NSW DEPARTMENT OF
PRIMARY INDUSTRIES

SOILpak - dryland farmers on the red soil of Central Western NSW
Readers' Note

This document is part of a larger publication. The remaining parts and full version of the publication can be found at:

http://www.dpi.nsw.gov.au/agriculture/resources/soils/guides/soilpak/central-west

Updated versions of this document can also be found at the above web address.

PART C. DIAGNOSING SOIL CONDITION

diagnosis

C1. Soil pit digging: where, how and when?

PURPOSE OF THIS CHAPTER

This chapter explains where, how and when to dig an observation pit to examine the soil profile. Other methods of inspecting the soil are also discussed. The method you choose will depend upon time, cost and the information you wish to obtain.

This chapter should be read before using the SOILpak soil description sheet for dryland farming (Chapter C2 and Appendix 6).

CHAPTER OVERVIEW

The following points are covered:

- how to ensure that the pit(s) represents the paddock
- locating pit position using GPS equipment
- how to dig a pit using a backhoe
- preparing a backhoe pit for examination
- the spade, and other alternatives to backhoe pits
- suitable times of the year to examine the soil profile.

WHERE TO DIG

You are examining the soil profile to make conclusions about soil suitability for crop production. Your conclusions will affect your management decisions, so the pit must be dug in an area that is typical of the paddock of interest.

Use clues such as yield differences, aerial photographs or soil colour as a basis for deciding where to dig a hole or pit. It is useful to look at a site with no apparent problems to appreciate the degree of compaction in poor areas. The digging of inspection pits in nearby areas that have never been farmed also provides a useful comparison.

For post-harvest assessments aim to include the best-yielding, average-yielding and worst-yielding sections of a paddock in the soil sampling program. If, however, a paddock is known to be very uniform in terms of crop performance, one sampling site may be sufficient.

Choose an area away from headlands for inspection. Walk in at least 15 m across the main direction of traffic. Dig holes and pits perpendicular to the direction of plant lines. This will allow you to examine the effect of wheel tracks on soil structure. If controlled traffic farming is in place include at least one wheel track.

A spade can be carried with you at all times. Put spades in farm vehicles so that they will be available if questions arise about the current soil structure.

LOCATION OF PITS USING GPS EQUIPMENT

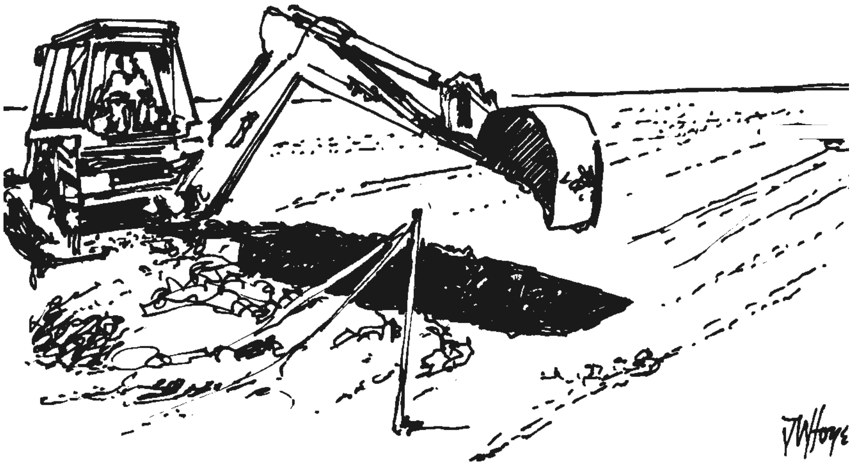
Recently developed Global Positioning System (GPS) instruments can be used to locate your position in a paddock. This allows you to record your sampling site location (for example, where you have dug a pit) and easily return to it for a follow up soil examination. Accuracy of GPS units vary with cost; errors of ± 100 m for a hand-held unit with no correctional capabilities (costing a few hundred dollars) down to errors of ± 10–20 mm for a less-portable unit costing several thousand dollars.

The use of positioning systems, in conjunction with yield maps, will allow you to locate and examine the soil at sites of say, high yield, average yield and low yield. Basic yield maps can be made by hand harvesting at key sites. Yield sensors, used in conjunction with harvesting equipment, allow more detailed yield maps to be made (Figure B12-1). Yield mapping is a subject of current research and development.

The availability and use of yield sensors and positioning systems is likely to increase. The use of positioning systems, and the subsequent mapping of yield and soil factors, provide the basis for increasing the efficiency of farming operations. They will allow soil in a paddock to be treated according to its needs, rather than as a single homogeneous block. This approach is referred to as precision agriculture or site-specific farming.

More information on positioning systems associated with precision agriculture can be obtained from the Australian Centre for Precision Agriculture, based at the University of Sydney. They have a web site, located at http://www.usyd.edu.au/su/agric/acpa.

Figure C1-1. Backhoe digging an inspection pit



BACKHOE PITS

A backhoe pit (Figure C1-1) provides a good overview of the entire root zone and soil profile to a depth of between 1 m and 1.5 m. It allows easy sampling of the subsurface soil and subsoil.

Features that are difficult to assess by digging in the soil manually are clearly visible in a backhoe pit. Structure, cracks, macropores, compacted layers and the effect of wheel tracks are able to be assessed.

How to dig a backhoe pit

It is important that what you see in a pit has not been changed by driving the backhoe over the area where the pit will be. Avoid digging pits exactly on top of the sites of previous backhoe pit investigations.

Before driving into a paddock, decide exactly where you want your pit. Reverse the backhoe up to the chosen site so that you can dig in undisturbed ground (Figure C1-2). After the pit has been dug the backhoe can be driven away forwards. The backhoe should never be driven over the site as it will compact the soil.

Keep the sides of backhoe pits vertical. Vertical sides make a better profile (depth is easier to measure). Minimise the amount of sideways

Figure C1-2. Moving a backhoe to and from the pit

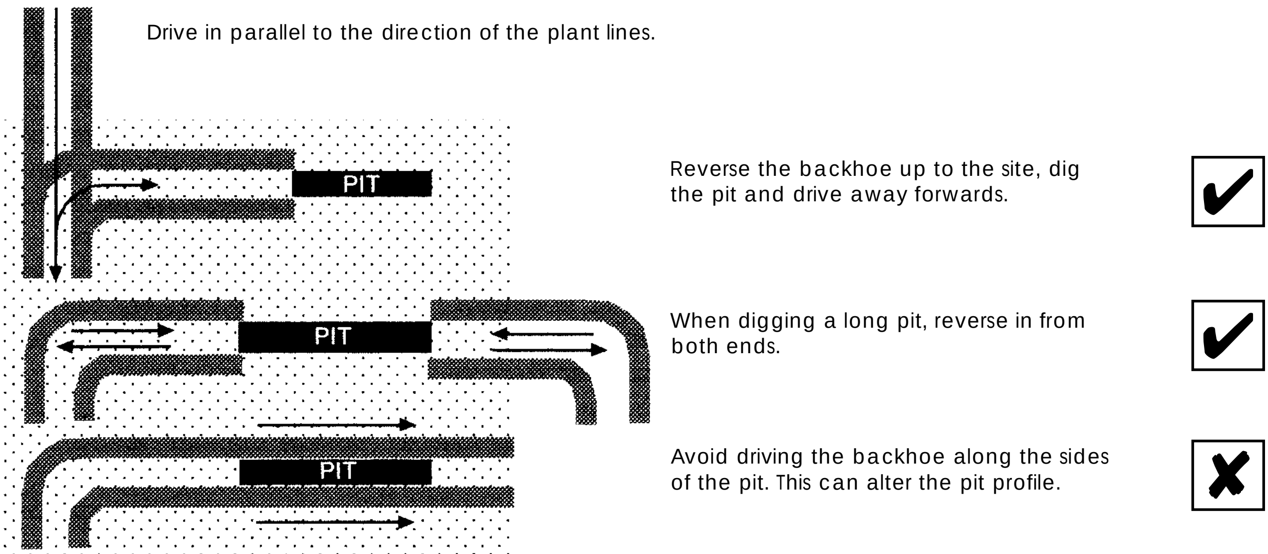
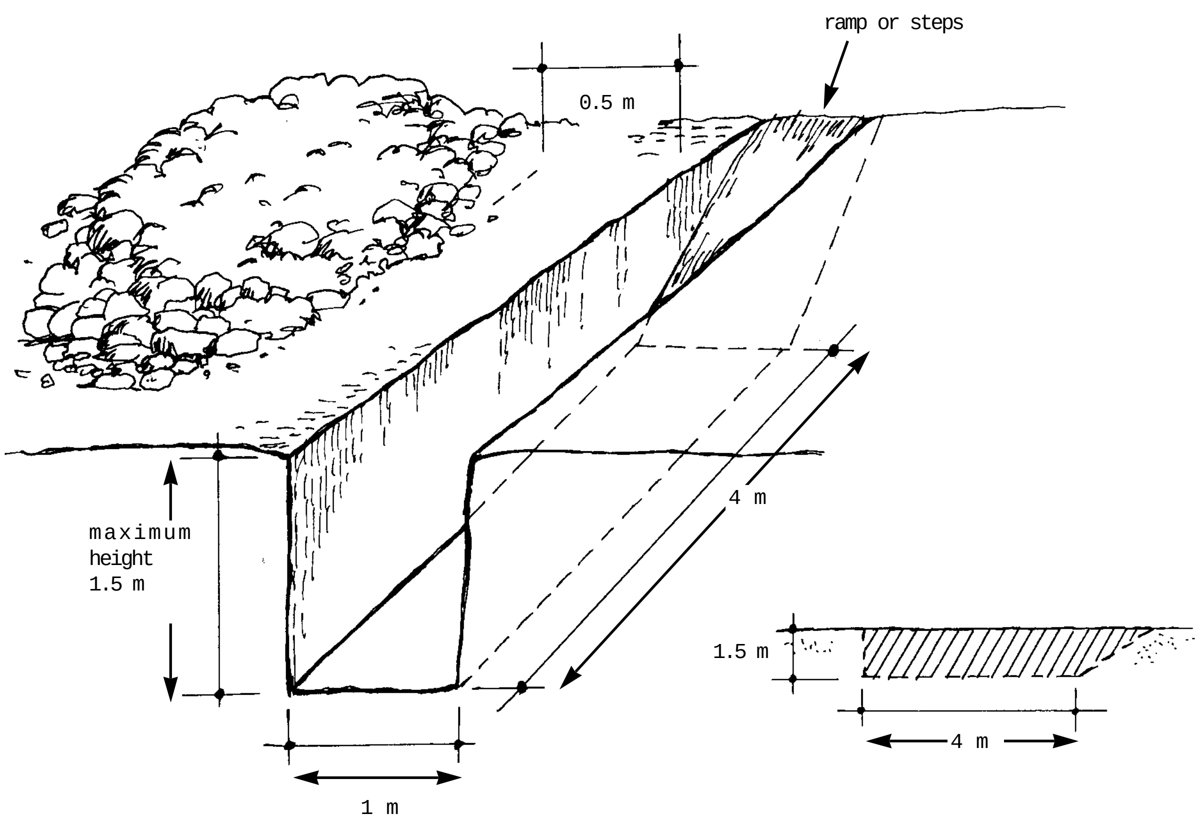


Figure C1-3. The recommended dimensions for a soil pit



heave as the backhoe bucket moves in and out of the hole (heave disturbs the soil profile).

Backhoe pits should be wide enough to stand in so that the exposed soil profile is easily examined. Because plant roots often extend well below 1 m, you will need to dig to about 1.5 m with the backhoe. A little extra depth allows you to examine the whole profile in comfort, and to allow room for the soil you will be removing from the walls. Access to pits is easier if steps or a ramp are dug at one end.

The recommended dimensions for an inspection pit are shown in Figure C1-3. A width of 1 m is shown, although sometimes it may be more convenient to make the pit 0.5 m wide. For particularly important pits which need to be photographed, a secondary pit can be dug at right-angles to the main pit to provide extra width.

If digging a pit that needs to be longer than the reach of the backhoe arm, back in from each end to prevent compaction from backhoe wheels (Figure C1-2).

Important warnings

Check on the location of underground cables and pipes before digging a backhoe pit. Striking such objects during excavation endangers the backhoe operator, and the cost of damage repair may be great! (Figure C1-4.)

- Keep the backhoe boom well clear of overhead power lines.
- In New South Wales, the maximum allowable depth for backhoe pits without benching (Figure C1-5) is 1.5. m. Workcover has stipulated that it is illegal for people to get into pits that are any deeper because of the danger of wall collapse. The danger of

Figure C1-4. Without good planning, digging a backhoe pit can be hazardous

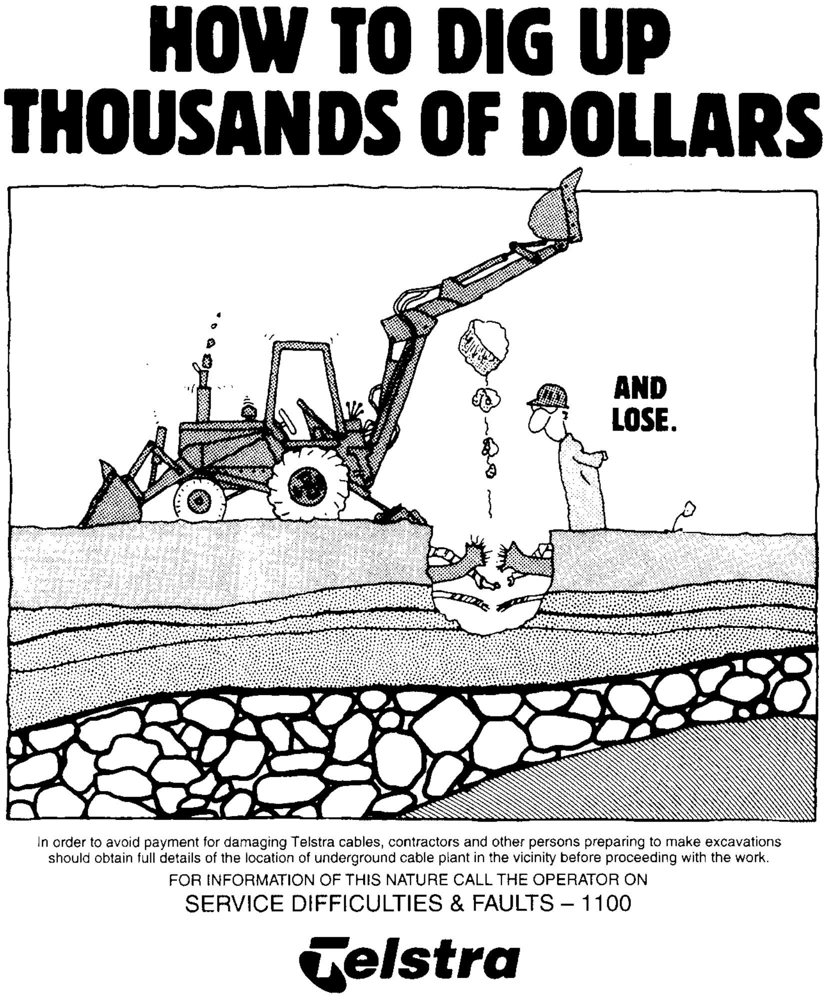
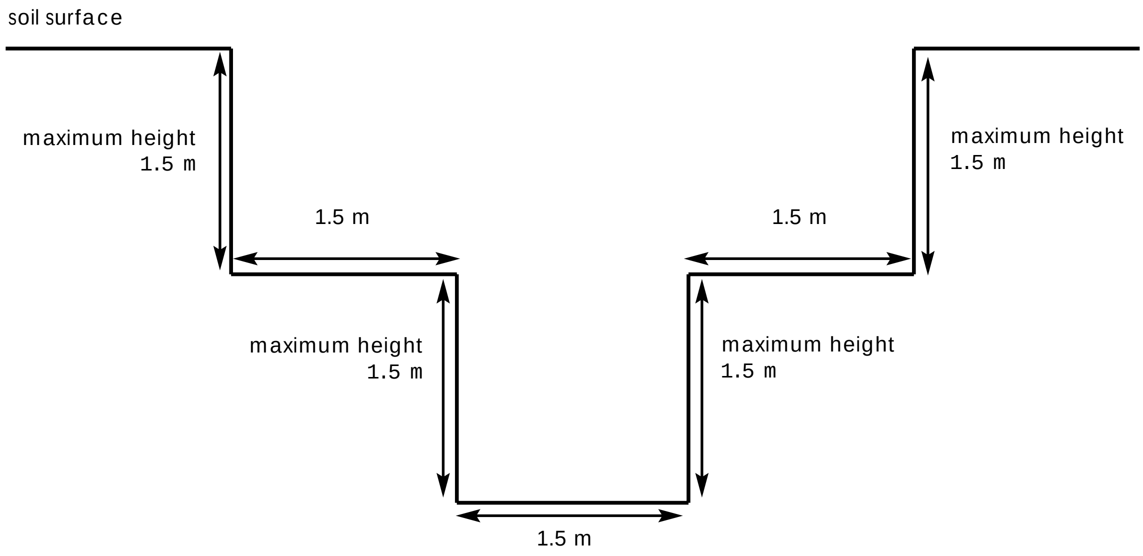


Figure C1-5. Benching allows pit inspections deeper than 1.5 m



collapse is reduced if the excavated soil is dumped well clear of pits (Figure C1-3).

- Clean excavating equipment carefully to prevent the spread of diseases, pests and weeds.
- If investigating in unfarmed areas or a paddock with livestock, and pits are to be left unattended, consider the erection of a temporary fence around each pit to avoid injury to livestock.

If possible, pile the excavated soil on the uphill side of a pit. Then, if it rains heavily, the pile will stop some runoff getting into the pit. Cover pits if rain is imminent.

Fill in pits soon after inspecting them 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 with a tall and flexible plastic peg.

Preparing a backhoe pit for examination

Clear away any soil spilt on the soil surface above the face you wish to examine. This is important as it allows you to locate the original surface as a reference for the depth of features.

Before examining the exposed soil profile it is imperative that an undisturbed soil face is revealed. The backhoe bucket will have smeared the sides of the pit, making it impossible to determine the natural structure and colour of the soil. A chisel, asparagus cutting knife, or pocket knife can be used to flick out the smeared soil and reveal the undisturbed soil behind.

Work across the pit face and then from top to bottom, prising out the damaged exterior of the pit face. This systematic trimming will enable you to remove marks left by your knife.

While clearing a fresh face take note of the ease (or difficulty) of flicking away smeared soil. This will give an indication of any compacted or hardset layers. At this stage you are ready to fill in a SOILpak description sheet.

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See Chapter C2 for more information on SOILpak soil description sheets.

INSPECTION HOLE ALTERNATIVES- SPADE, CORER AND AUGER

There are a number of alternative and supplementary methods to the backhoe pit for assessing soil structure. These include the use of a spade, a coring tube, or an auger. Information gained with these alternative methods should be recorded on a SOILpak soil description sheet for interpretation and later reference.

Spades, coring tubes and augers are useful if it is impractical to dig a backhoe pit for some reason such as lack of machinery or wet conditions.

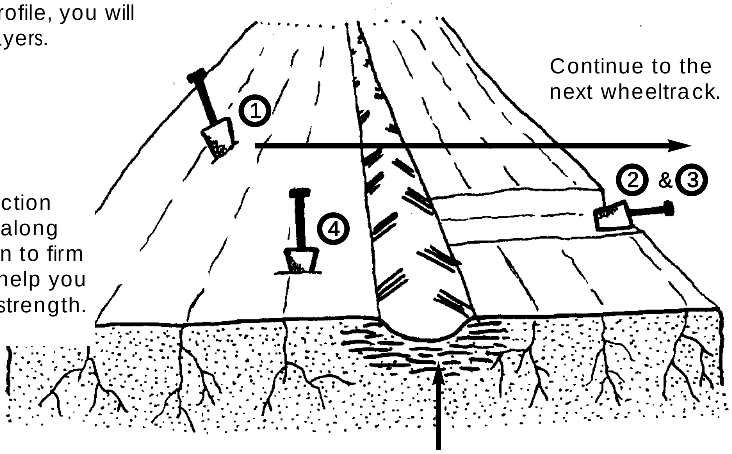
They are also useful for sampling at a number of sites. Some of these alternative methods can be used as a quick method of confirming, over an entire field, the diagnosis of soil structure from a small number of backhoe pits.

Alternatively the methods can help to select a representative site in which to dig a backhoe pit for a more detailed evaluation.

Spade

Several soil experts prefer to use a spade when examining soil structure, due to its simplicity, portability and low cost. A spade (or

Figure C1-6. Using a spade to assist in soil structural diagnosis



perhaps a mattock or crowbar) is best used for digging small holes to examine the topsoil (to approximately 30 cm).

Some users have found that it is easier to sample the subsoil if the spade blade is cut to a width of approximately 15 cm at the cutting edge.

An intact soil sample can be taken using a spade. The soil sample can then be prised apart to examine relevant soil features and to obtain soil samples for water stability and chemical tests. The morphological features of plant roots may also be examined from a spade soil sample.

Start by pushing the spade in at approximately 25 cm intervals—parallel to the main direction of traffic (Figure C1-6). Note how deep you can push the spade to get an idea of where hard or compacted zones may lie. In very dry soil you may need your foot for leverage, whereas in wet soil you will probably get better feedback by just pushing the spade in by hand. Continue across the paddock (perpendicular to plant lines) including where traffic has been. In situations where the direction of traffic varies throughout the year (*not* recommended), focus on traffic lines created by the sowing and harvesting equipment.

If you find hard zones below the soil surface (especially directly under the plant lines), or at the surface, examine the soil in more detail. Use the spade to scrape away any loose soil (moisture will affect how easily the loose soil can be removed) and note the depth, and condition of the loose soil.

Look at the top of the hard layer that you have uncovered—you can use your hand to lightly scrape away very loose soil. Take particular notice of the number of biopores (old root channels, tunnels created by ants, termites and earthworms), presence of thin cracks (large cracks are not found in red soil, but some small ones may be present) or smeared layer caused by an implement. If cracks or biopores are visible with a spacing of less than 3 cm, plant roots should have little trouble penetrating the soil.

