that should be assessed in the field and/or the laboratory and why they are important. More information about each soil property and how it is assessed is given in Sections 4.5.2 – 4.5.15.

Table 4.1 *Checklist of soil properties and their significance*

Soil Property	Field	Lab	Significance
Soil structural form	✓	✓	Severity of compaction damage affects seedling establishment, root growth, flow of water and air into and through the soil.
Soil structural stability	✓	✓	Collapse of structural form upon the addition of water leads to the formation of hard layers which adversely affects air and water movement, root penetration and seedling establishment.
Soil structural resilience		✓	Ability of a soil to regain desirable structural form after damage, e.g. via shrink-swell processes. Also see CEC.
Soil water content for tillage	✓		Tillage at water contents above the plastic limit is likely to degrade soil structure.
Soil texture	✓	✓	Influences soil structure and affects seedling emergence, water infiltration, water holding capacity, trafficability and ease of tillage.
Soil permeability	✓	✓	Movement of water into the soil is important so that plants have access to water and to limit run off from irrigation. Drainage is important to prevent waterlogging.
Soil water holding capacity	✓	✓	Plants need access to as much readily available water as possible to prevent drought stress.
Soil colour	✓		Indicator of whether the soil is well drained or not. Mottling indicates that the soil is sometimes waterlogged.
Waterlogging severity	✓		Sign of excessive application of irrigation water, poor drainage and/or poor soil structure. Can lead to crop losses associated with soil salinisation and alkalisation due to accumulation of sodium salts and carbonates.
pH	✓	✓	Degree of acidity or alkalinity. Can affect nutrient availability and element toxicity.
Salinity/electrical conductivity (EC)	✓	✓	The presence of excessive salt can adversely affect plant water uptake and create toxicities.
Exchangeable cations and cation exchange capacity (CEC)		✓	Guide to nutrient status of the soil and indicator of soil structural stability and resilience.
Nutrients		✓	Guide to whether fertiliser additions are required. Plant growth is poor if they are not provided with a balanced and adequate supply of nutrients.
Soil organic matter content		✓	Stabilises soil aggregates, provides energy and nutrients for microorganisms, adds to the CEC.
Soil mesofauna	✓		Play a key role in nutrient cycling, soil mixing and in creating biopores (improving soil structure). Some mesofauna are harmful to crops.
Soil microorganisms		✓	Affect organic matter decomposition and nutrient cycling.
Water repellence	✓	✓	Prevents water entering the soil uniformly.

4.5.2 Soil structure

Soil structure is made up of three components: structural form, structural stability, and structural resilience.

Structural form (compaction)

Soil structural form is the arrangement of the solid components of soil and the spaces in between, which are called pores.

Ideally, soil should have pores for the flow of water and gases (transmission pores), and pores that contain water and dissolved nutrients for plant growth (storage pores).

In badly compacted soil the pore space is reduced so water transmission through the soil is slowed and water storage and aeration is reduced.

Compaction problems in the field may be indicated by deformed taproots (e.g. right-angled deflection, rapid tapering of the root diameter, see Figures 3.3, 3.4 and 3.5) or pooling of water following rain or irrigation.

A soil with good structural form breaks up easily into small aggregates of soil. This type of soil is often referred to as a friable soil.

A sandy soil does not have many aggregates but if it allows good water infiltration and drainage and has good aeration its ‘structure’ can be suitable for vegetable growing. However, sandy soil can be particularly susceptible to compaction, and compacted layers will negatively affect the productivity of the soil. While clay-rich soil types are also susceptible to compaction, natural swelling and shrinking of the clay as it wets and dries can reduce the compaction effects. Sandy soil does not have this natural process to alleviate compaction.

Changes in structural form can be recorded after a single cultivation, or in the long-term. Assessments of structural form can be used to check past decisions and plan future management. For example, before deciding to deep till, examine the soil to see if there is a need for that operation. If there is a hard compacted layer measure its depth so that you can set the depth of cultivation tines to break the pan (always check after a short run to make sure that the tillage operation is achieving the desired outcome).

A simple numeric system for rating soil structural form is given in *SOILpak for vegetable growers* (McMullen, 2000). This rating system is referred to as the ‘SOILpak score’ and is based on visual and tactile (feel) assessment of the compaction of soil samples (on a scale of 0.0–2.0). Use Table 4.2 as a guide to assessing structural form.

Table 4.2 *A numeric system for assessing structural form*

1. Score your soil between 0 and 2 for each soil feature (0.0, 0.5, 1.0, 1.5 or 2.0).
2. Average the score by adding up the scores for each feature and dividing by the number of features you examined.

SCORE			
Features (listed in descending order of importance)	**Poor Structure (0.0)**	**Moderate structure (1.0)**	**Good structure (2.0)**
Aggregate size — width of natural subunits produced by moderate hand pressure	Mostly more than 50 mm wide.	5–50 mm wide.	Mostly less than 5 mm wide.
Ease of fracture	Difficult for a spade or knife to penetrate; soil made up of large, tightly fitting blocks.	Moderate hand pressure needed to separate clods/ aggregates.	Parts readily into porous subunits.
Aggregate shape (see Figure 4.6)	Massive, platey or shell-shaped.	Mixed shapes.	Many-faced, cube-shaped with rounded corners, lens-shaped.
Fracture faces	Soil breaks along the line of force applied in any direction into units with sharp corners; internal faces have no protruding subaggregates.	Some natural separation planes with shiny faces, but most fracturing is along the line of force to produce angular corners and smooth, dull internal faces.	Natural fracture planes dominate; most of the faces are smooth and shiny. Often there are protruding, many-faced, round-cornered aggregates.
Small aggregates within larger aggregates	Less than 10% of breakdown products are shiny-faced aggregates (clays) or larger than single grains (loams).	50% of breakdown products are shiny-faced aggregates (clays) or larger than single grains (loams).	More than 90% of breakdown products are shiny-faced aggregates (clays) or larger than single grains (loams).
Porosity (internal porosity of smallest aggregates)	No visible pores.	Moderate number of pores.	Many pores (greater than 5%).
Extra notes for very dry soil	Requires a very strong blow with an implement to break the blocks, revealing smooth, dull faces with sharp corners; flinty.	Hard hand pressure required to break the blocks.	Falls apart with light hand pressure to produce small, natural aggregates.

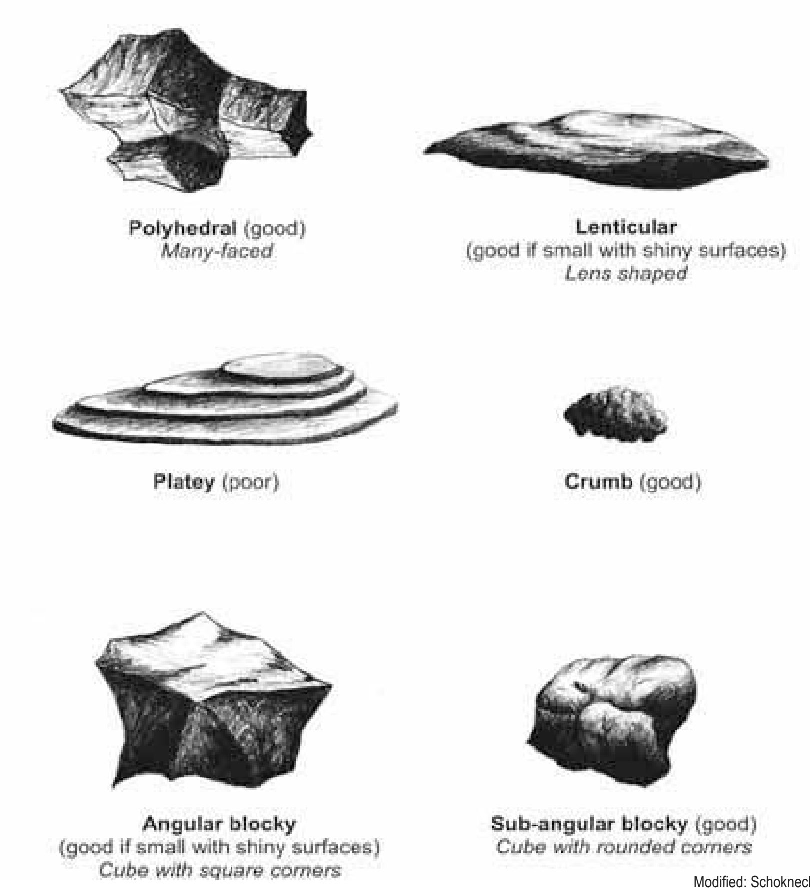
Table 4.2 shows that a soil sample with large (mostly greater than 50 mm diameter) platey aggregates that are very difficult to break will have a ‘SOILpak score’ of zero. A soil sample with small (mostly less than 5 mm diameter) rounded aggregates that part readily into porous component aggregates will have a ‘SOILpak score’ of 2.

Refer to the *Healthy Soils for Sustainable Vegetable Farms: DVD* and/or the *Healthy Soils for Sustainable Vegetable Farms: Resource Manual* for a detailed description of how to assess structural form using the ‘SOILpak score’.

More complex methods of assessing structural form include:

- image analysis of micro cross-sections of soil
- soil strength measurement using penetrometers and shear vanes
- bulk density measurements
- aggregate friability from crushing strength measurements.

When measuring soil strength it is important to take note of the water content as the effect of compaction tends to become less obvious as the soil becomes wetter. These measurements usually are made only by soil scientists.



Modified: Schoknecht (1997)

Figure 4.6 *Common shapes of soil aggregates*

Structural stability (in water)

When water is added to aggregates of soil, the aggregates may collapse. There are two types of aggregate collapse when water is added to soil — slaking and dispersion.

Slaking occurs when aggregates of soil collapse into smaller fragments (microaggregates) on wetting (Figure 4.7). If the aggregates are strongly bound by organic matter, they will remain intact. Otherwise they will be observed to fall apart within seconds. This highlights the importance of organic matter in soil used for vegetable growing.

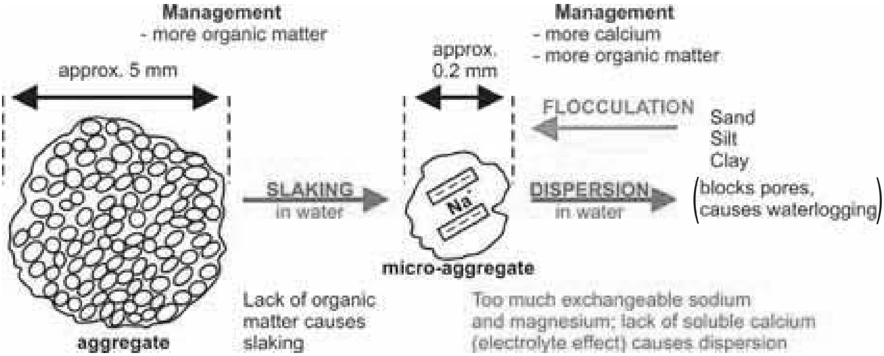


Figure 4.7 *Processes associated with slaking and dispersion of soil aggregates (not drawn to scale)*

Slaking occurs in most soil types used for vegetable growing. It may or may not be desirable.

For cracking clay soil types, slaking to form microaggregates is beneficial because it leads to the regeneration of good structural form. This is termed self-mulching. In contrast, slaking is a problem in loamy soil with poor shrink-swell potential as it can set very hard when dry.

Dispersion is a more severe form of structural collapse and is the separation of soil into single particles (Figure 4.7). It is usually caused by too much sodium (a sodic soil) and is aggravated by a lack of soluble calcium.

Dispersion usually results in undesirable hard layers where air and water movement, root penetration and seedling establishment are adversely affected. Hard surface crusts are an indication of a dispersive soil. This condition is known as 'hardsetting'.

To get an indication of how stable your soil is, add some soil aggregates to a dish (a white jar lid is ideal) of distilled water or rain water. After 10 minutes, observe whether the original aggregates have disintegrated into microaggregates (slaked) or whether the aggregates have dispersed (indicated by cloudiness around the aggregates in the distilled water). Examples of slaking and dispersion are shown in Figure 4.8.

There are two accurate and practical measures of dispersion severity that can be done at home: the ASWAT (Aggregate Stability in Water) test and the Dispersion Meter test.

The ASWAT test gives a dispersion index ranging from 0 (very stable) to 16 (severe dispersion).

It includes remoulding the soil after being moistened, which simulates the impact of cultivating the soil when wet. The ASWAT test is summarised in Figures 4.9 and 4.10.

Figure 4.8 *Aggregates of soil that have slaked but not dispersed (left) and slaked and dispersed (right)*

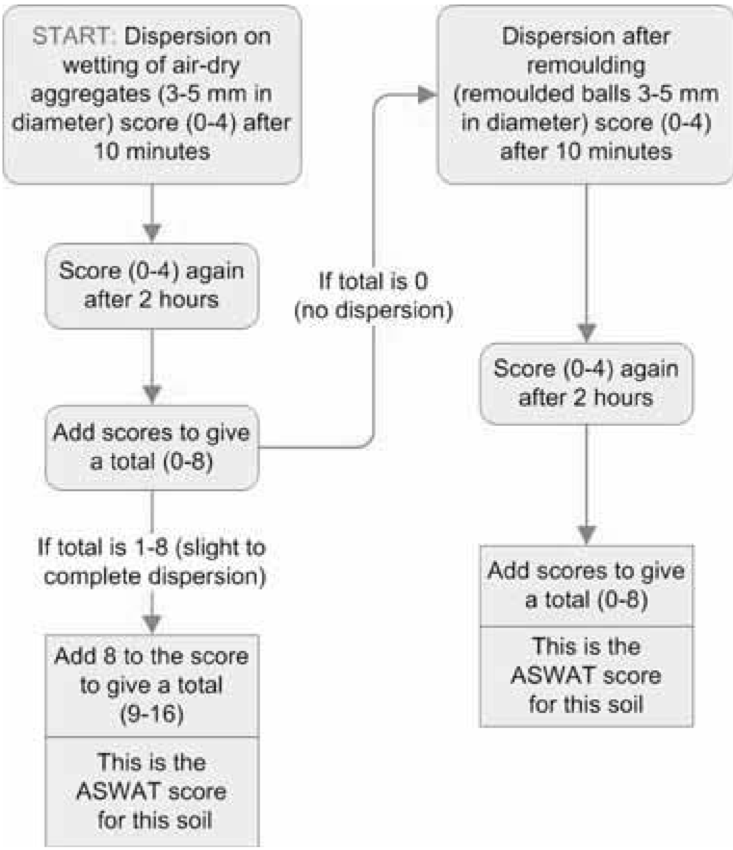
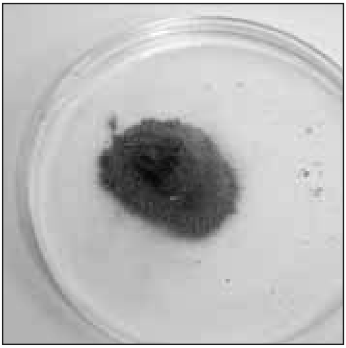


