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Seeking Solutions

Water Resources Series No. 4

Understanding Salt and Sodium in Soils, Irrigation Water and Shallow Groundwaters

A companion to the software program, SWAGMAN® - Whatif

C W Robbins, W S Meyer, S A Prathapar and R J G White

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by

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How do we sustain irrigated agriculture?
Where do we go from here?
Peter Fawcett, farmer, Griffith.

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PREFACE

Understanding Salt and Sodium in Soils, Irrigation Water and Shallow Groundwaters is a companion booklet to *SWAGMAN®-Whatif*, a computer model that lets you see how salts, soils, water and water tables interact. *SWAGMAN®-Whatif* also lets you assess the effects of management practices that you might undertake in a particular area.

This booklet gives background information to help you understand salts, sodium and their interactions with water and soils. It explains where sodium and salts come from, how to identify salt-affected soils, and gives instructions on taking soil and water samples for analysis. It also gives suggestions on how to reduce the harmful effects of salts and sodium, and tells you where to get advice in making reclamation and management decisions for each situation.

Managing salt and sodium affected soils, together with waters used for irrigation, is complex. It is not possible to cover all technical aspects or possible treatment approaches in this booklet. Instead, we have given a simple overview of the major principles involved in diagnosing and managing salt and sodium affected soils and irrigation waters.

It is difficult to summarise salt and sodium effects on soils and plants without using some technical terms, so a comprehensive glossary has been included.

Introduction

Soils in almost all of Australia hold vast amounts of salt. In many situations this salt is harmless, because it remains below the root zone of the plants. However, in some natural situations, and increasingly in cleared and cultivated areas, irrigation waters and rising groundwaters have carried salts into the zones of plant growth, devastating even the most fertile soils. In Australia, more than 30 million hectares of land is salt-affected, resulting in lost production which may exceed one billion dollars annually.

Salt crystals on tree trunk

Salts, in particular sodium salts, turn productive soils into toxic, structureless wastelands. Until recently, our approach to managing soils for salt has been hampered by a lack of understanding. Now, however, with a greater appreciation of the interaction of soils, salts and water, as well as more accurate diagnostic methods that have enabled us to calculate well-defined critical limits, our approach to management can be comprehensive.

Not only do we now have the information needed to manage our soils against the occurrence of salinity, but we also can take steps to reclaim the vast amounts of soil that salinity has rendered useless in recent years. Such efforts can only succeed with the cooperation of all those involved in managing any particular area. One person's lack of understanding in managing his or her land can waste the efforts of the rest. This is the reason for the production of this booklet. It is an attempt to make widely available a publication that gives a basic explanation of the principles of managing our soils and irrigation waters against the salting of our land.

Salts and Ions in Soil and Water

What Are Salts and Ions?

Salts

The solid part of soil is made up of particles of silicon, clay, organic matter and various salts. There are many different salts that are formed when acids and bases are mixed.

Examples of reactions of acids with bases to produce salts.

If *baking soda*, which is sodium bicarbonate *($NaHCO_3$)*, is neutralised with hydrochloric acid (HCl) (*muriatic acid* used for soldering), common *table salt*, *(NaCl)* (sodium chloride), carbon dioxide gas *(CO_2)*, and water, *(H_2O)*, are formed.

$$NaHCO_3 + HCl \rightarrow NaCl + CO_2 + H_2O$$

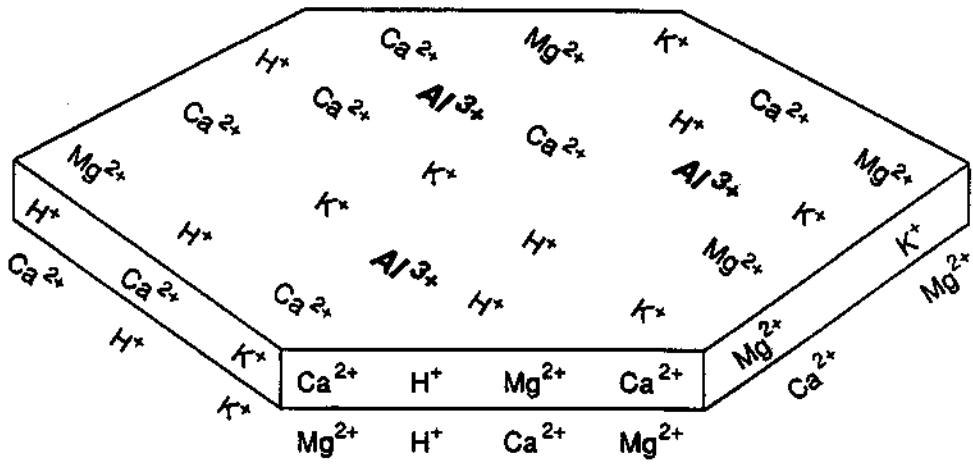
Neutralising sulfuric acid, *(H_2SO_4)*, *(battery acid)* with calcium oxide, (CaO), (*quicklime*, used in making brick mortar) produces the slightly soluble salt, *gypsum*, *($CaSO_4$)* and water.

$$H_2O + CaO + H_2SO_4 \rightarrow CaSO_4.^2H_2O$$

The presence of excessive amounts of salts, particularly those containing sodium, will adversely affect soil structure and impair plant growth.

The extent to which various salts interact with soil particles and plant functions depends largely on their solubilities - how well they dissolve in water. Sodium and calcium chloride salts are very soluble; salts like gypsum are only slightly soluble, and salts like calcium carbonate, $CaCO_3$, (lime[1]) are even less soluble.

Figure 1. The adsorption of cations (positively charged) on the negatively charged surface of a platy clay mineral. Some of these cations will be replaced with Na^+ as the soil becomes salinised.



[1]In general use the term *lime* may also be used to mean calcium oxide or calcium hydroxide, $Ca(OH)_2$, (also known as *slaked lime*). When talking about soil components, only calcium carbonate (sometimes called *free lime*) is meant. The other two compounds do not exist in soil as they would react with the carbon dioxide that is always present, and are converted to other compounds. Similarly, in general agriculture, the term *lime* is often used for any calcium compound that is applied to improve soils.

Soluble ions

When a salt dissolves in water, it dissociates, or separates, into cations and anions. Cations carry a positive electrical charge and anions carry a negative electrical charge. The cations of most concern in salt-affected soils are calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), and occasionally, potassium (K^{+}). The anions of concern are chloride (Cl^{-}), sulfate (SO_4^{2-}), carbonate (CO_3^{2-}), and bicarbonate (HCO_3^{-}).

Because of the water present in soils, the salts that interest us most are usually found as ions. It is the effects of these ions on both growing plants and the soil itself that concern us most.

Exchangeable cations

In addition to soluble cations, another category of cations is of concern in soils. These are the exchangeable cations. These positively charged ions are generally attracted to and attached onto clays and organic matter, which carry a negative electrical charge. This negative charge must be satisfied by an equal quantity of positively charged ions. In salt-affected soils, this charge is satisfied by an excess of sodium and, sometimes, magnesium cations. In normal soils, the charge is satisfied mainly by calcium and magnesium ions, although both sodium and potassium cations will still be present.

In soils with a pH of less than 7.0 (*acid* soils), hydrogen ions (H^{+}), and aluminium ions (A^{3+}), also make up part of the exchangeable cations. The cations are very tightly held by the negative electrical charges. These are referred to as *exchangeable cations* because they can only be removed from the charged surface by being exchanged with another cation from the soil solution.

