



SOILpak – northern wheat belt - Readers' Note

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

<http://www.dpi.nsw.gov.au/agriculture/resources/soils/guides/soilpak/northern-wheat-belt>

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

This document is subject to the disclaimers and copyright of the full version from which it is extracted. These disclaimers and copyright statements are available in the appropriate document at the above web address.

E1

Soils of the northern wheat-belt

Purpose of this chapter

This chapter gives an overview of soil types that are farmed in the northern NSW and southern Qld wheat-belt.

Chapter contents

- black earths
- grey, brown and red cracking clays
- Krasnozems and Euchrozems
- texture-contrast soils
- young alluvial soils
- red earths
- prairie soils

Associated chapters

You may need to refer to the following chapters:

- A2: Ideal soil for farming
- C1: Examining the soil profile

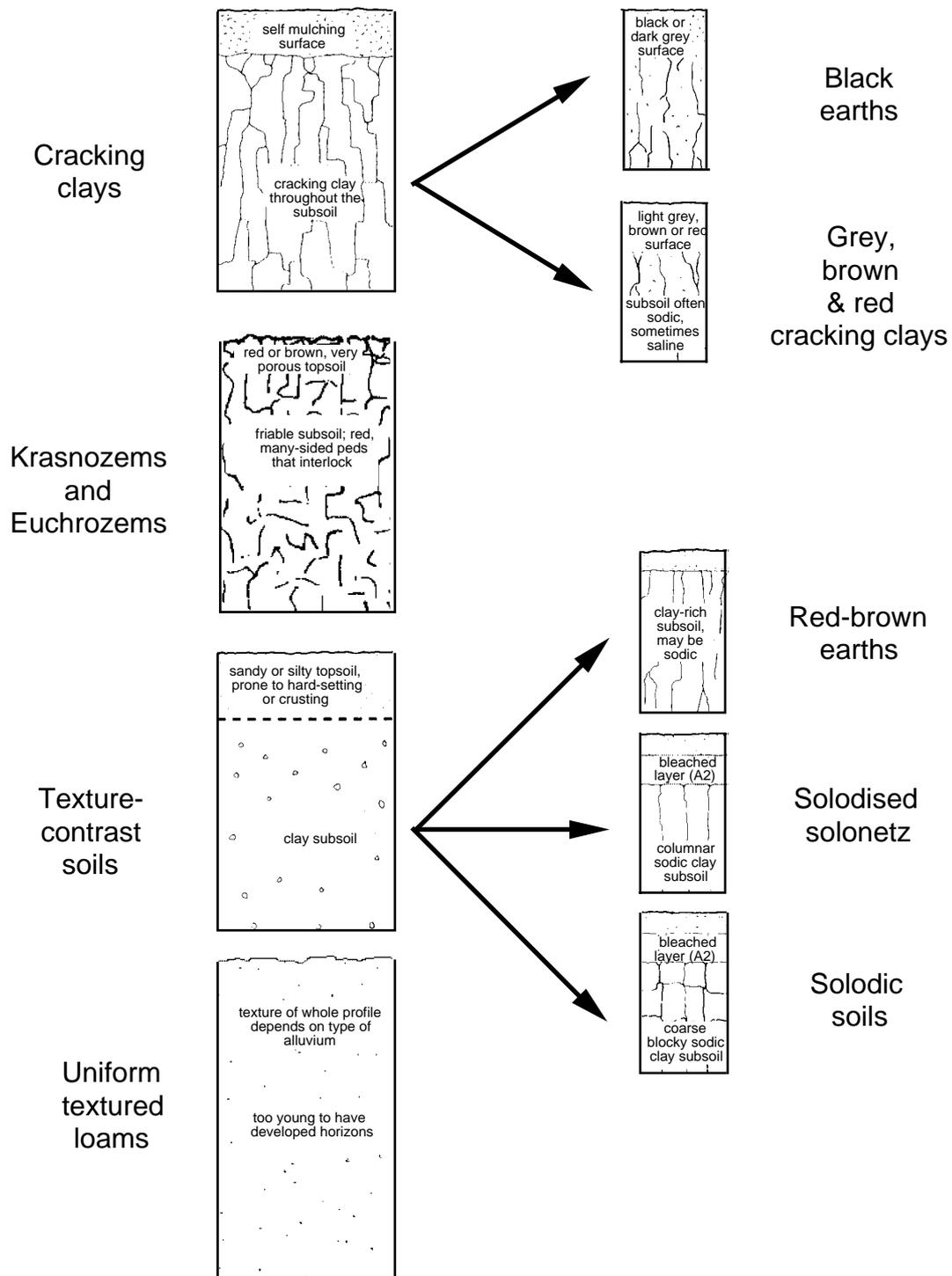


E1

Soils of the northern wheat-belt

Figure E1-1

Main types of soil occurring in the northern wheat-belt



Main soil types **Figure E1-1** gives an overview of the main soil types of the northern wheat-belt. The types shown in **Figure E1-1** are very general, and a general description does not cover all soils. However, it is really much more important to know how to manage a soil than to be able to give it a specific name.

Black cracking clays (black earths) These soils are similar in appearance to the grey and brown cracking clays (see below) but are black to very dark brown in colour and tend to have higher clay contents (50-80% clay). They commonly contain higher amounts of strongly swelling smectite clay than the grey and brown cracking clays. When dry they crack to the surface more frequently than the grey and brown cracking clays and commonly have a strongly self-mulching surface. Linear and normal gilgai are common but are generally less developed than gilgai on the grey and brown cracking clays. The subsoils exhibit strong structure throughout the profile. Subsoils may be brown or grey in colour and usually contain carbonate nodules.

Black earths growing cereals are located mainly on the gently undulating plains or mid to lower slopes of rolling hills of basalt and their associated Quaternary alluvial plains. Less commonly they are associated with fine grained sedimentary rocks on the lower slopes of undulating rises. The major occurrences are on the Darling Downs region of south-east Queensland, the Liverpool Plains region of New South Wales and the central Queensland region in an arc from Nebo to Rolleston (the Central Highlands). Other areas include the Nandewar Range outwash plains north-east of Narrabri, the plains around Coonamble and the undulating rises north of Warialda.

Black cracking clays on alluvial plains are invariably deep but may be shallower where developed directly on basalt. Typically the depth is less than 1 m on crests and upper slopes and 1 to 1.5 m on lower slopes.

Black cracking clays have a high plant-available water capacity (150 to 260 mm is common). However, shallow forms are more likely to have plant-available water capacity of 100-150 mm.

Generally black earths are highly prized for cereal production but large areas of these soils are now low in chemical fertility after decades of continuous cropping. Some black earths have a coarser self-mulching or non-mulching surface in which it is more difficult to establish summer crops.

Grey, brown and red cracking clays These soils are grey or brown in colour, have relatively uniform, high clay contents (45-70%) throughout and are at least 0.8 metres deep. The majority are generally much deeper. When dry the soils crack open to the surface but the surface condition may be either loose and self-mulching or firm and sealed with platy surface crusts. Calcium carbonate concretions are common in the upper profile and less often gypsum concentrations can be found, usually below the carbonate.

Red cracking clays are rare.

Gilgai microrelief is common, and the degree of gilgai development determines the ease of cultivation. Shrink-swell clay minerals such as smectites are responsible for the cracking and self-mulching behaviour and gilgai development of this group of soils. They may also have appreciable proportions of quartz and the clay minerals kaolinite and illite.

The grey and brown cracking clays are associated with a wide variety of landscapes and vegetation and occur extensively in the Murray-Darling Plains of northern New South Wales and southern Queensland and throughout the Eastern Highlands from the Liverpool Plains in the south to the Central Highlands region in the north. Grey cracking clays are more extensive than the brown cracking clays along drainage lines and on flood plains.

Cracking clays up to 2m thick are located mainly on undulating rises or low hills. Deeper soils are located on either gently undulating or flat plains.

Those cracking clays on gently undulating or flat plains often have moderate to high concentrations of salt (usually sodium chloride) in the subsoil. There is a gradual increase in salt with depth to a peak in the 1.2 to 1.5 m zone. This indicates the long term depth of soil wetting.

Due to their inherent moderate to high chemical fertility and the capacity to store moisture during a fallow these soils are well regarded for rain-grown cereal agriculture. Plant available water capacity is usually in the 100 to 180 mm range.

**Krasnozems and
Euchrozems**

These soils are brown to red, and are high in iron and aluminium oxides. They have clay loam or light clay surface soils grading into deep clay subsoils. The subsoils are strongly structured (many-sided peds) and are highly permeable. The dominant clay mineral is kaolinite. They are non-sodic, non-saline and have a high plant-available water capacity (greater than 200 mm). Krasnozems are more highly leached than euchrozems.

Cereal growing areas with these soils are confined to the basaltic landscapes of the inland Burnett region, the New England Tablelands around Inverell and to a lesser extent the upland areas of the Darling Downs and the Atherton Tablelands.

**Texture contrast soils:
red brown earths,
solodised solonetz and
solodic soils**

These texture contrast (duplex) soils have shallow, loamy topsoil (20-30% clay) abruptly overlying black, red or brown, clay subsoil (50-70% clay). The topsoils are usually less than 0.2 m thick and may be bleached in the lower part. When dry the soil surface commonly sets hard or forms a surface crust. These soils are best suited to short periods of cropping as part of a pasture rotation

The subsoils have moderate columnar, prismatic or blocky structure. The main difference between the various soils in this group is the presence of high sodium levels (ESP>5) and possibly columnar structure in the upper subsoil of the solodised solonetz. But even the red-brown earths are sodic in the deeper subsoil. Otherwise they have similar properties including those critical for cereal production such as plant-available water capacity and seedbed condition. However, soils at the lower end of the range of plant-available water capacity are usually solodised solonetz or solodics.

Red-brown earths occur on the better-drained sites on older alluvium at the edges of the Macquarie, Namoi and Gwydir flood-plains, and on the eastern edge of the Pilliga Scrub, south of Narrabri. Significant areas are cropped on the western edge of the New England Tableland from Bingara to North Star and on the Liverpool Plains.

Texture contrast soils are also cropped in the Western Downs-Maranoa area of Queensland from Goondiwindi to Roma and in the Callide and Dawson Valleys of central Queensland.

Uniform textured loams

Soils with a wide range of clay content occur on recent alluvium. They have various surface properties depending upon their texture and organic matter content. They are non-saline and non-sodic in their natural state, but surface crusting often occurs.

Less common soils (not shown in Figure E1-1)

Red earths

Red earths are not common in the northern wheat-belt. They are red, deep massive sandy loams which become increasingly clayey with depth. These soils are low in clay content and the main clay mineral is kaolinite. Red earths have low sodicity, low salinity and high permeability.

Prairie Soils

Prairie soils are strongly structured black soils with thick clay loam or light clay surface soils which grade into slightly more clayey subsoils. Soil chemical fertility is moderate to high and may include reserves of nutrients present in the subsoil. Generally these soils are well drained, although salinity and sodicity may increase to modest levels in the subsoil. Prairie soils occur in the rolling country between Inverell and Yetman. They crack less than cracking clays, and so repair damaged soil structure more slowly.

Acknowledgement:

Bernie Powell, Queensland Department of Primary Industries.

Figure E1-1 adapted from Agfact P5.3.6 'Soil Management for Irrigated Cotton'.

E2

Clay minerals

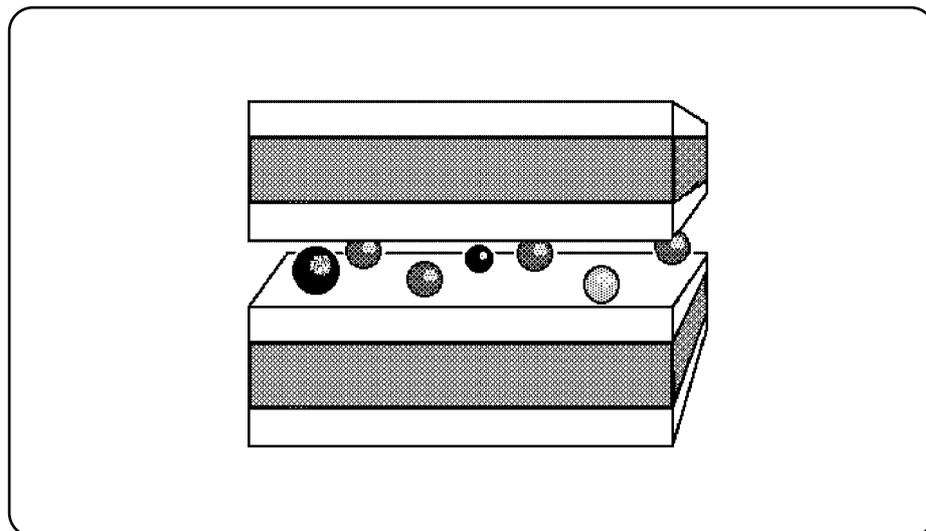
Purpose of this chapter To provide an understanding of the structure of the smallest soil particles - clay, and the effect these particles and the positive ions in the soil solution have on soil structure.

