

Chapter 5 – Measurement techniques and relationships

Electrical conductivity as a measure of salinity

Salinity in soils can be estimated conveniently from the electrical conductivity (EC) of a soil solution. Many salts dissociate to ionic form in water (which, when pure, has a very low conductance), so the electrical conductivity of a solution provides a measure of total concentration of salts.

Three measures of electrical conductivity are:

- $EC_{1:5}$ —the electrical conductivity of a 1:5 soil water suspension, used routinely in analyses
- EC_{se} —the electrical conductivity of the soil saturation extract, used for predicting plant response (commonly predicted from 1:5 and soil properties, or can be measured directly)
- EC_s —the electrical conductivity of soil at measured or predicted maximum field water content (approximating field capacity), used to assess salt movement through the soil (usually predicted from 1:5 and soil properties).

$EC_{1:5}$ provides a measure of the content of salts in a 1:5 soil water suspension, the most commonly used method of analysis. EC, chloride (Cl) and pH are usually measured together to provide additional information for interpretation. (Field and laboratory techniques for determining $EC_{1:5}$ are described in **Soil salinity** page 60.)

The ratio of 1:5 was established in response to difficulties that arise when using the traditional saturation extract mixing method with heavy textured Australian soils (described below). $EC_{1:5}$ is a convenient laboratory and field technique. However, it is not directly related to soil behaviour and plant response because the ratio is far more dilute than is normally found under field conditions and it is fixed irrespective of soil texture. $EC_{1:5}$ results tend to provide an underestimate of the electrical conductivity of sandy soils compared with clay soils.

Plants respond to salinity at water contents equal to or drier than saturation. EC_{se} is the most dilute soil solution concentration that plants could be likely to encounter and has been successfully used to relate plant response to soil salinity for a wide range of soil textures. This saturation water content, a well-accepted standard (USSL 1954), is used because it is the lowest reproducible soil:water ratio for which enough extract can be readily removed for analysis, and it relates in a predictable manner to field soil water contents and soil textures (Rhoades 1983).

A common method for determining saturation water content is mixing the soil with water until the soil paste glistens and begins to flow, and then extracting the solution by filtration under vacuum or pressure, or by centrifuging. An alternative method is to wet the soil sample on a tension table where the soil is placed on a porous material hydraulically linked to free water usually 1 cm below the sample. However, there are problems with these techniques because the wetting end point is not easily reproducible, and with the tension wetting method, the quantity of water taken up by the soil depends on the rate of wetting, the nature of the clay and the amount of exchangeable sodium. (Details of methods are given in Rayment and Higginson 1992.)

Water (and hence salt) movement in soils becomes very small once the soil water content is drier than maximum field water content (roughly equivalent to the field capacity). EC_s represents the salt content at the point where soil profile drainage has essentially ceased, and is determined using centrifuge or other displacement methods. However, technique problems with wetting and extraction result in similar errors to determining EC_{se} . The salinity at maximum field water content is used when estimating leaching fractions and in solute movement studies and modelling as the soil solution is assumed to be in equilibrium with the soil matrix.

Table 7 illustrates the relative dilutions above field water content for each of the EC measures.

Table 7. Relative dilution above maximum field water content (field capacity) for three measures of soil salinity, $EC_{1:5}$, EC_{se} and EC_s .

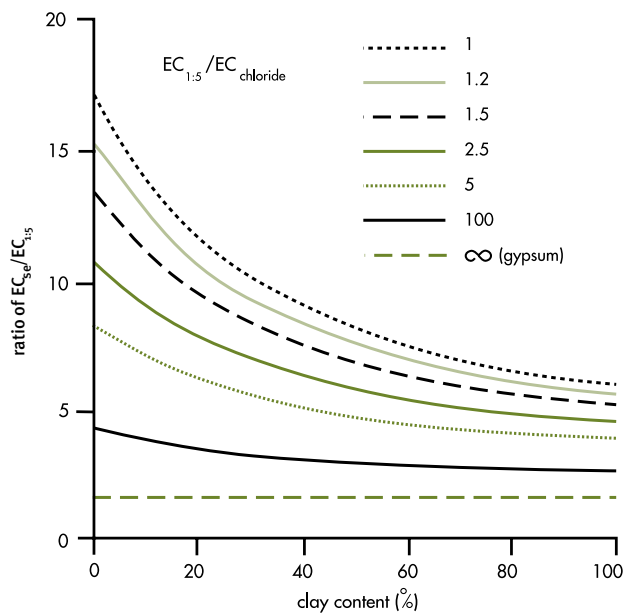
Measure	Dilution above maximum field water content (upper drained limit)
EC_s	1 time at depth, equal to field capacity in surface soil
EC_{se}	2 to 3 times at depth, equal to saturated surface soil
$EC_{1:5}$	5 to more than 40 times, depending on soil texture

Converting from $EC_{1:5}$ to EC_{se}

It is possible to provide mathematical relationships between the EC measures based on water content differences but, because the chemistry of solutions involving dissolution and precipitation and ion exchange are profoundly affected by water content, considerable errors can occur in relating the corresponding EC values.