Salt and Ion Effects on Plants and Soils

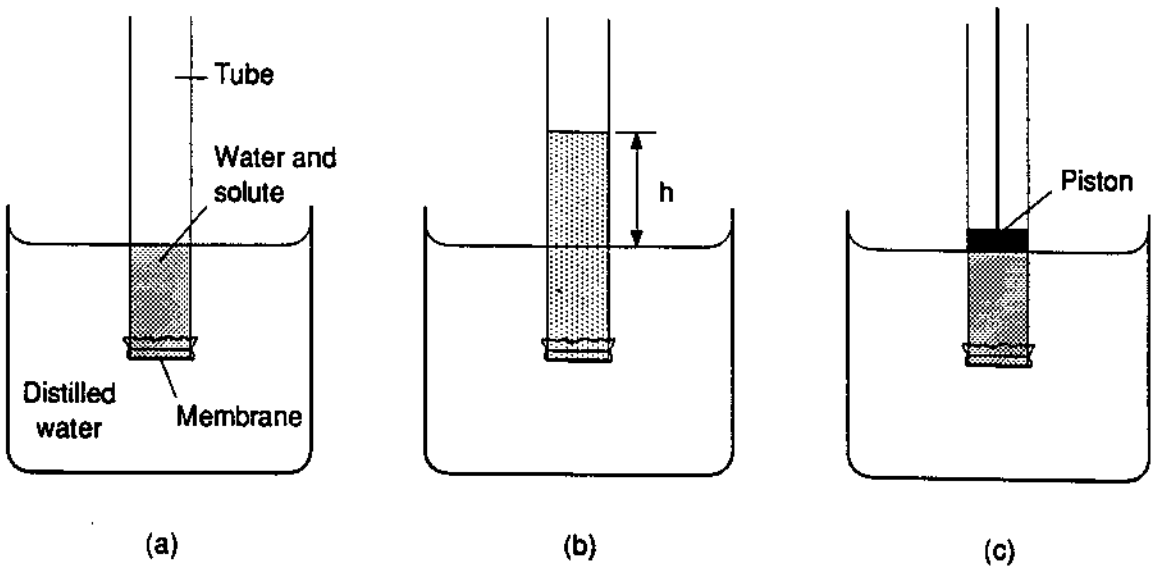
The osmotic effect

Osmotic potentials develop when any salt or sugar dissolves in water. This can be illustrated by visualising a cylinder with a semi-permeable membrane bottom through which water can pass but solutes cannot. The cylinder is placed in a tank of distilled water (see Fig. 2). If the tank and cylinder are filled with water such that both compartments have equal water levels, and salt or sugar is then added to the cylinder, water will move through the membrane from the pure water side into the higher solutes side. The difference in the two water levels is equal to the difference in the osmotic potentials. This process of water movement in response to solute concentration differences is called osmosis. The greater the difference in the solute concentrations across the membrane, the greater the energy or osmotic potential difference.

Osmosis and osmotic pressure

Plant roots are semi-permeable membranes. The sap of plant roots contains sugars and salts that create a potential difference between the root sap and the soil water. This enables water to move readily from the soil into the roots of a plant that is growing in moist, non-salty soil. As the soil dries, its remaining water is held more tightly to the soil particle surfaces and the salt concentration in the soil solution increases. The soil water suction increases, causing the rate of water flow into the plant to decrease. If no more water is added to the soil, a point in the drying process is reached where the roots can no longer take up enough water to meet the plant needs, and plant growth stops and the plant eventually dies. Thus, the less dissolved salt there is in the soil solution phase, the drier the soil can become before water uptake by the roots becomes limited. Conversely, the higher the salt concentration, the less available the soil water is to the plant. All soluble salts contribute to the osmotic effect.

Figure 2. (a) The tube contains a solution; the beaker contains distilled water. (b) The semipermeable membrane permits the passage of water but not solute. The movement of water into the solution causes the solution to rise in the tube until the osmotic pressure, resulting from the tendency of water to move into a region of lower water concentration, is counterbalanced by the height, h, and density of the column of solution. (c) The force that must be applied to the piston to oppose the rise of the solution in the tube is a measure of the osmotic potential. It is proportional to the height and density of the solution in the tube.



In summary, the lower the salt concentration is in the soil, the more available the water that is present is to the plants.

Specific Ion Effect

Most ions found in soils are needed for healthy plant growth. However, some ions are needed only in small quantities, and higher concentrations can be toxic.

The *specific ion effect* is the adverse or toxic effect on plant growth that is peculiar to each ion, in addition to its osmotic effect. Some plants are very sensitive to chloride and sodium ions and show signs of leaf margin or tip burn, leaf bronzing or necrotic (dead) spots. Other plants are quite tolerant to these ions. Some crops show sensitivity to high carbonate and bicarbonate ion concentrations in the soil solution which inhibits iron uptake by many plants, causing the plants to be pale green to yellow. This is often referred to as *lime-induced chlorosis*. High potassium concentration in the soil can inhibit some crops, especially grasses, from taking up the normal amounts of magnesium.

There are also correlations between salt injury and soil nitrate levels. Many crops are more sensitive to high salt concentrations when the soil nitrate levels are below those required for optimum growth rate. Under certain conditions, higher than usual nitrate applications will partially offset salinity-induced yield reductions.

Boron concentration above 2 ppm in the soil solution is toxic to most crops. In a few areas, boron or borate ion damage to plants is a problem associated with salt-affected soils.

Effects on Physical Properties of Soil

The stability of soil aggregates depends on the electrostatic forces on the soil particles and the ions in the soil solution. When soil or clay particles are surrounded mostly by Ca^{2+} ions they are held quite tightly together. Aggregates of these soils tend to stay together, even in water. However, if the clay particles are surrounded mostly by Na^{+} ions, the binding of the particles is weaker. When water is added to these soils, the water molecules force their way between

the clay particles and cause them to fall apart. Thus the soil disperses on wetting and has a poor physical structure. Plants find it hard to survive and grow well in these soils.

If the *sodium adsorption ratio* (SAR_e) of a saturation paste extract is greater than 13 ($SAR_{1:5}$ greater than 5 for a 1:5 soil:water extract) or the exchangeable sodium percentage (ESP) is greater than 15, the soil may become dispersed. This is especially true when the *total soluble salts* are low (*electrical conductivity* - EC_e - less than 4 dSm^{-1}). Under these conditions, the soil particles disperse, the soil surface may seal over (*crust*), and restrictive layers may develop within the soil profile. These conditions impede air movement and water infiltration into, and through, the soil. One of the most serious problems in reclaiming sodic soils (see page 15, **Management to Remove or Minimise Soluble Salt Problems - Sodic Soils**) is getting water to move through the soil so that undesirable salts can be leached out and exchangeable sodium can be replaced with calcium.

Calcium is the most desirable ion to have as the dominant soluble and exchangeable cation. Ideally, calcium should make up about 60% of the soluble cations and 80% of the exchangeable cations, when magnesium is also present. Keep in mind that 'hard water makes soft soils and soft water makes hard soils'. This means that irrigation water containing predominantly calcium and magnesium salts (low SAR) tends to promote more friable soil conditions. Waters with low calcium and high sodium ratios (high SAR) tend to cause soils to disperse, form crusts, become compacted, and have very low infiltration rates and poor air movement properties.

Sources of Soil Salts

Most soluble salts and exchangeable cations in soils come from weathering of rocks, sediments and minerals that served as the soil parent materials. Salts can also be added to the soil surface as wind blown minerals from salt plains, from sea mist, from flood-transported salt laden sediments, from rain and from irrigation water. Natural weathering processes such as stream bed grinding, dissolution by water and acids from rain water and plant roots, oxidation by air and water, and alternating freezing and thawing bring ions into solution. In high rainfall areas, water leaches the salts from the soil as they form. In arid and semi-arid areas, annual evaporation is greater than the annual precipitation, and the salts are not always leached from the soil as fast as they are released. With time, they accumulate in the root zone at concentration levels that affect plant growth.

Salts often accumulate in soils above shallow water tables. The water table may be naturally occurring, it may have been induced by irrigation of poorly drained areas, by irrigating up-slope from low lying areas, by vegetation changes, by removal of deep-rooted plants up slope from impervious geological layer outcrops, or by construction of roads or channels that block natural surface or subsurface lateral drainage. As water moves from the water table to the soil surface by capillary rise, or *wicking*, and evaporates from the soil surface, salts carried by the water are left on or near the surface. Over time, the salts become sufficiently concentrated to inhibit plant growth. This kind of salt problem is usually found in low lying, flat landscapes and along slow moving streams, drains, and marshes.