Chapter contents

- clay minerals - their structure
- swelling and shrinking - the role of cations
- clay as a colloid: dispersion and flocculation

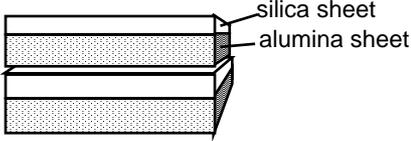
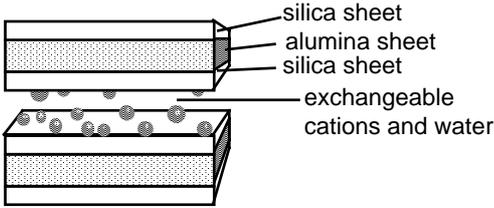
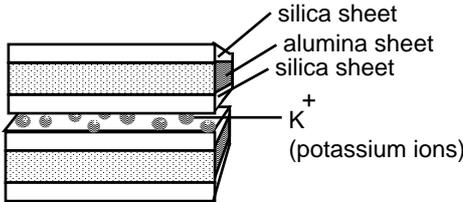
Associated chapters You may need to refer to:

- A2: Ideal soil for farming
- E4 Organic matter



E2 Clay minerals

Figure E2-1 The structure of some common types of clay minerals found in soils.

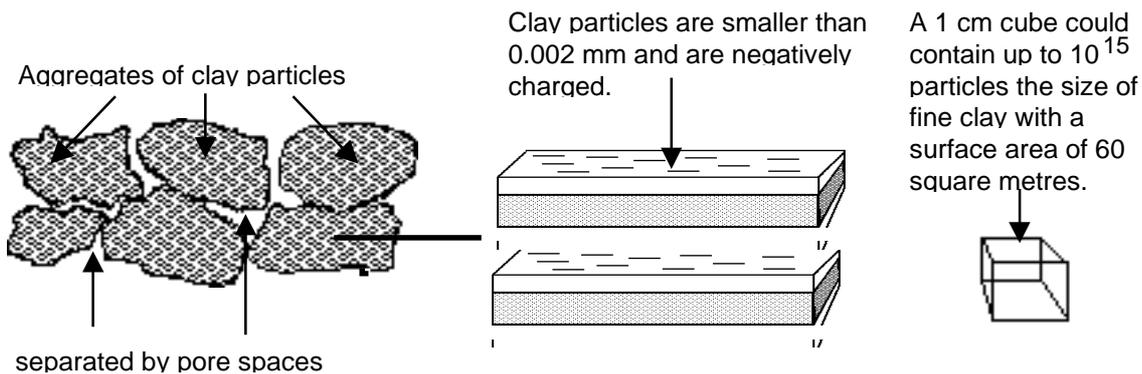
Clay structure	Characteristics
<p data-bbox="263 595 391 629">Kaolinite</p>  <p data-bbox="523 667 683 719">silica sheet alumina sheet</p>	<p data-bbox="821 622 1332 656">Little expansion on absorption of water.</p> <p data-bbox="821 689 1045 723">Used for ceramics.</p>
<p data-bbox="263 875 639 909">Smectite (montmorillonite)</p>  <p data-bbox="587 943 794 1084">silica sheet alumina sheet silica sheet exchangeable cations and water</p>	<p data-bbox="821 902 1342 936">Large expansion on absorption of water.</p> <p data-bbox="821 969 1326 1032">This clay mineral has a major effect on the behaviour of cracking clays.</p> <p data-bbox="821 1066 1417 1099">Used in agriculture as 'bentonite' for sealing dams.</p>
<p data-bbox="263 1225 327 1258">Illite</p>  <p data-bbox="555 1292 735 1458">silica sheet alumina sheet silica sheet K⁺ (potassium ions)</p>	<p data-bbox="821 1252 1332 1285">Little expansion on absorption of water.</p>

Clay is made in soil. It is the smallest sized of all soil mineral particles. Clay is made from the weathering products of various minerals and is composed of crystalline sheets of metal oxides and silicon oxides. The particles are composed of sheets of aluminate (aluminium oxide) and silicate (silicon oxide).

The characteristics of the clays change with their chemical composition (see **Figure E2-1**). Cracking clay soils contain a large proportion of smectite (montmorillonite) clay mineral. This mineral swells markedly when it absorbs water.

Clay size and surface area Clay particles are small: less than 0.002 millimetre in diameter. Their size however gives a small volume of clay particles a large surface area (see **Figure E2-2**). This large surface area makes available many reactive sites for exchange of ions in a small volume of soil. The clay acts as a colloid.

Figure E2-2 Clay particle size and surface area.



10^{15} means 1 followed by 15 zeroes: 1,000,000,000,000,000 (one quadrillion).

Why is clay negatively charged? The basic building blocks of the clay minerals are silicon atoms surrounded by four oxygen atoms (silicate) or aluminium atoms surrounded by six oxygen atoms (aluminate). These groups of atoms are arranged in sheets. The atoms in these sheets are tightly bound and are not exchangeable with other ions in the soil solution.

Within the sheets, negative oxygen atoms closely surround the positive silicon or aluminium atoms and the positive and negative charges cancel out. However, oxygen atoms which are exposed on the surface of the clay crystal are not wholly balanced by positively charged atoms. A net negative charge results.

Also, aluminium (only three positive charges, Al^{3+}) can replace some of the silicon (four positive charges, Si^{4+}) in the crystal structure and the negative charge increases.

Importance of negative charge The negative charge on the surface of clay particles attracts positive ions (cations). This is important for the storage of cations that can be used by plants as nutrients. It also allows us to **chemically alter** soil structural characteristics by changing the cations that are adsorbed onto the clay surface.

Dispersion and flocculation of clay

Colloidal clay

Clay is a colloid. Colloidal particles have special properties due to their very small size. Firstly, their large surface area in relation to their mass makes them very reactive; in clays, this reactivity is shown as an electrostatic attraction of cations. Secondly, colloids can exist in water as either suspensions (dispersed) or as gels (flocculated).

The tendency of a colloid to flocculate or disperse depends on three things:

- the nature of the colloidal particles;
- the total salt concentration (see the 'Salt ain't just salt' box);
- the nature of the adsorbed ions.

Nature of colloidal particles

Colloidal particles are either hydrophilic (water-loving) or hydrophobic (water-hating). Hydrophilic colloids (such as starch) form stable suspensions and do not readily flocculate. Hydrophobic colloids (such as clay) form unstable suspensions and flocculate easily. (Here 'unstable' refers to the suspension, not to the soil aggregates.)

The nature of the colloidal clay particle (hydrophobic) means that **clay will flocculate if allowed to**. This is good for soil structure!

Total salt concentration

The more concentrated the salts (electrolytes) in the soil solution, the more likely it is that clay will flocculate. This is the 'electrolyte effect'. (The salt is not necessarily common salt, sodium chloride. Any soluble salt, such as gypsum, will have this effect.)

Salt ain't just salt. An 'electrolyte' is any salt. It is not necessarily common salt (sodium chloride). It could be any combination of cation and anion. Salts in soil can come from the weathering of soil minerals. Weathering releases cations such as sodium, potassium, calcium, iron and magnesium. Anions produced by weathering include sulphate, chloride, carbonate and phosphate. In agriculture, salts added to soil include: gypsum (calcium sulphate), lime (which, when dissolved, forms calcium salts with whatever anions are present), ammonium or nitrate salts in fertiliser or manure, various forms of phosphate, potassium salts, and trace elements, for example, zinc sulphate. In large amounts or small, each adds to the total salt (electrolyte) concentration of the soil solution.

Nature of adsorbed ions

The type of cations adsorbed onto the surface of the clay influences flocculation. Calcium adsorbed onto the clay surface allows the clay to flocculate when the total salt concentration is fairly low. Sodium adsorbed onto the clay surface will not allow the clay to flocculate until the total salt concentration is much higher.

Practical implications of the above

The interplay of total salt concentration and the nature of the adsorbed cations has the following practical implications:

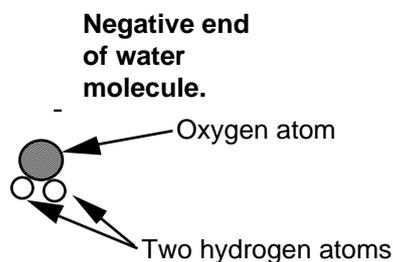
- saline soils are usually friable because the clay, even though it may have high exchangeable sodium, becomes flocculated in the concentrated soil solution.
- saline water applied to soil will allow the clay to flocculate. If the water is saline due to high levels of soluble calcium, the flocculation will persist. If, however, the water is saline due to high levels of sodium, the flocculation will last only as long as the soil solution remains concentrated. When rain washes excess salts from the soil, the soil solution becomes dilute and the clay disperses.
- gypsum acts on clay in two ways. Firstly, by raising the level of soluble salts in the soil solution, gypsum allows the clay to flocculate even if the clay has a high percent of exchangeable sodium (this is the electrolyte effect). Secondly, soluble calcium in the gypsum replaces sodium on the cation exchange sites. The calcium-dominated clay will remain flocculated after the free sodium is washed from the soil and the total salt concentration falls. In practice, however, several follow-up applications of gypsum are necessary to maintain the electrolyte effect until the full depth of topsoil becomes non-sodic.

Water: its structure and importance in swelling clays

The structure of the water molecule is important in how it reacts with charged particles. Water is a dipolar molecule: it has a positive and a negative end. This allows a water molecule to be attracted to both negative and positive ions and particles, and to other water molecules ('head' to 'tail').

Figure E2-3: The dipolar water molecule.

This end of the molecule is attracted to positive charges, such as the positive end of other water molecules, or cations in solution.

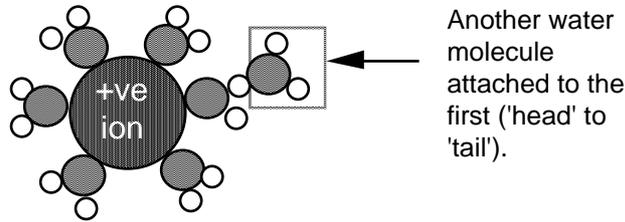


Positive end of water molecule.

This end of the molecule is attracted to negative charges, such as the surface of a clay particle, or the negative end of other water molecules, or anions in solution.

Water surrounds cations in a shell of oriented water molecules - a hydration shell (see **Figure E2-4**).

Figure E2-4: The hydration shell (water molecules clustered around a cation).



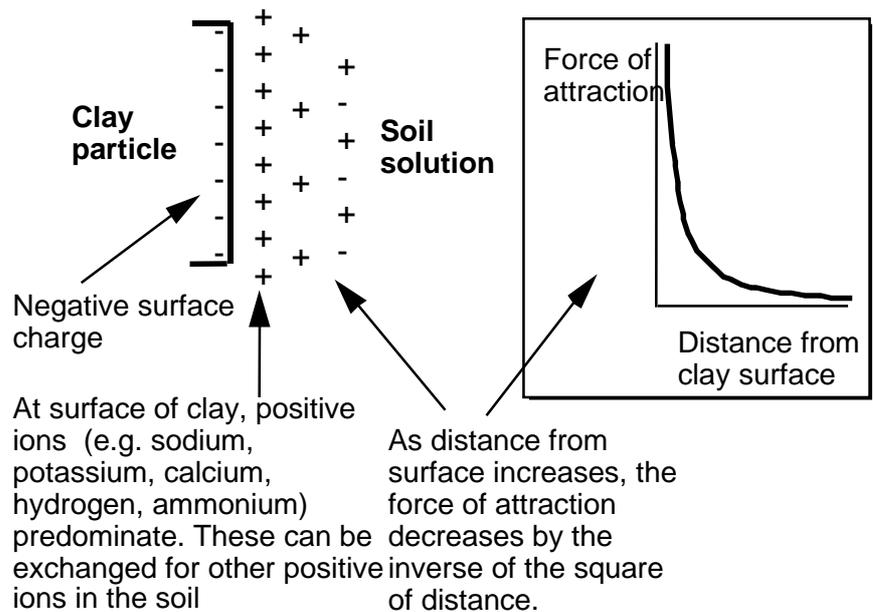
The diffuse double layer

The surface of a clay particle, being negatively charged, attracts positive ions. When the clay is wet, the exchangeable positive ions on the surface of the clay move into the soil solution surrounding the clay particle. They are, however, still attracted to the clay surface and consequently swarm close to the clay surface.