With the top of the firm layer now exposed, dig out a spadeful of soil. Firm soil is not necessarily a result of compaction. It could be because your soil is naturally hardsetting. The degree of hardsetting mainly depends on soil texture, which cannot be altered. The problem of hardsetting is exacerbated by low organic matter levels and cultivation, however.

Keep the soil on the blade of the spade and note the orientation and the depth from which it came. Look for platy or massive structures, within the spadeful of soil, that are associated with vehicle compaction. Where the soil is hardset, pore spaces often are poorly connected and have a honeycomb-like appearance. An abundance of roots between a ploughed layer and firmer soil underneath, is a good indication of a compaction problem.

In a spadeful of soil dug as described, natural crack-lines or planes of weakness may be expanded making them easier to see than when they are undisturbed in the face of a backhoe pit. Solutions of paint can also be used to highlight crack-lines and biopores.

When examining soil structure to depth it will be easier if you dig a small hole first, then take a slice of soil from the side of the hole for examination.

A spade is particularly useful to quickly assess the impact, either good or bad, of a tillage operation.

You can use a spade in conjunction with a backhoe pit. Dig down parallel to the edge of the pit until the soil feels firm. Throw the spadeful of loose soil into the pit. Repeat the process along the top edge of the pit. If a hard layer exists it can be more obvious when using this technique than by just looking at the vertical face of the pit.

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See Chapter E3 for more information on hardsetting soil.

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See Chapter C4 for more information on assessment of soil structure.

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See Chapter C4 for more information on using paint to highlight crack-lines and biopores.

For the spade method

Advantages:

- Simplicity.
- Accessibility.
- Speed—more, but smaller replicates than with a backhoe.
- Feel—the feel of the soil as you are digging can provide detailed information about the structure.
- May make it easier to see natural crack lines and biopores.
- A good technique to use when the soil is very moist.

Cautions:

- Difficulty assessing the subsoil.
- The cross-sectional view of the soil will not be as good as with a backhoe pit.
- Moisture can greatly alter the feel of the soil when digging; dry soil is hard even when in good structural condition.

Coring tube

Coring tubes can be useful if it is not possible to dig a pit; but you still want to sample to depths greater than that readily accessible using a spade. A coring tube takes a soil sample with minimal disturbance.

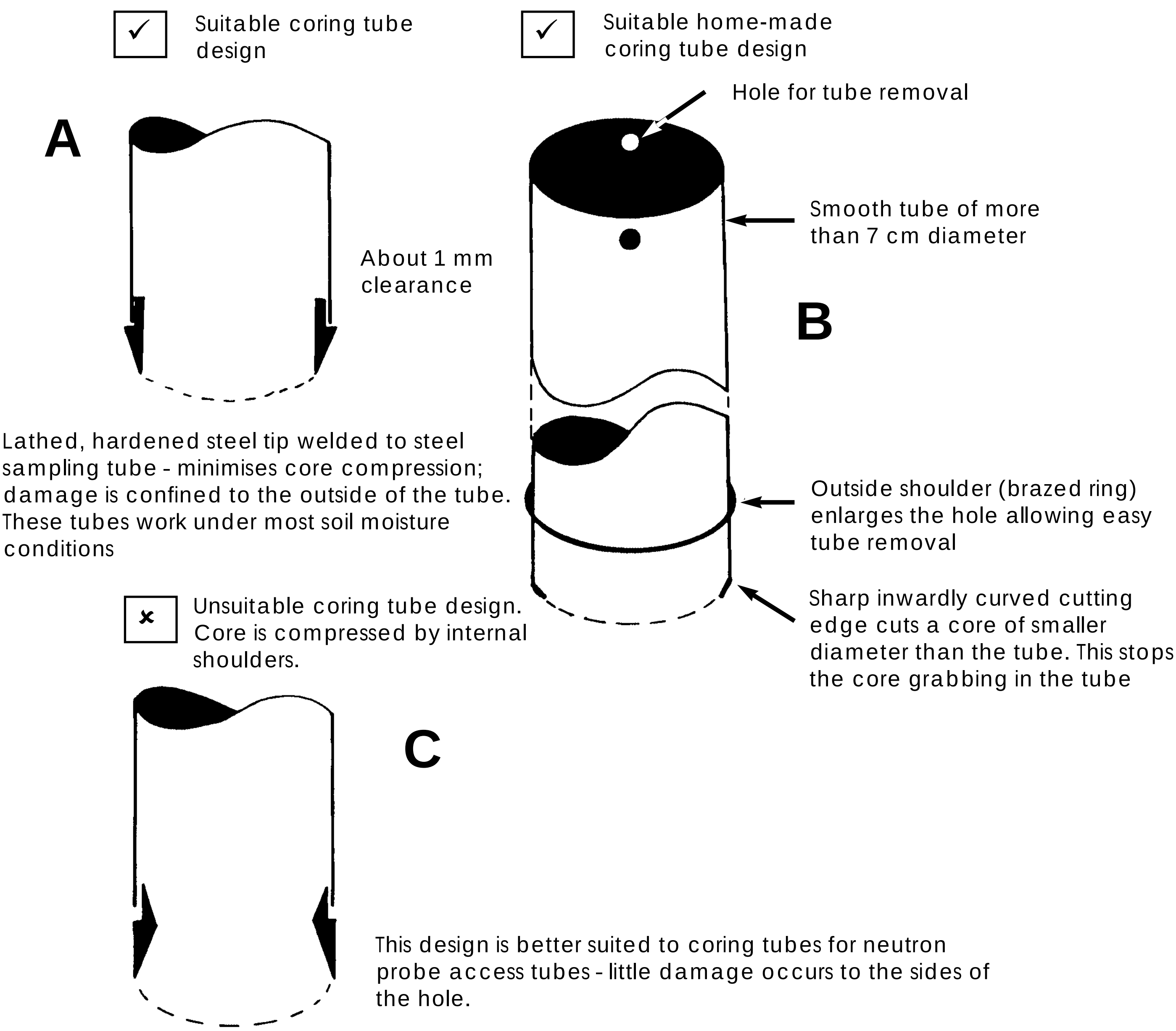
The tube will smear the soil around the outside of the core, and there will be some distortion of the sample. However, the centre of the core usually retains its structure reasonably well. Severely compressed or expanded cores should be rejected.

A soil core will show soil layers and structure. The depth of different soil features can also be closely estimated. Samples can be taken from the core for other soil tests.

Soil cores are particularly useful when developing a paddock for cropping for the first time, or for a paddock that has been under pasture for some time, when the emphasis is on soil chemical properties rather than the severity of soil compaction.

Figure C1-7 shows three designs for coring tubes made from steel tube of 1.6 mm wall thickness. Exhaust pipe (50 mm diameter) may be used. Larger tubes (75 or 100 mm diameter) give better cores but in hard red soil it may be difficult to get them into the ground without bending them.

Figure C1-7. Cross-sectional view of three coring tube designs



The shape of the cutting tip should force excess soil outside the tube (designs A and B) leaving the core relatively undisturbed. Design C is unsuitable for examining soil structure—it is better suited to creating a relatively undisturbed hole (e.g. for neutron probe access tubes) at the expense of remoulding the core.

Generally the force required will be too great to insert a coring tube by hand or with a heavy wooden mallet. A tractor with a hydraulic ram is effective.

Use a lubricant (e.g. oil) inside and outside the tube to prevent the soil from sticking. If the soil samples are for chemical testing, oil may contaminate the samples. Phosphate-free and nitrogen-free oils are available but are expensive.

Often the success of soil coring will depend upon moisture conditions. Good samples are difficult to obtain from loose soil, wet profiles (the soil core may stick to the soil tube), or extremely dry profiles (the soil core tends to crack and fall apart as it is removed).

After removing the soil core from the tube (e.g. by inserting a blunt wooden handle inside the cutting end and pushing the core out) expose the structure within the core by picking off the smeared outer layer (a boot knife is a convenient tool). Often the soil structure will become more obvious as the soil dries and the cracking pattern becomes conspicuous.

A convenient way to store cores for later reference is in split PVC pipes. The core can be placed directly into the PVC pipe by lying the tube in the pipe and pushing the core directly into the pipe.

For soil cores

Advantages:

- Cores can be kept as a record of soil types and problems.
- Deep samples can be taken more conveniently than with the spade method.
- Less disruptive than backhoe pits.

Cautions:

- Slow.
- Machinery and operator required.
- Core can stick in tube.
- Small sample.
- Outside of core smeared.
- No guarantee that structure is completely undisturbed; moist soil may compress.

Soil auger

Soil augers greatly modify the structure of a soil sample. However, they can be used successfully to sample for soil moisture or for chemical analysis. They may also be useful for a quick field examination of soil texture and colour before digging backhoe pits.

Some care allows the depths from which each auger sample is taken to be monitored. Place some plastic on the ground next to where you wish to dig the auger hole. Fill the auger with soil and then

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See Chapter C3 for more information on soil moisture and texture.

remove the soil onto the plastic. Using a ruler or tape measure, measure the depth to which the sample was taken. Progressively, soil samples from down the soil profile can be layed out on the plastic and the approximate soil depth written next to the soil samples.

For soil augers

Advantages:

- Simple and fast.

Cautions:

- Not suitable for removing soil for structural assessment.

WHEN TO DIG INSPECTION PITS

For existing developments, the following times are suitable for inspecting the soil using one of the above-mentioned methods:

- ***Immediately after harvest.*** While the plant lines are still in place you can easily locate wheel tracks. Look for lateral spread of wheel compaction if traffic has been confined to set wheel tracks, and examine the structure of the soil between the tracks. Also examine the structure of the subsoil. The soil structure can be related to the events during seed bed preparation or harvest and to the last crop's performance. Examples of growing-season problems are stunted plants and poor water infiltration. You can plan your tillage and fertiliser operations for the coming season from the results of the pit inspection, and there is time for the soil to settle after the pit is filled in.
- ***After a crop or pasture*** grown specifically to improve soil structure, to check whether the soil structure has improved. Deep tillage may be required to further improve the soil structure.
- ***After a test run of tillage equipment***, to see if the operation was effective, and not creating more problems than it was supposed to solve. Problems include excessive cloddiness, too much dust and/or smearing at the base of the tines. Equipment may require adjusting, or it may be best to cease tillage until conditions improve.
- ***After changes in management practice,*** to determine whether a soil problem is being overcome by a new agronomic approach. The grower and adviser can see, for example, the results of changing to direct drilling and stubble retention.

C2. Features of the SOILpak soil description sheet

PURPOSE OF THIS CHAPTER

The soil description sheet provides a focus for this manual.

Once soil information from the field and laboratory has been carefully measured and recorded on the description sheets, informed practical decisions can be made about soil management for dryland farming. The sheets form a permanent record of soil condition.

CHAPTER OVERVIEW

The following points are covered:

- a brief explanation of why the various features shown on the description sheet need to be recorded
- equipment needs.

Other chapters to refer to:

- Chapter C1: 'Soil pit digging: where, how and when?'
- Chapter C3: 'Soil moisture (before tillage), soil texture and available water'.
- Chapter C4: 'Soil structure assessment'.
- Chapter C7: 'Salinity assessment'.
- Chapter C8: 'Other tests'.

INTRODUCTION

SOILpak soil description sheets for dryland cropping are in a plastic sleeve at the back of this manual (Appendix 6). They are accompanied by an example of a filled in sheet.

The numbers recorded on the sheets are compared with the critical limits described in Chapter A2 (and in other relevant chapters), and closeness to the ideal is determined. Management options are then considered to deal, if economically feasible, with any problems that have been identified.

Over time, the recorded information can be used to show trends in soil physical and chemical fertility. If you have a soil problem, the information you collect over several years will allow you to monitor your success in rectifying the problem. If you do not have any problems you will be able to assess whether your current soil management practices prevent soil deterioration by comparing your current and future description sheets.

WHY EXAMINE SOIL?

Examining a soil and assessing its physical, chemical and biological condition is the foundation for good crop management. The SOILpak soil description sheet aims to make this task easier for you.

When you know the condition of your soil you can make an informed decision about soil use and management.

When looking at a soil profile and deciding upon future soil management, consider three things:

- The past—previous tillage, crop rotations, pasture phases, fertiliser application and climatic conditions.
- The present—what you are currently observing in the pit.
- The future—your prediction of the behaviour of the soil under various management options, knowing the types of farming machinery that are available at this site for the next crop, and considering the difficulty of predicting weather conditions.

Much can be learnt from observation of the soil in the field. Laboratory testing can be used to back up this information. Laboratory testing may only be required every 5 years, particularly if it is found that the chemical status of the soil is close to ideal. Most laboratory testing is for soil chemical properties.

Soil measurements can be used for two types of management decisions:

- Long term strategies—for example, the length of cropping and pasture phases; and
- Short term tactical decisions—for example, whether a planned tillage operation is necessary.

EXPLANATION OF THE SOILpak SOIL DESCRIPTION SHEET FOR DRYLAND FARMING

At a first glance, the SOILpak soil description sheet may appear unnecessarily detailed and complicated. With practice, though, it soon becomes straight-forward. If the evaluation is to be comprehensive, and repeatable over time to investigate trends in soil condition, it is not feasible to simplify the assessment procedures any further (based on existing knowledge). Financial benefits of the investigation are likely to far outweigh the costs.

Do not worry if you cannot fill out every section of the sheet the first time, but aim to eventually achieve this goal.

The timing of soil examination was discussed in Chapter C1. The soil may, for example, be described after harvest of a crop to plan paddock preparation for the next crop, or after a pasture phase to determine if structure has improved. For the red soil types common in Central Western NSW it is strongly recommended that they be examined when dry. Problems are often more difficult to detect when the soil is moist. The soil profile is usually dry after harvest.

The SOILpak soil description sheet for dryland farming has been divided into six different sections and the rationale for including the features listed on the sheets is as follows:

1. Farm and field information

Record the following information:

- ***Grower's name and address.***
- ***Paddock number/name and area in hectares.***
- ***Depth to the watertable.***
- ***Crop/pasture sequence for the past three years.***
- ***Presence or absence of harvests on wet soil.***
- ***Presence or absence of bent or deformed roots.***
- ***Presence and absence of disease symptoms***.
- ***Extra information.*** Any extra information that you feel is relevant should be recorded. If the examination is being carried out at a particular site for a particular reason this can also be noted. Some specific reasons for carrying out a soil examination include poor seedling emergence, large yield variability and an apparent lack of soil moisture. The more accurate and detailed your records are, the easier it will be to link the information collected on the description sheet to crop performance.
- ***Sketch of pit location in a paddock.*** This allows a pit position to be relocated in the future. When you sketch the paddock, note particular features that will enable you to return to the same site. On the pit location sketch also note the following:

  —high- and low-yielding areas of the paddock
  —paddock aspect and slope
  —areas which are prone to waterlogging
  —the position of contour banks and waterways.
- ***Map/GPS grid reference of sampling point.*** Pit location is made easier if you note the map grid reference. Use the 'Geocentric Datum of Australia' (GDA) system, rather that the 'Australian Geodetic Datum' (AGD) which will be phased out by the Year 2000. An example of a grid reference is 147° 03' 41.0'' E, 33° 52' 11.6'' S. The position of this grid reference for the GDA system differs from the matching AGD coordinate by about 205 m. Global Positioning Systems (GPS), which record paddock site position via the use of satellites, provide a convenient way of determining spatial position (and, if necessary, elevation).

- ***Sketch of main pit features.*** This is particularly important. After a pit face has been trimmed, the sketch provides an overview of the location of zones with poor structure and with favourable structure. Show wheel track location and the position of plant roots plus any relevant surface features (e.g. crusts, large clods). Note whether or not the soil has an attractive 'earthy' aroma.

  On your sketch note the depth of different layers in the soil, if they are easily distinguished. These layers are often easily observed by changes in colour (a piece of slightly moist soil can be used to mark the colour of the different layers on your sketch). A good way to remember what the soil looked like in each pit you examine is to take a photograph. The best time to take a photo is when the sun is behind you, with clouds to minimise shadows on the pit face. Use a scale in the photograph (any object of known size, for example a knife or tape measure, will do).

- ***Crop performance.*** Note the last crop grown in the paddock being investigated and its harvest date

  The performance of wheat and other dryland crops is mainly evaluated by looking at *grain yield* in tonnes per hectare. *Grain protein* is also usually measured. This is a good starting point. However, well-run businesses also need to closely examine the efficiency of use of their inputs. The following are key factors (which can be greatly improved by high-quality soil management).

  —*Grain yield per mm of water* (received as rainfall) used by the wheat crop (crop water use efficiency[CWUE])

  —*Grain yield per kg of nitrogen* applied as fertiliser (and from soil reserves). To calculate this, nil-N strips are needed close to the sample site. N content and the weight of sampled plants in the unfertilised areas are measured at harvest.

  Efficiency of N use is calculated using:

  Grain yield (kg/ha) per kilogram of applied fertiliser N (and N supplied from the soil reserves)

  $$= \frac{\text{grain yield}}{\text{total N applied to last crop (+ N uptake in unfertilised strips).}}$$

  As the severity of soil compaction or hardsetting increases, more rainfall is required and N rates must be increased to maintain yield—the efficiency of their use, therefore, declines.

  —*Crop water use efficiency* values in the range 15–20 kg grain per hectare per millimetres of water are considered to be good.

  —*Grain yield per dollar spent on land preparation* is another key factor given that some growers appear to over-cultivate the subsurface soil and subsoil of their paddocks.

- ***Anticipated crop/pasture program.*** Record your anticipated paddock management program (i.e. crop or pasture type and timing). This information may help you to decide which soil features are most important to examine. For example, a crop that has a high nitrogen demand may benefit if you measure soil nitrogen. Options such as nitrogen application or establishment of a legume-based pasture phase can then be considered.

- ***Overview of the colour and texture of the soil surface.*** Provide a brief overview of the colour and texture of the soil surface. For a detailed soil description more information about colour and texture is recorded in Section 4 of the description sheet. Soil colour should be determined using a newly exposed pit face or face of a freshly broken clod.

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See Chapters C9 and D1 for more information on water use efficiency.

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See Chapter C6 for more information on estimating the amount of ground cover.

2. Surface features

Consider the following surface features within a 20 m radius of a pit:

- ***The amount and type of surface cover.*** Types of surface cover include wheat stubble, pasture and weeds. Note whether stubble is standing or loose on the ground.
- ***The configuration of 'permanent' wheel tracks (controlled traffic).*** Record the distance between the tracks and the presence of any compaction near the wheel tracks.
- ***The presence of a surface crust and/or signs of dispersion.*** This is a sign of a sodicity problem.
- ***Signs of erosion.*** Look for rills (small channels) where water has run off (if there are signs of water erosion note paddock slope and length). If you have noticed dust clouds rising from your paddock then you have a problem with wind erosion.
- ***Water repellence.*** A soil that is water repellent resists wetting when dry. If, when you add a drop of water to your soil, it does not enter the soil but remains on the soil surface your soil is water repellent. The phenomenon of water repellency generally occurs on sandy topsoil and is due to organic coatings on the sand grains which resist water entry into the soil. Generally, it is not a problem in Central Western NSW, but be aware of it.

3. Soil suitability for root growth and water intake

In this section record your first impressions of soil suitability to:

- root growth
- the ability of water to infiltrate into the soil.

Take into account the feel of the soil when you were digging or preparing the pit face. Can you see pores and roots extending below the topsoil? These observations will help you to estimate whether the soil is suitable for root growth and water intake, or not.

With practice, this judgment should be accurate enough to allow rapid assessment of soil condition.

4. Profile tests

To encourage consistency of measurement, soil assessment (in the pit) should be carried out mid-way down the following depth intervals:

- topsoil (0–10 cm)
- subsurface soil (10–30 cm)
- upper subsoil (30–60 cm)
- mid subsoil (60–90 cm)
- lower subsoil (90–120 cm) (optional).

For chemical testing, samples should be taken from depths of 0–10 cm, 15–25 cm, 40–50 cm (upper subsoil), 70–80 cm (middle subsoil) and, if necessary, 100–110 cm (lower subsoil).

If you notice any distinct layers between or within any of these depth intervals you should sample them separately and record the depth.

a) In the pit

- ***Biopores***. Biopores made by termites, ants, earthworms and old root channels are easily recognised—their presence or absence should be noted. They are valuable to the soil because they can improve the physical and chemical status of your soil.
- ***Texture and moisture.*** Record the texture and moisture status of each layer. The water content of the soil at the time of observation can influence the results of your examination. This is particularly true for soil types which exhibit hardsetting upon drying. If you are sampling at a number of sites on your property try to sample at the same time so that all samples are at approximately the same water content. If you sample one site when it is very dry and another when it is very wet, it is difficult to compare the two sites from a structural point of view.
- ***Mottling.*** Record the presence or absence of mottling. A mottled soil (or layer) has patches of different colours or shades of colour. The colour of the soil is an indication of whether it is well drained (red soil) or not (yellow soil) or if the topsoil is high in organic matter (a dark topsoil). A very pale brown surface soil indicates that the soil may benefit from the addition of some organic matter. A mottled soil (e.g. red with yellow patches) suggests that the soil is periodically waterlogged. Note the percentage of each colour in the mottle.
- ***pH.*** Obtain a first approximation of soil pH in the paddock using a ‘Raupach test kit’. This is a measure of soil acidity/alkalinity. pH is important because it influences nutrient availability and structural stability.
- ***Slaking.*** Slaking is a process whereby clods (aggregates) of soil collapse in water to form micro-aggregates. If the clods are strongly bound by organic matter, they will remain intact. Otherwise you can see them fall apart, often within seconds. Record whether or not this process occurs by placing some clods in a dish of distilled water or rain water. Slaking leads to hardsetting in soil with poor shrink/swell potential.
- ***Dispersion after 10 minutes.*** Dispersion is the separation of slaked microaggregates into clay, sand and silt particles. It is assessed over a period of 2 to 4 hours using the ASWAT test (see the following text under sub-heading ‘b) At home and in the laboratory’). However, observation of the degree of dispersion after 10 minutes (indicated by cloudiness around clods in the distilled water) provides a useful first approximation of the severity of this problem.
- ***Natural lime and gypsum.*** The presence of lime (calcium carbonate) nodules and/or gypsum usually indicates the presence of alkaline conditions, and may be associated with poorly-drained, sodic conditions. Lime nodules fizz when acid (e.g. hydrochloric acid) is poured on them, whilst naturally occurring gypsum is characterised by its sparkling, crystalline form.
- ***Manganese nodules.*** Hard, dark manganese nodules indicate periodic saturation of the soil sometime in the past—they fizz when hydrogen peroxide is poured over them.
- ***SOILpak score.*** The SOILpak scoring procedure allows you to assess how compact the soil is, and if the soil structure is ideal for

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*See Chapter C3
for more information on
soil moisture (before tillage), soil texture and available water.*

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*See Chapter C8
for more information on
on measuring pH.*

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*See Chapters B7 and D5 for
more information on
the interpretation of pH values.*

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*See Chapter C4
for more information on
the SOILpak scoring procedure.*

plant growth. In loamy soil (clay content less than 35%), some of the factors listed do not allow clear distinction of soil condition over a range of water contents, so are not assessed.

b) At home and in the laboratory

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See Chapter C4 for more information on the ASWAT test.