All irrigation waters contain at least some dissolved salt. In many areas, good quality water containing low concentrations of dissolved salts is not available for irrigation, and the water that is used contains more salt than is desirable. If a sufficient quantity of water does not move through the soil to carry (leach) the salts below the root zone, salts from the irrigation water will accumulate in the root zone. The amount of water needed to leach salts from the root zone will depend on the water quality and amount of salt present. Less water is needed if it is of high quality.

There is often a concern about fertiliser in terms of adding salts. If the fertiliser or manure is uniformly spread over the soil, the salinity effect is usually not measurable. Soluble fertilisers such as muriate of potash, KCl, (potassium chloride) or ammonium nitrate, (NH_4NO_3), applied uniformly at 340 kg ha^{-1}, will initially raise the EC_e by about 0.3 dSm^{-1}. This will have very little effect on most crops and would be of short duration. Irrigation or rain will quickly remove the effect. If, however, the fertiliser is

banded near seeds or small plants, the salinity, or osmotic, effect on the individual plants can be severe. The less soluble fertilisers such as phosphates will have much less effect. High concentrations of ammonium ions, (NH_4^+), from nitrogen fertiliser or manure, on the other hand, can be toxic to germinating seeds and seedlings (a specific ion effect), and may be confused with a salt effect (an osmotic effect). Most manure application rates will not produce measurable salt effects; however, some feedlot manures may contain high sodium chloride concentrations. If sufficiently heavy applications of high sodium chloride manure are applied to a slightly sodic soil, infiltration rates may be reduced.

Salt spills or intentional dumping of salt solutions from mines, cheese factories, food processing plants, municipal sewage water, power plant cooling tower water, heavy wood ash applications or other industrial activities often cause salt or sodium problems. Soil reclamation is very difficult when salts are added in high concentrations to soils that are normally low in salts, especially soils in the lower rainfall areas.

Salinity in irrigation area - Lake Wyangan, Griffith

Soils

Nomenclature

Soils can be grouped, according to how affected they are by salt, as (a) **normal**, (b) **saline**, (c) **saline-sodic** or (d) **sodic soils**. These are the currently accepted names used in classification. Other terms, such as *alkali*, *white alkali*, *black alkali*, and *salty* also have often been used to describe these soils; however, they do not mean the same thing to all people, and often cause considerable confusion.

Categories

Normal soils *do not contain sufficient soluble salts to reduce the yields of most crops, nor do they contain sufficient exchangeable sodium to affect soil structure. The upper limit of* ***electrical conductivity in the saturation paste extract*** *(EC_e) of these soils is around 4 dSm^{-1} and the* ***exchangeable sodium percentage*** *(ESP) upper limit is around 5 for Australian soils.*

These upper limits are indicative values only, as certain salt-sensitive crops would have reduced yields even at these upper limits. For example, if crops such as beans, apples, pears, citrus, many ornamentals, small fruits or berries were grown on soils with an EC_e of 3.5 dSm^{-1}, a significant yield reduction would be expected (Appendix 2). Also, irrigating most soils from a large volume sprinkler system with water containing high levels of sodium - an **adjusted SAR** (SAR_{adj}) (see page 14) of more than 12 - would produce serious runoff problems, due to the adverse sodium effect on soil structure.

A normal soil, then, is one where soluble salts or exchangeable sodium do not adversely affect yield or quality of the more salt tolerant crops.

Saline soils *contain sufficient soluble salts (EC_e greater than 4 dSm^{-1}) in the upper root zone to reduce yields of most cultivated crops and ornamental plants. Sodium makes up less than 15% of the* ***exchangeable cations*** *(ESP less than 15).*

Water entry and movement through these soils is not inhibited by sodium. In the past these soils have been called *white alkali*, *salty* or *Solonchak* soils. The predominant cations are calcium, magnesium, and in a few cases, potassium. The predominant anions are chloride and sulfate. Bicarbonate may be present to a lesser extent in high magnesium or potassium soils.

In very severe cases, saline areas may appear as white crusts, or as white or tan areas with a floury dusty surface when dry if the predominant anions are chloride. In furrowed areas, there may be white or salty stripes along the furrow edge or between the furrows.

Osmotic effects and chloride toxicity are the predominant causes of yield reduction and plant injury.

Saline-sodic soils *are similar to saline soils in that the EC_e is also greater than 4 dSm^{-1}. Saline-sodic soils differ from saline soils in that more than 15% of the* ***exchangeable cations*** *are sodium and the* ***saturation paste extract*** *SAR_e is greater than 13.*

The anions are predominantly chloride and sulfate with some bicarbonate when the pH is greater than about 7.5. As long as the EC_e remains above 4 dSm^{-1}, infiltration rates and hydraulic conductivities are generally as high as in normal or saline soils. On leaching with good quality, low calcium irrigation water, unless these soils contain gypsum, they will change to sodic soils because the EC_e will decrease without the ESP decreasing. When this happens, the undesirable properties of sodic soils will be expressed.

High osmotic and specific ion effects are the predominant causes of plant growth reduction in these soils.

Sodic soils *are lower in soluble salts than are saline-sodic or saline soils. The EC_e is less than 4 and often less than 2 dSm^{-1}. The pH of a 1:5 soil:water extract is usually at least 1 pH unit greater than the* ***saturation paste pH****. The ESP is greater than 15 and* ***saturation paste extract*** *SAR (SAR_e) is greater than 13.*

Higher carbonate and hydroxide ion concentrations exist in these soils than in other soils, and that causes the calcium to precipitate out of solution as $CaCO_3$, or lime. The combination of high ESP and pH and low EC_e causes the clay and organic matter to disperse. This dispersion of soil particles destroys the soil structure and causes the soils to 'run together' and form 'slick spots' when wet. These spots have extremely low rates of water intake, and if they are in low or flat areas, water will stand for extended periods without soaking into the soil. The dry soil often has a black greasy or oily-looking surface and no vegetation growing on it.

It is not uncommon to have a mix of two or more kinds of salt-affected soil within a single field. Salt-affected soil characteristics are usually highly variable from one part of a field to another.

The four definitions are summarised in Table 1.

Classifying Saltiness of Irrigation Water

Criteria

Irrigation water quality is based on three criteria: **total salt concentration (EC_w), sodium adsorption ratio (SAR_w)** and **adjusted sodium adsorption ratio (SAR_{adj})**.

Categories

Low salinity *irrigation water has an EC_w between 0 and 0.7 dSm^{-1} (Total Soluble Salts TSS, 0-420 mg L^{-1}).*

All crops can be grown with this salt concentration in the water as long as periodic leaching takes place. On moderately to well-drained soils, salts in the soil will not increase and may even decrease with time under these conditions.

Moderately saline *irrigation water has an EC_w between 0.7 and 1.3 dSm^{-1} (TSS, 420-800 mg L-1).*

Very salt sensitive crops require specialised practices to avoid salt injury. Moderately tolerant crops can be grown if sufficient leaching is allowed to prevent salt buildup in the root zone.

Highly saline *irrigation water has an EC_w between 1.3 and 3.0 dSm^{-1} (TSS, 800-1800 mg L^{-1}).*

Table 1. Chemical characteristics of salt and sodium affected soils for Australian conditions.

Soil salinity class	EC_e	ESP	SAR_e	$SAR_{1:5}$
Normal soil	<4.0	<5	<3	<5
Saline soil	>4.0	<15	<13	<5
Saline-sodic soil	>4.0	>15	>13	>5
Sodic soil	<4.0	>15	>13	>5

This water should only be used on well drained soils with high infiltration rates and no shallow water table. Only salt tolerant crops can be successfully grown. Sprinkler irrigation during hot weather is not advisable. Excess water must be applied for salt leaching. Adverse degradation of underlying aquifers will be a concern.