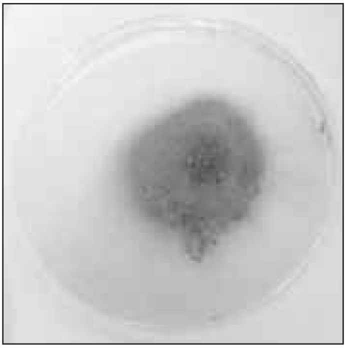
Figure 4.9 *The ASWAT test procedure*

Figure 4.10 *Degrees of dispersion and dispersion scores*

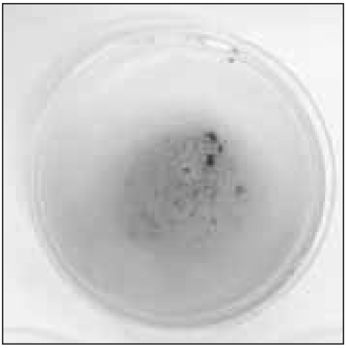
Dispersion score 0: Nil dispersion



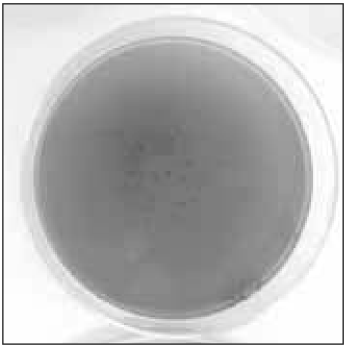
Dispersion score 1: Slight dispersion recognised by slight milkiness of water adjacent to aggregate



Dispersion score 2: Moderate dispersion with obvious milkiness



Dispersion score 3: Strong dispersion with considerable milkiness and about half of the original volume of the aggregate dispersed outwards



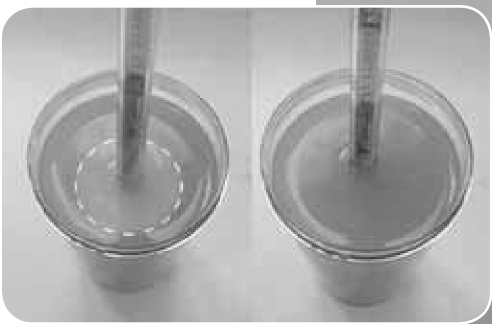
Dispersion score 4: Complete dispersion leaving only sand grains in a cloud of clay

The Dispersion Meter test indicates a level of dispersion (none, low, medium or high) by lowering a Dispersion Meter (available from Arris Pty Ltd — see the Arris website: www.arris.com.au) into a 500 ml clear plastic container containing 1 part soil to 5 parts distilled water (1:5 soil:water) (Figure 4.11).

Refer to the *Healthy Soils for Sustainable Vegetable Farms: DVD* and/or the *Healthy Soils for Sustainable Vegetable Farms: Resource Manual* for a detailed description of how to assess dispersion severity using either the ASWAT test or Dispersion Meter test.

There are several important laboratory tests that indicate how dispersible a soil may be. These include exchangeable sodium percentage (ESP) and electrochemical stability index (ESI) — see Section 4.5.11 for information on how to calculate them from soil test results.

In general, non-saline soil is likely to be dispersive if its ESP is greater than 6. Australian soils are defined to be sodic if they have an ESP greater than 6. Sodicity refers to a high proportion of sodium on the clay surfaces in a soil compared with other cations.



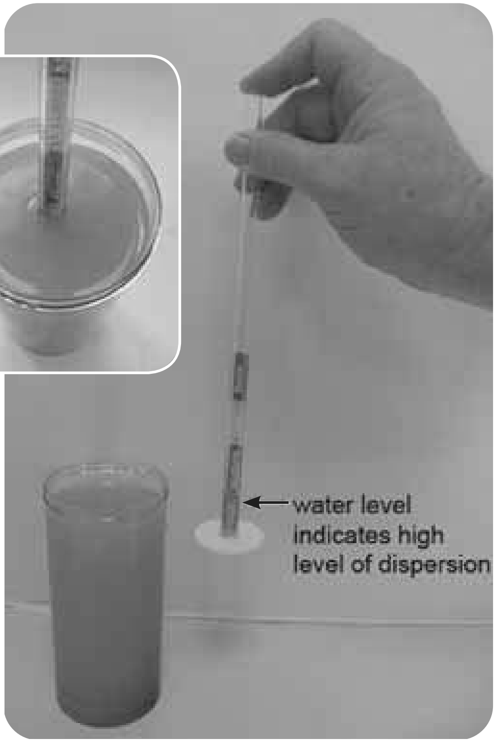


Figure 4.11 *Placing the Dispersion Meter in the container with the 1:5 soil:water suspension and lowering it to the point where the white disc is no longer visible. The water level in the Dispersion Meter indicates the severity of dispersion. In this example it is a high level of dispersion.*

Source: Kelly and Rengasamy (2006)

However, if a soil is saline its ESP can be greater than 6 and still not disperse upon wetting. As electrical conductivity (EC) increases, dispersion decreases regardless of how sodic a soil is. Conversely, very low EC values mean that a soil may become dispersive where the ESP is as low as 2. The balance between the various exchangeable cations and the concentration of total salts (salinity, as measured by EC) determines whether a soil will disperse in water. The balance is measured by the ESI. Soil with an ESI value of 0.05 or less is likely to be dispersive.

Another commonly measured sodicity parameter of soil and irrigation water is the Sodium Adsorption Ratio (SAR). SAR is the concentration of sodium divided by the square root of calcium plus magnesium in the soil solution. Like salinity, SAR (for soil) can be measured using either saturation extracts or 1:5 soil:water extracts. Relationships exist between SAR and ESP:

- for saturation extracts $ESP \approx SAR_e$
- for 1:5 extracts $ESP \approx 2SAR_{1:5}$

Structural resilience (rebound potential)

Structural resilience is the ability of a soil to regain a desirable structural form after disruptive forces (e.g. compactive pressures under the wheels of heavy machinery) have been removed.

Regeneration usually occurs in clay-rich soil that swells when wet and shrinks when dry, although soil fauna (for example, earthworms and ants) and plant roots can produce similar benefits in both swelling and non-swelling (sandy, loamy and silty) soil.

The sum of exchangeable cations (referred to as cation exchange capacity or CEC) increases as the amount of clay in a soil increases and provides an index of the ‘rebound potential’ of a soil after it has been compacted. This is because the shrink-swell potential of a soil usually increases as its CEC becomes greater.

Shrinking and swelling of a clay soil by drying and re-wetting will loosen compacted layers. Soil with a high proportion of fine sand and silt, a lack of organic matter and a low CEC value tends to be ‘hardsetting’ and is not very resilient. Sandy soil tends to stay compacted unless some remediation work such as ripping is done.

4.5.3 Soil water content for tillage

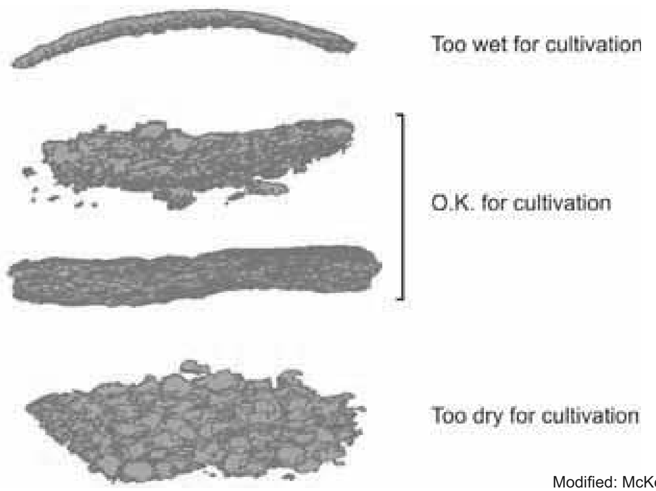
Soil structure can be degraded if the soil is tilled when it is too wet or too dry.

When the soil surface is dry and brittle, tillage will cause the soil to be pulverised, creating dust. If you are creating a large dust cloud as you cultivate, the soil is too dry. Valuable nutrients can be lost through the creation of dust. However, dry tillage of compacted clay-rich subsoil can be beneficial.

When cultivating duplex soil (soil with a loamy or silty topsoil overlying a clay-rich subsoil) aim to thoroughly dry the whole soil profile and then wait for some rainfall to moisten the topsoil so that dust formation is minimised.

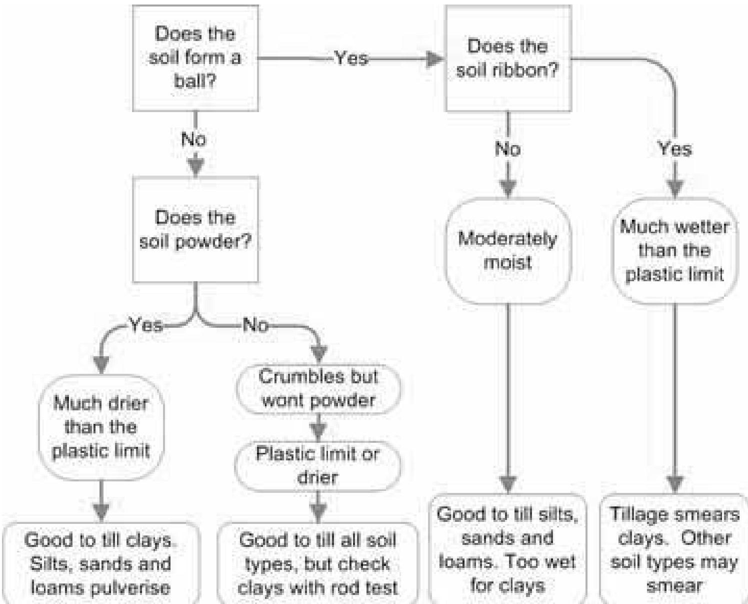
Tillage when the soil is too wet will cause the soil to smear and compact. Smearing occurs when wheels or tillage implements slide across the surface of wet soil and change its structure so that it seals off against water and root penetration. This is the case for both loamy soil and clay-rich soil.

Soil scientists use a term called the 'plastic limit' as a guide to the ideal soil water content for tillage. As a general rule, a handful of soil that can be moulded into a ball but is not quite moist enough to be rolled into a rod of soil 3 mm thick is at the right water content for cultivation (Figure 4.12 and Figure 4.13). At this moisture content the soil is said to be just below the 'plastic limit'.



Modified: McKenzie (1998)

Figure 4.12 *Rolling soil into a rod of soil 3 mm thick is a good indication of whether the soil water content is suitable for tillage*



Source: Anderson *et al.* (1999)

Figure 4.13 *How to determine whether your soil is suitable for tillage*

4.5.4 Soil texture

Soil texture is an estimate of the amount of sand, silt and clay in a soil. It is a soil property that usually only needs to be determined once for each soil inspection zone as it is unaltered by most agricultural activities. However, addition of organic matter and deep cultivation that mixes subsoil clay with the topsoil can alter the texture.

Texture strongly influences the structure of the surface layers of soil and therefore affects seedling emergence, water infiltration, trafficability and ease of tillage. It also affects water infiltration and water-holding capacity of the soil.

Clay-rich soil is less prone to hardsetting and holds more nutrients than loams because they have a higher cation exchange capacity. However, clays are more likely to have poor aeration, a slow rate of warming after irrigation, and poor workability and trafficability after rain (Figure 4.14). They also tend to hold more plant available water when wet but plants are less able to extract water from them when they are dry.

Field texture is determined by the way the soil behaves when a small handful of soil is moistened and kneaded into a ball (a bit larger than a golf ball), often referred to as a bolus, and then pressed out between the thumb and forefinger to form a ribbon (Figure 4.15). Use Table 4.3 and Figure 4.16 to assist you in determining the texture of your soil.

Refer to the *Healthy Soils for Sustainable Vegetable Farms: DVD* and/or the *Healthy Soils for Sustainable Vegetable Farms: Resource Manual* for a detailed description of how to assess soil texture.