- ***ASWAT.*** The Aggregate Stability in WATer (ASWAT) test takes 2 hours to carry out. It is a measure of the degree of dispersion (i.e. the degree of collapse of soil micro-aggregates into the component sand, silt and clay). As the soil becomes more dispersive, it becomes more prone to waterlogging when wet, and is more likely to set hard when dry.
- ***Laboratory tests.*** Laboratory tests (pH, electrical conductivity, cation exchange capacity [CEC], exchangeable sodium percentage [ESP], electrochemical stability index [ESI], ratio of exchangeable calcium to exchangeable magnesium [Ca/Mg], calcium carbonate [$CaCO_3$] content, organic matter content, available water and nutrient content) should only be carried out by laboratories certified by National Association of Testing Authorities (NATA). Otherwise, large errors may occur. Note which laboratory you are sending your samples to.

Measurements of pH, EC, ESP, ratio of exchangeable calcium to exchangeable magnesium, $CaCO_3$ content and organic matter content all help to explain why a soil is, or is not dispersive. ESI ($EC_{1:5}$ divided by ESP) is a particularly useful index of soil dispersibility.

Electrical conductivity data are also used to indicate how saline a soil is. A first approximation of soil electrical conductivity can be obtained using a field meter. However, laboratory tests will be more accurate.

Apart from adversely affecting soil stability in water, alkalinity (high pH) makes many soil nutrients increasingly unavailable.

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See Chapter C4 for more information on soil characteristics that affect the dispersibility of a soil and structural resilience.

The sum of exchangeable cations (Cation Exchange Capacity [CEC]) is a measure of structural resilience, i.e. its ability to decompact by shrinking and swelling.

Testing for available water is an optional extra. It is recommended for use in areas where soil texture and colour obviously vary from one part of a paddock to another.
Amounts of nitrogen and phosphorus in the soil can be measured and are important for crop growth. Note the results of any other nutrient tests.

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See Chapter C8 for more information on soil nutrient testing.

5. Conclusions

For each of the three main depth intervals, make conclusions about the following features:

- ***Severity of compaction (as measured by the SOILpak score).***
- ***Suitability of soil moisture for tillage.***
- ***Soil stability in water (as measured by the ASWAT test).***
- ***Natural regeneration potential, which takes into account soil CEC (a measure of soil shrink-swell potential) and the presence or absence of earthworms and ants.***
- ***Soil pH.***

- ***Salinity hazard.***
- ***Nutrient deficiencies.***

6. Recommendations

Based on the conclusions made about soil condition on the description sheet, problem areas can be identified and management options selected to improve soil condition for dryland crop production. On the description sheet indicate whether or not certain management areas need attention, for example, does soil organic matter need to be increased or are levels acceptable. The description sheet guides you to make recommendations about the following features (chapters with details of the management options are given in brackets):

- ***Deep tillage soon to break up hardset or compacted layers (Chapter D4).***
- ***Increasing biopore numbers using a specific crop or pasture phase (Chapter D4).***
- ***Soil organic matter (Chapters D4 and E6).***
- ***Surface cover (Chapters C6 and D3).***
- ***Gypsum/lime application to improve stability (Chapter D4).***
- ***pH adjustment (Chapter D5).***
- ***Bed height (if relevant).***
- ***Application of nitrogen or other nutrients for the next crop (Chapter D***8).

Your selection of options will be influenced not just by soil condition; but also by commodity prices, available machinery and anticipated weather conditions.

It is also important to consider the following:

Where serious compaction has been observed, think about precautions that can be taken to stop it from happening again; for example, use of narrower tyres or 'permanent' wheel tracks.

If a salinity/watertable problem is identified or suspected, refer to regional watertable information and seek further advice.

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See Chapter A2 for more information on the critical limits for an ideal soil for dryland farming.

EQUIPMENT NEEDS

Equipment needs for soil assessment are outlined in Table C2-1.

CHECKLIST

The following checklist is a quick reminder of things to do when digging a soil pit and filling in a SOILpak soil description sheet:

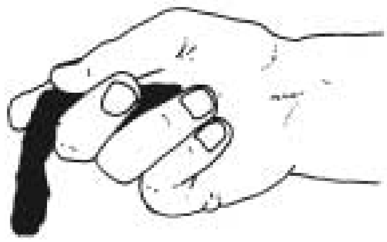
1. Start filling in Section 1 of the description sheet (field history, etc.).
2. Decide where to dig the pit (take into account wheel tracks, plant growth, yield, etc.).
3. Dig pit. Keep sides straight and unheaved.
4. Pick back the pit face to remove smears and reveal undisturbed soil.
5. Feel—make a mental note of how the soil feels as you clean the face of the pit.
6. Sketch the soil profile and the location of the pit in the paddock and finish Section 1 of the description sheet.

7. Observe surface features (Section 2).
8. Give your first impressions of soil suitability for root growth (Section 3).
9. Work through Section 4 of the soil description sheet.
10. Collect samples where the SOILpak scoring was carried out.
11. Carry out the ASWAT test on these soil samples.
12. Send away some of the soil to a NATA-certified testing laboratory.
13. When the results are sent back by the laboratory, complete Section 4 of the description sheet.
14. Fill in the conclusions (Section 5) to summarise the results.
15. Make recommendations (Section 6) and develop management strategies based on your findings.

Table C2-1. Checklist of implements and reagents to have on hand before commencing soil assessment in the field

Implement/reagent	Use
spade	Moisture probing, examining features close to the surface over more of an area than just a pit, and for removing loose soil at the top and edges of a soil pit.
pry bar	For use in very hard dry soil.
auger	Quick soil moisture probing.
strong knife /screwdriver /trowel/chisel/asparagus knife (depending on preference)	For cleaning the face of a pit from smear marks and to remove clods for examination.
small pointed knife	To expose structural features.
SOILpak soil description sheets, clip-board and pens	For recording observations.
tape measure or ruler	For depth recording.
several litres of distilled water or rain-water	Texture and dispersion tests.
steel frame (20 cm x 20 cm x 10 cm), white acrylic paint, diluted and transported in 4-litre fuel cans	Highlighting of continuous vertical macropores.
hand lens	To examine microstructure.
petri dishes	For carrying out dispersion and lime test.
dilute hydrochloric acid	To test white nodules for lime.
hydrogen peroxide	To test black nodules for manganese (Mn).
towel	For cleaning gear.
plastic bags, labels and rubber bands	For collecting soil samples.
Munsell colour chart (not essential)	For determining soil colour.
camera (not essential)	Permanent recording of features.

C3. Soil moisture (before tillage), soil texture and available water



PURPOSE OF THIS CHAPTER

This chapter explains how to estimate soil water content before tillage and also how to estimate the texture and available water of your soil.

CHAPTER OVERVIEW

The following points are covered:

- why you should determine soil moisture status before tillage
- ways of estimating soil moisture in the paddock:
  —plant symptoms and weather
  —moulding in the hand
  —other methods
- how to estimate soil texture by hand
- decisions to be made from texture observations
- available soil water.

SOIL MOISTURE AND TILLAGE

As the water content of a soil changes, the consistency of the soil goes through a series of different states (Figure C3-1). Tillage at the wrong water content is likely to degrade soil structure.

Vigorous tillage operations on red earths and red-brown earths when the surface soil is dry and brittle will cause it to be pulverised, creating dust. If you are creating a large dust cloud as you cultivate, the soil is too dry. However, dry tillage of compacted clay-rich subsoil is likely to be beneficial. Clay-rich soil is less prone to dust formation than silty soil.

When cultivating duplex soil (soil with a loamy or silty topsoil overlying a clay-rich subsoil), aim to thoroughly dry the whole profile and then wait for approximately 30 mm of rainfall to moisten the topsoil so that dust formation is minimised.

The plastic limit (PL) is the water content (by weight) above which a soil becomes plastic (can be remoulded). The plastic limit depends on both the amount and type of clay and the amount of organic matter in the soil. It occurs between field capacity (FC) and permanent wilting point (PWP). Plastic soil is good for making roads, earth dams and earthenware pots—but not seed beds.

Tillage when the soil is too wet will cause the soil to smear and compact. This is true for both loamy soil and clay-rich soil. The resulting high strength of the soil will hinder seedling emergence and root growth. Soil that has been smeared or remoulded is more likely to disperse in water than undisturbed soil.

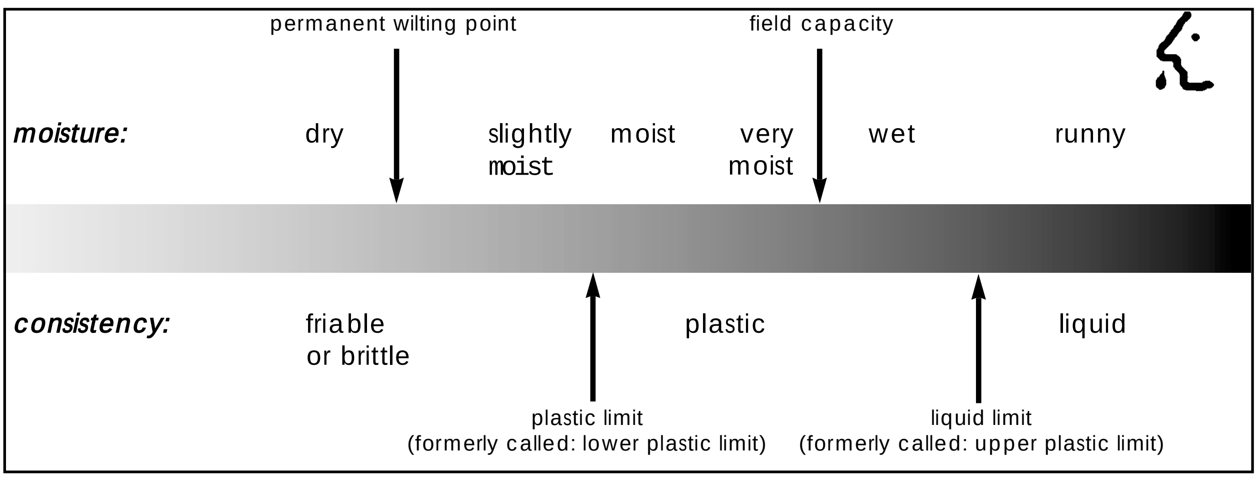
The liquid limit is the water content above which the soil starts to flow like a liquid. Liquid soil is called a slurry and is good for face-packs and filling cracks in a wall.

A water content slightly drier than the plastic limit is best for tilling the soil. That is not to say you should never till a soil that is wetter than the plastic limit, but you should disturb that soil as little as possible.

The deeper you till, the more important it is for the soil to be at this optimum water content through the full depth of tillage (and deeper).

The following section discusses methods to determining soil moisture when you are considering tillage operations.

Figure C3-1. Soil moisture and consistency



WAYS OF DETERMINING SOIL WATER CONTENT

Plant symptoms and weather

Plant symptoms and weather can be used to predict the moisture status of your soil.

If your previous crop was at or near the permanent wilting point at harvest and there has not been any subsequent rain, your soil should be at or below the plastic limit (Figure C3-1). Most crops will dry soil in the root zone (where roots are active) to a similar soil water content. The depth to which the different species can extract moisture does vary.

In some cases plant symptoms are not a good indicator of the moisture status of your soil. On sodic clay soil types (soil with high contents of exchangeable sodium) plant symptoms such as wilting may indicate that the soil is dry. However, soil moisture may still be in the moderately moist range even though the moisture is not available to plants. Hence such a soil is moist enough to smear if tilled. This will also occur when the soil is saline.

Deep cracking in a clay soil that shrinks and swells indicates that the water content of the soil is below the plastic limit. The red soil of the Central West does not show significant cracking in the topsoil.

Using plant symptoms and weather to determine soil moisture

Advantages:

- Simple observations of crop and weather.

Cautions:

- Rain subsequent to crop ripening will make this method unreliable.
- Be careful on sodic soil.

Moulding of soil samples in the hand

Moulding freshly collected soil from the various sampling depths indicated on the SOILpak soil description sheets into a ball in your hand will allow you to estimate closeness of the soil water content to the plastic limit.

Attempt to roll it into rods with a diameter of 3 mm (Figure C3-2). Roll it out on a flat surface (e.g. a plastic covered book) using a firm pressure and try to shape it into a rod. Do not work the soil in your hands too long, as the heat of your hands will dry it and it will no longer be at the field water content.

The moisture status of the soil is classified as dry, at the plastic limit (PL), or wet. It gives only a rough guide to soil consistency and suitability for tillage.

- Dry soil does not make a ball when squeezed in the hand, and fragments into powder or smaller fragments (at or drier than wilting point, and at nil available water). Rods cannot be formed.
- At the plastic limit, clay loam and clay soil forms a crumbly ball but just fails to make a rod of 3 mm diameter.
- Moist soil forms a ball on squeezing in the hand but does not ribbon unless high in clay. Clay loam and clay soil can be rolled into a rod with a diameter of 3 mm. Wet soil feels sticky and leaves a wet outline on the hand when squeezed.

Figure C3-2. 'Closeness to plastic limit' determination using the rod test

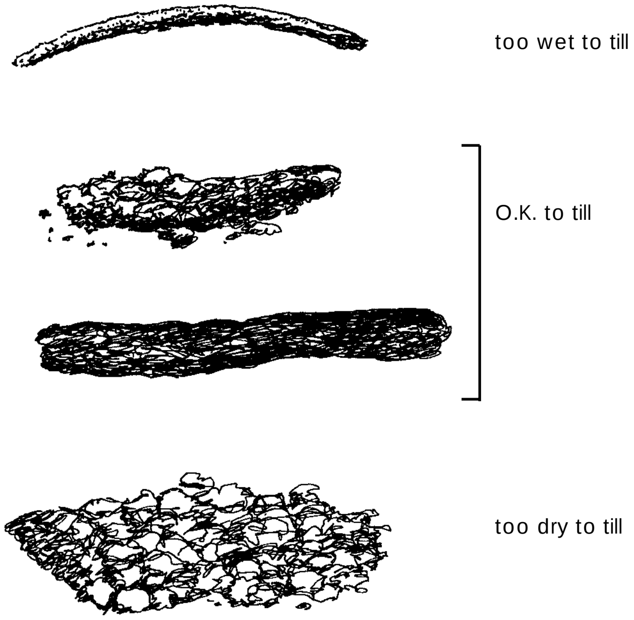


Table C3-1. Guide for assessing soil moisture status

Soil moisture status	Sands, sandy loams	Loams	Clay loams, clays
Dry	Will flow through fingers, or fragments will powder.	Will not ball when squeezed in hand. Fragments will powder.	Will not ball when squeezed in hand. Fragments will break to smaller fragments or peds.
Plastic limit	Does not form a ball or rod. Fragments do not powder.	Does not form a ball or rod. Fragments do not powder.	Will ball. Will not ribbon. Just fails to make 3 mm rod.
Moist	Appears dry. Ball will not hold together.	Forms crumbly ball on squeezing in hand.	Will ball. Will not ribbon. Will form a rod of 3 mm diameter.
Very moist	Forms weak ball, but breaks easily.	Will ball. Will not ribbon.	Will ball. Will ribbon easily.
Wet	Ball leaves wet outline on hand when squeezed, or is wetter.	Ball leaves wet outline on hand when squeezed, or is wetter. Sticky	Ball leaves wet outline on hand when squeezed, or is wetter. Sticky.

Source: adapted from McDonald et al., 1990.

Table C3-1 can be used to assess soil moisture status.

The potential of clay-rich soil to be damaged through remoulding is great when the soil is wetter than the plastic limit, and low when the soil is drier than the plastic limit. Loam soil can be damaged when tilled at water contents much drier than the plastic limit because of dust formation. The texture of the topsoil of red earths and red-brown earths means that there is a very narrow window of soil water contents that are suitable for tillage. This is why red soil is often called 'Sunday soil', i.e. too wet for tillage on Saturday, too dry on Monday.

Figure C3-3. Guide for assessing soil moisture status by hand—summary of method

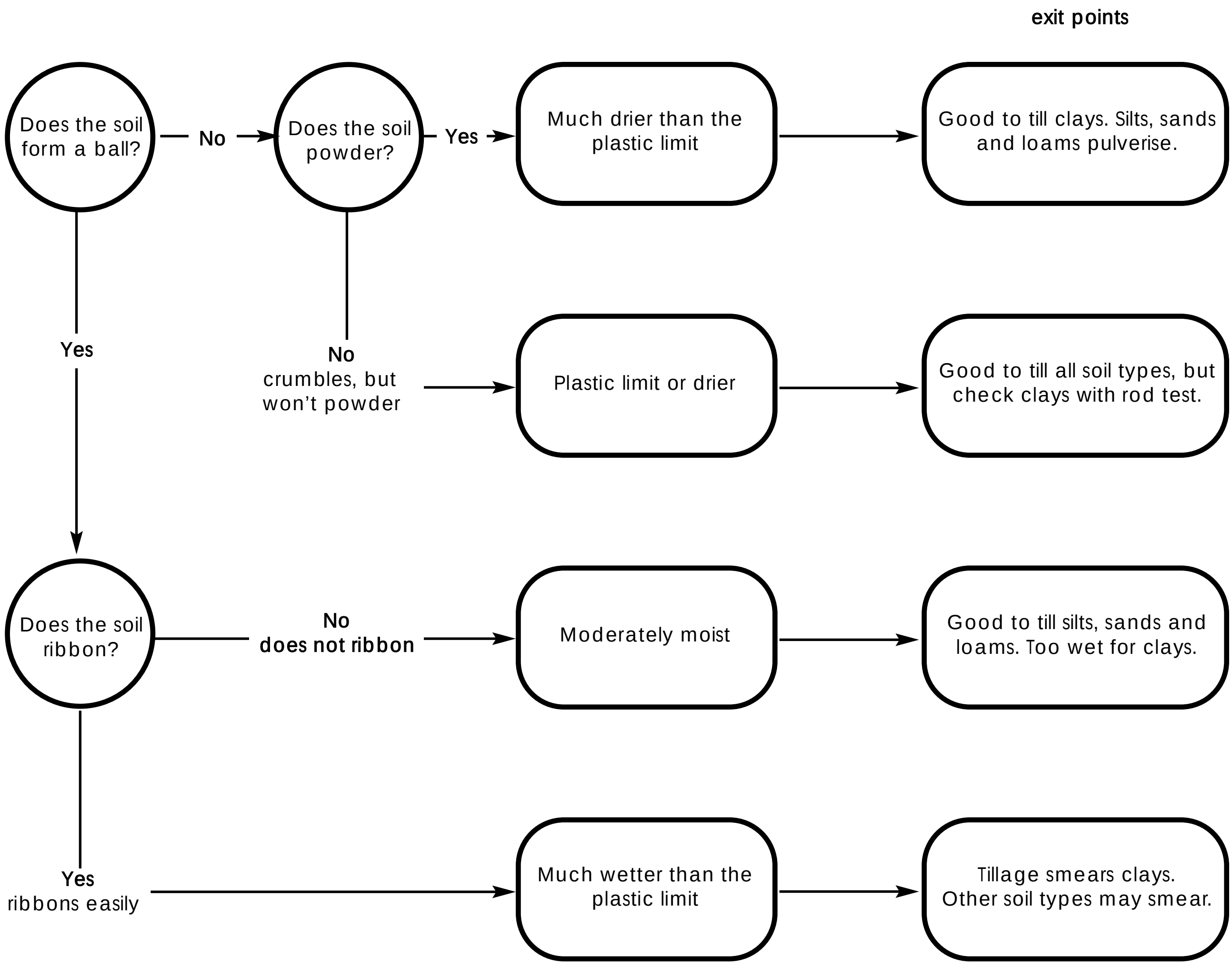


Figure C3-3 summarises how to assess the soil moisture status of a soil by hand. It also indicates when it is good to till different types of soil, based on soil moisture status.

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See Chapter C9 for more information on precise methods for measuring soil water content.

Other methods

Other methods for measuring soil water content include soil sampling and weighing and moisture probes such as neutron probes.

DETERMINING SOIL TEXTURE

Field texture is a measure of the proportions of gravel, coarse sand, fine sand, silt and clay in the soil. Gravel is soil material greater than 2.0 mm in diameter and is removed when determining the texture of a soil in the laboratory.

Texture measurements need only be done once at any particular sampling point because it is a soil property that changes only very slowly over time. Operations such as deep tillage that invert the soil may expose subsoil, therefore changing surface texture. Subsoil exposure by tillage or erosion in a red-brown earth will cause surface texture to become more clay-rich.

Texture of the soil surface strongly influences the structure of surface layers. This affects:

- seedling emergence
- water infiltration
- water holding capacity
- trafficability
- ease of tillage.