Very highly *saline water has an* EC_w *of 3.0 to 5.0* dSm^{-1} *(TSS, 1800-3200 mg* L^{-1}*).*

Water in this salinity range is acceptable only under conditions of extremely porous, well drained soils and very salt tolerant crops. A lower salinity water may be needed for seedling germination. Degradation of subsurface water supplies is likely under lands irrigated with this quality of water.

Water with an EC_w in excess of 5.0 dSm^{-1} (TSS, 3200 mg L^{-1}) should not be considered for irrigation under any conditions.

The SAR of an irrigation water should be considered along with the EC_w in determining the ultimate suitability of a water for an irrigation. The higher the SAR_w, the greater the probability that infiltration rates and water flow through the soil will become a problem. The effect on soil of sodium in the irrigation water will be modified by bicarbonate and carbonate concentrations. A correction to the value of SAR_w can be made to account for this, and will be discussed later (see page 14).

The four definitions are summarised in Table 2.

Table 2. Chemical characteristics of salt-affected irrigation waters for Australian conditions.

Water salinity class	EC_w range	TSS
Low salinity	0 - 0.7	0 - 420
Moderately saline	0.7 - 1.3	420 - 800
Highly saline	1.3 - 3.0	800 - 1800
Very highly saline	3.0 - 5.0	1800 - 3200

Proper Sample Collecting Methods

Soils

Visual selection of sampling locations

The locations of soil sample collection should initially be based on visual observations in the field. The categories of soil types given previously (see page 7, **Salinity Classification of Soils and Irrigation Waters**) include some descriptions of the appearance of various salt-affected soils.

If the land has not been recently cultivated or is in native vegetation, the vegetation will give a good indication of where the saline or sodic areas are. Plants vary in their salinity tolerance; and the presence of certain species is indicative of soil salinity conditions.

Plants that can tolerate salinity up to an **electrical conductivity** of about 3 dSm^{-1} in a **saturated paste extract** (EC_e), or 0.6 dSm^{-1} in a 1:5 extract, include

Hill wallaby grass (*Danthonia eriantha*) and Wimmera rye grass (*Lolium rigidum*).

Moderate soil salinity levels (EC_e of up to about 7 dSm^{-1}, or 1.4 dSm^{-1} in a 1:5 extract) can be tolerated by plants such as

Saltmarsh grass (*Puccinellia stricta*)
Sea barley grass (*Hordeum marinum*)
Couch grass (*Cynodon dactylon*)
Tall wheat grass (*Agropyron elongatum*)
Windmill grass (*Chloris truncata*)
Spiny rush (*Juncus acutus*)
Toad rush (*Juncus bufonius*)
Buck's horn plantain (*Plantago coronopus*)
Coast sand spurrey (*Spergularia media*)
Salt angianthus (*Angianthus preissianus*)
Strawberry clover (*Trifolium fragiferum*)
Swamp weed (*Selliera redicans*)
Swamp paperbark (*Melaleuca ericifolia*).

Other species[2] which may be present

Zoysia macrantha
Sporobolus virginious
Sporobolus mitchellii
Eragrostis pergracilis
Eragrostis dielsii
Eragrostis australasica
Maireana aphylla
Chenopodium nitrariaceum
Chenopodium auricomum
Diplachne fusca
Phragmites australia
Atriplex vesicaria
Atriplex nummularia
Rhagodia spinescens
Baumea juncea
Gahnia trifida
Typha domingensis.

Some species will only grow in moderately saline soils and do not do well in less saline soils. These include

Annual beard grass (*Polypogon monspeliensis*)
Australian salt grass (*Distichlis distichiphylla*)
Curly rye grass (*Parapholis incurva*)
Slender barb grass (*Parapholis strigosa*)
Creeping brookweed (*Samolus repens*)
Ice plant (*Mesembryanthemum crystallinum*)
Water buttons (*Cotula coronopifolia*).

Other species include

Hainardia cylindrica
Samolus eremaeus
Gunniopsis spp.
Trianthema spp.
Mollugo spp.
Puccinellia spp.
Cyperus gymnocaulos
Cyperus laevigatus
Bolboschoenus caldwellii
Muehlenbeckia coccoloboides.

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[2]We are indebted to Mr Geoff Sainty (Sainty and Associates), and Dr Surrey Jacobs (Royal Botanical Gardens, Sydney) for this information.

Severely salt-affected areas (EC_e of 7 to 20 dSm^{-1}, or 1.4 to 3.5 dSm^{-1} in 1:5 soil extracts) will usually have only limited plant cover. If the salinity has recently increased, dead trees and shrubs will be present in the area. Plants that will tolerate these salinity levels include

Beaded glasswort (*Sarcocornia quinueflora*)
Round-leaf pigface (*Disphyma clavellatum*)
Sea blite (*Suaeda* spp.) and
Samphire (*Hallosarcia*).

Other species include

Pachycornia triandra
Solerostegia spp.
Gunniopsis quadrifida.

These species will seldom be found on non saline soils and are a good indicator of high soil salinity levels.

Crop height and colour can help identify saline or sodic areas in cultivated fields. Some crops are more salt or sodium tolerant than others, and the degree of injury will vary with crop and management practices (Appendix 2). Crops such as beans or potatoes will show greater salt injury than peas, onions, corn, or wheat, while barley or lucerne show the least salt damage.

Collecting the soil samples

• Strategic sampling
With the visual variability in vegetation and soil surface features in mind, samples should be taken to cover the different soil situations, within the limits of the number of samples to be collected. This may be the first place that outside help should be considered - keeping in mind who is going to pay the chemical analysis bill. A few, strategically located sample sites will give maximum information at a minimum cost.

Soil samples should include a few samples from the best part of each field as a reference. Take at least one or two samples from the poorest areas, some from spots with very poor growth, intermediate looking areas, and some from the better areas.

• Sampling depths
Sampling depth and number of depths to be taken presents an additional choice. Here again cost becomes a factor. If one depth is used, the sample should probably be from the surface down to 0.25 to 0.35 m. If two sample depths are used, the upper sample should probably be from the surface down to 0.20 or 0.30 m, and the second should be from 0.20 to 0.40, or 0.30 to 0.60 m, depending on soil condition. Sampling by soil horizons is most desirable, such as from the surface down to the bottom of the plough layer, and from the bottom of the plough layer down to the bottom of the next horizon. Occasionally, a 5 to 10 mm thick sample of existing soil crusts or salt layers right at the top of the ground surface is desirable.

• Composite samples
The best soil samples are composites. A composite sample is obtained from a number of samples taken from the same soil depth, over an area that appears to be uniformly salt-affected. These smaller samples are thoroughly mixed together and a single sub-sample, the composite sample, is taken from the mix for chemical analysis.

• Sample volume and storage
One litre (or 1 kg) of soil is usually adequate for each sample. Record sampling date, depth, relative crop growth and appearance, previous and current or next crop, location by field and within the field. Samples should be air dried (do not dry in an oven), thoroughly mixed, and sticks and stones larger than 10 mm should be removed and the samples stored in sealed containers. Any clean, durable container that is easily handled can be used. The samples should be stored in a dry, cool location until they are delivered to the testing laboratory.

Water

Collecting water samples

• When to sample
Water samples from bores (wells) should be taken only after the pumps have run for at least half an hour, so that water standing in

the bore casing and the area next to the bore is removed and a representative sample is obtained. Usually, bore water quality will not change throughout the growing season. In cases where an aquifer is consistently being lowered by pumping, water quality may change with time. In this case, it would be wise to sample the bores over time.