This region of attracted positive ions in solution and the negatively charged surface of the clay is termed the diffuse double layer. It is called 'diffuse' because a net positive charge of ions extends away from the surface (see **Figure E2-5**). The further from the surface, the less is the net positive charge of the solution.

The force of attraction on the cations by the clay reduces quickly as distance from the clay surface increases (see **Figure E2-5**).

Figure E2-5 The double layer at the face of a clay particle.



For one cation to leave the double layer it must be replaced by another from the soil solution. Plant roots, in order to take up cations as nutrients, give up hydrogen ions (H^+) in exchange.

Strength of attraction of exchangeable cations

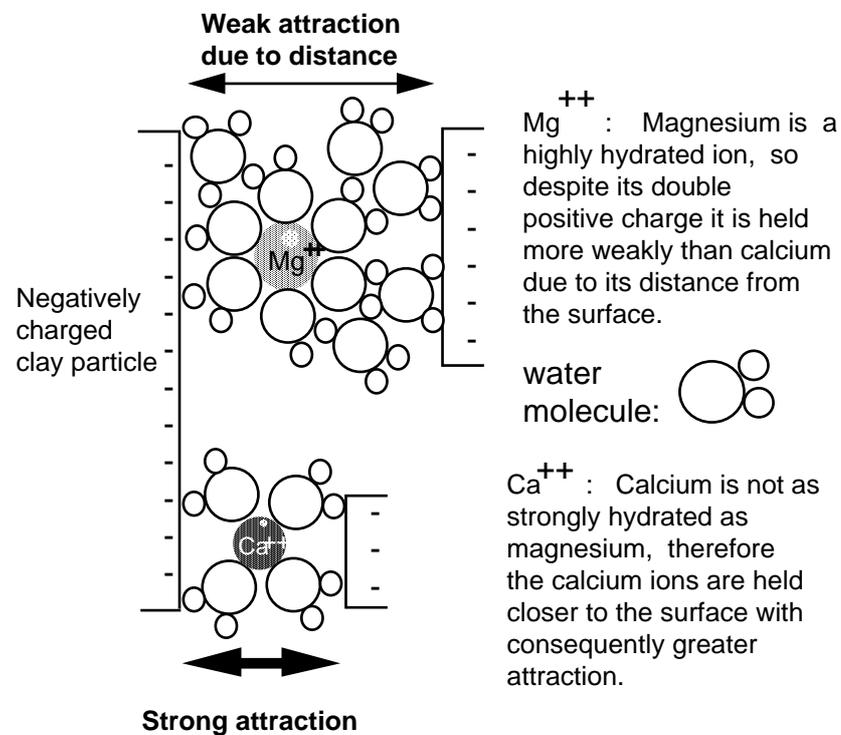
The cations adsorbed onto the surface of the clay particle can greatly affect how the clay behaves. The cations act as a link between the clay particles.

The binding force onto and between the clay plates is dependent on a number of factors including:

- the charge of the cations;
- the size of the cations including their hydration shell; and
- the thickness of the double layer outside the surface of the clay particles (**Figure E2-5**).

The strength of the bond depends on the cations present. Sodium ions have a single positive charge; their clay-binding ability is poor. Calcium ions have a double positive charge; their clay-binding ability is good. Magnesium is intermediate because, although it has a double positive charge like calcium, when hydrated it is larger than a hydrated calcium ion. This is illustrated in **Figure E2-6**.

Figure E2-6 Strengths of attraction of common soil cations.



Exchangeable sodium percentage (ESP) Exchangeable sodium percentage (ESP) is a measure of the number of sodium ions adsorbed onto the surface of the clay particles, compared with other positive ions. Soils with low ESP generally have better aggregate stability in water than soils with high ESP.

High ESP and dispersive soils In a dispersive soil with a high ESP and low salinity, the weak bonding of the clay particles by sodium ions can be broken. As water enters between the clay particles it hydrates the sodium ions. This in turn forces the plates away from the ions and lowers the attractive force between the particles and the ions. The plates may move far enough apart for attraction forces to be overcome. The result is dispersion.

SOILpak

The most abundant element in the Earth's crust is oxygen. Oxygen is a chemical constituent of rocks, and occurs as oxides of silicon and aluminium in clay minerals.

Nearly 95% of the **volume** of the Earth's crust is taken up by oxygen. The "solid" earth is a well-packed set of oxygen anions (negatively charged ions), crowded closely together, with the small cations (positively charged ions) of the other seven abundant elements tucked here and there. Even Uluru (Ayre's Rock) is a heap of oxygen and little more.

E3

Crusting and hard-setting

Purpose of this chapter

To explain the reasons for the formation of crusts and the formation of hard-set soils.

Chapter overview

This chapter covers the following points:

- slaking
- dispersion
- packing and particle sizes
- soils that are not self-repairing
- the role of organic matter
- exposure of subsoil.

Associated chapters

You may need to refer to the following chapters:

- B8: Does my soil need gypsum?
- D-s8: Sodicty
- E2: Clay minerals
- E4: Organic matter



E3

Crusting and hard-setting

Slaking

Slaking is the breaking down of soil into smaller aggregates through wetting. Slaking is most marked when a dry soil wets quickly. It is a natural occurrence and is due to three factors:

- water weakens the bonds between particles and may cause some swelling;
- as water enters a lump of soil, it may entrap air and compress it towards the centre of the lump. The air escapes by forcing the lump apart;
- uneven wetting of a lump of soil causes uneven swelling and sets up a strain between the wet and dry parts.

Self-mulching cracking clays slake into small aggregates that remain intact. The aggregates join together in a thin, weak crust. On drying, the crust shrinks and small cracks form through it. Therefore in self-mulching clays, crusting is not serious.

Dispersion

Dispersion is the breakdown of soil aggregates to individual clay, silt and sand particles. It is most often associated with sodic clays. The bonds between negatively-charged clay particles and positively-charged sodium ions are weak when the soil is wet, and the clay particles drift apart. When the soil dries, it sets into a crust or hard clods.



Go to Chapter D-s8 or E2 for more information on sodic clays.

Clay dispersion is less likely to happen in a soil with vegetation. Plant roots and other organic bonding agents help to hold soil particles together.

Working a wet soil that is prone to dispersion breaks down the structure very easily. Take extreme care with soil moisture contents (see **Chapter D Section 6**).

Packing and particle sizes

A soil that is a mixture of different particle sizes can pack down to a high density. Structural breakdown in the form of slaking can cause repacking. This compaction will inhibit plant growth by restricting water and air movement and root penetration.

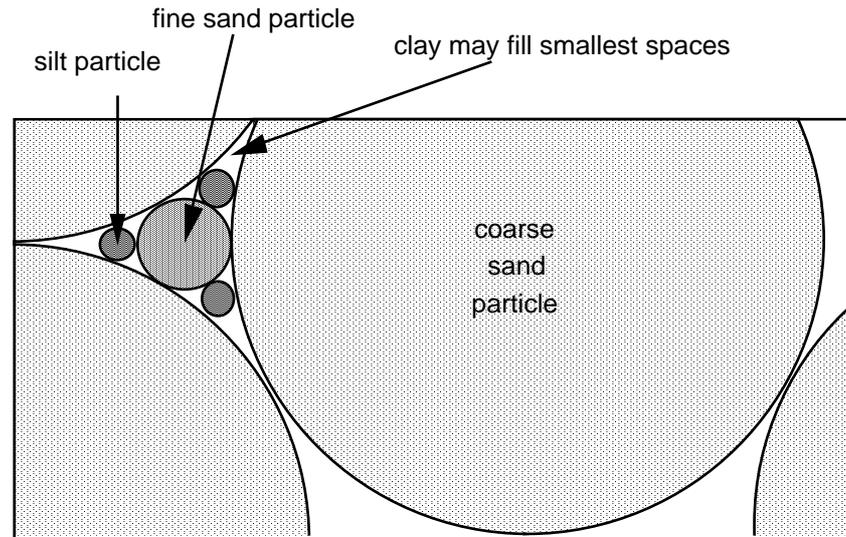
In fine sands and silts which are low in organic matter and clay, the bonds between particles are weak when wet. Such soils may slake to very small aggregates or even disperse into individual particles. The soil slumps and small particles pack between larger particles. (**Figure E3-1** shows this type of packing schematically.)

Hard-setting

If a soil has little clay, it shrinks very little as it dries and so no cracks form.

If there is some dispersion, the result is worse as the little clay that there is blocks pores. The result is close packing and very small pore sizes. When such a soil dries, it becomes very hard because of its tightly packed structure, and we call it a hard-setting soil.

Figure E3-1 Theoretical packing of spherical particles.



Typically, hard-setting soils have a very low content of swelling and shrinking clays. Once they are hard-set, it is necessary to till them, either mechanically or biologically, to restore their structure. It is easy to get into a cycle of degradation, where tillage is necessary because of low levels of organic matter, but that same tillage destroys more organic matter.

Soils that swell and shrink

Soils that swell on wetting and shrink on drying do not hard-set. They may, at worst, form a thin fragile crust after rain.

Sodic clays, which are prone to dispersion, also have a high potential for swelling and shrinking (sodic clays swell and shrink more than similar non-sodic clays). They crust, but the crust cracks on drying. This allows vegetation to establish and reduces further crusting. Gypsum application improves the surface structure of sodic clays.

Soils that do not swell and shrink

Soils that crust or hard-set, but do not swell and shrink greatly, are more difficult to repair. Mechanical ripping temporarily recreates pore space. A long-term solution is to stabilise soil structure by increasing soil organic matter content.

Organic matter provides the bonds that stabilise a soil. There is less crusting or repacking of particles if these bonds are in place. Pasture is often the most cost effective way to put organic matter into the soil. It also encourages earthworms and other organisms that are important in improving soil structure.



Go to Chapter E4 for more information on organic matter.

More organic matter and less tillage encourages soil animals. Soil porosity, and thus infiltration and storage of rain, increases.

If a pasture phase is not practicable do not leave the soil bare. Reduce tillage and retain stubble cover. Choose crops that leave lots of stubble, and fibrous rooted rather than tap rooted crops, unless there is a hardpan. Fibrous roots improve hard-setting topsoils; tap roots create channels through hard pans.

It is often difficult to establish plants on a bare, hard-set soil. Several types of implement create a rough surface that will trap rain in the hollows and assist infiltration. One such implement is shown in **Figure E3-2**.

Figure E3-2: A 'crocodile planter', one type of implement used to create a rough surface on a hard-set soil.



Photograph: Ian Daniells.

SOILpak

E4 Organic Matter

Purpose of this chapter

To explain the role of organic matter in soil.

Chapter overview

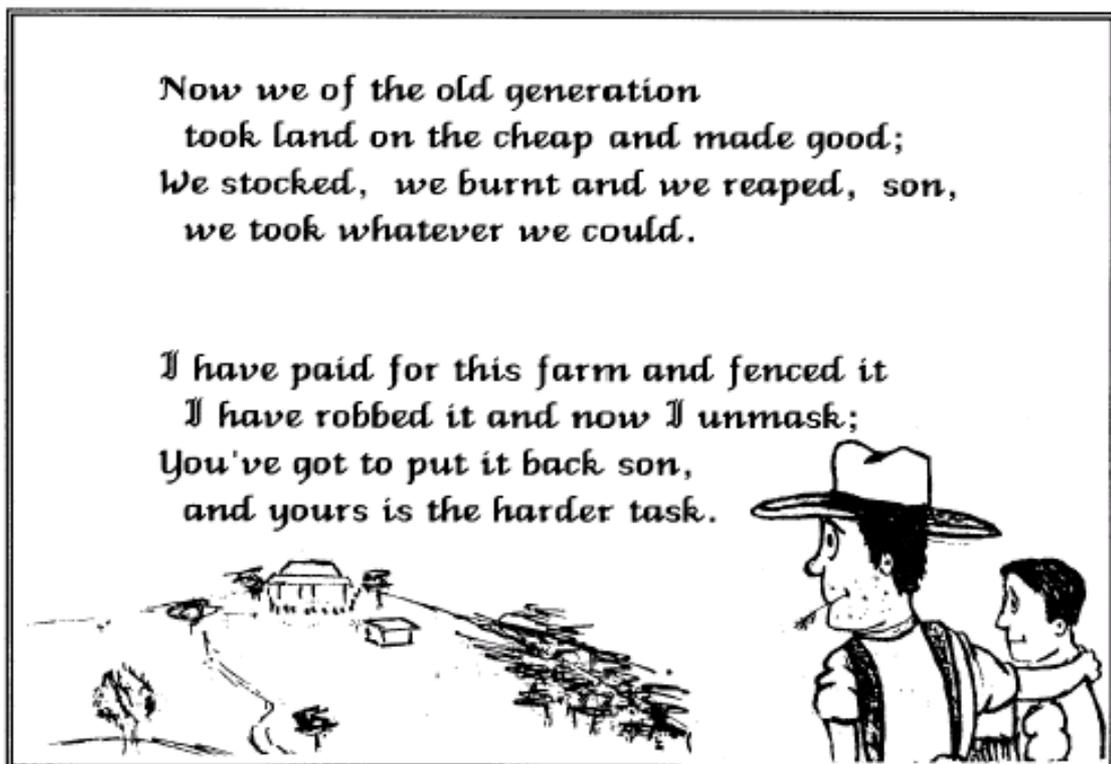
This chapter covers the following points:

- forms of organic matter
- why organic matter is important
- organic matter and soil structure
- organic matter and soil nutrition

Associated chapters

You may need to refer to the following chapters:

- E3: Crusting and hard setting
- E5: Plant nutrients



E4

Organic matter

What is organic matter?

