



Chapter 7

Managing Limiting Soil Factors

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7 Managing Limiting Soil Factors

7.1 Introduction

This chapter describes several soil-related factors that can limit plant growth and the management methods that can be used to remove or reduce their impact.

To get the best from fertilisers, you must first eliminate or reduce any soil-related factors that limit pasture growth.

Specific soil factors that can limit plant growth include:

[Slaking and dispersion](#) – (sodicity).

[Compaction.](#)

[Waterlogging.](#)

[Salinity.](#)

[Soil pH.](#)

Learning outcomes

At the completion of this chapter, you should:

- Recognise soil factors that limit plant growth.
- Understand the management options for minimising the limiting factors.

7.2 Slaking and dispersion

[Slaking](#) is related to soil structure and particularly to structural stability, which is the soil's ability to retain aggregates and pore spaces under various environmental conditions. Slaking is the result of lack of organic matter. [Dispersion](#) is usually a problem of soil chemistry (namely, high levels of exchangeable sodium), although it can occur in non-sodic soils due to excessive mechanical disturbance of the soil, with associated loss of organic matter. Slaking and dispersion can occur together. When this happens, both problems will have to be managed.

7.2.1 Slaking

Slaking is the breakdown of aggregates into smaller aggregates or single particles. It occurs when a dry clay soil becomes wet. The clay swells and the air within the pore spaces in the aggregates is compressed. This builds up pressure, resulting in the 'explosion' of the aggregate – See Figure 7.1, or the animation on [Victorian Resources Online](#).

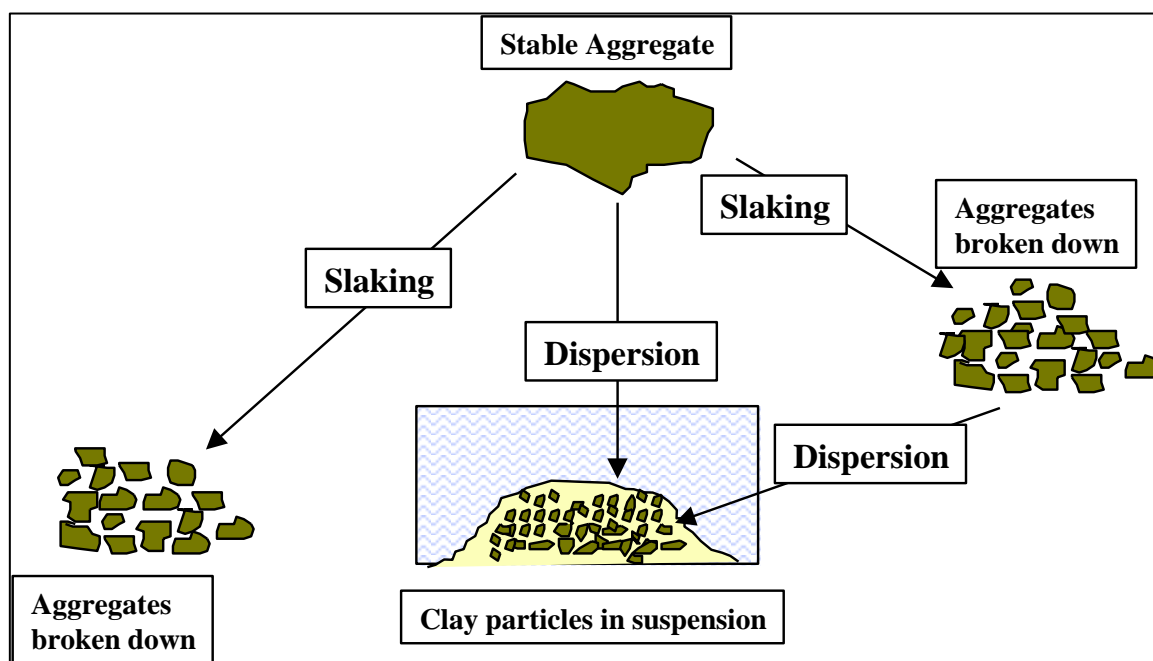


Figure Error! No text of specified style in document..1 Diagrammatic illustration of slaking and dispersion

Slaking is severe in some soils with low organic matter and can occur within minutes of the soil becoming wet. When a slaked soil dries, crusting (**hardsetting**) of the soil can occur. This limits water infiltration and seedling emergence. The hardsetting can be limited to the top few millimetres of soil or can extend through the entire soil profile.

7.2.2 Dispersion

Dispersion is the separation of the clay particles from the aggregates when the soil is wet - See Figure 7.1. Clay particles carry a negative electrical charge and tend to repel each other. Calcium, magnesium, sodium and potassium all carry positive charges and are attracted to the clay particles, forming a 'bridge', or bond, between the negatively charged clay particles.

Calcium (Ca^{2+}) ions, followed by magnesium (Mg^{2+}) ions, are the strongest 'bridge formers' because they have two positive charges. Potassium (K^{+}) and sodium (Na^{+}) ions only have one positive charge, and their bonding of the clay particles is much weaker. If calcium is forming the bridge, the clay particles will hold together when they are wet. However, if sodium is forming the bridge, the bonding is much weaker and the clay particles tend to separate and repel one another when they are wet (in other words, they tend to disperse).

Cloudy or muddy water in puddles is an indication that a soil may be dispersive. A continual stream of cloudy water running out of a mole drain outlet is also indicative of a dispersive clay-type soil. Mole drainage and open drains in dispersive soils may lead to severe soil erosion.

When dispersion occurs, the dispersed clay particles fill up the pores between soil particles and aggregates; and when the soil dries out, the dispersed clay blocks up soil pores. This restricts seedling emergence, water and air movement, and root penetration. Dispersed soils are generally hardsetting and may form a surface crust - See Figure 7.2. Dispersion with no slaking results in a 'concrete-like' lump being formed.



Another test can be done to determine whether a soil is dispersive and will respond to gypsum. Place a small handful of soil into each of two clear glass jars half filled with distilled or rain water. Add a small handful of gypsum to one of the containers only (label it with a marker). Shake the two jars and leave them for 24 hours. If the soil is dispersive and responsive to gypsum, the soil will settle out in the jar with gypsum and will remain cloudy in the jar without gypsum. See [Section 7.2.5](#) for further information on gypsum and dispersive soils.

7.2.4 Management of slaking soils

Slaking, which is related to soil structure and particularly to soil stability, can be managed by increasing the level of organic matter in the soil.

Organic matter reduces slaking by reducing the rate of aggregate wetting and by more strongly binding the soil particles together.

The best ways to increase the organic matter level in the soil are to:

- Grow highly productive pastures, especially perennial ryegrass and white clover and, where possible, deep-rooted legumes, such as lucerne.
- Use minimum tillage or no-tillage techniques for crop and pasture establishment.

See Chapter 5 on Soil Biology for further information on increasing organic matter levels.

Organic matter levels and stable soil aggregates can be easily destroyed by: excessive cultivation; cultivation when the soil is too dry or too wet; or stock trampling (pugging), particularly when the soils are wet. Cultivation increases the rate at which organic matter is broken down by soil organism activity (mineralisation of soil organic matter). Cultivation machinery compacts the soil, as does stock trampling. In fine-textured soils, cultivating when the soil is too wet breaks down aggregates, and cultivating when the soil is too dry creates large clods that are not easily penetrated by roots or seedlings.

7.2.5 Management of dispersive soils

In the short term, [gypsum](#) will reduce dispersion on sodic soils.

Lime can be used to reduce dispersion (to a lesser extent) on acidic sodic soils, but it is much less soluble than gypsum. In both cases, the sodium cations attached to clay particles are replaced with the stronger-bonding calcium cations. Some magnesium cations will also be replaced by calcium cations. The clay particles then bond together, or aggregate, by flocculation. However, aggregates formed solely by flocculation generally are not very stable.

In the longer term, dispersion management involves increasing the organic matter level in the soil, which will help to form stable aggregates that hold together.

See Chapter 5 on Soil Biology for more information on increasing organic matter levels.

The sodium cations that are exchanged for calcium cations on the clay particles don't disappear. They enter the soil solution, where they can reattach to clay particles when the opportunity arises. Adequate drainage; resulting in removal of sodium-rich soil water from the root zone, will give longer-term responses to gypsum applications.



7.2.5.1 What is gypsum?

Gypsum is the common name for hydrated calcium sulphate ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$).

There are two basic sources of gypsum: mined gypsum (natural deposits) or by-product gypsum.

Natural deposits of gypsum occur in many parts of inland Australia and vary widely in purity. The effectiveness of these sources of gypsum depends largely on the purity of the deposit and how finely the gypsum is ground.

7.2.5.2 Classification of gypsum products

Gypsum products are classified under state legislation in Australia into three grades, based on their sulphur and calcium content:

- Grade 1 gypsum must contain a minimum of 15% sulphur and 19% calcium.
- Grade 2 gypsum must contain a minimum of 12.5% sulphur and 15.5% calcium.
- Grade 3 gypsum must contain a minimum of 10% sulphur and 12.5% calcium.

The regulations also require that the label on any gypsum product must specify the fineness by stating the percentage of gypsum capable of passing a 2-mm sieve.

For more information on gypsum refer to: <http://www.incitecpivotfertilisers.com.au/en/Soil%20,-a-%20Plant%20Tests/~/-media/Gypsum%20Fact%20Sheet.ashx>

7.2.5.3 Uses of gypsum

The main use of gypsum is as a source of calcium to improve soil structure in dispersive soils.

Some farmers apply gypsum as a source of sulphur.

In dairying areas throughout Australia, some farmers apply gypsum on clay soils in the belief that it will help reduce waterlogging by improving soil structure. However, many clay loam soils, despite having waterlogging problems, will not improve in soil structure (and consequently drainage), after an application of gypsum. This is because these soils already contain adequate amounts of calcium ions, clay dispersion is not a problem, and adding further calcium in the form of gypsum is usually a complete waste of time and money. Soil testing is recommended to determine if calcium is required.

In the Northern Victoria irrigation areas on the red-brown earths the soils generally have low calcium levels and in some cases are also sodic (See [Victorian Resources Online](#)). In northern Victoria, particular attention should be given to laser-leveled paddocks with exposed subsoils that will have low organic matter. In laser-leveled paddocks, gypsum should be incorporated into the plant root zone before sowing. It is usually applied before the final grading.

However, in northern Victoria, good pasture cover is the priority on recently lasered permanent pastures. Gypsum topdressing is considered if pasture cover is poor (usually related to poor structure or sodic soils) or on paddocks that have been badly pugged, exposing the subsurface soils. The aim of the topdressing is only to stabilise the surface soil. This will result in the soil retaining its crumb structure and improving water penetration in the summer by not sealing over.



In the Upper Torrens region of South Australia, calcium in the form of Nutrilime™ is being applied to correct low Ca:Mg ratios. The soils here were originally high in magnesium and had a low Ca:Mg ratio. Many years of irrigation using water with very high magnesium levels has aggravated the problem and this is resulting in the collapse of the soil structure.