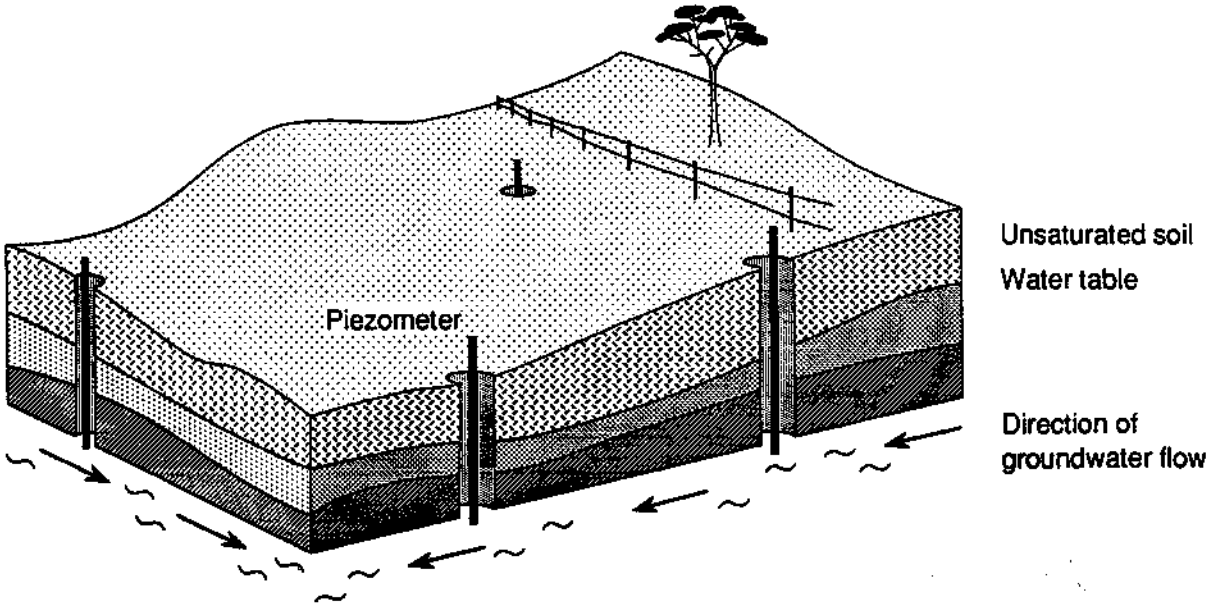
Irrigation water quality in large river systems with large storage reservoirs will usually not change over the season, but water in small storage systems and stream systems with fluctuating flows may change as the flow changes. Water samples should be taken only during the irrigation season and should also be taken if 'new' volumes of water move into the water supply.

• Sample volume and storage
Once the bore or stream water quality has been established, it will probably not be necessary to sample every year unless changes occurred that could cause water quality changes.

Water samples of 250 mL are sufficient for most irrigation water quality analysis. Sample containers should be clean and free from oil, salts, or chemical contaminants. Rinse each container with the water to be sampled before saving the sample. Use tight closures and record the sample date, time, place, water flow (approximate), irrigation method and crops to be grown. Refrigerate (do not freeze) the samples until analysed and analyse as soon as practical. Indicate which water samples go with which soil sample when more than one water source is available. Both water quality data and soil salinity status are needed to make proper management decisions.

• Sampling from a water table
When a shallow water table is suspected, make bore holes down into the water table near each corner of the field of concern. Water samples should be taken from each hole, and the depth to the water surface should be measured once the water has stopped rising in each hole. If the water table surface elevations from a fixed reference level are measured at the four points, the water table flow direction can also be determined. These sampling procedures should be carried out at the beginning and end of the irrigation season. This will give an indication of irrigation and seasonal effects on the water table depth and quality. These water samples should be collected and analysed by the same procedures as the irrigation water samples.

Figure 3. Determination of water table depth and direction of flow.



Soil and Water Analysis

Tests

Once the samples are collected and labelled, take them to either a private or a state government soil testing laboratory. Samples to be tested for salinity and sodium are handled differently than samples collected for fertiliser analysis and recommendations. When salinity or high sodium is a concern, the following tests should be requested.

Soils

1. **Saturation paste** (not extract) **pH.**

2. **Saturation paste extract analysis.** The extract should be analysed for **calcium, magnesium, sodium** and **electrical conductivity (EC_e).** For some areas, **potassium** should be requested.

3. **Carbonate, bicarbonate, chloride,** and **sulfate** should be run on enough **saturation paste extracts** to get an idea of which anions are dominant.

4. If the **pH** is greater than 8.5 and the EC_e is less than 4.0 dSm^{-1}, or the calculated **sodium adsorption ratio (SAR_e)** is greater than 10, the **exchangeable sodium percentage (ESP)** should be obtained for these samples. The **cation exchange capacity (CEC)** is required to calculate ESP, but need not be run on more than 4 samples per field as it is a relatively fixed value. It does not need to be obtained again because it will not change significantly with time or treatment.

Some laboratories would rather use a 1:1 or 1:5 soil:water extract than a saturation paste extract. Information from saturation paste extracts takes longer to get but is more accurate in describing the salinity status of the soil[3]. Soil:water extracts cannot be interpreted as reliably.

Water

Irrigation and **groundwater analysis** should include **EC_w, calcium, magnesium, sodium, chloride, carbonate, bicarbonate** and **sulfate,** and, occasionally, **potassium.** In areas of known boron toxicity, **boron** should also be determined.

Be sure that your samples are analysed by the correct methods, otherwise the results are impossible to interpret relative to known standards.

Interpreting the Results

Laboratory results may have to be converted from one set of units to another in order to use the commonly recommended standards. **Saturation percentage, pH, boron concentration, exchangeable sodium percentage (ESP), sodium adsorption ratio (SAR), percentage lime** and **percentage gypsum** data usually do not need to be changed. **Electrical conductivity (EC),**

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[3]Note: For any soil sample with the same SAR_e, regardless of soil type, the SARs calculated from other types of extracts will vary greatly and non-uniformly. The reason for this is apparent from the formula shown in the glossary; when calculating SAR from diluted solutions the SAR is calculated from the diluted Na value, but from the square root of the diluted Ca and Mg values. Thus, as you dilute the extract the SAR decreases with the effect being greater for lower saturation percentages and sandier soils. The following table illustrates this.

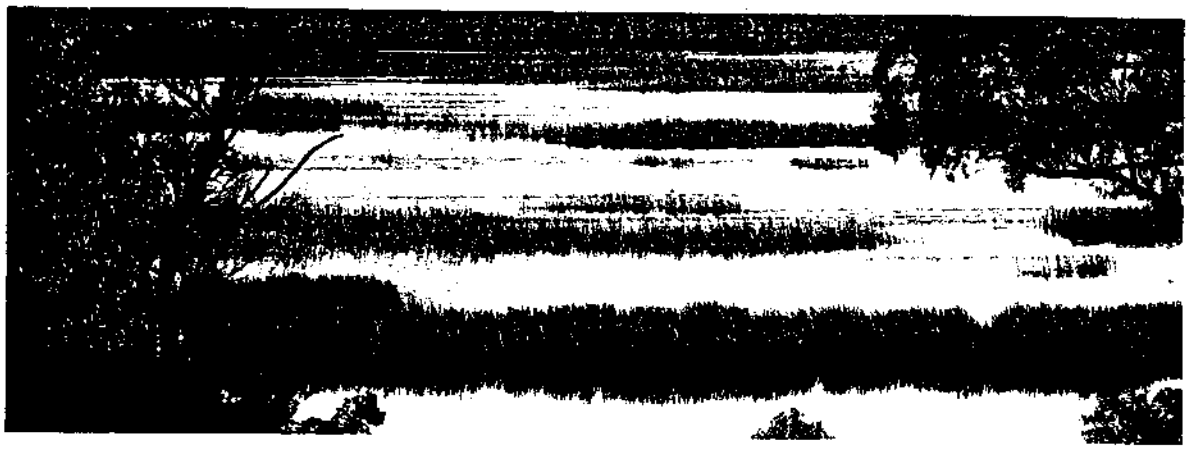
Saturation Percentage	Saturation paste Extract SAR_e	1:1 Extract SAR	1:5 Extract SAR
12.5 (Sandy loam)	14.1	5.0	2.2
25 (Silt loam)	14.1	7.1	3.2
50 (Clay loam)	14.1	10.1	4.5
75 (Clay soil)	14.1	12.3	5.5
100 (Clay subsoil)	14.1	14.1	6.3

cation exchange capacity (CEC), and the **cation** and **anion concentrations** may be in one of several units and should be converted to standard metric system units. These units and their conversion factors are shown in Appendix 1.

