NSW DEPARTMENT OF
PRIMARY INDUSTRIES

SOILpak – vegetable growers - Readers' Note

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Chapter D1. Soil examination and structural rating

PURPOSE OF THIS CHAPTER

To describe the how to examine and rate your soil

CHAPTER CONTENTS

- gathering farm and paddock information
- examining surface soil

ASSOCIATED CHAPTERS

- A3 ‘Features of soil’
- B1 ‘Common problems’
- B6 ‘Does my soil need gypsum?’
- B8 ‘Dispersion’
- B9 ‘How do I control erosion?’
- D2 ‘Soil texture tests’
- D3 ‘Chemical tests’
- D4 ‘Slaking and dispersion’
- D5 ‘Sodic soil management’
- D7 ‘Cultivation and soil structure’
- D8 ‘Landforming and soil management’
- E1 ‘Key checks for productive irrigated soils’

SOIL TESTING AND STRUCTURAL RATING

This part of the SOILpak involves observations and measurements that can be done to gauge the condition of your soil as a medium for vegetable growth. The following topics are discussed in this section.

1. FARM AND PADDOCK INFORMATION

Before you examine the soil profile, spend a little time describing the paddock. Such background information will help you to place in context the features that you find on and beneath the soil surface.

Table D1–1 and the other tables in this chapter give examples of how you would fill in details for section 1 of the soil description sheet found in Appendix 2.

Farmer, property, paddock

Record the location of the inspection. If this is your own property, the name of the farmer may seem unnecessary, but a horticulturist using the sheet may visit many farms and will need a record of the location.

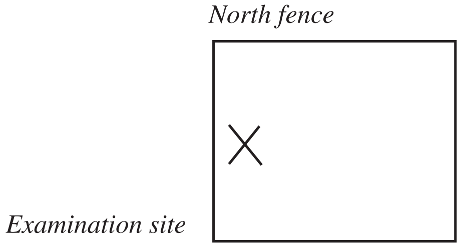
Table D1–1. Farm and paddock information

1. Farm and paddock information

Farmer: *Trevor Fosdyke* Property: *"Carlton"* Paddock: *Driveway* Date: *13/2/97* Inspected by: *Trev*	Paddock history: *previous crops, yield, fertiliser, tillage, disease?* Reason for inspection: *Check for any probs. before sowing vegies – suspect a "plough pan" from prior cultivations*

Sketch a map of site, extra notes etc.

Paddock was disced when wet. May be a plough pan



Reason for inspection

Clarify why you are examining a soil. The reason for inspection often suggests a cause of the current paddock condition, and that in turn suggests which features to examine first. After examining those features, you can reassess your first impression.

Paddock history

Sometimes the first sign of a soil structural problem is poor crop growth. Seedling emergence may be sparse; seedlings may be slower to emerge and develop; plants may be shorter than plants in other paddocks; or there may be variation in plant height within one paddock. A crop may appear to run out of soil moisture because its roots cannot penetrate a hard layer to reach moisture lower down, or moisture from irrigation does not penetrate very far into the soil.

Take into account the effect that the previous crop may have had on soil fertility. For example, a previous crop may have depleted the soil nitrogen. Did you apply enough fertiliser? If you didn't use fertiliser, was the bare fallow long enough to mineralise organic nitrogen? How many crops since a legume phase? Any periods of waterlogging? Was the ground compacted during harvest?

Accurate and detailed records are a great help in determining the cause of poor crop growth. From your farm diary (if possible, for the last five years), note:

- crops grown
- their yields
- if applicable, their protein content
- plant diseases
- monthly rainfall for the same period

- lime or gypsum applications
- fertiliser applications.

Of course, poor growth may be due to many factors other than a degraded soil structure: cold weather, disease, inadequate soil water, poor nutrition, waterlogging and so on.
Make a sketch of the site as a record. You may want to go back to the same site and investigate further.

2. INITIAL OBSERVATIONS

Initial observations

- record depth at which layers/horizons seem to change
- record some features of any observable horizons in Table D1–2.

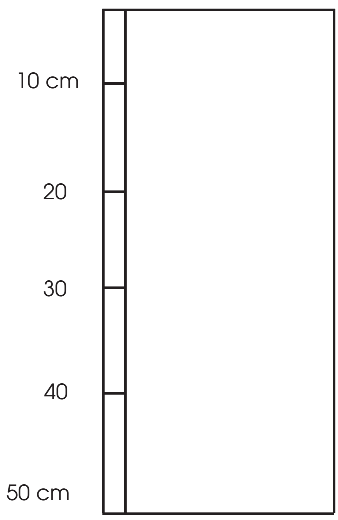
Table D1–2. Initial observation recording sheet

2. Initial observations

(i) record depth at which layers/horizons seem to change
(ii) record some features of any observable horizons in table

Observable horizon depth	Moisture	Colour	Texture	Bleaching	Lime or Gypsum	Cementing	Dispersion (0 – 16)

Indicate where horizon boundries occur (if any), and any additional info.on profile diagram



Soil Group (see introduction chapters for description of soil groups)

- Sandhill soil ☐
- Red-brown earth ☐
- Transitional red-brown earth ☐
- Alluvial soil ☐
- Self-mulching clay ☐

The initial observations are used to gain a basic understanding of the soil you are dealing with. From these observations the soil can be also grouped into one of five soil groups used in this SOILpak. Since many of these features, such as colour, texture and horizon depth, are unlikely to change quickly, this observation need only be carried out once at the same site.

Method

1. Pick a site. This may be representative of the paddock or an area of particular interest.
2. Dig a hole. The deeper the better, but at least 40 cm. The hole should be large enough to get a clear view of one side of the hole.
3. Using a knife, flick out small amounts of soil from the soil face to remove smearing caused by the shovel.
4. Using colour and texture, try to determine different layers in your soil. The soil texture test is described in Chapter D2. Record these layers (horizons) on your soil description sheet.
5. Measure the depth at which boundaries between horizons occur, and record this on the soil description sheet, along with the colour and texture of each horizon.
6. Make an assessment of the soil moisture, bleaching, and lime or gypsum for each horizon, and record the details.
7. Take soil samples from each layer to conduct dispersion tests. Slaking and dispersion tests are required when assessing surface structure (the next section of the soil description sheet). The dispersion test for soil from each horizon can be conducted when assessing surface soil dispersion.
8. Using the information obtained from your initial observations and Chapters C1 to C5, place the soil that you examined into one of the five soil groups listed on the soil description sheet.

Remember: The depth and texture of the topsoil (if there is any topsoil) are important in determining the soil group.

Colour

The assessment of intact soil colour is for the colour of intact aggregates, as distinct from the smallest aggregates. Colour may be useful for distinguishing between soil horizons. Red colours can indicate a freely drained soil (unless sodic). Yellow, greenish or bluish colours may indicate poor drainage. Plant residues buried in wet soil may induce a bluish colour in the surrounding soil; decomposition of the organic matter uses up oxygen and creates an anaerobic zone for a short time. Mottling (blotches of colour different from the main soil colour) indicate that the soil may have been periodically waterlogged in the past, but not necessarily now.

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To assess intact soil colour, break a moist aggregate and judge the colour. Use broad categories.

Texture

Soil texture is an estimate of the amount of clay, silt, and sand in a soil. Soil texture is assessed by the behaviour of a small handful of soil when moistened and kneaded into a ball and then pressed out between thumb and forefinger. It depends mainly upon the proportions of gravel, coarse sand, fine sand, silt and clay in the soil.

When to assess surface soil texture

Texture is a basic property of a soil. It changes extremely slowly (over thousands of years). However, operations such as deep tillage may bring up subsoil, and earthworks may expose subsoil, changing surface soil texture.

It is important to repeat the assessment at various depths. Texture at various depths is, together with soil colour, an indicator of soil type. Soil type is important in determining soil management.

Soil moisture

Soil moisture can be rated as:

- dry
- moderately moist
- moist
- wet.

Tillage at the wrong soil moisture content can degrade soil structure. You can also assess moisture for sowing. If you are contemplating deep tillage, a knowledge of subsoil moisture will help you decide on the likely effect.

Bleaching

Look for a layer that is paler than the upper part of the topsoil. It need not be white—just a paler colour. It may be a continuous layer, or may occur as scattered patches across a paddock.

Some soils have a bleached layer in the lower part of the topsoil. This bleached layer is paler than the upper part of the topsoil, but is still part of the topsoil.

The bleaching is caused by waterlogging, usually because a poorly permeable subsoil prevents the topsoil from draining.

A bleached layer alerts you to past waterlogging. The subsoil may be restricting drainage from the topsoil, as well as restricting root growth. Subsurface drainage may be necessary.

Cementing

Look for a hard layer. You can distinguish a cemented layer from a plough pan (compacted layer) as follows. A cemented layer does not slake when a dry piece is placed in water, and it does not soften when it is wet. The opposite is true of a plough pan. Sometimes soils have a layer of naturally hard material. The layer is chemically cemented and may consist of lime, iron or silica. Such a layer impedes drainage and root growth.

Deep tillage is the accepted way to break up a cemented layer.

☞ *See Chapter D4 for more information on slaking and dispersion.*

Lime or gypsum

Lime can occur as particles too small to see, or as white nodules up to 5 cm across. If the soil fizzes when a dilute acid (dilute hydrochloric acid or vinegar) is dropped on it, lime is present.

Gypsum occurs as crystals that are colourless, white or tinged pink. The crystals are usually needle shaped, but are occasionally are shaped like whole fingernails.

Both lime and gypsum are sources of calcium. Lime is calcium carbonate, and gypsum is calcium sulfate. Lime may occur in neutral or alkaline soils. It is a good sign if it is found close to the surface, since it helps to promote structural stability.

Gypsum will occur deep in the soil profile (usually below 70 cm), and so will not be seen with a shallow hole.

3. SURFACE SOIL

Table D1–3. Structural features of the soil surface

3. Soil surface

Structural features of the soil surface (for each feature, enter notes or simply tick)
Hard-set ....
Crusted ....
Pugged (damage from stock) ....
Cracked ....
Self-mulched ....
Cloddy ....
Friable ....

Cover % (crop, stubble, weeds):	Slaking (0 –4):	Dispersion (0–16):

Significance of surface structure

The structural form of surface soil influences water infiltration, run-off of water and, therefore, soil erosion and seedling emergence. Some soils can appear very well structured but still have infiltration problems. This is why it is important to do the slaking and dispersion tests, and to note whether the soil shrinks and swells. A soil that disperses is likely to form a surface crust and may also set hard on drying. A soil that slakes badly may do the same. A soil that shrinks and swells is able to repair its structure.

What does 'soil surface' mean?

The soil surface is the soil and surface cover that you see without digging. Surface cover (vegetation and plant residues) can be considered to be part of the soil surface, because surface cover influences soil surface properties. You may need to separate the components of the soil surface by removing the surface cover to see the actual soil.

How to assess surface soil structure

To examine the surface soil you may need a screwdriver or blunt knife to prise pieces out. Dig until you come to soil that has a different structure from the surface. Note the depth of the surface soil. The surface soil may be a 1 cm thick crust above better structured soil, or it may be a recently cultivated layer 10 cm thick above uncultivated soil.

The surface soil may take one of the following forms:

- The tilled layer in a recently cultivated soil that has not had rain to settle it. Such a surface layer may consist of fine aggregates or coarse clods. However, if rain on a cultivated soil creates a crust, then the crust is the surface soil because its structure is different from that of the soil below. The soil below is then referred to as subsurface soil.
- The loose material above a firm (not recently tilled) topsoil. Such a layer may consist of loose, fine aggregates on a self-mulching soil, or a layer of separate grains of sand.
- Compacted, crusted or hardset soil, before you come to better structured soil. If the thickness is up to 1 cm, it is a crust. If the thickness is much greater, possibly the full depth of the topsoil, it may be a hardsetting soil.

To describe the surface structure follow these steps:

1. Note on the soil description sheet any of the surface features listed (Table D1–3).
2. Assess the amount of surface cover on the soil surface and record your assessment in the box on the soil description sheet.
3. Take samples of the surface soil for slaking and dispersion tests. Record the results on the soil description sheet.
4. Enter depths on the sheet for zones in the soil profile that you identify as being different from layers above and or below.
5. Conclusion: What are the main structural features of this soil (if any) that may be restricting maximum plant growth? Using information gathered in the sections 1–4 of the soil description sheet, state what soil group you have examined.

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See Chapter D4 for more information on the slaking and dispersion test.

Describing the surface features

Hard set

Self-mulching clays do not hardset. In these soils a hard surface layer may be due to pugging or dispersion.

Loams may hard set when the organic matter content is low. Check the paddock history. A long history of cropping with little or no pasture may be the cause. Retain stubble or sow pasture to protect the soil surface from raindrop impact, and to improve organic matter content.

Tillage to break the hardset layer may be required to establish plants, but till when the soil is close to the plastic limit to avoid dust formation, compaction or smearing. Minimum tillage or no till is of most benefit after the soil has been restored to good structure.

Crusted

Self-mulching clays: A fragile crust may occur, but is usually not significant enough to cause plant growth and infiltration problems.

Non self-mulching clays: a crust is likely due to the dispersive nature of these soils.

Red brown earths and transitional red brown earths: A crust may be due to low organic matter content, particularly in a fine sandy loam or a silty loam. If this is a cropping paddock, look at your paddock history to see how long it has been since the paddock was down to pasture. Have there been seedling emergence problems? A surface cover may reduce the tendency to crust. Increase the surface roughness to form hollows that will detain water and assist infiltration. Harrows will break a thin crust and may assist seedling emergence.

Cloddy
Self-mulching clays: A cloddy tilled layer will mellow (improve in structure with wetting and drying, or frost). Further tillage before mellowing is unlikely to improve soil structure. After the soil structure has mellowed, till only the depth of dry soil.

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See Appendix 1 for a description of 'plastic limit'.

Red brown earths and transitional red brown earths: A cloddy layer may require further tillage (only when a seedbed is required) when the soil is close to the plastic limit. A cloddy surface soil may be favourable for water infiltration.

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See Chapter D4 for more information on slaking and dispersion testing.

Dispersive
Determine the slaking and dispersion score of the surface soil. Record this in the separate boxes at the end of section 3 of the soil description sheet. It may help to determine whether gypsum will improve a crusted or hardset soil.

Cracked
A description of the intensity of cracking may be useful. It may influence your decision on the appropriate action for other features.

Pugged
Cracking clays recover from pugging as they dry and crack. Pugging damage on a cropping paddock can be alleviated by tillage when the soil is dry. Pugging damage to a self-mulching clay is probably best left to repair itself.

Loamy topsoils (red brown earths, transitional red brown earths) under heavy grazing pug when wet and pulverise when dry. Till a pugged cropping paddock when the soil is at the plastic limit. A pugged loam pasture will improve in time. Reduce the grazing pressure and allow root growth to open up the soil.

Friable
A friable surface is well structured. Provided that there are no root-restricting layers in the soil profile, this is a suitable soil for minimum tillage.

Significance of surface cover

The surface cover reduces the impact of raindrops, thereby protecting the surface structure. Cover also slows down water running over the surface, thereby increasing the intake of water to the soil at each irrigation or rainfall event. Large amounts of surface cover at sowing time can pose a problem to some planting implements.

4. SOIL PROFILE FORM AND RATING

The form of soil structure is a description of the arrangement of soil particles into larger units, and of the pore spaces between the units. It affects the movement of water through the soil, the movement of air into and out of the soil, and the ease of penetration by roots. Soil structural form is distinct from other aspects of soil structure such as structural stability and structural resiliency. In common usage, 'soil structural form' is often referred to simply as 'soil structure'. It does not take into account the effect of cultivation and traffic and how the soil structure will respond.

Of a number of paddocks with similar soil texture, those paddocks with good soil structure are more versatile than those with poor soil structure. You have a greater range of options when the soil structure is good.

Poor soil structure indicates the need for different management strategies: perhaps a change in irrigation frequency, minimising tillage or reduced stocking rates on wet soil.

Section 4 of the soil description sheet has columns for recording your assessments of several soil structural features. These assessments are used to form structure scores for individual zones or horizons in the soil profile.

The features, from left to right on the soil description sheet, are in priority order. They start with aggregate size, the feature that has the most influence upon the suitability for plant growth. After assessing and recording the structural features for each horizon, use Table D1–4 to decide upon structure scores for each zone or horizon.