Reclaimed soils in the lower Murray region of South Australia are experiencing structural problems, waterlogging and poor pasture growth due to high sodium levels. These soils are also benefiting from high application rates of gypsum.

7.2.5.4 Determining the need for gypsum

Requirements for gypsum can be predicted from soil tests - See Chapters 8 & Chapter 9. However, predictions based on cation measurements alone may be inaccurate. Therefore, a clay dispersion test should also be done (see [Section 7.2.3](#) and Chapter 9.2.2.4).

7.2.5.5 Rates and application notes

Gypsum can be incorporated into the soil before sowing or before the final laser grading. Alternatively, it can be spread over the soil surface (topdressed).

Gypsum does not dissolve readily, although it dissolves more readily than lime (see Table 7.1), so it should be applied well before sowing to allow time for it to react with soil. Application rates of about 2.5 to 5 tonnes per hectare are needed on many soils, and the effect lasts from 1 to 20 years depending on the soil type and rate used.

Table Error! No text of specified style in document..1 Solubility of lime and gypsum

PRODUCT	SOLUBILITY AT 20°C (grams/100 litres)
Lime	1.4
Gypsum	260

When only the soil surface needs to be treated with gypsum it is topdressed and lower application rates are required. Rates of 1.2 to 2.5 t/ha are commonly used, and repeat applications may be required the following year.

Note that in a topdressing situation on irrigated, southern Australian dairy pastures:

- Wait until a long rotation in the autumn.
- Graze the paddocks out completely.
- Topdress the gypsum before natural rainfall.

Cattle may be reluctant to graze the pastures until the gypsum fines have been washed off the leaves.

Gypsum and lime are both a type of salt, so application to an already saline soil may temporarily increase the total soluble salt levels.

Unless drainage is adequate, the sodium (displaced by the calcium) may not be flushed or leached beyond the plant root zone. Improved drainage may be necessary so that the excess sodium can be leached out of the soil. If drainage is not adequate, it is possible that the soils may quickly revert to their waterlogged and dispersive nature.



When buying gypsum by the tonne, it is important to know the water content of the product as well as its particle sizes when comparing products, as high freight costs may be incurred.

Pasture growth responses to topdressed gypsum on existing pasture are uncommon unless sulphur is deficient.

7.3 Compaction

A compacted soil is one in which the soil aggregates have been compressed so that the pore spaces between the aggregates have been substantially decreased.

Compaction reduces water and air infiltration, restricts pasture root growth and slows pasture growth rates.

The compacted layer may be at the soil surface as a result of wheel compaction; slightly below the surface from pugging; or at some depth in the soil profile as a hard pan, either naturally occurring or from the use of cultivation implements.

7.3.1 Naturally occurring compaction

Natural compaction is generally a reflection of a change in soil structural conditions and can occur through leaching as the more mobile soil constituents move downward and form **hard pans** at depth in the soil profile. For example, in some soils, iron is leached out of the surface layers and accumulates at depth to form a hard pan that is very difficult to penetrate. These hard pans are referred to as 'coffee rock' and are found commonly in the Heytesbury district of southern Victoria and in the southern part of the Mt Lofty ranges, South Australia. Similar 'buckshot' layers are found in the older basalt plains soils. Clay particles can also be leached downwards to form a clay-pan layer that is virtually impermeable.

Compaction also occurs naturally within the soil profile. The lower horizons are usually more compacted than the upper ones due to the weight of the upper layers and the lower organic matter content of the lower layers.

7.3.2 Induced compaction

Induced compaction is soil compaction caused by farming practices. It can make rapid and severe changes to soil porosity (the amount of pore spaces in a soil), and some of these changes can have long-lasting effects.

Dry soils are relatively strong and usually do not compact. However, when soils are wet, they have less strength and are more easily compressed. Cultivation, grazing, or fertiliser spreading at this stage will reduce the soil's ability to drain excess water away quickly, which can make waterlogging more severe. Heavier-textured soils, such as clays and loams, are more affected because they naturally drain more slowly. Management should be adjusted to take these factors into account and this could be achieved by cultivating, grazing or spreading fertiliser when soils are dry.

7.3.3 Degree of compaction

The degree of compaction of a soil affects the bulk density of the soil. Bulk density of a soil is the weight of a unit volume of dry soil and its pore spaces. It is usually measured in grams per cubic centimetre (g/cm^3) or megagrams per cubic metre (Mg/m^3). Both of these units have the same numerical values. In other cases, soil compaction may be expressed as t/m^3 .

A friable, well-aerated soil will have a low bulk density. That is, it will have more pore spaces per cubic centimetre, and therefore, a lower weight. Conversely, a compacted soil will have a high bulk density as there is more soil and fewer pore spaces.



Bulk density is related to both texture and structure. Sandy soils have a higher bulk density, because their particles tend to be closer together and sandy soils also are usually lower in organic matter. Clays and loams usually have a lower bulk density because they are made up of smaller particles that are usually well-granulated and have formed aggregates. This is assisted by their higher organic matter content. The structure of a soil is affected by the balance of macropores (large soil pores) and micropores (small soil pores). Thus, as a soil becomes less well-structured and loses macropores, it increases in bulk density. Management, as well as soil type, affects this characteristic of any soil.

Compacted layers can be easily assessed by pushing a pointed rod into the soil. Often a hard pan is found around 10 to 15 cm from the surface.

7.3.4 Managing compaction

On compaction-prone soils, management practices can reduce the likelihood of compaction.

Compaction may be avoided or reduced by:

- Increasing the level of organic matter in the soil. This will improve soil structure, reduce the bulk density of the soil and promote freer drainage when soils are wet.
- Using low-pressure tyres with a large soil contact area.
- Keeping animals and machinery off wet areas can help to reduce compaction. Cultivation of wet soils should be avoided. If grazing is restricted while the soils are wet, there may be a need for investment in hard [stand-off areas](#) to protect the soil resource.
- Overcoming waterlogging through surface and subsurface drainage (see [Section 7.4.5](#)) can substantially help to conserve the soil structure. It is imperative, where subsurface drains are installed, to allow 24 to 48 hours for excess water to drain away. Ideally, the watertable should be at least 300 mm below the soil surface before the pasture is grazed.
- Modern techniques of minimum tillage or no-tillage are less damaging to soil structure. Frequent or fast cultivation pulverised soil aggregates, breaking down soil structure and macropores, therefore hastening compaction.

A deep or shallow ripping can loosen the compacted layer. This is a 'temporary fix' if the underlying cause of the compaction is not corrected. Also, unless water can get away, the deeper cultivated or ripped soil will wet up more easily (to the tyned or ripped depth) and be even more prone to compaction damage.

When mechanically aerating or ripping, ensure soil conditions are not overly dry or wet. If the soil is cultivated when it is wetter than its plastic limit, soil fracturing does not occur and the soil smears forming a plough pan or compaction layer. Soil compaction due to deformation results in a reduction in porosity and pore size, and when dry, the compacted soil presents a barrier to root penetration. Cultivating the soil when it is drier than its plastic limit allows the plough to fracture the soil producing a desirable seed bed. Soils retain moisture and if worked mechanically above a certain moisture level, deformity of the soil can occur. The point at which this occurs is called the "plastic limit".

To assess if a soil is wetter or drier than its plastic limit, collect some soil about the size of a golf ball at least 10 cm below the proposed depth of cultivation. Roll the soil between the palms of your hands and attempt to form a rod (cylinder) about 50 mm long and 4 mm thick. The soil is drier than its plastic limit if cracks appear in the cylinder and therefore the soil is suitable for cultivation. If the



cylinder stays intact then the soil is wetter than its plastic limit, and cultivation will cause compaction (Moody and Cong, 2008).

7.4 Waterlogging

Waterlogging occurs when most or all of the macropores become filled with water rather than air. It occurs more easily in soils that have a greater proportion of micropores than macropores, because the macropores promote free drainage while the micropores tend to hold on to water. Both compaction; which presses the soil particles and aggregates closer together, and dispersion; which fills the pore spaces with clay particles, tend to promote waterlogging.

7.4.1 Causes of waterlogging

Waterlogging is a common problem on many soil types, particularly in predominantly clay soils. Waterlogging may be due to periods of heavy rainfall, dispersion, compaction, poor irrigation management, rising watertables, or a combination of poor surface drainage (across the paddock) and poor subsurface drainage (down the soil profile). Figure 7.4 shows a well-aerated soil and a waterlogged soil.

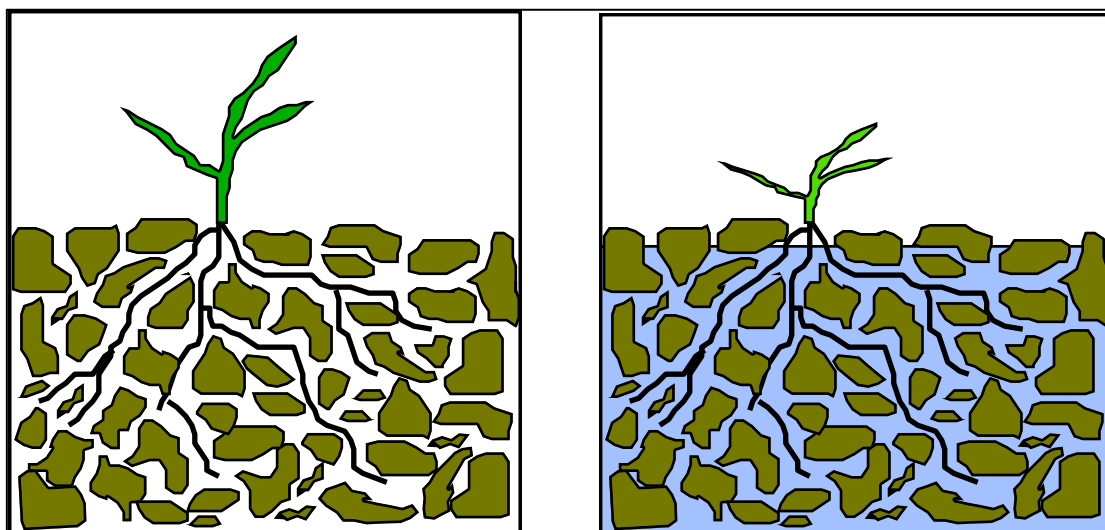


Figure Error! No text of specified style in document..4 Well-aerated soil (left) and waterlogged soil (right).

In rain-fed WA dairy soils, waterlogging occurs in flat areas on soils comprising 0.5 to 2.0 m sand to sandy loam soils over a very impervious clay layer. This forms a surface aquifer and the pasture root zone is no deeper than 20 cm.

7.4.2 Effects of waterlogging

Soil strength decreases as the soil gets progressively wetter, resulting in a greatly increased potential for damage to the soil structure. Waterlogging prevents air and many nutrients from reaching the roots, thus seriously inhibiting plant growth. Also unfavourable gases and compounds are produced in the root zone due to the anaerobic (no oxygen) conditions favouring anaerobic soil micro-organisms at the expense of aerobic micro-organisms - See Chapter 5. A build-up of salt is also more likely under poorly drained irrigation pastures.