However, as $EC_{1:5}$ is the most convenient method for determining salinity in soils, techniques for converting to other measures of EC are required. Figure 25 shows the relationships between $EC_{1:5}$ and each of EC_{se} and EC_s . These conversions can be carried out using the SALFCALC component of the SALF software package, an easy-to-use calculator program for converting between measures of salt content at different water contents, based on soil properties (refer to the appendix *Useful software packages* page 141). Detailed methods for converting between $EC_{1:5}$ and EC_{se} are provided in Shaw (1994) and summarised in this section.

Figure 25. Figure to estimate the conversion factor between $EC_{1:5}$ and EC_{se} based on clay content and $EC_{1:5}/EC_{se}$ ratio (Shaw 1994).



To relate $EC_{1:5}$ measurements to plant salt tolerance data, soil leaching and soil behaviour, it is necessary to convert $EC_{1:5}$ to EC_{se} (saturation extract).

For pure solutions of salts that are totally soluble in 1:5 soil:water suspensions, the EC of soil at saturation extract would be directly proportional to the EC of the 1:5 suspension.

Expressed as a mass balance equation:

$$Q_{se}EC_{se} = Q_{1:5}EC_{1:5} \dots \dots \dots 5$$

where

- Q_{se} is water content equivalent to soil saturation (saturation percentage *SP*)
- EC_{se} is electrical conductivity of salt solution at the water content Q_{se}
- $Q_{1:5}$ is water content at equivalent of 1:5 soil:water suspension
- $EC_{1:5}$ is electrical conductivity of salt solution at 1:5 soil:water dilution.

To derive EC_{se} , the equation can be rearranged to:

$$EC_{se} = EC_{1:5} \frac{Q_{1:5}}{Q_{se}} \dots \dots \dots 6$$

$Q_{1:5}$ can be assessed as (500 + 6ADMC) for a 1:5 soil:water suspension (where ADCM is air dry moisture content expressed as kg/100 kg). Thus it is possible to convert from $EC_{1:5}$ to EC_{se} if the ratio of water contents ($Q_{1:5}:Q_{se}$) is known.

However, it is not this simple for a number of reasons (as discussed in detail in Shaw 1994):

1. Saturation water content has to be predicted from other soil properties such as air dry moisture content and clay content.
2. Soils contain slowly soluble salts, such as gypsum, sodium carbonate and bicarbonate, and calcium carbonate. These salts are more soluble in dilute solutions, and their solubility depends on the composition of other salts present. For instance, gypsum is more soluble if sodium chloride is present and less soluble if calcium chloride is present. Hence the composition of salts will affect the electrical conductivity of the solution as a whole.
3. $EC_{1:5}$ is usually measured on the solution of soil:water suspensions after mixing and standing. Where some clay remains in suspension, the charge on the clay contributes to $EC_{1:5}$. EC_{se} is measured on extracts without any clay contribution.
4. Increasing dilution results in ion exchange with a preference for monovalent ions such as sodium on the exchange complex. This creates a sink for calcium, resulting in slightly enhanced solubility of calcium salts at greater dilutions compared with non-ion pair forming salts.
5. As a solution becomes more concentrated, dissociated ions pair together forming neutral ion pairs such as $CaSO_4^0$. Since these ion pairs do not conduct electric current, the EC at high concentrations of salts that form ion pairs is reduced. Thus the direct conversion of $EC_{1:5}$ to EC_{se} may overestimate EC_{se} at high salinity levels.

To accurately estimate EC_{se} from $EC_{1:5}$, both the ratio of water contents and the composition of salts need to be known. The water content ratio can be estimated from surrogate soil properties, which include clay content, ADCM, CEC, -33 kPa water content, -1 500 kPa water content, and texture (as related to clay content) (details in Shaw 1994 and applied in the SALFCALC software package).

