Chapter 4

Salinity & Sodicity

Summary

- Salinity is the presence of soluble salts in the soil solution
- Salinity decreases plant growth by:
  - Osmotic stress, which reduces the plant's capacity to extract soil water.
  - Specific ion effects, such as chloride (Cl^-) toxicity
  - Creating an imbalance in ions (Ca^{2+}, K^+, Na^+) required for optimal plant function
- In dryland cropping zones of south-eastern Australia short term changes in soil salinity has been termed transient salinity and is an important process affecting crop production
- Sodicity is the presence of excess sodium (Na^+) attached to clay particles
- Sodicity decreases plant growth by:
  - Slowing root growth due to high soil strength and limiting gas exchange in the rhizosphere
- Transient salinity and sodicity generally occur in semi-arid environments such as the Victorian Wimmera and Mallee
- In saline/sodic soils all of these constraints operate simultaneously to decrease the effective root zone of crops, thus limiting plant available water
- Field research in Victoria/South Australia indicates that soil salinity and sodicity can substantially reduce crop yields. The following crops are inhibited by subsoil salinity or sodicity as indicated below:
  - Lentil: EC_e (10 – 40 cm) > 2.2 dS/m
  - Canola: ESP (80 –100 cm) >16 %
  - Wheat: ESP (60 – 100 cm) > 19 %

Saline soil

Salinity is the presence of soluble salts in the soil solution. Excess soluble salts in the root zone reduce plant growth through either osmotic stress or specific ion toxicities.

Salinity generally occurs in arid and semi-arid regions, where leaching of the profile is restricted (Bernstein 1975). Within Australia salinity affects 5.3% (386,300 km^2) of the continent (Northcote and Skene 1972), although this area increases significantly if sodic soils that are also saline are taken into account. Soluble salts in Australian soils come from the weathering of primary minerals, aeolian recycling or cyclic accession, where salts are transported inland by winds off the ocean. Within the Victorian Wimmera and Mallee, soils contain naturally high concentrations of salts, where the chief source of primary salt is cyclic accession and aeolian recycling.

Within the broader landscape, the natural occurrence of salinity is known as primary salinity and is a process linked to climate and geologic control. Although broad scale processes can explain primary salinity, those areas which are natural discharge zones, tend to be insensitive to local management and are avoided by agriculture. In contrast, secondary salinity relates to the movement of salts into the root zone due to rising water tables or ground water activated by either land use change or irrigation. In dryland cropping zones of south-eastern Australia short term changes (temporal) in soil salinity has been termed transient salinity (Rengasamy 2002) and is an important process affecting crop production. Seasonal rainfall and crop evapo-transpiration, rather than shallow saline water tables, drive transient salinity.

Transient salinity usually occurs in poorly draining soils and in arid and semi-arid environments where salts are contained within the root zone. Here, salt concentrations rise and fall as water extraction by crops causes a draw of salt towards the surface and as the soil dries, the soil solution becomes more concentrated with salts. However this process is balanced by subsequent rainfall and leaching. Consequently, this continual short-range oscillation of salts in the profile relates to the variable balance between rainfall and crop water use.

Elements contributing to soil salinity include the cations (positively charged) Sodium (Na^+), Potassium (K^+), Calcium (Ca^{2+}), and Magnesium (Mg^{2+}), and anions (negatively charged) Chloride (Cl^-), Sulphate (SO_4^{2-}), Carbonate (CO_3^{2-}), Bicarbonate (HCO_3^-) and Nitrate (NO_3^{2-}). In assessing salinity, it is the concentration of ions in solution, rather than the type that is important. In the absence of water these salts can combine to produce different crystalline compounds. A common example is table salt, which is crystalline (c) Sodium Chloride (NaCl). When NaCl is placed in water it dissolves into its salt (aqueous) constituents as follows:

$NaCl\ (c) \rightarrow Na^+\ (aq) + Cl^-\ (aq)$

It is the dissolved (aq) form of salts that is mobile in the soil and potentially most damaging to crops. Salt compounds differ in their capacity to dissolve in water. For example, in one litre of pure water a maximum of 357 grams of NaCl (table salt) could be dissolved, where as for $CaSO_4.2H_2O$ (gypsum) only 2.6 grams could be dissolved. The solubility of various salt compounds is compared in Table 4.1.

Table 4.1. Solubility of various salt compounds

Salt compound	Name	Solubility (grams per litre)
$CaCO_3$	Lime or calcite	0.01
$CaSO_4.2H_2O$	Gypsum	2.6
$MgSO_4.7H_2O$	Epsom salts	710
NaCl	Table salt	357
$NaHCO_3$	Sodium bicarbonate	103
Na_2SO_4	Sodium sulfate	200

When multiple salts are in solution, their interaction can influence solubility. For example, the solubility of gypsum increases in the presence of NaCl, thus in salt-affected soils, the amount of gypsum in solution could be potentially three times as much as in non-saline soil (Figure 4.1) (Shaw *et al.* 1987). Alkaline soils in south-eastern Australia have high concentrations of naturally occurring NaCl, this, combined with high solubility, makes NaCl the major contributor to stress experienced by plants in saline soil. Calcium salts may accumulate through continued application of gypsum and/or lime, resulting also in increased soil salinity. The low solubility of gypsum (approximately 2.6 g/L) however, means that the maximum osmotic pressure (stress) contributed by gypsum is about 100 kPa. In contrast the highly soluble nature of NaCl can increase the osmotic pressure dramatically (Rengasamy per comms). For example, 5 t/ha of NaCl at a soil water content of 20% can produce an osmotic stress of 1530 kPa, where as 5 t/ha of gypsum at the same water content will produce only 100 kPa. This is assuming that gypsum is the only salt. Again when salts in soil are mixed, they will have a pyramiding impact on osmotic stress.