Where soil drainage is poor, numerous effects are seen. The severity of these effects will depend on things such as the duration of waterlogging and the soil texture. In light-textured soils the effects will not be as detrimental.



Waterlogging effects include:

- Plants are stunted and yellow as nitrogen is lost due to denitrification which is caused by a lack of aeration – see Figure 7.5.
- Improved pasture plants are replaced by tolerant weeds (docks, smartweed, rushes, sedges, couch, etc.).
- Pastures become fouled with mud and utilisation is reduced.
- Pasture growth rates decline.
- Soils become pugged and water ponds on the surface.
- Responses to applied fertiliser are poor.
- Nutrient balance in the pasture is upset with lower nitrogen, potassium, magnesium and chlorine in the pasture.
- Change in soil biology from aerobic to anaerobic soil organisms - See Chapter 5.



Figure Error! No text of specified style in document..5 Sorghum plants waterlogged for an extended duration showing poor growth and discolouration. (Photograph supplied by David Hall).

7.4.3 Managing waterlogged soils

When waterlogging has occurred, prevention of further damage to the pasture and soil structure is the first priority. This can only be done by keeping vehicles and animals off waterlogged areas. A grazing management technique called '**on-off grazing**' can significantly reduce pugging damage and increase pasture utilisation. With the 'on-off grazing' technique, stock are only allowed to graze the paddock for a short period (2 to 4 hours) and are then held in a **stand-off area**, such as a feedpad, a laneway, an old sand quarry, or the dairy shed yard.

Long-term management involves removing the cause of the waterlogging. Waterlogging may be caused by a soil chemical or physical problem, such as dispersion (see [Section 7.2.2](#)) or compaction (see [Section 7.3](#)), or by a high watertable or poor irrigation management.



In districts where waterlogging is caused by a high watertable, management strategies aimed at controlling the level of the watertable will be required, and these are outlined in [Section 7.5.7](#), 'How can we best manage salinity', and [Section 7.4.5](#), 'Reducing waterlogging through drainage'.

If the problem is related to poor irrigation management, see [Section 7.4.4](#), 'Reducing waterlogging through irrigation management'.

7.4.4 Reducing waterlogging through irrigation management

Waterlogging is one of the most limiting factors affecting **flood-irrigated** pasture production in southern Australia. Unfortunately, white clover is the most susceptible pasture species to waterlogging.

In a flood irrigation situation, waterlogging can occur because it takes too long to get water:

[On to a bay](#)

[Off of a bay](#)

7.4.4.1 Water On

A compromise needs to be found between irrigating quickly to reduce waterlogging, and allowing enough time for adequate soakage of water into the bay. With a well-designed bay on suitable soils, the required amount of water should be applied in 2 to 4 hours. However, up to 6 hours is generally accepted as reasonable. The time needed to apply the required amount of water can be varied by adjusting the flow rate. On lighter, more permeable soils, a shorter irrigation time is appropriate to reduce water losses beyond the pasture root zone. If the area at the bottom of the bays is not producing well due to waterlogging, or there is no drainage reuse system, watering 'short' can be a water saving compromise - See [Victorian Resources Online](#).

Four factors commonly cause slow watering and can lead to a waterlogging problem. These are:

- Inadequately sized (small) farm channels and channel structures.
- Small bay outlets.
- Weeds in channels restricting the water flow.
- Irrigated ground that is high.

Any of these factors will restrict the flow of water, cause the wheel to slow down and slow down irrigation.

Leaking bay outlets may also be the cause of a waterlogging problem at the top of an irrigation bay. Refer to the Target 10 Irrigation and Drainage Reference Manual. See [Victorian Resources Online](#) to find out how to address these problems.

7.4.4.2 Water Off

Water should not be left lying on the bay. It should be drained away as quickly as practicable to prevent ponding and waterlogging. Ideally, there should be no water lying on the bay 24 hours after irrigation has commenced.

Drainage off the bay will be affected by:

- Bay slope.
- Soil type.
- Condition of the drain at the bottom of the bay.
- Length of bay.



- Evenness of slope.
- Presence of spinner cuts.
- Pasture height, type and density.

Water will stay longer on longer bays, on bays that are flat or are on heavy soil types, or where the drains at the bottom of the bay are in poor condition.

Longer bays (longer than 400 m) do not drain well, particularly in winter when evaporation rates are low. The water has to move a longer distance to reach the drain, and the bay stays wetter longer.

Spinner cuts running down the bay will improve drainage. The spacing of the spinner cuts across the bay will depend on the severity of the drainage problem. A spacing of 15 to 20 m between spinner cuts is often used.

It is important that there is a well-defined drain at the bottom of the bay. This drain should connect with the rest of the farm drainage system so that it carries runoff to a reuse system, to a regional or community drain, or to a natural watercourse.

There are a large number of factors to consider when trying to overcome an irrigation waterlogging problem. Developing a [whole-farm plan](#) provides a means to ensure that an irrigation layout is well planned and well designed. A good irrigation layout is essential to minimise waterlogging problems and optimise pasture production.

7.4.5 Reducing waterlogging through drainage

Overcoming waterlogging through drainage may help preserve soil structure.

In high-rainfall dairy pastures, increases in pasture utilisation of 40% to 60% have been measured on drained ([subsurface drainage](#)) compared to undrained paddocks.

Improved pasture yields and pasture composition have also been measured on drained paddocks. Soil salinity levels are also often lowered by subsurface drains because the drained water removes some of the salt.

Drainage systems need to be planned, constructed and maintained effectively to have a long-term, positive effect on both the on-farm and off-farm environments.

Because the drainage water often has to flow onto neighbouring properties, drainage works are best done in cooperation with the neighbouring landholders and in conjunction with the relevant water authorities.

Drainage of the soil can reduce waterlogging effectively but at a cost. Other strategies, such as 'on-off grazing' (see [Section 7.4.3](#)) and agistment, are used on some farms.

7.4.5.1 Surface drainage

Improvement in surface drainage should be investigated first, as it is the simplest and cheapest option. Surface drainage involves maintaining existing drains and installing additional drains that are adequately sized and positioned, usually placed along fence lines or through depressions. If possible, emphasis should be placed on preventing water from the upper paddocks flowing over onto the lower paddocks.



However, many farmers mistakenly believe their waterlogging problems are due to surface water alone, when they are actually often due to subsurface water or to a combination of surface and subsurface water. In these cases, a combination of surface and subsurface drainage may be required.

7.4.5.2 Subsurface drainage

Poor subsurface water movement is caused by an impediment to the water moving down the soil profile. Possible impediments include a heavy soil texture, compacted layers, and natural or induced hard pans in the profile (which can create a raised watertable). Poor subsurface water movement can also be caused by subsurface water moving downhill from upper slopes or by springs.

In irrigation areas, groundwater pumping is a common form of subsurface drainage.

In high-rainfall areas of Australia, the main forms of subsurface drainage are [subsurface pipe drains](#) or [mole drains](#) or a combination of both. The type of drain installed depends on soil characteristics, rate of drainage required, and topography.

Note: In irrigation areas, your irrigation supply authority should be contacted before installing subsurface drainage. In some regions, permission is required from the local irrigation supply authority to discharge water from subsurface drainage systems off the farm.

Subsurface pipe drains

Free-draining topsoils with an impermeable layer at a depth of more than 0.7 metres, or deep, free-draining soils subject to rising watertables, require pipe drains. Pipe drains are constructed by placing a slotted PVC or corrugated plastic pipe in a trench and then surrounding the pipe with a permeable backfill, such as stone or gravel - see Figure 7.6.

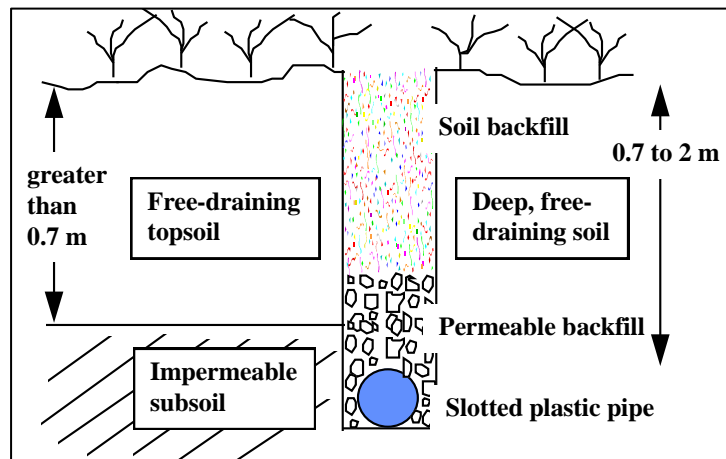


Figure Error! No text of specified style in document..6 Subsurface pipe drain

Subsurface pipe drains are expensive to install but are very effective and economically viable in the correct situations. They can last for many years, provided they are correctly installed and consistently maintained.



Mole drains

Clay and clay loam soils with poor natural drainage and with clay less than 40 cm from the surface are generally suitable for mole drainage – see Figure 7.7. A mole drain can be made simply by pulling a metal object (i.e. a ripper blade with cylindrical foot, or mole plough) through the soil, leaving an open channel. Mole drains cost less than tile drains but require more maintenance.

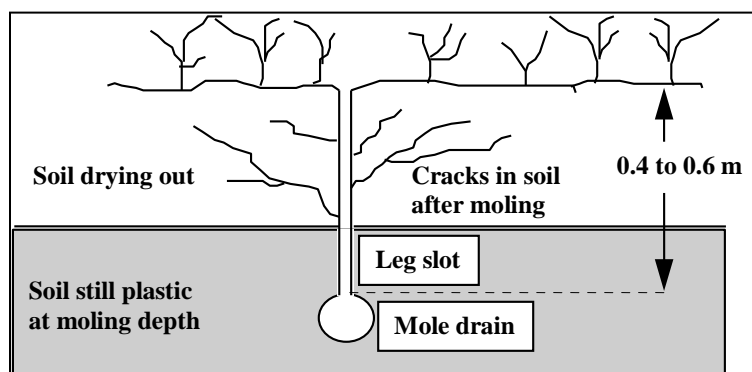


Figure Error! No text of specified style in document..7 Mole drain

The clay through which the mole is pulled must be plastic when wet (retains shape of mole) and stable (not prone to cracking, dispersion or slaking). If installed correctly in appropriate soil, mole drains may function adequately for 3 to 7 years. For more information on mole drainage see http://www.agric.wa.gov.au/objtwr/imported_assets/content/lwe/water/drain/bulletin4610.pdf

7.5 Salinity

7.5.1 What is salinity?

When we refer to salinity in agriculture, we are referring to the level of salt in the soil and the soil solution.

The most frequently found salt in saline conditions is common salt, more correctly known as sodium chloride (NaCl). Other dominant salts found are sodium carbonate and sodium bicarbonate and to a lesser extent sulphates of sodium, calcium, magnesium and potassium and chlorides of calcium, magnesium and potassium.

Saline soils are those with sufficiently high levels of salt in the root zone to adversely affect plant growth.