Source: Hickey, NSW DPI

Figure 4.14 *Wet, clay-rich soil at Hay (NSW) makes harvesting difficult*

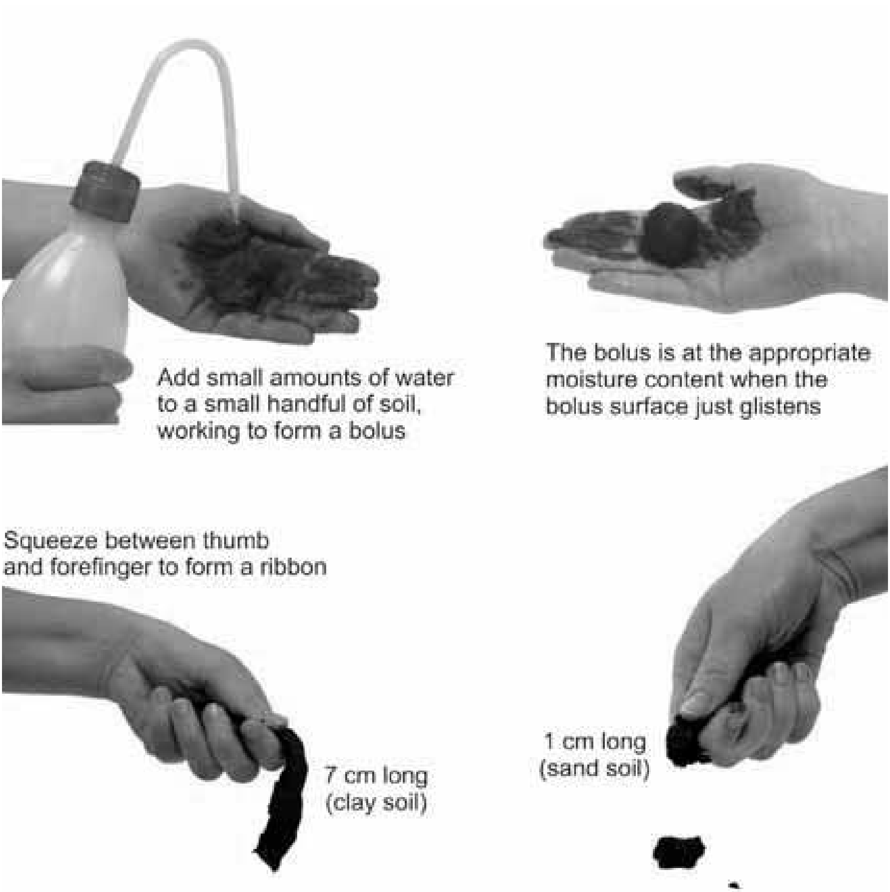


Figure 4.15 *Formation of a ball and ribbon to determine soil texture*

Table 4.3 *Broad field texture classes*

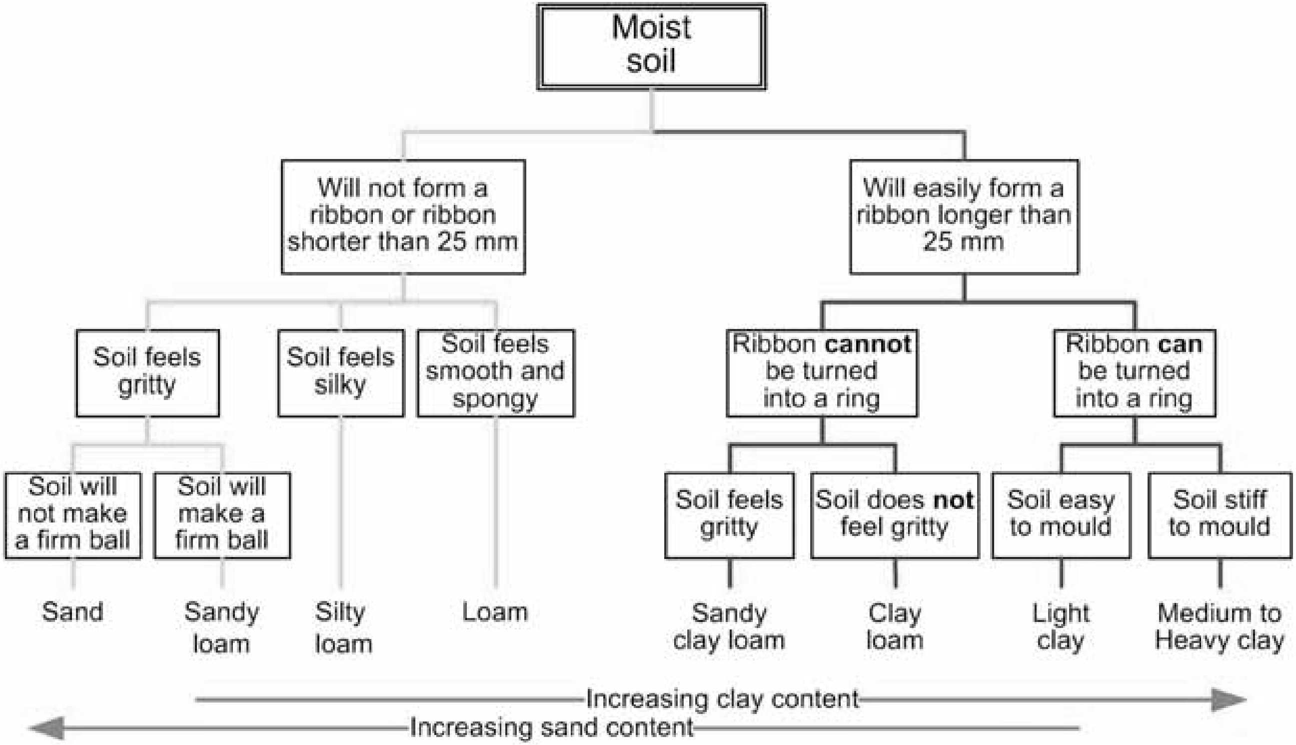
Field texture group	Description	Approximate clay content
Sand	Nil to slight coherence. Ribbon of 0–15 mm.	Less than 10%
Sandy loam	Coherent but very sandy to touch. Ribbon of 15–25 mm.	10–20%
Loam	Coherent, spongy and greasy feel with no obvious sandiness or silkiness. Ribbon of about 25 mm.	About 25%
Silt loam	Coherent, very smooth to often silky when manipulated. Ribbon of about 25 mm.	About 25% and with silt 25% or more
Sandy clay loam	Strongly coherent, sandy to touch with medium size sand grains visible in finer matrix. Ribbon of 25–40 mm.	20–30 %
Clay loam	Coherent plastic bolus. Smooth to touch with no obvious sand grains. Ribbon of 40–50 mm.	30–35%
Light clay	Plastic bolus. Smooth to touch with slight resistance to shear. Ribbon of 50–75 mm.	35–40%
Medium to heavy clay	Plastic bolus. Smooth to touch. Feels like normal to stiff plasticine. Moderate to firm resistance to shear. Ribbon of 75 mm or more.	40% or more

Based on: McDonald *et al.* (1990)

Soil texture can also be determined in the laboratory through a particle size analysis (PSA). PSA data can be used to check on the accuracy of field determination of soil texture.

Soil texture data is required to estimate available water (see Section 4.5.5) and is needed to convert $EC_{1:5}$ data to EC_e in salinity investigations (see Section 4.5.10).

Figure 4.16 *Flow diagram to assist in determining soil texture*



4.5.5 Soil permeability and water holding capacity

The movement of water into a soil and through the soil profile is influenced by factors such as the presence/absence of surface crusts, compaction, soil texture, sodicity and slope.

After prolonged heavy rainfall, when the soil profile is full of water, including all of the air spaces, the soil is said to be ‘saturated’. After the surplus water drains and there is no more free drainage the soil is said to be at its maximum water storage capacity, often referred to as ‘field capacity’.

As water is removed by plants and by evaporation from the soil surface it becomes more and more difficult for plants to extract water as it clings more tightly to soil particles and in small pore spaces. When water extraction becomes difficult for plants and more water is required to maintain growth rates, the soil is said to be at the ‘refill point’.

Eventually, if the soil continues to dry, it will hold some water which cannot be extracted by plant roots and plants wilt and cannot recover. This is called the ‘permanent wilting point’ (PWP). It is important to note that plant production will slow/stop before PWP is reached.

Soil within the root zone needs to be able to store as much water as possible in the plant available range but also drain well enough so that aeration is quickly re-established after irrigation or rainfall. Plants grow best when they have a suitable balance of water and air in their root zones.

There are three types of stored soil water (Figures 4.17 & 4.18):

- Readily available water — water held between field capacity and refill point.
- Plant available water — water held between field capacity and permanent wilting point.
- Unavailable water — water stored in very small pores or held so tightly around soil particles that it cannot be extracted by plant roots.

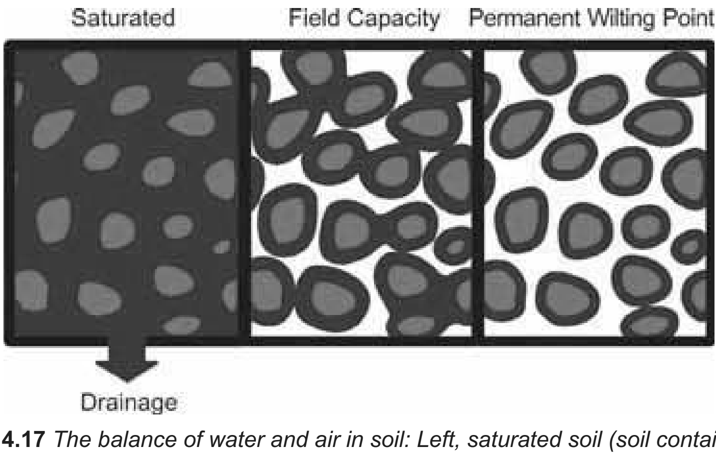
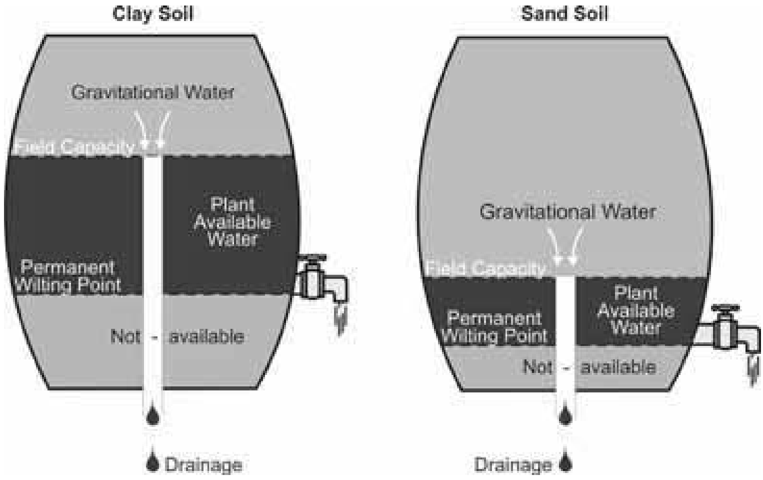


Figure 4.17 *The balance of water and air in soil: Left, saturated soil (soil contains no air); centre, soil at field capacity (good balance of air and water); right, soil at wilting point (no water available to plants).*

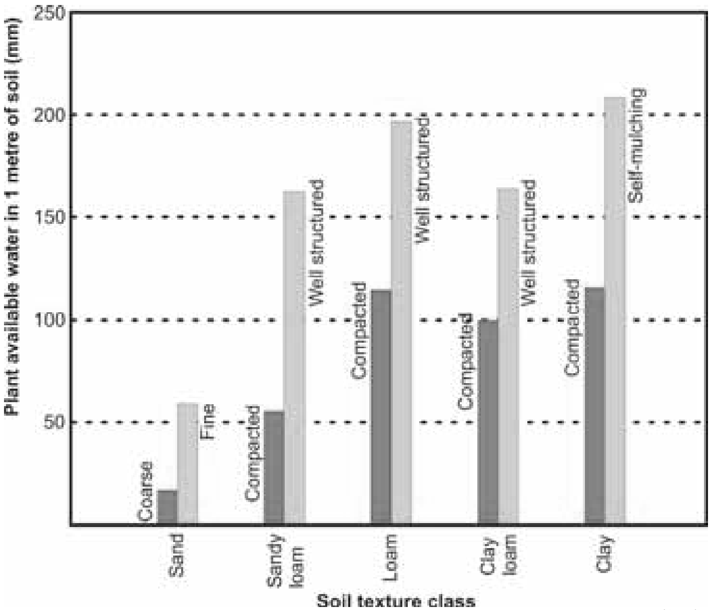


Source: Doneen & Westcot (1984)

Figure 4.18 *The soil moisture characteristics of a clay and a sand soil*

The amount of water held in soils (and how strongly it is held there) can be measured in the field with moisture probes such as tensiometers, gypsum blocks, capacitance or dielectric probes, time domain reflectometers or neutron probes.

Soil texture and structure information can be used to roughly estimate soil water holding capacity and is important in planning irrigation design and operation (Figure 4.19).



Based on: Moore *et al.* (1998)

Figure 4.19 *The amount of water that can be held in the soil varies with soil texture and structural form*

4.5.6 Soil colour

Soil colour is an important part of soil analysis. It can be an indicator of whether a soil is well drained (red soil, Figure 4.20) or poorly drained (yellow or light grey soil). Topsoil high in organic matter tends to have a dark colour. A soil displaying mottling (e.g. red subsoil with yellow or grey patches) indicates that the soil is sometimes waterlogged (Figure 4.21).

When inspecting your soil, note the colour of the inspection zones and whether there is any mottling (percentage). Soil colour should be determined using a newly exposed pit face or the face of a freshly broken clod.

Figure 4.20 *Well drained red clay*

4.5.7 Waterlogging severity

Waterlogging and drainage problems are potentially the greatest hazards for intensive irrigated vegetable crops. Waterlogging can be a symptom of a number of factors, including excessive application of water and/or poor drainage. It can lead to crop losses due to anoxic (toxic) soil conditions and to soil salinisation and alkalisation.

Waterlogging is often associated with poor soil structure at the surface or deeper in the profile. Therefore it is important to get to know your soil throughout the profile. Soil pits are an important tool in identifying the potential causes of waterlogging.

When examining soil pits, indicators of waterlogging include mottling, soil that is a bluish colour, and the presence of manganese oxide nodules (Figure 4.21).

Hard, dark nodules of manganese oxide indicate waterlogged conditions for at least some of the time. If a nodule is manganese oxide it will fizz when hydrogen peroxide is poured over it.

The presence of lime (calcium carbonate) nodules and/or gypsum often is associated with poorly-drained, sodic conditions, although limestone rubble beneath the root zone may also indicate good drainage ('Terra Rossa' soil).

Source: John Rasic Pty Ltd

Figure 4.21 *Waterlogged subsoil*

4.5.8 pH

Soil pH is a measure of how acidic or alkaline a soil is. A pH value less than 5.5 is considered acidic while a pH value greater than 8.5 is considered alkaline. The degree of acidity or alkalinity increases as the pH diverges from 7.

Soil pH is important because it affects the availability of nutrients that are essential for plant growth and the activity of microorganisms (e.g. fungi and bacteria). This is because the solubility of nutrients depends on soil pH and the solubility of nutrients in the soil solution is an important indicator of their availability to plants. Some nutrients may become unavailable as the soil becomes increasingly acidic or alkaline, while others may become available in toxic amounts. However, if the nutrient supply in a soil is depleted or naturally low, deficiencies will occur regardless of pH.

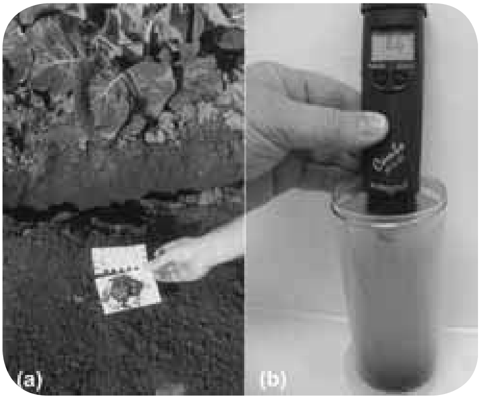
Soil pH can be measured easily in the field using pocket pH meters, powder indicator kits and test strips (Figure 4.22). These are available at rural supply stores, hardware stores and garden centres. It should be noted however, that the accuracy of these methods is limited — they provide a rough estimate only.

Soil pH can more accurately be measured in the laboratory. The two common methods in Australia are measuring pH in water and measuring pH in 0.01 M calcium chloride ($CaCl_2$). A soil-to-solution ratio of 1:5 is used for both methods.

The field methods give a value of pH similar to that obtained when pH is measured in water. However, measuring pH in 0.01 M $CaCl_2$ is a more accurate procedure.

When pH values are reported it is important to state whether the pH was measured in water or calcium chloride as pH values in water are about 0.5 to 1 units higher than pH values in calcium chloride, for most soil types.

When inspecting your soil profile you may notice lime (calcium carbonate) nodules and/or gypsum. The presence of either usually indicates soil conditions with pH greater than 7.5. Lime nodules fizz when acid (e.g. hydrochloric acid) is poured on them, whilst naturally occurring gypsum is characterised by its sparkling, crystalline form.