Table D1–4. Structural form and rating

4. Soil profile: structural form and rating

Depth (cm) (%)	Aggregate size (cm)	Ease of fracture	New roots	Aggregate shape	Fracture faces	Peds within aggregates	Porosity (0–2)	Colour of smallest aggregates	Structure score (0–2)

When to assess soil structure

It is possible to record differences due to a single cultivation, as well as long-term changes. Use your assessment as a systematic way to check past decisions and plan future management. For example, before deciding to deep till, examine the soil to see if there is a real need for that operation. If there is a hardpan, measure its depth so that you can set the depth of the cultivation tines to break the pan. Check again after a short run with the machine to see if it is doing the job.

Depth

Enter depths on the sheet for zones in the soil profile that you identify as being distinctive. These zones may be the same as those described in the initial soil observations (section 2). However these horizons may need to be subdivided if structure varies greatly within each horizon.

Aggregate size

Small aggregates indicate a good tilth; large aggregates indicate cloddiness.

When you are examining wet soil it can be difficult to determine the natural fracture plane between aggregates, and hence their size. Very dry soil can have high strength because of interlocking aggregates. Use enough force to expose natural faces: hitting a dry lump with a hammer may be the best technique.

How to assess aggregate size

Break a lump of soil into smaller and smaller pieces, using moderate hand pressure. Take note of the size of the lump just before you begin tearing through the fabric of the soil, leaving a fine grainy surface. This is the point at which you are no longer breaking the soil along natural fracture planes: you are tearing the aggregate apart.

Note the most common size or note size differences where you have aggregates of widely varying size. For example, in a cloddy tilled layer, some clods may be larger than 4 cm, with the remainder of the soil made up of clods smaller than 1 cm or dust.

Ease of fracture

How to assess ease of fracture

Well structured soil parts along natural faces (the aggregates 'part' from one another). Poorly structured soil breaks where you apply the force: rather than along natural faces.

When you are examining dry soil, distinguishing between 'parting' and 'breaking' requires some experience. Think of dry, poorly structured soil as snapping apart. Dry, well structured soil crumbles into small aggregates: it is friable.

When examining wet soil, parting of aggregates from one another is easier to detect. Don't squash the soil, but tease it apart. If it fractures easily, it is well structured. If it will not part but stretches like dough or plasticine, or tears apart, such a piece of soil is poorly structured.

New roots

Significance of new roots

Roots, where present, are the best indicators of soil structure. New roots are indicators of current structure. Roots grow where they can: along the easiest path. A prolific growth of new roots **throughout the soil** indicates good soil structure. Where roots follow cracks and grow around aggregates rather than penetrating them, the structure is poor. Good soil structure allows roots to grow straight. Roots may bend or branch above a compacted layer. Unrestricted roots are round in cross section, where as roots in a compacted soil may show flattening or bulging.

How to assess roots

Follow some plant roots as you dig through the soil. Note any abrupt change of direction. This is a good way to detect a hardpan. If the soil is too hard for plant roots to grow vertically, they may turn and grow horizontally. Check also that roots growing vertically are not deformed. If there is evidence of healthy root growth well below the plough layer, there is no need to dig further.

Caution: Roots bend for reasons other than a restricting soil layer. Herbicide damage, soil diseases, and unfavourable soil pH can all cause roots to bend or branch. Also, do not confuse branching due to compacted soil with proliferation of lateral roots on a well structured soil.

Aggregate shape

How to assess aggregate shape

Look for undisturbed lumps of soil from the side of the hole that you dug, or from the middle of a new spadeful.

Using the description of aggregate shape and size in Figure D1–1, observe and record the aggregate shape and size for each horizon. The shape of aggregates depends upon the forces acting on the soil. Tillage and traffic change the shape from what is considered natural.

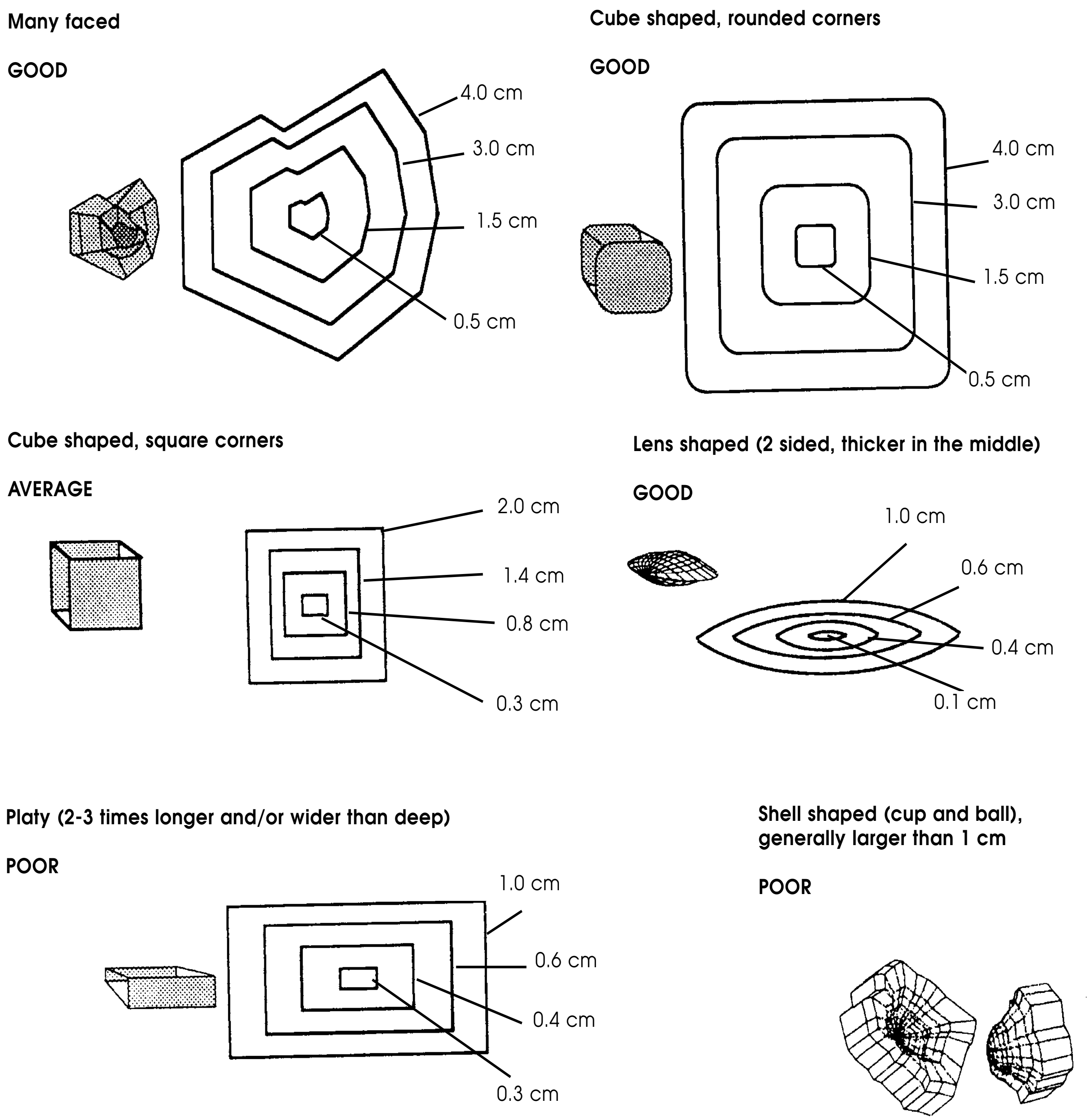
Massive. Massive aggregates are dense and have few pores. They appear dull. ‘Featureless’ would be an apt description. Massiveness is a sign of poor structure.

Many-faced aggregates. Many-faced aggregates are a sign of good structure. They may be loosely joined as a thin, fragile crust (not usually strong enough to inhibit seedling emergence) or bound into a very porous, crumbly aggregates.

Cube with square corners. These aggregates occur naturally in non-self-mulching clays and have sharp edges, but may also be the products of a massive block fractured by drying. Knowledge of similar soils in the area helps here: look under trees or pasture to see if that soil type naturally has aggregates with square corners.

Platey aggregates. Platey aggregates (Figure D1–2) show as obvious horizontal layering in the soil profile, or may show in the way a lump of soil parts. Prise a lump from the soil and remember its orientation. Break it into smaller pieces by forcing it in different directions. If it parts more easily along horizontal fractures than in other directions, and produces flat plates, it is platey. Platiness is a sign of poor soil structure.

Figure D1–1. Common aggregate shapes and sizes



A thick platey layer is worse than a thin one. Platiness is common under wheel tracks and does not usually occur deeper than 30 cm below the surface.

Cube with rounded corners. These aggregates occur naturally, together with many faced aggregates, below the surface. They may fit together in larger aggregates and are a good sign.

Lens-shaped aggregates. Lens-shaped aggregates occur naturally in clay subsoils and are a sign of good structure. Such aggregates may be hard to find, because often we see only part of a large lens-shaped aggregate (half a lens appears as wedge-shaped). Lens- or wedge-shaped aggregates usually part into smaller aggregates. They occur at all angles in the soil, although larger aggregates typically have a face at 45° to the horizontal.

Figure D1–2.

Platey aggregates. (Justin Hughes)

Shell-shaped aggregates. Shell-shaped aggregates are another sign of degradation in clays. You may find clods that separate along a cup-and-ball-shaped fracture, suggesting that one clod has been pressed into another. This is a sign of poor soil structure. Shell-shaped aggregates are distinct from lens-shaped ones: shell-shaped aggregates are tightly curved and have dull faces.

Fracture faces

In clays, the fracture faces may be shiny, indicating a natural fracture plane between aggregates, or dull, indicating that the soil has been remoulded (Figure D1–3). In loams, rough faces with many pores indicate good structure.

Figure D1–3.

Dull and shiny aggregates. (Justin Hughes)

What to look for

Examine the faces of a lump of soil removed from the side of a hole. Break the lump apart to reveal the faces between the aggregates. A good way to learn to recognise the different kinds of fracture face is to compare soils that have been treated differently: for example, compare soil from a pasture with soil from a wheel track, or soil from a plough pan with soil from below the pan.

Moderating factors

Do not confuse natural shiny faces with the shiny smeared layers made during cultivation.

Proportion of small aggregates (peds)

Significance

This observation refines the observation of aggregate size by demonstrating the internal structure of larger aggregates. It confirms other observations, such as ease of fracture, aggregate shape and fracture faces.

Moderating factors

Moisture content has a large influence on the soil's behaviour in this test. However, it is possible to distinguish soils that are puggy when wet, or brittle when dry, from those that are friable.

How to assess the proportion of smallest aggregates

Roll an aggregate gently between the thumb and forefinger to break it down. Record the proportion of the breakdown products that are shiny faced (in clays) or that are more than single grained (in loams).

Porosity

What to look for

Look at the soil and feel how it breaks. Attempt to break a lump into smaller and smaller pieces. The feel of the soil (crumbly for good structure; doughy, flinty or powdery for poor structure) also tells you if the soil is porous. Rate porosity by the potential pathways for root penetration. Score porosity as 0 (no visible pores), 1 (moderate number of pores) or 2 (many pores).

What is porosity?

Porosity refers to the number of pores in the soil. Pores are the spaces between and within aggregates. Macropores are relatively large and most can be seen with the naked eye. They include the spaces between aggregates caused by cultivation, shrinking and cracking, and channels made by plant roots and insects and earthworms.

Significance of porosity

Pores large enough to see are the means by which water, nutrients and air are able to move into and through the soil. Root growth is sparse within non-porous clods, consequently limiting nutrient and moisture extraction.

Moderating factors

In dry soils it is more difficult to feel porosity, because even well structured soils are hard when dry. It is best to assess the soil when it is moderately moist.

Colour of smallest aggregates

Significance

Well structured soils generally have strong colours because of their high organic matter content and/or high iron content. Therefore, dark grey or reddish brown colours indicate good structure. Pale colours such as light grey or a slight brown indicate less well structured soil. Bluish colours indicate a tendency to waterlogging. **Note** that this observation is the lowest priority in scoring the overall structure.

Structure score

The structure score is determined by the scores assessed as per Table D1–5.

Note that sodic layers have an ESP > 6: see 'Chemical tests', Chapter D3; or DI > 8: see 'Dispersion index' on page D4–6; these are likely to score less than 1.

Now that you have assessed you soil structure you can minimise structural damage by using the correct implements and tilling techniques (Figure D1–4).

Figure D1–4.

The Connor Shea 8000™ series minimum tillage seeder, showing flat coulter discs for cutting stubble and narrow T-boot tines. This machine can sow pasture seed directly into the cover crop stubble or pasture that has been sprayed off and helps minimise structural damage. (Ben Rose)

Table D1–5. A numeral system for classifying soil structure

Features **Firm soil, moist**	**Score** **Firm 0 (F0)** **Poor structure**	**Firm (F1)** **Moderate structure**	**Firm 2 (F2)** **Good structure**
Aggregate size: width of natural subunits produced by moderate hand pressure	Mostly more than 50 mm wide	5–50 mm wide	Mostly less than 50 mm wide
Ease of fracture	Difficult for a spade or knife to penetrate; soil made up of large, tightly fitting blocks; breaks like plasticine	Moderate hand pressure needed to part blocks	Parts readily into porous subunits
New roots	Very few new roots	Medium number of new roots	Prolific growth of new roots throughout the sample
Aggregate shape	Massive, platey or shell-shaped	Mixed shapes	Many-faced, cube with rounded corners, lens or wedge
Fracture faces	Soil breaks along the line of force applied in any direction into units with sharp corners; internal faces have no protruding subaggregates	Some natural separation planes with shiny faces, but most fracturing is along the line of force to produce angular corners and smooth, dull internal faces	Natural fracture planes dominate; most of the faces are smooth and shiny. Often there are protruding, many-faced, round-cornered aggregates
Peds within aggregates: proportion of smaller aggregates revealed by rolling the sub units between thumb and forefinger	Less than 10% of breakdown products are shiny-faced aggregates (clays) or larger than single grains (loams)	50% of breakdown are shiny-faced aggregates (clays) or larger than single grains (loams)	More than 90% of breakdown products are shiny-faced aggregates (clays) or are larger than single grains (loams)
Porosity: internal porosity of smallest aggregates	Porosity rating mostly 0	Porosity rating mostly 1	Porosity rating mostly 2
Colour of smaller aggregates	Bluish	Light grey or slightly brown	Dark grey to strong, deep red
Extra notes for dry soil	Requires a very strong blow with an implement to break the blocks, revealing smooth, dull faces with sharp corners; flinty	Hard hand pressure required to break the blocks	Falls apart with light hand pressure to produce small, natural aggregates
Loose soil, moist Features	Loose 0 (L0) Poor structure	Loose 1 (L1) Moderate structure	Loose 2 (L2) Good structure
Aggregate size	Diameter of the dominant fraction usually more than 20 mm	Diameter of the dominant fraction usually between 5 mm and 20 mm	Diameter of the dominant fraction usually less than 5 mm

Table D1–5. A numeral system for classifying soil structure (continued)

Features **Loose soil, moist (continued)**	**Score** **Firm 0 (F0)** **Poor structure**	**Firm (F1)** **Moderate structure**	**Firm 2 (F2)** **Good structure**
Ease of fracture into constituent natural sub-units, if present	At least half the soil is large, dense and massive clods; dull and smooth fracture faces	At least half of the larger compound aggregates can be parted by moderate hand pressure into their constituent natural aggregates	Comprised wholly of natural aggregates that may be separate or compound (very easily parted by hand into their constituent natural aggregates). When broken, the aggregates separate along many-angled, often shiny faces. If shiny faces are not evident, the soil has obvious pores and is friable
Aggregate shape	Cube-shaped with square, sharp edges, or shell-shaped	Mixed shapes	Many-faced, or cube-shaped with rounded edges
Porosity: internal porosity of smallest aggregates	Porosity rating mostly 0	Porosity rating mostly 1	Porosity rating mostly 2
Extra notes for dry soil	A large proportion of large, hard, flinty clods with sharp edges	As above, but compound aggregates are firmer; some are flinty	As above

Chapter D2. Soil texture tests

PURPOSE OF THIS CHAPTER

To describe how to test your soil texture

CHAPTER CONTENTS

- soil texture testing

ASSOCIATED CHAPTERS

- A3 ‘Features of soil’
- D4 ‘Slaking and dispersion’
- D5 ‘Sodic soil management’
- D6 ‘Improving soil structure by crop rotation’
- D7 ‘Cultivation and soil structure’
- E1 ‘Key checks for productive irrigated soils’
- E2 ‘Management strategies for key checks’

TESTING YOUR SOIL TEXTURE

Soil texture is an estimate of the amount of clay, silt and sand in a soil. Soil texture is assessed by the behaviour of a small handful of soil when it is moistened and kneaded into a ball and then pressed out between the thumb and forefinger. It depends mainly upon the proportions of gravel, coarse sand, fine sand silt and clay in the soil.

