



## **SOILpak – southern irrigators - Readers' Note**

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# Chapter E1. Sodicity and soil management

## WHAT IS SODICITY?

Sodicity is a term which refers to the amount of sodium held in a soil. A cation is a positively charged ion which can be held loosely on clay particles in a soil. Sodium is one of several cations; others include calcium, magnesium, potassium and hydrogen. When sodium makes up more than about 6 per cent of all cations bound to clay particles, structural problems begin to occur. The amount of sodium as a proportion of all major cations in a soil is the main measure of sodicity, and is termed exchangeable sodium percentage (ESP). This can be calculated from chemical soil tests (see Chapter C9: *Other chemical tests*).

## WHY IS SODICITY A PROBLEM?

**Sodicity refers to the amount of exchangeable sodium cations in the soil. The elements contained in the soil are usually combined to form salts. Salts are made up of elements with positive and negative ions (cations and anions). Sodium and calcium are cations (positive charge) whereas chloride is an example of an anion (negative charge). Some elements can move freely in the soil water, and can be readily taken up by plants or leached away. However, many cations are at any time, bound loosely to the surfaces (or exchange sites) of clay particles and are not free to move in the soil solution. These are the exchangeable cations. When sodium makes up more than about 6% of the total cations bound to clay particles, the soil is said to be sodic.**

**Cations in solution will often bind 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 with other cations on the exchange sites. Similarly, if a solution high in calcium (a cation) is applied to a soil, the proportion of calcium bound to clay particles may increase, usually by swapping positions with the sodium. The process of cations swapping from solution to clay surfaces and vice versa is called *cation exchange*.**

High sodicity is one reason clay soils swell excessively when wet. The clay particles move so far apart they separate (disperse). This weakens the aggregates in the soil, causing structural collapse, and closing of soil pores. For this reason water and air movement through sodic soils is severely restricted. A test for dispersion is described in Chapter C7.

Sodicity of the surface soil is likely to cause dispersion of surface aggregates, resulting in surface crusts. It can also contribute to slaking in some soils.

Dispersion is largely responsible for muddy water problems in rice, although the situation is made worse by excessive cultivation. However

sodic soils are usually suited to rice production since water movement into the watertable is comparatively low.

For crops other than rice, sodic layers in the soil may prevent adequate water penetration when irrigated and therefore water storage is low. Additionally, waterlogging is common in sodic soils since swelling and dispersion closes off pores reducing internal drainage.

### Self-mulching clays

These soils are well structured and are non-sodic at the surface. Clay particles are generally dominated by calcium rather than sodium. This is the reason self-mulching clays are well structured. However, the deeper subsoil of these soils can be sodic, and therefore waterlogging is possible.

### Non self-mulching clays

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

### Red-brown earths

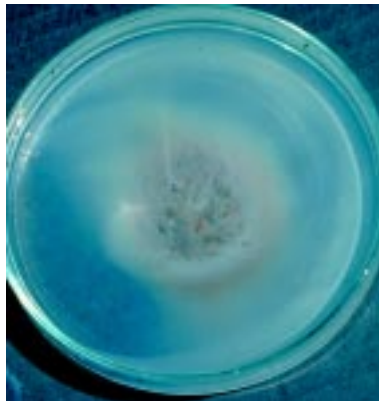
Topsoils of red-brown earths are usually non-sodic, and relatively low in clay content. Subsoils are generally sodic and higher in clay content, causing slow water movement through the subsoil. A “perched” watertable can form above the subsoils of red-brown earths. Since water penetration of the topsoil is generally good, the deeper the topsoil the more water can be stored at each irrigation.

### Transitional red-brown earths

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

### Sandhill soils

Topsoils of sandhill soils are very low in clay content and are non-sodic. Subsoils may be sodic and can cause plant growth problems if the subsoil begins within the rootzone of the crop being considered.



*Sodic soil will disperse in non-saline water. A test for dispersion is described in chapter ‘slaking and dispersion’.*

## MANAGEMENT OF SODIC SOILS

The first step in determining if a soil needs treatment for sodicity is to determine how sodic it is. A dispersion test to indicate sodicity is described in Chapter C7: *Slaking and dispersion*. If this test gives a dispersion score of 6-16 then the soil may be gypsum-responsive. In this situation a soil test to calculate *exchangeable sodium percentage* is warranted (Chapter C9). For surface soil, Table E1 is a guide to gypsum response for surface soil.

**Table E1. Gypsum application rate with respect to soil ESP**

Exchangeable Sodium Percentage (ESP) of soil	Gypsum application rate (t/ha)
greater than 6, less than 10	2–5 t/ha
greater than 10	5 t/ha

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

- (i) Gypsum 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 amounts of sodium and chlorine that is toxic to plants. Gypsum will increase salinity without any detrimental effect on plants.**
- (ii) Calcium from the gypsum will swap with some of the sodium held on the clay surfaces soil(cation exchange). This will reduce the sodicity of the soil.**

**The effect of gypsum on soil structure is mainly through increasing the soil salinity, especially at low application rates. Gypsum is also a relatively soluble product and hence will leach out of the soil in 1–2 years.**

Gypsum (calcium sulphate) can have its most beneficial effect at sowing time. Gypsum can provide better soil tilth, and reduce crusting in sodic surface soils, and hence improve establishment. If gypsum is used where surface soil is sodic, application should be timed so that rain/irrigation has not leached gypsum from the surface soil by sowing.

Cultivation practices on sodic soils should be aimed at preserving soil organic matter in the surface soil. This is usually achieved by less aggressive or reduced tillage. Non-inversion tillage should be carried out as it leaves the more sodic subsoil at depth. More information regarding tillage practices are outlined in Chapter E4: *Cultivation and soil structure*.

### Influence on the topsoil

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

The depth of non-sodic topsoil is an important consideration in determining the likely response to gypsum in improving sodic subsoils. Since a non-sodic topsoil is usually a better environment for plant growth, responses to gypsum will be low or unlikely when there is good depth of topsoil.

As a rough guide, when non-sodic topsoil is greater than 15–20 cm in depth, then gypsum responses are unlikely. Remember, it may take a few months before gypsum leaches into the subsoil and begins to take effect.

### **Gypsum test strips**

Test strips are highly recommended before applying large amounts of gypsum. You may also 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 if 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 soil  $\text{pH}_{(\text{CaCl}_2)}$  above 6. In soils where pH is above 6, lime is of little benefit. If pH is below 6, lime will help to reduce both acidity and sodicity problems. A mixture of lime and gypsum may be a good option on sodic soils where the pH is 5–6.5, to provide a more long lasting effect than gypsum only. Again, test strips are strongly recommended.

### **Cultivating sodic soils**

Sodic soils are more prone to structural degradation than non-sodic soils. Cultivation practices should therefore be minimised and conducted in a careful manner. Excessive cultivation of these soils will cause major soil structure problems. In rice this may be evident as ‘muddy water’, while in non-ponded situations, crusting, hardsetting and poor water penetration will result. For more information about cultivation practices see Chapter E4.

### **Deep ripping and gypsum**

Deep ripping often improves water penetration, aeration and plant growth on poorly structured soils. However the benefits of deep ripping are short-lived, especially on sodic soils.

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

Gypsum will leach out of the soil even when applied at heavy rates. Therefore ripping and gypsum will need to be carried out every two to three years if the effect is to be maintained. Remember that non-inversion tillage (tyned implements rather than discs) should be used for this operation.

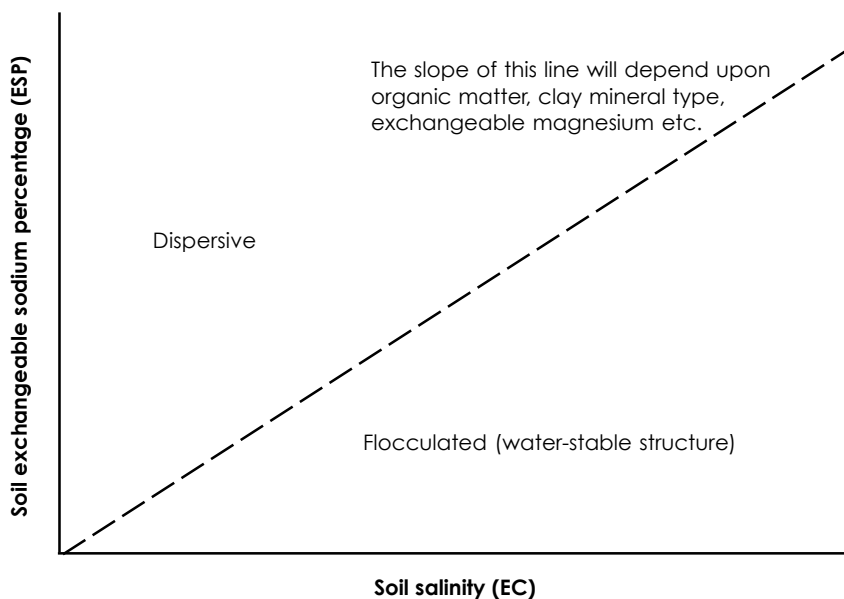
## Using saline irrigation water

Many farmers are now using bore water to irrigate crops and pastures. However this must be carried out with caution as some problems may be experienced, including:

- a build-up in soil salinity and therefore a decrease in crop production.
- an increase in soil sodicity, since most groundwater in the Murray and Murrumbidgee valleys is sodic, ie., contains considerable amounts of sodium.

As soils become more sodic they become more dispersive, and poorly structured. However, if the soil remains saline and sodic, it will not disperse (see Figure E1 below).