Compared to loams, clays tend to be less prone to hardsetting (which causes water infiltration and seedling emergence problems), and hold more nutrients. However, clays are more likely to have poor aeration and poor workability and trafficability after rain. Non-sodic clay soil surfaces develop a porous, crumbly (self-mulching) surface.

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) and then pressed out between the thumb and forefinger to form a ribbon. The ball formed is called a 'bolus'.

Take a sample of soil sufficient to fit comfortably into the palm of your left hand (if you are right-handed). Moisten the soil with water, a little at a time, and work it until it just fails to stick to your fingers. This is when its water content is approximately at 'field capacity'.

Continue moistening and working until there is no apparent change in the feel of the bolus (usually 1–2 minutes). When the bolus has been worked and is at the right moisture content (soil should not stick to your hand), transfer the bolus to your clean (right) hand to feel the soil and form a soil ribbon. This method is shown in Figure C3-4.

The behaviour of the worked soil and the ribbon produced by pressing out between thumb and forefinger characterises the texture. Use Table C3-2 to determine soil texture in the field.

The moisture of the sample will influence the length of the ribbon formed. Be careful not to knead the ball for too long as it will dry out. Re-wet to field capacity if it reaches this point.

It is easy to determine if there is sand in the soil by working the bolus while holding it close to your ear. You will be able to hear the sand grains rubbing against one another. If the bolus feels very silky then there is a high level of silt present. A high clay content will make the bolus very firm and difficult to squeeze.

Decisions to be made from texture observations

Structure and salinity assessment

Texture measurements are used to separate loams (less than 35% clay) from clays (more than 35% clay) for structure assessment (see

Figure C3-4. Determining field texture

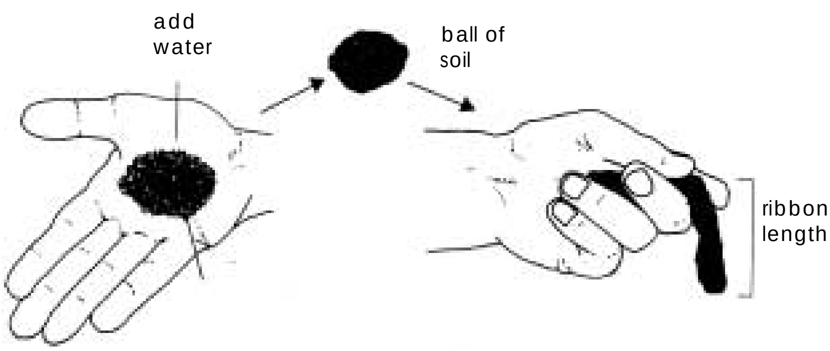

Table C3-2. Behaviour of moist bolus for texturing soil

Field texture grade	Behaviour of moist bolus	Approximate clay content (%)
sand	Coherence nil to very slight, cannot be moulded; sand grains of medium size; single sand grains adhere to fingers.	commonly less than 5%
loamy sand	Slight coherence; sand grains of medium size; can be sheared between thumb and forefinger to give minimal ribbon of about 5 mm.	about 5%
clayey sand	Slight coherence; sand grains of medium size; sticky when wet; many sand grains stick to fingers; will form a minimal ribbon of 5–15 mm; discolours fingers with clay stain.	5–10%
sandy loam	Bolus coherent but very sandy to touch; will form ribbon of 15–25 mm; dominant sand grains are of medium size and are easily visible.	10–20%
loam	Bolus coherent and rather spongy; smooth feel when manipulated but with no obvious sandiness or 'silkiness'; may be somewhat greasy to the touch if much organic matter is present; will form ribbon of about 25 mm.	about 25%
silty loam	Coherent bolus; very smooth to often silky when manipulated; will form ribbon of about 25 mm.	about 25% and with silt 25% or more
sandy clay loam	Strongly coherent bolus, sandy to touch; medium size sand grains visible in finer matrix; will form ribbon of 25–40 mm.	20–30%
clay loam	Coherent plastic bolus, smooth to manipulate; will form ribbon of 40–50 mm.	30–35%
clay loam, sandy	Coherent plastic bolus; medium size sand grains visible in finer matrix; will form ribbon of 40–50 mm.	30–35%
silty clay loam	Coherent smooth bolus, plastic and often silky to the touch; will form ribbon of 40–50 mm.	30–35% and with silt 25% or more
light clay	Plastic bolus; smooth to touch; slight resistance to shearing between thumb and forefinger; will form ribbon of 50–75 mm.	35–40%
light medium clay	Plastic bolus; smooth to touch; slight to moderate resistance to ribboning shear; will form ribbon of about 75 mm.	40–45%
medium clay	Smooth plastic bolus; handles like plasticine and can be moulded into rods without fracture; has moderate resistance to ribboning shear; will form ribbon of 75 mm or more.	45–55%
medium heavy clay	Smooth plastic bolus; handles like plasticine; can be moulded into rods without fracture; has moderate to firm resistance to ribboning shear; will form ribbon of 75 mm or more.	50% or more
heavy clay	Smooth plastic bolus; handles like stiff plasticine; moulded into rods without fracture; has firm resistance to ribboning shear; will form ribbon of 75 mm or more.	can be 50% or more

Source: McDonald et al., 1990.

Chapter C4). They allow $EC_{1:5}$ data to be converted to EC_e in salinity investigations.

Generally, the higher the clay content the smaller the amount of water that drains through the soil. However, good soil structure overcomes the potential for poor internal drainage in a heavy clay.

Available water

The texture of the soil also affects the water holding capacity and internal drainage of the soil.
There are three categories of stored soil water:

- ‘readily available water’ (water held between ‘field capacity’ and ‘refill point’, the point at which plants begin to have problems extracting soil water)
- ‘plant available water’ (water held between ‘field capacity’ and ‘permanent wilting point’)
- ‘unavailable water’ (water stored in very small pores that cannot be extracted by plant roots).

The amount of ‘unavailable water’ in the soil tends to become greater as clay content increases.

Texture assessment will give you a crude estimate of soil water holding capacity. Loams (sometimes with more than 180 mm ‘plant available water’ per metre of soil) tend to have more available water than clay-rich soil (120–180 mm/m; sometimes greater in self-mulching clay) and sandy soil (less than 120 mm/m). To obtain accurate data about available soil water, however, it is necessary to measure soil water holding capacity in a laboratory equipped with pressure plates. Calculation of ‘readily available water’ requires field measurements with a moisture probe.

To provide a check on the accuracy of the field estimates of soil texture, some of the samples should be sent to an accredited Soil Physical Testing Laboratory for a more precise particle size analysis (PSA).

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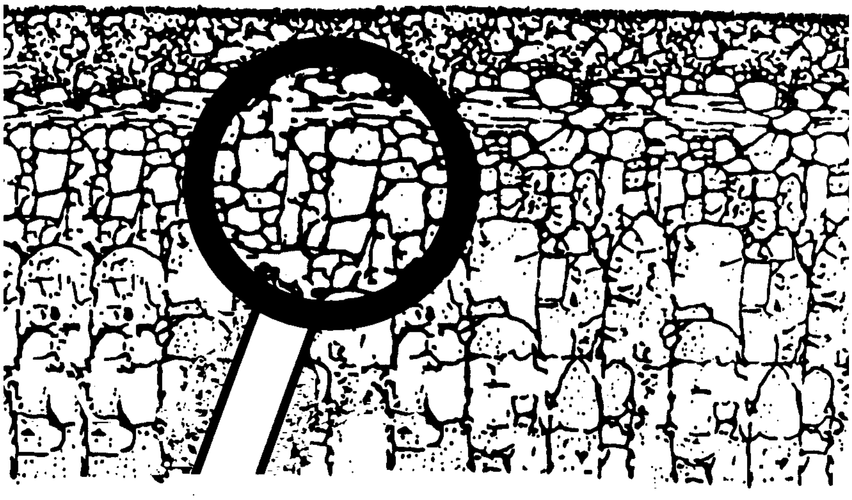
See Chapter C9 for more information on readily available water, calculating the refill point, and plant available water.

C4. Soil structure assessment



PURPOSE OF THIS CHAPTER

This chapter explains how to assess and interpret soil structural condition using information from the paddock and the laboratory.

Three distinct aspects of soil structure need to be considered:

- degree of compaction (structural form)
- stability of the soil in water (structural stability)
- regeneration potential of a soil after it has been compacted (structural resilience).

CHAPTER OVERVIEW

The following points are covered:

- observations in the paddock and laboratory tests
- making a decision about soil physical fertility
- conclusions and management options.

Other chapters to refer to:

- Chapter C1: 'Soil pit digging: where, how and when?'
- Chapter C2: 'Features of the SOILpak soil description sheet'.

INTRODUCTION

Soil structure is the arrangement of pore space and solid material in the soil. A cropping soil should have a structure with not only fine pores but also larger pores and cracks that are continuous from the surface with the subsoil. Soil structure influences infiltration, redistribution of water, aeration, available water, the non-limiting water range, seedling emergence, root growth and heat transport within the soil.

The aim of this chapter is to explain the methods available for observing soil structure in a pit (dug with a backhoe or spade) and laboratory methods that give information about soil structure. The three distinct aspects of soil structure mentioned above (structural form, stability and resilience) are considered.

Record your observations on the SOILpak soil description sheets provided (Appendix 6) where indicated.

Compare your results to the given 'critical limits' and make land management decisions for the next stage of your farming operation.

DEGREE OF COMPACTION/REMOULDING AND HARDSETTING

Compaction of a soil causes its bulk density to increase; whereas remoulding involves rearrangement of soil pores without an increase in bulk density of the soil. Both processes can restrict the root growth of plants by increasing soil strength when it is dry and by reducing aeration when the soil is wet. Compaction and remoulding can extend from the soil surface to depths below the cultivated layer.

Field signs

Surface condition

Surface condition can give broad clues about structural condition and associated factors.

Features of the surface of the soil which indicate soil structure problems are:

- large clods (diameter greater than 2 cm)
- crusting
- wheel tracks covering a large percentage of the paddock
- a smooth scald surface (a scald).

Other surface features that are important include surface cover (type and percentage cover) and signs of erosion.

Surface features will have a bearing on the kind and number of tillage operations needed—for example large clods may need another cultivation to produce a fine seed bed. Surface condition may affect sowing rates and herbicide rates.

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See Chapter C6 for more information on stubble.

Root shape

To assess soil suitability for root growth, dig up 10 plants (preferably taprooted plants or weeds) across the main direction of traffic and determine the proportion of malformed roots (Figure C4-1). Also examine root growth in the soil pit in relation to soil structure.

Deformed roots may indicate a hard layer. If bent roots are present in any layer of soil be especially careful to look for evidence of compaction (e.g. platy clods) or remoulding in the root zone.

Bent or branching roots do not automatically indicate a hard layer.

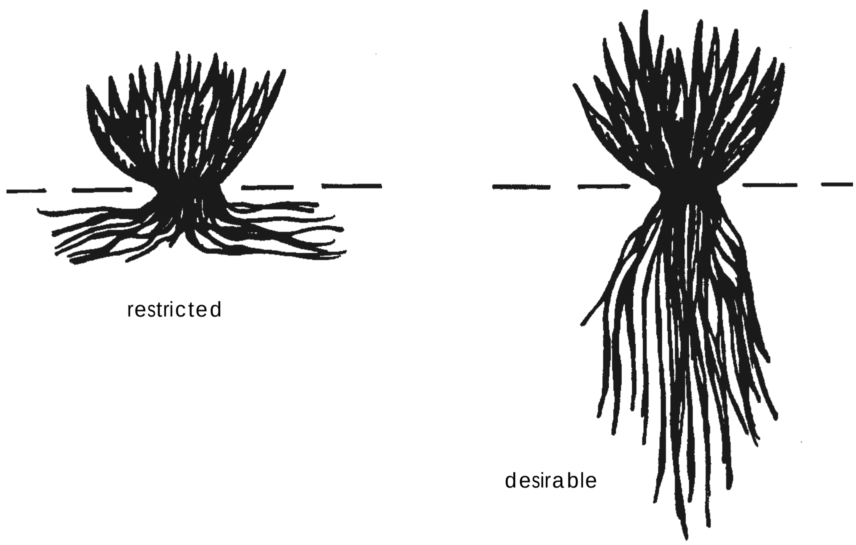
Bent or branching roots do not automatically indicate a hard layer. Roots may bend or branch in response to nutrients or water availability. During very wet seasons, water is readily available in the surface layers, and the plants have little need to develop deep roots. In dry seasons, roots may have been unable to develop because only the surface soil layer was moist. Also acid sensitive crops such as canola can have restricted root growth due to acidic layers in the soil.

Bent roots caused by compaction in one season do not necessarily mean that compaction will be present or will be bad in the following season, i.e. the crop with the bent roots may have partly restored soil structure.

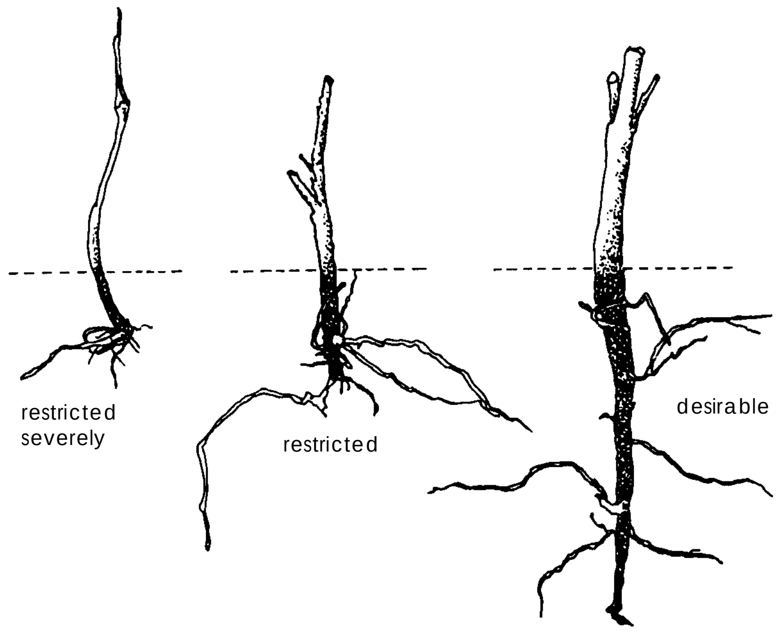
Wheat has a fibrous root system, therefore making it harder to determine if root growth is restricted. If your soil is hardset or compacted these roots will most likely be concentrated in the topsoil. If growth is restricted by poor structure, the roots tend to be in a small lump and matted together at the interface of the compacted and surface soil layers.

Figure C4-1. Root shapes of young fibrous rooted and taprooted plants, following compaction

Fibrous root system



Tap root system



Tiller number and other indicators of moisture stress

Moisture stress can be a result of compaction. There is no one indicator of moisture stress in wheat and other dryland crops. The wheat plant has great ability to compensate, and the effect of moisture stress on grain yield depends on when the stress occurs.

Early moisture stress often shows up as reduced tillering. Other factors also influence tiller number, such as time of sowing, plant density, disease, soil nutrition and grazing pressure. Later in crop development moisture stress reduces the number of grains per head and finally, grain size.

Like root shape, tiller numbers can aid in the diagnosis of compaction. A combination of the two (bent roots and few tillers) indicate a need to look carefully at the SOILpak scores (low scores indicating compaction and poor soil structure).

SOILpak 'degree of compaction/remoulding and hardsetting' score

The SOILpak scoring system is a semi-quantitative system of assessing structural form. Each structural factor is scored on a scale of 0 to 2, with 0 being the worst score and 2 being the best score. A soil with an overall score greater than 1.5 has relatively good structure while a soil with a score less than 0.5 has a compaction or hardsetting problem and methods to improve it should be implemented.

Determine the SOILpak score at depths of 0–10, 15–25, 40–50 and 70–80 cm (and at other appropriate depths if required) under a representative plant line. You should do this at a few sites if a controlled traffic management strategy is not in place in order to get an average score. These depths represent the midpoints of the topsoil, subsurface soil, upper subsoil and mid subsoil.

To obtain a score, carefully excavate and then dismantle, using gentle hand pressure, a sample of soil with dimensions of approximately 75 mm high, 75 mm wide and 75 mm deep.

Beginners can give each soil sample one of five scores—0.0, 0.5, 1.0, 1.5 or 2.0. More advanced users of the scoring system can subdivide the score further (as many as 20 subdivisions). The meanings of the scores, in simple terms is as follows:

- 0 = terrible
- 0.5 = poor, but not the worst I have seen
- 1 = moderate
- 1.5 = good, but not the best I have seen
- 2 = excellent.

If the soil is firm, refer to Table C4-1 to determine its SOILpak score. If the soil is loose (like the topsoil after cultivation), refer to Table C4-2.

On the description sheet (Section 4a), note the score for each of the listed soil factors (SOILpak score components) then calculate their average (fill in the 'average component value' on the description sheet). In most cases, the scores for a particular sample match up well and an average value is easily calculated. Note that three of the listed factors are disregarded if the clay content, estimated by texturing, is less than 35%.

If, however, one of the values deviates greatly (by more than 0.3) from the other component scores, use the following equation for contradictory scores, to determine the ‘average component value’. The equation contains ‘weighting factors’, which indicate the relative importance of each factor.

The ‘average component value’ is adjusted to obtain the final ‘SOILpak score’, if necessary, according to the presence or absence of the following ‘over-ride factors’:

- inter-connected pores from the soil surface
- thin smeared layers
- abrupt texture change within layers
- excessive dust (loams)
- surface crusting/hardsetting.

More information about these ‘over-ride factors’ is given later in this chapter. If there are no ‘over-ride factors’ then the ‘average component value’ is equal to the final ‘SOILpak score’.

This procedure appears complicated at first, but it soon becomes second nature and fast. A simpler procedure would give inaccurate results (too prone to bias), invalidating comparisons of soil structure over time.

An equation to deal with contradictory scores

Usually there is strong agreement between scores for each of the evaluated factors. However, sometimes the score for one factor for a particular sample of soil contradicts the score for another factor (i.e. differs by a value more than 0.3). For example, the score for ‘clod width’ may be 1 while the score for ‘fresh roots’ is 1.5. Under such circumstances it is necessary to use an equation (see below) where each of the factors is given a weighting according to its priority. The weighting factors are shown in Tables C4-1 and C4-2.

The equation can still be used if one of the listed factors is unavailable at a particular site, for example where fresh root behaviour cannot be included in an investigation. An example of the scoring procedure is shown in Table C4-3.

$$\text{SOILpak Score} = \frac{(S^1 \text{ x } W^1) + (S^2 \text{ x } W^2) + .. + (S^8 \text{ x } W^8)}{(W^1 + W^2 + ... + W^8)}$$

Where:

S = score, on a scale of 0.0 to 2.0, for each of the factors that can be considered

W = weighting allocated to each of the factors, in Table C4-1

For loose soil, see Table C4-2, a five-factor equation is used.

The likely biological significance of each factor contributing to the SOILpak score is presented in Table C4-4.

Table C4-1. SOILpak scoring procedure in firm soil[A]
NOTE: In loamy soil (clay content less than 35%), ignore factors 2, 5, and 8.

Factor—listed in descending order of importance	Weighting in equation	SOILpak score component		
		Firm 0.0 (poor structure)	**Firm 1.0 (mod. structure)**	**Firm 2.0 (good structure)**
MOIST SOIL[B]				
(1) Width of primary clods[C] produced by moderate hand pressure (see Figure C4-2).	**8**	Mostly > 50 mm wide.	5–50 mm wide.	Mostly < 5 mm wide.
(2) Ease of breakage of soil sample.	**7**	Difficult for spade or knife to penetrate; soil made up of large tight fitting clods.	Moderate hand pressure needed to part the component clods.	Parts readily into porous component clods.
(3) Behaviour of fresh roots.	**6**	Very few fresh roots, if a crop is growing, or soon after harvest.	Medium number of fresh roots, but concentrated between aggregates.	Prolific growth of fresh roots throughout the sample.
(4) Shape of clods produced by moderate hand pressure (see Figure C4-2).	**5**	Platy or conchoidal[D].	Mixed shapes.	Polyhedral or sub-angular blocky.
(5) Features of fracture faces.	**4**	Breakage, along the lines of force applied in any direction, into units with sharp corners; internal surfaces with no projecting sub-clods.	Some natural separation planes with shiny faces, but with most fracturing taking place along the line of applied force to produce angular corners and smooth, dull internal surfaces.	Natural fracture planes dominate; most of the faces are smooth and shiny, although often there are protruding, multi-faced subangular units.
(6) Proportion of primary clods within the compound clods, produced by rolling the compound clods between thumb and forefinger.	**3**	Less than 1/3 of the breakdown products are shiny faced aggregates.	1/3–2/3 of the breakdown products are shiny faced aggregates.	More than 2/3 of the breakdown products are shiny faced aggregates.
(7) Internal porosity of primary clods (see Figure C4-3).	**2**	0%	0.5%	>5%
(8) Approximate colour of the interior of primary clods (use Munsell Colour chart as a guide).	**1**	Yellowish, may be mottled.	Light grey, slightly brown.	Black, dark grey, or reddish brown.
EXTRA NOTES FOR DRY[B] SOIL				
		Requires a very strong blow with a heavy implement to break the compound clods, revealing smooth, dull surfaces with angled corners; flinty.	As above for factor 2, but more force (hard hand pressure) needed to part the compound clods.	Falls apart with light hand pressure to produce small primary clods.