Texture varies from place to place. Many paddocks are not uniform, and it is wise to check the texture in several places within a paddock. Texture variation may help to explain differences in plant growth between parts of a paddock or between different paddocks. Compare a sample of soil from one sampling place with soil from another place to help you to gauge relative differences in texture. Gauging relative differences in texture is easier if two soil samples are assessed at the same time: one in each hand.

Take a sample of soil sufficient to fit comfortably into the palm of your hand. If hard and dry, crush into small crumbs underfoot. Moisten the soil with a little water, and knead it until the ball of soil no longer sticks to your fingers. Add more soil or water to attain this condition. Continue kneading and moistening until there is no apparent change in the feel of the soil ball; this usually takes one to two minutes. The ball of soil is now ready for you to assess the texture: see Table D2–1.

Table D2–1. Guide to determining soil texture

Filed texture group	Coherence	Feel	Other features	Ribbon length mm	Texture grade	% clay
Sands	Nil	Sandy	Single sand grains stick to fingers	Nil	Sand (S)	< 5
	Slight	Sandy	Discolours fingers with organic stain	5	Loamy sand (LS)	5
	Slight	Sticky	Sandy grains stick to fingers and discolours with clay stain	5 to 15	Clayey sand (CS)	5 to 15
Sandy loams	Just coherent	Sandy	Medium sand readily felt	15 to 25	Sandy loam (SL)	10 to 25
	Just coherent	Sandy	Fine sand can be felt	15 to 25	Fine sandy loam	10 to 25
Loams	Coherent	Spongy, greasy	No obvious sandiness or silkiness	25	Loam	25
	Coherent	Smooth	Silky; very smooth when manipulated	25	Silt loam (SiL)	25
Clay loams	Strong	Sandy	Medium sand in a fine matrix	25 to 40	Sandy clay loam (SCL)	20 to 30
	Coherent	Smooth, sandy	Fine sand, can be felt and heard	40 to 50	Fine sandy clay loam (FSCL)	20 to 30
	Strong	Smooth	No obvious sand grains	40 to 50	Clay loam (CL)	30 to 35
	Coherent	Smooth	Silky	40 to 50	Silty clay loam (SiCL)	30 to 40
Light clays	Coherent	Plastic	Fine to medium sand	50 to 75	Sandy clay (SC)	30 to 40
	Coherent	Plastic	Smooth and silky	50 to 75	Silty clay (SIC)	35 to 40
	Coherent	Plastic	Smooth with slight resistance to shearing	50 to 75	Light clay (LC)	35 to 40
Medium & heavy clays	Coherent	Plastic	Smooth; handles like plasticine; moderate resistance to shearing	75+	Medium clay (MC)	45 to 55
	Coherent	Plastic	Smooth; handles like plasticine; firm resistance to shearing	75+	Heavy clay (HC)	> 50

TERMS USED IN TABLE D2–1

Coherence
The ability of the ball to hold together.

Sandy
Feels gritty, and you can see coarser sand grains. Very fine sand grains (too small to see, and feel a bit like silt) make a grating sound as you rub the soil between your fingers.

Spongy
Typical of loams; also, a high organic matter content creates a spongy feel.

Silky
The smooth, soapy, slippery feel of silt.

Plastic
The ball can be deformed and it holds its new shape strongly. Typical of clays.

Resistance to shearing
How firm the soil feels as you form a ribbon. (Place the ball of soil between your thumb and forefinger and squeeze, sliding your thumb across the soil.) The firmness is a good way to distinguish light, medium and heavy clays. A light clay is easy to shear, a medium clay is stiff, and a heavy clay is very stiff, usually needing two hands to form a ribbon.

Ribbon
Make a ribbon by kneading the ball of soil with your thumb, gently pressing it out over your forefinger. The longer the ribbon you can make, the more clay is in your soil.

Chapter D3. Chemical tests

PURPOSE OF THIS CHAPTER

To describe how various chemical tests can help you find out more about your soil

CHAPTER CONTENTS

- pH
- organic matter
- salinity
- exhangeable cations and clay dispersion

ASSOCIATED CHAPTERS

- A3 'Features of soil'
- B5 'Does my soil need lime'
- B7 'Managing saline soils'
- B8 'Dispersion'
- D4 'Slaking and dispersion'
- D5 'Sodic soil management'

CHEMICAL SOIL TESTS

Several commercial laboratories offer soil chemical testing services that describe the nutrient status of soil and give fertiliser recommendations. These services usually do not include direct measurements of soil structure. However, chemical testing, as well as providing valuable information about the chemical fertility of the soil, can also give some indirect information about a soil's physical condition. This can help you to decide how to manage it (Figure D3–1).

Figure D3–1.

Deep rippers, hillers and 'dammer dykers' assembled on one tool frame. The deep rippers help break up the sodic subsoil in clays. (Ben Rose)

SOIL PH

The standard method of measuring soil pH is with a suspension of 1 part air-dry soil by weight to 5 parts liquid by volume. The recommended liquid is 0.01M $CaCl_2$ (calcium chloride). Results in this case are reported as pH ($CaCl_2$). Distilled water is sometimes used in place of calcium chloride, in which case results are reported as pH (water). Soil tested in $CaCl_2$ solution gives pH values about 0.5–0.8 lower than the same soil tested in water.

Interpreting soil pH

The pH ($CaCl_2$) of many vegetable-growing soils can vary down the profile and between sites, from strongly acid (less than 5) through to strongly alkaline (greater than 8). Values of pH between 5 and 8 are very common.

A low pH (less than 5) is detrimental to plant growth, not because of the acidity itself, but because of imbalances in nutrient levels. Phosphate is poorly available, and aluminium and/or manganese may be present in toxic concentrations. Lime is needed to raise the pH.

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See Chapter B5 for more information on the effect of pH on vegetable production.

A pH greater than 8 indicates possible high levels of exchangeable sodium or magnesium, and therefore a tendency for the clay to disperse (producing poor soil structure). Phosphate, iron, zinc and manganese are poorly available.

A desirable pH ($CaCl_2$) range for plant production is 5.5 to 7.5.

ORGANIC MATTER

Changes in organic matter levels over time (several years) will indicate the effects of a management system on soil condition. A high level of organic matter generally indicates better soil structure. In cracking clays, organic matter may not be quite as important to soil structure as it is in other soils. Be wary of reported organic matter contents that do not state the method used.

Converting organic matter values

The average carbon content of soil organic matter is approximately 57%. Multiply the values for the organic carbon % by 1.75 to convert to organic matter %.

Interpreting organic matter values

Most soils in Australia, even in their natural state, are low in organic matter compared with soils in other parts of the world. Cultivation history, sample depth and soil type affect organic levels markedly. The following ranges are only a guide, and individual values could lie outside these ranges.

A virgin grey or brown cracking clay could have an organic matter content anywhere between 1.4% and 4.0% in the surface 0.1 m.

Typically, the red brown earths have organic matter levels of about 1.75% in the topsoil.

In the broad context of various soil types, regard an organic matter below 1% as very low, 1%–2% as low, 2%–4% generally satisfactory, and greater than 4% as high. As with much soil data, information on organic matter content becomes more useful when compared over different locations, management histories and times.

SALINITY – ELECTRICAL CONDUCTIVITY

Electrical conductivity (EC) is a measure of the ability of a liquid to pass an electric current. EC increases as the salinity (salt concentration) of the liquid increases. The units are dS/m (deciSiemens/metre)

EC_e is the electrical conductivity of a saturated soil-water extract. The water is removed from a just-saturated soil sample by a centrifuge or vacuum pump, and the electrical conductivity of the water extract is tested. EC_e is the preferred method of estimating soil salinity, because it best reflects how salinity will affect plant growth. However, it is very time consuming and is not a routine method.

$EC_{1:5}$ is the electrical conductivity of a suspension of one part air-dry soil by weight to five parts water by weight, as for pH (water). This is the most common method because it is easy to do. However, it is difficult to interpret. $EC_{1:5}$ values need to be converted to EC_e values so they can be interpreted.

Total soluble salts (TSS) used to be a popular way of expressing soil salinity and is still used by a few laboratories. TSS is not recommended, because it cannot be easily related to plant growth.

Converting EC values

Tables of salt tolerance use values of EC_e. If your result sheet shows TSS, first convert the values to $EC_{1:5}$ and then to EC_e.

Interpreting EC_e

Conventionally, saline soils are defined as those with an EC_e value greater than 4 dS/m. However, much lower levels of salinity than this can affect the growth and yield of sensitive plants such as maize, most legumes (beans, peas, clovers and, to some degree, lucerne) and some grasses

Saline soils are often friable, because the high salt concentration allows the clay particles to flocculate (form clusters) even when the soil has a high exchangeable sodium percentage.

Step 1

Convert TSS to $EC_{1:5}$ if necessary:

TSS units are mg kg^{-1} (ppm) or g/100 g (%). The following two formulae approximately relate $EC_{1:5}$ and TSS:

$EC_{1:5}$ (dS/m) = TSS (mg kg^{-1}) x 0.00031

$EC_{1:5}$ (dS/m) = TSS (g/100g) x 3.1

Example: TSS % of 0.015 g/100 g:

$EC_{1:5}$ = 0.015 x 3.1

= 0.047 (dS/m) (approx.)

Step 2

Convert $EC_{1:5}$ to EC_e:

To obtain an approximate value for EC_e multiply the $EC_{1:5}$ by a factor that depends on the soil texture (Table D3–1).

Table D3–1. Multipliers for converting $EC_{1:5}$ (dS/m) to an approximate value of EC_e (dS/m).

Soil texture	Multiply $EC_{1:5}$ (dS/m) by this number
Sand, loamy sand, clayey sand	23
Sandy loam, fine sandy loam, light sandy clay loam	14
Loan, fine sandy loam, silt loam, sandy clay loam	9.5
Clay loam, silty clay loam, fine sandy clay loam, sandy clay, silty clay, light clay, light medium clay	8.6
Medium clay	7.5
Heavy clay	5.8

Example: if a sample of medium clay has an $EC_{1:5}$ of 0.4 dS/m, then:

EC_e = 0.4 x 7.5 dS/m
= 3 dS/m (approx.)

Miscellaneous units for electrical conductivity
1 dS/m (deciSiemens/metre) equals
1 mS/cm (milliSiemens/centimetre)
or
1 mmho/cm (millimho/centimetre)

EXCHANGEABLE CATIONS

A few laboratories report exchangeable cations as mg kg^{-1} (ppm). It is more useful to express them as centimoles of positive charge per kilogram of soil (cmol (+) kg^{-1}), numerically equal to milliequivalents per 100 g of soil (me/100g). This takes account of the different valencies and atomic weights of different cations. Use the numbers in Table D3–2 to convert the units.

Table D3–2. Converting mg kg^{-1} to cmol (+) kg^{-1}.

Cation	Divide mg kg^{-1} by this number
Calcium (Ca)	200
Magnesium (Mg)	120
Potassium (K)	390
Sodium (Na)	230
Aluminium (Al)	90

Step 1
Convert mg kg^{-1} to cmol (+) kg^{-1}, **if necessary**

Step 2
Calculate the cation exchange capacity:

After converting the cation concentrations to cmol (+) kg^{-1}, add them to give an approximate value for the cation exchange capacity (the 'effective' CEC). Express each cation as a % of the effective CEC, as in the example (Table D3–3).

Caution: Never add values expressed as mg kg^{-1} or ppm. The result is meaningless.

Table D3–3. Example of calculating exchangeable cations as % of effective CEC.

Cation	mg kg^{-1}	cmol (+) kg^{-1}	% of effective CEC
Calcium (Ca)	3000	3000/200=15.0	100 x 15.0/34.9=43.0
Magnesium (Mg)	2020	2020/120=16.8	100 x 16.8/34.9=48.1
Potassium (K)	351	351/390=16.8	100 x 0.9/34.9=2.6
Sodium (Na)	512	512/230=2.2	100 x 2.2/34.9=6.3
Aluminium (Al)	nil	0	0
Total (effective CEC)		34.90	

Other cations (manganese, iron, copper and zinc) are usually present in only trace amounts and so do not contribute significantly to the total. In addition, soils with pH ($CaCl_2$) above 5 contain very little exchangeable aluminium, and so the effective CEC is the sum of the four cations calcium, magnesium, potassium and sodium. In the example, the effective CEC is 34.9.

Step 3

Note the ESP:

The exchangeable sodium percentage (ESP) in the above example is 6.3. This value gives a guide to the potential for clay dispersion. A clay soil with an ESP greater than 5 is prone to dispersion on wetting if its salinity is low.

Step 4

Calculate the Ca:Mg ratio:

Calculate the ratio of exchangeable calcium to exchangeable magnesium (Ca:Mg ratio) after converting the units to cmol (+) kg^{-1}.

Using the example in Table D3–3:

Ca:Mg ratio = 15.0/16.8 = 0.89 (no units)

EXCHANGEABLE CATIONS AND CLAY DISPERSION

The balance between the various exchangeable cations and the concentration of total salts (salinity, as measured by electrical conductivity) determines whether clay will disperse in water.

In general, non-saline soils with an exchangeable sodium percentage (ESP) above 5 are liable to disperse in water. The soil in the example in Table D3–3 has an ESP of 6.3 and may disperse.

A Ca:Mg ratio of less than 2 (particularly, less than 1) also indicates a tendency to disperse. The soil in the example in Table D3–3 has a Ca:Mg ratio of 0.89. Considering this and its ESP of 6.3, it is likely that such a soil would disperse if it were non-saline.

Free lime or gypsum can give false values for exchangeable calcium (overestimated by as much as 50%). Laboratories should use the Tucker method for exchangeable cations to minimise this error. This method uses an ammonium chloride leaching solution at pH 8.5, and measurement of the sulfate and carbonate content.

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In clay soils the higher the Ca:Mg ratio, and the lower the Na %, the higher the likelihood of the soil being self-mulching. Self-mulching clays usually have Ca:Mg ratios of 2 to 4, and a Na % of 3% or less. Non-self-mulching clays generally have Ca:Mg ratios of about one, with the Na % usually exceeding 5%.

Therefore, the Ca:Mg ratio and the exchangeable sodium percentage (Na %) are important indicators of the soil structural stability and land-use potential of clay soils.

Methods for testing exchangeable cations used by some laboratories can give false values for exchangeable sodium, if the soil is saline. Where the electrical conductivity (1:5 soil/water) exceeds 0.3 dS/m, the soil should be treated to remove soluble salt. If not pre-treated, such soils will produce inflated test values for exchangeable sodium, over-estimating ESP and indicating a need for gypsum where none may be needed.

Chapter D4. Slaking and dispersion

PURPOSE OF THIS CHAPTER

To describe how to interpret slaking and dispersion in a soil

CHAPTER CONTENTS

- slaking
- dispersion
- slaking scores
- management decisions in relation to slaking and dispersion

ASSOCIATED CHAPTERS

- A3 'Features of soil'
- B6 'Does my soil need gypsum?'
- B8 'Dispersion'
- D5 'Sodic soil management'
- E1 'Key checks for productive irrigated soils'

SLAKING

Slaking is the breakdown of a lump of soil into smaller fragments on wetting. It is caused when clay swells and the trapped air bursts out. Organic matter reduces slaking by binding mineral particles and by slowing the rate of wetting. This process occurs in all soil groups of the main vegetable-growing districts.