**Figure E1. The approximate relationship between soil salinity, soil sodicity and soil structure**



As Figure E1 indicates, a sodic soil can be well structured if the soil is saline enough to prevent dispersion. On the other hand, if soil sodicity is high but its salinity is low, the soil is more likely to disperse. This is the reason why saline water, or gypsum (a calcium salt) improves soil structure in sodic soils.

However, use of saline-sodic water (ie. water of  $EC_w > 3$  dS/m and SAR  $> 3$ ) for irrigation should be avoided since:

- Soil sodicity is likely to increase. If sodicity increases and soluble salts are leached out (the chloride is washed down but most of the sodium stays behind attached to the clay particles) of the soil by fresh water, the soil will become poorly structured.
- Soil salinity will increase. This will occur particularly quickly if the soil has poor permeability (as in a rice soil). Saline water ( $EC_w > 1$  dS/m) should be avoided in rice since permeability is low, and evaporation is high. These two factors will rapidly increase the salinity of water and soil.
- Increase in soil permeability. As the soil becomes more saline, soil structure may improve, causing an increase in permeability (Figure E1). This may increase accessions of water to the watertable.



# Chapter E2.

## Crusting and hardsetting

### WHAT IS CRUSTING?

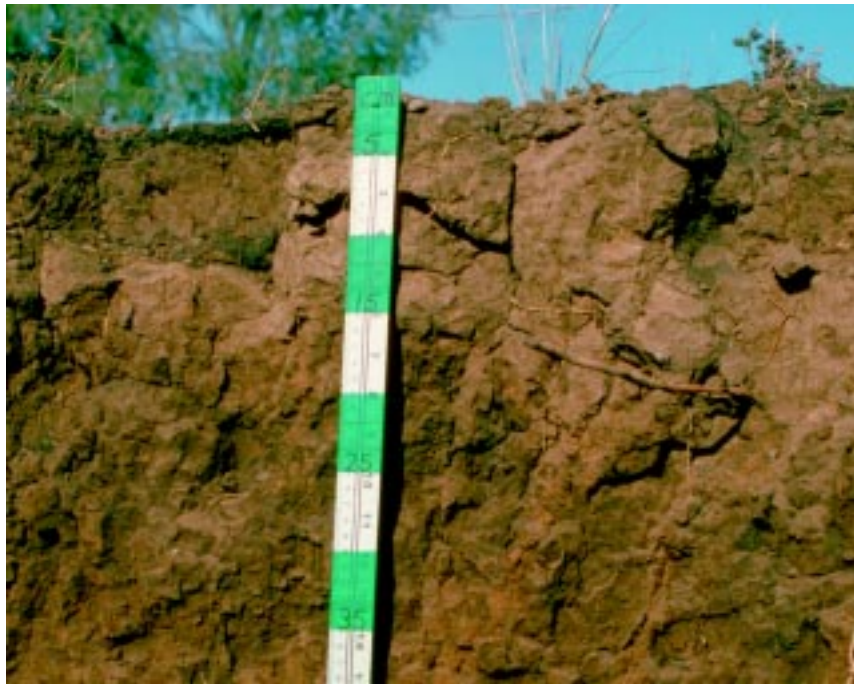
Soil crusts are hard surface layers up to one centimetre thick with very fine or no shrinkage cracks. They occur mainly on bare soil when soil aggregates are broken down via slaking and dispersion or by the force of raindrops. Particles separate from aggregates and seal the surface of the soil, restricting air and water movement, and seedling establishment. Crusting is common in most soils of the Murray and Murrumbidgee valleys. The thickness, strength and continuity of the crust will determine how much plant growth is affected.



*A crusted topsoil*

### WHAT IS HARDSETTING?

Hardsetting refers to a layer that is dense, has no visible aggregates, and few cracks. Hardset layers may be quite soft when wet, but are very hard when dry. Many red-brown earths and transitional red-brown earths have hardset topsoils. Hardset soil surfaces are much thicker than crusts (up to 30 cm thick), but are thought to be caused by structural instability (slaking and dispersion). When cultivated dry, hardset soils will leave large clods. The structure of hardset layers is said to be massive, or structureless.



*A hardset topsoil. Note large massive clods*

### WHAT CAUSES CRUSTING AND HARDSETTING?

**Crusting and hardsetting are problems caused by slaking and dispersion, particularly when the soil has a loamy texture. Slaking and dispersion problems are more common when;**

- **soils contain sodic clays**
- **soil is low in organic matter**
- **soil has no plant residue (stubble, plant material) to protect the soil surface from raindrop impact**
- **soil is wet rapidly, e.g. flood irrigation**
- **soil is cultivated or is damaged by stock trampling it when it is wet.**

Hardsetting and crusting are characteristics caused primarily by slaking and dispersion. Many soils of the Murray and Murrumbidgee valleys are prone to slaking and dispersion since they contain sodic clays, and are low in organic matter.

Sodic clays are prone to dispersion. Soils low in organic matter lack the cementing agents which help bind soil into water-stable aggregates. Therefore any factor that increases a soil's tendency to slake and disperse will increase the likelihood of crusting or hardsetting.

Loamy texture will increase a soil's chances of hardsetting. A loamy soil has a relatively even mix of clay, sand, fine sand and silt particles. This causes the soil to pack down due to its high density after slaking. Smaller particles (clay and silt) block spaces between sand particles. Loamy soils hardset but tend not to crack when drying. Clay soils generally do not hardset since they crack upon drying.

Cultivation may increase a soil's tendency to slake and disperse, particularly when cultivation is aggressive or carried out at an incorrect soil moisture content. If cultivation buries the organic rich surface layer, slaking problems are likely to be worsened. Deep inversion

cultivation may bring sodic clays to the surface. More information on cultivation is outlined in Chapter E4.

Crusting has the potential to reduce yields through reduced establishment and poor infiltration. Hardsetting can reduce yields through slow crop growth, poor infiltration, and impaired root growth. It is therefore necessary to adopt management techniques which reduce the severity and incidence of crusting and hardsetting, and which optimise yields. Some of these techniques are:

- If a surface crust has formed after sowing and before emergence, a light harrowing to break the crust may be useful.

**Soil organic matter or soil organic carbon (as measured in a soil test) is NOT the same as plant residue (stubble, weeds, roots etc). Soil organic matter is what is left of plant residues after breakdown of plant residues by soil organisms (bacteria, fungi, earthworms etc.). It is visible in the topsoil as a darker colour, and is the 'substance' which helps to bind soil particles into aggregates.**

- Keep some plant residue on the soil surface to reduce raindrop impact. Heavy rain can cause a crust to form, even on well-structured soils. The soil can be shielded from the impact of raindrops with stubble and other plant residues. Retaining plant residues will help to increase soil organic matter. This will reduce slaking and dispersion, and therefore help to reduce the incidence of crusting and hardsetting.
- If a soil is sodic then gypsum application may help to prevent crust formation.
- Reduce tillage and cultivate only at correct moisture content. Adopt non-inversion tillage and less aggressive forms of cultivation. Direct drilling may be an option on crusting soils, while hardsetting soils are likely to benefit from tillage that breaks up the hard layer, without being too aggressive.
- Rotate to a pasture phase. A productive pasture adds organic matter to a soil and hence improves the structure of that soil. Remember that the benefits of the pasture phase are lost if pasture paddocks are grazed under heavy stocking rates (especially when paddocks are wet).
- Over-cultivation, or incorrect tillage techniques at the end of the pasture phase will reduce the effectiveness of the pasture in reducing slaking and dispersion.
- A rice crop may be another option to reduce hardsetting in a loamy topsoil. However, cultivation after the rice should be minimal (direct drilling or reduced tillage for the next crop) to make the most of the organic matter added by the rice roots.



*A hardset soil surface (few cracks visible)*

# Chapter E3. Landforming and soil management

## INTRODUCTION

Landforming includes such activities as laser grading, landplaning, and activities that involve 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 assist in irrigation efficiency.

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

- Damage to 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 contents (see Chapter C8).

***Dispersion* refers to a process in which aggregates in the soil break down into their component particles when wet by irrigation water or rainfall. Dispersion is the process that causes 'muddy water' in rice.**

**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 'exchangeable sodium percentage' (ESP). The higher the ESP, the more dispersive a soil tends to be. Dispersion is more likely to be a problem when ESP values are higher than 6.**

- Exposure of subsoils in cut areas. Topsoils contain the bulk of plant nutrients. Once this is removed, so too are the nutrients that plants require for good growth. Additionally, the exposed subsoils are generally more dispersive than the topsoils because they are higher in sodium (ie. more sodic). A simple test for soil dispersion is included in Chapter C7. Sodic soils are poorly structured, hard to cultivate, and will generally form a crust after the application of water.

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

## SOIL PROPERTIES AND LANDFORMING

The different soil groups used in this SOILpak have distinct properties with implications for landforming.

### 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 topsoil. In red-brown earths (RBEs) this depth is generally 10–40 cm, but 15–20 cm is most common. Transitional red-brown earths (TRBEs) have a topsoil of only 5–10 cm. This means that subsoils are often exposed when landforming TRBEs. As the topsoils of both RBEs and

TRBEs are of a loamy texture, they can be damaged severely if cultivated when too dry (see Chapter C8). 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 around 20 cm of loamy topsoil. It is desirable to have as much depth as possible remaining after landforming. Therefore, the most successful practice to overcome poor yields in cut areas is topsoiling. This is the process where topsoil is replaced on cut areas. As can be seen in Table E2, the topsoil is a store of the most important nutrients for plants. Additionally, the topsoil assists with water storage.

Subsoils of RBEs and TRBEs are of medium to heavy clay texture. Exchangeable sodium percentage is usually high. Therefore, they are poorly structured and dispersive.