High salt levels affect plant growth in two ways:

- They reduce the plant's ability to take up water (an osmotic effect).
- They cause toxicities (usually chloride and sodium) and nutrient imbalances by changing the plant's ability to take up a wide range of nutrients.

Natural saltland (primary salinity) existed in Australia before European settlement; however, the extent and severity of salinity has increased markedly due to changes in the management of land and water (secondary salinity).

7.5.2 The processes of salinity

The processes of salinity are shown in Figures 7.8 (dryland) and 7.9 (irrigation).



Rainfall or irrigation water can leave the soil surface in several ways. It can be used by plants or removed by runoff and evaporation. The remaining water seeps through the soil until it reaches a dense rock layer (often referred to as bedrock) or a clay or other hardpan layer that it cannot penetrate. The soil then begins to fill up with water, starting from this layer. The top of the saturated zone in the soil is known as the **watertable**. **Recharge**, or groundwater recharge, is the name for water added to the watertable in this way.

When the watertable rises to within 1 or 2 metres of the soil surface, the water can move into the plant root zone by capillary rise. **Capillary rise** occurs when drier soil on top of the watertable sucks up the ground water, similar to the action of a sponge. The **capillary zone** is the area above the watertable that is affected by capillary rise.

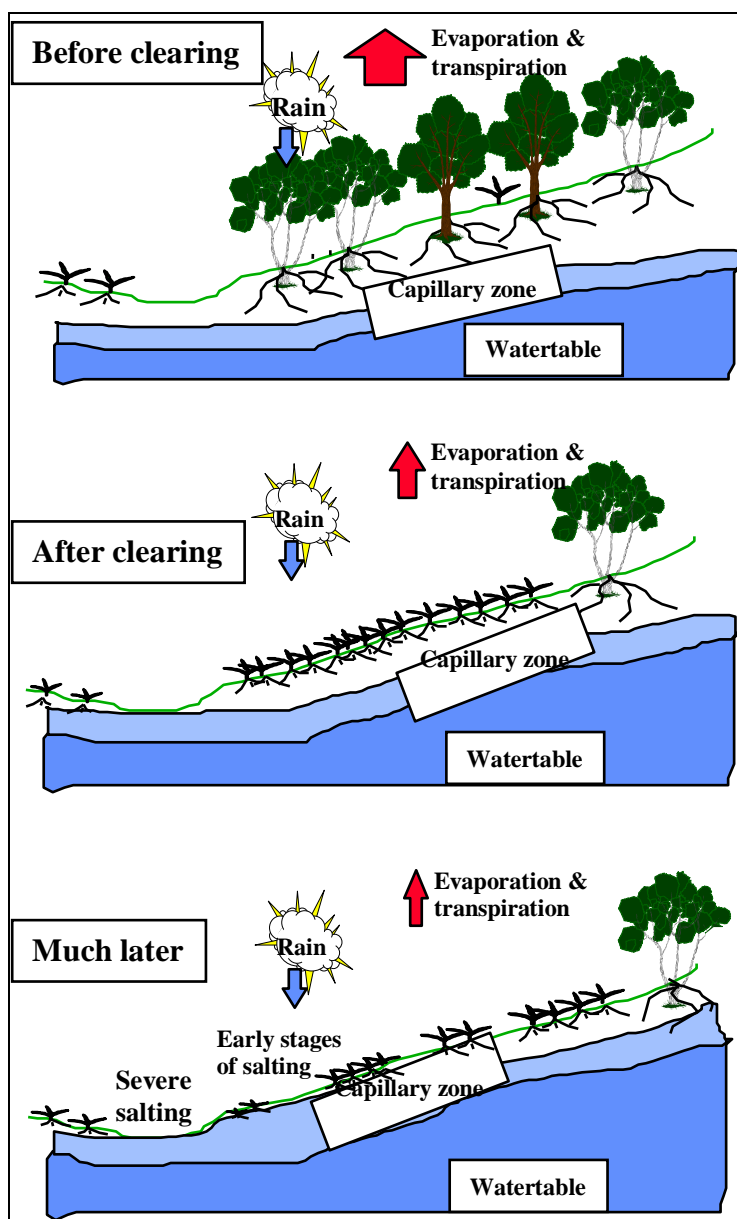


Figure Error! No text of specified style in document..8 Processes



The height of capillary rise depends on the soil type. It is greatest in loam soils, which have a variety of particle and pore sizes. In sandy soils, there are bigger spaces and the force needed to lift water through them is greater. In clay soils, small pore size slows water movement.

As the watertable rises, the salts in the soil are dissolved. If capillary rise brings salty water into the plant root zone, the plants are affected by the salts. In extreme cases, capillary rise will bring the salty water to the soil surface. This is known as **discharge**. The salt makes it hard for the plants to take water from the soil, and the plants may show signs of water stress. Eventually, they may die of dehydration if the salinity levels are too high. Pastures suffering from the effects of salinity can become invaded by salt-tolerant weeds; and as salinity increases, the proportion of salt-tolerant grasses increases.

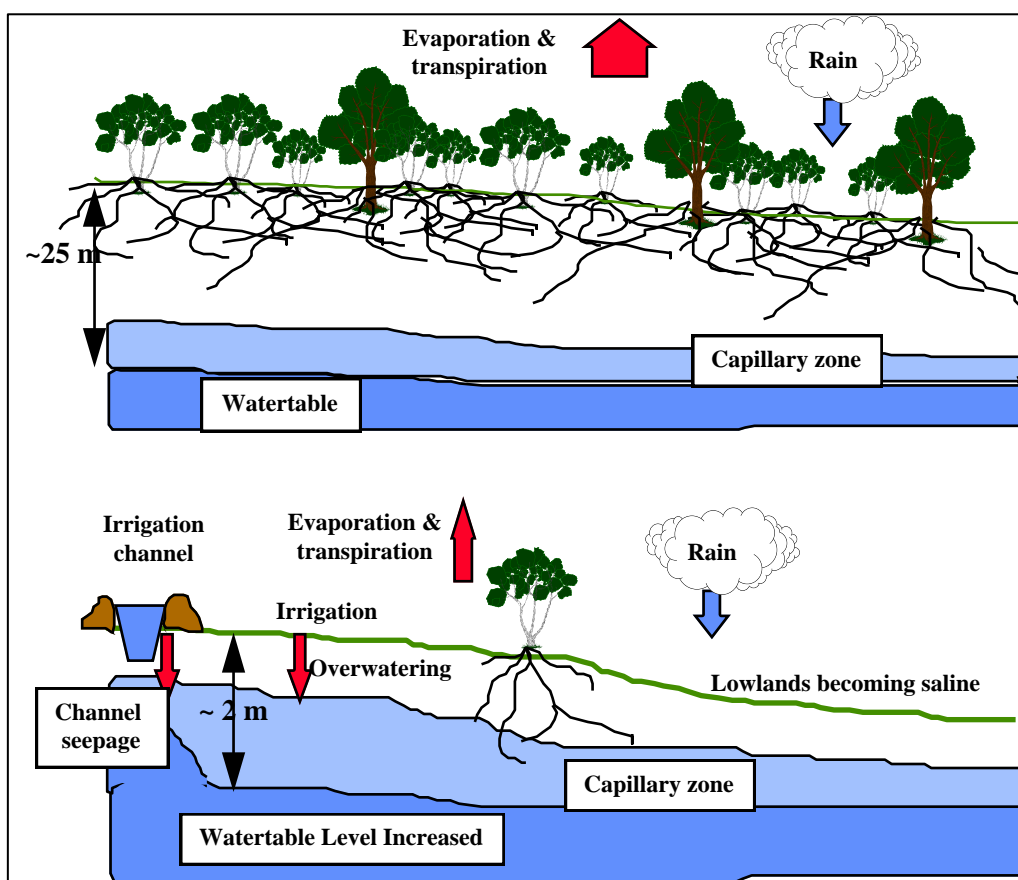


Figure Error! No text of specified style in document..9 Processes and causes of irrigation salinity

The early symptoms of salinity are often incorrectly thought to be caused by something else, such as waterlogging or a lack of fertiliser; and a yield loss of up to 30% can occur before definite signs of salinity become visible.

7.5.3 The causes of secondary salinity

The main cause of many of the secondary **dryland salinity** problems is the clearing of deep-rooted native trees from recharge areas. Trees and other large vegetation use and transpire much more water than pasture or cropping does. When these large plants are cleared from the recharge area, more water seeps into the watertable.

The main cause of **irrigation salinity** is poor irrigation methods, such as slow watering, that allow water to pond for long periods and seep into the soil. In addition, seepage from irrigation channels and drains and from dams results in recharge.



7.5.4 Soil classification and salinity measurement

Soils have been divided into five classifications to help identify the degree of the salinity problem. The classes range from very low to extreme levels of salinity and are named A+ (very low), A, B, C and D (extreme) – See [Figure 7.10](#). Most of the Northern Victoria irrigation area is type A+ or A soil, but there are significant areas of classes B, C and D, particularly to the west. The growth of most pasture species is unaffected by salinity levels of class A or B soils. Only salt-tolerant plants like barley grass grow in class D soils.

Salinity is measured by determining the **electrical conductivity** (EC) of a water or soil sample. Electrical conductivity is a measure of the capacity of soil or water to carry an electric current. The main unit of measurement for soil salinity is deciSiemens per metre (dS/m). **EC_e (dS/m)** is a salinity measure used by researchers that allows for the effect of soil texture on salinity. Further information about measuring salinity is provided in Chapter 9.2.10.

The estimated returns from applying irrigation water to dairy pastures growing on soils with different degrees of salinity are shown in Table 7.2. This shows how large an effect soil salinity can have on economic returns. Similar economic effects would occur with the application of fertiliser to the various classes of saline soil.

Table Error! No text of specified style in document..2 Estimated returns from applying 1 megalitre of irrigation water to different classes of saline land (1992 data)

SOIL SALINITY CLASS	EC _e (dS/m)	APPROX. AMOUNT OF SALT (ppm)	SPECIES THAT WILL GROW	GROSS MARGIN
A+ Very low	Less than 1.8	n.a.	All pastures and clovers	\$170
A Low	1.8 to 3.8	Less than 1800	Most pastures, crops, legumes	\$120
B Moderate	3.8 to 6.5	1800 to 3000	Grass, some legumes	\$55
C High	6.5 to 8.6	3000 to 4000	Grass, not clover	\$5
D Extreme	More than 8.6	More than 4000	Salt tolerant plants, some barley grass	-\$15

Source: Adapted from Norman *et al.* (1995).

Soil salinity levels determine what grows in the soil and are a major reason for lower productivity. Lower salinity soils give better return for your money. Therefore, in salt-affected areas, it is important to know the classifications of your soil so areas of C and D class can be managed differently to the more productive A and B class soils.

7.5.5 What does salinity look like?

Salinity will affect plants differently depending on their stage of growth. They are usually most at risk during seedling emergence and early seedling growth. If salinity weakens them at an early stage in their growth, they are more prone to stress caused by other problems, such as poor soil structure, disease, insects, nutrient deficiencies, or waterlogging. Plants may die from the combined effect of several of these rather than just one.