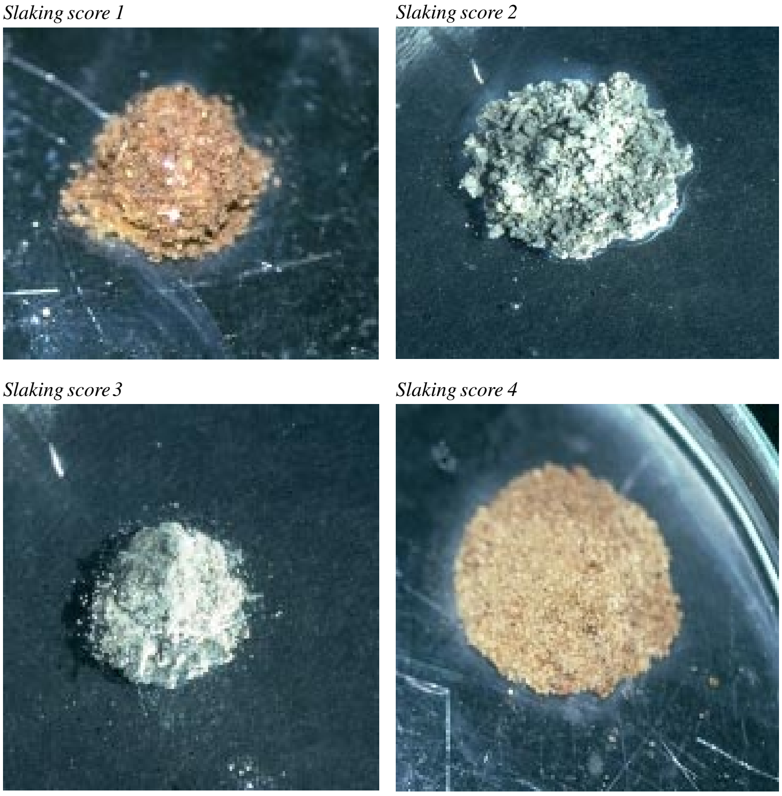
DISPERSION

Dispersion (the separation of soil into single particles) is governed by soil texture, clay type, soil organic matter, soil salinity and exchangeable cations. The dispersion index that is calculated here combines dispersion on wetting (immersing an air-dry aggregate in water), and dispersion after remoulding (immersing a piece of soil in water that has been kneaded and worked while moist).

Slaking and dispersion are soil characteristics that will have a large influence on the behaviour and management of a soil. A scoring system is used to allow comparisons between different soils (Figure D4–1). The two scores that can be calculated and used are:

- the slaking score (0–4)
- the dispersion index (0–16).

Figure D4–1. Slaking scores



SIGNIFICANCE OF SLAKING

Most cultivated soils in Australia are prone to slaking. The results can be either good or bad, depending on the size of the fragments produced.

Slaking is involved in the process of self-mulching, which occurs in many cracking clays. Self-mulching produces a loose surface layer of granular aggregates. Sometimes a thin, fragile crust caps the layer, but the crust is not strong enough to affect seedling emergence.

Crusting or hardsetting soils slake into very small fragments that run together and then set hard on drying. This condition is evident in many red brown and transitional red brown earths. The slaking test allows you to identify such problem soils.

SIGNIFICANCE OF DISPERSION

A soil that disperses on wetting has a very unstable structure. It can form a surface crust or hard clods on drying. Pores below the surface can become blocked by dispersed soil particles. Dispersive soil is likely to swell strongly when wet, further restricting water and air movement. Dispersion of soil slows down the intake of water to the root zone following rainfall or irrigation. This condition will result in poor water storage at each irrigation. Dispersion after remoulding means that, under wet conditions, the soil is likely to disperse after cultivation.

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See Chapter D5 for more information on sodic soil management.

SLAKING SCORE

Method

1. Take soil samples (usually only surface soil is tested for slaking) and allow them to air dry for 1 to 5 days, depending on how dry or wet the soil is.

2. Take several (at least three) small (3 to 5 mm diameter) crumbs of dry soil and place them in a dish or saucer of rainwater (or distilled water) deep enough to completely cover the samples.
3. Cover the dish to prevent wind from disturbing the water.
4. Assess the slaking score (0–4) after 5 minutes.
   After five minutes, score slaking as follows:
   Score 0 if the lump remains intact
   Score 1 if the lump collapses around the edges but remains mainly intact
   Score 2 if the lump collapses into angular pieces
   Score 3 if the lump collapses into small (less than 2 mm diameter) rounded pieces, forming a cone
   Score 4 if the lump collapses into single grains (you can see sand grains).

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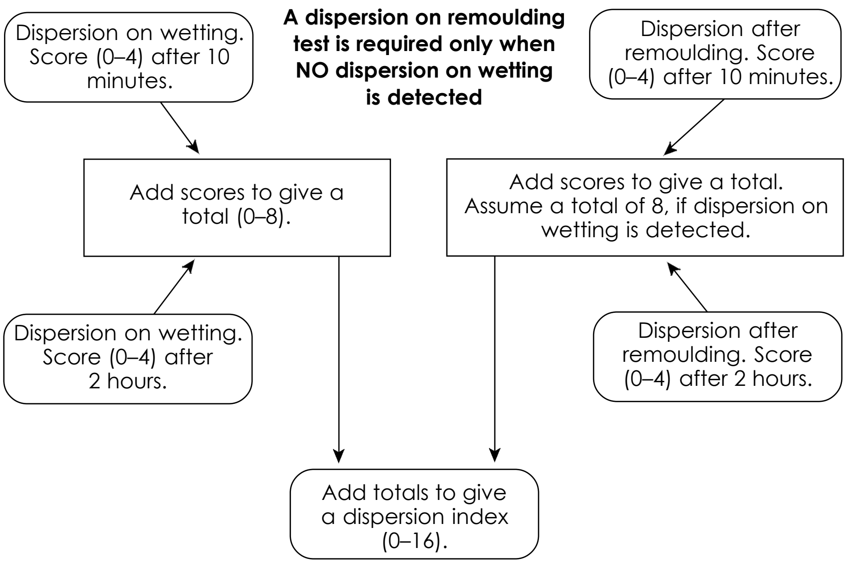
Tip: You may find it easier to use soil aggregates of 10 to 20 mm diameter to assess slaking. However, for dispersion tests you need to use aggregates of 3 to 5 mm diameter; therefore if you use the smaller size you can assess both slaking and dispersion on wetting in the one test.

DISPERSION INDEX

The dispersion index combines four separate dispersion scores (0–4); see Figure D4–2 for a full explanation.

Figure D4–2. The dispersion index combines four separate dispersion scores.



Dispersion on wetting

1. Take soil samples (usually only surface soil is tested for slaking) and allow them to air dry overnight
2. Take several (at least three) small (3 to 5 mm diameter) crumbs of dry soil and place them in a dish or saucer of rainwater (distilled water) deep enough to completely cover the samples.
3. Cover the dish to stop wind disturbing the water.
4. Assess the dispersion score (0–4) after **10 minutes** and **2 hours**. See Figure D4–3.

Samples used for the slaking test can be left in the distilled water and used to assess the dispersion scores.

Figure D4–3. Dispersion scores

Scoring dispersion

Dispersion score 0 : Nil dispersion

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

Dispersion score 2: Moderate dispersion with obvious milkiness

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

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

Dispersion after remoulding

If the soil does not disperse on wetting, repeat the test using soil that you have remoulded. The idea is to duplicate the state of the soil after cultivation.

1. Mix some soil with rainwater (distilled water) and remould it with a knife for one minute. Alternatively, you may use the sample after kneading it by hand to determine the texture.
2. Place small lumps (3 to 5 mm diameter) of the remoulded soil into a dish of rainwater deep enough to cover the samples. Remoulded samples should not be allowed to dry before they are immersed in the water.
3. Score dispersion after remoulding in the same way as dispersion on wetting.

Scoring dispersion

Score 0 Nil dispersion

Score 1 Slight dispersion, recognised by slight milkiness of water adjacent to the aggregate

Dispersion score 2 Moderate dispersion with obvious milkiness

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

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

See Figure D4–3.

DECISIONS TO MAKE IN RELATION TO THE SLAKING SCORE

Slaking score 0–1

This soil is stable to wetting. This is typical of pasture soils. No action is needed.

Slaking score 2

This is typical of self-mulching clays. They form a loose, granular surface layer, with perhaps a thin, fragile crust. If the soil does not disperse no action is necessary.

Slaking score 3

A score of 3 suggests that the surface may form a crust. This is typical of most soils covered in this manual, especially when cultivated. However, this is only a problem in non-swelling topsoils (sands, loams and some clay loams). Reduced cultivation, stubble retention and gypsum applications are all used to overcome this problem.

Slaking score 4

This soil is very likely to crust and hardset (sands and loams). Reduced cultivation, stubble retention and more frequent irrigations may be necessary on these soils.

DECISIONS TO MAKE IN RELATION TO DISPERSION INDEX

Dispersion index

0	
1	A very stable soil. Will resist dispersion after tillage.
2	Soil is still prone to compaction.
3	
4	Soil will disperse if cultivated wet, and deserves caution.
5	
6	Soil disperses strongly if cultivated wet.
7	May benefit from direct drilling and stubble retention.
8	
9	Possible need for gypsum. Investigate further with laboratory
10	tests. See Chapter D3.
11	
12	
13	
14	Clay disperses strongly, providing a poor environment for plant
15	growth. Gypsum application is necessary.
16	

Chapter D5. Sodic soil management

PURPOSE OF THIS CHAPTER

To describe how to manage sodic soils

CHAPTER CONTENTS

- problems caused by sodicity
- on-farm management of sodicity

ASSOCIATED CHAPTERS

- A3 'Features of soil'
- B6 'Does my soil need gypsum?'
- B8 'Dispersion'
- D4 'Slaking and dispersion'
- E1 'Key checks for productive irrigated soils'

WHAT IS SODICITY?

Sodicity is a term given to the amount of sodium held in a soil. Sodium is a cation (positive ion) that is held loosely on clay particles in soil. It is one of many types of cations that are bound to clay particles. Other types bound to clay particles include calcium, magnesium, potassium and hydrogen. When sodium makes up more than about 5% of all cations bound to clay particles, structural problems begin to occur, and the soil is said to be **sodic**. The amount of sodium as a proportion of all cations in a soil is the main measure of sodicity used, and is termed the exchangeable sodium percentage (ESP). This can be calculated from chemical soil tests.

☞ *See Chapter D3 for more information on chemical soil tests.*

Salinity is a measure of the concentration of the **soluble** salts contained in the soil. These salts are free to move in the soil water and can be readily taken up by plants. These salts, which move freely in the soil solution, are made up of positive and negative ions (cations and anions). At any time, many cations are bound loosely to the surfaces of clay particles and **are not** free to move in the soil solution.

Cations in solution will often swap with those bound to clay particles. Therefore, if saline water with a high proportion of sodium is applied to a soil, the proportion of sodium bound to the clay particles may increase due to swapping of sodium in solution on to the clay particles. Similarly, if a solution high in calcium (a type of cation) is applied to a soil, the proportion of calcium bound to clay particles may increase. The process of cations swapping from solution to be bound to clay surfaces and vice versa is called cation exchange.

WHY IS SODICITY A PROBLEM?

High sodicity causes clay to swell excessively when wet. The clay particles move so far apart that they separate (disperse). This weakens the aggregates in the soil, causing structural collapse and closing-off of

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See Chapter D4 for a test for dispersion.

soil pores. For this reason water and air movement through sodic soils is severely restricted.

In vegetable crops, sodic layers or horizons in the soil may prevent adequate water penetration when during irrigation, making the water storage low. Additionally, waterlogging is common in sodic soil, since swelling and dispersion closes off pores, reducing the internal drainage of the soil.

Sodicity of the surface soil is likely to cause dispersion of surface aggregates, resulting in surface crusts.

Self-mulching clays

These soils are well structured and non-sodic at the surface. There is generally more calcium rather than sodium attached to the clay particles; this is why self-mulching clays are well structured. The deeper subsoil of these soils can be sodic, so waterlogging is possible.

Non-self-mulching clays

These soils are sodic at or near the surface; the sodicity increases with the depth. Therefore, these soils are likely to have water storage and waterlogging problems. Establishment of crops is often difficult due to crusting and poor tilth.

Red brown earths

The topsoils of red brown earths are usually non-sodic, and relatively low in clay content. The subsoils are generally sodic and higher in clay content. This means that water penetration of the subsoil is low. Therefore a 'perched' watertable can form above the subsoils of red brown earths. Since water penetration of the topsoil is generally good, the deeper the topsoil the more water can be stored at each irrigation.

Transitional red brown earths

The topsoils of transitional red brown earths can sometimes be sodic. This will cause crop establishment problems such as crusting. The subsoils are generally sodic and will therefore swell and restrict air and water movement. If the topsoil is non-sodic, water will move though the topsoil relatively rapidly, but only very slowly into the subsoil. Water storage may be poor if the topsoils are shallow. In some soils of the Murrumbidgee Valley and at Colleambally, the subsoils are non-sodic clay, and appear to be well structured when they are exposed by landforming.

Sandhill soils

The topsoils of sandhill soils are very low in clay content and non-sodic. The subsoils may be sodic, and can cause plant growth problems if the subsoil begins within the root zone of the crop being considered.

ON-FARM MANAGEMENT OF SODIC SOILS

Determining whether your soil needs treatment

The first step in determining whether a soil needs treatment for sodicity is to determine how sodic it is. A dispersion test is described in Chapter D4. If this test gives a dispersion score of 6 to 16, then the soil may be gypsum responsive. In this situation do a soil test to calculate the exchangeable sodium percentage (ESP). (See Chapter D3.) Table D5-1 is a guide to the gypsum response of surface soil.

Table D5–1. Gypsum application rate with respect to soil ESP

Exchangeable sodium percentage (ESP) of cut area	Gypsum application rate t/ha
Greater than 5, less than 10	2–5 t/ha
Greater than 10	5 t/ha

Using gypsum

Gypsum contains calcium sulfate. Calcium sulfate is a salt, but unlike sodium chloride (the main component of salt in saline watertables) it is not toxic to plants. Gypsum will help to reduce swelling and dispersion of the soil through two mechanisms. These are:

1. Gypsum slightly increases the salinity of the soil solution, and hence reduces swelling. The same effect can be seen when using saline bore water, but this often contains high levels of sodium and chlorine that are toxic to plants. Gypsum will slightly increase salinity without any detrimental effect on plants.
2. Calcium from the gypsum will swap with the sodium that is held on the clay surfaces. This reduces the sodicity of the soil and is called cation exchange.

Gypsum can have its most beneficial effect at sowing time. It can provide better soil tilth, and can reduce crusting in sodic surface soils, hence improving establishment. If you use gypsum where the surface soil is sodic, time the application so that rain or irrigation does not leach the gypsum from the surface soil by sowing time.

Cultivation practices on sodic soils should be aimed at preserving soil organic matter in the surface soil. This is usually achieved by less aggressive, reduced tillage. Non-inversion tillage is useful for leaving the more sodic subsoil at depth.

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See Chapter D7 for more information regarding tillage practices.

In many soils of the Murray and Murrumbidgee Valleys (especially red brown earths), the topsoil is non-sodic and of reasonable depth (10 to 40 cm). However, these soils will often have sodic subsoils. Gypsum applications to these soils will have little effect on the topsoil but will increase the structure, aeration and permeability of the subsoils. This is likely to increase water storage and reduce waterlogging.

The depth of the non-sodic topsoil is an important consideration in the likely response of a sodic subsoil to gypsum improvement. Since a non-sodic topsoil is usually a better environment for plant growth anyway than a sodic topsoil, responses to gypsum will be low or unlikely when there is good depth of topsoil—the existing soil structure will allow optimum plant growth.

As a rough guide, if the non-sodic topsoil is greater than 15 to 20 cm deep, then a gypsum response may be unlikely. Remember, it may take a few months before gypsum leaches into the subsoil and begins to take effect.

Gypsum test strips

It is highly recommended that you do test strips before applying large amounts of gypsum. You may want to try some test strips at various rates (2.5 t/ha and 5 t/ha, for example). If a whole paddock is being treated, leave an untreated strip to show whether gypsum has had an effect. If the treated soil responds to gypsum, you will notice increased soil friability, less power needed for tillage, improved infiltration, less waterlogging, and better seedling emergence.