**Table E2. Some important properties of a transitional red-brown earth**

	depth	pH	organic carbon %	ESP	available phosphorus (Colwell)	nitrogen ppm
topsoil	10 cm	5.4	1.9	4.5	24	74
subsoil	at 20 cm	7.2	0.6	11	9	20

Table E2 shows that the properties of a TRBE need consideration prior to landforming. The subsoil that could be exposed may be severely lacking in properties that will promote plant growth. Nitrogen and phosphorus are low and plant growth is likely to be poor.

Subsoil ESP is high and therefore dispersion is likely. This will cause problems such as crusting and poor water penetration. As most subsoils are likely to be relatively poor environments for plant establishment and growth, their exposure should be avoided. If subsoils are exposed, they should be ameliorated with gypsum and/or fertiliser. Poultry manure has had excellent results on exposed cut areas.

### Self-mulching and non self-mulching clays

Non self-mulching clays are generally sodic at or near the surface. Their subsoils are usually very sodic and sometimes saline. Self-mulching clays are non-sodic and well structured from the surface, but can be sodic and poorly structured at depth.

Both of these soils are of a clay texture, and therefore should be landformed at a moisture content below the plastic limit (see Chapter C8). Landforming is a particularly aggressive form of cultivation that will increase the likelihood of dispersion in sodic soils.

### PRE-LANDFORMING MANAGEMENT

A number of strategies should be considered before landforming that may reduce the cost of the operation itself, as well as the effects of landforming on production.

- 1) Try to stay with the natural slope as much as possible. This will reduce the volume of cut and fill. If on very flat country (if not used for rice), beds may be an option to improve drainage.
- 2) Shorten bay length. This reduces the amount of cut and fill, and also the distance that soil must be moved, thus reducing the cost.

However more supply and drainage channels are needed with shorter bays.

- 3) Split grades can be used to match layout to natural slope and soil type.
- 4) Where soils have shallow topsoils (eg. TRBEs), subsoils will be exposed during most landforming cuts. One technique to overcome this problem is to invert the topsoil prior to landforming with a mouldboard plough. This means that some topsoil is likely to remain on the cut areas.

## MANAGEMENT DURING LANDFORMING

As already mentioned, landforming at inappropriate moisture contents is damaging to soil structure. When clay soils are worked too wet (above the plastic limit) compaction is very likely.

When loam soil are worked too dry, 'bulldust' is produced. This is an indication of severe structural damage, and should be avoided. It is acknowledged that there are many good reasons for landforming to take place when soil conditions are not exactly correct. Nevertheless every effort should be made to landform at optimal moisture content, otherwise serious and costly structural deterioration may result.

As exposed subsoils are generally poor environments for plant growth, *topsoiling* is highly recommended to improve plant growth on cut areas. Topsoiling is the process in which cut topsoil is set aside during landforming, and replaced on heavily cut areas. A heavily cut area should receive at least 10 cm of topsoil for best results.

Topsoils improve infiltration and water storage of a soil, as well as acting as a store of plant nutrients. Research has shown that topsoiling produces superior yields to other types of soil amelioration (gypsum, phosphorus, zinc etc.) on heavily cut sites.

## POST-LANDFORMING MANAGEMENT

### Crop selection

Following landforming it is desirable to get a paddock back into production as soon as possible to boost income. A crop must be chosen from which a reasonable yield can be obtained, given that the soil is likely to be poorly structured. A crop will begin the process of improving soil structure in a degraded soil. The best crop to grow following landforming is either a winter cereal or rice. Winter cereals are a good option since they may benefit most from the improved drainage resulting from landforming. Furthermore, winter rains can provide much of the water needs of the crop.

Rice is also a good option after landforming. If landforming is carried out in summer or autumn and a winter cereal is not grown, then weeds should be left to grow on the area before planting a rice crop in spring. Any plant growth will help to improve the structure of the soil. As rice returns large amounts of organic matter back to the soil because of its roots, it is a good 'soil conditioner' after landforming.

Growing summer crops (other than rice) first after landforming should be avoided, unless the soil is a self-mulching clay and has not sustained too much damage during landforming. Newly landformed soils may have poor water penetration at each irrigation, and it may be difficult to avoid high yield losses due to water stress resulting from this.

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, necessitating further levelling. It is therefore important that an annual crop is grown during this ‘settling down’ period so that a ‘touch up’ landforming can be carried out afterwards. A pasture should not be sown straight after landforming for this reason.

Raised beds or hills should be formed in the autumn to allow a winter crop to be planted and/or soil to settle before planting summer crops in the spring.

### Rice ground preparation after landforming

After landforming fill areas tend to compact while cut areas set hard or run together. The following points need to be considered:

- It is important to plough ground while there is good moisture, otherwise clods will be brought up in cut areas, making seedbed preparation difficult. Soil can be drier for self-mulching and non self-mulching clays, since these soils will not ‘powder’ as readily as loams
- 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 to make seedbed preparation easier.

### Soil nutrients in ‘cut’ 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 contents in subsoils are very low and therefore almost all crop nitrogen needs must be met by fertiliser. Yield responses can be expected at 100 kg N/ha for winter cereals. Because of the risk of poor germination at such high rates, it is advisable to pre-drill 50 kg N/ha and apply a further 50 kg N/ha about eight weeks after sowing if establishment is satisfactory.

*Phosphorus:* Phosphorus is a relatively ‘immobile’ nutrient in the soil; water will not move it far from where it is applied. Therefore little (if any) phosphorus applied to topsoils moves into subsoils. It is necessary to apply phosphorus to exposed subsoils at heavy rates. It is a good idea to obtain a soil test on the area exposed to determine fertiliser rates. Table E3 gives general guidelines for phosphorus application to cut areas.

**Table E3. Phosphorus application guide**

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

*Zinc:* There is no suitable soil test to determine zinc availability in soils. Zinc availability is related to soil pH; as pH increases zinc availability decreases. Subsoils with a pH above 8 are therefore likely to be zinc-responsive. Experience has shown that cut areas of grey self-mulching clays are likely to respond. Zinc should be applied at rates of about 10 kg Zn/ha. Zinc is usually applied in the form of zinc oxide (‘Zingro’

approximately 60 per cent zinc) or with 'Zinc super'-type superphosphate fertilisers. Zinc should be considered a form of insurance and applied separately to cut areas.

### IMPROVING STRUCTURE AND WATER PENETRATION OF CUT SOILS

*Gypsum:* Gypsum helps to improve soil structure in exposed clay subsoils if they are sodic to begin with. Subsoils of all soil groups are generally sodic. The exception is some self-mulching clays, especially when cuts are not deep. A soil test is recommended to determine exchangeable sodium percentage (see Chapter C9). Gypsum will help to create better structure in exposed sodic subsoils. This will greatly assist crop establishment by reducing crusting and producing finer (smaller) aggregates for good seed/soil contact.

Gypsum also improves internal drainage of the soil when heavy application rates are used. If rice is to be grown within twelve months of application, rates should be **no higher than 2 t/ha**, because of increased water usage. Table E4 gives guidelines for gypsum application rates to cut areas.

**Table E4. Gypsum application guide**

Exchangeable Sodium Percentage (ESP) of soil	Gypsum application rate (t/ha)
greater than 6, less than 10	2–5 t/ha
greater than 10	5 t/ha



# Chapter E4.

## Cultivation and soil structure

### INTRODUCTION

Cultivation (tillage) is a practice 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 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 old, our climate is hotter and drier, and organic matter breaks down quickly. Therefore, cultivation is potentially disastrous for many Australian soils, if not carried out 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:

- Cultivation is often a form of weed control.
- Cultivation can play a part in pest management. For example, tillage is recommended to reduce the number of over-wintering *Heliothis* pupae in paddocks where susceptible summer crops are grown.
- Cultivation may be required to incorporate herbicides and soil ameliorants, such as lime.
- Cultivation may reduce the incidence of soil-borne diseases. Soil-borne diseases such as *Rhizoctonia* can be a problem in some soils where crops are planted using direct drill or zero till (see also Chapter E6).
- Cultivation reduces soil strength. High soil strength (hard or compacted soils or soil layers) has been shown to reduce the vigour of crops, especially seedlings. High soil strength of poorly structured soils is one reason for poor seedling vigour in direct-drilled crops.

### 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:

*Soil organic matter* may be visible 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 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 therefore is harmful to soil structure. Therefore reducing tillage can improve soil structure.

- 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 worsen soil crusting.

### SOME GUIDELINES FOR CULTIVATION PRACTICES

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

#### ***Aggressive cultivation***

- landplanes
- heavy disc implements
- wide-board

#### ***Less aggressive cultivation***

- chisel plough
- scarifier
- roller

- Minimise cultivation as much as possible. The less a field is cultivated, the less the damage to soil structure. If soil conditions and machinery are suitable, consider direct drilling. This may require increased use of herbicides for weed control.
- When cultivating try to use less aggressive forms of cultivation. Implements such as levelling equipment and disc ploughs are likely to degrade soil structure very quickly.
- Cultivate at appropriate soil moisture content, especially when using aggressive implements. A soil moisture test for tillage is presented in Chapter C8: *Soil moisture before tillage*.

- When using implements that mix soil throughout the cultivation depth, it is best to restrict depth of working to five centimetres 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, and 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 (top 1cm).
- For deep cultivation use non-inversion implements, such as chisel ploughs or scarifiers with narrow points. A deep cultivation (15–20 cm) can be useful to increase infiltration of water and encourage early root growth. Such an implement is best followed by a roller. A one pass tillage implement is an alternative.