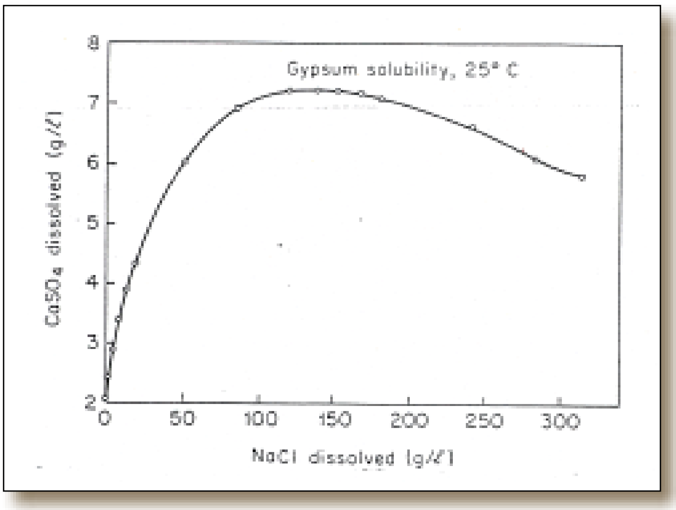

Figure 4.1: Solubility of gypsum given increasing NaCl (sodium chloride) concentration (Shaw et al. 1987).

Units of salinity

Soil salinity can be measured by determining the electrical conductivity of a solution, obtained by saturating or diluting a soil with water. Measuring salinity in a saturated extract (EC_e) gives a different result compared with that measured in a dilute solution ($EC_{1:5}$). The saturated method is a robust measure of salinity in relation to plant growth as it takes soil texture into account. Soil texture is important because the water content at saturation, and the dilution of salts, changes with texture. For example, a 10 cm layer of light (sandy) soil at saturation may contain 15 mm of water whereas for a heavy (clay) soil may contain 30 mm of water. A large range of units is used to describe salinity but the *Australian Laboratory Handbook of Soil and Water Chemical Methods* (Rayment and Higginson 1992) adopted deciSiemens/metre (dS/m) as the standard measure of electrical conductivity and salinity. Arbitrarily, a soil is considered saline when the conductivity of a soil/water paste is greater than 4.0 dS/m (Allison *et al.* 1969).

Soil salinity however, is routinely measured using a 1:5 soil/water suspension ($EC_{1:5}$) because it is relatively quick and inexpensive (Rayment and Higginson 1992). Soil salinity measured as $EC_{1:5}$ can be converted to EC_e using a multiplication factor based on texture (Shaw 1999). These are listed in Table 4.2.

Table 4.2: Conversion figure for estimating EC_e from $EC_{1:5}$ based on soil texture.

Texture	$EC_{1:5}$ to EC_e
Sand	× 12.5
Sandy loam	× 10.0
Loam	× 8.0
Clay loam	× 8.0
Light clay	× 7.0
Heavy clay	× 6.0

Table 4.3: Conversion factors for converting various salinity units to dS/m. Total soluble salts, TSS.

Unit conversion			Factor
mS/cm	to	dS/m	× 1
mmho/cm	to	dS/m	× 1
mS/m	to	dS/m	× 0.01
μS/cm (EC units)	to	dS/m	× 0.001
μmho/cm (EC units)	to	dS/m	× 0.001
meq/L (NaCl)	to	dS/m	× 0.0912
ppm or mg/l (TSS) (for mixed salts)	to	dS/m	× 0.0015625
ppm or mg/l (TSS) (for NaCl)	to	dS/m	× 0.002
bar or kPa (Osmotic potential)	to	dS/m	× -2.78

Sodic soil

Sodicity is the presence of Sodium, attached (exchangeable) to clay particles (plates) of the soil matrix. Sodic soils, by definition, contain excessive concentrations of exchangeable Sodium (Bernstein 1975) and are estimated to cover 27 % (1,997,000 km^2) of the total land area in Australia (Northcote and Skene 1972) and up to 85 % of land used for cropping in Victoria (Ford *et al*. 1993). This compares with 1.0 % (95,600 km^2) in North America (Rengasamy and Olsson 1991).

Measurement

Soil sodicity can be identified by using either field-based (qualitative) or laboratory (quantitative) methods. The field-based diagnostics can be as simple as obvious symptoms in the paddock or the use of common household items to conduct simple tests. These methodologies are covered in 'Field Diagnostics', (Chapter 7).

Laboratory analysis of sodicity measures the Exchangeable Sodium Percentage (ESP) and in soil solutions as the Sodium Adsorption Ratio (SAR). Additionally, as the concentration of salts in the soil solution (salinity) control the affect of sodicity on soil structure, the stability can be estimated using an electrochemical stability index. These three methods are as follows.