If the **SAR** has not been calculated, it can be derived from the cation concentrations (the glossary shows how this is done.

If water analysis gives a value for **SAR**, it should be **adjusted SAR (SAR_{adj})**. Often it also is given, incorrectly, for soil analysis. SAR_{adj} should only be used for irrigation water. Its calculation takes into consideration the fact that the water will undergo chemical reactions that will change the **effective SAR** of the water moving through the soil. The final **SAR** of soil in contact with water is affected by the values for **pH, carbonate** and **bicarbonate** in the irrigation water. Depending on these values, sometimes $CaCO_3$, or lime, will dissolve from the soil and lower the calculated **SAR**. In other situations, lime will precipitate from the soil solution, and the calculated **SAR** will increase.

Management to Remove or Minimise Soluble Salt Problems



Wetland

Once the salinity source and types of salts have been identified, a management plan can be developed to make the best use of the available resources.

Soils

Normal soils irrigated with good quality irrigation water should produce most crops without any salinity or drainage problems. Poor irrigation methods and inadequate drainage will inevitably cause soil degradation as water tables rise, salts are deposited in the root zone and good physical structure is destroyed. These are no longer 'normal' soils.

Saline soils, in the absence of a water table and carefully irrigated with good quality water, will usually reclaim themselves as salts are leached below the root zone. Initially, the rate of reclamation will depend on the amount of water travelling through the profile (the *leaching fraction*). After that, soil salinity will also be a function of the water quality and mineral weathering within the soil.

If the salts have come from a shallow water table, the water table must be lowered, by providing drainage or intercepting the incoming water, before reclamation can be accomplished. In some situations, it may not be economical to lower a water table, and an alternative land use might be a better choice.

Once the water table is lowered, all that is generally needed is leaching of the soluble salts with good quality water. Additions of gypsum, sulfur, soil amendments or other calcium salt materials do not help reclaim saline soils.

Saline-sodic soils irrigated with good quality water, in the absence of a shallow water table, have the potential of developing into sodic soils. This will occur if the soluble salts are leached out of the profile without calcium being added to replace the exchangeable sodium. In such a situation the EC_e decreases, while the SAR_e remains high.

The exception to this is when naturally occurring gypsum is present in the profile near enough to the surface that ploughing can mix the gypsum with the surface soil.

If the salinity and sodium are coming from a shallow water table, reclamation must

include drainage or intercepting the groundwater. As the salts are leached from the soil, calcium can be added as gypsum or calcium chloride, or if the soil contains lime near the surface, sulfur or iron (ferrous) sulfate can be added to dissolve lime as a means of making calcium available in the soil solution. Sulfuric acid has also been successfully added to these soils as a means of dissolving lime and making calcium available for reclamation. Adding these amendments is of little value unless leaching also takes place.

Sodic soils irrigated with good quality water nearly always present infiltration and leaching problems because they are generally sufficiently compacted and dispersed that water infiltration rates are very low.

If a high water table is part of the problem, it must be lowered as the first step in the reclamation process.

Reclaiming a sodic soil requires the reduction of the ESP to below a value that will depend on the soil texture and irrigation method, but which will fall in the range from 6 to 12. Such a reduction can be achieved by increasing the exchangeable calcium concentration, or by increasing the EC_e to above 4 dSm^{-1}. When saline water containing high amounts of calcium is available, it can be used to increase the infiltration rate by increasing the soluble calcium and the EC_e. Then, as the sodium is replaced, better quality water can gradually be used.

If gypsum is used for sodic soil reclamation, the **gypsum requirement** is calculated to determine the amount of gypsum needed to reclaim the soil to a particular depth. The calculation for gypsum requirement is given in the glossary.
Other choices include adding calcium chloride or sulfur, sulfuric acid or ferrous sulfate as a means of dissolving soil lime to supply the needed calcium. Sulfur does very little good on the soil surface and must be incorporated to aid reclamation. Coarse organic matter such as straw, corn stalks, or sawdust or wood shavings used for animal bedding, that decomposes slowly, can help open up sodic soils when used with other reclamation practices. Heavy manure or old lucerne hay applications that are worked into the soil dissolve lime and release calcium as they decompose.

Sodic soils do not contain natural gypsum in the surface, otherwise they would be saline-sodic. Sodic soils are usually the most expensive type of salt-affected soils to reclaim and under many conditions they may not be economical to reclaim.

Water

Irrigation water is a source of salt. If salinity problems have developed from salts and minerals in the irrigation water, there are only a few options available. The most desirable option would be to use better quality irrigation water (lower salt and/or sodium). If this is not a valid choice, it may be possible to leach salts from the soil during non-cropping periods. In areas without shallow water tables, it is often possible to irrigate late in the autumn so that the soil is wet going into the winter. The winter precipitation will then be more effective in moving salts below the root zone. When the total salt load in the irrigation water is low, but the SAR or SAR_{adj} is high, its use will increase the exchangeable sodium in the soil. However, gypsum added to this water can lower the SAR_{adj} and overcome an otherwise undesirable cation ratio in the water. Low EC_w, high SAR irrigation water treated with sulfuric acid can also be helpful when used on soils containing lime.

It is not uncommon for shallow water tables to develop from excessive application of irrigation water over an entire irrigation area. Soil salts gradually become a problem as the water evaporates from the soil surface. If one farmer in an area applies less water, his problem increases faster than his neighbour who continues to irrigate excessively, because more salts move up from the water table below his soil. Under these conditions, it may become mandatory to require all irrigators to use less water before the overall problem can be resolved. There may be legal problems in implementing this kind of an approach, even though it would be in everyone's best interest.

Choice of Crops

Choosing the right crops and best management practice will increase the chances for successful crop production and soil reclamation. Each crop and plant species has its own tolerance to high pH, soil salinity, and drought. Soil water content also has a strong influence on a plant's reactions to high pH and salts contained in the soil. Appendix 2 shows a sample of available data that can be used to help choose crops or ornamentals on the basis of soil salinity. Tables are also available for pH, boron, ESP and water quality sensitivity for different crops.

Management for Seedlings

Most seedlings are more sensitive to salt effects than older plants. This is due mostly to the seedling roots being in the upper part of the soil profile, which is often saltier and drier than deeper in the profile. Seedlings require time to produce sufficient sugars in the sap to offset the osmotic effect of the salts in the soil solution. The seedling's greater susceptibility to salt injury can often be minimised by preplant irrigation which both increases the soil water content and flushes some of the salt deeper into the soil. Additional light irrigations are often helpful after planting or emergence to allow the tender seedlings time to become established. Increasing the soil water content dilutes most salts, thus decreasing the osmotic effect on plants. This dilution, in combination with higher water content, makes it easier for the plants to extract water from the soil. An irrigator may have a choice between two or more waters of different quality. When possible, the less salty water should be used to establish the seedlings and then the poorer quality water can be used on more mature or more salt-tolerant crops.

Summary of Soil Management

To remove the soluble salts from the soil three things have to happen:

1. Less salt must be added to the soil than is removed;
2. Salts have to be leached downward through the soil and;
3. Water moving salts upward from shallow water tables must be removed or intercepted to avoid the accumulation of salts in the root zone. In sodic and saline-sodic soils, the exchangeable sodium must also be replaced with another cation, preferably calcium and the sodium must be leached from the root zone.

Soil amendments (sulfur, gypsum, iron sulfate, and sulfuric acid) are only beneficial on sodic and saline sodic (with no gypsum) soils and only when leaching takes place. These materials are added to replace the sodium so it can be leached from the soil. If high exchangeable sodium is not a problem, as in normal or saline soils, these materials will not be beneficial except when the sulfur is needed as a plant nutrient. If a soil contains natural gypsum, even in a saline-sodic soil, amendments will be of little use.