Soil organic matter consists of living roots and organisms (for example, earthworms, bacteria and fungi); decomposing residues of plants, animals and microbes; exudates from plant roots and microbes; and humus - the dark-coloured, relatively stable fraction.

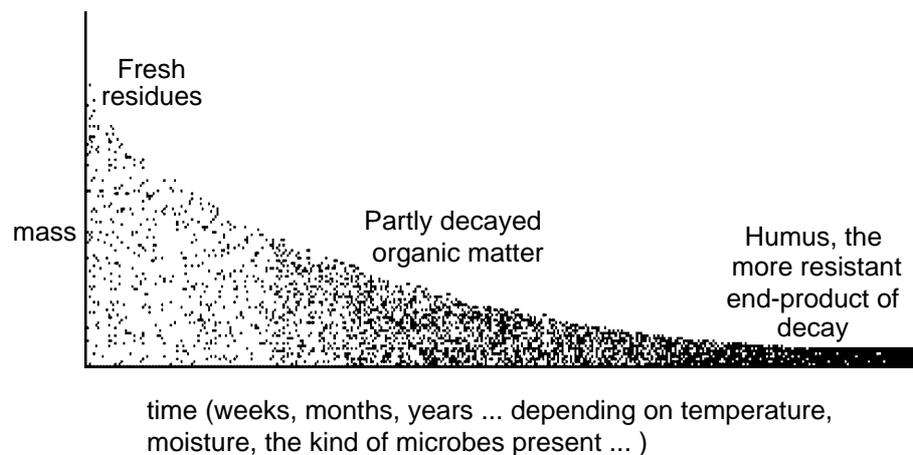
The importance of organic matter

Compared to soils in other countries, most soils in Australia are low in organic matter. Our dry climate limits the production of plant material and the high temperatures mean that organic matter decomposes quickly. Possibly 75% of soils in Australia have an organic matter level of less than 1.75% in their natural state.

Organic matter contains many nutrients essential to the growth of plants. However, plants can not take up nutrients in organic forms. The soil provides the environment to process organic matter so that plants can make use of the nutrients. The soil also provides the earthworms, termites, fungi, bacteria, mites, and other soil life to carry out this processing.

Soil organisms use the organic matter as food and in so doing oxidise part of it to carbon dioxide gas. The organic matter loses mass and eventually, the more resistant components remain as humus (**figure E4-1**).

Figure E4-1 Organic matter decay. As organic matter decays, it loses mass as part of it oxidises to carbon dioxide. Soluble plant nutrients are also released.



If soil organisms are scarce or inactive, it will take a long time for organic matter to break down. In areas of very high rainfall and low temperatures (for example the tops of the Great Dividing Range) soil

organisms are inhibited and plant residues break down very slowly. The high rainfall leaches the soil which becomes acid. Soil acidity, lack of oxygen in the soil (waterlogging due to the high rainfall) and the low temperatures make the soil organisms inactive. Plant residues decompose only partly and form thick deposits of peat.

Organic matter and soil structure

As organic matter decomposes in the soil it helps to bind and stabilise the soil. The organic matter breaks down, becomes intimately mixed with the soil, and becomes a part of the soil. The bonds it forms provide resistance to wind and water erosion. The soil also maintains a more open pore structure for better infiltration and plant root growth.

Organic matter as a binding agent is most important in lighter textured soils, such as sands, silts and loams. In clay soils, the clay itself acts as a binding agent. The cracking clays have the potential to regenerate their structure by the swelling and shrinking of clay with wetting and drying. In the less clayey soils, that potential is limited, and so the maintenance of structure depends more on organic matter and the soil life that feeds on it.

Soil that is low in organic matter tends to erode, set hard or crust.

Organic matter and plant nutrition

Organic matter is a source of plant nutrients, particularly nitrogen, phosphorus and sulphur. The nutrients won't leach in this stable form and are available to plants on a slow release basis. Organic matter levels fall with continuous cultivation, particularly if there is no pasture phase, and soil nutrient status declines. The more organic matter present in a soil, the less fertiliser a crop needs.

When organic matter decomposes, it forms humus: the stable end-product of decay. Humus, like clay, has negative charges which loosely hold positively-charged ions (cations). Thus humus adds to the soil's cation exchange capacity, and is particularly important in soils with little clay.

The cycling of nutrients in the soil is complex. One of the most important, nitrogen, is constantly recycled between the air, and the organic and mineral fractions in the soil, with various inputs and outputs.



Go to Chapter E5 for more information on the nitrogen cycle.

Ways of increasing soil organic matter

Often the most cost effective way to increase organic matter is through a pasture phase. A legume-based pasture is ideal because the legumes supply their own nitrogen. Pasture encourages the soil organisms as there is a food source and no disturbance to the soil.

Perennial pasture is more effective than annual pasture at increasing soil organic matter. Annual pasture, like a crop, lasts for only part of the year and is preceded by, and followed by fallow.

A practical way to return some organic matter to a soil in broadacre cropping is by retaining stubble after harvest. This is also valuable for erosion control. However, too much can be a problem for the next sowing.

To achieve the balance between enough cover for erosion protection and too much stubble for machinery operation, it may help to graze the stubble. As a last resort, burn the stubble just before sowing. Stubble can cause a disease problem if the same type of crop follows: overcome the disease problem with crop rotation.

Adding organic matter from elsewhere is costly on the broadacre scale. Manure is not widely available, and its application is limited by transport and spreading costs. Processed organic fertilisers applied at recommended rates would not make an appreciable difference to soil organic matter content.

To maintain and increase organic matter:

- retain stubble
- minimum till or direct drill
- include pasture in rotations
- avoid long bare fallows.

The following factors increase the rate of loss of organic matter:

- cultivation
- repeated wetting and drying of soils
- burning stubble
- summer bare fallowing
- high temperatures.

During fallow, very little organic material is returned to the soil, and what is there decomposes at an accelerated rate, especially if tillage is involved.

SOILpak

Soil organic matter contains 57% carbon. Carbon, in pure form, could be lampblack, graphite or diamond.

E5

Plant nutrients

Purpose of this chapter

To describe the forms of various plant nutrients in soil, and their conversion between different forms.

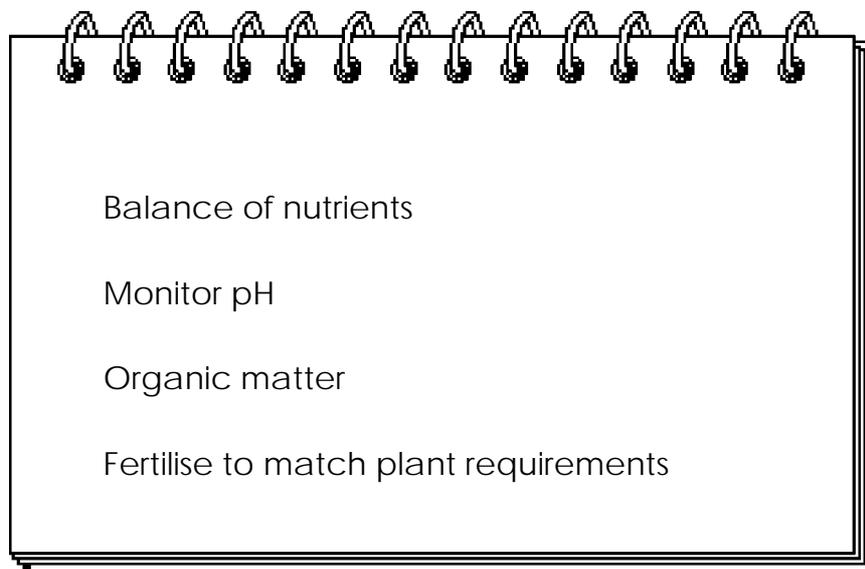
Chapter contents

- nitrogen
- phosphorus
- potassium
- calcium
- magnesium
- sulphur
- trace elements

Associated chapters

You may need to refer to the following chapters:

- B10: Does my soil need fertiliser?
- D-s3: Improving soil chemical fertility



E5

Plant nutrients

Nitrogen

Nitrogen is a constituent of all plant cells: in plant proteins and hormones, and in chlorophyll. Nitrogen is often the limiting factor for grain protein content.

Nitrogen deficiency results in reduced production of the green pigment chlorophyll, allowing the yellow leaf pigments to show. Nitrogen can be mobilised within the plant and moved from old to young leaves. Thus nitrogen deficiency shows as yellowing of the older leaves.

Nitrogen is very abundant in nature, being 78% of gasses in the air. However, most of it is in forms that are not available to plants. To be available to plants, nitrogen must be in a soluble form: nitrate or ammonium. **Figure E5-1** shows the transformations of nitrogen.

Nitrogen fixation

Symbiotic bacteria, *Rhizobium*, live in nodules on legume roots and fix nitrogen from the soil air. The legumes benefit by gaining available nitrogen, and the bacteria benefit by gaining sugars from the legumes. The nitrogen-rich plant material eventually adds to the soil organic matter.

Non-symbiotic (free living) nitrogen fixers include the bacteria *Clostridium* (anaerobic) and *Azotobacter* (aerobic) and some species of blue-green algae: *Nostoc* and *Anabaena*. *Clostridium* and *Azotobacter* need a supply of readily decomposable organic matter. Carbon-rich organic matter, rather than nitrogen-rich organic matter, is more effective for nitrogen fixation.