Exchangeable Sodium Percentage

Exchangeable cations (K^+, Na^+, Mg^{2+} and Ca^{2+}) in alkaline soils are determined by extraction with a 1M NH_4Cl (pH 8.4) solution for 60 minutes (Rayment and Higginson 1992). Prior to extraction, soluble salts are removed by prewashing with 60% aqueous alcohol (Tucker 1974). This prewashing is done in saline soils as the salts in solution will otherwise cause an over estimation of cations. The extracts are analysed for K^+, Na^+, Mg^{2+} and Ca^{2+} using an inductively coupled plasma-optical emission spectrometer (ICP-OES). ESP is calculated on a relative % basis, and defined as:

$$ESP = ([Na^+]/\sum[Na^+][K^+][Mg^{2+}][Ca^{2+}]) \times 100$$

Where exchangeable sodium and cation exchange capacity are expressed in cmol(+)/kg (meq/100 g soil)

Sodium adsorption ratio

The Sodium Adsorption Ratio (SAR) is the relative concentration of sodium compared to Calcium and Magnesium in a water solution. This is a common test for measuring irrigation water quality and is expressed as:

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

Where Na^+, Ca^{2+} and Mg^{2+} are expressed in me/L. Sodium Adsorption Ratio is an effective way of estimating sodicity because it approximates the activities of various ions in solution. The concentration of Ca^{2+}, Mg^{2+} and Na^+ can be determined either in saturated extract of soils or 1:5 soil/water suspensions.

Electrochemical stability index

For a given sodicity value, as EC increases soil dispersion decreases. Conversely, very low EC values mean that a soil may become dispersive where the ESP of the soil is only 2. Therefore, instead of measuring only ESP, the electrochemical stability index (ESI) = $EC_{1:5}$/ESP has been suggested as a better measure of dispersive behaviour of soils (Hulugalle & Finlay 2003). A critical ESI value for Australian soils is 0.05. Soils with ESI less than the critical value have the potential to disperse.

In Australia, sodic soils are defined as those having an ESP greater than 6 %, within the top metre of soil, and those with an ESP>15 highly sodic (Naidu and Rengasamy 1993; Northcote and Skene 1972). This compares with a threshold value of 15 % assigned to U.S. soil classification systems (Allison *et al.* 1969). The lower threshold value for Australian soils is due to the lower concentration of soluble minerals other than Sodium being able to buffer the effects of Sodium. Sodicity in non-saline soils causes collapse of fine soil structure and the development of massive structure, which on drying causes the soil to have high strength.

Sodicity and salinity (partners in crime)

Sodicity differs from salinity by being a.) specific to one salt (Sodium) rather than a range of salts and b.) a measure of ions on clay surfaces rather than in solution. Because NaCl is the dominant salt in alkaline soils, Sodium exists in both the soil solution and on clay surfaces. Consequently, salinity and sodicity usually occur together, Figure 4.2. It is the varying concentrations of Na^+ in the soil solution and on the clay surface that largely define the physicochemical properties of soils.

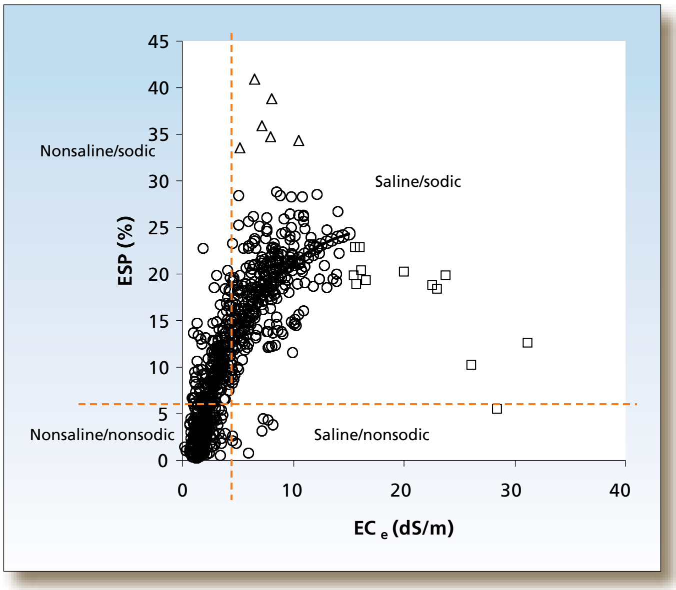

Figure 4.2: Salinity and sodicity for 150 soil profiles in the Victorian southern Mallee. Broken orange lines represent arbitrary critical values for salinity (EC$_e$ >4 dS/m) and sodicity (ESP > 6%). (Nuttall et al. 2003b)

In well-structured soils, negatively charged clay particles are held together by Calcium ions (Ca^{2+}). However, in low rainfall environments, accumulation of Sodium (Na^{+}) from fallout in rainfall over thousands of years, displaces Ca^{2+} from the clay particles. Hypothetically the clay particles now become bound by Na^{+} ions, making the soil sodic (Figure 4.3 a) however, 10 times the concentration of Na^{+} is now required to keep the clay structured. Unfortunately this concentration of Na^{+} relates to the soil being saline. Consequently you can have well-structured sodic clay that is too saline for plant growth. Further, because Na^{+} is highly soluble, fresh water from rainfall dilutes the Na^{+} in the soil solution and between the clay particles. As a result the concentration of Na^{+} drops, the clay particles separate, Figure 4.3 b, and the clay is soupy when wet but on drying becomes massive and hard (Figure 4.3 c).