Getting Advice

State agency agronomists can provide additional help or refer you to soils specialists who have experience with saline or sodic soil problems. Soil Conservation Service personnel are a good source of help or they can direct you to someone who can advise you on management decisions. An on-site inspection of your particular situation will allow these specialists to be more helpful.

State agencies that can help are:

NSW

NSW Agriculture and Fisheries
PO Box K220
HAYMARKET NSW 2773
Ph: (02) 217 6666

Soil Conservation Service,
PO Box 198
CHATSWOOD NSW 2057
Ph: (02) 413 5555

Department of Water Resources
PO Box 3720
PARRAMATTA NSW 2150
Ph: (02) 895 6211

VIC

Department Agriculture & Rural Affairs
PO Box 500
EAST MELBOURNE VIC 3002
Ph: (03) 651 7011

Rural Water Commission
590 Orrong Road
ARMADALE VIC 3143
Ph: (03) 508 2222

WA

Department of Agriculture
Baron-Hay Court
SOUTH PERTH WA 6151
Ph: (09) 368 3333

Conservation and Land Management
50 Hayman Road
COMO WA 6152
Ph: (09) 367 0333

QLD

Department of Primary Industries
GPO Box 46
BRISBANE QLD 4001
Ph: (07) 239 3111

SA

Department of Agriculture
GPO Box 1671
ADELAIDE SA 5001
Ph: (08) 226 0222

Wayne talks to farmer - Griffith

APPENDIX 1

Units and Conversion Factors for Salinity Terms

To convert from Column A units to Column C units, multiply A by B.
Conversely, to convert from Column C units to Column A units, divide C by B.

Term	Column A Units	Column B Conversion factor A to C	Column C Units§
CEC	me 100 g^{-1}	.10.0	mmole charge kg^{-1}
	cmole charge kg^{-1}	10.0	mmole charge kg^{-1}
EC	mmhos cm^{-1}	1.0	dSm^{-1}
	S m^{-1}	10.0	dSm^{-1}
	mmhos cm^{-1}	0.001	dSm^{-1}
	EC units	0.001	dSm^{-1}
	TSS units (ppm) or mg L^{-1}	0.00167	dSm^{-1}
Ca	ppm	0.025	mmole L^{-1}¶
	me L^{-1}	0.5	mmole L^{-1}
Mg	ppm	0.041	mmole L^{-1}
	me L^{-1}	0.5	mmole L^{-1}
Na	ppm	0.043	mmole L^{-1}
	me L^{-1}	1.0	mmole L^{-1}
K	ppm	0.026	mmole L^{-1}
	me L^{-1}	1.0	mmole L^{-1}
Cl	ppm	0.028	mmole L^{-1}
	me L^{-1}	1.0	mmole L^{-1}
SO_4	ppm	0.010	mmole L^{-1}
	me L^{-1}	0.5	mmole L^{-1}
CO_3	ppm	0.017	mmole L^{-1}
	me L^{-1}	0.5	mmole L^{-1}
HCO_3	ppm	0.016	mmole L^{-1}
	me L^{-1}	1.0	mmole L^{-1}

§ The units in the right hand column are the currently preferred SI units.
¶ mmole L^{-1} are equal to mole m^{-3}.
Example: To convert 40 ppm Ca to mmole L^{-1}, multiply 40 ppm by 0.025 to give 2.0 mmole Ca L^{-1}.

Abbreviations of Units

me L^{-1}:	milliequivalents per litre
cmole(+) kg^{-1}:	centimoles of (positive) charge per kilogram
mmhos cm^{-1}:	millimhos per centimetre
S m-1:	Siemens per metre
dS m^{-1}:	deciSiemens per metre
EC units:	Electrical Conductivity units (µS cm^{-1})
TSS:	Total Soluble Salts

APPENDIX 2

Relative Yield with Increasing Electrical Conductivity (Salinity) in the Root Zone

PLANT NAME		Electrical Conductivity - EC_e (dSm^{-1})														
Common	*Scientific*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		Relative Yield (%)														
Apple	*Malus sylvestris*	100	91	75												
Barley, grain	*Hordeum vulgare*	100	100	100	100	100	100	100	100	95	90	85	80	75	70	65
Bean	*Phaseolus vulgaris*	100	81	62	43	25	6	0								
Beet	*Beta vulgaris*	100	100	100	100	91	82	73	64	55	46	38	29	20	11	2
Broccoli	*Brassica oleracea*	100	100	98	89	80	71	61	52	43	34	25	16	6	0	
Cabbage	*Brassica oleracea*	100	98	88	79	69	59	50	40	30	20	1	1	1	0	
Carrot	*Daucus carota*	100	86	72	58	44	30	15	1	0						
Corn, forage	*Zea mays*	100	99	91	84	76	69	61	54	47	39	32	24	17	10	
Corn, grain, sweet	*Zea mays*	100	96	84	72	60	48	36	24	12	0					
Cotton	*Gossypium hirsutum*	100	100	100	100	100	100	100	98	93	88	83	78	73	67	62
Cucumber	*Cucumis sativus*	100	100	94	81	68	55	42	29	16	3	0				
Grape	*Vitis spp.*	100	95	86	76	66	57	47	38	28	18	9	0			
Lettuce	*Lactuca sativa*	100	91	78	65	52	39	26	13	0						
Lucerne	*Medicago sativa*	100	100	93	85	78	71	64	56	49	42	34	27	20	12	
Onion	*Allium cepa*	100	87	71	55	39	23	6	0							
Orange	*Citrus sinensis*	100	95	79	63	48	32	16	0							
Orchard grass	*Dactylis glomerata*	100	97	91	84	78	72	66	60	53	47	41	35	29	22	16
Pea	*Pisum sativum* L.	100	100	90												
Peach	*Prunus persica*	100	94	73	52	31	10	0								
Pear	*Pyrus spp.*	100	91	75												
Plum	*Prunus domestica*	100	91	73	55	36	18	0								
Potato	*Solanum tuberosum*	100	96	84	72	60	48	36	24	12						
Radish	*Raphanus sativus*	100	90	77	64	51	38	25	12	0						
Raspberry	*Rubus idaeus*	100	80	62												
Rockmelon	*Cucumis melo*	100	100	95	80											
Rose	*Rosa spp.*	100	74	36	0											
Ryegrass	*Lolium perenne*	100	100	100	100	100	97	89	82	74	67	59	52	44	36	29
Safflower	*Carthamus tinctorius*	100	100	100	100	100	100	97	90	85	80	75	50			
Sorghum	*Sorghum bicolor*	100	100	100	100	98	90	84	78	70	63	56	50	43	36	29
Squash	*Cucurbita maxima*	100	100	90	74											
Strawberry	*Fragaria spp.*	100	67	33	0											
Tomato	*Lycopersicon esculentum*	100	100	95	85	75	65	55	46	36	26	16	6	0		
Trefoil	*Lotus corniculatus*	100	100	100	100	100	90	80	70	60	50	40	30	20	10	0
Wheat	*Triticum aestivum*	100	100	100	100	100	100	93	86	79	71	64	57	50	43	36
Wheatgrass, crested	*Agropyron desertorum*	100	100	100	98	94	90	86	82	78	74	70	66	62	58	54
Wheatgrass, fairway	*Agropyron cristatum*	100	100	100	100	100	100	100	97	90	83	76	69	62	55	48
Wheatgrass, tall	*Agropyron elongatum*	100	100	100	100	100	100	100	98	94	89	85	81	77	73	68
Wildrye	*Elymus triticoides*	100	100	98	92	86	80	74	68	62	56	50	44	38	32	26

Glossary

Alkali or alkali soil: Old terms that are no longer used in soil science because of their variable meanings. Soils are now more usefully categorised under saline and sodic soil categories (page 7).

Acid or acidic soils: Soils that have a pH less than 7. Usually found in sites that are highly leached.