The chemistry can be assessed from the concentration of chloride salts in proportion to total salt content. Since the dominant anions in soil water extracts are Cl^- and SO_4^{2-} (with smaller proportions of HCO_3^- , CO_3^{2-} and NO_3^-), and since chloride is often measured

routinely with $EC_{1:5}$, the proportional contribution of chloride to the EC can be calculated. The ratio $EC_{1:5}/EC_{Cl}$ provides an estimate of the very soluble and sparingly soluble salts present by converting the chloride percentage of the 1:5 soil:water suspension (kg/100 kg soil) to an equivalent EC (dS/m). As EC_{Cl} (dS/m) can be closely approximated by $6.64 \times \%Cl_{1:5}$, this calculation can be readily made as:

$$\frac{EC_{1:5}}{EC_{Cl}} = \frac{EC_{1:5}}{Cl\% * 6.64} \dots\dots\dots 7$$

Table 8. Relationship between texture class and texture grades and approximate clay contents of McDonald and Isbell (1990).

Texture class	Texture grades of McDonald and Isbell (1990)	Median clay content (approx.) %
sand	sand	5
loamy sand	loamy sand, clayey sand	7
sandy loam	sandy loam	15
silty loam	loam, silty loam	25
clay loam	clay loam, silty clay loam	32
light clay	light clay, light medium clay	40
medium clay	medium clay	50
heavy clay	heavy clay	65

If chloride is expressed as ppm or mg/kg, the bottom line of the above equation becomes:

$$\frac{EC_{1:5}}{EC_{Cl}} = \frac{EC_{1:5}}{(Cl/10\ 000) * 6.64} \dots\dots\dots 8$$

The concentration of very soluble salts will change linearly with changes in water content (as modelled in the mass balance equation at the start of this section). However, the concentration of sparingly soluble salts that form saturated solutions at the water contents under discussion will not change linearly with changes in water content. In these cases, EC_{se} cannot be accurately estimated from $EC_{1:5}$ if a linear relationship is assumed. The proportion of the EC contributed by soluble salts must be known for reasonably accurate conversions.

These calculations can be carried out using SALFCALC. Alternatively, an appropriate conversion factor from $EC_{1:5}$ to EC_{se} can be determined from Figure 25 by reading a value from the curve which represents an appropriate clay content and represents the $EC_{1:5}/EC_{se}$ line.

As a rule of thumb, 50% of soils will have an $EC_{1:5}/EC_{se}$ of between 1 and 2, 40% between 2 and 6, and 10% greater than 6 (Shaw 1996). Texture groups and median clay contents are provided in Table 8 to allow approximate conversions.

Leaching fraction

An estimate of leaching fraction is important when considering the suitability of a soil for irrigation or for determining the likely impact of land use change on the amount of water moving below the root zone to the groundwater system. Measurement of leaching under field conditions presents large logistical problems and the use of deterministic solute models to predict leaching requires water application estimates, plant water use estimates and detailed description of soil hydraulic properties. Therefore, a simple empirical approach was developed by Shaw and Thorburn (1985) to predict salt leaching for dryland soils and which is also applicable to irrigation. This model provides the basis for the SALFPREDICT model which is discussed in **Soil salinity** (page 60) and **Useful software packages** (page 141).

The estimate of leaching fraction under steady state conditions is based on the concept that the mass flux of solute applied to a soil profile will equal the mass flux of solute leaving the profile at steady state. For a solute such as chloride that undergoes no chemical transformation and negligible plant uptake, the relationship can be expressed:

$$LF = \frac{EC_i}{EC_d} = \frac{D_d}{D_i} \dots\dots\dots 9$$

where

- i* is input
- d* is drainage below the root zone.

There are several methods available for estimating leaching fraction under both steady state and non-steady state conditions. These methods are summarised in Table 9.

Long-term irrigation (steady state)

Where soils have been under irrigation for some years steady state conditions should exist. Under these conditions the leaching fraction model (USSL 1954) will be valid. LF can be calculated from the previous equation:

$$LF = \frac{EC_{iw+r}}{EC_s} \dots\dots\dots 10$$

Table 9. A summary of the methods and data required for estimating leaching fraction for different conditions.