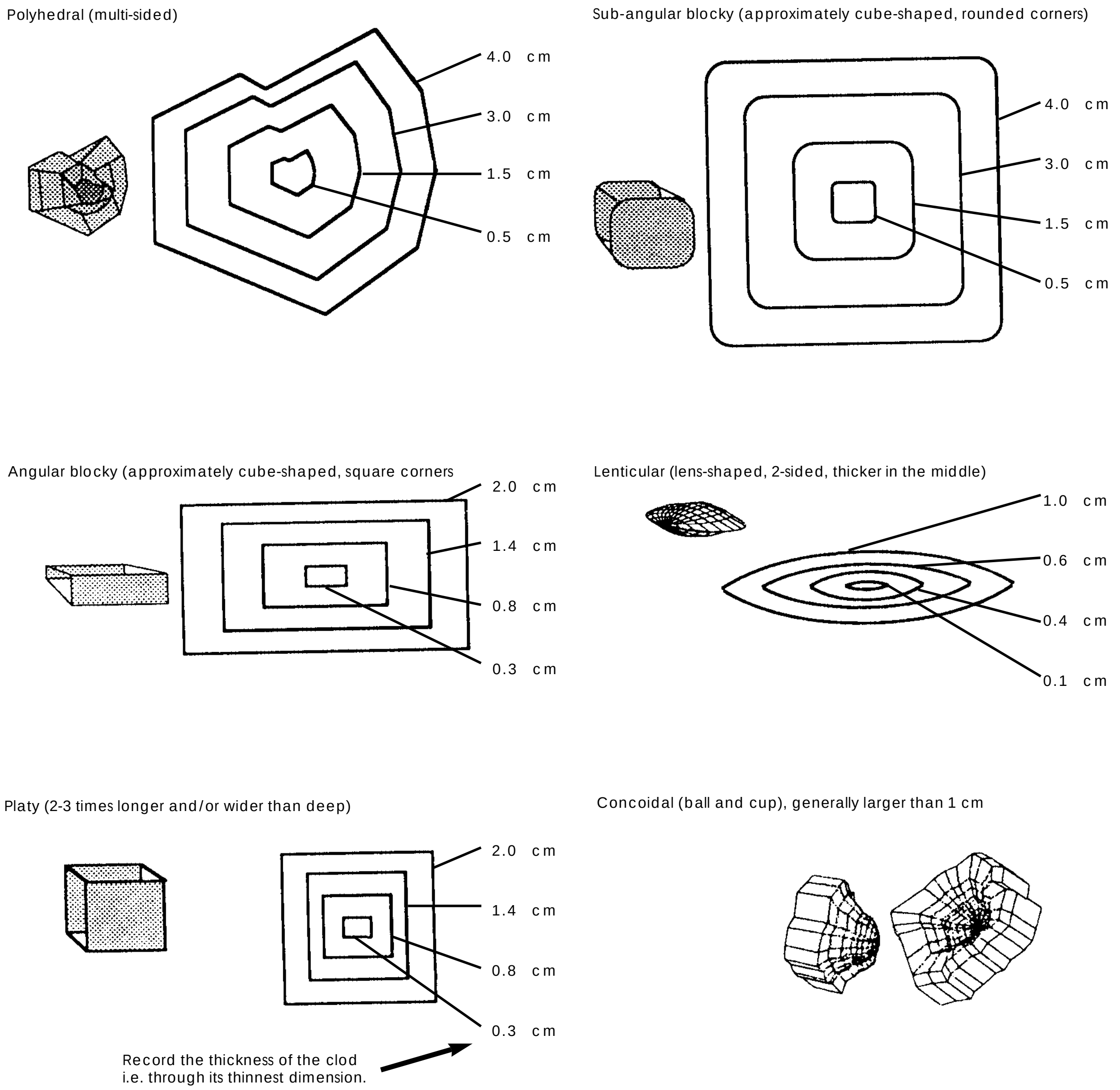
[A] ‘Firm soil’ is defined as soil below the tilled layer or below the natural loose mulch. It has aggregates that fit together along faces, which usually require at least gentle hand force to lever apart. It may also be found at the surface in association with crusting.

[B] ‘Moist’ soil is defined as having a water content between ‘wilting point’ and ‘field capacity’. ‘Dry’ soil is defined as having a water content less than the wilting point.

[C] The term ‘clod’ refers to soil aggregates/lumps/fragments/peds that have been modified in any way by the activities of farmers. ‘Compound clods’ are clusters of smaller ‘primary clods’ (also referred to as ‘microaggregates’).

[D] ‘Ball and socket’ appearance.

Figure C4-3. Common clod sizes and shapes



Natural: polyhedral, sub-angular blocky (and lenticular and angular blocky, if small and faces are shiny).
Signs of demage: platy, concoidal, massive (and, lenticular and anular blocky, if large and faces are dull.

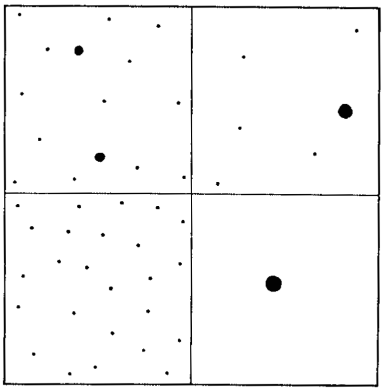
Table C4-2. SOILpak scoring procedure in loose soil[A]
NOTE: In loamy soil (clay content less than 35%), ignore factor 2.

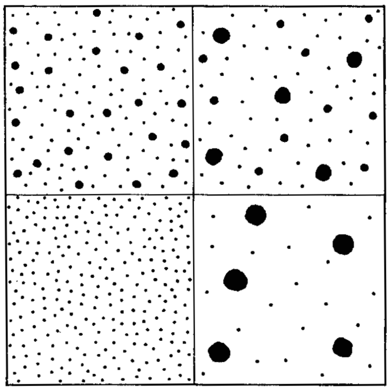
Factor—listed in descending order of importance	Weighting in equation	SOILpak score component: Loose 0 (poor structure)	Loose 1.0 (mod. structure)	Loose 2.0 (good structure)
***MOIST SOIL*[B]**				
(1) Clod size (see Figures C4-2 and C4-4).	**5**	Diameter usually > 20 mm or < 0.5 mm (dusty).	Diameter usually between 5 mm and 20 mm.	Diameter usually 1–5 mm.
(2) Ease of breakage.	**4**	Difficult to break.	Can be parted by moderate hand pressure into smaller clods.	Separates very easily into smaller clods.
(3) Clod shape (see Figure C4-2).	**3**	Angular blocky with sharp edges, or conchoidal.	Mixed shapes.	Polyhedral or sub-angular blocky.
(4) Proportion of primary clods within the compound clods, produced by rolling the compound clods between thumb and forefinger.	**2**	Less than 1/3 of the breakdown products are shiny faced aggregates.	1/3–2/3 of the breakdown of products are shiny faced aggregates.	More than 2/3 of the breakdown products are shiny faced aggregates.
(5) Internal porosity of primary clods (see Figure C4-3).	**1**	0%	0.5%	>5%
EXTRA NOTES FOR DRY*[B] *SOIL				
		A large proportion of large, difficult to break flinty clods with sharp edges.	As above, but compound clods will be firmer; some will be flinty.	As above.

[A] ‘Loose soil’ is defined as loose seedbed, loose tilled layer (even if cloddy), loose surface mulch; soil that can be removed by scraping (not digging) with the hand, a trowel or a spade. Very loose soil may be found at depth in association with salinity, which promotes fine aggregation.

[B] ‘Moist’ soil is defined as having a water content between ‘wilting point’ and ‘field capacity’.
‘Dry’ soil is defined as having a water content less than the wilting point.

Figure C4-2. Clod internal porosity reference chart.





Source: Hodgson (ed.), 1997

Dealing with unusual circumstances—the use of 'over-ride factors'

Where the piece of soil has been given a SOILpak score of less than 1.5, but the layer that it comes from has at least two continuous vertical lines of weakness from the soil surface—e.g. root, worm, ant, termite channels (macropores) or old crack lines—that could be used by crop roots to bypass hard or anaerobic layers of soil, the score for that layer is upgraded by 0.5 units. The application of a white paint solution (see below) will highlight such features.

If a continuously smeared horizontal layer with a thickness greater than 5 mm is observed within the layer under consideration, down-grade the SOILpak score to 0.5 if it is above 0.5.

The presence of a sharp or abrupt texture change within a layer (boundary width < 2 cm) may impede root growth and water movement; if evident, downgrade the SOILpak score to 1.0 if it is above 1.0.

For light-textured soil (clay content < 35%), downgrade the SOILpak score to 1.0 (if it is above 1.0), if there is evidence of excessive dust (> 30% powdery soil).

Where there is a surface crust on the surface soil layer with a thickness greater than 5 mm, down-grade the SOILpak score of the topsoil to 1.0 if it is above 1.0. If hardsetting is obvious in any of the soil layers, also downgrade the SOILpak score to 1.0 if it is above 1.0.

Use of white paint to highlight continuous vertical channels connected to the soil surface

Various types of dyes and tracers have been used to highlight soil pores. One very suitable tracer is a diluted white acrylic paint, which contrasts well with dark coloured soil. The following technique can be used to trace inter-connected pores in horizontal sections of soil. It is based on procedures developed by the University of Sydney and CSIRO Land & Water, Canberra.

1. Prepare the surface

A level area of soil is cleared at the top of the layer under consideration (usually just the soil surface). Smearing on this surface is removed using a simple technique of picking the surface with a shovel or knife to expose a natural ped surface. The exposed area is then carefully cleaned of loose fragments with a soft brush.

An open-ended square steel frame (approximately 40 x 20 cm) with tall sides (approximately 10 cm) is placed carefully over the soil

Figure C4-4. Contrasting clod size in loose surface soil

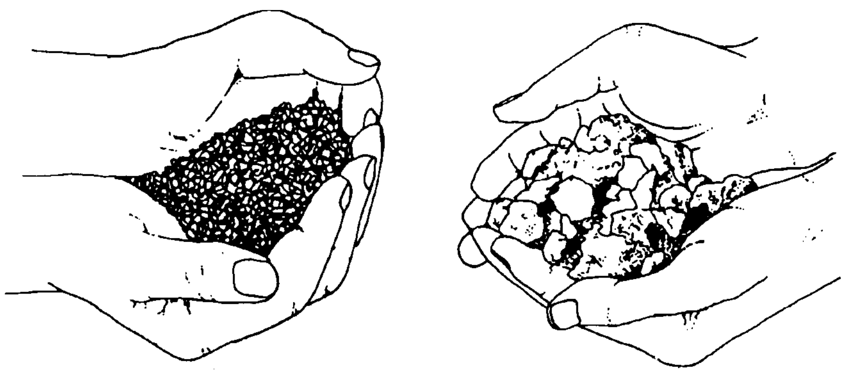


Table C4-3. An example of the SOILpak score scoring procedure that is used when the score for a particular sample of soil (with the dimensions 75 x 75 x 75 mm) contradicts the score for another factor (difference > 0.3). The soil under consideration is firm and dry.

Factor	Score	Weighting in equation 6.1 (A)	Score x weighting (B)
1. Width of primary clod	0.4	8	3.2
2. Ease of fracture	0.4	7	2.8
3. Fresh root behaviour	–	6*	–
4. Clod shape	0.4	5	2.0
5. Features of fracture faces	0.3	4	1.2
6. Pedality of primary clods	0.5	3	1.5
7. Internal porosity of primary clods	0.0	2	0.0
8. Colour of clod interior	0.5	1	0.5
Totals		30 (A)	11.2 (B)
SOILpak score (B / A)		**11.2 / 30 = 0.4**	

* Not included in total because of missing observation.

Table C4-4. Likely biological significance of the factors listed in Tables C4-1 and C4-2

Soil morphology factor	Biological significance
Clod width.	As clods become wider, taproot obliquity is likely to increase.
Ease of breakage of soil sample.	As clod strength increases, taproots and their laterals, and fibrous root systems will find it increasingly difficult to grow between, and through, the component clods because of poor aeration and/or mechanical impedance.
Clod shape.	As clod platiness increases, taproots are more likely to develop a zigzag pattern as they grow downwards. Platy and conchoidal clods usually are hard and compact, without much scope for entry and exploration by root hairs.
Features of fracture faces.	The incidence of clods with shiny faces appears to be associated with a decrease in the strength of inter-aggregate bonding, and of a decrease in aggregate size, which improves root growth and water movement. Shiny faces are associated with soil that shrinks and swells and become more obvious as the number of shrink-swell cycles increases.
Proportion of primary clods within the compound clods, produced by rolling the compound clods between thumb and forefinger.	The very narrow, but stable, fissures between small, primary clods should allow root hairs to enter compound clods and extract water and nutrients, unlike large, apedal aggregates which do not subdivide easily into smaller components.
Internal porosity of primary clods.	The presence of biopores—e.g. old root and fauna channels—within primary clods should encourage soil exploration by root hairs and aid in available water retention.
Colour of the interior of primary clods.	Poor soil aeration caused by compaction often is associated with a blue tinge. Red and brown colours generally indicate an adequate supply of oxygen for root growth. However, well-structured soil can develop a bluish tinge (sometimes accompanied by manganese nodules) in the presence of a perched watertable. Yellow and pale mottles in a red, brown or darker coloured soil indicates temporary waterlogging (perhaps a result of poor drainage at some time of the year), which adversely affects the root growth of most crops and pasture.

and pushed into the soil a few centimetres (approximately 3 cm). The outside of the frame is then built up with loose soil to prevent leaks occurring.

2. Add the paint

A mixture of white acrylic house paint and water is prepared (approximately 1:7, paint:water, by volume) in buckets and poured carefully into the frame (Figure C4-5) using an object under the flow to prevent direct disturbance of the soil surface. The frame is filled until the soil is ponded by 2–3 cm of paint (approximately 4 L, depending on infiltration rate). The frame is then covered with plastic sheeting to prevent evaporation and left overnight or at least long enough to enable most of the paint to infiltrate.

3. Expose the structure

Once the paint has infiltrated, the frames can be lifted out of the way. Soil at depths of 5 cm (half-way down through the topsoil) and 20 cm (half-way down through the subsurface soil) is exposed by careful excavation with a mattock or hoe to observe how much paint is present. The appearance of paint in a biopore or an old crack line (Figure C4-6) provides definite proof that the macropore was connected to the soil surface.

When this technique was carried out on the topsoil of a red earth near Warren, very fine crack lines, not easily seen, were highlighted by the paint solution.

If a permanent record is required, a thin layer of quick-setting Araldite® is then quickly mixed and spread on the prepared soil surface (approximately 20 x 20 cm). Once hardened, this thin layer is peeled off slowly to expose the structure of a relatively undisturbed surface of the white-paint-stained soil. It may then be photographed, under shade and next to an object of known length.

For more precise investigations, entire soil samples are impregnated with an epoxy resin containing fluorescent dye. After the resin has set hard, the impregnated soil is removed, ground, photographed under standard ultra-violet lights, and assessed using a computer-based image analysis program (SOLICON). Details of this procedure are available from the Department of Agricultural Chemistry and Soil Science, The University of Sydney.

If the soil is more moist than the plastic limit when paint is added, the rate of drop of the paint solution within the steel frame provides a rough indication of soil infiltration rate (how fast water can flow into the soil). Measure how many millimetres the paint solution drops over a 10 minute period and multiply by six to get infiltration rate in mm/hr. As a guide, rates of 0–10 mm/hr for the soil surface are considered very low (lots of runoff during rain storms), rates > 70 mm/hr are very high (runoff unlikely).

Interpretation of SOILpak scores

Table C4-5 describes management options that should be considered (if economically viable) for the full range of SOILpak score data.

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See Chapters D3 and D4 for more information on management options.

Figure C4-5. Pouring a white paint solution into a soil to assess the presence of continuous vertical macropores.

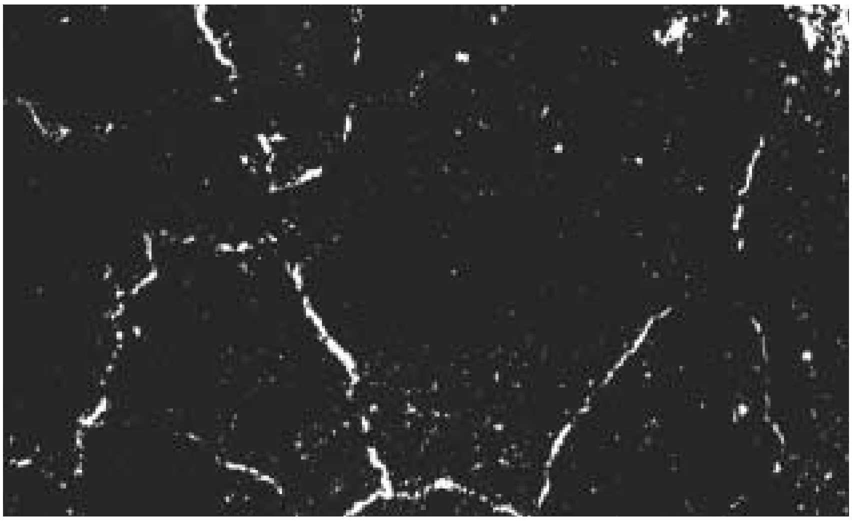

Figure C4-6. Old crack lines and biopores, highlighted by white paint solution.

Other procedures for measuring the severity of soil compaction

Several other procedures are available to measure severity of soil compaction. They are listed briefly in Table C4-6, together with a brief explanation of why they are not recommended for routine use.

STABILITY IN WATER

Slaking and dispersion are indicators of the stability of your soil in water, that is the action of your soil when it is subjected to water. Does your soil maintain its structure in water, or do the clods collapse?

There are two main types of clod collapse when water is added to the soil:

- 'slaking', where large structural units collapse to form microaggregates; and
- 'dispersion', which is a more severe form of structural collapse because when a clod disperses it collapses into individual soil particles (sand, silt, clay).

Dispersion is shown by cloudy water developing around a clod when it is added to water.

Slaking can be a desirable process in terms of structural form regeneration. For example, some cracking clays slake to form microaggregates by the process of self-mulching. This does not lead to serious waterlogging or soil hardness problems. However, this is not the case for the red soil types of Central Western NSW because they have poor shrink-swell potential.

If the microaggregates resulting from slaking disperse to produce the constituent sand, silt and clay, an undesirable massive structure may result. Water and air movement, root penetration and function, and seedling establishment often are affected adversely. The red soil types of Central Western NSW are prone to dispersion. Therefore the risk of soil dispersion should be assessed so that preventative action can be taken.

Table C4-5. Response to the 'degree of compaction' diagnosis

SOILpak score 'critical values'	Compaction severity	Management options to consider
0.0–0.4	severe compaction	Biological drilling and biopore production. Mechanical disruption. Gypsum/lime (if the soil stability tests indicate that structural collapse is at least partly due to sodicity).
0.5–1.5	moderate compaction	Biological drilling and biopore production test strips. Mechanical disruption test strips. Critical N management test strips.
1.6–2.0	negligible compaction	Minimum tillage.

Table C4-6. Alternatives to the SOILpak 'severity of compaction/smearing' scoring procedure

Method	Situations where the method could be used when assessing structure	Drawbacks
1. Penetrometer.	Useful if used immediately before and after a tillage operation, where the soil water content throughout the profile is about the plastic limit. Penetrometers have good depth resolution.	Results need to be corrected for water content —the calibration equations vary from site to site. Penetrometers give misleading results in sticky soil, due to build-up of soil on the cone.
2. Shear vane.	Provides useful reference data at key sites —allows cross-checking of the SOILpak scores.	Results need to be corrected for water content —the calibration equations vary from site to site.
3. Tensile strength of oven-dry clods.	Fast; and can be carried out with cheap equipment. Relates well to friability test results.	Risk of sampling bias in moderately- and well-structured soil.
4. Bulk density cores.	Provides useful reference data at key sites —allows cross-checking of the SOILpak scores, and gives information about air-filled porosity.	Time consuming. Soil water content needs to be close to the plastic limit. No information given about how well the pores are inter-connected.
5. Clod shrinkage analysis.	In compacted soil, can be compared easily with the large amounts of published data.	Time consuming. Risk of sampling bias in moderately- and well-structured soil.
6. Image analysis after resin impregnation.	Provides very useful reference data at key sites —allows cross-checking of the SOILpak scores.	Time consuming and expensive. Requires specialised equipment. Soil water content needs to be close to the plastic limit.
7. Infiltration rate.	Surface infiltration rates determined using a disc permeameter are a good indication of the continuity of pores from the soil surface.	Time consuming. Data often highly variable and influenced strongly by initial soil water content. Potential for operator bias.
8. Calculation of non- and partially-limiting water ranges.	Provides excellent information that can be related directly to crop management.	Time consuming and expensive (requires detailed strength, aeration and water content data).

The effect of organic matter on slaking

Slaked soil tends to set very hard when dry, particularly when accompanied by dispersion.

One way of reducing slaking in loamy soil is to reduce the rate at which soil is wet. This cannot be controlled in dryland farming, although straw mulch maintains the surface at a higher water content than loose soil and protects the soil surface during a fall of rain. More importantly, organic matter can physically bind the microaggregates together, reducing slaking—fungal hyphae are particularly beneficial. Apart from the addition of natural organic material, synthetic polymers may be applied (if economically viable) to make soil less prone to slaking in water.

Most red-brown earths and red earths are low in organic matter, especially after several years of excessive tillage, so are very prone to slaking.

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See Chapter E6 for more information on organic matter and soil biota.

Measurement of soil organic matter

When soil test laboratories are asked to measure the organic carbon content of a soil, they generally use the Walkley-Black test. It is a crude procedure that cannot distinguish between biologically useful (labile) carbon and carbon that is inert (for example, charcoal). The test results are of limited value, but can be used to compare and rank paddocks, and to monitor a paddock over time in response to the use of a management treatment such as a pasture rotation.

To convert organic carbon content to organic matter content, multiply organic carbon content by 1.75.

In very general terms, total soil organic matter contents are regarded as:

- very low—less than 1%
- low—1–2%
- generally satisfactory —2–4%
- high—greater than 4%.

When measuring organic matter content you should sample your topsoil at depths of 0–2 cm, 2–5 cm and 5–10 cm (as indicated on the SOILpak soil description sheet) because of the dependence of organic matter content on depth. As organic matter is concentrated at the soil surface we expect organic matter content to decrease with depth.

Researchers at the University of New England have developed a procedure, based on the use of a potassium permanganate solution, to indicate the amount of carbon that is active (labile). CSIRO, Adelaide is doing similar work. Labile carbon is a more sensitive indicator of improvements in soil organic matter status than ‘Total C’.