Anion: A single atom or small group of atoms with a negative charge, such as chloride (Cl^-), sulfate (SO_4^{2-}), carbonate (CO_3^{2-}), or bicarbonate (HCO_3^-).

Cation: A single atom or small group of atoms with a positive charge, such as calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+), or ammonium (NH_4^+).

Cation exchange: The replacement of a cation held on the surface of a negatively charged material, such as clay or organic matter, by another cation from the soil solution. See Exchangeable cations (page 3).

Cation exchange capacity (CEC): The total quantity of cations that can readily be exchanged on a unit amount of soil material, expressed as milliequivalents per 100 grams of soil - me 100 g^{-1}; centimoles of charge per kilogram of soil - cmol (positive) charge kg^{-1}; or, preferably, as millimoles of charge per kilogram of soil - mmol(+) kg^{-1}.

Electrical Conductivity (EC): The property of a material to conduct electricity. The ease with which electrical current passes through water is proportional to the salt concentration in the water. Consequently, the total salt concentration of a soil solution can be estimated by measuring the EC. The higher the EC, the greater the salt concentration. The value of the EC for a particular soil sample will vary according to the preparation of the sample (EC_e specifies the EC of a saturation paste extract). The preferred unit of measurement is deciSiemens per metre (dSm^{-1}).

Evapotranspiration: The loss of water from plants and the soil surface to the atmosphere in a given time period, through evaporation as well as transpiration from leaves. Usually expressed as millimetres of water depth.

Exchangeable sodium percentage (ESP): The percentage of the cation exchange capacity neutralised by sodium, that is, the proportion of the total cation sites on the surface of a soil material that are occupied by sodium. It is calculated as:

$$ESP = \frac{Exchangeable\ sodium}{Cation\ exchange\ capacity} \times 100$$

Field capacity (field moisture capacity): The maximum amount of water that a well-drained soil can hold after any excess has been allowed to drain, that is, the amount of water the soil will hold against gravitational drainage. It is defined as the water content remaining in a soil 2 to 3 days after being saturated and then allowed to drain, with no evapotranspiration taking place. Field capacity of a particular soil layer is usually specified in millimetres (mm) of water per millimetre of soil depth (volumetric basis) or as kilogram of water per kilogram of soil (weight basis).

Gypsum requirement (GR): The amount of gypsum needed to lower the ESP of 10 cm of soil to a desired level. It is is expressed in approximate tonnes needed per hectare and is calculated as:

GR = (Present ESP minus desired ESP) x CEC x 0.0015

The factor of 0.0015 assumes 80% reclamation efficiency, a desirable SAR_{adj} in the irrigation water and that CEC is in mmoles(+) kg^{-1}. If the CEC is in me 100 g^{-1} or cmol(+) kg^{-1} units, the factor is 0.015.

Infiltration rate: The maximum rate at which ponded water can enter the soil. It is usually given in millimetres per hour or per day (mm h^{-1}, mm d^{-1}).

Leaching: The removal of soluble salts from the soil and soil solution, by the downward movement of water.

Leaching fraction (LF): That fraction of the infiltrated irrigation water that percolates below the root zone:

$$LF = \frac{\textit{deep drainage water}}{\textit{infiltrated irrigation water and rainfall}}$$

Milliequivalent (me): A measure of ionic charge.

Osmotic potential: The pressure exerted across a semipermeable cell wall or membrane as a result of unequal solute (dissolved salts or sugars) concentrations on either side of the cell wall or membrane. The solvent will move from the side with the lowest solute concentration through the membrane into the side with the higher solute concentration. This process of solvent movement is known as osmosis.

Parts per million (ppm): Concentration based on the number of parts of solute in a million parts of **solution** (the mixture of the **solvent** and the **solute**), that is, a concentration of 15 ppm sodium chloride would give 15 milligrams of sodium chloride in 1 kg (approximately) of water.

pH: A measure of the acidity or basicity of a material or solution. A substance with a pH of less than 7 is an acid and more than 7 is a base, 7 being neutral. The value of the pH for a particular soil sample will vary according to the preparation of the sample.

Reclamation efficiency (in relation to gypsum requirement): A fraction obtained by dividing the theoretical **gypsum requirement** by the actual gypsum application rate that is required to lower the **exchangeable sodium percentage (ESP)** to the desired level. The best reclamation efficiency that can be obtained, with good quality (low SAR_w) irrigation water and adequate internal drainage, is eighty per cent. This means that an application rate 1.25 times that calculated by the gypsum requirement would be needed to achieve the desired ESP under optimum conditions.

Saline soil: A soil with an excess of salts (not only sodium chloride, NaCl) in it.

Salt-affected soils: Soils that are either chemically or physically changed by high concentrations of different salts. The changes are such that some plant growth is adversely affected.

Saturation paste: A useful paste for soil analysis, prepared by mixing distilled water with the soil sample. The water content of a saturation paste is approximately twice that contained at field capacity.

Saturation paste extract: The solute obtained from a saturation paste. This extract gives the most accurate analysis of the salinity status of a soil. In this text, the abbreviations of measurements obtained from a saturation paste extract are subscripted with an 'e'.

Saturation percentage: A figure calculated by dividing the weight of oven-dry soil by the weight of water needed to wet the soil to saturation, then multiplied by 100 to obtain a percentage.

Sodic soil: A soil with an excess of sodium ions on the soil exchange complex. Excess sodium will generally cause soil to have poor physical structure.

Sodium adsorption ratio (SAR): The SAR of the soil solution or irrigation water is a relationship between Na^+ and Ca^{2+} plus Mg^{2+} concentrations that predicts the Na^+ status of the soil exchange complex when the exchange of cations within the soil comes into equilibrium with the soil solution or infiltrating irrigation water. The value of the SAR for a particular soil sample will vary according to the preparation of the sample (SAR_e specifies the SAR of a **saturation paste extract**, SAR_w specifies the SAR of irrigation water or groundwater). SAR is calculated as:

$$SAR = \frac{Na}{\sqrt{[Ca + Mg]}}$$

where the cation concentrations are expressed in units of mmol L^{-1} or moles m^{-3}.

If the units are in milliequivalents L^{-1}, then the sum of Ca and Mg is divided by 2. That is:

$$SAR = \frac{Na}{\sqrt{[(Ca + Mg)/2]}}$$

SAR_{adj}: The SAR_{adj} is the SAR of the irrigation water, corrected for the effect that the carbonate and bicarbonate concentration and pH of the water will have on the soil in contact with that water. The effect that water, carbonate, bicarbonate and pH have on soil is measured through a change in soil ESP. Calculating SAR_{adj} for soil extract data gives incorrect information, as it only applies to water. For additional information and methods of calculating SAR_{adj} see Jurinak (1990), listed under FURTHER READING.

Soil amendment or ameliorants: Any material such as lime, sulfur, gypsum, sawdust, sand or straw used to alter the physical or chemical properties of a soil. Fertilisers, which are added to supply plant nutrients, are not soil amendments or ameliorants.

Soil dispersion: The process of soil particles disaggregating, that is, falling apart and dispersing when in contact with water.

Soil exchange complex: A whole range of organic and inorganic particles within soil which have some electrical charge. Ions can move onto and off these particles.

Soil horizon: A visibly different layer within a soil profile. Differences between layers may be caused by differences in colour and/or texture.

Soil profile: The description of the changes in texture, colour and composition of the soil with increasing depth from the soil surface.

Soil:water extract: The solute made by shaking a soil sample with an excess of pure water usually expressed on a volume:volume basis.

Solute: That part of a salt or chemical that is dissolved in water.

Specific ion effect: The effect, usually toxic, that a particular ion has on plants.

Total Soluble Salts (TSS): The total amount of all salts dissolved in water, usually expressed in ppm or preferably milligrams per litre (mg L^{-1}).

Water table: The upper free water surface of ground water; that is, the level below the soil surface where water stands in an open hole in the soil.

Further Reading

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