## DIRECT DRILLING

Direct drilling is a technique where crops or pastures are sown into uncultivated soil. In general soil is only disturbed in a narrow slot along each sowing line. This technique offers many benefits since soil structure will improve over a number of years. Yields, timeliness of sowing and ease of paddock preparation will all improve as soil structure improves. Long-term farm productivity will also increase.

### Direct drilling in hardsetting soils

In soils with naturally poor structure (eg. hardsetting soils), direct drilling does have some problems. Early growth of direct-drilled crops is often much slower than conventionally cultivated crops, the possible reasons for this being:

- the mixing of soil with conventional cultivation reduces the incidence of biological factors (soil-borne diseases). This ‘mixing’ does not occur with direct drilling and therefore 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 (high soil strength) grow slower than those in ‘soft’ soils. High soil strength experienced by plant roots is thought to produce hormones in the plant that reduce shoot and root growth.

## CULTIVATION TECHNIQUES FOR POORLY STRUCTURED /HARD SOILS

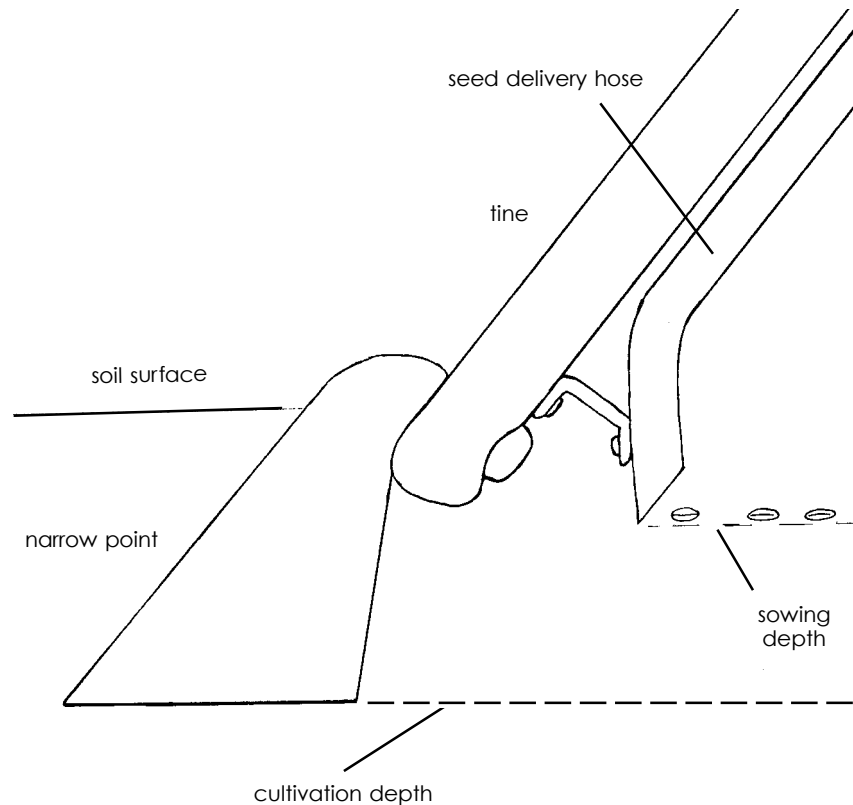
Some poorly structured soils may have poor infiltration of water, and poor plant vigour due to very hard soil. This soil should be ‘softened’ using cultivation.

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

It can also be carried out for sowing if the sowing rig has a high tine break-out strength (usually more than 1.55 kN or 350 lbf), and points

that allow cultivation well below sowing depth. Many rigs set up to deep band fertiliser have this capacity.

**Figure E2. A sowing tine configuration for direct drilling**



A roller or press wheels should be used when cultivating the soil to depths of 15–20 cm. Rollers can level the soil and break clods without the aggressive dragging action of harrows. Rollers also give good seed/soil contact for improved emergence.

These principles are the basis of a ‘one-pass tillage system’, designed by NSW Agriculture. This implement has proved suitable for red-brown and transitional red-brown earths, but is as yet untried in non self-mulching clay soils.

### 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 allowing plants to access deeper soil. However, deep ripping must be conducted with some caution, as problems may occur. Some useful ‘rules’ for deep cultivation are:

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

**(i) Rip only to compaction depth**

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

Poorly structured/restrictive layers are often found in soils of the Murray and Murrumbidgee valleys. These layers are usually dispersive clays. Soils should be ripped to at least 15 cm in this situation. However, ripping of dispersive soils will be more successful when combined with gypsum.

**(ii) Use non-inversion points**

Organic matter is usually concentrated in the top 2–3 cm. Implements that invert the soil will bury much of it deeper, resulting in the soil surface becoming more prone to slaking. Crusting and hardsetting may then become a problem (or more of a problem). Deep cultivation that inverts the soil may also bring dispersive subsoil to the soil surface. Points/tines that do not invert the soil should be used. Trying to force blunt chisel points through a compacted layer is often ineffective and consumes more fuel. Correct ripping points should be used.

**(iii) Deep rip dry soil only**

Deep tillage of wet soil is unlikely to have any benefits. The soil needs to be dry to produce cracks for deep ripping to have a beneficial effect. (Soil should be drier than the plastic limit, see Chapter C8.) Deep tillage of wet soil can reduce crop yields. This is thought to be due to smearing and the compaction caused by the weight of the tractor and implement, when the soil is wetter than plastic limit.

A suitable time for deep ripping is just after the soil has been dried out to depth with a winter crop. Winter cereals and canola are useful crops for drying the soil, but one of the best is safflower due to its deep roots and late (mid summer) finish.

**(iv) Use gypsum when deep ripping sodic/dispersive soils**

Deep ripping will have a relatively short-term effect on soils that are dispersive. Dispersive soils are usually those with an ESP > 6 (see Chapters C7 and E1).

Dispersive soils will swell and disperse when wet, and therefore cracks created by the ripper will soon collapse. To maintain the cracks created by the ripper, gypsum should be applied prior to ripping (see Chapter E1).

**MACHINERY DESIGN FOR DEEP RIPPING****Attack angle**

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

**Narrow points or sweeps?**

Narrow points and sweeps both have applications for ripping. Narrow points have the advantage of working effectively to greater depths. However they are likely to cause some smearing and

compaction at the bottom of the cultivation layer, especially when the soil is wet. Sweeps do not smear the soil as much as narrow points when the soil is wet, but cannot effectively work to the same depth as narrow points.

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 this implement produces a better tilth, leaving the soil less 'cloddy' than conventional rippers, while allowing the implement to be worked at a greater depth with reduced fuel consumption.

Such a machine is not commercially available. However many rippers can be modified to the configuration outlined above.

### **IMPROVING SOIL STRUCTURE**

Switching to direct drill or minimum till farming will help improve soil structure over time. If a soil has had a history of aggressive and/or repeated cultivations it may be advisable to rotate to a pasture phase, or grow rice or possibly canola.

If direct drilling is adopted in a paddock that has degraded structure, problems such as poor tilth, slow early growth and lower yields may be experienced until soil structure improves. Minimum till and direct drill will help to maintain soil structure for longer periods of time, compared to conventional cultivation.

Where topsoils are crusting or hardsetting, a surface mulch may help to improve the structure of the soil surface.

If a pasture phase has involved heavy stocking, with resulting soil compaction and pugging, minimum tillage or even conventional tillage may be warranted to loosen the soil for the first crop before attempting direct drilling.

# Chapter E5. Improving soil structure by crop rotation

## INTRODUCTION

Soils with poor structure will require improving to produce high yielding crops and pastures. Poor soil structure may be visible as or indicated by:

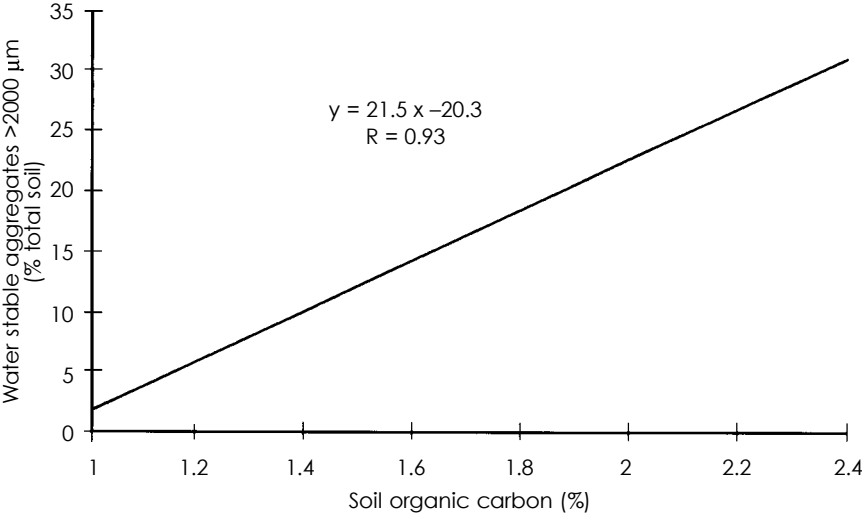
- crusted or hardset topsoil (massive structure)
- pugged (damage by livestock) topsoil
- slaking score > 2
- ESP > 8
- compacted zones, such as those under wheel tracks or ‘plough pans’

**Soil structural stability refers to a soil’s 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 in loamy soils is related to the proportion of water stable aggregates more than 2 mm in diameter. In clay soils the critical size may be much smaller.**

Some soil structural problems are naturally occurring, for example sodicity. However most problems are caused or made worse by human activity. Inappropriate use of cultivation is largely responsible for soil structural decline. Some useful cultivation techniques are outlined in Chapter E4. However it is necessary to improve the structure of the soil first, before undertaking any ‘conservation tillage’ (eg., direct drilling). A crop or pasture 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.