In several years time it is likely that greatly improved procedures will be available to measure the various forms of soil organic carbon, and to provide practical interpretation of the results.

Field signs of dispersion

Separation of sand, silt and clay in the field after heavy rain (Figure C4-7) is a reliable indicator of soil dispersion. Dispersion is caused usually by too much sodium attached to the clay surfaces, in association with a lack of electrolyte in the soil solution (this is especially important in red soil where organic matter has been

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See Chapter E4 for more information on sodicity and salinity.

depleted). Where sodicity occurs below the soil surface, excessive swelling and constriction of macropores (a process which, unfortunately, is difficult to detect visually) is likely to be a problem.

ASWAT dispersion test

Determine the ASWAT (Aggregate Stability in WATer) score at depths of 0–10, 15–25, 40–50 and 70–80 cm under representative plant lines. Record the scores on the SOILpak soil description sheet (Section 4b). The procedure is as follows:

- Place air-dry clods (3–5 mm diameter) in a dish containing distilled water (or rainwater, if desired).
- After 10 minutes and 2 hours immersion, a visual judgement is made of the degree of dispersion on a scale of 0 to 4:
  —a score of 0 indicates no dispersion (Figure C4-8)
  —a score of 1 is slight dispersion, recognised by a slight milkiness of water adjacent to the clod
  —a score of 2 is moderate dispersion with obvious milkiness
  —a score of 3 is strong dispersion with considerable milkiness and about half the original volume dispersed outwards
  —a score of 4 is complete dispersion leaving only sand grains in a cloud of clay (Figure C4-9).
- Add the 10 minute and 2 hour scores together giving a range of values between 0 and 8.
- For those clods that scored 0 the amount of dispersion after remoulding is determined. Soil is mixed with distilled water to a plastic consistency and remoulded with a knife for one minute. Small balls are formed and placed in a dish containing distilled water. The degree of dispersion of this remoulded soil is assessed as for the dispersion on wetting—the 10 minute and 2 hour scores for remoulded soil are added together.
- For those air-dried clods (non-remoulded) that dispersed on wetting, 8 is added to the sum of the scores for the 10 minute and 2 hour assessments, giving a range of values between 9 and 16.

Figure C4-7. Dispersion as a result of heavy rain caused separation of light coloured sand on the soil surface.

It is assumed that the air-dry aggregates that disperse would show rapid and complete dispersion and score 8 when remoulded.

Therefore 0 indicates no dispersion and 16 indicates severe dispersion.

Because this procedure cannot be done in less that 2 hours, and requires the use of air-dry clods, it is best to do it at home.

Interpretation of the ASWAT test results

Table C4-7 describes management options that should be considered (if economically viable) for the full range of ASWAT test data.

To confirm (and understand more thoroughly) the conclusions in Table C4-7 about soil dispersibility, the following laboratory tests are recommended.

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See Agfact AC.10 'Improving soil structure with gypsum and lime' for more information on management options such as gypsum and lime application.

Follow-up laboratory tests

There are several follow-up tests that can be done at key sites to refine the ASWAT test recommendations.

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See Chapter D4 for more information on gypsum and lime.

Exchangeable sodium percentage (ESP)

An excess of sodium ions attached to clay particles leads to increased swelling of the clay and increases the likelihood of dispersion. Surface soil forms a crust or sets into hard blocks on drying. Subsoil will have a decreased permeability to water and air.

Take soil samples (approximately 0.8 kg) from key sites of interest identified by the ASWAT test. Have them analysed for exchangeable sodium percentage (ESP) at a NATA-certified laboratory. Ask them to analyse the samples using the 'Tucker method', which is the only reliable procedure that is available for exchangeable cation analysis in soil containing free lime (calcium carbonate) and gypsum (calcium sulfate).

A soil with an ESP greater than 5 is referred to as sodic, although ESP values as low as 2 can cause soil structure problems if the concentration of salt in soil solution is very low.

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See Chapter E4 for more information on sodicity and salinity.

Exchangeable calcium/magnesium (Ca/Mg) ratio

The exchangeable calcium/magnesium (Ca/Mg) ratio is important for soil stability. Magnesium counteracts the beneficial effects of calcium on soil structure and aggravates the adverse effects of sodium. It is measured at the same time as exchangeable sodium (see above), calcium and potassium (Tucker method).

A Ca/Mg ratio of less than 2.0 (and particularly less than 1.0) indicates a tendency towards clay dispersion and poor soil structure.

Electrical conductivity and pH

Electrical conductivity (EC) of a soil is a measure of its salinity. As EC increases, soil dispersion decreases for a given sodicity value. Conversely, very low EC values mean that a soil may become dispersive where the ESP of the soil is only 2.

Therefore, instead of looking just at ESP values, the 'Electrochemical Stability Index' (ESI) needs to be calculated. ESI is equal to EC1:5 divided by ESP. A tentative critical ESI value is 0.05. An economically-viable response to gypsum and/or lime can be expected where ESI values are at, or below this level.

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See Chapters C7 and C8 for more information on measuring soil salinity and pH.

Figure C4-8. Clods of soil that have slaked but not dispersed.

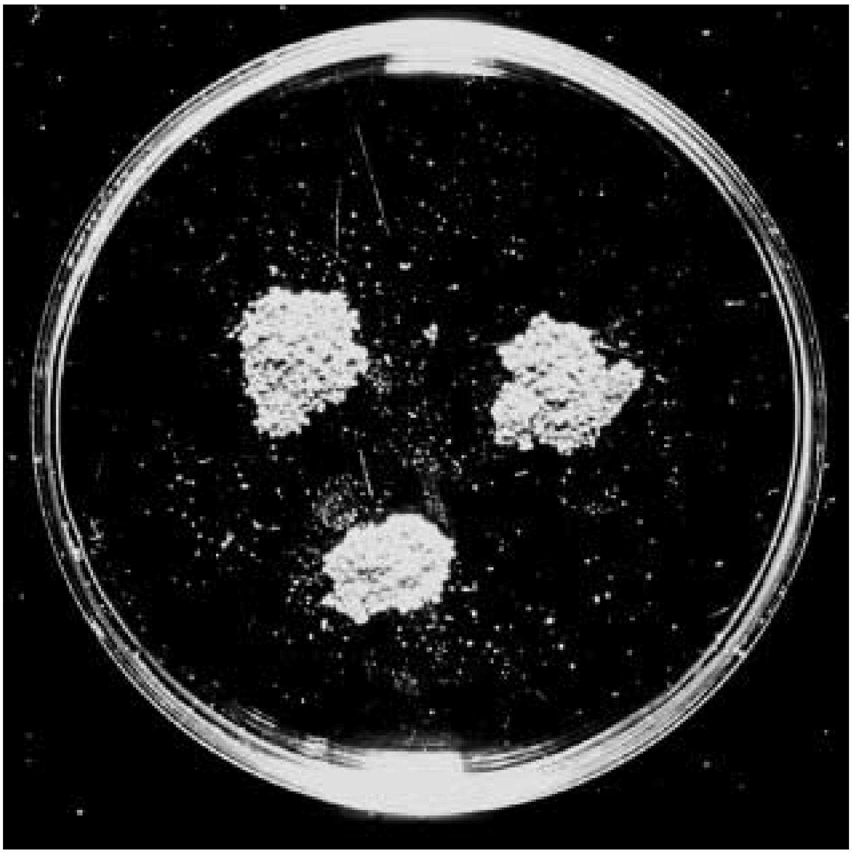

Figure C4-9. Clods of soil that have slaked *and* dispersed.

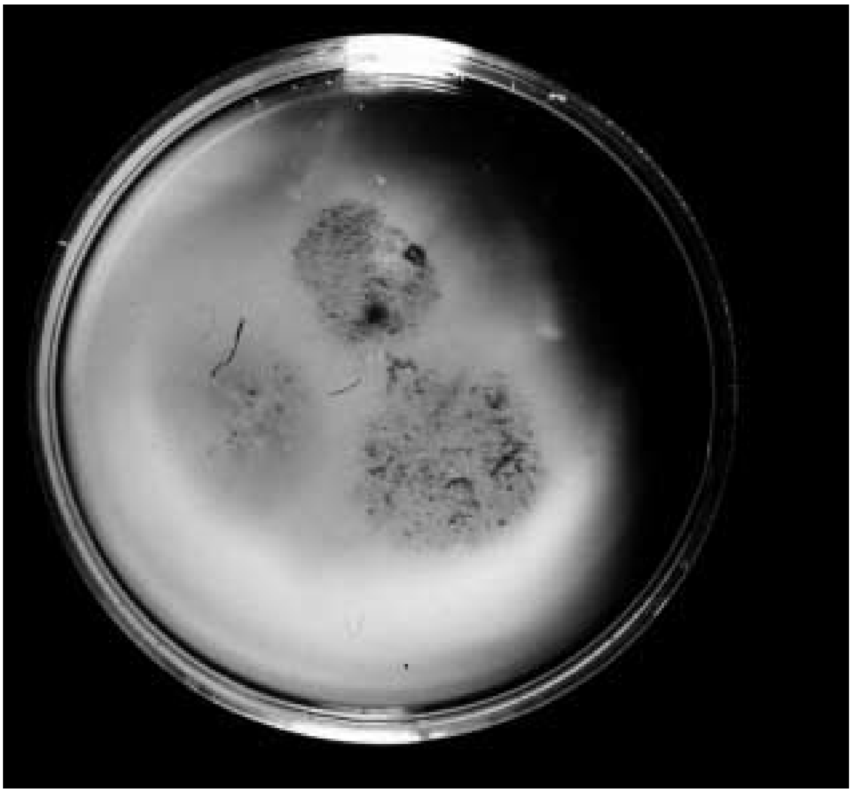

Table C4-7. Response to the soil structural stability diagnosis

ASWAT score 'critical limits'	Severity of dispersion under the plant lines	Management options to consider
7–16	serious dispersion	Gypsum application, possibly with finely divided lime if the soil is not alkaline. Increase organic matter content.
2–6	moderate dispersion, if the soil is remoulded	Avoid working the soil when it is moist (also applies to the above category). Increase organic matter content.
0–1	negligible dispersion	Protection of soil from dilution by excess water (this reduces soil EC), and from the force of raindrop impact and overland flow (also applies to the above two categories).

As soil pH increases the charge on some clay particles becomes more positive, so the soil becomes more dispersive.

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See Chapter E4 for more information on the chemistry of sodic and saline soil.

Calcium carbonate content

As the calcium carbonate content of a soil becomes greater, the likelihood of the soil being dispersive decreases even when ESP values are high. When calcium carbonate concentration is above 0.3% (particularly if it is finely divided rather than in the form of nodules), soil stability in water is likely to be acceptable.

SOIL STABILITY UNDER THE INFLUENCE OF COMPACTIVE FORCES

The ability of soil to maintain its structure when compactive forces (for example, under the wheels of a tractor) are applied is dominated by soil water content. As soil water content increases, soil resistance to deformation decreases.

At a given water content, there is variation in strength between soil types. For example, at a given water content, soil strength tends to increase as the content of cementing agents such as calcium carbonate becomes greater. However, soil resistance to compaction/remoulding is not usually measured in the paddock or laboratory because of the overwhelming (and, due to rain, often uncontrolled) influence of soil water content. Compaction under wheel tracks is inevitable, regardless of inherent soil properties.

The main priority is to restrict compaction to narrow bands in 'permanent' wheel tracks. Apart from areas where poor surface drainage can be corrected (for example, by procedures such as gypsum treatment of sodic areas), compaction control is a matter of machinery management rather than soil management. The use of well-defined permanent wheel tracks should be the rule on all properties, not the exception. Random movement of tracks is to be discouraged as the first pass does the most damage.

STRUCTURAL RESILIENCE

A resilient soil is a soil with the ability to develop a desirable structure by natural processes after destructive forces (such as the compactive pressures under the wheels of heavy machinery) have been removed.

Desirable processes include:

- loosening and mixing of hard layers by soil fauna such as earthworms and ants (particularly important in loamy soil)
- formation of continuous, stable vertical channels in the soil by root systems
- development of shrinkage cracks.

Measurement of soil resilience

Field signs

The presence of shrinkage cracks when a soil is dry clearly shows that a soil is resilient. If a soil is wet, place a piece of it in an oven (temperature of 110°C) for several hours to see whether or not it shrinks strongly. The loamy topsoil of the red soil of Central Western NSW does not have the capacity to form large shrinkage cracks.

The presence or absence of earthworms and/or ants and termites in the topsoil indicates the short-term potential of soil improvement by these organisms. Much remains to be learnt about this topic.

Laboratory tests

The sum of exchangeable calcium, magnesium, sodium and potassium in soil, also referred to as the 'Cation Exchange Capacity' (CEC), provides a rough index of the shrink-swell potential (resilience) of a soil. As CEC increases, the soil becomes more structurally resilient.

A recently-developed resilience test from CSIRO Land & Water, Canberra, can also be used by laboratories. Referred to as the 'Modified Coefficient of Linear Extensibility (COLE) Test', it is a measure of how much soil aggregates shrink under standard conditions.

As the ESP of a soil increases, so does the amount of soil swelling (and shrinking). Whilst this is desirable from a resilience point of view, there are likely to be serious problems with dispersion. Therefore, the only option for improving soil shrink-swell potential is to increase clay content (e.g. by deep inversion ploughing), although usually this is not economically feasible. Sodic subsoil, if brought to the soil surface, is likely to need gypsum treatment. Therefore, it usually is necessary to live with resilience problems, rather than modifying them.

Interpretation of CEC and COLE test results

Table C4-8 describes management options that should be considered (if economically viable) for the full range of CEC and COLE (resilience) test data.

NOTE

Remember, to encourage the growth of plant roots:

- minimise soil compaction
- maximise soil stability in water
- if compaction occurs, strongly resilient soil is easier to repair by natural processes than poorly-resilient soil.

Table C4-8. Response to the soil structural resilience diagnosis

Critical limits CEC (cmol(+)/kg)	COLE value (%)	soil resilience (regeneration potential)	management options to consider when overcoming compaction problems
less than 20	less than 3	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. Otherwise, rely upon plant root systems and soil fauna to permeate the soil with macropores (may have to be preceded by mechanical loosening).
20–40	3–12	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.
greater than 40	greater than 12	good shrink-swell potential	Rely mainly upon shrink-swell cycles to loosen compacted soil.

C5. Structure assessment after soil modification

PURPOSE OF THIS CHAPTER

The aim of this chapter is to encourage you to inspect a soil after a major tillage operation or after a particular crop or pasture has been grown to ameliorate the soil.

Results of the post-tillage (or post-crop/pasture) inspections should be compared to pre-tillage (or pre-crop/pasture) assessments at the same sites—a judgement can then be made about whether or not the selected tillage operation (or crop or pasture) was successful.

CHAPTER OVERVIEW

The following points are covered:

- why you should assess structure after soil modification
- field observations
- resin impregnation and image analysis.

Other chapters to refer to:

- Chapter C1: 'Soil pit digging: where, how and when?'
- Chapter C4: 'Soil structure assessment'.

INTRODUCTION

After a serious compaction problem is identified, use of a pasture or alternative crop and/or deep tillage may be required to loosen the soil.

Unfortunately most farm managers assume that their selected option has been successful, rather than digging a hole to see how effective the operation has been. Those that do carry out an inspection often are shocked to discover that structure problems have been made worse rather than being improved.

This chapter encourages you to carry out post-tillage and/or post-pasture/crop observations, and then make appropriate adjustments to your future soil and equipment management programs.

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See Chapter D4 for more information on selecting a suitable option for improving soil structure.

ASSESSMENT PROCEDURES AFTER SOIL MODIFICATION

Rapid field observations

In a paddock that has just been decompacted by alternative crop, pasture and/or tillage, return to at least one of the post-harvest inspection sites and dig another pit.

Carefully observe the condition of the soil. Sketch the main pit features (Section 1 of the description sheet), then re-assess the SOILpak score (Section 4a) for the topsoil and subsurface soil or the entire root zone (topsoil, subsurface soil and subsoil). Follow the guidelines for the assessment of soil structural condition given in Chapter C4. Aim for a SOILpak score greater than about 1.5. Record your observations and findings on a SOILpak soil description sheet.

The depth to which you sample depends on the type of soil modification used. For example, after a pasture phase, shallow tillage or gypsum application, SOILpak scores for only the topsoil and subsurface soil may be required while SOILpak scores for the entire root zone are required after biological drilling.

Resin impregnation and image analysis

To obtain a permanent record of post-treatment soil structural form, either vertically or horizontally, impregnate the soil with epoxy resin. The blocks of soil are then excavated, ground back and photographed under UV light. The resulting image may then be scanned, and quantitatively described using the SOLICON system. Contact the Department of Agricultural Chemistry & Soil Science, The University of Sydney for further details.

Paint can be used as a quick alternative to resin.

Figure C5-1 illustrates (with the use of resin impregnation and image analysis) the consequences of deep ripping a wet clay soil when it is too wet. Soil on each side of the vertical slot of the ripping tine was badly compacted below a depth of 25 cm. Although the soil shown in Figure C5-1 has been ripped deeper than soil normally would be on dryland farms in Central Western NSW the compacting result is the same whenever a soil is ripped when it is too wet.

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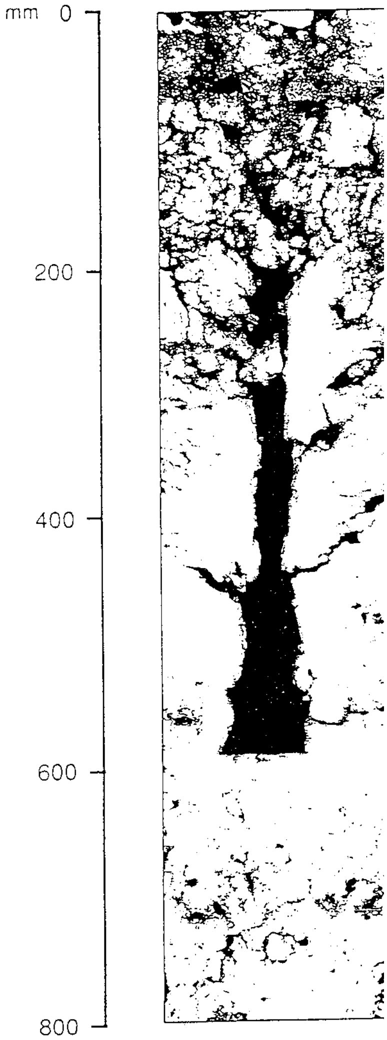
See Chapter C4 for more information on the paint method.

This SOLICON procedure is particularly useful for designers of improved tillage equipment.

COMPARISON OF PRE-TREATMENT AND POST-TREATMENT ASSESSMENT

Compare the post-treatment results to the pre-treatment assessment

Figure C5-1. Subsoil damage caused by deep tillage in a moist clay soil



Source: Koppi et al., 1994.

and judge whether soil structural form is better, unchanged or poorer. If it is poorer, determine why the modification method did not work and develop ways of improving the performance of the management inputs. If the soil structure has improved, implement management practices that maintain the good structure. Examples of failed modification are:

- A dispersive topsoil cultivated and left bare for several months afterwards, during which time there was significant rainfall.
- The roots of a crop used for biological drilling were unable to penetrate the hard layer (it may have been more successful had the soil had adequate soil water).

It is important to remember that soil may be better structured after tillage, but worse a couple of months later, e.g. after rain. Inspect the soil a few months after a tillage operation (especially after rain).

C6. Stubble

PURPOSE OF THIS CHAPTER

The issue of what constitutes a desirable cover of surface mulch for soil under dryland cropping is not well understood. Nevertheless, some general guidelines about this very important topic are presented below.

CHAPTER OVERVIEW

The following points are covered:

- description of the type of stubble cover that is needed to protect the soil against raindrop impact and erosion
- surface mulch specifications for dryland farming systems
- carry-over of diseases when organic residues are retained on the soil surface
- the need to maintain effective weed control when mulching the soil surface with organic residues
- nutrient tie-up in stubble
- determining how much surface cover there is.

Other chapters to refer to:

- Chapter B2: ‘Using stubble to manage topsoil’.
- Chapter C2: ‘Features of the SOILpak soil description sheet’.
- Chapter D2: ‘Erosion control’.
- Chapter E6: ‘Organic matter and soil biota’.

INTRODUCTION

Protecting the soil surface with crop residues has several benefits, including:

- erosion control
- providing food for desirable soil organisms
- moisture conservation
- protection from extremes of temperatures.

It is crucial that soil erosion be minimised on farms. Transportation of soil particles by water and/or wind erosion may result in off-farm movement of soil nutrients and pesticides, as well as the loss of important topsoil. The most effective way of preventing erosion is to protect the soil surface with crop residues. Some general guidelines are presented below about the type of cover that is required.

Possible adverse side-effects of retaining stubble include disease carry-over, insect build-up, nutrient tie-up and weed control problems, but close monitoring of their presence or absence will minimise their impact.

SURFACE MULCH SPECIFICATIONS FOR DRYLAND FARMING SYSTEMS

Surface mulch coverage should be greater than 50% for erosion control. To visualise this, refer to Figures B2-1 and B2-2. To allow for decomposition of stubble over a fallow start with at least 70% surface cover.

- The residue should be at least partly anchored to prevent it from washing or blowing away.
- Any residue that has been cut—for example wheat straw that has passed through a header—should be as short and evenly-spread as possible to minimise the risk of blockages during subsequent tillage operations. However, it should not be ground up too finely—otherwise it may decompose too quickly.
- As a guide, for stubble to pass through sowing equipment, the stubble should be about half the length of the closest distance between tines. Stubble height is not a problem to consider at sowing. It is a management problem to be addressed at harvest time. The use of straw and chaff spreaders and/or second cutter bars are options to consider. For example, if your stubble is too high to manage at sowing time because your harvester cuts the straw too high, a second cutter bar could be installed on the harvester so that the stubble does not have to be slashed before sowing.
- The residue needs to be sufficiently resistant to decomposition to allow persistence during the summer months when erosion risk is at a peak. This means that the ratio of carbon to nutrients such as nitrogen and sulfur should be as high as possible.