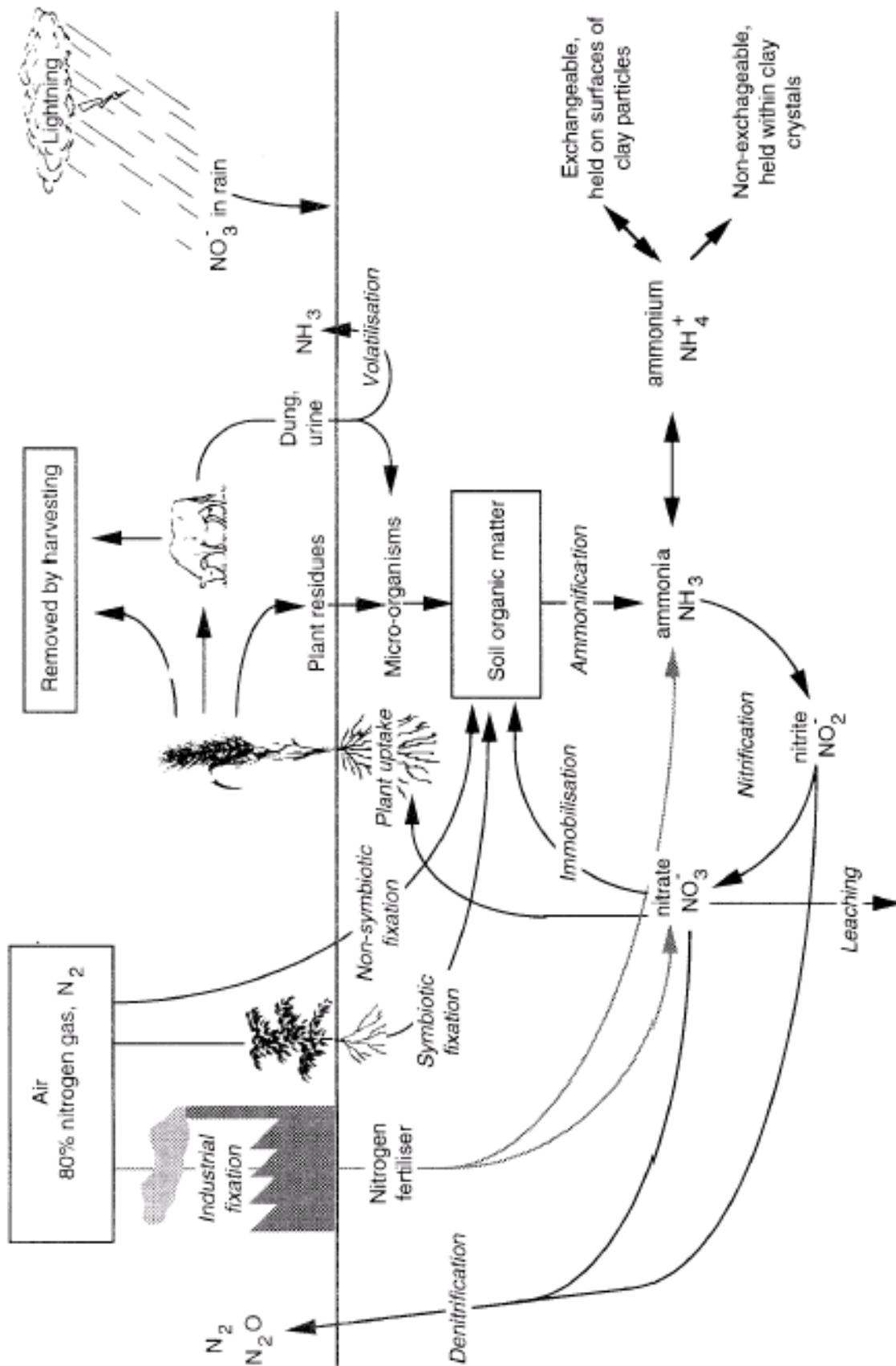
The amount of nitrogen fixed by these soil organisms depends upon the supply of available nitrogen in the soil. With plentiful nitrogen available, little more is fixed.

Fertiliser factories fix atmospheric nitrogen by combining it with hydrogen to form ammonia, NH_3 . The ammonia may be liquified to produce anhydrous ammonia, oxidised to produce nitric acid (and hence, ammonium nitrate), added to sulphuric acid to form ammonium sulphate, or converted to urea.

Plant residues

The amounts of nitrogen returned to the soil in plant residues vary with the yield and the kind of plant. Grain legume crop residues commonly contain 2% N. The N content of wheat straw varies widely, from 0.2 to 1%.

Figure E5-1: The nitrogen cycle in soil.



Fossil fuel or solar power. The fixation of nitrogen from the air requires energy. In the manufacture of nitrogen fertiliser, this energy ultimately comes from fossil fuels such as oil and coal. The energy used by nitrogen fixers in soil comes from plants - and plants run on solar power.

Soil organisms use plant residues as a food source, oxidising the carbon to carbon dioxide. The carbon content of the organic matter therefore declines, and so its nitrogen content increases. The carbon:nitrogen ratio of residues such as straw may be as high as 60:1. After decomposition, the carbon:nitrogen ratio reduces to between 12:1 and 10:1.

In the process of decomposition, micro-organisms may take up nitrogen from the available soil pool. This nitrogen is later released as the carbon:nitrogen ratio falls. The short term tie-up of available soil nitrogen deprives growing plants of their nitrogen supply.

Animal wastes

Dung and urine from grazing animals, and from soil animals, is returned to the soil. Some enters the organic matter pool through soil organisms and some is lost as ammonia gas (volatilisation).

Lightning

The intense heat of lightning causes nitrogen and oxygen in the air to combine as nitric oxide. Dissolved in rain, it falls as dilute nitric acid and adds to the soil nitrate pool.

Mineralisation

Soil micro-organisms decompose organic matter to soluble, so-called 'mineral' forms. First, ammonia is produced. Dissolved in soil water as the ammonium cation, it can be held on the negatively-charged cation exchange sites of clay minerals or organic molecules. As exchangeable ammonium, it is available for plant uptake, but is held against leaching.

Ammonium can enter the crystal lattice of clay minerals, to be 'mineral fixed' and not readily exchangeable with other cations. In this form it is not available for plant uptake.

Ammonia is converted by other micro-organisms to nitrite and then to nitrate. In an aerobic soil, most of the mineral nitrogen is in the nitrate form. This is available for plant uptake. Being an anion, nitrate is not held on negatively-charged clay minerals and is prone to loss by leaching.

Nitrate can be taken up by micro-organisms as they decompose carbon-rich residues. The nitrogen is 'immobilised' as it enters the organic pool once more: in this case, the bodies of the micro-organisms.

Denitrification

Some soil micro-organisms use nitrite and nitrate for respiration in the absence of oxygen. Thus in waterlogged soil, mineral nitrogen is denitrified to nitrogen gas or nitrous oxide gas. Nitrous oxide is implicated in the 'greenhouse effect' of earth warming.

Volatilisation

Nitrogen can be lost from the soil as ammonia gas. This is most likely in:

- a dry soil (there is no water to dissolve the ammonia);
- a soil with low cation exchange capacity, such as a sand (there are few exchange sites to hold the ammonium cations); and
- an alkaline soil (there are no soil acids to react with ammonia and form soluble salts). Only slight losses occur from soils with a pH below 7. Losses are high in calcareous soils when ammonium fertilisers are used.

Ammonia loss can be high when ammonium or urea fertilisers are broadcast over the soil surface, rather than incorporated. Nitrogenous organic wastes such as manures lose much ammonia when allowed to decompose on the soil surface.

Anhydrous ammonia gas is a common form of nitrogen fertiliser. Losses through volatilisation are not serious provided that: the gas is injected well below the surface of the soil; the soil has sufficient moisture to dissolve the ammonia gas; and the sorption capacity of the soil is not exceeded.

Leaching

Nitrogen is lost by leaching mainly as the nitrate form, although ammonium may be lost from sandy soils.

In intensively cropped soils where no fertiliser is used, the leaching loss is small. Frequent cropping keeps the nitrate content of the soil low, and less water passes through the soil. Fallowing beyond the time when the soil profile is full of water leads to leaching losses.

Nitrate leaching from the soil presents a potential pollution problem. If nitrate enters the groundwater and this groundwater is used for domestic supplies, it presents a serious health hazard. If the groundwater discharges into surface water bodies, nutrient enrichment may cause algal blooms. Nitrate leaching is also a major cause of soil acidification in agricultural land.

To minimise leaching, use farming strategies that use nitrate before it is lost below the root zone:

- in pasture, nitrate is taken up by plants as it is mineralised from organic matter. Perennial grasses and lucerne are preferable to annual grasses because their deep roots extract water (and therefore nitrate) more effectively;
- apply nitrogen fertiliser in several small applications rather than one large dose, and time the applications to meet crop needs;
- use opportunity cropping: sow a crop as soon as the soil profile is 75% full of moisture. Choose the crop to suit the time of year.

Phosphorus

Phosphorus is a constituent of plant cells, essential for cell division and development of the growing tip of the plant. Without phosphorus, plants are stunted and spindly. Deficiency symptoms also include dull greyish-green leaves and red pigment in leaf bases and dying leaves. If plants are starved of phosphorus as seedlings they may not recover, even when phosphorus is applied later.

Most soils in Australia are naturally low in phosphorus, although cracking clays often have high levels, and the red soils of the northern wheat-belt are not as deficient as those in the south. Native plants are adapted to these low levels, but introduced crops and pastures are not.

The most common form of phosphorus fertiliser is superphosphate. However, all manures contain phosphorus, and manure from grain-fed animals is a particularly rich source.

Phosphorus is not prone to leaching except from sandy soils under high rainfall. However, the availability of phosphorus derived from phosphate fertilisers decreases quickly as the phosphorus is converted to insoluble forms in soil.

Phosphorus in the soil Fertiliser phosphorus does not move far from where it is applied because it reacts rapidly with the soil. Phosphorus sorption occurs when clay minerals bind phosphate ions, and when phosphate forms insoluble compounds. In acid soils, it forms iron phosphate and aluminium phosphate; in alkaline soils, it forms calcium phosphate. These compounds have low solubility, and low availability to plants.

Because phosphorus is so easily fixed in the soil, crops and pastures take up only 5-20% of phosphorus applied in fertiliser. Fixed phosphate becomes remobilised, often over several years. The current phosphate availability in a soil may reflect the history of phosphate fertilising from years ago.

Improving the uptake of phosphorus

If a crop seems to get little benefit from phosphorus fertiliser, it may be that the soil phosphorus level is already high enough and the plants do not need any more.

In soils with low phosphorus availability, place the fertiliser close to the seed when sowing. This is very effective: you need only half the rate of phosphorus compared with broadcast fertiliser.

If the soil is strongly acid, lime it. This will reduce the availability of iron and aluminium in the soil. Therefore, the amount of phosphorus tied up by iron and aluminium will decrease, leaving more available for plant use.



Go to Chapter D-s4 for information on soil organisms (VAM) that help in phosphorus nutrition

Eutrophication

Eutrophication is the enrichment of water by the addition of nutrients. The extra nutrients encourage the growth of algal blooms. Blue-green algae may produce toxins poisonous to man and animals. For blue-green algae to grow, phosphorus must be present in the water.

Phosphorus (even if fixed) can be lost from soil by erosion. Soil eroded from farmland carries away nutrients, including phosphorus. Eroded soil entering waterways adds to eutrophication.

Even without soil erosion, water running off recently-fertilised land can carry away phosphorus before the fertiliser enters the soil.

Point sources of pollution, such as sewage effluent and drainage from dairies and feedlots, add to phosphorus in waterways.

Responsible use of phosphate fertiliser

Use these guidelines to avoid waste and pollution when fertilising with phosphate:

- match the supply of fertiliser to plant needs;
- don't fertilise dams, streams or swampy areas;
- don't topdress bare ground;
- don't topdress when heavy rain is expected; and
- maintain good ground cover around dams and streams.

It was while he was examining urine, seeking the "philosopher's stone" (the magic elixir believed to change baser metals into gold), that the German chemist Hennig Brand discovered phosphorus.

Other nutrients

Potassium

Potassium deficiency tends to be confined to the sandier soils of the region, so is not a widespread problem. Sulphate of potash (potassium sulphate) is recommended if potassium is deficient. Muriate of potash (potassium chloride) also corrects potassium deficiency, but prolonged use is not recommended. It adds to soil chloride, and chloride at high levels is toxic to plants.

Potassium can also become deficient on intensively used areas such as irrigated lucerne paddocks, and areas constantly cut for hay or silage. These represent heavy nutrient removal. Potassium deficiency can also occur from nutrient transfer such as in strip grazing where animals then return dung and urine to a different area.

Calcium

Calcium is generally deficient in acid, sandy soils, which are not common in the northern wheat-belt. In fact, many of the clay soils in this area have gypsum (calcium sulphate) or lime (calcium carbonate) occurring naturally within the root zone. Most additions of calcium fertilisers are to correct an imbalance in the ratio of calcium, sodium and magnesium in the soil. The balance of these ions is just as important than just the amount of calcium.

Lime, gypsum, dolomite and superphosphate (a mixture of calcium phosphate and calcium sulphate) all supply calcium. Lime is more often used to correct acidity or sometimes sodicity problems, rather than to correct a calcium deficiency. Gypsum is also commonly used to correct sodicity. Dolomite is useful for calcium and magnesium deficiencies.

Magnesium

Magnesium deficiencies occur mainly on sandy acid soils in high rainfall areas, so are not common in the northern wheat-belt. Dolomite, magnesite or Epsom salts (magnesium sulphate) are the common fertilisers used.

Sulphur

Sulphur deficiency is not a problem in soils high in organic matter, but it leaches easily once it is converted to sulphate in the soil. Soils that have been farmed for a long time are therefore prone to sulphur deficiency. Sulphur deficiency occurs in pasture over a large area of the northern and central slopes and plains.

Superphosphate, gypsum, elemental sulphur and sulphate of ammonia are the main fertiliser sources.

Trace elements

Trace element deficiencies are fairly uncommon in the soils of the northern wheat-belt. Where deficiencies do occur, the minerals are insoluble and unavailable to plants because the soil is too acid or too alkaline. Soil testing for pH will help to determine if there is a problem. Soil testing is of little value to show the availability of trace elements, but plant tissue testing may help. Deficiencies can be treated with salts of the relevant mineral.

Zinc deficiency occurs on alkaline clay soils, particularly where earthworks or erosion have removed topsoil. Zinc sulphate is used to remedy deficiency.