Many studies have show that organic matter content of the soil has a strong influence on soil stability, ie. its resistance to slaking and dispersion (Figure E3). In the figure organic matter is indicated by the

**Figure E3. The effect of soil organic matter on structural stability (Tisdall and Oades, 1982)**



organic carbon percentage, and soil stability (structure) by water stable aggregates. A soil that does not slake or disperse will usually be very structured, allowing for excellent plant growth under irrigated conditions.

A build-up in soil organic matter is therefore likely to benefit soil structure, and plant growth. Figure E3 indicates that soil organic matter decline is most rapid in the following situations:

- cultivation
- a period of bare fallow
- when crop residues are removed

Some suggested methods of improving soil structure include:

- (i) a productive pasture phase
- (ii) one or more rice crops
- (iii) a canola crop
- (iv) a broadleaved leguminous crop such as soybeans or faba beans.

It must be stressed that the benefits of soil improvement through rotation to these crops will be quickly lost if conservation tillage practices are not used in the following cropping phase.

## **PASTURE**

Many studies indicate that structure of soils (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. To improve structure in a poorly structured soil, a pasture phase is useful, since it allows soil organic matter to build up (see Figure E3). Pastures continually input organic matter to the soil via roots and decaying shoots. Pastures are not cultivated and hence allow soil organic matter to increase, thereby improving soil structure.

**Increases in structural stability (resistance to slaking and dispersion) is related to the amount of root material plus Mycorrhizal fungi produced by a pasture (Tisdall and Oades, 1980b).**

**A separate trial showed that ryegrass had the ability to dramatically improve the physical properties of a subsoil of a red-brown earth exposed by landforming. While gypsum was applied to aid ryegrass establishment, all the gypsum was leached out of the upper profile when measurements were taken. The ryegrass doubled the number of water-stable soil aggregates >2mm (very important for good soil structure) in the top 20 cm of exposed subsoil. At the same time the strength of the soil (similar to hardness) in the top 10 cm decreased to less than half its original value.**

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 offer more protection of the soil surface than crops do since 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 soil surface structure causing crusting to occur.
- Plant residues on the soil surface break down to form compounds that assist to increase the structure of the soil.
- Plant residues encourage the activity of soil animals such as earthworms (see Chapter E6: *Soil improvement through biological activity*).

Pasture type will also influence the soil. Grass pastures, especially those with extensive finely branched roots, such as ryegrass, have shown to have the most benefit. Additionally, grass pastures act as hosts for beneficial fungi that helps bind soil particles into aggregates. Ryegrass dramatically improves soil structure due to its large fibrous root system which 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.

## EFFECTS OF GRAZING ON SOIL

***Bulk density* is defined as the mass of oven-dry 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 (>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 soil is wet, high stocking rates are used, and the stock are grazed for extended periods of time.

On a clay soil at Leeton, sheep stocked at approximately 20 sheep/ha led to a dramatic decline in production compared to an unstocked treatment. At 20 sheep/ha grazed for five weeks (commencing a day after irrigation water had drained), pasture production was 58% lower than the unstocked treatment. This difference was attributed to an increase in bulk density of the topsoil (see Figure E4), and the direct effect of sheep damaging pasture plants when grazing and walking on them. Between 34%–58% of reduced pasture production was due to changes (increases) in the bulk density of the soil. Bulk density is likely to remain high, until cultivated, or until the soil undergoes extensive cracking when dry (clay soils only).

**Figure E4. The effect of stocking rate and duration of grazing on soil bulk density (Witschi and Michalk, 1979)**

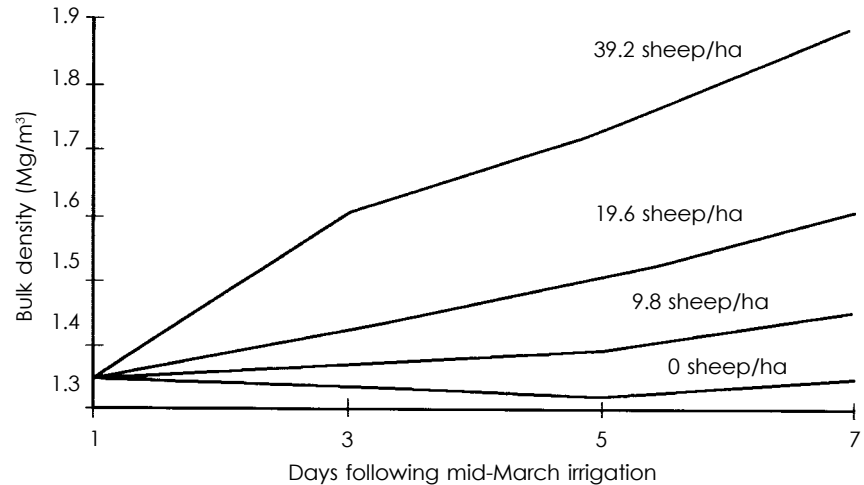
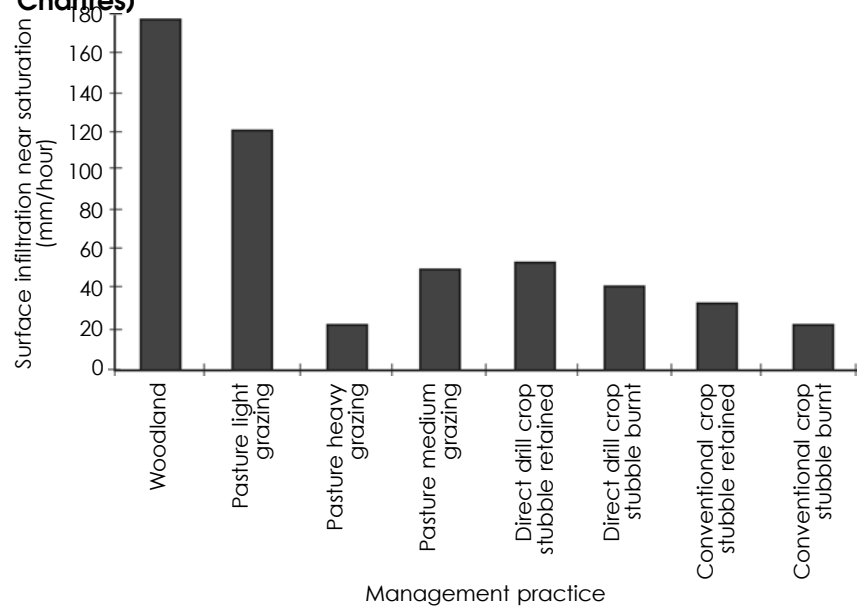


Figure E5 illustrates the comparative effect of different management practices on surface infiltration. This is a good indicator of soil structure (ie., the higher the surface infiltration the better). It is interesting to note that heavy grazing of pastures will cause the lowest infiltration rates in this study. To obtain maximum soil structure benefits from pastures, lighter stocking rates should be used if possible, or the paddock should be reserved for hay cutting.

**Figure E5. Effect of management on infiltration rates of surface soil for loamy textured soil (Geeves, Cresswell, Murphy and Chartres)**



When grazing stock on annual pasture it is important to allow the pasture to establish before grazing commences. A period of two to three weeks would be suitable in most instances. An establishment period allows a build-up of plant material on the surface of the soil that will help to protect soil from damage. This will help to produce a productive pasture by protecting the soil and pasture plants when they are most vulnerable to damage.

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In summary the following steps should be taken during a pasture phase to minimise damage from livestock:

- Do not graze soil when wet. Allow soil to dry before introducing stock. Soil damage will be particularly bad when soil is wet, and there is little plant cover.
- On annual pastures, keep stock off the pasture for a period of two to three weeks after the first watering to allow the pasture to establish.
- Use lighter stocking rates and/or short grazing periods.

## **CANOLA**

Canola crops are often reported to make the topsoil of a paddock softer or more 'spongy'. Research has indicated that canola (like many other crops) can improve the physical condition of topsoil, thus improving the growth of subsequent crops.

Canola significantly improves water infiltration rates and decrease soil strength (hardness) compared to soils under wheat. Several reasons are given for this reported soil improvement (Packer et al. 1994):

- The effect of the broadleaf crop protecting the soil surface from raindrop impact.
- Canola produces an intensive system of fine lateral roots in the surface soil that would increase biological activity, especially the production of soil-binding agents which increase aggregate stability.
- Specific types of organic matter produced by canola roots such as 'mucigels'.



# Chapter E6. Improving soil through biological activity

Soil organisms improve soil structure, bring about chemical changes in the soil's constituents and add to soil nitrogen by fixation from the air. The following factors increase biological activity:

- retention, not burning, of crop residues
- stubble mulching rather than incorporation of crop residues
- minimum or no tillage
- opportunity cropping to avoid long, bare fallows
- liming if necessary to increase soil pH
- well managed, not over-grazed, pasture
- good soil chemical fertility to promote plant growth and increase organic matter in the soil
- absence of adverse conditions such as waterlogging and salinity

Soil organisms are the 'intestines' of the soil because they digest plant residues to turn it into nutrients in forms available to plants.

## EARTHWORMS

Earthworms benefit the soil. Contrary to what many people have thought in the past, most soils in the cropping zones of Australia are not too hot and dry for earthworms. They do not like coarse sandy soils, saline conditions and locations where lengthy periods of waterlogging occur. Earthworms are also sensitive to management practices.