Source: (a) NSW DPI

Figure 4.22 *pH testing in the field using (a) a pH powder indicator kit and (b) a pen-type pH meter.*

4.5.9 Water repellence

A soil that is water repellent resists wetting when dry and can produce highly uneven wetting patterns down the soil profile. If, when you add a drop of water to your soil, it does not enter the soil but remains on the soil surface (Figure 4.23), your soil is water repellent.

Water repellency generally occurs on sandy topsoil and is due to organic coatings on the sand grains which resist water entry into the soil. However, clay-rich soil containing large amounts of organic matter can also become water repellent under very dry conditions.

Source: Moore (1998)

Figure 4.23 *Droplet of water perched on a water repellent surface*

4.5.10 Salinity and electrical conductivity

Salinity is the presence of soluble salts in the plant root zone or on the soil surface. It can have a major impact on the performance of a crop and is arguably the biggest threat to irrigated agriculture.

A soil is defined as being saline when the level of salinity of soil water (concentration of ions) affects plant growth. However, plants have different susceptibilities to soil salinity.

In Australia, soil salinity is predominantly due to salts of sodium: sodium chloride (NaCl), sodium carbonate (Na_2CO_3) and sodium bicarbonate ($NaHCO_3$).

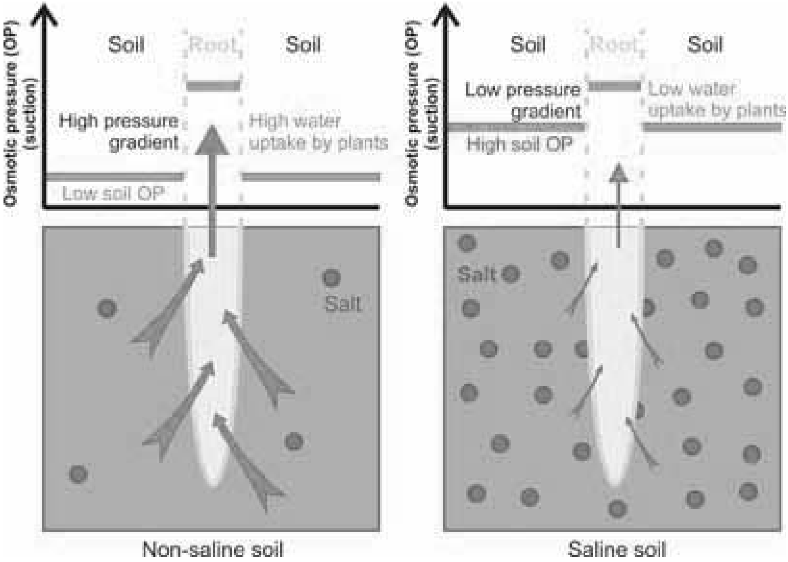
Salt occurs naturally in the soil but salinity can become a major problem when the groundwater rises to within 2 m of the soil surface, resulting in a concentration of salt in the root zone due to capillary action and evaporation. Salt can also be imported to a field via irrigation water and fertilisers.

Soil salinity affects plants in two ways:

1. The osmotic effect — affecting energy expenditure and water uptake.

2. Direct toxicity of salts — particularly from, but not limited to, sodium (Na^+) and chloride (Cl^-) ions.

The osmotic effect is shown in Figure 4.24. Water moving into roots is slowed down as the concentration of salt in the soil water increases. This reduces the water available to plants for growth and yield.



Source: Kelly and Rengasamy (2006)

Figure 4.24 *The relative water uptake by plants in saline and non-saline soil. In the saline soil the osmotic pressure associated with the salt reduces the pressure gradient between the soil and the root, reducing the flow of water into the root.*

General signs of salinity include:

- Poor crop growth
- Slow germination
- Leaves appear smaller and darker than normal
- Marginal and tip burning of leaves, followed by yellowing and bronzing
- Increasing numbers of salt-tolerant weeds
- Death of trees in surrounding areas (Figure 4.25)
- A white crust on the soil surface
- Unusually friable soil structure in low-lying areas
- Flocculation of suspended clay particles to give unusually clear water in puddles and drains
- Damp patches in otherwise dry soil.

The salinity of a soil is indicated by its electrical conductivity (EC). EC is a measure of the ability of a liquid to pass an electric current. EC increases as the salinity (salt concentration) of a liquid increases.

Although more accurately measured in the laboratory, electrical conductivity can be measured reliably in the field using a portable EC meter that has been properly calibrated.

Figure 4.25 *Tree death caused by severe salinisation*

Source: CSIRO Land and Water

The most common method of measuring EC in the laboratory is with a suspension of one part air-dry soil to five parts distilled water by weight ($EC_{1:5}$).

Measuring EC in water does not take into account the effects of soil texture — results from two different soil types cannot be compared directly.

The most accurate way of measuring EC is to use a saturated soil-water extract (EC_e). With this method, an EC measurement is performed on water removed from a just-saturated soil sample by a centrifuge or vacuum pump.

EC_e is the preferred method of estimating soil salinity because it best reflects how salinity will affect plant growth. However, this method is tedious, time-consuming and costly.

$EC_{1:5}$ values can be converted to approximate EC_e values by multiplying $EC_{1:5}$ by a factor that depends on soil texture (Table 4.4).

Table 4.4 *Multiplier factors for different soil textures to convert $EC_{1:5}$ to EC_e*

Texture	Factor (R)
Sand, loamy sand	13
Silty loam	12
Sandy loam, loam	11
Sandy clay loam, clay loam, silt clay loam	9
Sandy clay, silty clay, loamy clay	7
Medium clay, heavy clay	5

Clay content	Factor (R)
0 – 1	12.4
11 – 20	10.2
21 – 30	8.8
31 – 40	7.7
41 – 50	6.6
51 – 60	5.7
61 – 70	4.9
71 – 80	4.2

Note: If the salt in the soil is dominated by gypsum these conversions are unreliable.

Source: Cass *et al.* (1996)

Example: If a clay loam has an $EC_{1:5}$ of 0.4 dS/m, then
EC_e = 0.4 x 9
= 3.6 dS/m

The unit of measurement of EC_e is dS/m (deci-Siemens per metre). 1 dS/m is equal to 1 mS/cm (milli-Siemen per centimetre).

4.5.11 Exchangeable cations

The total amount of exchangeable cations (which is the ability of negatively charged clay minerals to hold cations) is called the cation exchange capacity. Some clay minerals (e.g. smectite) can hold more cations than others (e.g. kaolinite).

Cation exchange information provides farmers with valuable information about the structural stability, structural resilience, and nutrient status of their soil.

If the soil is alkaline and calcareous request your laboratory to use the 'Tucker Method' for measuring exchangeable cations. It is the only reliable procedure that is available for exchangeable cation analysis in soil containing free lime and gypsum.

Exchangeable cation data is used to calculate cation exchange capacity (CEC), exchangeable sodium percentage (ESP), and the electrochemical stability index (ESI).

Exchangeable cations (positively charged ions) include calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), sodium (Na^+) and aluminium (Al^{3+}). Other cations such as manganese, iron, copper and zinc are usually present but only in trace amounts so do not contribute significantly to the total amount of exchangeable cations. Soil with a pH above 5 (measured in $CaCl_2$) usually contains very little exchangeable Al.

The balance of exchangeable cations is important— the percentage of one exchangeable cation compared to another. For example, it is preferable to have a low percentage of sodium cations compared to calcium cations.

CEC is measured in centimoles of positive charge per kilogram of soil (cmol(+)/kg).

Some laboratories report exchangeable cations as mg/kg (ppm). Values must be converted to cmol(+)/kg to be able to calculate CEC from exchangeable cation data. If your exchangeable cation data is expressed as mg/kg or ppm use Table 4.5 to convert values to cmol(+)/kg.

Example exchangeable cation data is shown in Table 4.6 with calculations of 'effective' CEC and percentages of 'effective' CEC, ESP and ESI.

Table 4.5 *Converting exchangeable cation data expressed as mg/kg to cmol(+)/kg*

Cation	Divide mg/kg by this number
Calcium (Ca)	200
Magnesium (Mg)	120
Potassium (K)	390
Sodium (Na)	230
Aluminium (Al)	90

Source: McMullen (2000)

Table 4.6 *Example exchangeable cation data with calculations of CEC and percentages of CEC, ESP, and ESI*

Cation	cmol(+)/kg	% of 'effective' CEC
Calcium (Ca)	15	15/35 x 100 = 42.9
Magnesium (Mg)	17	17/35 x 100 = 48.6
Potassium (K)	1	1/35 x 100 = 2.9
Sodium (Na)	2	2/35 x 100 = 5.7
Aluminium (Al)	0	0
Total ('effective' CEC)	35	

$EC_{1:5}$ = 0.2 dS/m

CEC ('effective' CEC) is the sum of all the exchangeable cation values.
ESP = Na/CEC x 100 = 2/35 x 100 = 5.7%.
ESI = $EC_{1:5}$/ESP = 0.2/5.7 = 0.04 (no units).

Considering this soil has an ESP of 5.7% and is only slightly saline it is likely that it will be dispersive.

4.5.12 Nutrients

Vegetable crops will grow poorly if they are not provided with a balanced and adequate supply of nutrients. The main nutrients of interest are shown in Figure 4.26.

Generally, the best way to monitor nutrients in a crop is via plant tissue analysis. Soil tests tend to be more difficult to interpret. However, it is advisable to get testing of soil nutrients (e.g. nitrogen, phosphorus, potassium) done before you plant a crop or add fertiliser to the soil.

Without soil nutrient data it is impossible to know the requirements of your soil. Soil tests are useful to ensure that maintenance rates of fertiliser are not too high or too low. They are also useful to highlight situations where higher fertiliser additions (two to four times the maintenance rate) are required to overcome severe nutrient deficiencies.

Excessive amounts of applied fertiliser can cause unwanted environmental effects, either through deep drainage or runoff (Figure 3.9).

Figure 4.26 *Nutrients required by vegetable crops*

4.5.13 Soil organic matter

An essential feature of fertile and healthy soil is an adequate amount of organic matter. Soil organic matter consists of leaf litter, plant roots and branches (all in various states of decay), as well as organic materials associated with living soil microorganisms and soil animals (e.g. excreta).

While organic matter usually makes up less than 5% of the soil, it has a strong influence on soil physical and chemical properties.

Soil organic matter:

- acts as a stabilising agent for soil aggregates
- decreases erosion losses
- improves soil water holding capacity
- supplies plant nutrients
- provides energy and nutrients for microorganisms
- adds to the cation exchange capacity of a soil as, like the surfaces of clay particles, it is negatively charged and can hold onto cations such as calcium and magnesium.

The organic matter content of a soil is influenced by temperature and rainfall. Warmer climates tend to have less organic matter and wetter environments have more.

Soil organic matter is normally measured by the content of organic carbon in soil. Laboratories can measure organic carbon but be wary of reported organic matter contents that do not state the method used. Organic matter is calculated by multiplying the organic carbon content by 1.75.

Organic levels are affected by cultivation history, sample depth and soil type. Changes in organic matter levels from year to year indicate the effects of a management system on soil condition. Organic matter content data is most useful when compared over different locations, management histories and time.

4.5.14 Soil fauna

Soil fauna includes earthworms, ants, nematodes, beetles, mites, termites, centipedes and millipedes (Figure 4.27).

They are important because they play a key role in nutrient cycling, soil mixing and in creating biopores.

Biopores made by mesofauna (and old root channels) can improve the physical and chemical status of the soil by allowing water to drain more freely and by allowing roots to penetrate hard soil layers. Drainage in soil with earthworms can be up to 10 times faster than in soil without earthworms. Earthworm biopores also improve the infiltration of lime and nutrients into the root zone.

Earthworm casts are rich in available nutrients because their digestive systems concentrate the organic and mineral constituents in the food they eat (dead roots, leaves, manure). Nitrogen and phosphorus in the casts is readily available to plants.

When inspecting your soil, check for the presence or absence of mesofauna and biopores. You should also note the presence of harmful fauna such as root feeding nematodes (Figure 4.28).

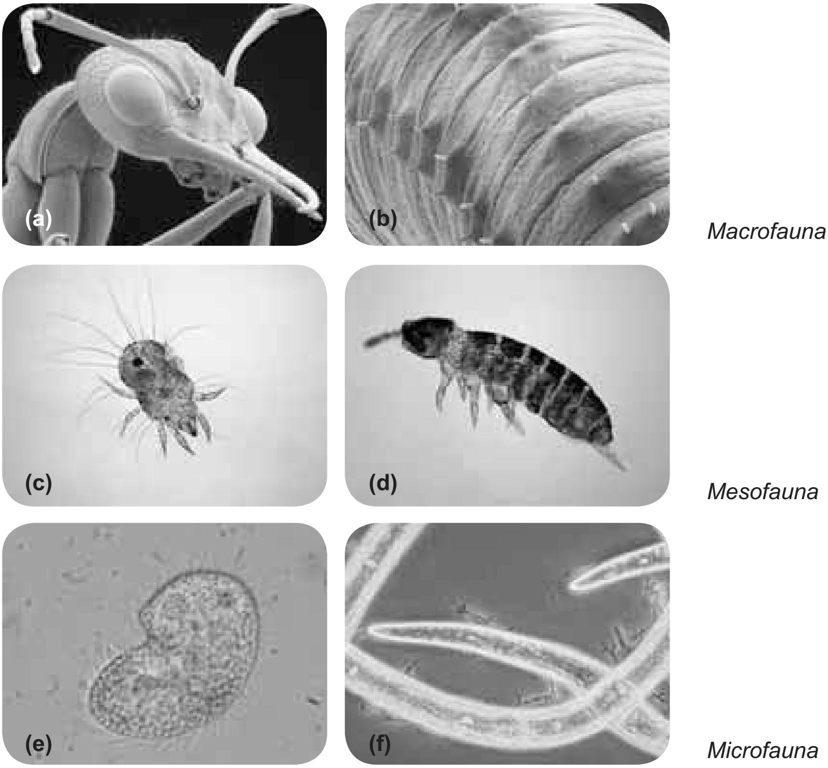
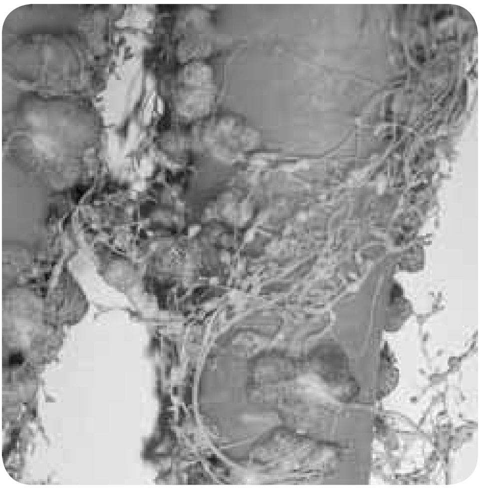


Figure 4.27 *Examples of soil animals.*
Macrofauna (a) Ant, (b) Worm segment. (Electron micrographs: McClure, CSIRO Land and Water). Mesofauna (c) Mite, (d) Collembola. (Microscope images: Gupta, CSIRO Land and Water). Microfauna (e) Protozoa, (f) Nematode. (Microscope images: Gupta, CSIRO Land and Water).