Condition/ model	Field data	Method
Long-term irrigation (steady state—5 to 10 years) USSL (1954)	EC and amount of irrigation water, rainfall, EC _{1:5} at bottom of the root zone 0.6 to 1.2 m. Maximum field water content or surrogate	EC _{1:5} converted to EC _s and leaching fraction calculated (SALFCALC)
Short-term irrigation (non-steady state) Rose et al. (1979) Thorburn et al. (1987)	Cl of irrigation water. Cl _{1:5} profiles taken at two times. Depth rainfall and irrigation. Maximum field soil water content or estimate surrogate soil properties	Deep drainage and leaching fraction calculated (SODICS)
Prior to irrigation Shaw and Thorburn (1985a)	Clay and CEC from 0 to 0.9 m, ESP at 0.9 m, annual rainfall and irrigation, and EC irrigation	Leaching fraction predicted from these parameters (SALFPREDICT)
New irrigation water salinity Shaw and Thorburn (1985a)	As above, plus quantity and EC of past and future irrigation water, annual rainfall	(SALFPREDICT)

EC_{iw+r} is the rainfall weighted input. EC_s is most readily determined from soil EC_{se} or EC_{1:5} measurements (taken at the bottom of the root zone). As EC_{1:5} is a less concentrated measurement than EC_s, the EC_{1:5} value will have to be converted to EC_s from the ratio of dilution. This procedure has been described in detail in the previous section and is shown in the examples following.

Firstly, the EC_{1:5} to EC_{se} conversion factor is determined. This factor depends on clay content and salt composition. Secondly, EC_s is usually about 2.2 times more concentrated than EC_{se}, so the EC_{1:5} to EC_{se} conversion factor is multiplied by 2.2 to give the EC_{1:5} to EC_s conversion factor. This is a rough approximation and depends on salt composition.

Short-term irrigation

As irrigation changes the salt balance, soil salinity will change (increase or decrease) after the commencement of irrigation until a new equilibrium is attained (steady state conditions). Until steady state conditions exist, EC_s will not give an accurate indication of LF.

Instead, the change in soil salinity which occurs between two sampling times can be used. The model used in this situation is that of Rose et al. (1979). The model is most suited to slowly permeable soils with long time periods required to reach equilibrium. The data required for use of the model are soil salinity profiles (preferably Cl) at two sampling times, the amount and salinity (Cl) of irrigation water used, and the maximum field water content of the soil. This final parameter is easily predicted from the equations of Shaw and Yule (1978) for most slowly permeable soils (Thorburn & Gardner 1986).

The equation of Rose et al. (1979) is:

$$S_2 = S_1 + \left(\frac{D_i S_i}{D_d \lambda} - S_1 \right) \left(1 - \exp \left(- \left(\frac{D_d \lambda t}{z \theta} \right) \right) \right) \dots 11$$

where

- S₁, S₂ are mean root zone salinities determined at two different times
- t is the time in years
- S_i is solute concentration of the irrigation water
- D_i is depth of infiltration
- z is depth of root zone
- θ is volumetric water content to which drainage will occur
- λ is a factor to account for soil salinity profile shape.

The value of D_d is the only unknown in the equation and can be calculated from the model. It can be used to calculate LF and give the average root zone EC value that will occur at that site at steady state. The model can also indicate the time period when steady state conditions will be reached and how much soil salinity will increase (or possibly decrease) until that time. If the final EC root zone value at steady state is too great for the crop to be grown, irrigation management would have to be changed before that time.

Calculations are performed most easily using the computer program SODICS of Thorburn et al. (1987). Before using this model, readers would be best advised to refer to Rose et al. (1979) and Thorburn et al. (1987 and 1985) for further details and examples.

Prior to irrigation

To assess the suitability of land for irrigation, the LF value that will occur under irrigation needs to be predicted. Shaw and Thorburn (1985a) and Shaw (1996) developed a method for directly predicting the LF (PLF) that would occur under irrigation.

The soil properties of dominant influence on soil leaching are clay content, clay mineralogy (CCR) (expressed as CEC/clay ratio, mole_c/kg of clay) and ESP. As a result of the relationship between soil properties, ESP and rainfall are specified for different soil groups across a wide range of rainfalls. LF under irrigation can then be calculated by substituting the depth of irrigation plus rainfall D_{i+r} for D_r . Because a change in electrolyte concentration will result in a change in leaching for a given soil ESP, an adjustment of the predicted leaching fraction is made.