A sodic soil will not always disperse, provided the salts in the soil solution are high enough to keep clay particles together, Figure 4.4, thus high salinity can potentially mask the physical impact of sodicity on soil structure.

Impact of salinity and sodicity on plant growth

Salinity

High levels of salt adversely affects plant growth through either osmotic stress or ion toxicity (Bernstein 1975), unless the plants are adapted to growing in very saline soils. Such extreme salt tolerant plants are called *halophytes*. Excess soluble salts also decrease the plant available water by raising the water content at which wilting occurs (water is held tighter to soil in saline conditions Figure 4.5 and Figure 4.6). Ordinarily plants draw water from the bulk soil by creating an osmotic potential (difference) across the soil/root boundary where a higher concentration of salt must exist within the root for water uptake to occur.

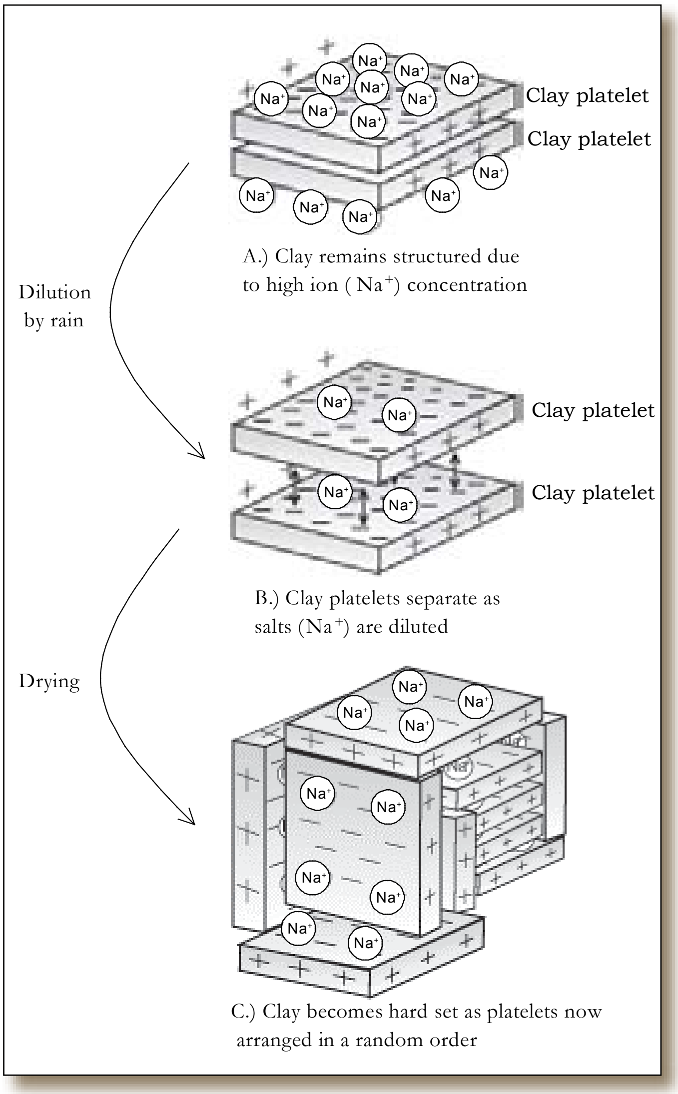

Figure 4.3: Path taken by a sodic clay as it disperses due to dilution of the soil solution and adopts a massive structure on drying. Images modified from Google image.

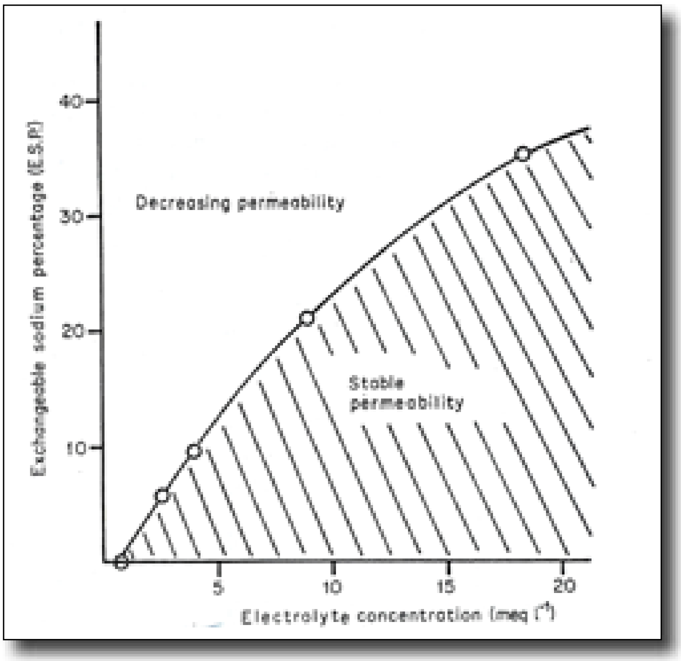

Figure 4.4: The permeability of soil in relation to sodicity (ESP) and salinity (electrolyte concentration). 1 dS/m = 11 meq/L (Talsma & Philips 1971).