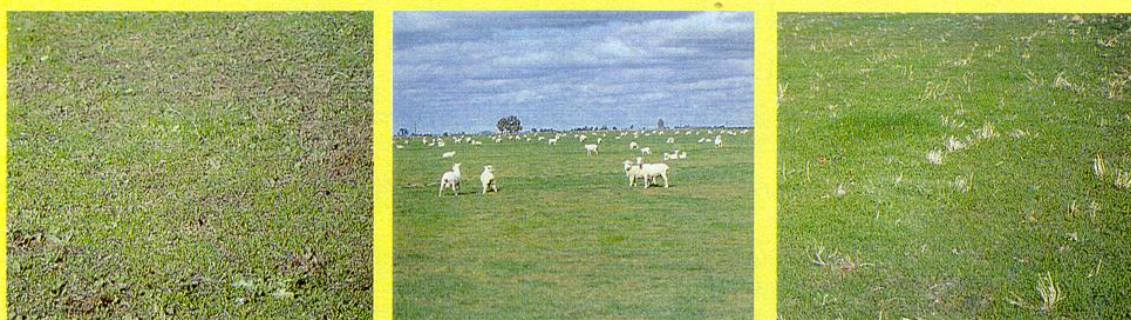
The leaves of salt-affected plants can initially appear smaller and darker than normal. Shoot growth is also reduced. As salinity levels increase, the effects become more pronounced. Low germination rates and seedling deaths reduce establishment, and surviving plants grow more slowly. The tips of leaves can appear burnt, and this can spread until the whole leaf is yellow. The photos in [Figure 7.10](#) show examples of A, B, C, and D soil salinity classes and the effect of their salt levels on productivity.



CLASS A Little or no salt. Growth of any pasture or crop is not limited by salt.



CLASS B Has sufficient salt to slow clover growth, which is patchy. Inclined to be weedy.



CLASS C Too saline for legumes. Grass dominant. Salt indicator plants appear (spargularia, red weed, suada).



CLASS D Too saline for all but some barley grass. Is bare or grows very salt tolerant plants (salt indicator plants, red weed, beadbush). Includes some soil too salty for any plants.



Figure Error! No text of specified style in document.10 Soil salinity classes A, B, C and D and their effect on productivity in the Kerang Irrigation Region of northern Victoria



7.5.5.1 General pasture symptoms

- Plant growth is poor and uneven.
- Grasses dominate because they generally are more tolerant to salinity than clovers and other legumes.
- Animals may lick and graze salty areas.

7.5.5.2 General soil symptoms

- White salt crystals may appear on bare soil surfaces in extreme cases.
- The surface soil may remain moist and greasy.
- Clay soils may appear loose and crumbly and when cultivated may have a soft and spongy texture.

7.5.6 Plant tolerance to salty conditions

The tolerance of the various pasture species to salinity does vary. In some cases, specific varieties may be recommended to assist more severe salinity problems because of their better tolerance to the particular conditions. Table 7.3 indicates the relative salt tolerance of some pastures and crops.

Table Error! No text of specified style in document..3 Tolerance of some pasture and crop plants to various levels of salinity

SALT TOLERANCE	PLANT SPECIES
Low	Clover (White, Sub, Persian, Crimson, Balansa)
Medium	Ryegrass (Perennial, Annual) Phalaris Tall Fescue Lucerne (<i>Sensitive to salinity until established</i>) Clover (Berseem, Strawberry) Millet
High	Barley Wheat Oats Barley grass Tall wheat grass

7.5.7 How can we best manage salinity?

The solutions to the salinity problem are not a matter of just treating the symptoms but of managing all the factors that influence the well-being of the water catchment.

As a whole, the community can help in lowering the watertable. Management of the whole catchment assists everyone's problems and so benefits everyone. Some of the practices available are mentioned below.

Community surface drainage reduces accessions to the watertable as well as providing a wide range of benefits on farms. Surface drainage programs in irrigation areas provide financial and technical support to survey, design and construct subregional community drainage schemes.



Subsurface drainage removes excess water from below the ground surface. Common methods are groundwater pumping from suitable shallow aquifers (in irrigation areas) and tile or mole drainage (see [Section 7.4.5](#)).

Whole-farm plans can be used to protect and enhance environmental features while increasing farm profitability. A whole-farm plan is a drawing or photograph of the farm showing existing natural and built features and details of the improvements to be made on the property, such as fencing by soil salinity class, drainage plans, or improved irrigation management.

Trees strategically planted on recharge areas, along laneways and fence lines and on irrigation reuse systems and channel banks provide several benefits. A significant one is the consumption of ground water by the trees, which assists in lowering the watertable; others include providing shade and shelter for livestock, improving property values and providing wildlife habitat. In irrigation areas, incentives are sometimes available to producers and community groups for each of these four practices. For more information contact your regional catchment management authority or natural resource management group – See <http://www.nrm.gov.au/about/nrm/regions/vic-mall.html>

As long as untreed recharge areas and irrigation practices continue to upset the natural water balance, the salinity problem will remain. Only when improved land and water management practices slow the rate of recharge to the groundwater system will it be possible to control salinity.

7.5.7.1 Practices for managing dryland salinity

Salinity is not a widespread problem in dryland dairying areas at present. However, steps that dryland farmers can take to manage dryland salinity include:

- Using more water in recharge areas by:
 - Retaining any remaining native vegetation.
 - Planting perennial pasture species, as they are deeper-rooted and use more water than annual species.
 - Replanting catchment areas with trees, which can be used for livestock fodder, firewood, posts and poles, sawlogs, honey, windbreaks, wildlife habitat, and erosion control.
- Controlling grazing in recharge areas so that as much pasture growth as possible remains on the soil.
- Fencing off saline areas and planting them in salt-tolerant trees or pasture species. These plants will help to keep the soil profile drier by using the saline water and will also help to prevent soil erosion, which often occurs on saline areas when the existing vegetation cover is killed by the salt.

In many cases, salinity in dryland areas is caused by problems on recharge areas that are not on the property on which the salinity occurs. In such cases, a catchment-wide approach to salinity management will be necessary, involving cooperation with neighbouring landowners and your local catchment management authority or natural resource management group.

7.5.7.2 Practices for managing irrigation salinity

All irrigation farmers can take steps to improve irrigation management. These include:

- Using a whole-farm plan for a structural approach to farm development.
- Matching and monitoring the water application to the needs of pastures and crops.



- Improving pasture and crop growth to use more soil water.
- Watering paddocks in less than 6 hours.
- Draining paddocks as quickly as possible after irrigation.
- Reusing all drainage water in future irrigations.
- Make sure that soil fertility and soil health is optimum
- Minimise soil compaction
- Monitor the soils salinity levels at various depths within the plants rooting zone (either by soil tests or installed monitoring devices e.g. gypsum blocks)

For more information on soil salinity refer to the Salinity Management Handbook, 2nd Edition.

http://www.derm.qld.gov.au/salinity/managing_salinity.html

7.6 Soil pH

Soil pH is a measure of the concentration of the positively charged hydrogen ions (H^+) in the soil solution. When a soil solution contains more H^+ ions, it is **acidic**. When there are fewer H^+ ions, the soil solution is **alkaline**.

The pH scale ranges from 0 to 14; a value of 7 is neutral – See Figure 7.11. Values less than 7 are acidic, and greater than 7 are alkaline. As the soil pH value decreases, the level of acidity increases. In other words, the soil solution becomes more acidic. As the pH value increases, alkalinity increases or in other words, the soil solution becomes less acidic).

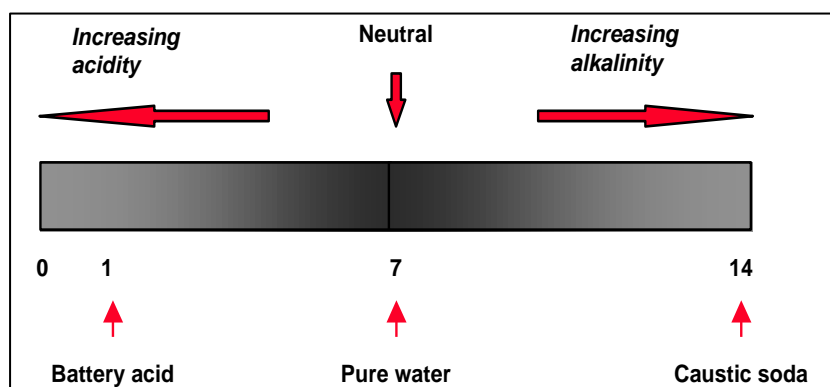


Figure Error! No text of specified style in document..11 The pH scale

The pH scale is 'logarithmic'. A one-unit decrease in the pH value signifies a tenfold increase in acidity. So a soil with a:

- pH of 6 is 10 times more acidic than a soil at pH 7.
- pH of 5 is 100 times more acidic than a soil at pH 7.
- pH of 4 is 1000 times more acidic than a soil at pH 7.

7.6.1 Measuring pH

See Chapter 9.2.4.



7.6.2 Causes of soil acidification

Soil pH is influenced by many factors, including soil type, organic matter, rainfall, fertiliser use and farming practices.

Soil acidification is a natural process in which the soil pH decreases over time.

Many of our farming practices increase the rate of acidification.

Soils with a light texture (in other words, a high sand content) and low organic matter content are most susceptible to acidification, particularly if high levels of nitrogen fertilisers are applied.

The major processes that increase the rate of soil acidification are:

- The addition and accumulation of organic matter, which creates organic acids; a weak acid.
- The removal from the paddock of plant and animal products that contain high levels of calcium, magnesium and potassium. These three elements are all bases and thus their removal increases acidity. The degree of acidification will depend on how alkaline the product is and how many kilograms of product are removed.
- The leaching of the exchangeable bases (magnesium, potassium and particularly calcium) from the soil caused by high rainfall.
- The leaching of nitrate nitrogen from the root zone.
- The application of acidifying fertilisers, such as those that contain elemental sulphur or that contain nitrogen as ammonium or urea - See Chapter 12.6.2.

7.6.3 Potential problems of acid soils

Problems that can occur in acid soils include:

- Aluminium and manganese toxicity to plants.
- Decreased availability of nitrogen, phosphorus, potassium, sulphur, molybdenum, magnesium, boron and calcium to plants.
- Decreased biological activity of soil microbes and thus reduced recycling of nutrients. For more information refer to Soil Biology Chapter 5.
- Suppression of rhizobia bacteria, which affects legume nodulation.
- Suppression of root growth and the plant's ability to take up water and nutrients.

For more information on soil acidity please refer to link: <http://soilquality.org.au/factsheets/soil-acidity>

7.6.4 Symptoms of soil acidity

The symptoms of soil acidity include:

- Uneven pasture growth.
- Poor nodulation of legumes.
- Stunted root growth and high incidence of root diseases.
- Invasion of acid-tolerant weeds (for example, fog grass, sorrel, geranium).
- Difficulty establishing lucerne, phalaris, and medics.