PLF_r is calculated from the general equation for each soil group using the general form $PLF_r = EC_r$ divided by 2.2 times EC_{se} where EC_{se} can be predicted utilising soil properties information (Shaw 1996) giving the following equation:

$$PLF_r = \frac{EC_r}{2.2 \times 10 \left(a + b \log \left(\frac{0.03 \text{ rainfall}}{ESP} \right) \right)} \dots 12$$

Exchangeable sodium percentage (ESP) of the soil under irrigation can be calculated following the procedure discussed later in the section on soil sodicity. The model SALFPREDICT has been developed to simplify these calculations and is included on a CD in the back cover of this book.

An assumption of the amount of irrigation water to be used in the future is required. If information on irrigation practice is not available, a value for D_{iw} can be estimated from:

$$D_{iw} = 1300 - D_r \dots 13$$

The value of 1300 mm is the 10-year average $D_{iw} + D_r$ in a survey of data from 10 Queensland irrigation areas, covering cotton to sugar cane. Variation of this figure will be required for supplemental irrigation on a limited basis and for different climate regimes.

New irrigation water salinity

Shaw and Thorburn (1985a) found that the change in LF between a rainfall situation and irrigation was closely related to the ratio of the weighted salinity of the irrigation water and the rainfall in the future situation, and the rainfall salinity itself. The relationship is:

$$LF_f = LF_p \frac{EC_{iw+r}}{EC_r} \dots 14$$

where

f, p are future and past LF values.

EC_{iw+r} is the weighted average salinity of rainfall and irrigation water and is calculated from the equation to calculate the conversion. That is, the equation above represents a special case where no irrigation water was used in the past management practice.

On the basis of experience with heavy textured soils in the Lockyer Valley using variable salinity irrigation waters, and because the soil responses to salt vary with physico-chemical properties, a non-linear adjustment was developed where the adjustment decreases with the increasing salinity of the applied water. The non-linear adjustment for salt concentration is used in SALFPREDICT to predict leaching fraction for irrigating with different salinity waters. Thus the EC ratio component of the equation given above is adjusted as follows:

$$LF_f = LF_p \left(2.65 \left(\frac{EC_{iw+r}}{EC_r} \right)^{0.5} - 1.35 \right) \dots 15$$

Accurate estimates require more detailed investigations of soil response to salinity and sodicity.

Root zone salinity

Plants respond to salinity throughout the root zone, so it is useful to be able to convert measurements at various depths in the root zone into a single number that can be used when considering plant response. Two measures of root zone salinity are commonly used: average, and water uptake weighted. Both require an estimate of root depth for the particular plant species under consideration.

Average root zone salinity

Because plants respond to the integration of atmospheric and soil conditions, averaging the salinity for the root zone depth (average root zone salinity) will provide a conservative measure of soil salinity conditions for estimating plant response. Several studies (Devitt et al. 1984; Rhoades 1982; Bernstein & Francois 1973) have shown average root zone salinity to provide an appropriate estimate of root zone salinity for determining plant response to salinity.

Average root zone salinity is calculated from soil profile salinity data by summing the salinity measurements for a series of root zone depth increments and dividing by the number of increments.

Water uptake weighted root zone salinity

Many Australian soils have reduced soil porosity, hydraulic conductivity and water storage capacity with depth, and increasing salinity with increasing depth. Thus a measure of root zone salinity weighted for the actual water uptake pattern of plants in the root zone would possibly provide a more realistic estimate of plant response than a measure that averages root zone conditions.

The weighted measure is based on the concepts that water is more available to plants in the less saline areas of the root zone and that water uptake by roots is not uniform throughout the root zone. In fact, the shape of the water uptake pattern with depth varies considerably with frequency of rainfall and/or irrigation.

Some general and specific approaches to water uptake with depth have been used based on root length density and more generic rooting patterns (for example, Hoffman and van Genuchten 1983). The approach is appropriate where subsoil salinities are high because roots cannot remove much water in these situations.

Shockley (1955) found that 40% of soil water extraction by plants occurred within the top quarter of the root zone depth, 30% in the second quarter depth, 20% in the third quarter depth and 10% in the fourth quarter. This relationship has been widely used (for example, Rhoades 1983), and is quite similar to that determined for cracking clay soils at Emerald under 10 to 14 day irrigation (Shaw & Yule 1978). Under conditions of frequent irrigation, higher proportions of soil water extraction are likely in the top 25% of the root zone.

Hoffman and van Genuchten (1983) considered another exponential water uptake pattern. Their pattern probably places too much emphasis on the surface soil depths and underestimates the amount of water available to plants at lower depths in the root zone.