Lime application to sodic soils

Lime (calcium carbonate), like gypsum, is a compound containing calcium. Therefore it can contribute to reducing the effects of sodicity. However, lime is relatively insoluble at a soil pH ($CaCl_2$) above 5. In most soils of the Murray and Murrumbidgee Valleys the pH ($CaCl_2$) is above 5, so lime is of little benefit. If the pH is below 5, lime will help to reduce both acidity and sodicity problems. A mixture of lime and gypsum may be a good option on sodic soils with a pH ($CaCl_2$) in the 5 to 6.5 range, to provide a more long-lasting effect than gypsum only. Again, test strips are strongly recommended.

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See Chapter D7 for more information about cultivation practices.

Cultivating sodic soils

Sodic soils are more prone to structural degradation than non-sodic soils. For this reason they must be cultivated minimally and carefully. Excessive cultivation of these soils will cause major soil structure problems. In vegetable soils this may be evident as crusting, hardsetting and poor water penetration.

Deep ripping and gypsum

Deep ripping has shown to benefit water penetration, aeration and plant growth on poorly structured soils. However, the benefits of ripping are short lived, especially on sodic soils.

One technique that has shown benefits on sodic soils is the application of high rates of gypsum (5 to 10 t/ha) before deep tillage. This technique is even more successful when gypsum is concentrated into the rip lines, by being applied either directly into them or in a band before each ripping tine. This method concentrates the gypsum, allowing it to stabilise the rip lines against slaking and dispersion for longer periods of time.

Even when gypsum is applied at heavy rates it will leach out of the soil. Therefore ripping and gypsum will need to done every 2 to 3 years if the effect is to be maintained.

Remember to use non-inversion tillage for this operation.

Using saline irrigation water

Many farmers are now using bore water to irrigate crops and pastures. However, be careful with this as you may experience problems, including:

- a build-up in soil salinity and therefore a decrease in crop production
- an increase in soil salinity in districts such as the Murrumbidgee Irrigation Area, where much of the ground water is sodic.

As Figure D5–1 indicates, a sodic soil can be well structured if the soil is saline enough to prevent dispersion. This is why saline water or gypsum (a calcium salt) improves soil structure on sodic soils. However, avoid using saline water for irrigation, since:

- soil sodicity is likely to increase. If the sodicity increases and soluble salts are leached out (washed out) of the soil by fresh water, the soil will become poorly structured.
- soil salinity will increase.

However, careful irrigation does have its place (Figure D5–2).

Figure D5–1. The relationship between soil salinity, soil sodicity and soil structure

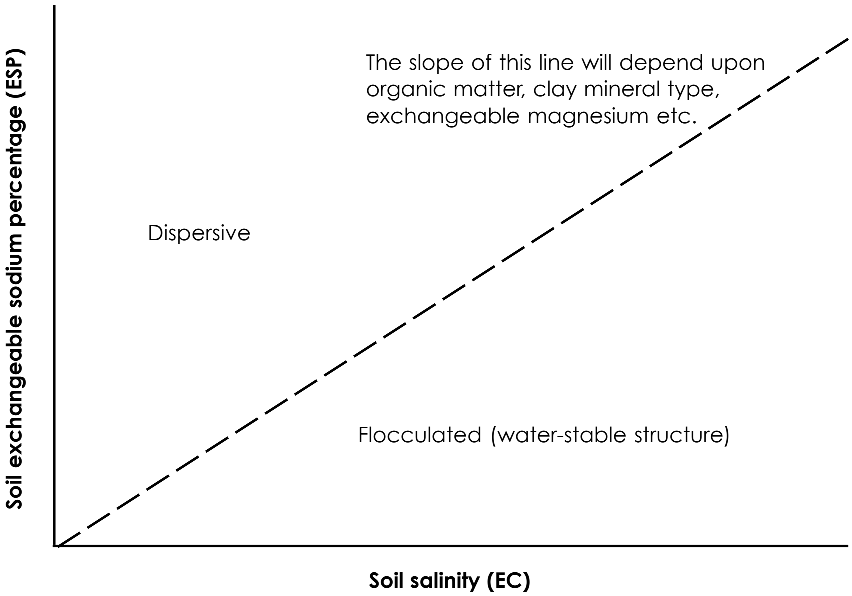

Figure D5–2.

Delegates at the Horticulture Downunder Conference, Barooga, inspecting trickle-irrigated tomato seedlings. Trickle irrigation is an important tool for overcoming soil salinity problems. (Bernie McMullen)

Chapter D6. Improving soil structure by crop rotation

PURPOSE OF THIS CHAPTER

To explain how to rotate crops and pastures to improve soil structural stability

CHAPTER CONTENTS

- contributors to soil structural stability
- effects of pasture and grazing

ASSOCIATED CHAPTERS

- A3 'Features of soil'
- D1 'Soil examination and structural rating'
- D7 'Cultivation and soil structure'

SOIL STRUCTURAL STABILITY

A soil's structural stability is its resistance to slaking and dispersion. A structurally stable soil will retain its structure when wet. Additionally, research has shown that improvements in the aeration and water penetration of loamy soils are related to the proportion of water stable aggregates that are bigger than 2 mm in diameter. In clay soils the critical size may be much smaller—0.25 mm.

Soils with poor structure need structural improvement to produce high yielding crops and pastures. Poor structure in the soil may be visible as:

- crusted or hardset topsoil (massive structure)
- pugged topsoil (damage from stock)
- slaking score greater than 2
- dispersion index greater than 8
- compacted zones, such as those under wheel tracks or plough pans.

Some soil structural problems are naturally occurring—for example, sodicity. However, most problems are caused by, or made worse by, human activity. Inappropriate use of cultivation is largely responsible for soil structural decline. However, you need to improve the structure of the soil first before you use any conservation tillage methods, such as direct drilling). A pasture or crop phase that allows a build-up of organic matter in the soil is usually the best method of improving soil structure and soil structural stability.

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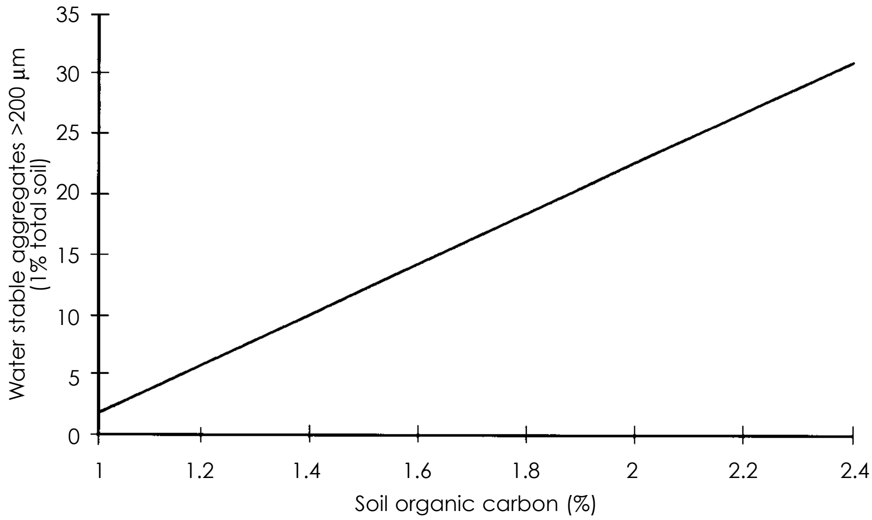
See Chapter D7 for more information on cultivation techniques.

Many studies have shown that the organic matter content of the soil has a strong influence on its stability, for example, on its resistance to slaking and dispersion (Figure D6–1). A soil that does not slake or disperse has the potential to be well structured if compaction is avoided, allowing for excellent plant growth under irrigated conditions.

Figure D6–1. Soil organic matter and structure



A build-up in soil organic matter is therefore likely to benefit soil structure and plant growth. Tisdall and Oates (1982) found that soil organic matter decline was most rapid in the following situations:

- after cultivation
- after a period of bare fallow
- when crop residues were removed.

One way to improve soil structure is by rotation of vegetable crops with pasture/cereal phases.

Note: If you do not use conservation tillage practices you will soon lose the crop benefits that come from soil improvement through rotation.

PASTURE AND SOIL STABILITY

Increases in structural stability (resistance to slaking and dispersion) are related to the amount of root material plus mycorrhizal fungi produced by a pasture.

Soil structure (as measured by the proportion of aggregates resistant to slaking) is best under virgin, uncultivated soil, followed by permanent pasture. The most unstable soils are those that alternate bare fallow with cultivation to produce crops. A pasture phase is useful for improving the structure of a poorly structured soil, since it allows the soil organic matter to build up. Pastures continually add organic matter to the soil via roots and decaying shoots. Pastures are not cultivated, and hence allow the soil organic matter and soil structure to improve.

Pastures must be productive to give maximum benefits to the soil. Therefore, an adequately fertilised and irrigated pasture will benefit the soil most through higher additions of organic matter.

Pastures protect the soil surface better than crops, since the surface cover is usually maintained throughout the year. This will benefit the soil in the following ways:

- The soil surface is protected from raindrop impact. Raindrop impact can destroy the soil surface structure, causing crusting to occur.

- Plant residues on the soil surface break down to form compounds that help increase the structure of the soil.
- Plant residues encourage the surface feeding of soil animals such as earthworms. Earthworm burrows benefit the soil by creating pores through the soil, encouraging the movement of water and air and the growth of plant roots.

The pasture type will also influence the soil. Grass pastures—especially those with extensive finely branched roots, such as ryegrass—have the most benefit. Additionally, grass pastures act as hosts for a beneficial type of fungus that lives in the soil in association with plant roots. This fungus (known as mycorrhiza), produces many long, thin filaments that act as a ‘glue’ to bind soil particles into aggregates. Ryegrass has been shown to improve soil structure dramatically because of its large, fibrous root system that acts as a good host for mycorrhizal fungi.

While ryegrass can help improve soil structure, so too can many other forms of pasture. Clover and lucerne pastures are likely to benefit subsequent crop growth by increasing soil nitrogen levels.

Vegetable growers, particularly those with limited land resources, must weigh up the benefits of using pasture in rotation to improve structure against the loss of production from not continuously cropping.

Vegetable growers in some areas should also consider crops in rotation for biological control, or biofumigation of some soil-borne pathogens and nematodes.

EFFECTS OF GRAZING ON SOIL

Bulk density is defined as the mass of oven-dried soil per unit volume. Soils with high bulk density have a smaller volume of pore space than soils with a low bulk density. Very high bulk density (greater than 1.6) is therefore undesirable for plant growth, since infiltration, aeration (supply of air to roots), and soil strength are likely to be below optimum.

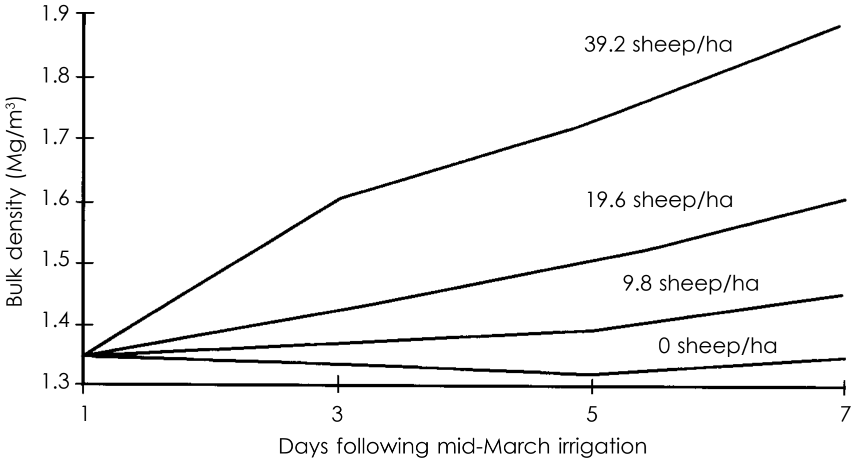
Compacted layers in soils have high bulk density, and therefore limit plant growth.

Grazing of pastures can have some negative effects on topsoil structure. Compaction of the topsoil is most likely when the soil is wet, when high stocking rates are used, and when stock are grazed for extended periods of time.

On one clay soil at Leeton, stocking at approximately 20 sheep/ha led to a dramatic decline in production compared with an ungrazed pasture. At 20 sheep/ha grazing for 5 weeks (starting 1 day after the irrigation water had drained off), pasture production was 58% lower than on the ungrazed pasture. This difference was attributed to an increase in bulk density of the topsoil (Figure D6–2), and the direct effect of sheep damaging pasture plants when grazing and walking on them. Between 34% and 58% of the decrease in pasture production was due to changes (increases) in the bulk density of the soil. Bulk density is likely to remain high until the soil is cultivated or undergoes extensive cracking when dry (clay soils only).

Many vegetable growers use livestock to clean up crop residues. Sometimes the cost in damage to soil management can outweigh the benefits.

Figure D6–2. Soil bulk density and stocking rate



Chapter D7. Cultivation and soil structure

PURPOSE OF THIS CHAPTER

To describe the effects of cultivation on soil structure

CHAPTER CONTENTS

- advantages and disadvantages of cultivation
- cultivation techniques
- machinery design
- semi-permanent beds

ASSOCIATED CHAPTERS

- A3 ‘Features of soil’
- B2 ‘Weed control’
- B9 ‘How do I control erosion?’
- D8 ‘Landforming and soil management’

EFFECTS OF CULTIVATION ON SOIL STRUCTURE

The soil organic matter can be seen as the darker layer beginning at the soil surface. Organic matter acts as a ‘glue’ to bind soil particles into aggregates. Therefore, a soil high in organic matter will generally be well structured. This is especially true in loamy textured soils.
A productive pasture phase over a number of years will improve the structure of most soils, because the organic matter content will increase under pasture. This improvement will begin at the surface (since this is where plant residue and manure from stock is deposited) and slowly move down into the topsoil over time.

When a soil is cultivated soil aggregates are broken up and soil is aerated. This exposes soil organic matter, speeds up the breakdown of soil organic matter, and is harmful to soil structure. Therefore, reducing tillage can improve soil structure.

Cultivation (tillage) is a practice that has been introduced to Australia from Europe by our farming pioneers. The principle of cultivation is to turn the soil into a fine tilth to provide the ideal environment for seeds to germinate. Cultivation was also a traditional form of weed control. The climate of most European countries is wet and cool, allowing organic matter to build up in soils even when they are cultivated. This system is better suited to the younger, more fertile soils of Europe. In Australia, regular intensive cultivation has degraded soil structure. Our soils are older, our climate is hotter and drier, and organic matter breaks down quickly. Therefore, cultivation is potentially disastrous for many Australian soils if it is not used correctly.

ADVANTAGES OF CULTIVATION

Cultivation is conducted for a variety of good reasons. It is important that cultivation of the soil does not create as many problems as it solves. Some advantages of cultivation are:

- It is often a form of weed control.
- It can play a part in pest management. For example, tillage is recommended to reduce the number of overwintering heliothis pupae in paddocks where susceptible summer crops such as sweet corn and tomatoes are grown.
- It may be required to incorporate herbicides and soil ameliorants, such as lime.
- It may reduce the incidence of soil-borne diseases. Soil-borne diseases such as rhizoctonia can be a problem in soils where crops are planted using direct drill or zero till.
- It reduces soil strength. High soil strength has been shown to reduce the vigour of crops, especially seedlings. High soil strength is one reason for poor seedling vigour in direct-drilled crops on poorly structured soils.
- It roughens the soil surface; this can help retain moisture.

DISADVANTAGES OF CULTIVATION

Cultivation has the potential to destroy soil structure and make soils more prone to other forms of degradation, such as erosion. Incorrect use of cultivation can have the following effects:

- There may be a reduction in soil organic matter and therefore a decline in soil structure. Good soil structure is important for good root growth and water penetration by rainfall or irrigation.
- Cultivation that mixes surface soil with subsurface soil will lead to a dilution of organic matter (which is most concentrated at the soil surface). This will mean that crusts are more likely to form after cultivation.
- Cultivation can make hardsetting and crusting problems worse, since soil organic matter and stable aggregates are destroyed.
- Cultivation can bring sodic material to the soil surface. This can cause or increase soil crusting.