*Tillage* reduces earthworm populations because it chops them into pieces, destroys their burrows, and hastens the decomposition of plant residues, their food supply. By incorporating plant residues into the soil, tillage removes the protective mulch that keeps the soil cool in the day, warm at night, and the surface soil moist for longer after rain.

The frequency and type of tillage affects the number of earthworms present. Their numbers under direct drilling can be up to four times higher than under conventional cultivation. With reduced cultivation, a single pass with narrow points does not destroy many earthworms. However, traditional broad points reduces earthworms numbers to the same extent as conventional cultivation.

Increased earthworm populations may not show up in the first year of direct drilling — it is a long term process.

*Stubble* removal reduces earthworm numbers dramatically, but stubble retention can boost numbers by up to 50%. Crop residue management affects the size of earthworms. For example, worms are smaller in paddocks where the stubble is burnt.

Measured earthworm populations in a trial in the dryland cropping zone of southern Australia are shown in Table E5.

**Table E5. Active earthworm population (numbers per m<sup>2</sup>)**

Tillage Type/ Stubble Treatment	Direct Drilled	Reduced Tillage	Conventional
Stubble Retained	17.0	14.1	4.2
Stubble Burnt	18.4	7.1	4.2

*Crop rotations* that include a pasture phase will result in higher earthworm numbers throughout the rotation, compared with continuous cropping. The amount of food and moisture available, which may depend on the previous crop, will influence earthworm populations. It is surprising how quickly numbers can build up in soil under a rice stubble.

*Soil acidity* reduces earthworm numbers. They will not survive where the pH is below 4. Lime will boost the growth of plants and worm numbers in such situations. Lime raises soil pH and adds calcium, which earthworms need.

*Irrigation* keeps the soil moist, favourable for earthworms, and also brings other beneficial conditions. Frequent flood irrigations, such as for perennial pastures, will not inhibit earthworm numbers and activity, as long as both surface and internal soil drainage are good.

The benefits and activity of earthworms can be summarised as follows:

**Earthworm burrowing:**

- improves soil porosity and structure
- increases infiltration and percolation (permeability)
- provides channels for the transport of soluble fertilisers
- increases rootzone aeration
- provides channels for root growth

**Earthworm feeding:**

- increases rate of organic matter turnover
- breaks up surface mat of organic matter, root mats and leaf litter
- breaks up and mixes organic matter with inorganic material
- increase soil microbial activity

**Earthworm casts:**

- produces a zone of nutrient enrichment for plant growth
- concentrates microbial activity and nutrient release
- contains nitrogen, phosphorus and potassium in forms available to plants

**TERMITES AND ANTS**

As termites and ants eat all forms of plant residues, soil fertility often increases near their nests. They help to breakdown organic matter, and the return of nutrients to the soil. Termites and ants are important soil improvers in dries areas where earthworms are less active.

**OTHER SOIL ANIMALS**

Healthy soils support a diverse range of other soil animals, such as dung beetles, slaters, springtails and centipedes. Many occur in large numbers, such as the spiders which sometimes cover tilled paddocks with their webs. All have their place in the conversion of stubble, other plant residues and animal manure into plant nutrients. Many of these directly improve soil structure, through the excreting of soil ingested with their food.

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## BACTERIA

Bacteria are single-celled organisms which usually occur in colonies in the form of chains or filaments. They are responsible for many of the chemical reactions in soil, including decomposition of organic matter and transformation of the various forms of soil nitrogen. Long-chain sugars produced by bacteria act as gums which bind soil particles together.

Soil bacteria feed on organic matter, and in the process, convert nutrients from organic forms, to inorganic forms which are available to plants. This process is called mineralisation. Nitrogen in organic matter, for instance, is converted first to ammonium and then to nitrites and nitrates.

Bacteria are small enough to live in the water which surrounds soil particles. Many survive by forming spores when this water dries out. Some spores, such as Anthrax, can survive for more than 20 years. When moisture becomes available, the spores germinate and the bacteria multiply rapidly. Because they respond to moisture more quickly than plants, the mineral nitrogen liberated early in the season may exceed the ability of seedling plants to take it up. This may lead to nitrate leaching in some years.

## FUNGI

Fungi are plants that germinate from spores and cling together in long strands called hyphae. These strands can form a mat called mycelium. When conditions are unfavourable for growth, spores are produced.

Most fungi live on dead plant residues, decomposing them and releasing nutrients for plant uptake. They are particularly effective in decomposing lignin, the tough material found in straw and wood. Not surprisingly, fungi are most abundant in the surface soil in woodlands and grasslands.

Fungi help improve soil structure by binding soil particles into aggregates. However, in sandy soils they may cause water repellence (non-wetting) which interferes with infiltration. Only a few fungi infect living plant tissues to cause plant diseases.

## PLANT RESIDUES AND STUBBLES

Many of the benefits from retaining stubbles have been pointed out. Stubbles can also protect the soil surface from raindrop action, wind and water erosion, extremes of temperatures, rapid evaporation, and soil slaking and dispersion.

However, there are some adverse side-effects, including disease carry-over, insect build-up, nutrient tie-up, weed control problems, and blockage of equipment and irrigation systems. Slime can build up in young rice crops from excess undecomposed green plant residues.

There are management practices which can be adopted to overcome most potential problems, such as the growing of break crops and disease resistant varieties, and the low cutting and spreading of winter crops at harvest. However, there may be occasions when there is no choice but to burn a heavy winter cereal or rice stubble.

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## IMPORTANT SOIL-BORNE DISEASES

The soil harbours a large number of plant pathogens, ie. microorganisms that cause plant diseases. Seasonal conditions are the main reason for disease outbreaks, but management practices are the next most important factor in determining whether pathogens can infect a crop.

Management practices that influence disease development can be as simple as tillage, timing of operations, and the volume of surface cover remaining after a crop is sown. Some of the more important crop diseases and appropriate management practices are outlined below:

*Rhizoctonia:* The spores of the Rhizoctonia fungus survive on organic residues in the soil, especially stubbles and from ploughed up pastures. The spores germinate with autumn rains and can attack the seedlings of cereals, pulses, oilseeds and pastures. It is more severe in lighter soils.

The spread of Rhizoctonia (bare patch) is favoured by direct drilling. The risk can be reduced if the soil is disturbed below where the seed is to be placed, or by adopting minimum tillage where an initial cultivation is carried out prior to the sowing operation. It is important to use adequate fertiliser, as good plant nutrition can reduce losses from Rhizoctonia.

*Blackleg of canola:* This is also caused by a fungus, and is the most common and serious disease of canola in NSW. It is carried over from season to season by the survival of the spores on canola stubble and trash, and on volunteer brassica weeds and canola plants. Its incidence is reduced by growing break crops, such as winter cereals. It is also important to adhere to the recommendation that canola should not be grown again in the same paddock for a minimum of four years.

*Brown leaf spot of lupins:* This disease is spread by the rain splash of fungal spores onto lupin seedlings. The spores can remain viable in the soil for several years. Other than long rotations, the retention of cereal stubbles is the most effective means of reducing the incidence of this disease. The stubble acts to reduce rain splash. Practices that involve a bare soil surface with little cover at sowing should be avoided.

*Sudden death of lupins:* There is growing evidence to suggest that this condition is caused by an interaction between soil hardpans and fungal pathogens, especially where waterlogging has occurred early in the season. Practices which improve soil structure, break hardpan layers and improve both surface and internal soil drainage will decrease the likelihood of this condition. Practices such as cultivating at optimal soil conditions, the use of narrow points and growing lupins on raised beds to overcome waterlogging should all help.

# Chapter E7. Irrigation scheduling

## INTRODUCTION

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

Water shortages sufficient to hinder crop growth can occur without producing obvious wilting of foliage, while waterlogging can also cause large yield reductions. 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, will assist in deciding when to irrigate.

## FACTORS AFFECTING IRRIGATION INTERVALS

The interval between irrigations and the amount of water to apply at each irrigation depends on how much water is held in the rootzone 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 each type in the soil determines the feel or texture of the soil, the size of the micropores between the particles and thus the amount of water that can be stored in them.

Soils are classified into texture classes such as clay loams, heavy clays, loams, sandy loams, etc. This is determined by the proportion of sand, silt and clay in the soil (see Chapter C6). Indicative plant-available water storage capacity of four soil texture classes is shown in Table E6.

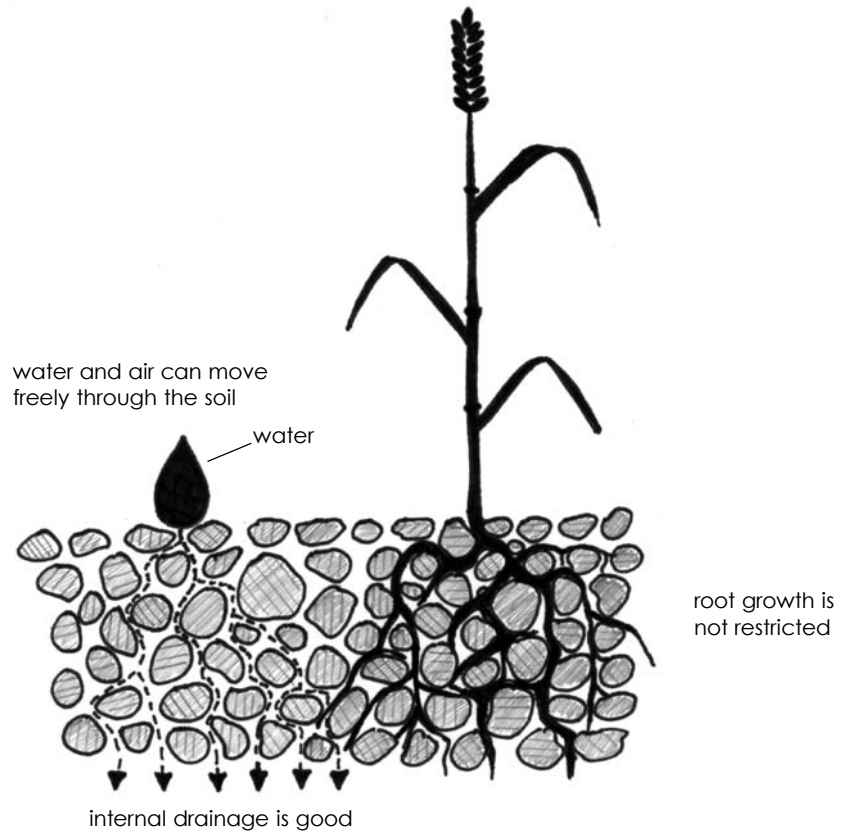
**Table E6. Available moisture according to texture (mm plant-available water/metre of soil depth)**

Soil texture	Range	Average
Sand	up to 65	50
Loam	155 to 175	170
Clay loam	155 to 172	165
Clay	137 to 147	140

**SOIL STRUCTURE**

Soil structure refers to the natural aggregation of soil particles which 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 E6) will contain many pores that will hold water and air and aid infiltration of water into the soil. A poorly structured soil (Figure E7) will not have as many pore spaces, will have reduced water-holding capacity and poor water infiltration, and will probably restrict root growth.