Molybdenum helps in nitrogen fixation, so is especially important for legumes. Remedy a deficiency by applying molybdenum superphosphate ('moly super'), or molybdenum trioxide as a seed treatment when inoculating legume seed, or by spraying young plants with sodium molybdate.

Copper is a constituent of some plant enzymes. It is essential for crimp in wool. Use copper sulphate to supply copper to plants.

Manganese is used in photosynthesis. It is present in high amounts and may be toxic in acid soils, but can be deficient in alkaline soils. Remedy toxicity by liming to raise soil pH.

Boron is used in the formation of cell walls and assists in the plant's use of calcium. Deficiency of boron shows in the growing points of stems. Apply borax to the soil to remedy boron deficiency.

SOILpak

A plant receives only 10% of its nutrition from the soil. The rest comes from the air. (Of all the nutrients in plant tissue, carbon, from carbon dioxide in the air, makes up 90%.)

E6

Managing the moisture budget for increased water use efficiency

Purpose of this chapter

This chapter explains management strategies for retaining and using rainfall whilst minimising evaporation, run-off and drainage.

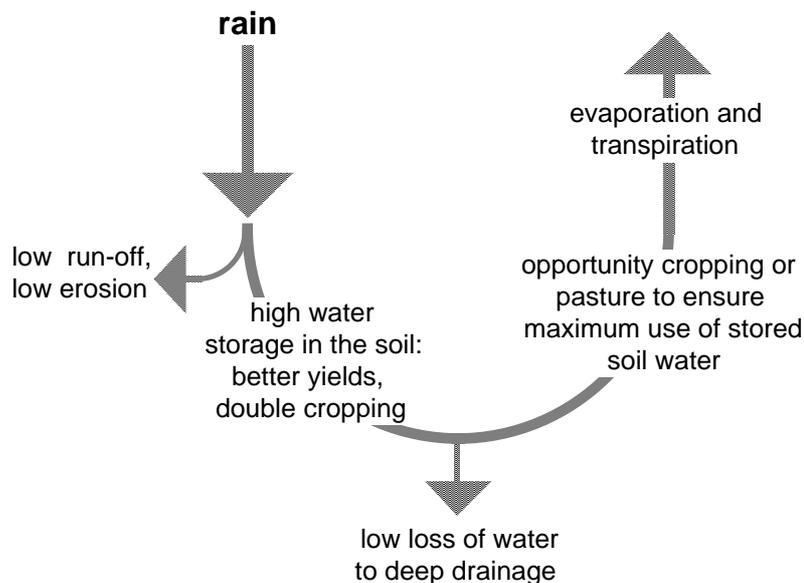
Chapter contents

- water use efficiency
- infiltration
- avoiding excessive run-off
- minimising evaporation and drainage
- different ways of measuring water use efficiency

Associated chapters

You may need to refer to the following chapters:

- B2: Weed control
- B11: Choosing the next crop
- D-s1: Erosion control
- E7: On-farm water storage



E6

Managing the moisture budget for increased water use efficiency

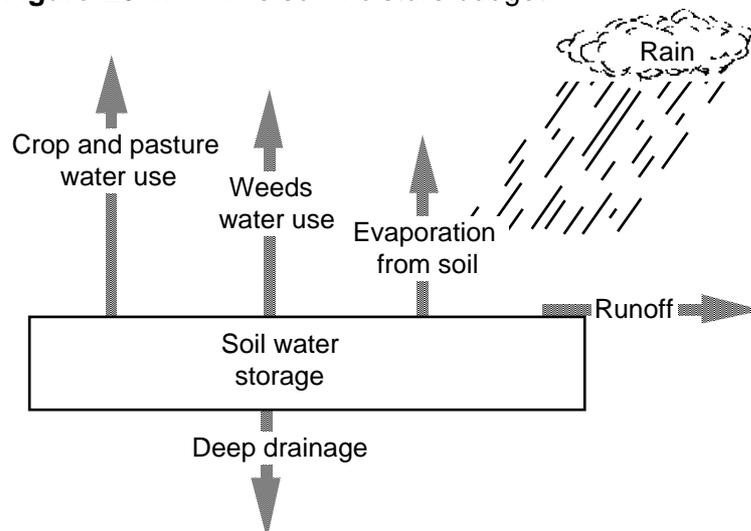
by Peter Hayman (NSW Agriculture, Tamworth) and David Freebairn (Queensland Department of Primary Industries).

Every year crops suffer some degree of moisture stress that affects yield. However, efficient farming systems maximise the yield produced for a given rainfall.

As shown in **Figure E6-1**, rain falling on the ground can contribute to six different processes:

- run-off from the surface;
- evaporation from the soil surface;
- drainage from the root zone;
- storage in the soil;
- use by weeds;
- use by crops and pasture.

Figure E6-1: The soil moisture budget.



The allocation of rain to those six processes is called a soil moisture budget. Farmers can manage that budget so as to minimise losses and to maximise the conversion of water into products.

Water use efficiency is a measure of how efficiently a farming system converts water into yield. It is usually calculated as kilograms of grain per hectare, divided by mm of water used by the crop.

There are different ways of identifying plant water use (see later in this chapter, 'Different ways of measuring water use efficiency'). A simple approach is to use rainfall and yield.

For example, suppose a wheat crop yields 2 tonnes (2,000 kg) per hectare and uses 500 mm of water from sowing to harvest. The water use efficiency is:

$$\frac{2,000 \text{ kg/ha}}{500 \text{ mm}}$$

or 4 kg/ha per mm of rain. A very poor efficiency! A common maximum water use efficiency for winter cereals is 10 kg/ha per mm of rain; for summer cereals, it is 15 kg/ha per mm of rain (see the 'Not all plants are equal' box below).

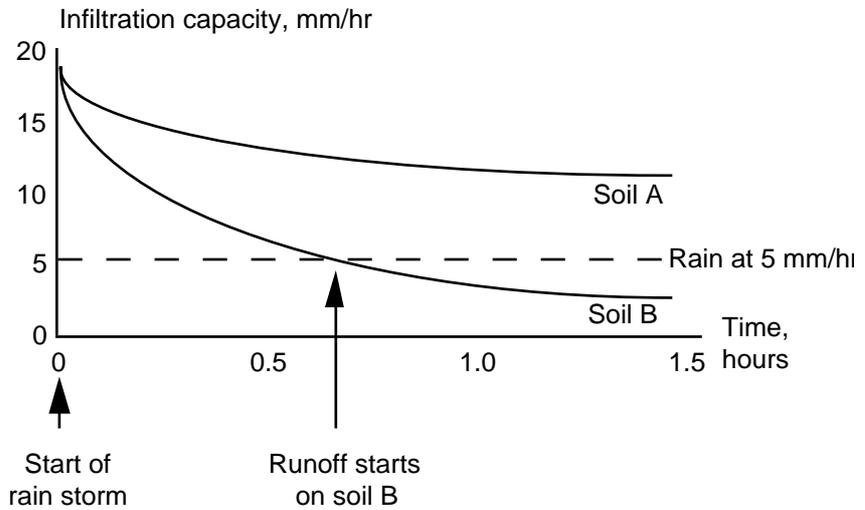
Not all plants are equal. Plants take in carbon dioxide from the air to make sugars by photosynthesis. Water is lost from the leaves as carbon dioxide enters. The atmosphere is very dry compared with green plant material, and carbon dioxide is very dilute in the atmosphere (only 0.03%). Therefore when leaf pores open to take in carbon dioxide, much more water is lost than carbon dioxide is taken in. Most tropical plants can use the carbon dioxide quickly; most temperate plants are not so efficient. A tropical plant such as sorghum loses from 250 up to 350 parts of water in taking in one part of carbon dioxide. A temperate plant such as wheat loses more: 450 to 950 parts of water for each part of carbon dioxide gained. Sorghum uses water more efficiently than wheat does!

Infiltration capacity

Infiltration capacity is the capacity of the soil to take in water. It is never constant, it changes. As water infiltrates, the soil's pore space becomes fuller and has less capacity to take in more water. Also, the soil's structure may change as water infiltrates. For example, clay and organic matter swell as they become wetter, and the swelling can close some pores. The soil may slump as it wets and the closer-packed particles may reduce infiltration. Raindrop impact on the soil surface can damage surface structure and seal the soil.

Figure E6-2 shows the decline in infiltration capacity during a rain storm for two different soils. Infiltration capacity starts high for both soils, but declines sooner in soil B than in soil A. Suppose that rain falls steadily at 5 mm/hr. Soil B's infiltration capacity falls to less than the rainfall rate after about 40 minutes. Water would then pond on the surface of soil B and run-off would start. Soil A is able to cope with this rain storm and no run-off occurs.

Figure E6-2 Decline in infiltration capacity during a rain storm for two different soils.



- Increasing infiltration**
- Minimise the time for which the soil profile is too full of water by using the first planting opportunity once the fallow has allowed the soil to become 75% full.
 - Ensure that the soil always has some stubble cover.
 - A pasture phase is often the most effective method of improving the infiltration properties of a soil. However, stock trampling (poaching) during wet weather can reduce infiltration.

For all soils, surface cover has the greatest effect on infiltration. Surface cover intercepts rain and absorbs the raindrops' energy. Surface cover reduces surface sealing and maintains a higher infiltration rate. Surface cover also slows down run-off, giving the water more time to infiltrate.

Figure E6-3 Using soil cracking to store more rainfall

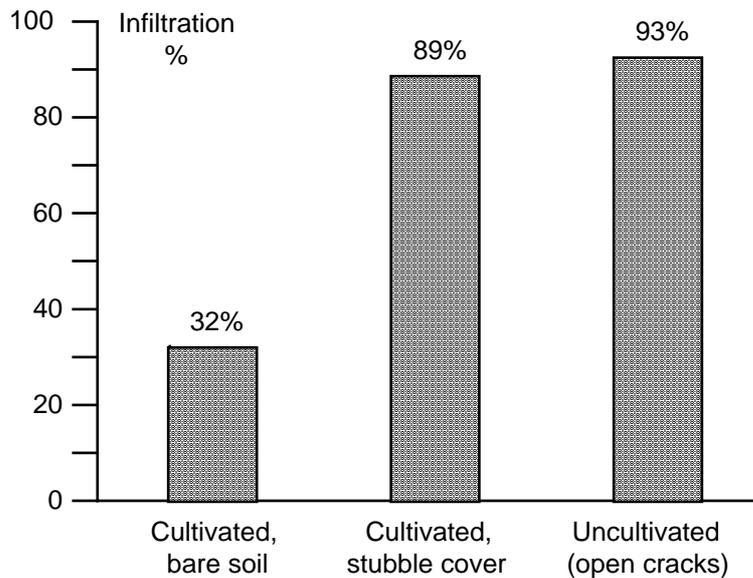
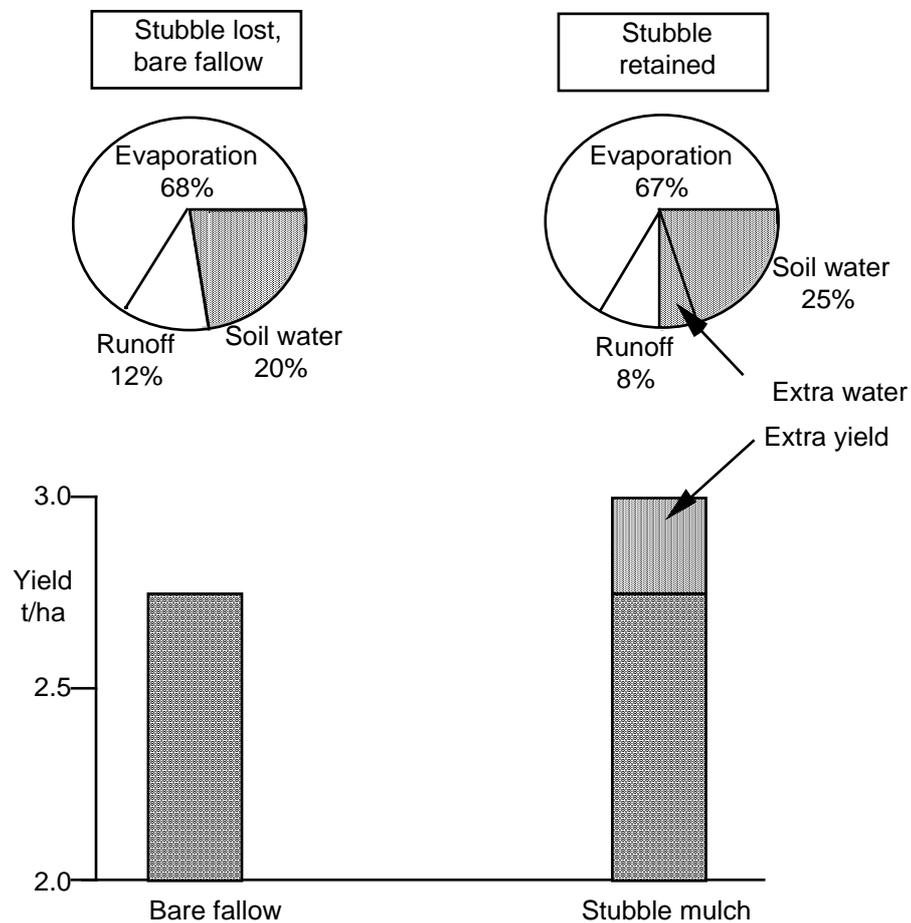


Figure E6-3 shows that for cracking clays, open cracks are just as important as stubble cover. Moreover, cracks can be important as pathways for water to move deeper into the soil, away from the evaporation zone.