Source: Pattison, DPI&F Qld

Figure 4.28 *Carrot with nematode damage*

Earthworms also help stabilise the soil by cementing soil particles together in water-stable aggregates.

In a square metre of moderately fertile soil, to a depth of 30 cm, there are about 50 million nematodes. In modern agriculture in developed countries 5–10% of agricultural production is lost due to plant-parasitic nematodes. In Australia alone, this amounts to around $400 million per annum. As many chemical nematicides have been withdrawn from use in agriculture, other methods of management need to be developed which rely on more sustainable farming systems and soil management.

4.5.15 Soil microorganisms

Soil microorganisms have a major role to play in organic matter decomposition and nutrient cycling. This group of organisms includes bacteria, fungi, algae and protozoa (tiny animals that feed on bacteria, fungi and algae).

Many beneficial organisms are present in most soil types under a broad range of land uses, but only proliferate when the soil and environmental conditions are suitable. Once problems with compaction, pH imbalance, nutrition, and dispersion have been rectified, the biological health will also improve.

Wherever possible, conserve organic matter (food for soil organisms) and provide stable moisture conditions (not too wet or excessively dry).

The measurement of soil biological health and the status of soil organic matter is an inexact science at present, but a great deal of effort is being expended by soil scientists to provide better procedures for vegetable growers.

4.6 Use of remote sensing information

Information about soil properties gained from soil inspection can be used to generate soil maps.

Remote sensing information such as EM (electromagnetic induction) surveys and aerial photographs can be used to fill in the gaps on maps of key soil properties, derived from soil pit/core information. An example is the prediction of subsoil salinity using EM results. However, before taking this step, ensure that a strong correlation exists between the remote sensing information and the soil properties of interest.

It is important to note that the use of EM surveys in comprehensive soil assessments will most likely introduce major errors in at least some of the maps of soil properties. This is because the spatial patterns of variation of each of the relevant ‘key soil properties’ (e.g. pH, compaction severity, depth to lime, clay content, water holding capacity, dispersion, salinity and nutrients) rarely coincide at any particular site. So, although the EM data correlate strongly with, for example, subsoil salinity, the same EM data might be unrelated to some of the other critical soil properties that relate to crop production and so may not be useful.

5 Threshold values for key soil properties

After you have assessed soil condition in the field and/or have received soil test results back from the laboratory, you can use this section to help with interpretation of the results.

5.1 Structural form/compaction severity

Field test: Figure 5.1 shows how to interpret ratings of soil structural form (sometimes referred to as the 'SOILpak score').

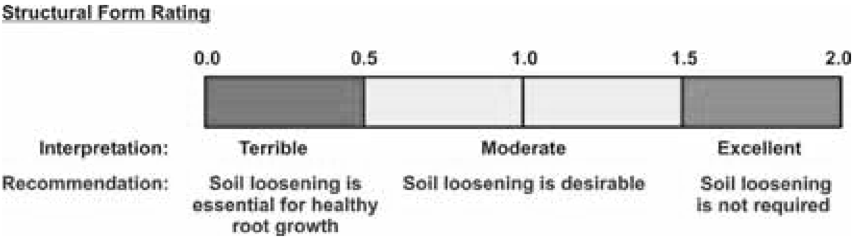


Figure 5.1 *Interpretation of a structural form rating*

5.2 Structural stability in water — slaking

Field test: Figure 5.2 provides an interpretation of the slaking behaviour of aggregates when they are placed in a dish of rainwater/distilled water for 10 minutes.

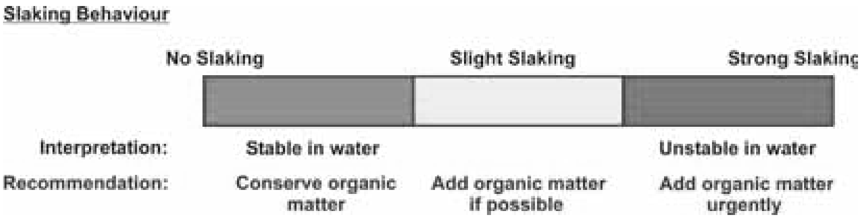


Figure 5.2 *Interpretation of slaking observations*

5.3 Structural stability in water — dispersion

Home test: Figure 5.3 shows how to interpret your ASWAT dispersion scores.

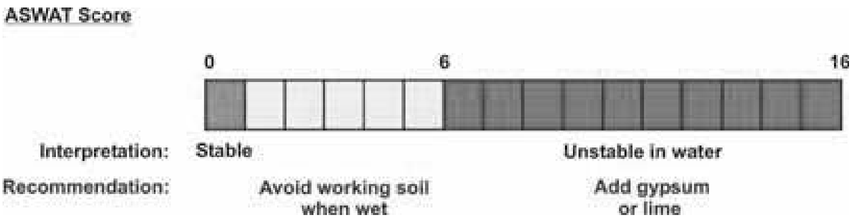


Figure 5.3 *Interpretation of ASWAT scores*

Home test: Figure 5.4 shows how to interpret your Dispersion Meter results.

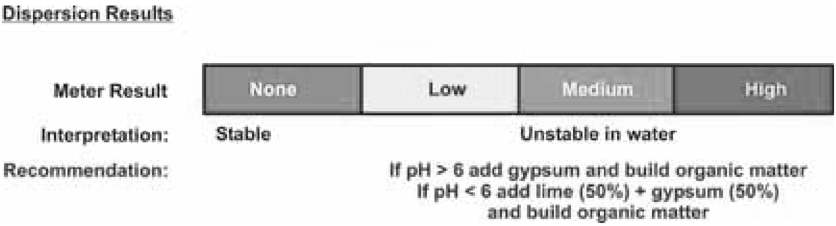


Figure 5.4 *Interpretation of Dispersion Meter results*

Laboratory test: Exchangeable sodium percentage (ESP); electrochemical stability index (ESI) data, calculated from exchangeable cation and electrical conductivity ($EC_{1:5}$) data. ESI can be used to predict the likelihood of a soil being dispersive when water is applied. A sodic soil (ESP greater than 6) can be well structured if the soil is saline enough to prevent dispersion. Table 5.1 gives the relationship between soil dispersibility in water and ESP and ESI.

Table 5.1 *Relationship between soil dispersibility in water and soil chemical properties*

Soil chemical property	Values associated with stability (low ASWAT scores)	Values associated with instability (high ASWAT scores)
Exchangeable sodium percentage (ESP)	<2%	>2% (low EC) >15% (high EC)
Electrochemical stability index (ESI)	>0.05	<0.05

> = greater than, < = less than

Source: McKenzie (1998)

5.4 Structural resilience

Laboratory test: Cation exchange capacity (CEC) can be used to estimate the structural resilience (shrink-swell capacity, rebound potential) of a soil. The relationship between CEC and structural resilience is given in Table 5.2.

Table 5.2 *Relationship between CEC and structural resilience*

CEC (cmol (+)/kg)	Soil resilience (regeneration potential)	Management options to consider when overcoming compaction problems.
<20	Poor shrink-swell potential	If the subsoil is a lot more resilient than the topsoil, consider bringing it to the surface with a mouldboard plough or slip plough. Otherwise, rely upon plant root systems or soil fauna to permeate the soil with macropores (may have to be preceded by mechanical loosening).
20–40	Moderate shrink-swell potential	Use shrink-swell cycles to loosen compacted soil, although mechanical loosening and biopore creation may be needed to accelerate the process.
>40	Good shrink-swell potential	Rely mainly upon shrink-swell cycles to loosen compacted soil.

> = greater than, < = less than

Source: McKenzie (1998)

5.5 pH

<u>Laboratory test:</u> The preferred pH ($CaCl_2$) range for vegetables is shown in Figure 5.5 and the effect of soil pH on plant nutrients is shown in Figure 5.6.

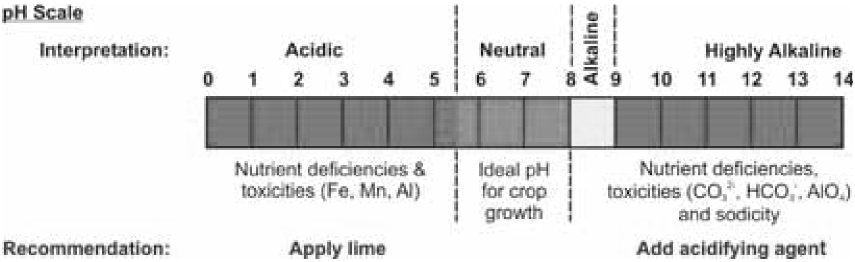


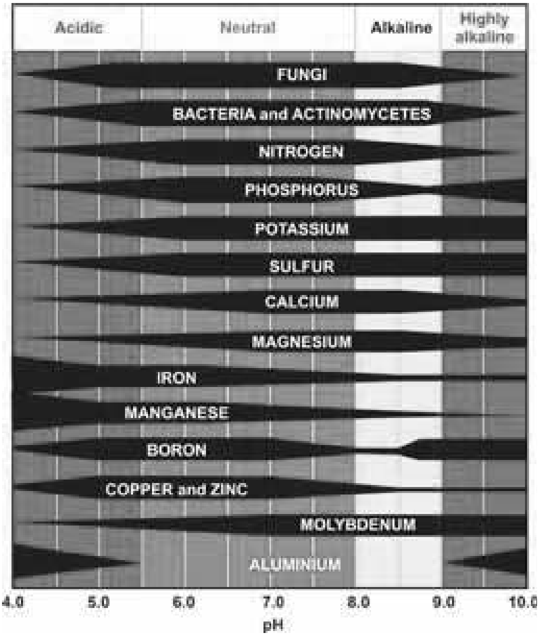
Figure 5.5 *Preferred pH range for vegetables*

5.5.1 Moderately to strongly acidic soil

In moderately acidic soil exchangeable cations such as aluminium, potassium, calcium, magnesium, iron, manganese, copper and zinc become more soluble. As the pH becomes more acidic the increased solubility of the major plant nutrients calcium, magnesium and potassium may lead to them being lost from the root zone by leaching.

In strongly acidic soil that contains large amounts of aluminium and manganese, their concentrations in the soil solution may increase to levels that are toxic to plants. Aluminium is not a plant nutrient and in highly acidic (and highly alkaline) soil it may severely restrict root growth.

The availability of molybdenum declines as the soil becomes more acidic so it can be deficient in acidic soil.



Modified: McKenzie *et al.* (2004) & *pers comm.* Rengasamy (2006)

Figure 5.6 *An overview of the effect of soil pH on plant nutrients*

5.5.2 Slightly acidic to neutral soil

In this range, the availability of plant nutrients is not restricted by pH. However, soil high in manganese may still contain concentrations that are toxic to some vegetables that are very sensitive to acidic conditions.

5.5.3 Neutral to slightly alkaline soil

As the pH becomes alkaline, the solubility of micronutrients such as manganese, zinc and copper falls rapidly and their plant availability begins to decrease.

5.5.4 Strongly alkaline soil

In alkaline soil, the availability of phosphorus, iron, copper, zinc and manganese are strongly reduced and regular tissue testing is needed to manage potential deficiencies. At a pH (in water) greater than 8.5, dispersion is likely to create soil structural problems as well. Aluminium toxicities can also seriously restrict root growth in strongly alkaline subsoil due to the aluminate anion.

5.6 Nutrients

Laboratory tests: It is best to use the services of accredited soil testing laboratories to interpret soil nutrient data. It is difficult to interpret soil test data without knowledge of the tests used to measure levels of different nutrients (there is more than one test available to measure phosphorus levels for example), soil type, climate and production systems and histories.

Discussing soil test results with regionally based horticulturists is helpful as they will have experience on how plants respond to fertiliser applications on different soil types and in different production systems. They will also have an idea of fertiliser needs for different soil types in the region. For example, soil derived from basalt will not usually require heavy applications of potassium, and sandy soil will usually require applications of boron and molybdenum, particularly if brassica crops are being grown.

Soil nitrate values are considered to be low at 5 mg/kg and good at 40–60 mg/kg. Maximum nitrogen (N) fertiliser rates (90–250kg of N/hectare) are recommended for a range of crops at the low level and 30–100 kg of N/hectare at the higher level.

Phosphorus is applied to vegetable crops at 10–110 kg/hectare, potassium at 0–140 kg/hectare, calcium (as lime) at 0–5 tonnes/hectare, and magnesium (as dolomite) at 0–4 tonnes/hectare, depending on soil test values and the crop to be planted.

5.7 Salinity

Field or laboratory test: Non-saline soil has an EC_e less than 2 dS/m. An EC_e greater than 8 dS/m is considered highly saline (see Figure 5.7).

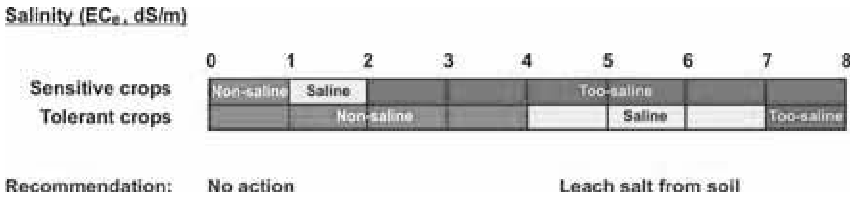


Figure 5.7 _Interpretation of soil salinity results_

Threshold salinity values for some vegetables are given in Table 5.3. Vegetable crops vary in their tolerance of salt. For example, beans and carrots are much more sensitive to salt than broccoli, cauliflower and zucchini. Most vegetable crops fall in the moderately sensitive to moderately tolerant of salt plant groups. Seedlings are more sensitive to salinity than mature plants.

Table 5.3 *Salt tolerance of vegetable crops*

Soil salinity EC_e (dS/m)	Vegetable
4.8	
	Zucchini
4.4	
4.0	Asparagus, beetroot, garlic
3.6	
3.2	Squash (scallop)
2.8	Broccoli
2.4	Tomato, pea, cucumber, pumpkin, cauliflower
2.0	Spinach
1.6	
	Capsicum, sweet potato
1.2	
	Bean, carrot, eggplant
0.8	
	Turnip

Modified: Shaw (1999)

5.8 Exchangeable cations

Laboratory test: The desirable concentrations of the main exchangeable cations influencing plant growth are given in Table 5.4.