**Figure E6. A well-structured soil**



**Figure E7. A poorly structured soil**



It is clear from Figure E6 that a well-structured soil will give plant roots an environment favourable to healthy growth and the extraction of water and nutrients.

The soil structure of many soils has been damaged by years of cultivation and compaction, and also by sodicity. This has led to the breakdown of structure and development of soil crusting and hardpans which reduce water penetration and retention, as well as restricting root growth (see Chapter C5). This results in reduced plant growth.

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

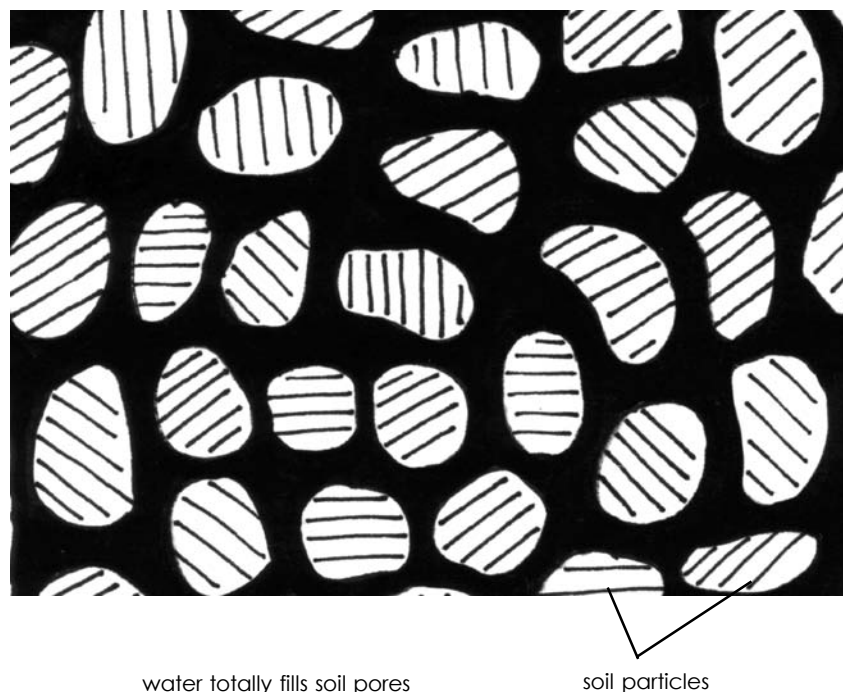
## SOIL WATER

Before discussing soil moisture status in your soils it is necessary to define a few terms used. These include field capacity, permanent wilting point, saturation, available soil water and refill point.

### Saturation

A soil is saturated immediately after it has been irrigated. Almost all of the soil pore spaces are filled with water and very little air remains (Figure E8). If drainage is adequate, water will drain away from the larger pore spaces and allow some air to enter the soil. This takes about 24 hours, depending on soil type. If the internal drainage of the soil is restricted the soil becomes waterlogged, with no air in the soil, and roots begin to die from lack of oxygen.

**Figure E8. Saturation (soil contains no air)**

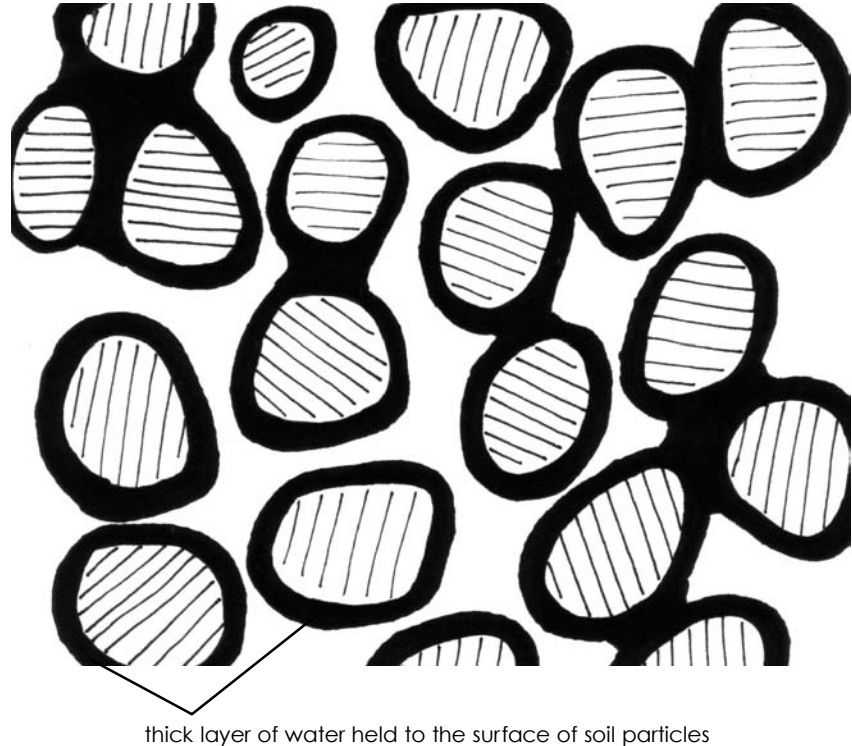


### Field capacity

Once the soil has drained by gravity for about 24 hours water is held in the pore spaces by surface tension around the soil particles, and little further drainage will take place (Figure E9). This condition is called

field capacity and the soil is holding as much water as it can. There is also enough air in the soil to supply plant roots with the oxygen necessary for roots to live and grow.

**Figure E9. Soil at field capacity (good balance of water and air)**



### Permanent wilting point

As plants take up water the roots are working against the surface tension that holds the water in the soil. In other words, the roots are sucking water from the pore spaces within the soil. Naturally, plants use the most easily extracted water first and as the soil dries out the plant must work harder to obtain water. Water is extracted from the soil until a point is reached when a plant's root system cannot obtain any more. This is called the permanent wilting point for that soil. The soil is not totally dry, but the remaining water is held so tightly that plant roots cannot extract it. As a soil approaches permanent wilting point plant growth slows. Plants may show signs of wilting during the day, but they recover overnight.

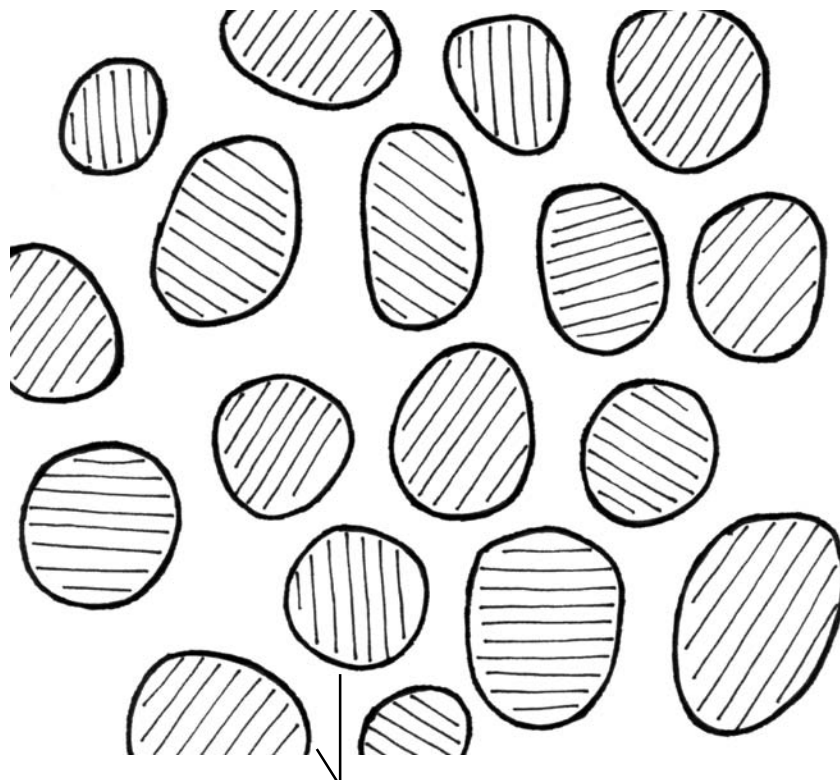
***Permanent wilting point*** is the soil water content at which plants wilt, and do not recover when evaporative stress lessens (at night) or when the soil becomes moist again.