Because the infiltration of water into a soil profile generally becomes slower soon after infiltration starts, any practice that holds rainfall on the surface, rather than letting it flow downhill, assists infiltration. Contour cultivation (across the slope) achieves this. Increasing surface roughness, for example pitting or making small depressions in the soil, can also help if there is little stubble. However, stubble cover is just as effective as surface roughness, and probably more effective on hard-setting soils.

Figure E6-4 Water balance and yield under two fallow management systems



Avoiding excessive run-off

A protective mulch of stubble on the soil surface can substantially reduce run-off from fallows, as shown in **Figure E6-4**. However, as the soil gets wetter, the proportion of rain that runs off increases, and the effect of cover decreases. If the soil profile is more than 75% full of moisture, there is no point in extending the fallow.

Seasonal conditions have a strong (and unavoidable) influence on soil moisture. However, the sequence and number of crops grown have a major effect on the timing of soil water deficits during the year. The cropping sequence therefore also governs run-off. For example, less run-off occurs with a summer crop because high crop water use coincides with the summer maximum for rainfall.

From a soil conservation viewpoint, tillage is the most important factor influencing stubble cover. The frequency and type of tillage determine how much stubble remains on the surface.

Reducing soil evaporation

There is little that can be done to stop the surface 10 cm of the soil drying out. This is the layer that is almost baked on a hot summer's day and for a short time water is lost from the wet surface almost as fast as from a free water surface. However, when this surface layer does dry it acts as an insulator to wet soil beneath it and soil evaporation is reduced to about 20% of the potential rate.

Evaporation from the sides of cracks can dry the subsoil, but a soil that is cracked is already fairly dry. The best strategy is to leave the cracks open and accept that there will be some water loss. Cracks help rain to infiltrate deeply. Eventually the cracks will close as the soil wets and swells, and evaporation from the subsoil will become negligible.

Black earths and cracking clays have a high moisture holding capacity. The surface 10 cm can hold as much as 35mm of rain, and subsequently lose it to the atmosphere if follow up rain doesn't come quickly. Stubble cover reduces the rate of evaporation from the surface, but under harsh drying conditions and erratic rainfall most of the moisture in the **surface** layer is lost even with stubble cover. As indicated in **Figure E6-4**, the main advantage of stubble is to reduce run-off (and thereby increase infiltration) rather than to reduce evaporation.

A healthy growing crop or pasture uses soil moisture productively rather than letting it evaporate from the soil. The plants also shade the soil and provide a microclimate to reduce soil evaporation.

Reducing drainage

On most of our soils, drainage below the root zone is a slow process which occurs when the soil is saturated. Minimising the time that the soil profile is full of moisture is the best way to minimise drainage. Then, even when a storm does come more of the rain can be absorbed by the soil. It is unlikely that there will be a large amount of drainage when the soil is cracked because in this condition, even though water flows down the cracks, the soil is dry and very absorbent.

Storing more water in the soil

Soil water storage depends largely upon the texture of the soil, and there is nothing you can do to change a soil's texture. However, stubble cover maximises infiltration, and good soil structure helps water to become evenly distributed through the root zone.

Soil moisture is a limited but renewable resource. Using the soil moisture through a productive crop or pasture ensures that there is room in the soil profile for further storage.

Reducing water use by weeds Once the surface soil has dried, the rate of water loss slows down as the dry soil forms an insulator between the very dry atmosphere and the wet soil below 10 cm. However, weed roots below 10 cm draw moisture, reducing the efficiency of the fallow. Weeds compete with a crop for moisture.

Many successful farmers use a combination of residual and knockdown herbicides with strategic grazing and tillage to control weeds. Cost effective weed control requires long term strategies using crop rotations to minimise weed burdens in a paddock, rather than just solving each weed problem as it arises. Weed control may even have begun in the previous crop.

The part played by soil structure Compaction, smearing or crusting decrease the volume of large pores that are important in infiltration. Excessive cultivation reduces the structural stability of soils. This is most often noticed as a loss of 'softness' and increased crusting of the soil. The reduced structural stability of the soil surface leads to poorer infiltration.

Deep tillage can improve water storage and root growth. However, deep tillage is useful only if there is a soil layer that clearly impedes water and root penetration.

The benefits of deep tillage are most apparent in dry times, when a crop or pasture is able to make use of the improved soil conditions and send roots deeper into the soil. In wet times when rain frequently replenishes soil moisture at shallow depths, deep root growth is unnecessary and deep tillage shows little benefit.

On sodic clay soils that have infiltration problems, it may be economic to apply gypsum. Gypsum is a moderately soluble calcium salt which enables clay to flocculate. Treated soils have higher infiltration rates, better internal drainage and weaker crust strength.



Go to Chapter B8, D-s8 or E2 for more information on sodic soils

Increasing the amount of water converted to yield

- When choosing a crop to sow, select the species and variety with the optimum maturity length and sowing time. If soil moisture is limited, a long-season variety of cereal may use all the water before grain fill.
- Grow healthy plants. Disease, weeds or nutrient deficiency will lead to less efficient crops and pastures.

Different ways of measuring water use efficiency

Rainfall method

This method assumes that 25% of fallow rainfall is stored in the soil for crop use (the remainder is lost as evaporation, run-off and drainage). Further, it assumes that the first 100 mm of stored water is used to establish the crop. The remaining stored water and growing season rainfall is converted into grain yield at a rate of 10 kg/ha for each millimetre of water. The formula for yield is then:

$$\text{Yield} = 10 \times (\text{growing season rainfall} + 25\% \text{ fallow rainfall} - 100)$$

Rainfall method:

Advantages:

- Very simple to use and only requires yield and rainfall records.

- Starting soil moisture may be quite different from 25% fallow rainfall.
- This doesn't allow for moisture left over from previous crops, or moisture at harvest of crop being analysed.
- Doesn't take into account the pattern of rainfall, but assumes that 25 mm of rain after sowing is as valuable as 25 mm at flowering.

Start & finish moisture method

Yield (kg/ha) per mm of water use as estimated by starting and finishing soil moisture and growing season rainfall. As in method 1, we assume that the first 100 mm of water establishes the crop. The remaining plant-available water produces yield at the rate of 10 kg/ha per mm of water.

$$\text{Yield} = 10 \times (\text{sowing soil moisture} + \text{in season rainfall} - \text{harvest soil moisture} - 100)$$

Start & finish moisture method:

Advantages:

- Simple to use: starting & finishing soil moisture can be estimated using a push probe.

Cautions:

- Doesn't take full account of pattern of rainfall.
 - Estimation of soil moisture can be time consuming.

Modelling method

Yield (kg/ha) per mm of water use, as modelled from a daily soil moisture budget.

Yield is a function of growth determined by a daily calculation of the soil moisture.

Modelling method:

Advantages:

- Allows for pattern of rainfall.
- You can easily change a parameter and see how sensitive the process is.

Cautions:

- Requires a calibrated model and a computer.

Daily water use under different land uses

In the table below are the daily amounts of water use under different land uses. For convenience, we will say that the evaporation from a pan of water is 10mm/day, a value you would expect on a hot dry day. The daily rate in the middle of winter is as low as 2mm.

Table E6-1: Typical values for water use when pan evaporation is 10 mm/day.

	Water use, mm/day
Seedlings	3-5
Green crop just prior to flowering	9-11
Heavily grazed pasture	4-5
Lush pasture (full ground cover)	8-10
Gum tree	6-8
Bare soil with dry surface	2-3
Bare soil with wet surface	8-10

Plants vary in the depth from which they extract water, the times of the year that they use water, and under what conditions of soil drying they continue to extract water.

A fully grown crop has the highest daily rate of water use. Water use during the fallow and seedling stages is very low. Perennial pastures and trees have lower daily water use but they use water all year.

Plants can use only the water that is available to them. Once a crop or tree has dried the profile, the daily water use declines markedly. Stressed plants also have lower water use; this includes plants that are stressed by waterlogging!

When we sit down to dinner each evening, our menu includes a great deal more water than the glassful we may drink with the meal. Many foods contain a surprising percentage of water by weight. For example, cucumber contains 96% water; watermelon, 92%; milk, 87%; apple, 84%; potato, 78%; steak, 74%; cheese, 40%; and bread, 35%.

E7 On-farm water storage

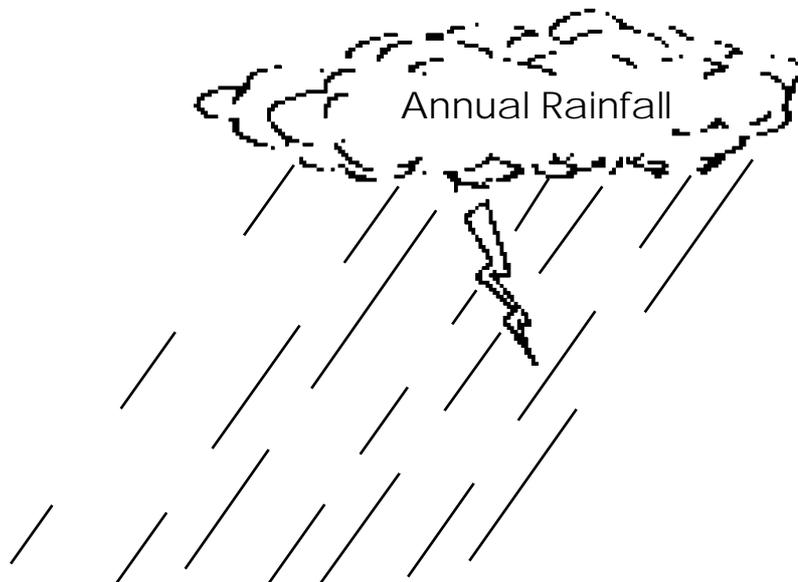
Purpose of this chapter To explain how farm dams can be used to store excess rainfall for later irrigation of small areas.

Chapter contents

- farm dams
- peak run-off rates

Associated chapters You may need to refer to the following chapters:

- D-s1 Erosion control
- E6: Managing the moisture budget for increased water use efficiency



E7 On-farm water storage

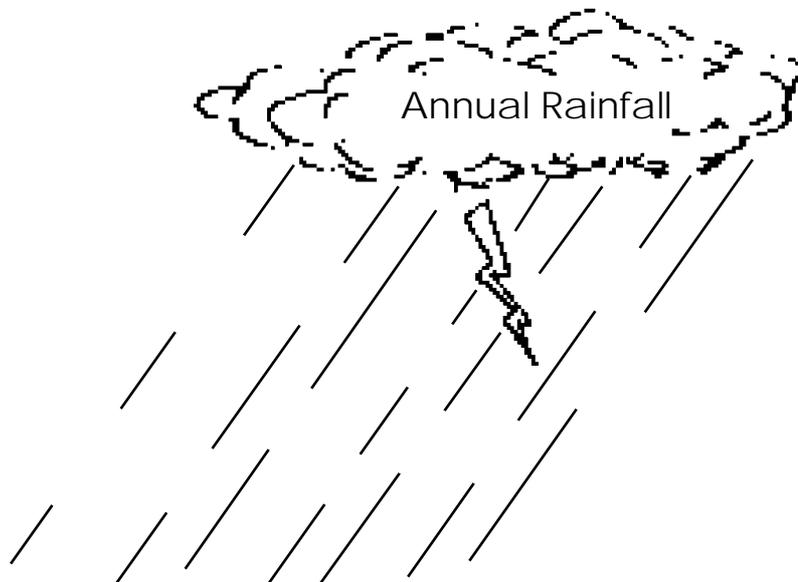
Purpose of this chapter To explain how farm dams can be used to store excess rainfall for later irrigation of small areas.