SOME GUIDELINES FOR CULTIVATION PRACTICES

Implements for aggressive cultivation

- landplanes
- heavy disc implements
- wide-board ploughs
- rotary hoes

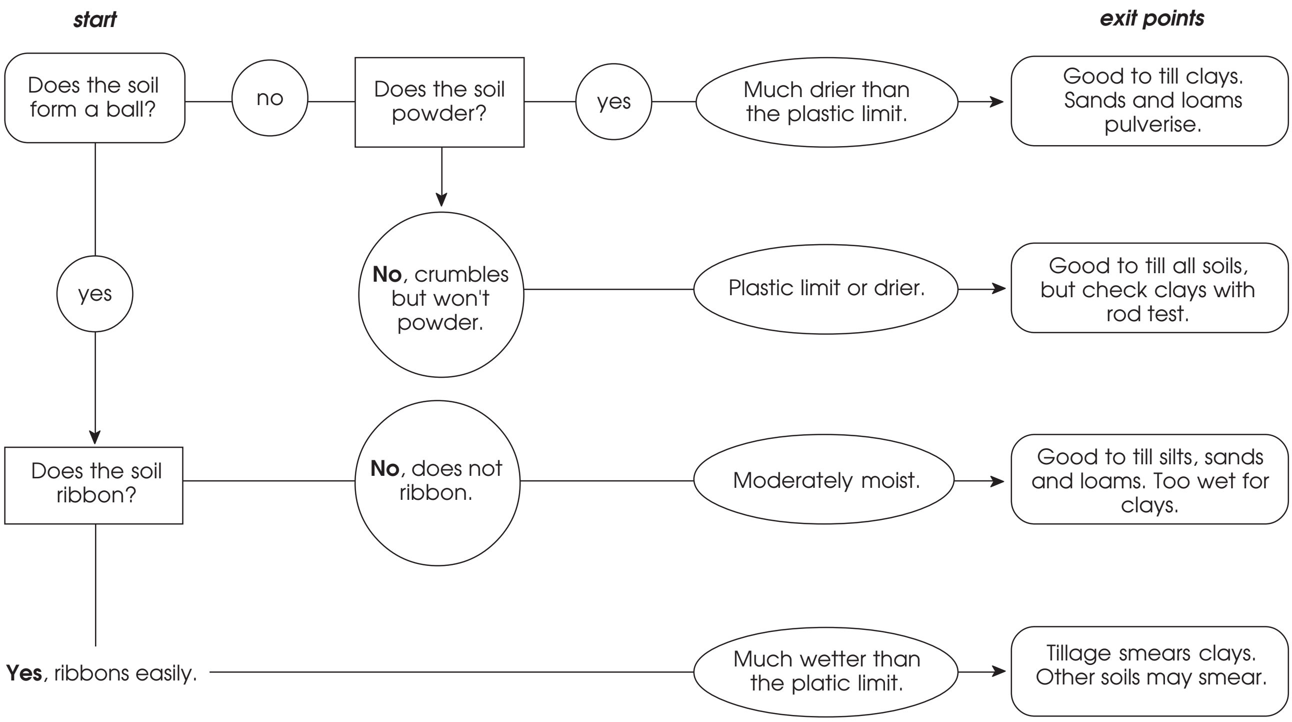
Implements for less aggressive cultivation

- chisel plough
- scarifier
- roller

The negative effects of cultivation can be minimised if certain rules are followed when cultivating. Some of these are:

- Minimise cultivation as much as possible. The less you cultivate a paddock the less likely you are to damage the soil structure. Depending on the vegetable crop or pasture, if soil conditions and machinery are suitable, consider direct drilling. You may need to use more herbicides for weed control.
- Try to use less aggressive forms of cultivation. The more aggressive forms of cultivation, such as levelling equipment, disc ploughs and rotary hoes, are likely to degrade the soil structure very quickly.
- Cultivate at an appropriate soil moisture content (especially when using aggressive implements)—see Figure D7–1.
- When you are using implements that mix soil throughout the cultivation depth, restrict the depth of working to 5 cm or less. The same applies to implements that bury the surface soil. When implements that mix soil are used to greater depths, soil organic matter becomes diluted. Additionally, sodic soil may be brought to the soil surface. Implements with narrow points are less likely to mix or ‘invert’ the soil. **Remember, the priority area in soil management is the soil surface (the top 1 cm).**

Figure D7–1. Soil moisture test for tillage



- When deep cultivating, use non-inversion implements (chisel plough, Agroplow® or scarifier with narrow points). A deep cultivation (15 to 20 cm) can be useful to increase infiltration of water and encourage early root growth. Implements used for this are best followed by a roller.

DIRECT DRILLING

Direct drilling is a technique where crops or pastures are sown into uncultivated soil. In general, the soil is disturbed only in a narrow slot along each sowing line. This technique offers many benefits to growers, since the soil structure will improve over a number of years. Yields, timeliness of sowing and ease of paddock preparation will improve with soil structure improvements.

Direct drilling is therefore a recommended technique for improving soil structure. If you use direct drilling you are likely to get long-term improvements to soil structure and productivity.

Direct drilling in hardsetting soils

In soils with naturally poor structure, such as hardsetting soils, direct drilling does have some problems. The early growth of direct drilled crops is often much slower than that of conventionally cultivated crops. The possible reasons for this observation are:

- the mixing of soil during conventional cultivation reduces the incidence of biological problems such as soil-borne diseases. This mixing does not occur with direct drilling, and so crop growth can be slowed down by biological factors.
- uncultivated soils tend to be much ‘harder’ than cultivated soils. Crops growing in soils that are hard (that is, that have high soil strength) will grow more slowly than those in ‘soft’ soils. The high soil strength encountered by plant roots is thought to produce hormones in the plants that reduce shoot and root growth.

Reduced tillage techniques are practised in some highland potato crops and are currently being assessed for sweet corn and processing tomato production.

CULTIVATION TECHNIQUES FOR POORLY STRUCTURED OR HARD SOILS

Hard, poorly structured soils may have poor water infiltration and poor plant vigour. These soils should be ‘softened’ with cultivation.

A non-inversion cultivation (using narrow points) to a depth of 15 to 20 cm will decrease soil strength while causing little damage to soil structure. This operation should be conducted at the plastic limit or drier, so that the soil ‘shatters’. This will make the soil softer and may help with water infiltration without damaging the soil further. This cultivation can be conducted using narrow ripper points fitted to a scarifier or chisel plough.

DEEP RIPPING

Deep cultivation (greater than 20 cm) may benefit soils with poor structure or compaction problems. Like most forms of cultivation, deep ripping can loosen and ‘soften’ the soil, giving plants access to deeper soil. However, deep ripping must be done carefully, as many problems may occur.

Some good rules for deep cultivation are:

- Cultivate only to the depth required, that is, just below the depth of the compaction layer.
- Use non-inversion cultivation implements (those that do not bury the topsoil).
- Dry the soil profile (with a crop) to cultivation depth before deep ripping.
- Combine deep ripping and gypsum application on sodic or dispersive soils.

Rip only to compaction depth

Draft requirements and fuel consumption will increase considerably with the working depth. To minimise both draft and fuel requirements you should cultivate about 10 cm below the compaction layer.

Poorly structured and restrictive layers are often found in soils of the Murrumbidgee and Murray Valleys. These layers are usually dispersive clays. Soils should be ripped to at least 15 cm in these situations. Ripping of dispersive soils will be more successful if it is combined with gypsum application.

Use non-inversion points

Implements that invert the soil will bury much of the soil organic matter (usually concentrated in the top 2 to 3 cm). This will mean that the soil surface will be more prone to slaking. Crusting and hardsetting may become a problem (or more of a problem). Deep cultivation that inverts the soil may also bring dispersive subsoil to the soil surface. It is therefore desirable to use points and tines that do not invert the soil. Trying to force blunt chisel points through a compacted layer is often ineffective and consumes more fuel. Use the correct ripping points.

Deep-rip dry soil only

Deep tillage of wet soil is unlikely to have any benefits, since the soil needs to be dry to produce cracks when deep cultivating to have a beneficial effect. (Soil should be drier than the plastic limit: see Figure D7–1. Deep tillage of wet soil has been shown to reduce yields. This is thought to be due to smearing and further compaction caused by operation of the deep ripper while the soil is still fairly moist (wetter than the plastic limit).

Before deep ripping the soil should be dried with a crop. This would involve growing a crop as normal until it is 3 to 4 weeks from maturity. From this point on, no irrigation should take place; the crop can then exhaust its store of water in the soil. Winter cereals and canola are useful crops for drying the soil.

Use gypsum when deep ripping sodic or dispersive soils

Deep ripping will have a relatively short-term effect on soils that are dispersive. Dispersive soils can be identified as those with a dispersion index greater than 8 or an exchangeable sodium percentage greater than 5.

Dispersive soils will swell and disperse when wet, so cracks created by the ripper will soon collapse. To maintain the cracks created by the ripper, apply gypsum before ripping.

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See Chapter D5 for more information on gypsum use.

MACHINERY DESIGN FOR DEEP RIPPING

Attack angle

The attack angle refers to the angle of the leading edge of the point of the ripping implement. A shallow attack angle of about 30° (22° to 45°) allows for good soil breakout (shattering) without stressing and wearing the ripper tines. Parabolic-shaped tines work well, since the workload is spread across a larger area of the tine.

Narrow points and sweeps both have applications for ripping. Sweeps have the advantage of working effectively to greater depths. However, sweeps are likely to cause some smearing and compaction at the foot of the cultivation layer, especially when the soil is wet. Narrow points do not smear the soil as much as sweeps, but cannot work effectively to the same depth as sweeps.

An ideal compromise is to use a ripper that has deep, narrow points working behind shallower sweep points. This configuration will give maximum shattering of the soil, while minimising compaction at the base of the rip line. The shallow leading tines should work at approximately half the depth of the deeper tines with narrow points.

Work done with such a machine in cotton-growing areas has produced favourable results. Soil ripped by such an implement produces a better tilth and is left less 'cloddy' than soil ripped by conventional rippers; this type of ripping also allows the implement to be worked at a greater depth with reduced fuel consumption.

These machines are not available commercially. However, many rippers can be modified to the configuration outlined above by adding the deep narrow pointed tines to the back of the shallow tine toolbar.

USING SEMI-PERMANENT BEDS

The use of semi-permanent beds is being widely adopted by many vegetable growers; with this method planting beds are retained for up to 10 years (Figure D7–2). Some ripping may be done, but ploughing is avoided if at all possible.

Figure D7–2.

Lettuce seedlings on permanent beds near Windsor. The tops of these semi-permanent beds are cultivated between each crop, but the beds themselves and furrows are kept for at least five crops. (Ashley Senn)

Why semi-permanent beds are a good production technique

- By concentrating on shallow cultivation and avoiding ploughing, costs are greatly reduced. Cultivation time, and therefore machinery maintenance and fuel costs, are typically reduced by one-half to two-thirds, but the crop is the same or better.
- Paddocks that are bedded-up drain better and, since the firm gutters are kept, access during wet conditions is improved. There is also less waterlogging.
- Soil compaction from traffic is confined to a smaller area of the paddock.
- The best soil is kept at the surface where most of the roots are. Manure and fertiliser are not lost by being buried too deeply.
- Organic matter levels are higher, and therefore soil structure is better. Organic matter is oxidised and destroyed when it is exposed to the air by cultivation.
- Because the soil structure is improved there is less surface crusting and more infiltration (soaking-in) of water. More rapid and even wetting of the soil is a major reason for the widespread adoption of permanent beds inland.

Some problems

- Existing plough pans (layers of compacted soil) will need to be loosened before setting up the semi-permanent beds. Soils may be hardsetting.
- Shallow cultivation, especially with rotary hoes in soil that is too wet or too dry, can also damage soil structure. Beds can also slump and lose their shape.
- If organic matter levels are high (this is unlikely), soil-borne diseases such as rhizoctonia may become more common.
- You may need to cope with large amounts of trash, for example, after broccoli.
- This technique cannot be used for potatoes and carrots because different widths of machinery are needed.

Chapter D8. Landforming and soil management

PURPOSE OF THIS CHAPTER

To explain how to use landforming to manage soils

CHAPTER CONTENTS

- advantages and disadvantages of landforming
- pre- and post-landforming management

ASSOCIATED CHAPTERS

- D7 'Cultivation and soil structure'
- D9 'Irrigation scheduling'

LANDFORMING AND SOIL MANAGEMENT

Landforming includes such activities as laser grading, landplaning, and activities that involves moving soil from one area of a paddock to another. The aim of landforming is usually to produce an even surface of a set grade to make irrigation more efficient.

DISADVANTAGES OF LANDFORMING

Landforming can have some undesirable effects that may reduce productivity in the short term. These are:

- Damage to the soil structure. Since landforming methods are particularly aggressive, soil structure can be severely damaged, resulting in poor crop emergence and poor water penetration. Structural damage is made worse when soil is landformed at incorrect moisture content.
- Exposure of subsoils in cut areas. Topsoils contain the bulk of plant nutrients. Once they are removed, so too are the nutrients that plants need for good growth. Additionally, the exposed subsoils are generally more dispersive than the topsoils because they are higher in sodium (that is, more sodic). Sodic soils are poorly structured and hard to cultivate, and will generally form a crust after water is applied.

The short-term losses associated with landforming can be minimised if a combination of management practices is used.

SOIL PROPERTIES AND LANDFORMING

The different soil groups described in this SOILpak have distinct properties with implications for landforming, especially the red brown and transitional red brown earths. The effect on sands and the deeper alluvial soils is not as significant.

Red brown and transitional red brown earths

These soils are characterised by a loamy topsoil overlying a clay subsoil. The critical factor for landforming is the depth of this loamy

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***Dispersion** is a process in which aggregates in the soil break down into their component particles when they are wet by irrigation water or rainfall.*

*The main cause of dispersion is high amounts of sodium bound to clay particles. A soil with high amounts of sodium bound to its clay particles is said to be **sodic**.*

*The amount of sodium bound to clay particles is measured in terms of the **exchangeable sodium percentage. (See Chapter D3.)** The higher the exchangeable sodium percentage, the more dispersive a soil tends to be. In general, a soil with an exchangeable sodium percentage (ESP) above 6 is considered to be sodic, and dispersion is more likely when ESP values are higher than 6.*

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See Chapter D4 for a simple test for soil dispersion.

topsoil. In red brown earths this depth is generally between 15 and 40 cm, but 15 to 20 cm is most common. Transitional red brown earths have a topsoil 5 to 10 cm deep. This means that the subsoils are often exposed when landforming is being done on transitional red brown earths. The subsoils of red brown earths and transitional red brown earths have a medium-to-heavy clay texture. The exchangeable sodium percentage is usually high. Therefore, they are poorly structured and dispersive. The topsoils of both red brown and transitional red brown earths are of a loamy texture. Therefore, they can be damaged severely if cultivated when too dry. Structural damage is evident during cultivation on these soils when dust is produced. The critical factor when cutting these soils is the depth of topsoil. The minimum depth for good infiltration (and therefore good water storage) is about 20 cm of loamy topsoil. It is desirable to have as much depth as possible remaining after landforming. For this reason the most successful solution to poor yields in cut areas is topsoiling. This is the process by which topsoil is replaced on cut areas. As can be seen in the example in Table D8–1, the topsoil is a store of plant nutrients. It also helps with water storage.

Table D8–1. Red-brown-earth soil properties

	Depth	pH	Organic carbon %	Exchangeable sodium %	Available phosphorus (Colwell)	Nitrogen ppm
Topsoil	10 cm	5.4	1.9	4.5	24	74
Subsoil	20 cm	7.2	0.6	11.6	9	20

Table D8–1 is an example of a transitional red brown earth and its properties that need consideration before landforming. It is obvious that the subsoil that may be exposed during landforming may be severely lacking in properties that will promote plant growth. Nitrogen and phosphorus are low, and plant growth is likely to be poor.

The exchangeable sodium percentage is high, so dispersion is likely. This will cause problems such as crusting and poor water penetration. Most subsoils are likely to be relatively poor environments for plant establishment and growth, and therefore exposure of subsoils should be avoided. If subsoils are exposed, then they should be ameliorated with gypsum and/or fertiliser. Experience shows that poultry manure has had excellent results on these areas. Poultry manure contains a range of essential nutrients and some organic matter, both of which are in short supply in exposed subsoils.