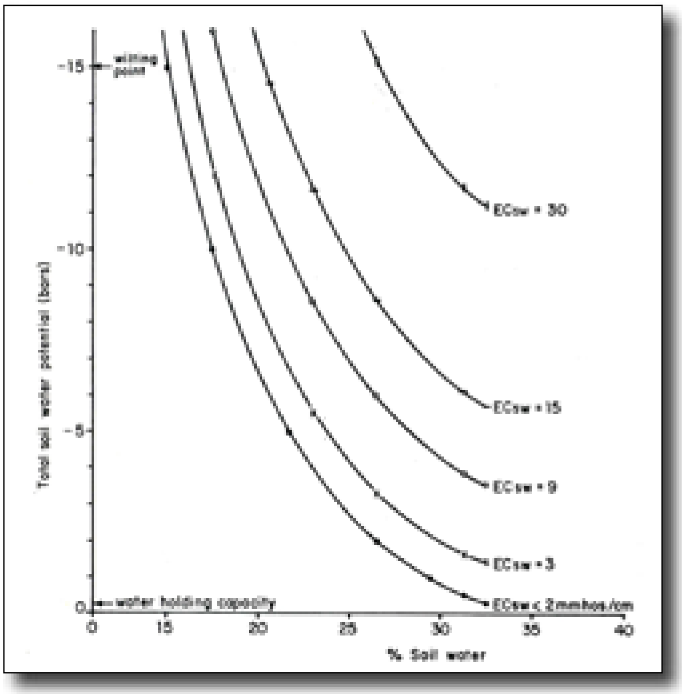

Figure 4.5: Impact of salinity on soil osmotic potential. An increase in osmotic potential due to salinity decreases the available soil water to plants (Warrence et al. 2002).

In a saline soil, the osmotic potential across the soil/root boundary is decreased and the plant becomes water stressed. For water uptake to continue there must be some osmotic adjustment, where the plant absorbs and compartmentalises salt or organic solutes, thus restoring the osmotic potential required for water uptake (Bernstein 1975), resulting in the appearance of wilting even though soil moisture may appear to be adequate. For plants that are non-halophytes, this adjustment comes at a cost as increased accumulation of salts upset metabolic process.

The absorption of excess salts may also cause specific ion toxicity, where excess accumulation of Na^+ and Cl^- within shoots and older leaves causes leaf burn, necrotic spots, leaf bronzing and in extreme cases, death of plants. The most common effect of salinity is stunting of plant growth (Figure 4.7), where top growth is usually suppressed compared with root growth (Maas and Hoffman 1977; Ray and Khaddar 1995). Root growth of wheat can also be reduced under saline conditions (Holloway and Alston 1992; Leidi *et al*. 1991).

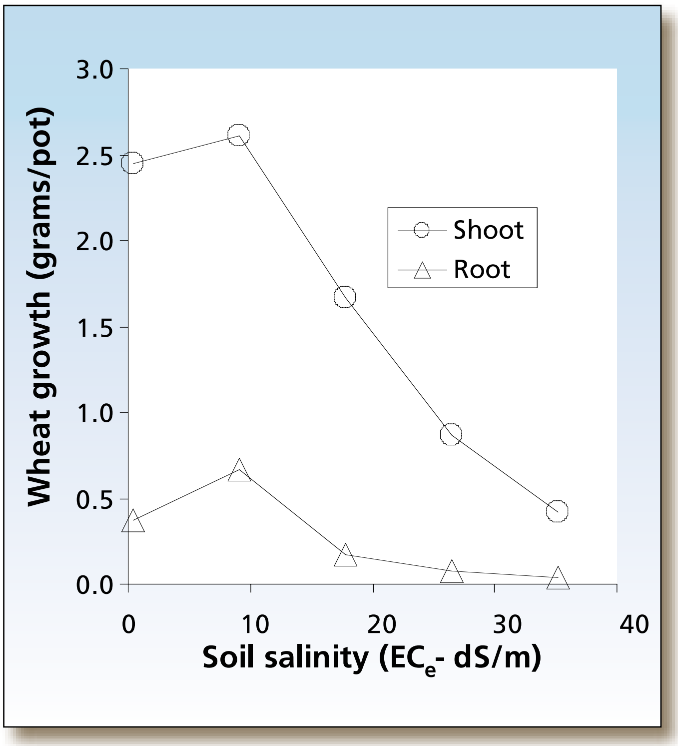

Figure 4.7: Average growth of three wheat (Triticum aestivum) cultivars, viz. Frame, BT Schomburgk and Schomburgk, 49 days after sowing, to increasing soil salinity (Nuttall et al. 2005).