Table 5.4 *Concentrations of some of the exchangeable cations affecting plant growth*

Cation	Desirable concentration of exchangeable cation (cmol(+)/kg)
Calcium (Ca)	more than about 1.5
Magnesium (Mg)	more than about 0.4
Potassium (K)	more than about 0.25
Sodium (Na)	as close as possible to 0.0
Aluminium (Al)	as close as possible to 0.0

A question often asked, is about “Ideal Cation Balance”. It is recognised that in cases of extreme imbalance some nutrients can compete with others for uptake by the plants, resulting in toxicities and/or deficiencies. However, the use of cation balance as a method of soil nutrition management has been generally discredited scientifically (for more information visit http://www.grdc.com.au/growers/gc/gc59/reppel12.htm).

5.9 Soil organic matter

Laboratory test: Use Figure 5.8 to interpret your soil organic matter content values.

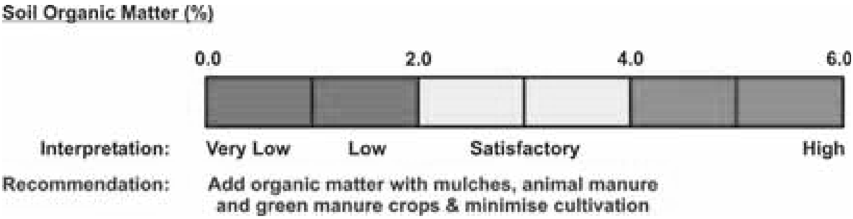


Figure 5.8 *Interpretation of soil organic matter content values*

6 Improvement of soil quality

No two vegetable farms, or for that matter paddocks, will have identical soil related problems. Therefore, most vegetable growers will need tailored soil management solutions, rather than a set and rigid approach.

This section provides a brief overview of methods that are available to improve soil condition for vegetable production.

When selecting management options following soil assessment, a combination of the following methods will usually be needed to optimise soil condition for the selected vegetable crop.

6.1 Soil compaction — biological solutions

In soil with the potential to swell and shrink when it is wetted and dried, rotation crops can be grown to loosen compacted soil by water extraction and shrinkage.

It is important to be aware of the following when using this approach:

- The rotation crops need to be well fertilised, particularly with nitrogen which tends to be very depleted in compacted soil.
- The selected species for soil loosening ideally should have an aggressive root system and a tolerance of waterlogging.
- In soil with only a moderate shrink-swell potential, the dry cracked soil (Figure 6.1) that remains after harvest of the rotation crop may have to be chisel ploughed as well to complete the de-compaction process.

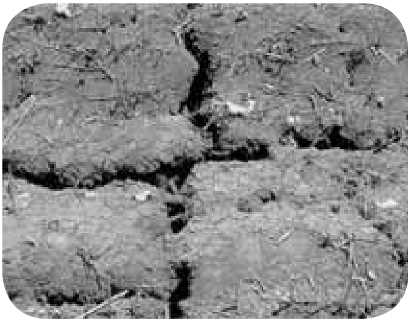


Figure 6.1 *Shrinkage cracks*

Rounded vertical channels (biopores) created by soil fauna (e.g. earthworms, ants) and roots (Figure 6.2) are useful for the transfer of water and gases from the soil surface to the subsoil. The channels remaining after the decomposition of old plant roots also can be very useful, particularly where there is negligible soil structural improvement via shrink-swell processes.

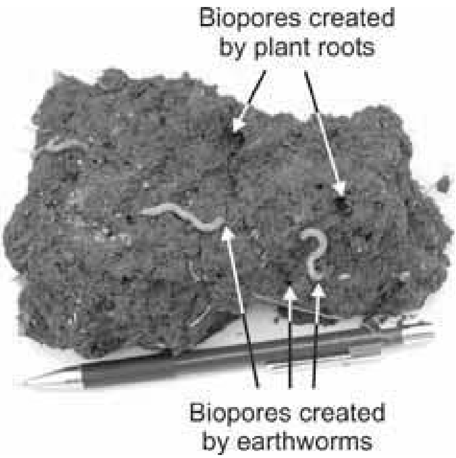


Figure 6.2 *Photo of earthworms and their biopores*

6.2 Soil compaction — tillage strategies

Where the soil is compacted and loosening has to be carried out quickly, tillage implements should be used (Figure 6.3). Deep tillage may also be needed for the deep incorporation of liming products.

Where the compaction problems are in the sub-surface or subsoil, ploughs or a Paraplow® are useful, provided that the soil is not wetter than the 'plastic limit'. More disruptive options for soil loosening include disc ploughing and mouldboard ploughing.

When planning a deep tillage operation, use soil inspections to define the nature of the compaction problem. This will ensure that the depth of tillage is not excessive.

Figure 6.3 *Deep rippers used to break hardpans, improving soil structure and deep drainage*

Where the soil surface is compacted, hardset or crusted, a broad range of techniques are available for soil loosening, including scarifiers and rotary hoes. If the soil surface has water penetration problems, it can be roughened using spading implements such as a 'Dammer Dyker'.

In light textured soil avoid aggressive cultivation of very dry soil. Otherwise, excessive dust formation is likely to be a problem.

Once a soil has been loosened, do everything possible to prevent a recurrence of the soil compaction. If this can be achieved through the use of controlled traffic farming, expensive deep tillage operations should not have to be repeated.

6.3 Soil structural instability in water — organic matter inputs

When producing vegetables, it is very desirable to have a friable soil structure that remains stable under moist conditions.

The addition of organic matter minimises slaking and improves the friability of soil and can also provide protection for young or emerging crops (Figure 6.4). Organic matter can be produced in situ via the use of vigorous rotation crops (green manure crops). Green manuring involves either turning in a green crop after spraying it with a non-selective herbicide, or by spraying it off with no tillage and allowing it to be incorporated over time.

Green manure crops are best sown with a minimum of soil preparation and weed control. Green manure crops include:

- Annual ryegrass — has a massive fibrous root system which contributes a large amount of organic material to the soil. The crop needs to be sprayed off before incorporation to prevent re-growth.
- Oats, rye or triticale — grow rapidly and produce a mass of bulk above ground. Should be sprayed off before seed set, followed by incorporation. They can be mixed with vetch to add a legume content. Avoid soil compaction by not feeding off to stock when the soil is wet.

- Legumes such as lupins (only in soil without free lime), vetch and field peas — can contribute up to 200 kg of N/ha to the soil. The seed may need inoculation to maximise nitrogen input. Maximum nitrogen benefits are gained when the crop reaches flowering. Beans or peas should not be sown after a legume cover crop.
- Canola, mustard and leafy turnips — select varieties that are high in glucosinolates (have a bio-fumigation effect). Brassicas require sulfur for good growth and should be incorporated six weeks before sowing your next crop, which should not be a brassica crop due to the danger of clubroot infection.

An alternative where there is insufficient available land for green manuring is to use animal manure as the source of organic material. This may involve applications of 10 or more tonnes/hectare. Care needs to be taken as animal manures can contain weeds and a significant amount of salt. Heavy metals can also be a problem in manures, e.g. arsenic in poultry manure and copper in pig manure.

Source: Applied Horticultural Research

Figure 6.4 *Broccoli growing through rye mulch to improve soil structure and reduce water loss through evaporation*

Keep cultivation to a minimum because decomposing roots are a valuable source of interconnected organic matter, and the above-ground components protect the soil surface with organic mulch. Cultivation reduces organic matter content by exposing it to rapid oxidation.

A broad range of attractive composted materials is available to vegetable growers. Apart from improving soil structure, they can be a valuable source of plant nutrients.

Man-made polymer products (e.g. water-soluble polyacrylamide or WS-PAM) also are available to improve the resistance of soil aggregates to slaking.

6.4 Soil structural instability in water — inorganic matter inputs

Gypsum (calcium sulfate) can be used to improve the structural form and stability of sodic clay soil (Table 6.1, Figures 6.5 and 6.6) (which is prone to excessive swelling and dispersion). However, it does little to improve the structure of clays that are not sodic, or the structure of soil that contains only a small amount of clay.

Gypsum improves soil structural stability in two ways:

1) It contains calcium ions, which replace undesirable sodium and magnesium ions on clay surfaces.
2) Dissolved gypsum provides a mildly saline soil solution that restricts dispersion (this is known as the electrolyte effect).

Note: It is generally preferred to use a coarse (crystalline) gypsum as it dissolves more slowly than fine gypsum, meaning the effect is sustained over longer periods. If the cheapest form of gypsum available is fine gypsum then apply smaller amounts each year to achieve the same result.

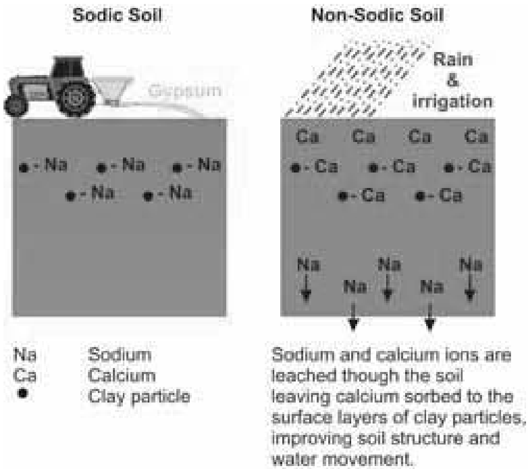
Table 6.1 *Soil dispersion and gypsum and lime application rates*

Dispersion	pH >6 gypsum	pH <6 gysum + lime
None	0	0
Low	2.5 t/ha	1.25 t/ha + 1.25 t/ha
Medium	5 t/ha	2.5 t/ha + 2.5 t/ha
High	10 t/ha	5.0 t/ha + 5.0 t/ha

Source: Kelly and Rengasamy (2006)

Figure 6.5 *Spreading gypsum*

Where the soil is both acidic and dispersive, lime application will provide structural stability benefits similar to those of gypsum. However, the application of lime to alkaline soil is not recommended because of a very low solubility under these conditions.



Source: Kelly and Rengasamy (2006)

Figure 6.6 *Correction of sodic soil with the application of gypsum and/or lime*

6.5 pH extremes

The pH of acidic soil can be raised (Table 6.2) by adding agricultural lime (calcium carbonate) or dolomite (a mixture of calcium carbonate and magnesium carbonate).

Take special care when adding large amounts of lime to strongly acidic soil (pH in $CaCl_2$ less than 5) as this can result in potassium and magnesium deficiencies. For sandy soil types, over-liming can cause deficiencies in trace elements such as zinc, manganese and iron.

Dolomite application will be of greater value for a soil that is deficient in both calcium and magnesium. Be careful not to add too much magnesium as it can interfere with potassium uptake and aggravate clay dispersion problems.

For the best results, lime or dolomite needs to be added to the soil at least six weeks before planting. This is to allow enough time for the lime to react in the soil. You are likely to be disappointed with the result of lime addition if you apply it only a few days ahead of planting. Lime moves very slowly through the soil and may take many years to reach an acidic subsoil.

Some vegetable growers use calcium hydroxide and calcium oxide ('hotlime') to increase soil pH. Hotlime is much more reactive than agricultural lime and raises soil pH more quickly. Please note that crops cannot be planted until seven days after incorporation of hotlime and also that hotlime is corrosive and has to be handled with great care.

Table 6.2 *Amount of lime required to raise soil pH by 1 unit per 10 cm of soil for different soil textures*

Soil texture	Lime rate (t/ha)
Sand	1.5 – 2.5
Loam	2.5 – 4.0
Clay loam	4.0 – 5.0
Clay	4.0 – 6.0

Note: 1. These liming rates are general guidelines and must be accompanied by ongoing soil pH monitoring to assess the effectiveness of the applications.
2. Reduce guideline value by 25% for soil with low carbon (<1.5%).
3. If treating soil at depths greater than 10 cm adjust the application accordingly. e.g. 20 cm will require two times the lime requirement.
4. pH change takes 12–18 months; in uncultivated soil, may take up to four years.
5. For sandy soil with low organic carbon care should be taken — use smaller and more frequent applications to reduce any likelihood of over-liming.

Modified: http://www.bettersoils.com.au/module6/6_8.htm

6.6 Surface architecture for the control of waterlogging and erosion

The shape of fields used for vegetable production can be modified to overcome waterlogging and erosion problems.

Steep areas should be avoided when growing vegetables because of the risk of soil loss by water erosion. However, where the soil is very deep and fertile, and where high value produce is being grown, consider the use of terraces and contour mulching (Figure 6.7) to reduce slope. The initial cost of terracing is high but the benefits will last for many decades.

Where there is a risk of waterlogging damage to vegetable crops on flat land, raised beds (Figure 6.8) can greatly improve productivity and returns to growers without spending large amounts of money.

Source: DPIW, Tas

Figure 6.7 *Contour mulching*

Figure 6.8 *Raised beds for celery production on flat heavily textured soil*

6.7 Drains to control subsoil waterlogging

Where there is a watertable too close to the surface, tile drains may be needed to minimise the risk of yield-reducing waterlogging events in the root zone. Interceptor drains should be considered where there is evidence of major lateral flow onto the development area from up-slope areas (Figure 6.9).

6.8 Additives to overcome water repellence

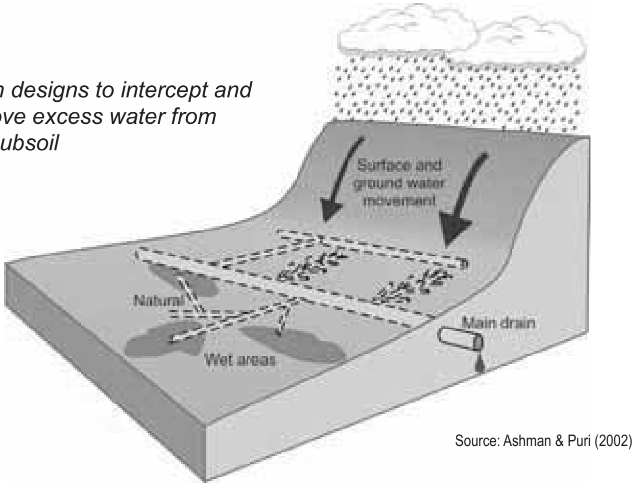
Research in Western Australia has demonstrated the value of clay addition to sandy soil prone to water repellence problems. Another management option is to apply wetting agents via the irrigation system.

Water repellence is usually only associated with sandy soil. However, it has also been observed on clay-rich soil containing large amounts of organic matter. Where irrigation water is applied via a drip irrigation system, pulsing of the applied water can help to overcome problems associated with poor lateral movement.