PRE-LANDFORMING MANAGEMENT

A number of strategies should be considered before landforming to reduce the cost of the operation itself, as well as the effects of the landforming on production (Figure D8–1).

- Try to stay with the natural slope as much as possible. This will reduce the volume of cut and fill. If you are working on very flat country, beds may be an option to improve drainage.
- Shorten the bay length. This reduces the amount of cut and fill and also reduces the distance that soil must be moved. This will help to reduce the cost of landforming. However, more supply and drainage channels are needed with shorter bays.

Figure D8–1.

Grader constructing a permanent grade bank. Note that the blade is set horizontal to make a flat-bottomed channel. Cost is about $500 per kilometre. (Ben Rose)

- Split grades can be used to match the layout to the natural slope and soil type.
- On soils that have shallow topsoils (for example transitional red brown earths), the subsoils will be exposed during most landforming cuts. One technique to overcome this problem is to invert the topsoil with a mouldboard plough before landforming. This means that some topsoil is likely to remain on the cut areas.

MANAGEMENT DURING LANDFORMING

Landforming at the wrong moisture content can damage the soil structure. When clay soils are worked too wet (above the plastic limit) compaction is very likely.

When loam soils are worked too dry, 'bulldust' (fine dust) is produced. This is an indication of severe structural damage and should be avoided. Sometimes there are good reasons for landforming to be done when soil conditions are not exactly right. Nevertheless, you should make every effort to landform at the right moisture content in order to avoid serious and costly structural deterioration (Figure D8–2).

Exposed subsoils on red brown earths are generally poor environments for plant growth. For this reason it is best to topsoil in order to improve plant growth on cut areas. A heavily cut area should receive at least 10 cm of topsoil for best results.

Topsoiling is the process by which cut topsoil is set aside during landforming and replaced on heavily cut areas. Topsoils help the water storage of a soil and act as a store of plant nutrients. Research has shown that topsoiling produces superior yields to other types of soil amelioration (such as the addition of gypsum, phosphorus or zinc) on heavily cut sites.

Figure D8–2.

Harold Adem of ISIA Tatura demonstrating a soil-moisture-measuring technique to MIA farmers. (Bernie McMullen)

POST-LANDFORMING MANAGEMENT

Crop selection

Following landforming it is often necessary to get a paddock back into production as soon as possible to get a flow of income. You must choose a crop from which you can get a reasonable yield, given that the soil is likely to be poorly structured. A crop will help to return some structure to a degraded soil.

A winter cereal followed by a vegetable crop is a suitable rotation after landforming.

Plant growth and irrigation will help to settle a soil after landforming. Quite often slight depressions and rises may be evident after this settling period, and further landforming will be necessary. It is therefore important to grow an annual crop during this ‘settling down’ period so that a ‘touch-up’ landforming can be done afterwards. For this reason do not sow a pasture as the first crop after landforming.

Hill beds in the autumn to allow a winter crop to be planted and/or soil to settle before planting summer vegetables in the spring.

Ground preparation after landforming

After landforming fill areas tend to compact, while cut areas set hard or run together. Consider the following points:

- It is important to cultivate ground at an appropriate moisture content.
- Chisel plough or offset disc only as required to form a seedbed. A chisel plough often penetrates easier than other implements. Ripping to 20 cm may be beneficial if there is a ploughpan or you need to make seedbed preparation easier.

Soil nutrition in landformed areas

Nitrogen

Since most available nitrogen in soils is located in the topsoil, crop growth on cut areas is quite often reduced by nitrogen deficiencies. Nitrogen levels in subsoils are very low, so almost all crop nitrogen needs must be met by fertiliser. Yield responses can be expected at 100 kg N/ha for winter cereals. Because there is a risk of poor establishment, it is advisable to pre-drill 50 kg N/ha and apply a further 50 kg N/ha about 8 weeks after sowing if establishment is satisfactory.

Phosphorus

Phosphorus is a relatively 'immobile' nutrient in the soil. This means that water will not move the phosphorus from where it is applied. Therefore little, (if any) phosphorus applied to the topsoil moves into the subsoil. It is necessary to apply phosphorus to exposed subsoils at heavy rates. It is a good idea to get a soil test done on the area exposed in order to work out the fertiliser rates. The exception to this is where large amounts of organic fertilisers (such as chicken manure) are applied. In these situations phosphorus will move through the profile. Table D8–2 gives general guidelines for phosphorus application to cut areas.

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See Chapter D3 for more information on chemical soil tests.

Table D8–2. Phosphorus application rates

Soil P (Colwell) ppm	Phosphorus application rate (kg P/ha)
below 10 ppm	40 kg P/ha
above 15 ppm	20 kg P/ha

Improving the structure and water penetration of cut soils

Gypsum

Gypsum helps to improve the structure of exposed clay subsoils (if they are sodic to begin with). Subsoils of all soil groups are generally sodic, with the exception of self-mulching clays, which may be non-sodic in some instances, especially when cuts are not deep. Get a soil test to determine the exchangeable sodium percentage. Gypsum will help to create better structure in exposed sodic subsoils. This will greatly help establishment by reducing crusting and producing finer (smaller) aggregates for good seed–soil contact. It will also improve the internal drainage of the soil when heavy application rates are used.

Table D8–3 is a guide to gypsum application to cut areas.

Table D8–3. Gypsum application rates

Exchangeable sodium percentage (ESP) of cut area	Gypsum application rate (t/ha)
Greater than 6, less than 10	2–5t/ha
Greater than 10	5 t/ha

Chapter D9. Irrigation scheduling

PURPOSE OF THIS CHAPTER

To explain how to plan and schedule your irrigation program

CHAPTER CONTENTS

- factors affecting irrigation intervals
- influence of soil water
- using the water balance method for scheduling

ASSOCIATED CHAPTERS

- A3 'Features of soil'
- D1 'Soil examination and structural rating'
- D2 'Soil texture tests'
- D7 'Cultivation and soil structure'

THE IMPORTANCE OF DETERMINING YOUR WATER NEEDS

All plants need water to grow and produce good yields. When plants are water stressed they close their stomata (the small holes in the leaf surface) and cannot photosynthesise effectively. Best growth can be achieved only if plants have a suitable balance of water and air in their root zones. Some stages in the growth of a crop are particularly sensitive to moisture stress.

Water shortages sufficient to hinder crop growth can occur without producing obvious wilting of foliage, while waterlogging can cause large yield reductions too. The grower must therefore rely on some other method of determining the water needs of the crop to avoid production or quality losses. This requires an understanding of the movement and storage of water in the root zone of the crop and the rate of water use by the crop.

FACTORS AFFECTING THE IRRIGATION INTERVAL

The interval between irrigations and the amount of water to apply at each irrigation depend on how much water is held in the root zone and how fast it is used by the crop. This is determined by

- soil texture
- soil structure/water penetration
- depth of effective root zone of the soil
- the crop grown
- the stage of development of the crop.

All soils are composed of solid particles of various sizes, organic matter, and pore spaces that hold air and water. The size of these pores, and the amount of water they hold, depends on the texture and structure of the soil.

Soil texture

Soil texture refers to the feel of the soil. There are three types of particles that make up the soil; these are classified as sand, silt or clay depending on their size. The proportion of these particles in the soil determines the feel or texture of the soil and the size of the micropores between the particles, as well as the amount of water that can be stored in them (Table D9–1).

Soils are classified into texture classes such as clay loams, heavy clays, loams and sandy loams, as determined by the proportion of sand, silt and clay in the soil.

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See Chapter D2 for more information on soil texture testing.

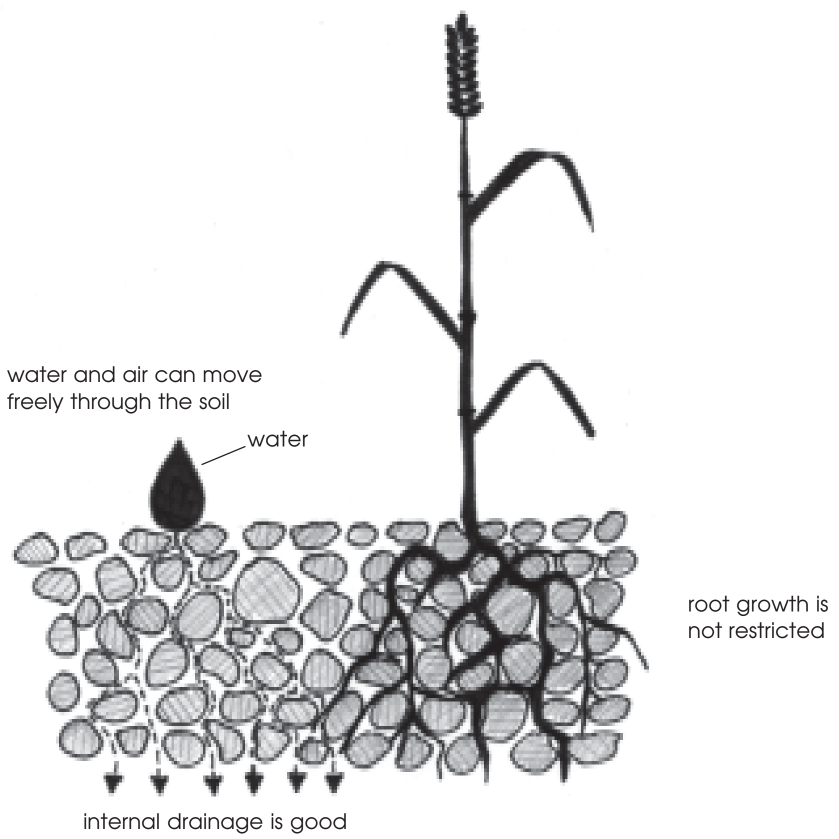
Table D9–1. Available moisture according to texture (mm of plant-available water per metre). Note that this is not a complete list of soil texture classes.

Soil texture	Range	Average
Sand	up to 65	49
Loam	155 to 172	164
Clay loam	155 to 172	164
Clay	137 to 147	137

SOIL STRUCTURE

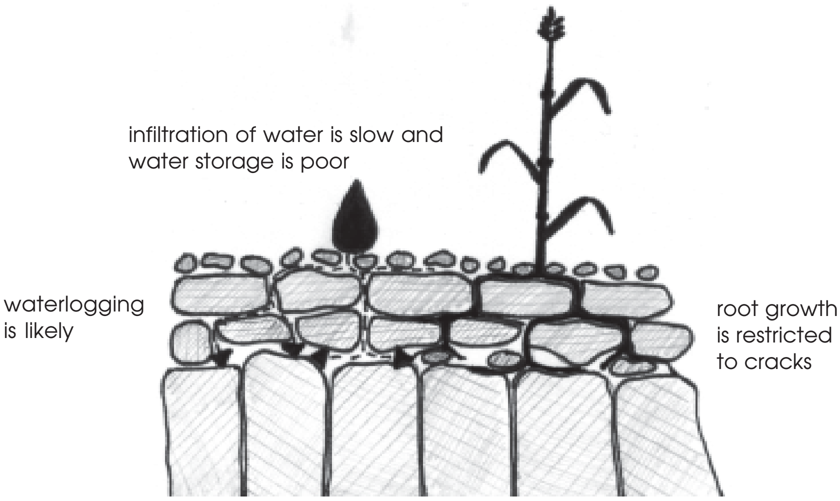
Soil structure refers to the natural aggregation of soil particles that are stable when wetted. The size and shape of these aggregates affect the way they stack together and the size of the pore spaces between them. A well structured soil (Figure D9–1) contains many pores that

Figure D9–1. A well structured soil



will hold water and air and aid infiltration of water into the soil. A poorly structured soil (Figure D9–2) has fewer large pores; it will have a reduced water-holding capacity and poor water infiltration, and will probably restrict root growth.

Figure D9–2. A poorly structured soil



It is clear from Figure D9–1 that a well structured soil will give plant roots an environment favourable to healthy growth and the extraction of water and nutrients.

The structures of many soils have been damaged by years of cultivation and compaction by traffic; others have been damaged by sodicity. This has led to the development of soil crusting and hardpans, which reduce water penetration and retention and restrict root growth. This results in a reduction in plant growth.

Some natural features of a soil may affect its structure independently of the soil management. For example, a sodic soil is likely to be poorly structured and will restrict air and water movement through the soil.

SOIL WATER CONSIDERATIONS

Before you consider your soil moisture status you need to understand a few terms. These include field capacity, wilting point, saturation, available soil water and refill point.

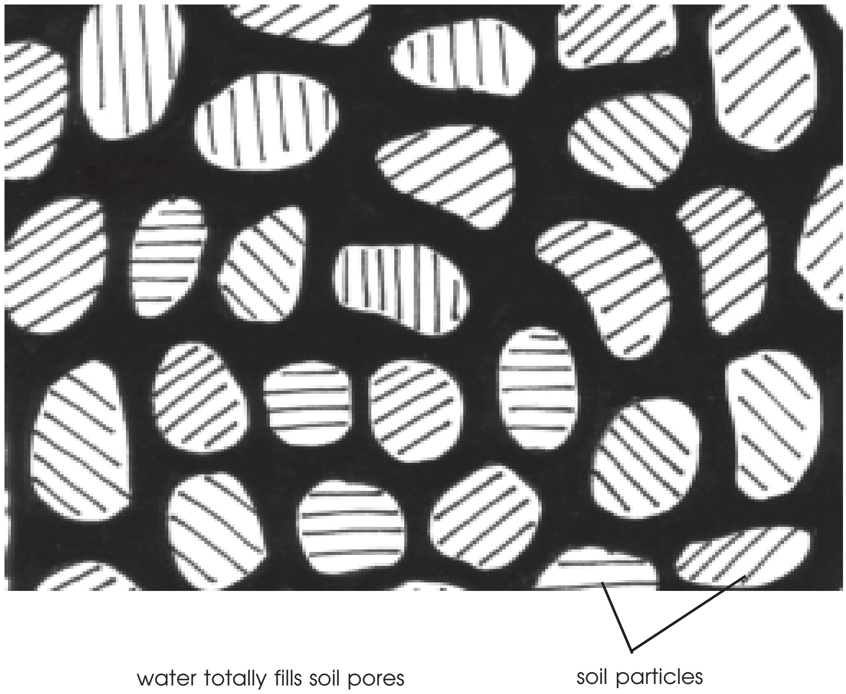
Saturation

Immediately after a soil has been irrigated it is at saturation (Figure D9–3). Almost all of the soil pore spaces are filled with water and very little air remains. If the drainage is adequate, water will drain away from the larger pore spaces and allow some air to enter the soil. This takes about 48 hours, depending on the soil type. If the internal drainage of the soil is restricted the soil becomes waterlogged. With no air in the soil, the roots begin to die from lack of oxygen.

Field capacity

Once the soil has drained by gravity for about 48 hours, water is held in the pore spaces by surface tension around the soil particle, and little further drainage will take place. This condition is called field capacity, and at this time the soil is holding as much water as it can

Figure D9–3. Saturation (soil contains no air)

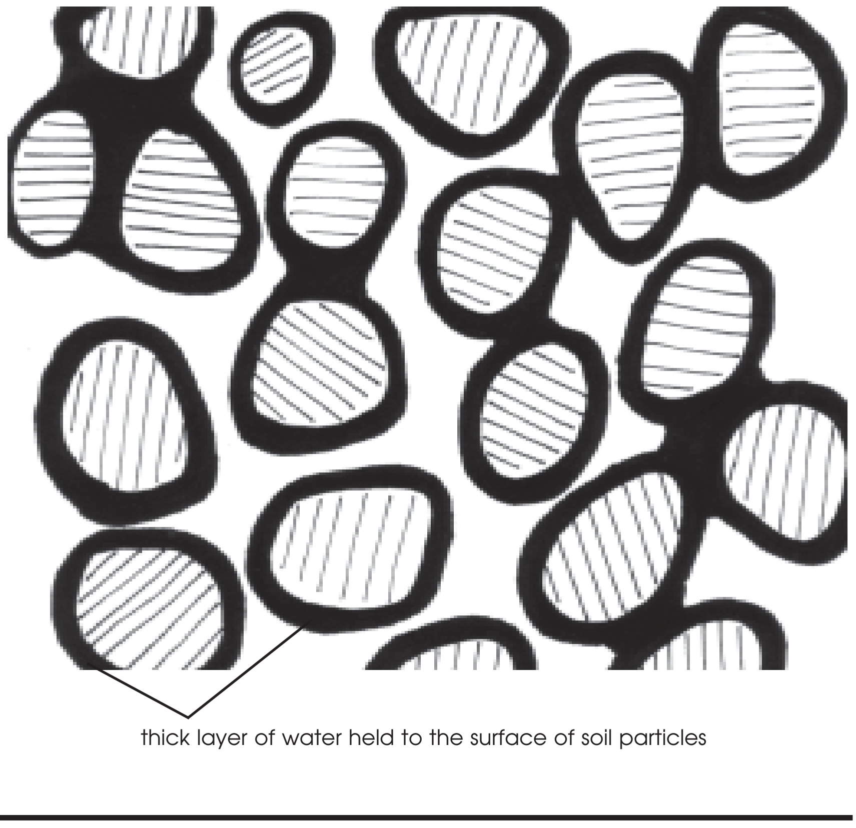


(Figure D9–4). In soil that is well structured there is also enough air in the soil to supply plant roots with the oxygen needed for them to live and grow.