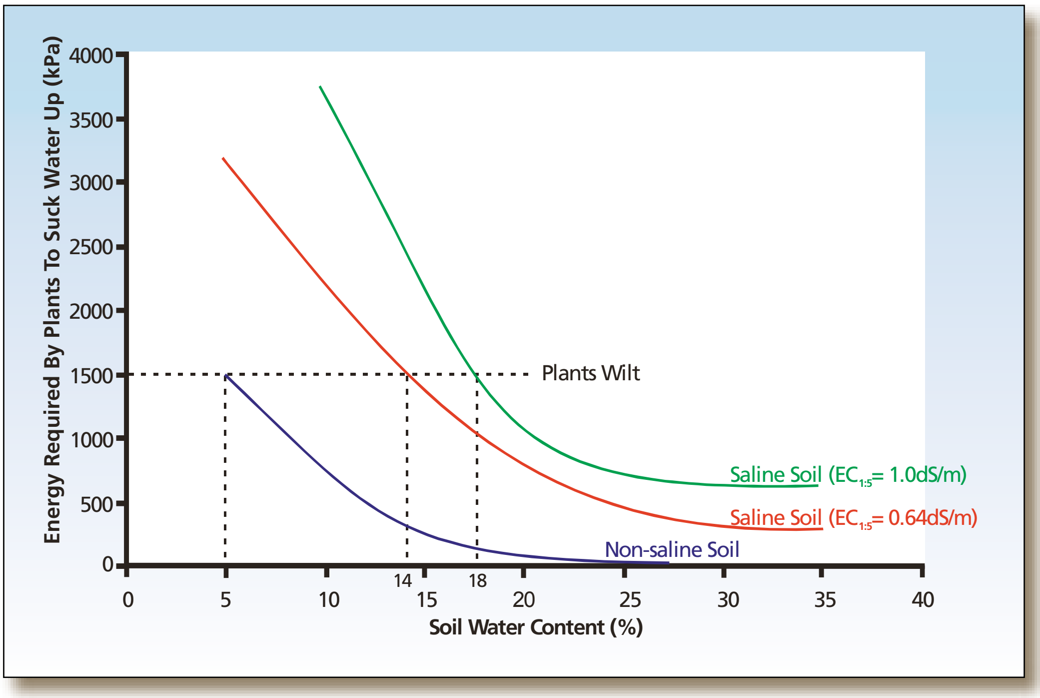

Figure 4.6:
Under saline conditions, the soil water content that plants wilt, increases (Rengasamy et al 2005).

Sensitivity of different crops to salinity

Within dryland crops, wheat and barley are relatively tolerant to salinity, although the sensitivity of cereals varies with growth stage.

Typically cereal crops are most sensitive during emergence and early seedling growth, more than during germination and later stages of growth and grain development (Francois *et al.* 1986; Maas and Hoffman 1977). Exposure of cereals to salt reduces yield potential by restricting the number of tillers (Holloway and Alston 1992) or reducing kernal size (Francois *et al.* 1986). Whole plant response also depends on the period of exposure to saline conditions (Munns and Termaat 1986). Short term exposure (days) leads to a reduced rate of leaf expansion. This response is reversible if salinity concentration is reduced soon after. However, under prolonged exposure (weeks), plant death will occur due to excessive accumulation of Na^+ and Cl^-.

The impact of salinity on plant growth is also influenced by soil water content, where dilution of the soil solution, either by irrigation or rainfall, reduces osmotic stress. However, as water is progressively lost through crop transpiration or by evaporation, salt concentration in the soil solution gradually increases, resulting in salinity and greater plant stress. In dryland systems, climate will significantly influence plant response to salinity, where most crops are more sensitive to salinity under hot, dry conditions i.e. high evaporative demand with irregular rainfall, rather than under cool moist conditions (Maas 1986).

Lentil crops were found to be particularly sensitive to salinity that occurred in the shallow subsoil on alkaline soils in the Victorian Wimmera and Mallee (Nuttall and Armstrong 2009). Lentil yields varied substantially on a spatial basis, both within and across paddocks (Figure 4.8 a) and rainfall explained greatest variation in yield. Subsoil salinity at 40 – 60 cm depth was the best indicator of the impact of subsoil constraints on lentil yield.

For example, the probability of obtaining a 1.0 – 1.5 t/ha lentil yield over 3 years was 74% when salinity was less than 3.2 dS/m in the 40 – 60 cm subsoil layer, but only 22% when salinity was greater than 3.2 dS/m (Figure 4.8 b). Soil Chloride did not affect yield on these soils.

Maas also developed a relationship to estimate the relative yield loss for any given soil salinity. The first value defines the threshold salinity (EC_e) at which no reduction in yield was observed compared with a non-saline control and the second, the percent decrease per unit increase in salinity (Maas and Hoffman 1977). Table 4.4 a & b lists the salt tolerance of various agricultural crops.

Sodicity

Sodicity in non-saline soils causes soil structure to collapse and massive structure to develop (Bernstein 1975). On drying, the massive structure causes the soil to have high strength (Leeper 1963). High soil strength slows growth of the primary roots by imposing large mechanical impedance to advancing root tips (Masle and Passioura 1987; Shaw *et al.* 1998). Gas exchange within the rhizosphere and uptake of water and nutrients can also