In this handbook, a 40:30:20:10 proportional water uptake pattern for each quarter of the root zone has been adopted for both dryland conditions and irrigated conditions where some water stress will occur.

Water uptake weighted root zone salinity probably provides a better representation of root zone salinity where subsoils are saline. This is typical of many less permeable soils in Australia since subsoil salinity indicates reduced wetting and thus limited water availability.

Average root zone salinity and water uptake weighted root zone salinity are compared graphically in Figure 26.

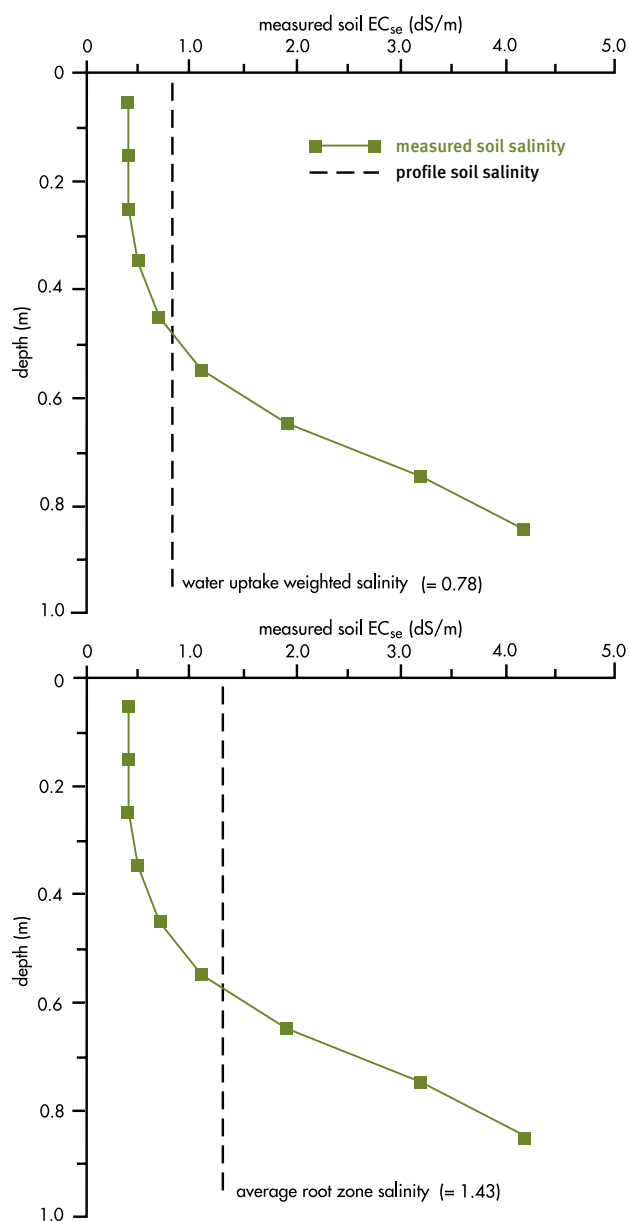
Using the generalised water uptake pattern of Shockley, weighting factors can be derived using the following regression equation (Shaw et al. 1987; based on data from Shockley 1955) for 0.1 m depth increments:

$$\sum (WF_1 + WF_2 + \dots + WF_i) = \left((1.042 \frac{i}{n}) - 0.00128 \right)^{0.6} \dots 16$$

where

- i is number of the 0.1 m depth increment for which the calculation is currently being performed
- WF_i is weighting factor for the current depth increment
- n is total number of depth increments (for example, $n = 9$ for a root zone depth of 0.9 m).

Figure 26. Graphical representation of two measures of root zone salinity: average root zone salinity, and water uptake weighted root zone salinity. Weighting factors are given in Table 10 page 46.



The weighting factors for 0.1 m depth measurements determined using this regression equation for three common root zone depths (0.6 m, 0.9 m and 1.2 m) are shown in Table 10. These factors are applied to actual EC_{se} values to provide weighted values that represent the likely effect of the EC_{se} values on a plant,

based on the concentration of salt and the activity of the plant's roots at that depth. The weighted EC_{se} values are then **summed** down the root zone to provide the measure of water uptake weighted root zone salinity. In Table 11, the weighting factors are presented for commonly used standard soil analysis depths on the assumption that depths below 0.1 m represent the EC of the depth increments on either side of the nominated depth as well as the nominated depth. As an example, the two measures are derived for a black earth soil at Emerald in Table 12.