Permanent wilting point is slightly drier than the plastic limit: the water content of a soil above which it can be remoulded (is plastic) and below which it cannot be remoulded (is brittle).

When plant symptoms show a soil to be at permanent wilting point, it is likely that the root zone is slightly drier than the plastic limit.

Plants do not grow in a soil where moisture is at or below permanent wilting point. They will not recover from moisture stress if moisture is not replenished quickly, and they will die. If crop good growth is expected, irrigated agricultural soils should not be allowed to approach permanent wilting point.

**Figure E10. Soil at wilting point (no water available to plants)**



thin layer of water on soil particle surfaces

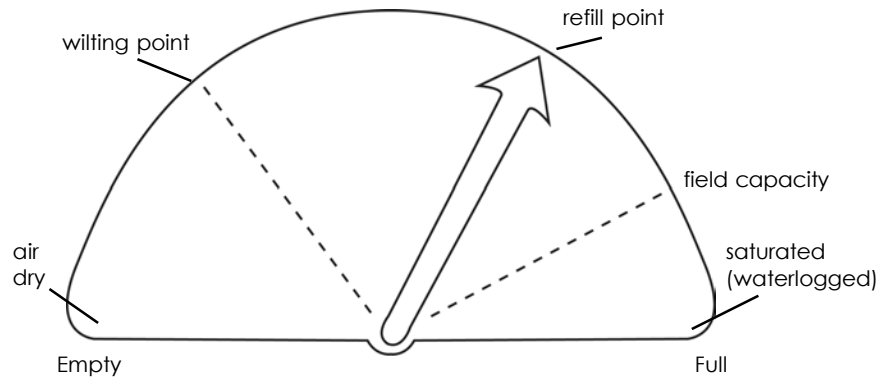
### Available soil water

The amount of water held in the soil between field capacity and permanent wilting point is known as the available soil water. 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 water per metre of soil (refer to Table E6).

Available water-holding capacities vary within a texture class due to the variation of soil structure and soil organic matter. A soil with better structure and more organic matter will have more pore spaces and be able to hold more 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 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 estimate how much water your soil holds in the root zone between field capacity and permanent wilting point, and aim to replenish it by irrigating when about half of this water is used. This is called the refill point. Crops are therefore irrigated before yield-reducing stress occurs.

**Figure E11. Soil moisture for irrigation scheduling**

### Root depth

Another factor which affects the amount of water available to crops is the effective root depth. For example most sub-clover pastures have an effective root depth of about 30 cm whereas perennial plants such as lucerne may exploit a greater depth of soil. In a soil with water holding capacity of say 100 mm/m, sub-clover can only exploit 30 mm of this (ie.: 100 mm x 0.3 m), but in some soils lucerne should be able to take up water from the full metre of soil.

The effective root depth will vary depending on the soil and the crop grown. Approximate root depths of the main crop and pasture types grown in the Riverina are shown in Table E7.

**Table E7. Effective rooting depth of some crops and pastures**

Crop or Pasture	Root Depth (m)
Wheat and other winter cereals	0.4 –0.7
Sub-clover pasture	0.3 –0.4
Perennial pasture	0.3 –0.4
Lucerne	1.0 –1.2
Maize	0.4 –0.7
Soybeans	0.4 –0.7

## SCHEDULING USING THE WATER BALANCE METHOD

Irrigation can be scheduled using a variety of different methods based on observations or measurements of soil, plants, the weather or a combination of these. A method to assess the approximate moisture content of soil by hand was provided in Chapter C8. All methods aim to determine when to irrigate to avoid water stress 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.

### Soil water

The first thing to know in scheduling is calculating soil water storage. Table E8 relates soil group to soil moisture available between field capacity and refill point (called allowable depletion) for average root zone depths for each soil group.

**Table E8. Approximate water storage according to soil group**

Soil group/condition	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	45–70
Well structured transitional red-brown earth	75
Non self-mulching clay	45–70
Self-mulching clay	85–90

The allowable depletion figures in Table E8 are a rough guide to the water available to plants in the different soils. Soil structure, sodicity and management will cause variation in water storage. An improvement in soil structure may result in an increase in water storage capacity of the soil.

To fine tune your allowable depletion figures for a soil, dig a hole and assess 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 prior to irrigation, then reduce your figure by 10 mm. Continue this process until you arrive at a suitable figure.

### Crop water use

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

Plant water use is directly influenced by evaporation. The higher the evaporation, the higher the plant's water use. Evaporation is affected mainly by humidity, temperature, wind and day length. Therefore plant water use in summer is much higher than in winter. The combined use of water by plants, and evaporation from the soil surface, is called evapotranspiration (which is similar to ETo).

Plants draw water from the soil via the roots and release this water as vapour into the air via the leaves. If the plant 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 through the plant. Soon after emergence, a crop will have only a small amount of leaf material, and therefore water use will be relatively low. Water use will be highest when a crop reaches maximum leaf area. Crop factor is a number used in calculating water use. It accounts for crop leaf area and stage of crop growth. Some crop factors of common crops for southern Australia are listed below.

**Table E9. Crop factors for various crops**

Month	Sub-clover	White clover	Wheat	Canola	Lucerne	Millet	Soybean	Maize
July	0.7	0.7	0.9	0.9	0.7	–	–	–
August	0.7	0.7	1.0	1.0	0.7	–	–	–
September	0.7	0.7	1.0	1.0	0.9	–	–	–
October	0.8	0.8	0.9	0.9	1.0	0.4	0.4	0.4
November	0.3	0.8	0.6	0.6	1.0	0.4	0.4	0.7
December	–	0.8	–	–	1.0	0.7	0.7	1.0
January	–	0.8	–	–	1.0	1.0	1.0	1.0
February	–	0.8	–	–	1.0	1.0	1.0	0.6
March	0.4	0.7	–	–	0.9	0.7	0.7	0.4
April	0.7	0.7	0.3	0.3	0.9	0.4	0.4	–
May	0.7	0.7	0.4	0.4	0.8	–	–	–
June	0.7	0.7	0.6	0.6	0.7	–	–	–

### Daily crop water use

An accurate method of calculating crop/pasture water use uses a crop factor and ETo. This is a number calculated from climate data that represents the water use (evapotranspiration) of a short even stand of grass pasture.

$$\text{Daily crop water use (mm)} = \text{crop factor} \times \text{ETo (mm)}$$

Example: A soybean crop during December has a crop factor of 0.7. On a particular day evapotranspiration from short grass (ETo) is 15 mm. Therefore potential crop water use (mm) =  $0.7 \times 15 = 10.5$  mm

### ETo data

Evaporation data (more correctly called reference evapotranspiration) can be obtained by calling NSW Agriculture's WaterWatch service on (02) 6960 1362. The service provides evaporation figures for the previous ten days and forward estimates for the next six weeks. The data is measured in Griffith, but is reasonably accurate for the Murray Valley as well as the Murrumbidgee.

### CALCULATING THE IRRIGATION INTERVAL

**Step 1.** Obtain the latest daily evaporation figures by telephoning the WaterWatch service, or by obtaining them from some other local source.

**Step 2.** Daily crop water use should be added up (accumulate the evaporation figures since the previous watering).

**Step 3.** Account for any effective rainfall in the period between irrigations. Effective rainfall is:

Total rainfall minus 5mm per rainfall event in spring, summer and autumn, OR  
Total rainfall in winter

Effective rainfall should be subtracted from the soil water depletion figure. Remember that water storage cannot exceed the initial amount determined for that soil. Any additional rainfall will evaporate, run off or drain through the soil profile.

**Step 4.** When soil water deficit equals the allowable depletion for your soil (Table E8), or the allowable depletion for a certain crop or pasture type as determined by local research or experience (e.g. 50 mm for perennial pastures in a RBE), the next irrigation should occur.

**Example:**

A wheat crop growing on a hardsetting red-brown earth (allowable depletion of 50 mm) is irrigated on 1 October. When will the next irrigation be due if evaporation figures for the month are as follows?:

To calculate when to irrigate you must record daily evaporation figures and calculate crop water use for each day. This is best done in tabular form as shown below.

Date	ET <sub>o</sub>	Rainfall	Cumulative Total
2/10	3.0		3.0
3/10	2.3		5.3
4/10	5.0		10.3
5/10	8.0		18.3
6/10	6.0		24.3
7/10	5.5		29.8
8/10	7.5		37.3
9/10	8.5		45.8
10/10	–	10 <sup>1</sup>	40.8
11/10	5.5		46.3
12/10	6.0		52.3
13/10		irrigate today	

<sup>1</sup> Actual rainfall is 10 mm, but effective rainfall is 5 mm.

This system of irrigation scheduling is relatively simple to use. When used correctly scheduling is likely to increase yields by avoiding periods of waterlogging and drought stress. Additionally, scheduling may assist in reducing additions to the watertable by reducing over-watering. Check the depth of wetting with a soil probe (made from steel rod) after irrigating.

An irrigation scheduling sheet, which you can photocopy and use yourself, is overleaf. Crop factor figures are needed for annual crops (e.g. maize, soybeans) to allow for stage of growth, but this column can be ignored for perennial crops and pastures (e.g. perennial pastures, lucerne).

**Irrigation Scheduling Sheet**

Paddock .....

Month .....

Soil type .....

Soil water storage (mm) .....

Crop/pasture type .....

<b>Date</b>	<b>ET0 (mm)</b>	<b>Crop Factor (CF)</b>	<b>Crop Water Use (mm) (= ET0 x CF)</b>	<b>Effective Rainfall (mm)</b>	<b>Soil Water Storage (mm)</b>
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2					
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