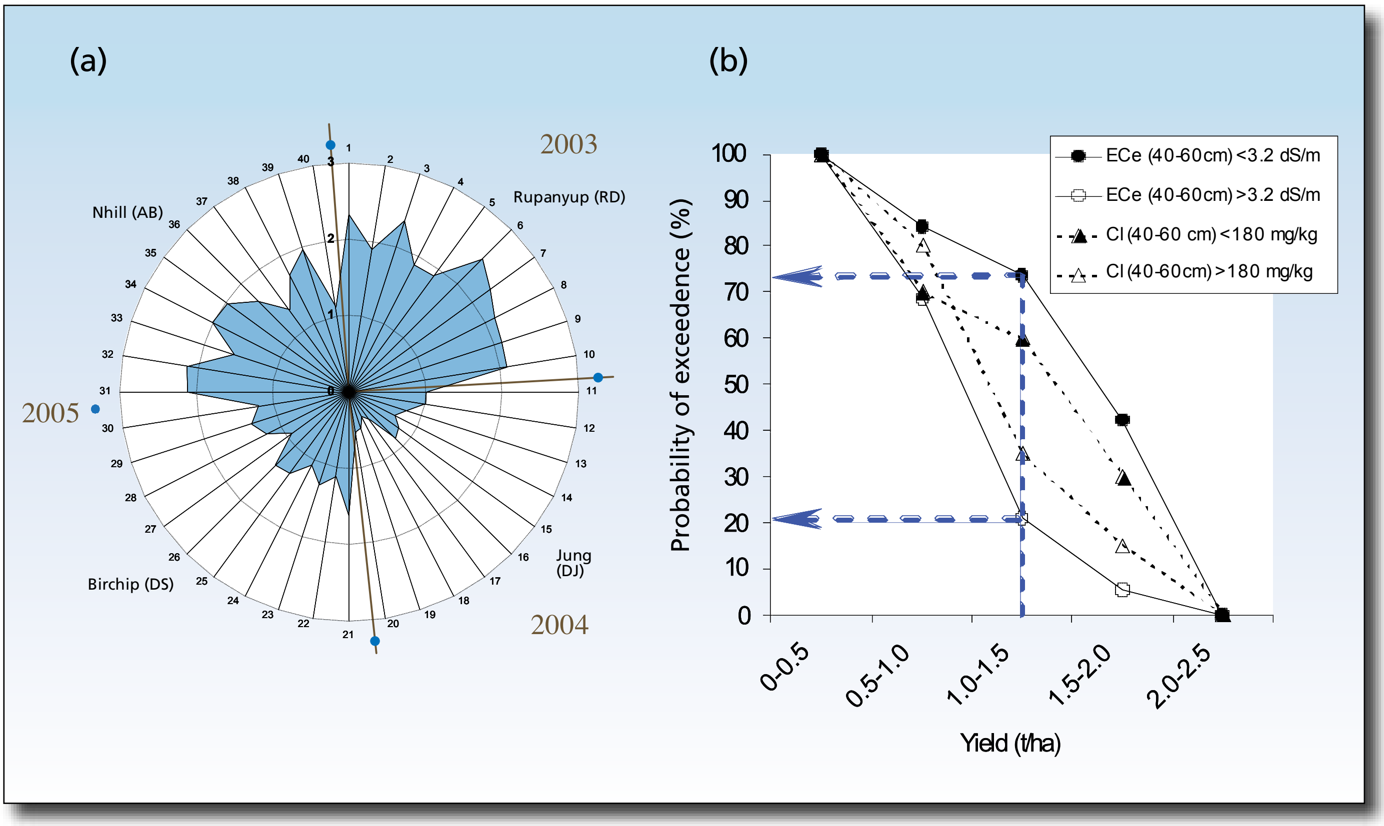

Figure 4.8 a: Variation in lentil yield (t/ha) across 4 paddocks over 3 years. For this radar graph, distance from the centre is yield and numbers on the circumference are the survey points within and across paddocks. (b): Probability of exceedence for lentil yield given subsoil (40-60 cm) salinity and chloride. (Nuttal and Armstrong 2009)

Table 4.4 a: Salt tolerance of agricultural crops, modified after (Maas and Hoffman 1977). Salinity ratings are tolerant (T), moderately tolerant (MT), moderately susceptible (MS) and susceptible (S).

Plant	**Salinity at initial yield decline (threshold)**	**Yield decrease per unit increase in salinity beyond the threshold.**	**Salinity tolerance rating**
Crop	**EC_e (dS/m)**	**%**	
Barley *Hordeum vulgare*	8.0	5.0	T
Bean *Phaseolus vulgaris*	1.0	19.0	S
Broadbean *Vicia Faba*	1.6	9.6	MS
Oats *Avena sativa*	-	-	MT
Safflower *Carthamus tinctorius*	-	-	MT
Triticale *X Triticosecale*	-	-	T
Wheat *Triticum aestivum*	6.0	7.1	MT
Wheat (semidwarf) *T. aestivum*	8.6	3.0	T
Wheat, Durum *T. turgidum*	5.9	3.8	T

be restricted due to waterlogging (Naidu and Rengasamy 1993; Passioura 1991).

On alkaline soils in south-eastern Australia the impact of high Na^+, both within the soil solution (salinity) and on the clay exchange sites (sodicity), are likely to occur together, resulting in osmotic and toxicity limitations on the plant, and soil physical effects acting simultaneously. In alkaline soils sodicity typically increases with depth, as clay content also increases. The affect of salinity and sodicity on crop growth was assessed using results of a survey of the growth of Frame wheat in farmers paddocks in the southern Mallee during 1999 (Nuttall *et al.* 2003). Rainfall around anthesis, soil water in the shallow subsoil (10 – 40 cm) at sowing, top soil nitrate and salinity and sodicity in the 60 – 100 cm layer were shown to be critical factors controlling grain yield, with subsoil constraints accounting for nearly 40% of the variability in grain yield. The impact of subsoil sodicity (Figure 4.9) was most apparent for yields in the range 3.0 – 3.5 t/ha, where the probability of wheat yielding in this range was 60% for sites where ESP <19% compared with 12% when ESP >19%. In comparison, salinity had a less pronounced affect on yield compared with ESP. Importantly, wheat yields were not affected by high boron in these soils. This reflects the advantage of growing Boron tolerant cultivars and also highlights the need for pyramiding additional Sodium tolerance so better adaptation of crops to these alkaline soils can be achieved.