Further research is needed to refine these suggestions.

PROBLEMS WITH ORGANIC RESIDUES ON THE SOIL SURFACE- FACTORS THAT SHOULD BE MONITORED

- Diseases such as root rots may be carried over to the next crop via stubble. Where these problems occur, grow a crop (or pasture) that

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See Chapter B9 for more information on using rotations to break disease cycles

is less susceptible to the disease in question or disease-resistant varieties. This will help to break the disease cycle. Avoid the burning of stubble because valuable nutrients are lost to the atmosphere, and soil organic matter reserves become depleted. Also, avoid the deep incorporation of stubble by discing, due to the risk of compaction and smearing in moist soil.

- Damaging insects may build up in crop residues, but control methods are available.
- Crops grown with mulches may suffer nutrient deficiencies, due to nutrient tie-up in the residues, unless extra fertiliser is added when required. Nutrient tie-up is not nutrient loss and the nutrients will become available in subsequent years.
- Weeds generally are more difficult to control where mulch is present, relative to bare soil. Incorporation of pre-emergent herbicides is also more difficult, although the introduction of granular formulations may ease these problems. If soil surface monitoring indicates a serious build-up of problem weeds, obtain advice about their control from an agronomist or use livestock wisely to reduce weed levels.
- Weed and disease problems are often only apparent in header trails. Aim for even stubble cover. This not only reduces weed and disease problems, but also protects more of the soil surface and reduces stubble handling problems.

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See Chapters B2 and D2 for more information on stubble management.

DETERMINING THE AMOUNT OF SURFACE COVER

To determine how much surface cover you have:

- Compare your paddock conditions to photographs or pictures of a known percentage surface cover. Figures B2-1 and B2-2 show 30% and 70% wheat stubble cover respectively. Queensland Department of Primary Industries has produced photostandards for winter cereals which you can compare your stubble cover to. (See Robinson, 1988, referenced in Appendix 1.)
- Stand in a representative part of the paddock with your feet half a metre apart. Visualise a square in front of your feet. Mentally divide the square into thirds and imagine that all the bare areas move into one third. If the bare areas fill less than one third, then cover exceeds 70%. Repeat five times in a paddock, then average out the results.
- Lay out a 100 m measuring tape diagonally across a number of plant lines. At every metre mark check to see if the tape intersects a piece of residue. The number of times the tape intersects stubble at metre marks is the percentage of surface cover. If the tape intersects stubble at every metre marking, you have 100% surface cover.

C7. Salinity assessment

PURPOSE OF THIS CHAPTER

This chapter outlines the signs of dryland salinity in the paddock and describes methods of measuring salt concentrations in the soil profile. Watertable monitoring and water quality are also discussed.

CHAPTER OVERVIEW

The following points are covered:

- recognition of a saline soil
- measuring salinity
  —in the paddock
  —in the laboratory
- watertable monitoring
- water quality.

Other chapters to refer to:

- Chapter B8: 'Salinity'.
- Chapter D6: 'Avoiding salinity problems'.
- Chapter E4: 'Effects of sodicity and salinity on soil structure'.

INTRODUCTION

A saline soil is one which contains sufficient soluble salts to adversely affect the growth of most plants. Salinity usually occurs as a result of groundwater rising to within 2 m of the soil surface, resulting in a concentration of salt in the root zone.

Soil with an EC_e greater than 4 dS/m is generally considered saline. The point at which the growth of different plants is adversely affected varies. Some species are very sensitive to salt while others, such as saltbush, are very salt-tolerant.

It is important to evaluate the soil salinity status when diagnosing the condition of your soil. Agriculture has altered the natural water balance of entire catchments and salinity is becoming a problem in many agricultural regions. Central Western NSW is no exception with localised problems now becoming evident.

All soil managers need to be able to recognise salinity problems, particularly during their early stages of development. It is an expensive issue to correct when well-advanced. Procedures for quantifying soil salinity, testing water quality, and monitoring groundwater are described below.

SIGNS OF SALINITY IN THE PADDOCK

If you notice any of the following signs of salinity on your farm, you should have tests done to confirm any problem.

Indicators of salinity (outlined in Chapter B8), include:

- salt tolerant plant species thriving while others show poor growth or die
- patches of bare soil, especially wet/greasy patches
- reduced vigour and poor growth of crops and pastures
- changes in leaf colour and shape in some species due to salt stress
- salt crusts on the soil surface when it is dry.

MEASURING SALINITY

Soil salinity can be very variable across a paddock or over a whole farm. It may also vary vertically within the soil profile. Soil may be saline at depth but not in the topsoil (it may be a future problem in the topsoil, however).

Soil samples can be taken to determine salt concentrations in the laboratory. If salinity is a major problem you may want to map salinity over a large area using electromagnetic methods. These are discussed in the following text.

Field test

The *Salt Action field kit*, developed by NSW Salt Action, contains a portable (hand-held) electrical conductivity (EC) meter and information about identifying salinity, how to quickly test for water and soil salinity, and interpreting readings.

Laboratory techniques

Methods of measuring salinity depend on electrical conductivity. Salinity is reported as the electrical conductivity (EC; dS/m) of a mixture of soil and water. The higher the EC of the mixture, the higher the salt content of the soil. There are two laboratory methods of assessing EC, saturation extract and soil suspension (1:5 soil:water extract).

The EC is measured by immersing the platinum electrodes of an EC meter into a filtrate or solution (extract). An electric current is passed between the two electrodes. The greater the salt concentration, the greater the current (conductivity). If no salt is present, very little electric current passes.

Saturation extract

Salinity is commonly expressed as the EC of a saturation extract (EC_e). It is not dependent on the texture of the soil, and is therefore more meaningful (in terms of what a plant root would experience) than the 1:5 soil:water extract method. The method for measuring EC_e is, however, much more time consuming than that for measuring the EC of a 1:5 soil:water extract ($EC_{1:5}$).

For the saturation extract method distilled water is added to a sample of soil while stirring until a characteristic saturation point is reached. A suction filter or centrifuge is then used to extract a sufficient amount of water to perform an electrical conductivity measurement.

1:5 soil:water extract

A much easier and more common method of assessing EC measures the conductivity of a 1:5 soil:water extract ($EC_{1:5}$). A mixture of (by weight) one part air-dry soil to five parts distilled water is made. After being shaken for 1 hour the suspension is allowed to settle before salinity is estimated by measuring the electrical conductivity of supernatant liquid.

One problem with this method is that in a soil with significant amounts of slightly soluble salts (e.g. gypsum) the slightly soluble salts will dissolve and increase the EC value. Therefore EC_e will be overestimated.

Another problem is that it does not take into account the effect of soil texture. Therefore the results from two different soil types cannot be compared. However, it is possible to convert $EC_{1:5}$ values to EC_e values if the texture of the soil is known. Multiplier factors are given in Table C7-1.

Table C7-1. Multiplier factors for different soil textures required to convert $EC_{1:5}$ to EC_e

Soil texture	Multiplier factor
Loamy sand, clayey sand, sand	23
Sandy loam, fine sandy loam, light sandy clay loam	14
Loam, loam fine sandy, silt loam, sandy clay loam	10
Clay loam, silty clay loam, fine sandy clay loam, sandy clay, silty clay, light clay, light medium clay	9
Medium clay	8
Heavy clay	6

***Source*:** Slavich and Petterson, 1993.

Some laboratories use units other than dS/m (deciSiemens per metre) as salinity units. Two commonly used conversion factors are as follows:

- 1 dS/m = 100 milliSiemens per metre (mS/m)
- 1 dS/m = 100,000 microSiemens per metre (µS/m) = 1000 microSiemens per centimetre (µS/cm)

Indirect methods

Electromagnetic devices

Large scale ground surveys of soil salinity can be carried out using electromagnetic induction (EM) devices. These devices measure soil salinity indirectly and measurements can be made quickly.

EM devices rapidly estimate soil salinity in the paddock by measuring the ease with which a magnetically-induced current passes through the soil.

Currently, there are three commercially available electromagnetic induction instruments:

- EM34-3
- EM31
- EM38.

They are useful for describing the spatial distribution of the apparent electrical conductivity (EC_a) across a paddock, farm or catchment.

To relate EM readings to soil salinity or potential salinity threat, calibration of the EM instruments for a specific site is required. EM readings can be affected by soil moisture, clay content, salinity and soil mineralogy.

The EM38 best describes the EC within the root zone (to a depth of approximately 1–2 m). It is most readily adapted for soil salinity assessment at these depths and in the identification of perched watertables. The EM31 is better suited to deeper subsoil studies (3.5–7 m).

Both the EM31 and EM38 instruments are used with a sampling interval of 25–50 m. In areas where salinity is evident, or detailed information is deemed necessary, a more detailed sampling interval can be adopted.

The EM34-3 is better suited to large-scale investigations. This is because of the depth of measurement achievable with the instrument (7–30 m). Therefore the spatial distribution of watertables, shallow aquifers and clay content can be obtained across a catchment. This information can then be related to potential threats and identification of areas requiring more detailed information.

The EM instruments can be used by hand or by ground-rig, or via the use of helicopters or aircraft.

To calibrate the EM38, EM31 and EM34-3, soil samples are required to depths, respectively, of 2, 7 and 15–30 m. EC_e of the soil samples is measured in the laboratory. A minimum of 15 sites need to be selected, with an additional five used to validate the calibrations. Areas with the largest and smallest EM values need to be included in the soil sampling scheme. Research is being carried out at The University of Sydney to improve the efficiency of calibration.

Computer software products such as 'Mapinfo' and 'Arcview' (Geographic Information Systems) are available to store, manipulate and map the large amounts of data generated by EM surveys. GPS instruments should be used to record the geographical position of each of the sampling points.

EM units can be used to identify sites with leaky subsoil. Soil with the lowest EC_e readings can be assumed to be the most leaky zones, due to the leaching of soluble salts.

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See Chapter C9 for more information on TDR..

Time domain reflectometry

Time domain reflectometry (TDR) is primarily used to measure the volumetric water content of the soil. Measurements of water content using TDR are affected by the electrical conductivity of the soil. TDR can therefore also be used to estimate salinity. As for the EM instruments, each new site requires calibration.

WATERTABLE MONITORING

Where the volume of rain exceeds evaporation and transpiration by plants, percolation into groundwater (referred to as 'recharge') takes place. Watertables may then rise. Rises may also be caused by the pressure of water, from other parts of the catchment, in strata underlying the root zone.

Groundwater within 2 m of the soil surface can rise further up the soil profile into the plant root zone through capillary action. This may lead to an accumulation of salt in the root zone and on the soil surface. In sloping paddocks, the groundwater may move laterally and seep into creeks and rivers at a lower altitude. The salt within this drainage water may cause problems down-stream.

There are two approaches to groundwater monitoring, observation wells and piezometers.

1. Observation well

An observation well is a length of fully-slotted tubing which is lowered into a bore hole and backfilled with sand or gravel around the outside of the tube. Water can freely enter the tube along its entire length, thus giving the position of the watertable in the soil (Figure C7-1). By observing a group of wells over time, trends in groundwater height can be monitored.

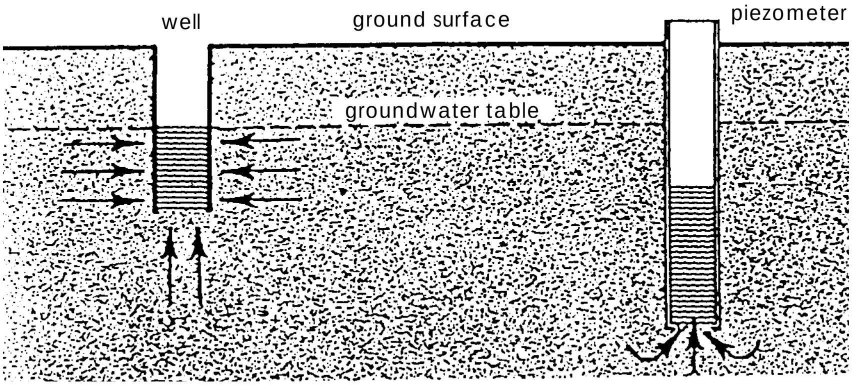
2. Piezometer

A piezometer is similar to an observation well, with a tube inserted and sealed into the soil, but only about 1–2 m is slotted to allow water to enter at a chosen depth. The tube is then sealed off with bentonite, clay or cement. Water moves into the tube through the bottom or slotted section of the tube (Figure C7-1). The height to which the water rises is a measure of the hydraulic pressure at the chosen depth. It is an indication of the force that is pushing the groundwater towards the surface. Placement of piezometers to different depths will provide clues about groundwater dynamics when monitored over time (Figure C7-2).

Quality of the water in piezometers and observation wells should be tested, as described in the next section ('Water quality'), to determine how saline it is.

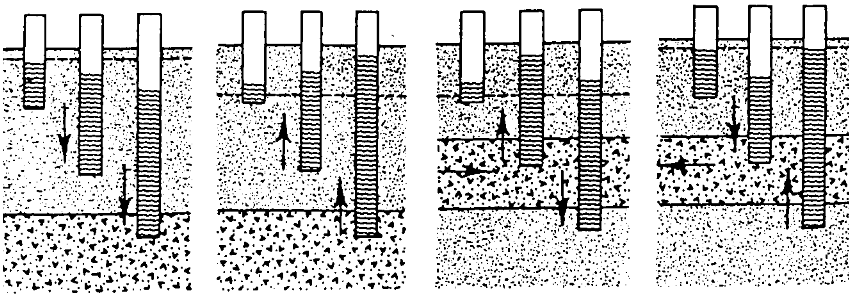
The quality of information from test wells and piezometers is strongly influenced by how well the tubes are installed. For example,

Figure C7-1. Groundwater measurements made by observation wells and piezometers



Source: Hunt and Gilkes, 1992

Figure C7-2. Use of piezometers to provide clues about sub-surface flow



A
The piezometers indicate that the groundwater is going down and that there is some natural damage.

B
The piezometers indicate a hydrostatic pressure, or that there is water coming up from a deeper strata.

C
The piezometers indicate a hydrostatic pressure in a stratum, and that water is being forced both up and down from the stratum.

D
The piezometers indicate that groundwater is moving into a stratum and going out of the area.

Source: Hunt and Gilkes, 1992

if soil on the sides of the excavated holes is compacted and/or smeared, water movement is likely to be very different to that occurring in undisturbed soil. Therefore it is vital that the installations be set up professionally.

WATER QUALITY

The EC of groundwater can be measured directly with an EC meter. If this water is saline and rising, the soil above it may suffer a decline in quality. Table C7-2 outlines how water with different EC levels can be used.

RESPONSE TO THE SALINITY DIAGNOSIS

If the soil is saline (as a result of dryland salinity), or about to become so, the options to consider include:

- avoiding bare fallows
- planting deep-rooted perennials in recharge zones
- investigating the use of hill/bed shapes that minimise salt accumulation (in soil that is already saline) around seedlings
- pumping and recycling groundwater (need input from hydrogeology consultants).

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See Chapter s D6 and E4 for more information on salinity..

Table C7-2. Water quality standards

EC (dS/m)	**Use**
0.0–0.8	Good drinking water for humans (provided there is no organic pollution and not too much suspended clay material). Good for irrigation, although some care must be taken for levels greater than 0.3 dS/m, particularly with overhead sprinklers which may cause leaf scorch on some salt sensitive plants. Suitable for all livestock.
0.8–2.5	Can be used by humans, although people would prefer water in the lower half of this range. When used for irrigation, requires special management including suitable soil, good drainage and consideration of salt tolerance of plants. Suitable for all livestock.
2.5–10.0	Not recommended for human consumption, although water up to 3 dS/m could be drunk if nothing else was available. Not normally suitable for irrigation, although water up to 6 dS/m can be used on very salt tolerant crops with special management techniques. Over 6 dS/m, occasional emergency irrigation may be possible with care or, if sufficient low salinity water is available, this could be mixed with the high salinity water to obtain an acceptable supply. When used for drinking water by poultry and pigs, the salinity should be limited to about 6 dS/m. Most other livestock can use water up to 10 dS/m.
> 10.0	Not suitable for human consumption or irrigation. Not suitable for poultry, pigs or any lactating animals, but beef cattle can use water to 17 dS/m and adult sheep on dry feed can tolerate 23 dS/m. However, it is possible that waters at or below these levels could contain unacceptable concentrations of toxic compounds. Detailed chemical analysis should therefore be considered before using high salinity water for stock. Water up to 50 dS/m (the salinity of sea water) can be used to flush toilets provided corrosion in the cistern can be controlled, and for making concrete provided the reinforcement is well covered.

Source: Chaffey, 1992**.**

C8. Other tests

PURPOSE OF THIS CHAPTER

This chapter contains brief descriptions of several soil tests that did not fit neatly into previous chapters within Part C of this manual.

CHAPTER OVERVIEW

Testing procedures are described for the following factors:

- nutrients
- mycorrhiza
- rate of soil loss
- pesticide residues
- pH.

Other chapters to refer to:

- Chapter C1. 'Soil pit digging: where, how and when?'.

INTRODUCTION

To complete the soil assessment process outlined in earlier chapters, it is necessary to consider:

- soil nutrients
- mycorrhiza
- rate of soil loss
- pesticide residues
- pH.

NUTRIENT TESTING

Without a well-balanced and adequate supply of nutrients, dryland crops and pastures will grow poorly, regardless of soil structural condition.

Generally, the best way to monitor nutrients in plants is through plant tissue analysis. Soil tests tend to be more difficult to interpret. Nevertheless, soil phosphorus (P), potassium (K) and sulfur (S) testing is advisable every few years. Annual soil nitrogen (N) testing is advisable particularly in the subsoil. Many dryland farmers now sample soil nitrate to a depth of 60 cm before sowing. Less-mobile nutrients such as P concentrate near the surface, so P testing should focus on the topsoil (0–10 cm). S should be monitored where canola is grown.

Some guidelines for the interpretation of nutrient testing are given in Chapter A2, 'The ideal soil for dryland farming'. It is common in Central Western NSW for soil N to be depleted at a higher rate than it is added to the soil as fertiliser.

For more information about nutrient testing and management, contact your local soil scientist, district agronomist or fertiliser supplier.

MYCORRHIZAE

Mycorrhizae are beneficial soil-borne fungi that attach themselves to the growing roots of crops. They allow roots to scavenge more effectively for nutrients (particularly immobile nutrients such as phosphorus, copper and zinc). They increase the uptake of nutrients by plants.

There are two types of mycorrhizae:

- ectomycorrhizae (associated with woody perennials)
- endomycorrhizae (also known as vesicular arbuscular mycorrhizae—VAM—and associated with the crops grown in Central Western NSW).

There are research programs that are currently looking at the opportunities that mycorrhizae offer to agriculture.

Poor plant performance can sometimes be attributed to a lack of VAM in the soil. Grain legumes and oilseeds generally have a high VAM dependency, and cereal crops have a low dependency. Some crops such as canola and lupins do not depend on them at all because they have evolved with other mechanisms for enhancing P uptake from P-deficient soil.

VAM numbers decline during long (weed-free) fallows because they cannot multiply independently of living roots. A lack of VAM is the cause of long fallow disorder in the subsequent crop. Because canola and lupins do not depend on VAM, growing these crops is the same as having a bare fallow in terms of VAM survival.

It is best to break a long fallow with a cereal crop because of its low dependency on VAM. During the growth of the cereal crop VAM numbers will build up which will be beneficial for subsequent crops that may have a high dependence (e.g. sunflower). Cereals also make the most of nitrogen mineralised from organic matter during a long fallow; legumes after a long fallow will use that mineralised nitrogen rather than fix their own.

Microbiological tests are being developed to determine whether or not a soil contains sufficient mycorrhizae for a particular crop. In the meantime, consult a soil biologist if further information is required.

RATE OF SOIL LOSS

Accurate monitoring of soil loss by wind and/or water erosion from paddocks is an expensive exercise. It usually is only carried out as part of research investigations.

However, preventative action can be taken in areas of concern if there is visual evidence of erosion. Signs to watch for are:

- rapid build-up of sediment in drains, runoff channels or dams
- rills caused by flowing water within paddocks
- dust movement when the weather is windy
- sand-blasting damage of seedlings after strong wind.

Protection of the soil surface with an organic mulch will do much to alleviate these problems.

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See Chapter C6 for more information on stubble.

PESTICIDE RESIDUES

The build-up of pesticide residues is not regarded as a major problem within the dryland farming systems of Central Western NSW, now that non-persistent chemicals are used.

Nevertheless, growers who remain in doubt about the degree of soil contamination within their paddocks can have it analysed comprehensively by commercial organic chemistry laboratories.

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See Chapter B13 for more information on soil management and the environment.

pH

Soil pH is a measure of how acidic or alkaline a soil is. For most plants, soil pH (in calcium chloride) should be in the range 5.5 to 7.0. If the soil is more alkaline, the availability of some nutrients (for example, zinc) becomes limiting. If it is more acidic, soluble aluminium may be released into the soil solution—most plants have a very poor tolerance of aluminium.

Soil pH is measured using one of three methods:

1. ***Raupach's field method.*** An approximate measure of soil pH can be obtained easily in the field using a 'Raupach' pH testing kit. It gives immediate results. Raupach indicator solution is added to a small sample of soil on a white tile until a smooth paste is obtained. The colour produced is highlighted by lightly dusting the paste with a white powder (barium sulfate). The colour is compared to a reference chart that shows pH to within half a unit.

2. ***pH in water***. Measuring pH in water gives similar values of pH to that found using Raupach's field method. pH in water is generally measured using a 1:5 soil:water extract. The pH is measured with a combined glass electrode and calomel electrode in the solution. Other soil:water ratios may be used but they give different values of pH.