Table 10. Water uptake pattern weighting factors for 0.1 m depth increments for three common root zone depths, derived using equation 16 (Shaw et al. 1987).

Soil depth increment (m)	Weighting factor for each 0.1 m increment where root zone depth is		
	0.6 m	0.9 m	1.2 m
0-0.1	0.35	0.27	0.23
0.1-0.2	0.18	0.14	0.12
0.2-0.3	0.15	0.11	0.10
0.3-0.4	0.13	0.10	0.08
0.4-0.5	0.11	0.09	0.07
0.5-0.6	0.08	0.08	0.07
0.6-0.7		0.08	0.07
0.7-0.8		0.07	0.06
0.8-0.9		0.06	0.06
0.9-1.0			0.06
1.0-1.1			0.05
1.1-1.2			0.03
Sum	1.0	1.0	1.0

Table 11. Water uptake pattern weighting factors for standard survey depths of three common root zone depths, derived using equation 16 (Shaw et al. 1987).

Soil depth (m)	Weighting factor for each standard depth increment where root zone depth is		
	0.6 m	0.9 m	1.2 m
0-0.1	0.35	0.27	0.23
0.1-0.2			
0.2-0.3	0.46	0.35	0.30
0.3-0.4			
0.4-0.5			
0.5-0.6	0.19	0.25	0.18
0.6-0.7			
0.7-0.8			
0.8-0.9		0.13	0.18
0.9-1.0			
1.0-1.1			
1.1-1.2			0.08
Sum	1.0	1.0	1.0

Converting leaching fraction to root zone salinity

To relate to plant salt tolerance for application in an irrigation situation, leaching fraction can be converted to a water uptake weighted root zone EC_{se} or an average root zone EC_{se} . Average root zone leaching fraction or water uptake weighted root zone salinity can also be calculated from leaching fraction to relate to plant salt tolerance using the relationships in Figure 27. These are derived from Rhoades (1983) as explained by Shaw et al. (1987), where the appropriate regression equations are given.

Smith and Hancock (1986) derived a neater mathematical solution to relate water uptake weighted root zone salinity to the leaching fraction at the bottom of the root zone:

$$EC_{wuw} = \frac{EC_i \ln LF}{LF - 1} \dots\dots\dots 17$$

where EC_i is EC of input water to soil surface.

Table 12. Average and water uptake weighted root zone salinity measures for a black earth soil from Emerald (root zone depth of 0.9 m).

Soil depth increment (m)	Analysed EC_{se} (dS/m)	Water uptake weighting factor (refer Table 10)	Weighted EC_{se} (EC x weighting factor)
0-0.1	0.4	0.27	0.23
0.1-0.2	0.4	0.14	0.12
0.2-0.3	0.4	0.11	0.10
0.3-0.4	0.5	0.10	0.08
0.4-0.5	0.7	0.09	0.07
0.5-0.6	1.1	0.08	0.07
0.6-0.7	1.9	0.08	0.07
0.7-0.8	3.2	0.07	0.06
0.8-0.9	4.2	0.06	0.06
	average root zone: (mean) = 1.42		water uptake weighted root zone: (sum) = 1.03

This equation is very similar to the dashed line in Figure 27. If the bottom of the root zone leaching fraction is known or predicted and the salinity of the input water (rainfall plus irrigation) is known, Figure 27 can be used to calculate root zone salinity and to evaluate plant salt tolerance data and irrigation water quality.

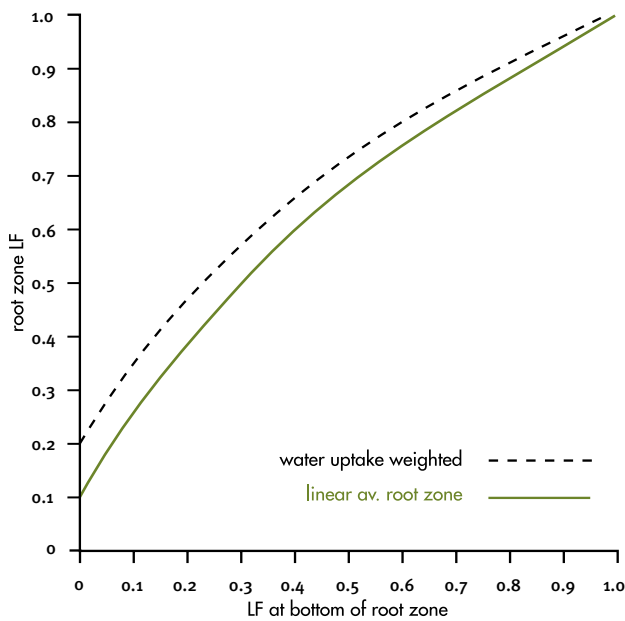
The EC_{se} under irrigation can be varied using the new leaching fraction instead of the assumed leaching fraction of 0.15 to relate to water quality criteria (see **Irrigation** page 81).