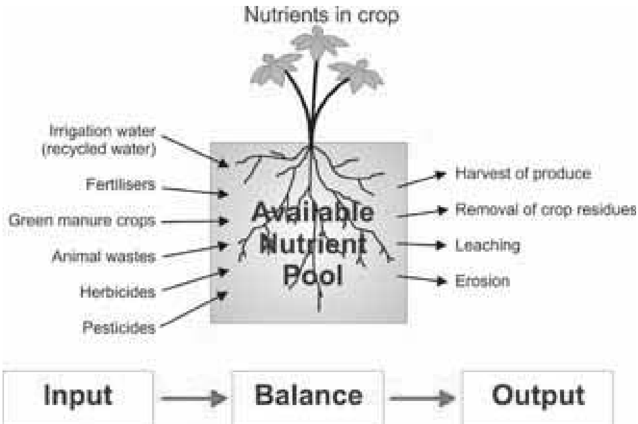
6.9 Nutrients

All vegetable farms need a regular supply of plant nutrients to maintain high yielding crops. It is vital that all of the essential nutrients needed by plants are present in adequate supply. A low supply of just one of them will limit growth until the nutrient is fully supplied. Macronutrients such as nitrogen, phosphorus and potassium are used by vegetables in large quantities and soil reserves can be rapidly depleted.

Figure 6.9 *Drain designs to intercept and remove excess water from the subsoil*



Growers need to build adequate soil nutrient reserves to supply the crop through the growing season. However, it is important not to over supply nutrients, which can lead to increased nutrient loss, costs and accelerated soil acidification with excess nitrogen use. Nutrient management is a 'balance' between nutrients supplied, the soil nutrient pool, and nutrients removed by losses through crop removal, leaching and other environmental losses (Figure 6.10).



Source: Kelly *et al.* (2001)

Figure 6.10 *Nutrient input and removal to consider when calculating nutrient budgets for a vegetable crop*

Some growers prefer to use an organic approach to soil nutrient management. They aim to supply the nutrient requirements of a vegetable crop in a balanced fashion via organic inputs such as green manure crops and animal manure. The benefit of manures is that they release nutrients slowly over a longer period than most manufactured fertilisers and they provide some organic matter. However they can contain a large amount of salt and may not provide the right balance of nutrients needed by the plant. Additionally they may not release nutrients at the correct time, or in sufficient quantity, for optimal production.

Organic matter also assists with nutrient management by improving the cation exchange capacity (CEC) of the soil. Soil with a high CEC is also less susceptible to nutrient loss by leaching.

Other growers use a more conventional approach, with much of the nutrient input being provided through inorganic fertilisers (Table 6.3). Commercial fertilisers have a better NPK (nitrogen, phosphorus, potassium) balance than animal manures.

Fertigation (the use of micro-irrigation systems to apply fertilisers) gives greater precision and less waste, particularly with nitrogen fertilisers.

Cadmium (Cd) levels in any fertiliser should be low so that you do not exceed the Maximum Permitted Concentration (MPC) in your vegetables. Preferably use fertilisers with less than 50 mg of Cd/kg of phosphorus. Use manures and composts with less than 1 mg of Cd/kg of product.

Table 6.3 *Nitrogen (N), phosphorus (P), and potassium (K) fertiliser application information*

Plant Nutrient	Typical fertiliser requirement for vegetables	Background Information	Fertiliser application information
N	150 kg of N/ha per crop	Easily leached; too much can result in excessive leafy growth and small fruit.	Best applied in small, regular side dressings (apply one-third of the N needed as a base application and split the remainder evenly during the crop's life).
P	80 kg of P/ha per crop	Does not move very much in the soil; many vegetable farms have more P in their soil than crops can use; do not apply P to soil with more than 150 mg/kg of P (either Bray or Colwell tests) for one year or more; avoid applying P to waterlogged soil or when a heavy rain storm is predicted within five days.	Needs to be applied a few weeks before planting; apply superphosphate, MAP or DAP to the area where plant roots will grow (banding); liquid phosphorus formulations are available for supplementary foliar or fertigation application.
K	80 kg of K/ha per crop	More stable in the soil than N but can leach over a season, particularly from sandy soil in coastal areas that experience heavy rainfall.	Should be applied in a number of applications in conjunction with N.

The following points need to be considered when adding fertiliser:

- The export of nutrients from a field each year through vegetable harvesting has to be counter-balanced by a nutrient replacement program (Figure 6.10). It is important to consider nutrient additions through incorporating crop residues, reclaimed water and applications of poultry manure when calculating nutrient requirements for your next crop.
- Know the target yield of your next crop.

- Nutrients can be made more available through processes such as more rapid breakdown of organic matter by soil biological activity, and better exploration of the soil profile by crop roots through the removal of constraints such as compaction.
- Large amounts of nitrogen (N) can be lost from a vegetable farming soil if waterlogging is a major issue. N loss from waterlogging is via the process of denitrification. N moves out of the soil in the form of nitrous oxide, which is a very potent 'greenhouse gas'.
- Place nutrients where roots will have most access to them (this requires an understanding of the root distribution of the crop).
- Time nutrient applications to the correct growth stage of the crop and for soil texture. For example, in sandy soil with low organic matter, readily leached fertilisers such as those containing potassium and nitrogen (urea and nitrates) can be lost if they are all applied at sowing. Smaller applications during the growing season are more efficient.
- The form a fertiliser is in needs to be matched to soil type. For example, granular fertiliser is commonly used to provide phosphorus to vegetable crops but on calcareous soil, soil-injected fluid fertilisers applied at sowing can be more effective.

6.10 Encouraging soil organisms

Soil organisms (except some bacteria) need a carbon-based food source (i.e. organic matter) to provide their nutrients and a moist habitat with access to oxygen. Also important is soil pH, temperature and salinity and minimising exposure to chemicals.

To encourage soil organisms:

- Maintain ground cover so as to prevent moisture loss and high temperature and to provide food.
- Increase soil organic matter with green manure crops and mulch and reduce the rate of breakdown by minimising cultivation.
- Prevent compaction or repair compaction if present.
- Maintain adequate moisture (ground cover and soil organic matter help to retain soil moisture). Worms can rapidly dehydrate in dry soil and if the surface dries, some species will burrow deep into the subsoil and remain inactive until the soil is wet. Mulching of sandy soil can be an effective way of keeping worms active in dry periods.
- Reduce the use of chemicals. Copper from fungicides can accumulate in the soil and affect earthworms.
- Check the pH and modify if necessary. A soil pH ($CaCl_2$) of more than 4.5 is preferred by earthworms. Acidifying fertilisers (e.g. phosphoric acid, ammonium sulphate) tend to deplete the earthworm populations.
- Improve poor drainage.
- Control soil erosion to minimise loss of topsoil and depletion of soil organisms.

7 Damage prevention strategies

7.1 Irrigation and drainage management plans

When designing an irrigation system for a modern vegetable farm (Figure 7.1), it is critical to have maps of soil hydraulic properties. The most important of these properties is the water holding capacity, sometimes referred to as 'Readily Available Water' (RAW).

Without such information, it is almost certain that sub-sections of a development will end up with too much water. This often leads to excessive deep losses of water and dissolved nutrients, which create unwanted environmental impacts on the local catchment and financial losses for the grower.

The application of too much water often creates waterlogging problems, which have an adverse impact on productivity. This is often seen where over-watering occurs in conjunction with heavy rain. Drainage systems therefore need to be designed in conjunction with the irrigation system.

Source: Henderson, DPI&F Qld

Figure 7.1 *Vegetable production using a modern drip irrigation system*

It is recommended that professionals be hired to measure and map soil hydraulic properties prior to the design of irrigation and drainage systems by accredited engineers.

7.2 Soil water monitoring

Excellent instruments have been developed locally in recent years to monitor soil moisture content in the root zone of vegetable crops and improve water use efficiencies.

Some instruments are simple to use, require reading in the field and may only give wet/dry indications, while others have wireless connections to a computer where soil moisture can be monitored and irrigation can be timed and forecasted (irrigation scheduling).

Soil moisture monitoring instruments allow you to:

- determine if you are irrigating too little or too much
- apply just enough water to crops to optimise yield
- minimise deep drainage losses
- detect waterlogging.

Instruments available include capacitance probes, tensiometers, time domain reflectometers, neutron probes and wetting front detectors (Figure 7.2).

It is strongly recommended that you identify your individual requirements before purchasing a soil moisture monitoring device. It is not wise to make a decision on price alone. As a minimum, a soil moisture monitoring instrument needs to provide water content readings for the plant root zone before and after irrigation and preferably, also after rainfall. Other factors to consider are:

- What information will I get from the device and how usable is it?
- How labour-intensive is it?
- What level of accuracy do I need?
- Does the device suit my soil type/s and crop/s?
- How durable is it?
- How much maintenance will it need?

If you need advice, speak with an irrigation officer, undertake an irrigation management course or talk with other vegetable growers who have successfully used the device that you are considering purchasing.

Source: Yiasoumi , NSW DPI

Figure 7.2 *Soil moisture sensing equipment: matric and gypsum blocks and tensiometers in a tomato crop*

7.3 Prevention of soil degradation caused by poor quality irrigation water

The consumption of irrigation water by vegetable crops often causes the concentration of unwanted salts and major pH changes in the soil after a long season of irrigation.

For example, the use of bore water or reclaimed wastewater can cause an accumulation of unwanted sodium and magnesium ions in the root zone. This often leads to soil destabilisation, particularly when fresh rainwater falls on the soil.

For salt sensitive crops such as lettuce, the accumulation of salt will limit growth unless adequate flushing (leaching) occurs.

Another issue is the development of pH extremes where irrigation water is dripped onto the soil. These extremes include: alkalinity due to irrigation with water containing high concentrations of carbonates, or acidity due to leaching and/or nitrification.

Where the applied irrigation water has a high concentration of chloride, the toxic ‘heavy metal’ cadmium may become more available to plants. Cadmium accumulation is an issue in soil that has received large amounts of superphosphate fertiliser, or from cadmium containing organic wastes.

Water testing is an inexpensive process. The results allow compounds such as gypsum to be added to the water in a systematic fashion so that soil degradation is avoided.

7.4 Control of vehicle compaction

Avoid driving farm machinery on your soil or cultivating your soil when it is too wet.

To minimise the proportion of vegetable fields adversely affected by compaction, use Global Positioning Systems (GPS) to steer farm machinery in straight lines.

Aim to have a consistent wheel spacing for all farm machinery (including harvesting gear). Use tyres or tracks that are as narrow as possible. Where extra traction is required, use tandem wheel and/or 4WD configurations rather than duals.

Further to this, a network of all-weather tracks on the farm makes access easier and helps to reduce in-field compaction problems associated with vehicle and machinery movements (Figure 7.3).

Figure 7.3 *All weather tracks to minimise vehicle compaction*
Note: windbreaks to protect crops

7.5 Prevention of acidification

The rate of soil acidification can be reduced by better management of nitrogen and soil water. The leaching of nitrate from the soil is a major cause of soil acidification.

Apply nitrogen in small amounts more frequently to minimise nitrate leaching. Also, use less-acidifying nitrogen fertilisers such as urea, rather than ammonium nitrate or ammonium sulphate.

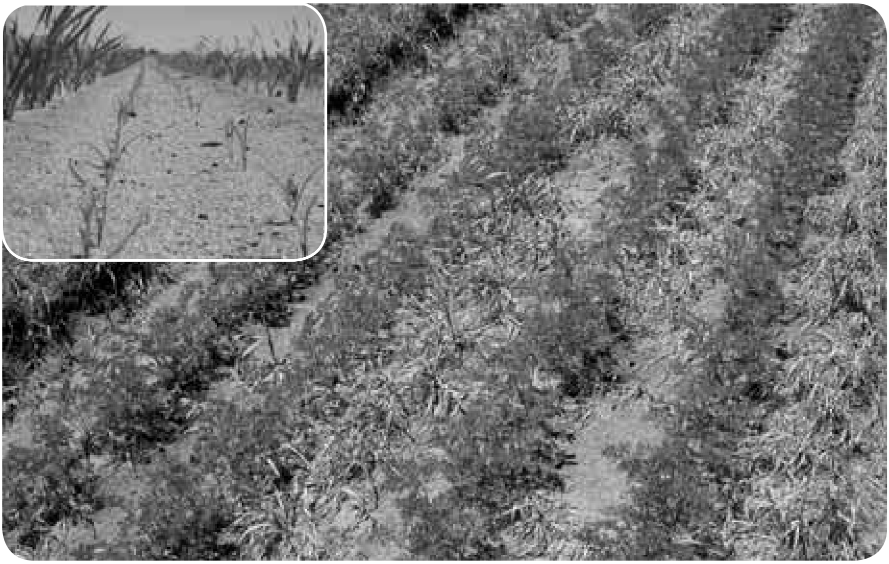
7.6 Minimising soil erosion

By implementing steps to control erosion you can reduce the loss of soil and nutrients, the silting of dams and channels, gullying and damage to plants by burial and sandblasting.

To control soil erosion:

- Avoid farming steep slopes. A slope range of 0%–10% is the preferred slope range and a slope of more than 20% should not be cropped.
- Manage water flow by not disturbing natural watercourses. Divert external run-off away from cropped areas and control and safely dispose of crop surface water.
- Avoid excessive cultivation and cultivating when the soil is very dry.
- Protect your soil by maintaining a vegetation cover (Figure 7.4).
- Repair dispersive soil with gypsum and organic matter.
- Establish windbreaks to reduce wind speeds.

Planting vegetables often requires a fine, flat seed bed, which is highly erodible. Slow-growing seedlings such as onions leave the soil surface exposed for many weeks, and this can result in loss of topsoil through wind and water erosion and se sandblasting, reduce loss of nutrients via leaching and enhance the organic matter content of the soil.



Source: McKay, DAFWA

Figure 7.4 *Young vegetable crop on sandy soil protected by a cover crop. Main image shows carrot crop after cover crop has been sprayed out. Inset showing young carrot crop protected by cereal cover crop*

7.7 Prevention of organic matter depletion

Soils high in organic matter (Figure 7.5) are desired for vegetable production, however some loss of organic matter from vegetable growing soil is inevitable. Decomposition is always going to occur, and ongoing replenishment will be necessary via green manuring or by addition of animal manure or compost.

However, unacceptably high losses can occur via a number of processes that need to be modified:

- Excessive tillage, leading to exposure and oxidation of the organic matter
- Over-heating of the soil surface in summer
- Loss of topsoil by water and wind erosion
- Burning or removal of crop residues.

In sandy soil in particular, cultivation can seriously deplete the soil of its valuable organic matter.

Figure 7.5 *Humus-rich soil*

8 Monitoring change

8.1 Profitability — returns in relation to soil management inputs

Soil management needs to be an integral part of farm business planning (Figure 8.1). This is because some of the soil management inputs (e.g. fertiliser, water, fuel for tillage operations) are becoming increasingly expensive and global competition amongst vegetable producers is reducing profit margins.

Therefore, soil management inputs should only be made where they are actually needed. Such decisions can only be made if there is a clear understanding of prevailing soil conditions, gained by regular soil inspection and monitoring.