3. ***pH in 0.01M $CaCl_2$***. A more accurate procedure, carried out in soil testing laboratories, is to measure the pH of a 1:5 soil:0.01 M calcium chloride extract at 25ºC. A calcium chloride solution is used rather than water because the latter dilutes the soil solution excessively; this leads to an over-estimation of pH by about 0.5 for most soil types. Therefore, when you report pH values, it is important to state whether pH was measured in calcium chloride ($CaCl_2$) or water (1:5). Results from the calcium chloride method are independent of the soil:solution ratio.

Soil acidity varies with rainfall and temperature. Therefore it is important to record sampling dates and to sample under similar conditions if you are comparing over different years.

When testing soil pH it should be determined for the topsoil, subsurface soil and subsoil, at least at the worst- and best-yielding sites within a paddock.

Field ('Raupach') kits for measuring pH are available from suppliers of geological equipment and some nurseries.

The use of fertilisers such as ammonium sulfate, organic matter conservation, nitrate leaching, and product removal tend to acidify a soil, whilst lime is used to increase pH.

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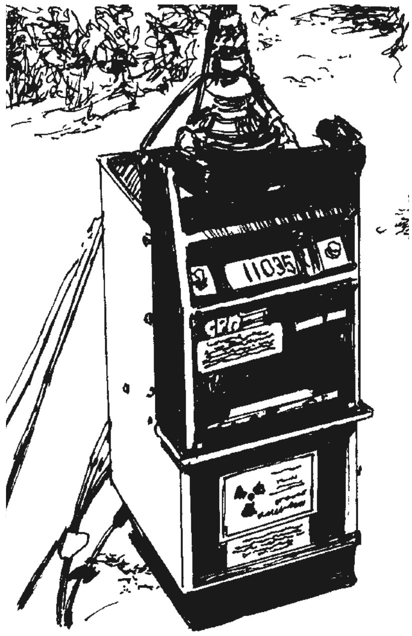
See Chapter D5
for more information on
methods for managing soil pH.

C9. Using soil moisture data to assess soil condition



PURPOSE OF THIS CHAPTER

This chapter outlines how you can use soil water extraction and intake information, measured by a range of techniques such as the use of moisture probes, to detect soil problems such as compaction.

CHAPTER OVERVIEW

This chapter covers the following points:

- methods for measuring soil water
- how to use soil moisture information
- daily water use
- typical moisture extraction in a well-structured soil
- typical moisture extraction in a compacted soil
- water use efficiency
- fallow efficiency

Other chapters to refer to:

- Chapter D1: 'Maximising water use efficiency'.

INTRODUCTION

As soil condition for crop and pasture growth becomes worse, there is a decline in the rate at which plant roots can extract water. Of particular importance are subsoil problems such as compaction, salinity and acidity.

This chapter describes how to assess soil conditions for plant root growth using moisture information. Some of the methods are rarely used by dryland farmers, but this may change in the near future.

METHODS FOR MEASURING SOIL WATER

Push probe

In Chapter C3 it was noted that soil water content can be estimated very roughly using crop symptoms, and by the feel of a soil.

Another quick way of estimating soil water content is to try to push a pointed steel rod (push probe) into the soil to a depth of approximately 1 m. It is assumed that as soil water content increases, resistance to penetration decreases. NSW Agriculture can give you instructions for making a push probe.

Advantages of the push probe:

- It is cheap.
- Many sites can be sampled quickly.

Cautions:

- Compacted layers are confusing—they give the impression that the soil is drier than it actually is.
- Different operators tend to have contrasting views of how hard to push the probe.
- Difficult to decide what constitutes wet soil.

Soil sampling and weighing

Use an auger (or, preferably, a hydraulically-inserted coring tube) to collect 50–100 g of soil at the depths of interest. The feel of the soil sample when squeezed will give you a rough idea of soil water content. However, it is recommended that you seal the soil in a plastic bag to prevent moisture loss from the sample.

At home, place the soil in a small tin which has previously been weighed. Weigh the tin plus moist soil, and place overnight in an oven set at 105°C. Remove the tin plus the oven-dry soil from the oven, and weigh it promptly.

Divide the loss of water in grams, by the weight of the oven-dry soil:

$$= \frac{(\text{tin + moist soil}) - (\text{tin + oven-dry soil})}{(\text{tin + oven-dry soil}) - \text{weight of tin.}}$$

This gives you the gravimetric water content of the soil (grams of water per gram of soil, g/g).

To change gravimetric water content (E/F in Table C9-1) to volumetric water content (cm^3 of water per cm^3 of soil; H in Table C9-1), multiply the gravimetric water content by the bulk density (grams of soil per cm^3 of soil) of the soil. Table C9-1 shows how to

Table C9-1. Example of calculating soil water content by weighing
Soil water content. Paddock No. 3 Core No. 2 Date: 11th April, 1997
Depth interval = 150 mm

A Depth (mm)	B Weight of moist sample with tin (g)	C Weight of dry sample with tin (g)	D Weight of empty tin (g)	E Weight of water in sample = B – C (g)	F Weight of dry soil = C – D (g)	G Bulk density (g/cm^3)	H Water content by volume = (E/F) x G	I Water in mm = H x depth interval (mm)
0–150	121	114	30	7	84	1.38	0.12	18.0
150–300	109	103	30	6	73	1.56	0.13	19.5
300–450	142	134	30	8	104	1.55	0.12	18.0
450–600	125	119	30	6	89	1.56	0.11	16.5
600–750	125	120	30	5	90	1.59	0.09	13.5
750–900	129	124	30	8	94	1.61	0.09	13.5

Total soil water (mm) over depth of core (sum of column I) = 99

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See Chapter E7 for more information on water available for plant growth.

calculate soil water content by weighing. Volumetric water contents are more useful for most purposes than gravimetric water contents. The volumetric water content can be translated into mm of water per specified depth of soil.

The soil water content measured by this method (and the procedures that follow) is not fully available to plants. Some remains in the soil after plants have extracted the available water (unavailable water is left). To estimate the available soil water content, subtract the water content of a soil profile under a severely wilted crop (i.e. at the 'permanent wilting point') from the water content of the soil. The difference is an estimate of plant-available water. Only water between the water content of the soil at field capacity and the water content of the soil at permanent wilting point is potentially available to plants.

Advantages of sampling and weighing:

- It is simple.
- The measurement of soil water content is accurate.

Cautions:

- It is time consuming as samples must be collected and taken home for weighing and drying.

Neutron probe

The radioactive source in a neutron probe emits fast neutrons through an aluminium access tube installed to a depth of 1.5 m in the soil. Collisions between these fast particles and hydrogen atoms slow the neutrons down, and the detector in the neutron probe measures the concentration of slow neutrons in its vicinity. This allows assessment of the concentration of hydrogen atoms in soil surrounding the access tubes.

Hydrogen atoms are present in soil organic matter, soil clay minerals and soil water. The concentrations of clay and organic matter do not change over short periods of time, unlike the concentration of soil water. Therefore you can use a neutron probe to compare soil water contents at different times. A single reading tells you very little; comparisons of readings at different times can tell you a lot.

Recently the use of neutron probes in cereal cropping areas has increased. They are being used to quantitatively assess subsoil moisture reserves before sowing.

Advantages of the neutron probe

- It will measure accurately below 10–20 cm.
- It can measure soil water content to a depth only restricted by the depth of the access tube.
- It is useful for monitoring changes in soil water content with time.
- It can quantitatively determine the suitability of soil condition for successful germination and emergence of cereal crops.
- Its measurement zone is larger than for soil cores or auger samples, so the neutron probe gives a better measure of what is happening in the paddock.

Cautions

- The topsoil data is not always accurate due to the interference of hydrogen in the surface air.
- The operator needs expertise in taking neutron probe measurements.
- It is expensive.
- Access tubes for the neutron probe must be inserted, and the probe needs to be carried across the field to access tube sites.

Capacitance probe

Capacitance probes utilise electrical capacitance to measure soil water content. A PVC tube containing an oscillator and parallel electrodes is inserted into the soil. An electromagnetic field is produced around the electrodes and surrounding soil by the oscillator. This causes the electrodes to act as capacitors (storers of electric charge). The degree of capacitance (related to the dielectric constant of the soil) is a function of soil water content. The apparent dielectric constant of the soil matrix reflects the amount of water in the soil; the dielectric constant (K) of water is 80, whereas for air and soil solids it is only equal to 1 and 2–4 respectively.

Advantages of the capacitance probe:

- Unlike the neutron probe, which has to be carried (sometimes through sticky mud) to the access tubes, capacitance probe results can be transmitted, whenever required, via cables to data recording equipment on the side of a paddock.
- It is accurate.

Cautions:

- Care must be taken with data interpretation in strongly-shrinking soil, due to the formation of air gaps around the access tubes, which may alter the instrument calibration.
- The operator needs expertise in using capacitance probes.

TDR

TDR (Time Domain Reflectometry) is a technique used to primarily measure the water content of the topsoil, compared to neutron probes which can measure water content at depth. With TDR soil water content is measured by converting the time a microwave pulse of electricity takes to reach the end of waveguides (thin, stainless steel rods) inserted into the soil. As the soil water content increases, the speed of the pulse along the waveguides is slowed down (if the soil is wet the apparent dielectric constant of the soil matrix is large, whereas it is small if the soil is dry).

Usually, three parallel waveguides approximately 15 cm long are inserted into the topsoil vertically. Monitoring can be done at depth but a pit has to be dug so that the waveguides can be inserted horizontally into the soil at the depth of interest.

TDR now allows simultaneous monitoring of soil salinity and soil water content.

Advantages of using TDR:

- It measures soil water content of the topsoil accurately.
- It can be used to monitor soil salinity.

Cautions:

- Air gaps around the waveguides affect measurements.
- Electrical conductivity affects measurements.
- The operator needs expertise in using TDR.

Tensiometers

In non-swelling soil, tensiometers may provide useful data. They measure soil water potential (indicated with a pressure gauge) rather than soil water content. Soil moisture characteristic (a graph of soil water potential versus the gravimetric water content) is required to convert soil water potential to soil water content. They also tend to be difficult to maintain.

Calibration of moisture probes

Moisture probe results from different sites cannot be compared with confidence unless the instruments used have been calibrated properly. Neutron probes, capacitance probes and TDR instruments all need to be calibrated so that readings taken with them can be converted to soil water contents. Nevertheless, the shape of the ‘raw probe reading’ vs. ‘time’ graph, on its own, can be useful for soil condition interpretation at a given site.

Computer programs to predict soil water content

The water content of the soil can be predicted using computer programs such as ‘HOWWET?’, developed by the Agricultural Production Systems Research Unit, a joint program between the Queensland departments of Natural Resources and Primary Industries, and CSIRO’s Tropical Agriculture, based in Toowoomba.

HOWWET? uses farm rainfall records to calculate how wet your soil is and also to determine how much nitrogen has been released from the soil organic pool during the fallow period. These estimates form a basis for management decisions such as when and what to plant, and fertiliser strategies. HOWWET? is designed to complement soil coring, push probes and soil tests.

Although HOWWET? has been validated using northern cropping data, it should be easily adapted for use in other environments.

HOWWET? can be purchased through QDPI information centres in Toowoomba and Dalby or downloaded free of charge from the products section of the APSRU web site (www.apsru.gov.au/).

HOW TO USE SOIL MOISTURE INFORMATION

To detect soil problems such as compaction with moisture measurements, you need a crop or pasture to extract water from a wet soil profile. Regular measurements of soil water at several depths at the same site allow you to monitor patterns of water extraction by the crop or pasture over depth and time. Measurements taken just before and just after falls of rain also can be very useful—they allow patterns of water intake to be assessed.

You can use moisture readings (converted to mm of soil water using the calibration equation where probes are used) to detect soil problems, in the following ways:

- poor moisture extraction from the subsoil may be associated with compaction, salinity and/or acidity
- entry of only a small proportion of rainfall into the soil may be associated with structural problems at the soil surface
- grain yield per mm of water, where values are less than about 10 kg/ha/mm, indicates that there may be soil limitations.

Follow-up soil measurements (see earlier chapters) are needed to confirm such possibilities.

Water measurements do not replace crop observations. They become a more effective tool if you use them to help explain other things you notice as a crop manager.

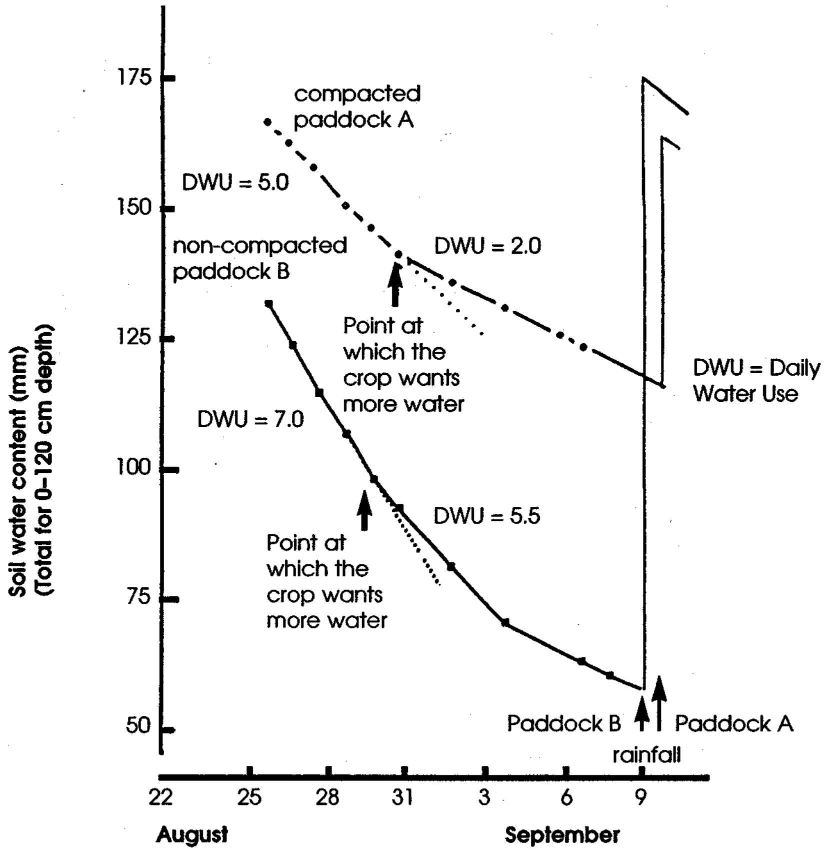
CHANGES IN TOTAL WATER CONTENT OVER TIME

Calculate the total soil water (0–120 cm) in the profile for each reading date (plant available water should also be calculated). Differences in total soil water (0–120 cm) between any two dates, divided by the number of days between those dates, gives you the average 'Daily Water Use' (DWU) for the crop/pasture over that period if no rain has fallen.

As the crop depletes soil moisture, it experiences more difficulty in extracting water, and the daily water use (DWU) declines. A decline in DWU means that the crop would benefit from more rainfall to replenish soil moisture reserves (in irrigation enterprises this point is termed the 'refill point'). A sharp decline in DWU signals compaction, especially if the point at which DWU declines is wetter than usual. This may mean that some of the soil water is unavailable due to poor access by roots (Figure C9-1). Remember, however, that this procedure works best when the weather is consistently fine; cloudy weather and/or sporadic rainfall complicates the interpretation.

In the example shown in Figure C9-1, soil water content was measured using a neutron probe. Frequent soil water content measurements using the weighing procedure is impractical because too many replicates are required to overcome paddock variation problems.

Figure C9-1. A comparison of a series of water content measurements, including Daily Water Use (over a depth of 120 cm), from a compacted and a non-compacted paddock on the same farm



Temporary waterlogging causes a slow-down in DWU. Capacitance probes are particularly useful for monitoring the rate of extraction of soil water just after rainfall.

MOISTURE EXTRACTION PROFILES

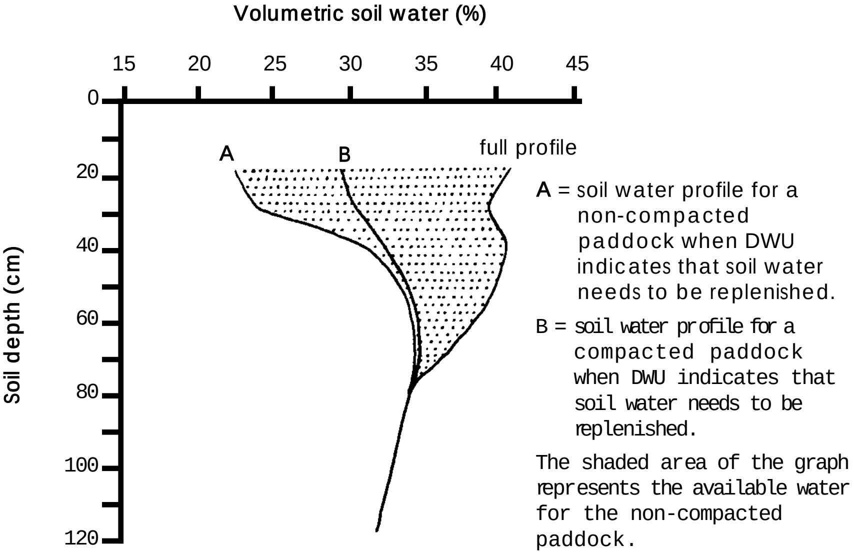
Graph your data as soil water content against depth for each reading date (Figure C9-2). Changes in water content at each depth will tell you the depths from which the crop/pasture is extracting the most water, and the depths where extraction is limited. Differences between good and poor paddocks may show up soon after rainfall.

Monitoring of soil water contents is much more common in irrigation enterprises than in dryland ones. It is important for irrigation timing. However, the use of this information by dryland farmers is likely to increase greatly in the future.

Figure C9-2 shows a soil water profile of a soil when it is full of water and when DWU indicates that soil water needs to be replenished for a compacted paddock and a non-compacted paddock. The plants growing in the compacted soil need additions of water when the soil water profile is much wetter than the plants growing in the non-compacted soil.

Lack of water extraction from the subsoil does not always indicate compaction. For example, if the subsoil is dry and the surface soil is wet, there is little subsoil water for the crop to extract. Such a situation may arise if steady, soaking rain wets and seals the surface of a dry profile of a dispersive soil. This sealing prevents deep

Figure C9-2. Soil water profiles for a compacted and non-compacted paddock



infiltration of rainfall. On one sodic soil, it was observed that only 10% of the annual rainfall of 600 mm entered the root zone. Growing wheat on this sodic soil was like trying to farm in the Simpson Desert.

Poor moisture extraction from the subsoil may also be due to excessive salinity and/or pH extremes. When the soil is saline the soil may be wetter than wilting point but the water is not available to plants.

WATER USE EFFICIENCY AND FALLOW EFFICIENCY

A well-structured soil will produce higher yields for a given amount of rainfall than a poorly-structured soil, in the absence of other limitations such as poor nutrition or disease. Conversely, the good soil can produce the same yield with less rainfall than the poor soil. Yield (tonnes per hectare) per mm of water used in evapotranspiration is a measure of 'Crop Water Use Efficiency' (CWUE).

CWUE (kg grain/ha/mm of water) is calculated as follows:

CWUE = grain yield (kg/ha) divided by [(mm of water in the soil at sowing) + (mm of water infiltrated into the soil during the season) – (mm of water in the soil at harvest)]

To measure 'water infiltration into the soil during the season':

- compare neutron probe readings before and after each fall of rain through the season
- calculate the rainfall increment (millimetres of water infiltrated into the soil)
- add the total for the season.

Where soil moisture data cannot be obtained, use April to October rainfall minus 110 mm as a rough approximation of water input to the soil. The subtracted value of 110 mm is an estimate of evaporation losses.

Another useful calculation is water storage efficiency during fallow (Fallow Efficiency; %):

Fallow Efficiency

$$= \frac{\text{increase in mm of water stored in the soil during the fallow}}{\text{mm of rainfall received during the fallow}} \quad \text{x } 100$$

A fallow efficiency ratio of 100% means that all rainfall received during the fallow has been stored in the soil profile. A value close to 0% means that little water received by the soil has been stored. It has been lost by runoff, evaporation, and/or transpiration by weeds. Aim for a high fallow efficiency as well as a good water use efficiency.

This water storage efficiency calculation can also be made for single large falls of rain during the growing season. A rain gauge will need to be installed close to the soil moisture monitoring sites.

INTERPRETING WATER USE EFFICIENCY DATA

A lower-than-usual water use efficiency for a given paddock will alert you to possible compaction or hard layers in the soil. Water use efficiency is a guide to which paddocks to check with backhoe pits. Poor water use efficiency may also be due to:

- disease
- weeds
- timing of rainfall during the growing season (expect a higher WUE in seasons when rain falls around flowering time for the crop compared to seasons when a lot of rain falls shortly after sowing or around harvest).

Comparing water use efficiency figures with other farmers in your area can provide insight into management factors such as sowing time, crop nutrition, and disease and weed control. Do not compare water use efficiency figures for different crops as some crops use water more efficiently than others.

Paddocks with high water use efficiencies are the best paddocks for cropping next season. For paddocks with low water use efficiencies, consider repair strategies such as a pasture phase.

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See Chapter D4 for more information on improving soil structure for seedling and root growth.

Note that water use efficiency applies to the previous season's water cycle. Any degradation that occurs following the termination of the growing season will not be exposed using this method. For example, soil damage during harvest or fallow will not be detected by water use efficiency calculations but may affect water use efficiency in the forthcoming season.

Water use efficiency may vary from farm to farm. The important thing is to look at the relative performance of different paddocks.

Example

Assume for paddock A:

- water use is 270 mm
- yield is 4000 kg/ha (4 tonnes/ha)
- CWUE = 4000/270 = 14.8 kg/ha per mm of water.

(CWUE is Crop Water Use Efficiency)

Assume for paddock B:

- water use is 250 mm

- yield is 2500 kg/ha (2.5 tonnes/ha)
- CWUE = 2500/250 = 10 kg/ha per mm of water.

We can see that there may be room for improvement in paddock B even though the overall water use was lower than for paddock A. You should aim for a CWUE of around 15 kg/ha per mm of water. Maximum CWUE's for dryland farming in Central Western NSW are considered to be around 20 kg/ha per mm of water.