Since LF is based on EC_s (field capacity), permissible irrigation water quality for a specified leaching fraction is calculated as:

$$EC_{iw} = 2.2 (EC_{se} LF) \dots\dots\dots 18$$

where the terms EC_{se} and LF are either average or water uptake weighted.

Figure 27. Relationships for assessing average root zone leaching fraction or water uptake weighted root zone leaching fraction, based on the 0.4, 0.3, 0.2, 0.1 water uptake pattern with depth of Rhoades (1983) (Shaw et al. 1987).



Sodicity in soils and waters

The two most common measures of sodicity are:

- exchangeable sodium percentage (ESP), which is the proportion of sodium adsorbed onto the clay mineral surfaces as a proportion of the total cation exchange capacity
- sodium adsorption ratio (SAR), which is the relative concentration of sodium to calcium and magnesium in the soil solution or (irrigation) water.

ESP is a measure of soil sodicity and SAR is a measure of soil solution or water sodicity. The relationship between the SAR of the soil solution at saturation and the ESP is given in USSL (1954) and is generally applicable to a wide range of soils.

Soils with high montmorillonite clay content (those that swell and shrink) can tolerate higher ESP than clay soils with limited capacity to swell and shrink (Shaw et al. 1994). This is because the restructuring of the soil during swelling and shrinking overcomes some of the problems caused by dispersed clay. However, wet dispersed soils (regardless of clay content) will have reduced infiltration and be prone to increased runoff and erosion.

Magnesium associated with sodium has commonly been thought to aid soil dispersibility (for example, Emerson and Bakker 1973). There is considerable evidence that this effect is much more applicable to illite soils than montmorillonite soils, although further research is required. Some researchers propose that low exchangeable Ca:Mg ratios in conjunction with ESP indicate enhanced dispersion. There is still debate about the role of Mg. The alternative view is that Ca causes flocculation, Na causes dispersion, and Mg acts in a fairly neutral manner and, in the absence of Ca, can increase the effects of Na to some extent.

High salt concentration will flocculate the clay and maintain aggregation and hydraulic conductivity. The actual thresholds at which this occurs vary with clay type and ESP. (This is discussed in further detail in **Irrigation** page 81.)

ESP

ESP is determined by routine CEC and exchangeable cation methodologies as outlined by Bruce and Rayment (1982) and Rayment and Higginson (1992). Soluble cations are removed via a washing step and the exchangeable cations (which are subsequently analysed) are displaced by ammonium ions (at a nominated pH). The total CEC is determined by displacing and analysing the ammonium ions.

ESP is calculated as follows:

$$ESP = \frac{100 Na^+}{CEC} \dots\dots\dots 19$$

In the absence of CEC data, the sum of the concentrations of the cations Na^+ , Ca^{2+} , Mg^{2+} and K^+ can be used as an approximation of CEC except:

- in acid soils (unless exchange acidity has been determined, see Bruce and Rayment 1982), where the summation of cation concentrations will provide an overestimate of ESP
- in alkaline soils where Tucker's solution at pH 8.4 (Rayment and Higginson 1992) has not been used to extract cations, since sparingly soluble calcium salts will inflate the value for Ca^{2+} concentration value and hence provide an underestimate of ESP.

In some variable charge soils (usually acid soils), the summation of the concentrations of the four cations may provide an overestimate of CEC, due to pH-dependent charge, and ESP calculated using this CEC may be an underestimate. A more appropriate measure of CEC is necessary for these soils.

SAR

Sodium adsorption ratio (SAR) is calculated as follows:

$$SAR = \frac{Na^+}{\left(0.5(Ca^{2+} + Mg^{2+})\right)^{0.5}} \dots\dots\dots 20$$

where ionic concentrations are in meq/L, determined from the soluble ions in the saturation extract. (If units of mmole_c/L are used, the calculation is the same as equation 20 above. However, if units of mmole/L are used, the concentration of calcium and magnesium ions should not be halved. Converting between these units is illustrated in *Useful conversions and relationships* page 158.)