Chapter contents

- farm dams
- peak run-off rates

Associated chapters You may need to refer to the following chapters:

- D-s1 Erosion control
- E6: Managing the moisture budget for increased water use efficiency



Said Hanrahan

"We'll all be rooned," said Hanrahan,
In accents most forlorn,
Outside the church, ere Mass began,
One frosty Sunday morn.

The congregation stood about,
Coat-collars to the ears,
And talked of stock, and crops, and drought,
As it had done for years.

"It's lookin' crook," said Daniel Croke;
"Bedad, it's cruke, me lad,
For never since the banks went broke
Has seasons been so bad."

"It's dry, all right," said young O'Neil,
With which astute remark
He squatted down upon his heel
And chewed a piece of bark.

And so around the chorus ran,
"It's keeping dry, no doubt."
"We'll all be rooned," said Hanrahan,
"Before the year is out."

"The crops are done; ye'll have your work
To save one bag of grain;
From here way out to Back-o'-Bourke
They're singin' out for rain."

"They're singin' out for rain," he said,
"And all the tanks are dry."
The congregation scratched its head
And gazed around the sky.

"There won't be grass, in any case,
Enough to feed as ass;
There's not a blade on Casey's place
As I came down to Mass."

"If rain don't come this month," said Dan,
And cleared his throat to speak
"We'll all be rooned," said Hanrahan,
"If rain don't come this week."

A heavy silence seemed to steal
On all at this remark;
And each man squatted on his heel,
And chewed a piece of bark.

"We want an inch of rain, we do,"
O'Neil observed at last;
But Croke 'maintained' we wanted two
To put the danger past.

"If we don't get three inches, man,
Or four to break this drought,
We'll all be rooned," said Hanrahan,
"Before the year is out."

In God's good time down came the rain;
And all the afternoon
On iron roof and window-pane
It drummed a homely tune.

And through the night it pattered still,
And lightsome, gladsome elves
On dripping spout and window-sill
Kept talking to themselves.

It pelted, pelted all day long,
A-singing at its work,
Till every heart took up the song
Way out to Back-o'-Bourke.

And every creek a banker ran,
And dams filled overtop;
"We'll all be rooned," said Hanrahan,
"If this rain doesn't stop."

And stop it did, in God's good time:
And spring came in to fold
A mantle o'er the hills sublime
Of green and pink and gold.

And days went by on dancing feet,
With harvest-hopes immense,
And laughing eyes beheld the wheat
Nid-nodding o'er the fence.

And, oh, the smiles on every face,
As happy lad and lass
Through grass knee-deep on Casey's
place
Went riding down to Mass.

While round the church in clothes genteel
Discoursed the men of mark,
And each man squatted on his heel,
And chewed his piece of bark.

"There'll be bush-fires for sure, me man,
There will, without a doubt;
We'll all be rooned," said Hanrahan,
"Before the year is out."

P. J. Hartigan ('John O'Brien')
(1879- 1952)

E7

On-farm water storage

Water: a resource

The problem of unreliable rainfall is made worse by run-off and erosion. Run-off reduces the effective rainfall; soil erosion reduces the water storage capacity of the soil.

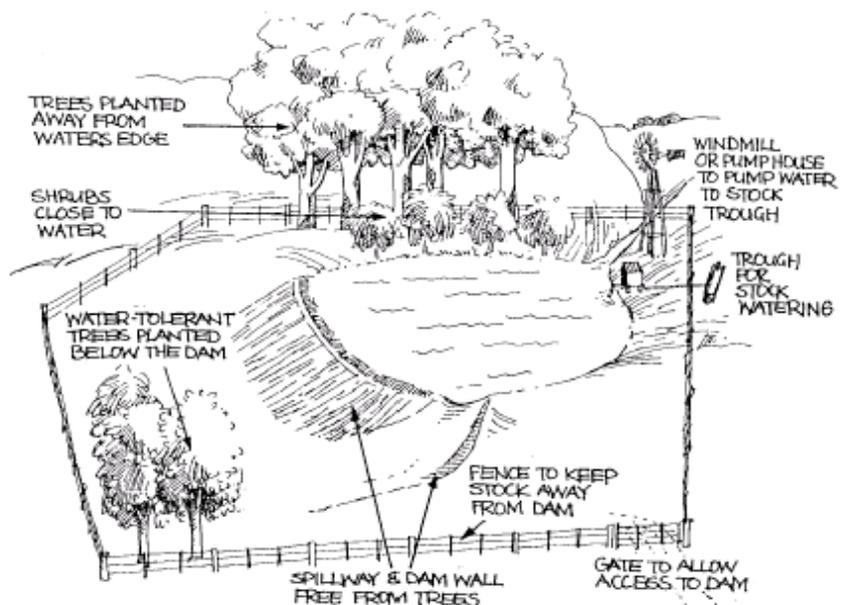
After soil, water is the dryland farmer's most valuable resource. The rain that falls on a farm should be used in a productive way. Water that runs off a farm is wasted and can cause costly damage to community property.

Some of the options available to improve the use of rainfall are:

- management of crop residues to improve infiltration and decrease erosion;
- crop rotations that make the best use of water; and
- the construction of dams to store excess rainfall for later irrigation.

As well as improving the use of rainfall, these measures may improve water quality in our rivers and reduce the frequency and magnitude of flooding.

Figure E7-1: Design for a farm dam.



Farm dams

Choose a dam site close to an irrigable area. You can then irrigate stored water onto a small area of the property set aside for that purpose. Irrigation allows double cropping in some years. Design the dam as in **Figure E7-1**.

Protect the dam from sun and wind to reduce evaporation: plant trees away from the water's edge, and shrubs close to the water. Plant water-tolerant trees below the dam to stabilise the overflow channel against erosion.

Keep the spillway and dam wall free from trees. Tree roots spearing through the compacted clay of the dam wall may cause leaks leading to wall failure. Trees falling over may pull the wall down with them. Tree roots may cause stormwater to swirl, resulting in possible erosion. A good mat of grass is best for walls and spillways.

Fence off the dam to keep stock out. Stock camping under the trees will destabilise the bank, adding to siltation. Animal manure washing into the dam will cause algae to grow. Pipe the dam water to stock troughs away from the dam.

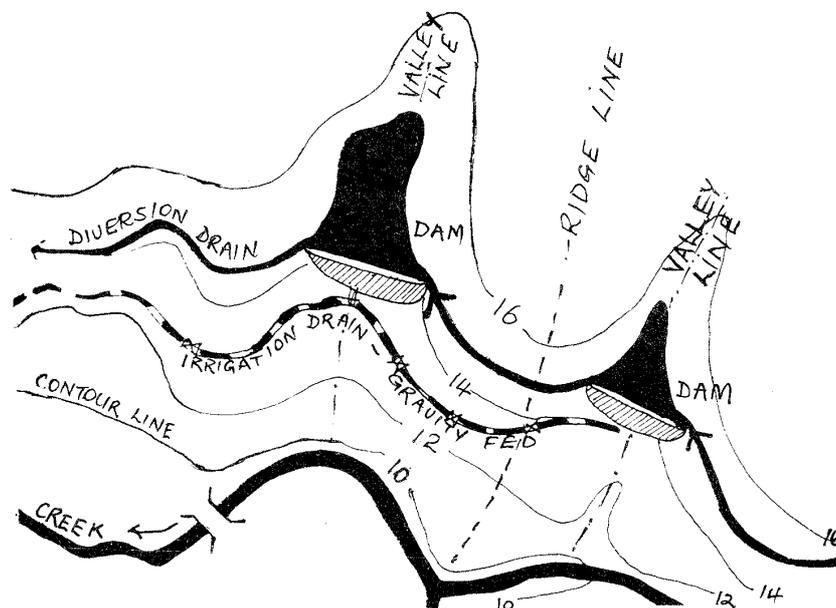
Put a gate in the fence, and ensure that your plantings allow access for vehicles. You may need to slash around the dam, or bulldoze the dam when it is empty. If possible, do not allow the dam to dry out completely or it may crack and be difficult to reseal.

The "Keyline" system

The "Keyline" system is P.A. Yeomans' concept of farm water storage and use for small-area irrigation. The Keyline system works best on sloping country where several small valleys (or gullies) lead to a main valley.

Yeomans identifies the "Keypoint" of a small valley as the point where the slope of the valley floor changes from convex to concave. This point is usually the highest practicable point in the landscape for building a dam.

Figure E7-2: Keypoint dams.



The keypoint is not hard to pick by eye. Keypoints in each side valley are linked by a "keyline" along the main valley. The keyline is a line that does not quite follow the contour, but descends slightly to carry overflow from one dam to another (**Figure E7-2**).

Storing rain for irrigation

Consider the water usage on an annual basis. Most run-off occurs from December to April, whilst irrigation may take place from July to September. It is therefore reasonable to expect to store and use the majority of run-off in most years.

Table E7-1 shows some data on the amount of irrigation water and the reliability of supply of water as run-off. This data applies to two sites in the eastern Darling Downs in Queensland. The principles apply to other regions, but the figures would change with climate and slope.

Dam size is expressed as the depth of run-off from the whole catchment required to fill the dam. The probability of 2-year irrigation failure is based on the dam not being filled to 50% capacity for two or more consecutive years.

Table E7-1 Irrigation water available and probability of supply for various dam sizes and two management practices

Dam size (mm)	Mean annual runoff stored (mm)		Probability filled to capacity (%)		Probability filled to 50% capacity (%)		Probability 2-year irrigation failure (%)	
	Bare fallow	Stubble mulch	Bare fallow	Stubble mulch	Bare fallow	Stubble mulch	Bare fallow	Stubble mulch
5	4.9	4.2	94	77	98	97	0	11
10	9.4	7.6	91	58	94	77	3	14
20	15.0	10.3	78	52	88	69	3	23
30	23.8	16.9	55	38	78	52	12	33

Acknowledgement: Freebairn, Wockner and Silburn.

Irrigation water available

Mean annual run-off stored is the millimetres of water that would result if the stored water was spread over the whole catchment. Spread over a smaller area (the area to irrigate), the stored water would be equivalent to more millimetres:

$$\text{Irrigation water available (mm)} = \frac{\text{run-off stored (mm)}}{\text{fraction of the catchment to be irrigated}}$$

For example, from **Table E7-1**, a dam large enough to hold 5 mm of run-off from the whole catchment would, in the average year, store 4.9 mm of run-off from bare fallow. Used to irrigate one-tenth of the catchment, it would provide:

$$\frac{4.9 \text{ mm}}{1/10} \quad \text{which equals } 49 \text{ mm.}$$

Stubble cover or bare? Stubble cover on the soil reduces the amount of run-off into the dam for use in subsequent irrigation. However, this fact must be weighed against the need to optimise soil water storage and reduce erosion over the whole catchment. The most efficient use of rainfall is to use it where it falls. Storage of excess water in dams makes good use of water that could otherwise contribute to erosion and flooding.

Irrigation strategy For a small dam (less than 10 mm capacity), the amount of water available depends upon dam size. The dam would fill and overflow in most years. For a larger dam, the probability of filling is less. Improve the reliability of water supply by budgeting the use of water over a longer period, by irrigating a smaller area, or by increasing the size of the dam. Irrigation strategy depends upon economics, attitude to risks, dam size and reliability of rainfall.

Peak run-off rates The design of run-off control structures (erosion control banks, waterways or dams) depends upon expected peak run-off rates. Reduction in peak run-off rates (through stubble and crop management) should lead to lower construction costs for these structures.



Go to Chapter E6
for more
information on
efficient use of rain.

Farm dams can also reduce the peak run-off rate from a catchment by collecting run-off and by reducing flow rates out of the dam.

Water quality Sediment laden water from agricultural areas damages public utilities such as roads, bridges and dams. Other productive lands are affected by flooding and poor drainage. The sediment in run-off water also contains nutrients which are lost from the catchment, and extra treatment is required when water is used for human consumption.

A stable drainage system is required to remove excess rainfall from agricultural catchments so that gullies do not form. Design the drainage system to include sections that reduce flow velocity and trap sediment, so leading to improved water quality downstream. Farm dams can be an important part of this system.

Acknowledgements David Freebairn, Queensland Department of Primary Industries, Toowoomba.

Peter Stace, NSW Agriculture, Wollongbar. Figure E7-1 of farm dam, and guidelines from 'Trees for the North Coast', NSW Agriculture 1992.

SOILpak

There have been violent conflicts in the competition for water rights. It is appropriate that the word 'rivalry' comes from the Latin *rivus*, a 'stream'.