Figure 8.1: *Vegetable farmer with cash flow outputs*

8.2 Environmental impact

To stay one step ahead of environmental legislation that is likely to become much more stringent, farm monitoring strategies should be established to deal with the following:

- Soil carbon inputs, outputs and storage
- Minimising the release of potent 'greenhouse gases' such as nitrous oxide from the soil
- Control of secondary salinisation, which can be caused by excessive deep drainage, in conjunction with an impeding layer in the subsoil: salinisation of the root zone can also be induced by a lack of leaching when using poor quality irrigation water.
- Prevention of contamination by chemicals
- Regulating chemical, physical and biological properties of the soil to ensure a 'healthy' landscape and production system for the future (Figure 8.2).

Figure 8.2: *Healthy river scene with abundant wildlife*

8.3 Industry certification schemes

Sustainable soil management is one of the foundations of successful horticultural production. This is recognised by a number of certification schemes that Australian growers are increasingly adopting, such as EnviroVeg Environmental Assurance, EurepGAP, the Freshcare Environmental Code and ISO14001. Certification to schemes such as these can be a commercial necessity to gain and maintain access to certain Australian and international retailers, food service operators and processors. The practices described in this publication will greatly assist growers who are striving to achieve certification.

9 Pulling it all together

9.1 Whole farm planning

The collation of soil information can be done in a number of ways. There is a trend toward the development of whole farm plans that are consistent with the requirements of Catchment Management Authorities (or other regional bodies). Soil information is an integral part of whole farm plans.

The soil information required for whole farm plans can be collated by farmers who have appropriate training or by consultants.

To be effective, soil information (e.g. maps, reports, management recommendations) provided by consultants should:

- be concise but comprehensive
- be practical
- take into account the landholder's observations
- be as accurate as possible (defensible in a court of law)
- be clearly presented with a minimum of jargon
- be available in convenient formats, e.g. written reports with a set of scaled colour-coded maps (see example in Figure 9.1), preferably with digital information for a geographic information system, and supplemented by photographs of the development site and representative soil profiles
- not be too expensive.

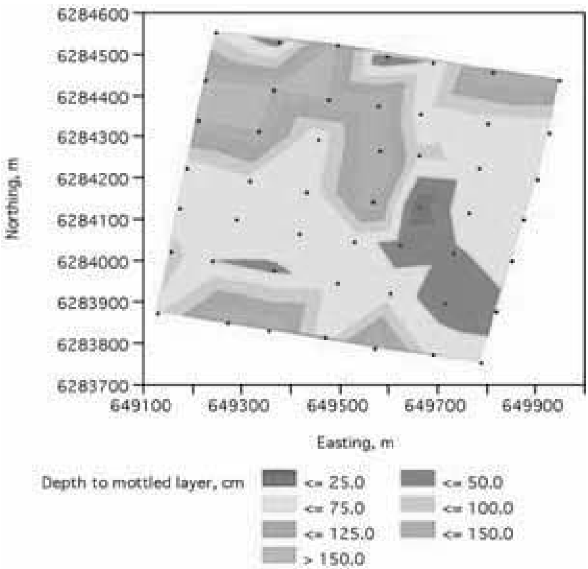


Figure 9.1 *Map showing depth to waterlogging, derived from soil pit observations. Reds and oranges on the map indicate a need for soil management inputs*

Apart from being valuable for the improvement of farm profitability, your soil information is likely to be very useful for catchment managers, particularly when combined with that of your neighbours.

9.2 Possible future trends

When it becomes possible to accurately measure a comprehensive set of topsoil and subsoil attributes 'on-the-go' with arrays of sensors mounted on GPS-guided farm machinery, then soil surveys will become very rich in data.

Continuous pH sensors as well as sensors capable of assessing N status in plants are currently being trialled worldwide. Other sensors aimed at directly measuring specific soil chemical properties (e.g. nitrate and sodium content) and physical properties (e.g. soil moisture content and soil strength) are under development.

These sensors would allow thorough interpretation of maps of crop yield and quality, and variable-rate soil amelioration maps would become more accurate.

A more likely outcome for rapid data acquisition, at least in the near future, is the development of near and mid-infrared spectroscopy (NIR and MIR) scanners for the rapid characterisation of soil chemical properties on standardised soil samples. These technologies have the possibility to dramatically reduce laboratory soil sampling costs as well as provide rapid in-field measurements.

Maps of crop yield and quality will become increasingly useful for defining sites needing further soil testing. This will allow whole-farm soil management plans to be fine-tuned.

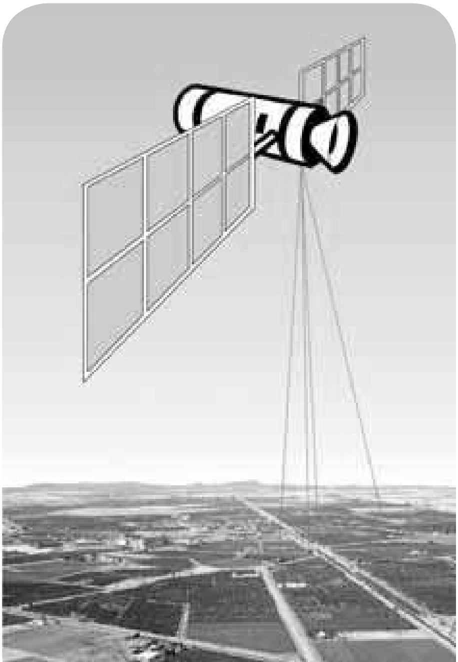


Image: CSIRO Land and Water

10 Help with soil assessment and management

10.1 Useful websites and references

If you would like more information about managing your soil you can refer to the following publications and websites. It is not uncommon for websites and addresses to change, so if you are unable to access one site, try another.

10.1.1 Websites

Australian Centre for Precision Agriculture
www.usyd.edu.au/su/agric/acpa

Australian Collaborative Land Evaluation Program (ACLEP)
www.clw.csiro.au/aclep

Australian Government Agriculture Portal
www.agriculture.gov.au

Australian Society of Soil Science Incorporated
www.asssi.asn.au

Australian Soil Resource Information System (ASRIS)
www.asris.csiro.au

Better Soils
www.bettersoils.com.au

Department of Agriculture and Food, Western Australia
www.agric.wa.gov.au

Enviroveg
www.ausveg.com.au/enviroveg.cfm

NT Department of Natural Resources, Environment and the Arts
www.nt.gov.au/nreta

NSW Department of Natural Resources
www.dnr.nsw.gov.au

NSW Department of Primary Industries
www.dpi.nsw.gov.au

Primary Industries and Resources South Australia
www.pir.sa.gov.au

Queensland Department of Natural Resources and Water
www.nrw.qld.gov.au

Queensland Department of Primary Industries and Fisheries
www.dpi.qld.gov.au

Tasmanian Department of Primary Industries and Water
www.dpiw.tas.gov.au

The Fertcare Program
www.fifa.asn.au/default.asp?v_doc_id=1130

University of Western Australia (Soil Health)
www.soilhealth.segs.uwa.edu.au

Victorian Department of Primary Industries (Victorian Resources Online)
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10.2 Accredited service providers

If you are going to the use the services of a professional for soil surveying, laboratory testing or fertiliser recommendations you should check to see if they are accredited.

For soil consultants: Ask if they are suitably qualified (tertiary qualification) and a member of the Australian Soil Science Society Incorporated (ASSSI) (website: www.asssi.asn.au) and/or CPSS (Certified Professional Soil Scientist) accredited.

For laboratories: ASPAC conducts a laboratory proficiency testing program for soil and plant analysis. Details of the program are on the ASPAC website: www.aspac-australasia.com. On the completion of the annual program, laboratories receive a certificate which indicates the soil and plant tests in which they are competent. The tests for which the laboratories are proficient on an annual basis will also be listed on the website. This will enable users of soil and plant testing to select a suitable laboratory for their soil and plant testing requirements.

For fertiliser recommendations: Use FIFA-certified fertiliser suppliers and advisors. For further information visit the FIFA website: www.fifa.asn.au

10.3 Training courses for growers and advisors

As part of the Land & Water Australia Healthy Soils for Sustainable Farms Programme, soil courses are planned for the vegetable industry (to begin in 2007).

Also to be developed and made available to vegetable farmers will be the *Healthy Soils for Sustainable Vegetable Farms: DVD* and the *Healthy Soils for Sustainable Vegetable Farms: Resource Manual*.

Glossary

acidic soil soil with a pH value less than 7.0.

aggregate a group of soil particles that cohere to each other (also known as a ped or clod). Soil aggregates are the small clumps soil breaks into when you dig it; small aggregates (microaggregates) clump together to form aggregates. The size, shape and percentage of aggregates are indicators of structural form.

alkaline soil soil with a pH value greater than 7.0.

ameliorate to improve.

anion an ion with a negative charge.

aquifer a water-bearing rock formation capable of yielding useful quantities of water to bores or springs.

Australian Soil Classification the system by which soil is classified in Australia, often referred to as the ASC.

biopore a large pore created by biological activity in the soil, e.g. old root channels and earthworm tunnels.

bolus a ball of moist soil which is kneaded to determine soil texture.

calcareous a soil containing significant amounts of naturally occurring calcium carbonate ($CaCO_3$ – lime), which fizzes when dilute acid is added.

cation exchange capacity the total amount of exchangeable cation, or the ability of negatively-charged clay minerals to hold cations, often referred to as the CEC. A guide to the nutrient status and structural resilience of a soil.

cation an ion with a positive charge.

clay soil particles smaller than 0.002 mm in diameter. Clay particles hold water and exchangeable cations.

clod a unit of soil modified by human activity. It often contains smaller clods.

compaction compression of soil into a smaller volume so that porosity is decreased.

crusts hard surface layer up to 1 cm thick, which occur mainly on bare soil when soil aggregates have dispersed.

deep tillage any tillage deeper than that needed to produce loose soil for a seedbed, or deeper than needed to kill weeds. Its usual purpose is to loosen a compacted subsoil.

denitrification the processes by which soil microbes convert soil nitrate to nitrogen gas and nitrous oxide gas which are unavailable to plants.

dispersion disintegration of soil aggregates into single soil particles upon wetting; the opposite of flocculation.

duplex soil a soil which shows a clear or abrupt change in soil texture between the topsoil and the subsoil, e.g. a loam topsoil overlying a clay subsoil.

$EC_{1:5}$ the electrical conductivity of a 1:5 soil:water extract.

EC_e the electrical conductivity of a saturated soil paste; the preferred measure of electrical conductivity as it is not dependent on soil texture and best reflects how salinity will affect plant growth.

electrochemical stability index (ESI) soil electrical conductivity (1:5 soil:water extract measured in dS/m) divided by exchangeable sodium percentage (ESP); a measure of soil stability in water.

erosion the wearing away of the land surface by rain or wind, causing soil movement from one point to another.

exchangeable cations the positively charged cations calcium, magnesium, potassium, sodium and aluminium.

exchangeable sodium percentage the amount of sodium in a soil expressed as a percentage of the total cation exchange capacity, often referred to as the ESP.

fertility the capacity of a soil to support plant growth. It has three components: chemical, biological and physical fertility.

field capacity the content of water remaining in a soil after free drainage is negligible (following rain or irrigation where the soil is saturated or full of water).

flocculation clustering of clay particles into microaggregates; the opposite of dispersion.

gypsum calcium sulfate, used to reduce swelling and dispersion in sodic soil.

hardsetting describes soil which dries very hard so that air and water movement, root penetration and seedling establishment are adversely affected.

infiltration the movement of water into a soil.

ion atomic or molecular particle carrying an electrical charge.

leaching downward movement of dissolved materials.

lime calcium carbonate, used to increase the pH of the soil (reduce acidity) and to improve structural stability in soil which is both acidic and dispersive.

mottling (of soil colour) blotches of different colours, indicative of past periods of intermittent waterlogging.

nitrification the process by which soil microbes convert ammonium to plant available nitrate.

nutrients required for good plant growth, e.g. nitrogen, phosphorus and potassium.

organic matter living and dead plant and animal material.

percolation the movement of water through the soil.

permanent beds a tillage system where the beds and wheel tracks are left in the same place for a number of crops.

permanent wilting point the water content of a soil at which plant roots cannot extract water, and plants wilt and cannot recover.

permeability ability of a soil to transmit water and gases.

pH a measure of how acidic or alkaline a soil is.

plant available water water held between field capacity and permanent wilting point.

plastic limit the water content of soil above which it can be remoulded (is plastic) and below which it cannot be remoulded (is brittle). Soil with a water content just below the plastic limit is said to be at the ideal soil water content for cultivation.

pore the space between soil aggregates.

porosity the degree to which a soil is permeated with pores.

readily available water water held between field capacity and refill point, often referred to as RAW.

refill point the water content of a soil where it becomes difficult for plants to extract water and more water is required to maintain growth rates.

root zone that part of a soil where the majority of live plant roots are located.

salinity an excess of water-soluble salts (dominantly sodium chloride in Australia) that restricts plant growth, indicated by electrical conductivity.

sand soil particles between 0.02 mm and 2 mm in diameter.

saturated soil soil which is so wet that it contains no air.

self-mulching refers to cracking clay surfaces that develop a crumbly layer of loose, small aggregates after a series of wetting and drying cycles.

shrink-swell behaviour ability of a soil to shrink when dried and swell when rewetted.

silt soil particles between 0.002 mm and 0.02 mm in diameter, intermediate between clay and sand.

slaking collapse of aggregates into microaggregates upon wetting.

sodicity an excess of exchangeable sodium causing dispersion to occur.

soil profile the vertical sequence of layers in the soil. The three main horizons are the A (topsoil), B (subsoil) and C (parent rock) horizons.

soil structure soil structure has three components: structural form, structural stability and structural resilience.

structural form the arrangement of the solid component of soil and the spaces in between (pores).

structural stability a measure of aggregate collapse (slaking and dispersion) upon wetting.

structural resilience the ability of a soil to regain desirable structural form after damage (e.g. compaction caused by heavy machinery).

soil texture the proportion of sand, silt and clay in a soil, estimated by the behaviour of a small handful of soil when moistened and kneaded into a ball and pressed out between the thumb and forefinger.

soil water water stored in, or in transit by drainage through, the soil.

SOILpak score a semi-objective rating (on a scale of 0.0 to 2.0) of soil structural form.

subsoil soil between the depths 30–120 cm.

subsurface soil soil between the depths of 10–30 cm.

topsoil soil between the depths of 0–10 cm.

unavailable water water stored in very small pores or held tightly around soil particles that cannot be extracted by plant roots.

waterlogging saturation of a soil with water caused by the application of excessive amounts of water and /or poor drainage.

watertable upper surface of groundwater, below which the layers of soil, rock, sand or gravel are saturated with water.