Wilting point

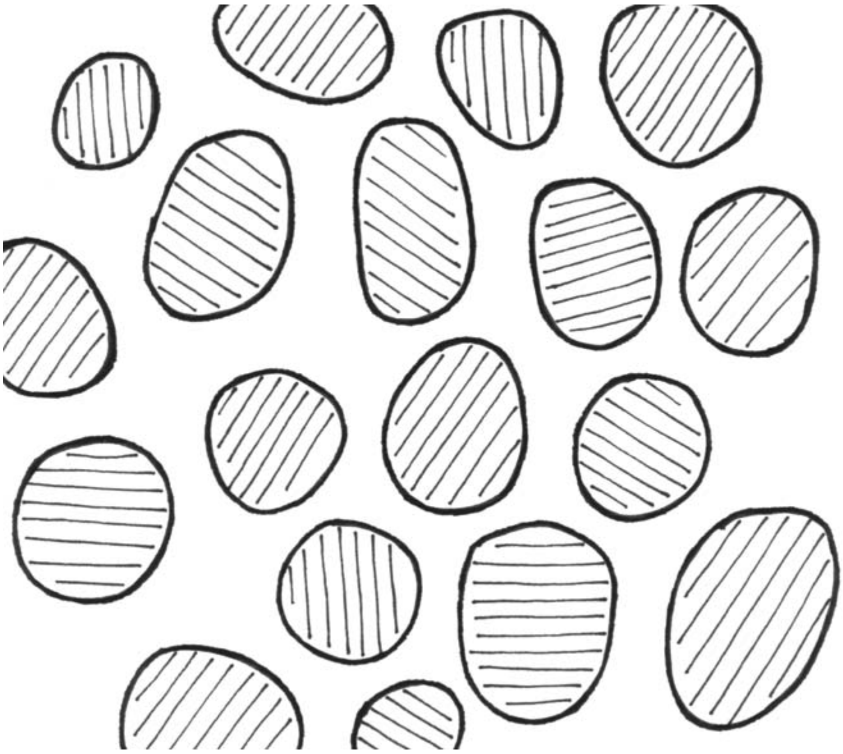
As plants use water from the soil the roots are working against the surface tension that holds the water in the soil. That is, the roots are sucking water from the pore spaces within the soil. Naturally, plants use

Figure D9–4. Soil at field capacity (good balance of water and air)



the most easily extracted water first, and as the soil dries out they must work harder to get water. Water is extracted from the soil until a point is reached when the plant's root system can no longer obtain water from the soil. This is called the wilting point for that soil (Figure D9–5). The soil is not totally dry, but the remaining water is held so tightly that the roots cannot extract it. As a soil approaches wilting point the plant growth slows. Plants do not grow in a soil at wilting point and will die if moisture is not replenished. Irrigated agricultural crops should never be allowed to approach the wilting point.

Figure D9–5. Soil at wilting point (no water available to plants)



Available soil moisture

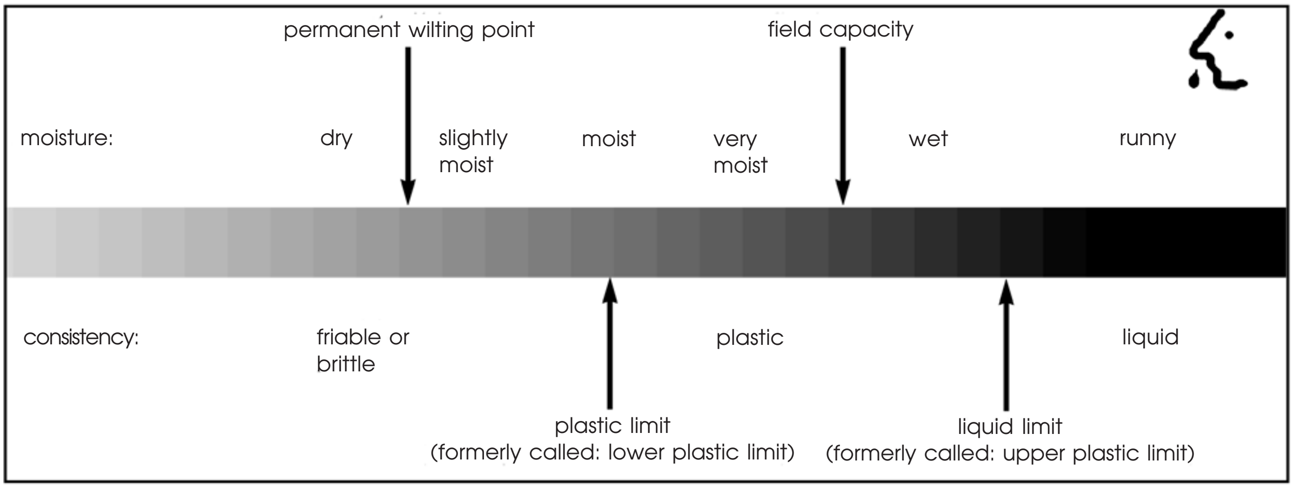
The amount of water held in the soil between the field capacity and the permanent wilting point is known as the available soil moisture. The amount of water in a soil can be expressed as a percentage, or in millimetres per metre of soil. For example, a soil with 15% water has 150 mm of water per metre of soil.

The available water-holding capacities vary within each texture class due to variations in soil structure and soil organic matter. A soil with better structure and more organic matter will have more pores of the right size to hold plant-available water than poorly structured soils. Organic matter retains water and binds soil particles to improve soil structure.

Refill point

Ideally, aim to keep the water content of the soil close to the field capacity for as much of the season as possible, without saturating the soil for periods of greater than 15 hours. A useful strategy to avoid crop stress is to define how much water your soil holds between field capacity and wilting point and then aim to replenish the water stored in the soil by irrigating when half of this has been used (Figure D9–6). Crops are therefore irrigated before yield-reducing stress occurs.

Figure D9–6. Soil moisture for irrigation scheduling



Root depth

Another factor that affects the amount of water available to crops is the effective root depth (the depth of the majority of the plants' feeder roots). For example, most subclover pastures have an effective root depth of about 30 cm, whereas perennial pastures such as lucerne may exploit a greater depth of soil. This means that on a soil that holds 100 mm of water per metre, subclover can exploit only 30 mm of water (that is, 100 mm/m x 0.3 m), but lucerne may (in some soils) exploit the full metre of soil and therefore have more water available to it. The effective root depth will vary depending on the soil and the crop grown.

SCHEDULING USING THE WATER BALANCE METHOD

Irrigation can be scheduled using a variety of different methods based on observations or measurements of plants, soil, the weather or a combination of these. All methods aim to determine when to irrigate to avoid water stress (Figure D9–7) and how much water to apply to refill the soil.

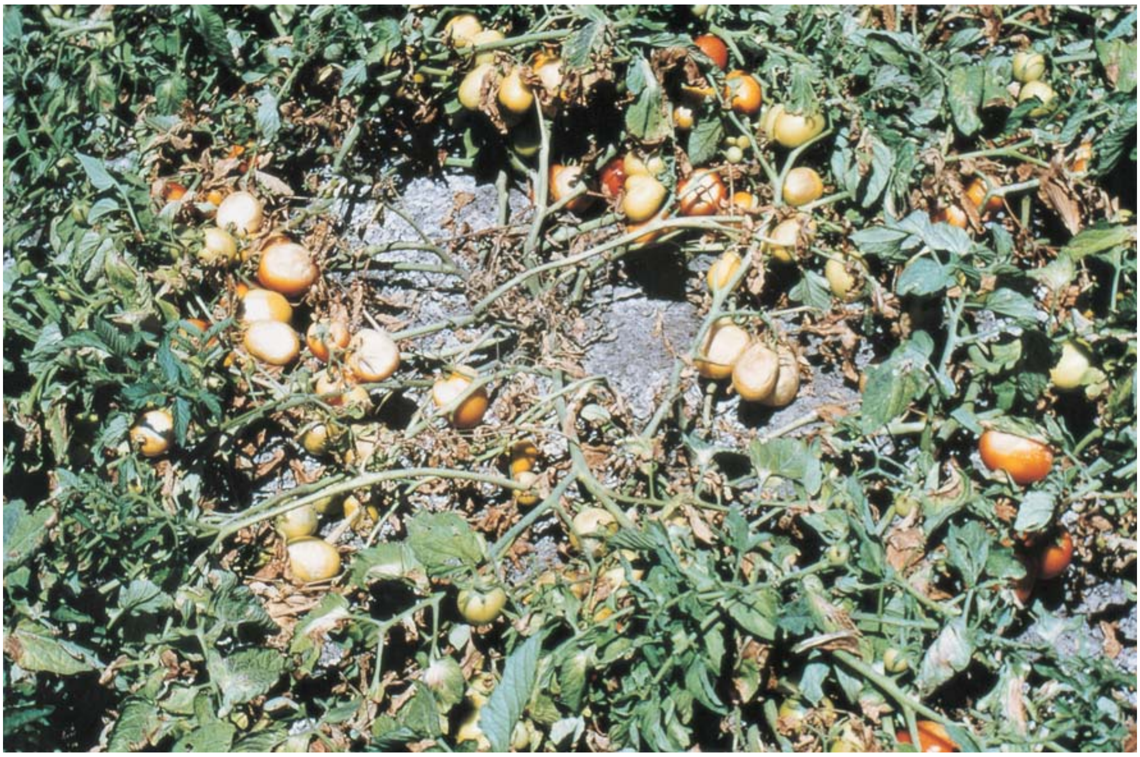
As already mentioned, various factors control how much plant-available water a soil will hold at each irrigation. Crop water use can be calculated using daily evaporation totals and crop factors. When crop water use is subtracted from water storage, an irrigation interval can be arrived at.

Calculating the soil water storage capacity

The first step in scheduling is to calculate the soil water storage capacity. Table D9–2 lists the soil moisture storage between the field capacity and the refill point (called the 'allowable depletion') for different soil groups.

The allowable depletion figures quoted in Table D9–2 are only a rough guide to the water storage capacities of different soils. Variations in soil structure, sodicity and management will cause variations in water storage. An improvement in soil structure may result in an increase in the water storage capacity of the soil.

Figure D9–7.



A processing tomato crop on clay soil that has collapsed due to waterlogging from excessive irrigation. Note the sunburn on the fruit, resulting in significant yield loss. (Bernie McMullen)

Calculating the plant water use

To fine-tune your allowable depletion figures for your soil, dig a hole and assess the soil moisture immediately before irrigating to see if your allowable depletion figure is correct. If the soil is still too wet for irrigation, increase the figure you use by 10 mm. If the soil is too dry just before irrigation, reduce your figure by 10 mm. Continue this process until you arrive at a suitable figure.

The water storage in a soil must be balanced against plant water use. Plant water use is affected by two main influences: the leaf area of the crop or pasture and the daily evaporation.

Plant water use is proportional to evaporation. The higher the evaporation, the higher the plant's water use. Evaporation is affected by humidity and temperature, so plant water use in summer is much higher than in winter.

Table D9–2. Approximate water storage according to soil group

Soil/group/conditions	Allowable depletion (mm of water) (field capacity refill-point)
Hardsetting red brown earth	45
Friable non crusting red brown earth	60
Transitional red brown earth	45 o 70
Well structured transitional red brown earth	75
Non-self-mulching clay	60 to 80
Self-mulching clay	85 to 90

Plants draw water from the soil via the roots and release this water as vapour into the air via the leaves. If the plant (or crop) has a large amount of fresh, green leaves, then water use will be higher. High water use is a desirable characteristic, since yields are well correlated with water use. Soon after emergence a crop has only a small amount of leaf material, so water use is relatively low, while water use will be highest when the crop reaches maximum leaf area. The **crop factor** is a number used to calculate the water use. It accounts for the crop leaf area. Crop factors vary between times of the year and stage of crop growth. Check with your local horticultural adviser for crop factor information.

The daily crop water use

To calculate the crop water use, multiply the crop factor by the daily or weekly evaporation totals.

Daily crop water use (mm) = crop factor x daily evaporation (mm)

Example:

In December sweet corn has a crop factor of 1.0. On a particular day the evaporation is 14 mm.

Therefore, crop water use (mm) = 1.0 x 14 mm
= 14 mm (on that particular day)

Evaporation data

Evaporation data can be obtained by:

- calling your local post office, which keeps weather data
- Waterwatch no longer available. Evaporation data can be obtained through the website www.clw.csiro.au/services/weather or check with your local horticultural advisor.

The service provides evaporation figures for the last 10 days and forward estimates for the next six weeks. The data are measured in Griffith, but are reasonably accurate for the Murray Valley and MIA.

Calculating the irrigation interval

- Subtract the daily crop water use from the allowable depletion figure appropriate for your particular soil (field capacity – refill point (mm)) (Table D9–2). This figure is the amount of plant-available water remaining in the soil at the end of the particular day (the soil water storage).
- Account for any effective rainfall in the period between irrigations.

Effective rainfall = total rainfall – 5 mm in spring, summer and autumn
= total rainfall in winter.

Add the effective rainfall to the water storage figure. Remember that the water storage cannot exceed the initial amount determined for that soil as the allowable depletion amount. Any additional rainfall will evaporate, run off, or drain through the soil profile.

- When the allowable depletion is zero, start the next irrigation.

Example:

A tomato crop growing on a hardsetting red brown earth with an allowable depletion of 50 mm is irrigated on 1 October. When will the next irrigation be due if the evaporation figures for the month are as shown in Table D9–3?

To calculate when to irrigate you must record the daily evaporation figures and calculate the crop water use for each day. This is best done in table form, as shown in Table D9–4.

This system of irrigation scheduling is relatively simple to use. When it is used correctly, scheduling is likely to increase yields by avoiding periods of waterlogging and drought stress. Additionally, scheduling may help to reduce rises in the watertable and minimise structural decline (Figure D9–8).

Table D9–3. Example: evaporation and rainfall figures

Date	Evaporation	Rainfall
2/10	3.0	
3/10	2.3	
4/10	5.0	
5/10	8.0	
6/10	6.0	
7/10	5.5	
8/10	7.5	
9/10	8.5	
10/10		10
11/10	5.5	
12/10	9.0	
13/10	5.0	

Table D9–4. Example: calculating irrigation frequency

Date	Evaporation (mm)	Crop factor	Crop water use (mm) (= evaporation × crop factor)	Effective rainfall (mm)	Soil water storage (mm)
1/10				*irrigation*	50
2/10	3.0	0.9	2.7		47.3
3/10	2.3	0.9	2.1		45.2
4/10	5.0	0.9	4.5		40.7
5/10	8.0	0.9	7.2		33.5
6/10	6.0	0.9	5.4		28.1
7/10	5.5	0.9	5.0		23.1
8/10	7.5	0.9	6.8		16.3
9/10	8.5	0.9	7.7		8.6
10/10		0.9		5.0[1]	13.6
11/10	5.5	0.9	5.0		8.6
12/10	9.0	0.9	8.1		0.5
13/10	5.0	0.9		*irrigate today*	

[1] Actual rainfall is 10 mm. However, effective rainfall = total rainfall – 5 mm in summer, autumn and spring.

Figure D9–8.

A cracking clay soil showing the large cracks that occur when these soils dry out. (Bernie McMullen)