- Formation of organic mats on the ground surface due to reduced biological activity.

7.6.5 Optimum pH range for pasture plants

Most pasture plants grow best in medium to slightly acid soil ranging from pH (CaCl₂) 4.8 to 5.8 (see Table 7.4), although they can tolerate levels below this.

Table Error! No text of specified style in document..4 The optimum pH range of pastures and crops

Pasture Species	pH (CaCl ₂)	pH (water)
Annual ryegrass	5.5	
Balansa, Berseen, Persians	5.2 – 7.5 ¹	
Barleys & Wheat*	4.3 to 5.5 – 7.5 ¹	5.5 to 7.0
Buffel	5.2 – 7.5 ¹	
Cereal Rye	4.3 – 7.5 ¹	
Cocksfoot	4.3 to 6.8 ¹	5.0 to 7.5
Consul Love Grass	3.8 – 7.5	
Cowpeas*		5.5 to 7.0
Fescue	4.3 to 6.4	5.0 to 7.0
Kale*		5.3 to 7.0
Kikuyu	4.1 – 7.5 ¹	5.5 to 8.0
Lucerne	4.8 ¹ 5.2 to 7.5	5.8 to 8.0
Lupins (Broad leaf)	4.3 – 7.5 ¹	
Lupins (Narrow leaf)	4.1 – 7.5 ¹	
Maize*	4.5 – 7.5 ¹	5.5 to 7.0
Medic	5.3 to 8.0	6.0 to 8.5
Millet	4.5 – 7.5 ¹	
Millet	4.5 – 7.5 ¹	
Oats	3.9 – 7.5 ¹	
Peas*		6.0 to 7.0
Perennial ryegrass	4.3 to 6.0	5.0 to 6.5
Phalaris	4.9 ¹ 5.2 to 7.3	6.0 to 8.0
Red Clover	4.4 – 7.5	
Red Clover*		6.0 to 7.0
Seradella	4.2 – 7.5 ¹	
Sorghum, Sudan Grass* USA	4.4 – 7.5 ¹	5.5 to 7.0
Sub clover	4.8 to 6.	5.5 to 7.0
Tall Wheat Grass	4.8 – 7.5 ¹	
Triticale	4.1 – 7.5 ¹	
Vetch*		5.5 to 6.8
White clover	5.0 to 6.0	5.8 to 6.5

Source: Adapted from ¹New South Wales Acid Soil Action Program. (2000), *Havlin *et al*, (1999).

7.6.6 Effect of pH on soil nutrients

One of the most significant impacts that acid soils have is the effect that the acidic environment has on the availability of important soil nutrients. As the pH of a soil changes, soil nutrients can become either more or less available for uptake by plants. This change in availability of nutrients can result in pastures showing either a nutrient toxicity or deficiency.



The effect that soil pH has on the availability of soil nutrients is shown for the two soil pH test methods: pH (1:5 water) - Figure 7.12; and pH (1:5 CaCl₂) - Figure 7.13. (Note: There are slight differences between mineral soils and organic soils in the availabilities of the various nutrients).

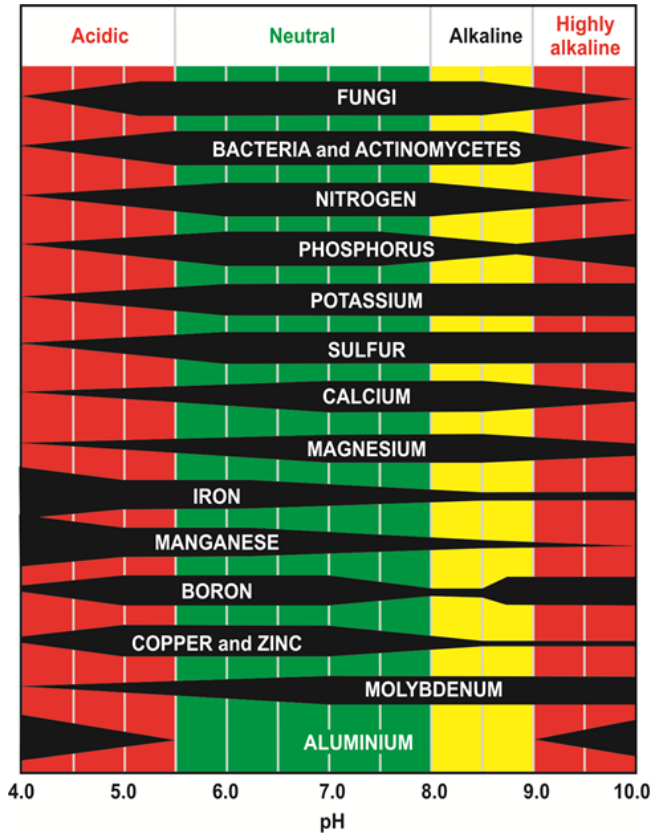


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Effect of pH (1:5 water) on nutrient availability. *Source:* Incitec Pivot LTD (2008) Agronomy Advantage Manual.

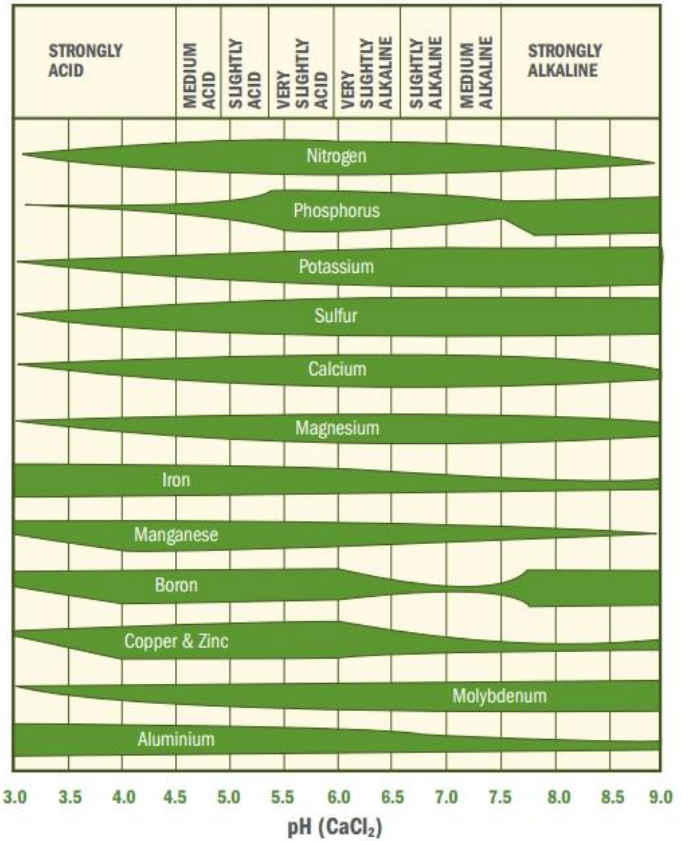


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Effect of pH (1:5 CaCl₂) on nutrient availability. *Source:* <http://www.sibelco.com.au/LinkClick.aspx?fileticket=VhVwW7>

The width of the bar represents the relative availability of that particular nutrient at that pH level.

In strongly acidic soils (pH (CaCl₂) less than 4.0), all the major plant nutrients (nitrogen, phosphorus, potassium, sulphur, calcium and magnesium) and the trace element molybdenum may become less available to plants (see Figure 7.13). If the pH (CaCl₂) is greater than 6, some trace elements, such as zinc, copper and boron, become less readily available, which may lead to deficiencies in plants.

Soils that are deficient in molybdenum may show a pasture response when lime is applied because the chemical reactions increase the availability of molybdenum for plant growth, especially legume growth. In many cases, what is seen as a lime response is actually a molybdenum response. For soils low in molybdenum, applying a fertiliser mix that includes molybdenum will cost less than applying lime where the pH is known to be adequate for plant growth. Caution should be exercised with the application of molybdenum as an over application of molybdenum can have an antagonistic effect on copper uptake from pastures. Molybdenum status is best assessed using plant tissue analysis of white clover (or other legume) or by applying a test strip - See Chapter 8.7 for more information on fertiliser test strips.



7.6.6.1 Aluminium and manganese

As soils become more acidic, it is common to see a rise in the plant availability of both aluminium (Al) and manganese (Mn), which can both be toxic to pasture plants and crops (see Figure 7.12). Aluminium toxicity is particularly common in acid soils and restricts root growth and function in sensitive plant species. For more information on critical aluminium levels for various pasture species see Chapter 9.2.9.7.

7.6.7 Effect of pH on biological activity

Living organisms are an important component of the soil. Good organic matter levels, good drainage and appropriate pH levels encourage their presence.

Earthworms are less active in very acidic soils, fungal organisms prefer a wide range of pH, and bacteria prefer slightly acid to neutral soils. Some of the important beneficial organisms (for example, nitrifying bacteria) are inhibited in both very acid and very alkaline soils. On strongly acidic soils and, in particular, those with a pH (CaCl₂) less than 4.5, the activity of the bacteria responsible for the conversion of organic material into plant-available nitrogen is significantly reduced. For more information refer to Soil Biology Chapter 5.

7.6.8 Soil pH across the dairying regions of Australia

For information on soil pH across the dairying regions of Australia see the links below:

- [Australian Soil Resource Information System](#) – See Figure 7.14.
- Chapter 6 - Soil types of the dairying areas

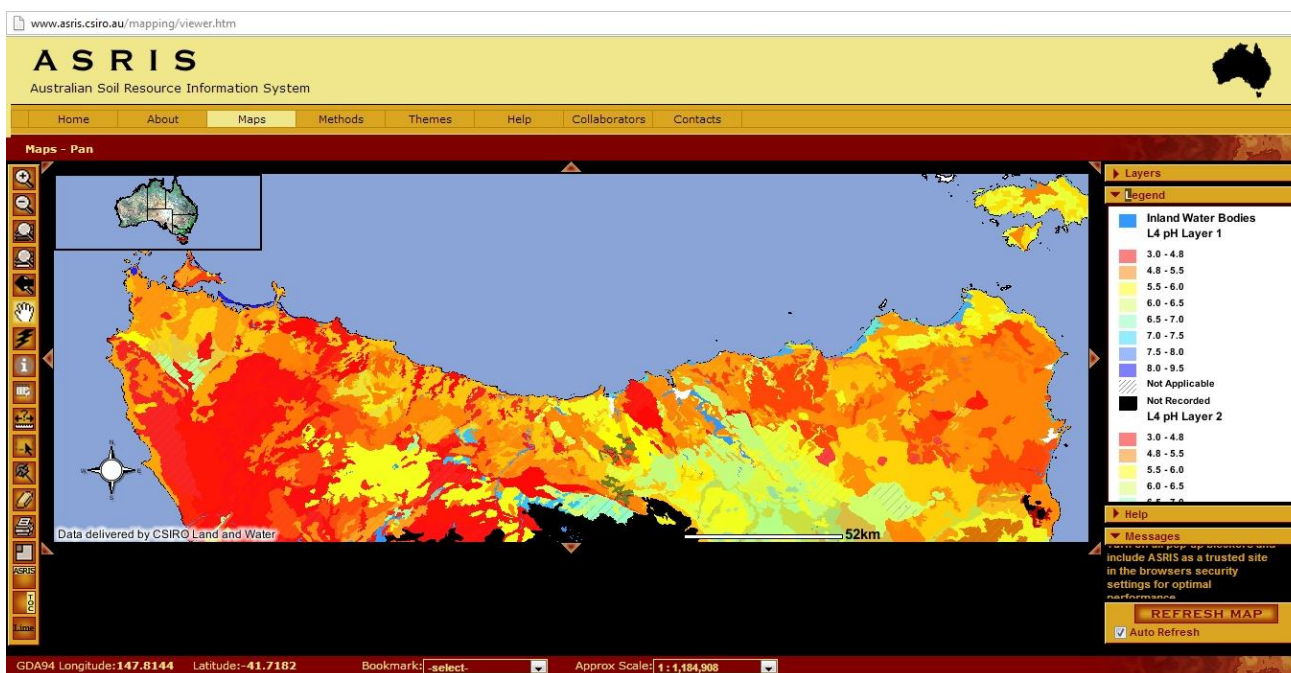


Figure Error! No text of specified style in document..14 A screen shot of a pH map from Northern Tasmania downloaded from the ASRIS website.

Source: <http://www.asris.csiro.au/index.html>



Table Error! No text of specified style in document..5 Limestone required ([fine and neutralising value \(NV\) > 95](#)) to lift pH (CaCl₂) of the top 10 cm of soil to 5.5.

Source: AgFacts NSW DPI, Soil acidity and liming.

Soil test ECEC (cmol (+)/kg)	Lime required (t/ha) to lift the pH (CaCl ₂) of the top 10 cm:			
	From 4.0 to 5.2	From 4.3 to 5.2	From 4.7 to 5.2	From 5.2 to 5.5
1	1.6	0.8*	0.3*	0.2*
2	2.4	1.2	0.5*	0.4*
3	3.5	1.7	0.7	0.5*
4	3.9	2.1	0.9	0.6
5	4.7	2.5	1.1	0.7
6	5.5	3.0	1.2	0.8
7	6.3	3.3	1.4	1.0
8	7.1	3.8	1.6	1.1
9	7.9	4.2	1.8	1.2
10	8.7	4.6	1.9	1.3
15	12.5	6.7	2.8	1.9

**It is recognised that low rates of lime are impractical to apply, but over-liming can cause nutrient imbalances, particularly in these light soils*

0.5 t/ha	1.0 t/ha	1.5 t/ha	2.0 t/ha	2.5 t/ha	3 to 4 t/ha	Split applications advised **

*** Do not apply greater than 4 t/ha in a single application, so as to minimise any problems that could arise from over liming.*

In order to use Table Error! **No text of specified style in document..5** the amount of lime applied is dependent on both the soil pH and **effective cation exchange capacity (ECEC)**. Soil pH is represented in a logarithmic way; meaning that soils having a pH (CaCl₂) 5.0 are 10 times more acidic than a soil of pH (CaCl₂) 6.0 and a soil with a pH (CaCl₂) 4.0 is 100 times more acidic than a soil of pH (CaCl₂) 6.0. Therefore, proportionately it takes greater amounts of lime to correct a lower soil pH than it does to correct a higher soil pH as reflected in Table Error! **No text of specified style in document..5**.

Soil texture plays an important role in the effectiveness of the lime application, due to its effects on the ability of limestone to move through the profile and the soils buffering capacity. The **effective cation exchange capacity** recognises that as the soil pH drops below pH (CaCl₂) 5.0, aluminium is becoming more soluble and plant available; increasing to possible toxic levels when less than pH (CaCl₂) 4.5. The higher ECEC values would indicate that the soil to be limed has a higher clay or organic matter content and a higher buffering capacity and as a consequence will require more lime to adjust the soil pH.

Two examples using Table Error! **No text of specified style in document..5**:

1. Your soil has a pH (CaCl₂) of 4.7 in the surface 10 cm and an ECEC of 6 cmol(+)/kg. Your aim is to increase the soil pH (CaCl₂) from 4.7 to 5.2 by incorporating the limestone into the top 10 cm prior to sowing the pasture. Follow the pH column down and the ECEC row across, and where they intersect is the limestone application rate of 1.2 t/ha. This amount in practical terms would be applied at 1.5 t/ha.



2. Your soil has a pH (CaCl₂) of 4.0 in the surface 10 cm and an ECEC of 6 cmol(+)/kg. Your aim is to increase the soil pH (CaCl₂) from 4.0 to 5.2 by incorporating the limestone into the top 10 cm prior to sowing the pasture. Follow the pH column down and the ECEC row across, and where they intersect is the limestone application rate of 5.5 t/ha. This amount in practical terms would be best applied in a split application of 3.0 t/ha in the first year and repeated in a couple of years or at the earliest convenience.

Liming is an expensive input into soil and pasture management, therefore it is crucial that an accurate soil sample is taken from the field which considers preferably both the surface and subsurface acidity.

The pH of the soil and aluminium levels will be the guide to the likely need for lime when resowing pastures. Lime is unlikely to be of benefit for dairying pastures on moderately acid (those above pH (CaCl₂) 5.1), neutral or alkaline soils.

For soils below pH (CaCl₂) 5.1, an application of lime incorporated into the soil top 10 cm by cultivation is recommended, depending on soil pH and sowing method.

Note: *Table Error! No text of specified style in document..5 is a rough guide only. For a more accurate estimate of lime application rates, ask your laboratory to do a **pH buffering test** – see Chapter 9.2.4.*

7.6.9.4 Lime application as a topdressing

Lime can be applied as a topdressing (in other words, spread over uncultivated soil or existing pasture) if a paddock is to remain in the pasture phase for several years.

In the past, surface-applied lime was not recommended because earlier research indicated that 18 to 24 months might be required before a rise in soil pH was measured. This period of time was often needed to allow movement of the lime into the soil (0.5 to 1 cm each year) and to allow for the chemical reactions to occur.

However, much uncertainty still surrounds the likely responses to surface-applied lime.

Without doubt, most pastures on very acidic soils (less than pH (CaCl₂) 4.3) will respond to surface-applied lime over a period of time. Pastures on soils with very high levels of aluminium or manganese will also respond. Recent experiments illustrate the lime quandary.

A Tasmanian experiment where lime was surface-applied over a range of soil types found that the pH (water) level rose by 0.1 unit for each 1 tonne/ha of lime applied. The more acidic the soil, the greater the pasture response. Even on soils with a pH (water) of 5.8, responses still occurred. Pasture responses varied between 1% to 15% extra annual pasture growth on most plots. If milk solids returned \$2.85/kg and lime cost \$42, then a pasture response of 0.7% per tonne of lime applied is the breakeven point. This trial measured responses of in excess of 1% to 2% per tonne of lime applied.

However, two separate research experiments conducted by DPI at Ellinbank and Hamilton also produced some interesting results:

The research conducted at Ellinbank demonstrated that the rate of downward movement of lime may be much quicker than previously thought in high-rainfall areas and on lighter soil types, than it is in drier areas and on heavier soil types. The pH levels rose significantly between 0 to 5 cm depths



and 5 to 10 cm depths (at the higher rates of 10 to 20 t/ha) within 12 months of application of the lime. Pasture responses to the lime treatments were variable and seasonal and came largely from the higher (above 10 t/ha) treatments. On many of the treatments, there was no immediate response; however, responses may or may not improve over time.

The work done at Hamilton also produced promising results for the effectiveness of surface-applied lime. After 3 successive years of a 5 t/ha application of lime, an increase in pH of up to 2 units was seen in the top 5 cm of the soil profile. In the 5-10 cm range of the soil profile, an increase of 0.5 to 1.0 unit was seen. Some of this response was seen after the first year of treatment, and the soils steadily improved over subsequent years. Another important observation from the Hamilton research was the effect of surface-applied lime on the available aluminium in the soil profile. Exchangeable aluminium levels on the limed treatments were up to 50% to 80% lower after 3 years than on those treatments that received no lime.

On the tropical grass pastures of the Atherton Tablelands region, Far North Queensland, the Krasnozem soils are naturally acidic. This, and the use of nitrogen fertilisers, means that lime is applied at 2.5t/ha every 5 years to maintain a soil pH (1:5 water) of at least 5.0, and preferably 5.2 to 5.4. Where these paddocks are planted to irrigated temperate pastures over winter, lime is applied every 3 years to maintain a soil pH of at least 5.5, and preferably 5.7 to 5.9. Where soil tests indicate magnesium is required, a lime dolomite blend (typically 3% Mg) is applied.

The current advice among many, although not all, advisers is that:

- If the soil is strongly acidic (in other words, below pH (CaCl₂) 4.3), then surface-applied lime (2.5 t/ha) is likely to improve pasture productivity (see [Table Error! No text of specified style in document..6](#)).
- In the pH (CaCl₂) range of 4.3 to 4.6, either apply 2.5 t/ha of lime or lay down lime test strips and observe for responses over several years.
- Above pH (CaCl₂) 4.7, lime is unlikely to result in a pasture response in the short term, but a pasture response may occur over the longer term.

Table Error! No text of specified style in document..6 Lime recommendations on existing pasture

EXISTING pH (CaCl ₂)	EXISTING pH (WATER)	RECOMMENDATION
4.7 and above	5.3 and above	No lime
4.3 to 4.6	5 to 5.3	Test strip or 2.5 t/ha
Less than 4.3	Less than 5	2.5 t/ha*

*Another 2.5 t/ha should be applied after 3 years on soils with a pH (CaCl₂) less than 4.3.

Note: Table 7.6 is a rough guide only. For a more accurate estimate of lime application rates, ask your laboratory to do a **pH buffering test** – see Chapter 9.2.4.

When surface-applying lime, a maximum rate of 5 t/ha is recommended for a single application to avoid smothering the plants and to avoid possible animal health problems.

If lime is to be applied to pastures as a topdressing, there is an advantage in using superfine or microfine lime to increase the rate of movement from the surface of the soil to depth.

Check your understanding of lime application rates by working through [Exercise 2](#).



7.6.10 The effective neutralising value of lime and dolomite products

There are many sources of lime and they vary in their ability to change the soil pH and the speed at which this happens. The effectiveness of lime is determined in two ways:

- **Neutralising Value (NV)** – The amount of calcium or magnesium as oxides or carbonates. Neutralising value is expressed as a percentage relative to pure calcium carbonate, which is given a value of 100 per cent (Gazey, 2011).
- **Effective Neutralising Value (ENV)** - Considers the purity (Neutralising Value), as well as particle size or fineness. The finer the product, the greater the surface area for the neutralising chemical reactions to occur.

The key indicators of agricultural lime quality are **neutralising value** and **particle size**, regardless of the lime source.

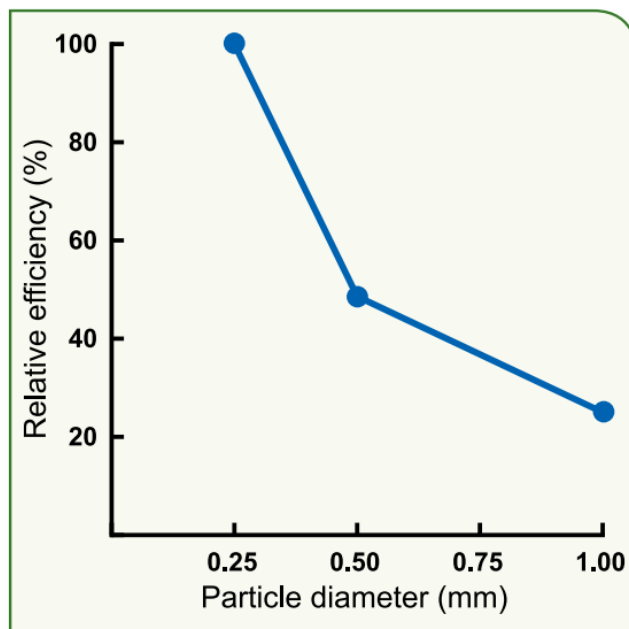
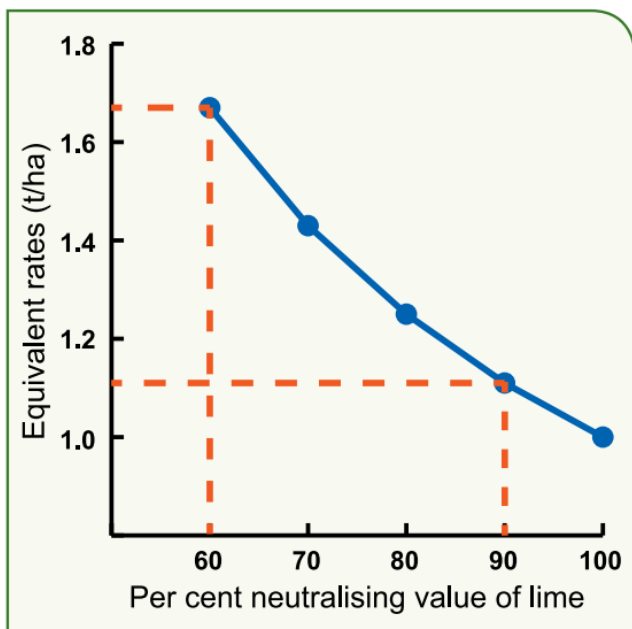


Figure Error! No text of specified style in document..17 Approximately 1.7 t/ha of 60 per cent NV lime is required compared to 1.1 t/ha of 90 per cent

Figure Error! No text of specified style in document..16 Figure Error! No text of specified style in document..16

Source: Gazey, 2011

http://www.agric.wa.gov.au/objtwr/imported_assets/content/lwe/land/acid/liming/bn_2011_lime_quality_audit.pdf


Figure 7.17 shows the rate of lime (t/ha) required to achieve the same pH change using lime products with neutralising values ranging from 60 to 100 per cent. The example shows that only 1.1 t/ha of 90% NV lime is required to achieve the same result as 1.7 t/ha of a 60% NV lime.

Figure 7.16 compares the relative efficiency (%) of agricultural limes with different particles sizes applied at 2.5 t/ha. It shows that lime with a particle size of 0.25 mm is five times more efficient in changing soil pH than lime with a particle size of 1 mm.

Different codes of practice for labelling of agricultural limes apply in each Australian state. For example, Figure 7.18 shows a product information sheet for a Lime WA Inc. accredited supplier. It shows particle sizes, neutralising value of each fraction, and the overall neutralising value of the





bulk product. It also shows the levels of Calcium, Magnesium and Sodium (quoted in pure, not carbonate form).



LIME WA INC.
Accredited Lime Suppliers
Code of Practice
Product Information Sheet

Approved Laboratory





Aglime of Australia

PO Box 212, Belmont, WA 6984
Tel : (08) 9277 5529 Fax : (08) 9277 5379
Loading : Kim Crossland
0427 632 471

GENERAL INFORMATION			
Pit Name	Aglime of Australia	Date of Analysis	February 12th 2011
Location	Cervantes	Laboratory No.	10A0308-020
Product Description	Limesand	Product Screened	Yes
Weigh System	Loadrite Loader Scales	Screen Size (mm)	1.00 mm

CODE OF PRACTICE APPROVED LABORATORY REPORT				
	THIS SAMPLE	RANGE FOR PIT	THIS SAMPLE	RANGE FOR PIT
Sieve Range (mm)	% Weight		% Neutralising Value	
0.000 – 0.125	2.6	2.6 - 9.1	92.6	91.4 - 94.9
0.125 – 0.250	66.9	57.0 - 76.9	93.3	91.3 - 93.9
0.250 – 0.500	28.9	17.2 - 37.0	95.2	95.0 - 97.0
0.500 – 1.000	1.4	0.2 - 1.6	89.4	85.5 - 96.2
> 1.000	0.1	0.1	Insufficient Sample	86.8 - 91.0
Weighted Average NV			93.7	91.7 - 94.5
Bulk NV	92.9	91.7 - 94.5	This product was sampled by the Department of Agriculture and Food, Western Australia and submitted directly to the ChemCentre for testing as part of the Lime WA Inc. independent audit program.	
Calcium (Ca) (1 M HCl)	34.8	33.1 - 35.8		
Magnesium (Mg) (1 M HCl)	1.7	1.5 - 1.8		
Sodium (Na) (1 M HCl)	0.3	0.2 - 0.3		
Moisture Content	2.2	0.6 - 11.0		

Statement by Supplier : The above analysis, provided by a Code of Practice approved laboratory, is a true representation of the product being supplied from the nominated pit. Pit ranges have been calculated from the last 9 samples analysed.

Date:- Position:- Signature:-

Disclaimer : Lime WA Inc. requires members to provide the above details in accordance with the industry Code of Practice requirements but makes no claims and provides no guarantees on the quality or suitability of the product supplied. Lime WA Inc. is not responsible for any claims and/or liabilities arising from the supply and/or use of the product supplied. However, users are invited to contact the Association on 0419 575 737 in the event of any dissatisfaction with the product description provided by accredited lime suppliers.

Figure Error! No text of specified style in document..18 Example product information sheet. Source: Gazey 2011 http://www.agric.wa.gov.au/objtwr/imported_assets/content/lwe/land/acid/liming/bn_2011_lime_quality_audit.pdf



7.6.11 How to calculate the cost of lime or dolomite

When you compare lime products, make sure that you select the most economical product available in your region.

The value of limes of various types and from various sources can be compared by making the following calculations:

1. Gather quotes from suppliers for the **total cost per tonne** to have various limes applied to the paddock (including the purchase price and the transport and spreading costs).
2. Obtain the **Effective Neutralising Value** for the limes. Most limes on the market have been tested to determine their ENV, and this information should be available from the supplier. This will provide a 'per unit' basis for comparison.
3. Divide the total cost by the **effective neutralising value** of each product:

$$\text{Unit cost} = \text{Total cost per tonne spread} \div \text{Effective neutralising value}$$

Example.

Say that there are two lime products available in your area.

Lime A has an ENV of 95 and costs \$60/t spread.

Lime B has an ENV of 70 and costs \$50/t spread.

Which is more economical?

Lime A: \$60 divided by 95 = \$0.63 per unit of ENV (as received basis).

Lime B: \$50 divided by 70 = \$0.71 per unit of ENV (as received basis).

Lime A is the lower cost lime to use based on its effective neutralising value and the total price.

Knowing these characteristics about lime (including dolomite) allows you to compare the cost-effectiveness of a variety of lime products and purchase the product that will be most cost-effective for your farm. However, you must also take into account other considerations, including the handling requirements of some products. The [lime comparison calculator](#) on the soilquality.org.au website can be used to calculate and compare the cost-effectiveness of agricultural limes. It considers the cost of: lime, transport, spreading; particle size distribution of the lime; and the neutralising value of each particle size range in the lime.

7.6.12 Lime products

By-product and natural limes contain calcium carbonate (CaCO_3), calcium hydroxide (Ca(OH)_2), or calcium oxide (CaO). Dolomitic limes contain magnesium carbonate (MgCO_3) in addition to the CaCO_3 . Pure lime is 100% calcium carbonate (CaCO_3).

Agricultural limestones usually occur in limestone rock deposits with calcium carbonate (CaCO_3) contents ranging from 48% to 97%. Agricultural lime is the most commonly used product for increasing soil pH in pastures and is usually the most cost-effective.

Burnt lime (also called quick lime) is calcium oxide (CaO). It is a faster-acting lime and has the highest neutralising value. This lime is mostly used in horticultural enterprises and is not usually applied to pastures. However, it needs to be used soon after its production because in time it reverts back to lime.



Slaked lime (also called hydrated lime or builder's lime) is calcium hydroxide ($\text{Ca}(\text{OH})_2$) and has a higher neutralising value than agricultural lime but is more expensive and not usually applied to pastures.

Lime kiln dust is the very fine dust (particle size of less than 0.1 mm) produced by kilns used to burn lime. It contains both limestone and burnt lime and is difficult to handle due to its fineness, so a contractor experienced in spreading the product should be used. **Cement kiln dust** has similar properties, plus it can contain significant amounts of potassium (commonly 3% to 5%).

Wet lime is also known as liquid lime. The effectiveness of liquid lime is determined by its NV, not its ENV. There are extra handling costs with wet lime. Wet lime is not usually applied to pastures.

Dolomite is a mixture of calcium carbonate and magnesium carbonate (CaCO_3 and MgCO_3). As the magnesium carbonate content of limestone increases, it is firstly called dolomitic limestone and finally dolomite (pure magnesium carbonate). The Limestone Association of Australia defines dolomite (as a product) as having a minimum magnesium carbonate analysis of 28% and a minimum calcium carbonate analysis of 35%. Dolomite is frequently used in horticulture as a source of magnesium (for example, in orchards) and is sometimes used on pastures.

Dolomite is used as a source of magnesium for magnesium-deficient soils. It can also be used as a source of magnesium for livestock. However, very high rates are required for this purpose (5 t/ha or greater). A Department of Agriculture study at Camperdown showed that 12.5 t/ha needed to be applied to obtain an effect. Experience is that dolomite is generally not effective in reducing [grass tetany](#), and livestock should be treated directly.

7.7 Summary

- Apart from nutrients, many other soil-related factors (for example, slaking, dispersion, sodicity, compaction, salinity, waterlogging and soil acidification) can substantially limit plant growth.
- Soil structure can be improved by increasing organic matter, improving drainage, and using gypsum on some soil types.
- The solution to salinity problems is not a matter of just treating the symptoms but of managing all the factors that raise the water table and influence the well-being of the water catchment.
- Applying lime to acidic soils will increase soil pH.
- Limes vary in their ability to reduce acidity.
- Limes should be applied on the basis of soil test analyses and purchased on the basis of effective neutralising values and cost.

[Exercise 3](#) provides practice in identifying soil-related factors that can limit plant growth.



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