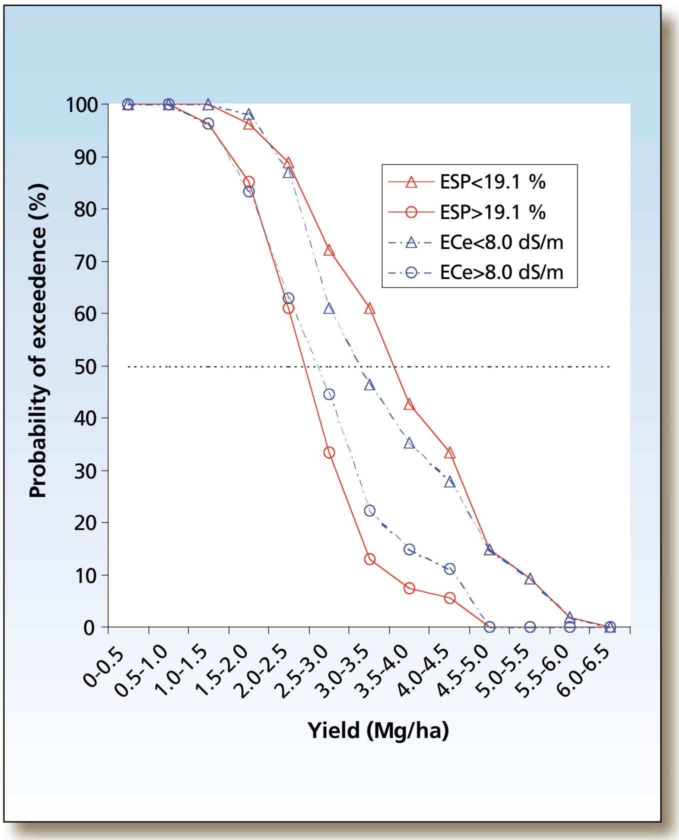

Figure 4.9: The probability of exceeding a given grain yield for wheat (Triticum aestivum) when the ESP (sodicity) of the subsoil (0.60-1.00 m) is either less than (<) or greater than (>) 19% and ECe (salinity) is either less than (<) or greater than (>) 8.0 dS/m

Table 4.4 b: Salt tolerance of grasses and other forages, modified after (Maas and Hoffman 1977). Symbols as for table 6.2 a.

Plant	**Salinity at initial yield decline (threshold)**	**Yield decrease per unit increase in salinity beyond the threshold.**	**Salinity tolerance rating**
Grasses and forage	**EC$_e$ (dS/m)**	**%**	
Alfalfa *Medicago sativa*	2.0	7.3	MS
Clover alsike *Trifolium hybridum*	1.5	12.0	MS
Clover Berseem *T. alexandrinum*	1.5	5.7	MS
Clover, strawberry *T. fragiferum*	1.5	12.0	MS
Fescue, tall *Festuca elatior*	3.9	5.3	MT
Hardinggrass *Phalaris tuberosa*	4.6	7.6	MT
Milkvetch, Cicer *Astragalus cicer*	-	-	MS
Ryegrass, perennial *Lolium perenne*	5.6	7.6	MT
Trefoil, narrowleaf birdsfoot *L. corniculatus tenuifolium*	5.0	10.	MT
Vetch, commom *Vicia angustiflolia*	3.0	11.	MS
Wheatgrass, tall *Agropyron elongatum*	7.5	4.2	T

Differing salinity and sodicity of alkaline subsoils (0.60-1.00 m) in the southern Mallee also had a big impact on the root growth and water extraction by wheat (Table 4.5). Very little water extraction occurred when ESP>19% or EC$_e$ > 8 dS/m however, for subsoils with lower salinity and sodicity (ESP <19% or EC$_e$ < 8 dS/m), water use (and grain yield) by the crop increased significantly. For this simple example a mean difference of 13 mm of soil water between the high and low salinity (EC$_e$) populations equates to 0.26 t/ha of grain.

Canola crops also showed sensitivity to sodicity in the deeper subsoil on alkaline soils in the Victorian Wimmera and Mallee. Variation in the yield of 3 different canola crops (Figure 4.10 a) was partly explained by subsoil sodicity at 80 – 100 cm, although both growing season rainfall and stored subsoil water explained the largest proportion of the variation in yields.

For example, the probability of getting a 1.6 –1.9 t/ha canola yield was 50% when sodicity was less than 16% in the 80 – 100 cm subsoil layer, but only 11% when sodicity was greater than 16% (Figure 4.10 b).

Table 4.5: Wheat root growth and water extraction in alkaline subsoils (0.60 – 1.00 m) in relation to ESP and ECe in the layer. Negative values represent water used by crop from this soil layer. Subsoils had >15 mm of available water at sowing.

	Root density (g/m^3)	**Water extraction (mm)**	
		Sowing to anthesis	**Sowing to maturity**
ESP < 19%	45	8	10
ESP > 19%	26	-3	3
ECe < 8 dS/m	49	8	13
ECe > 8 dS/m	21	3	0

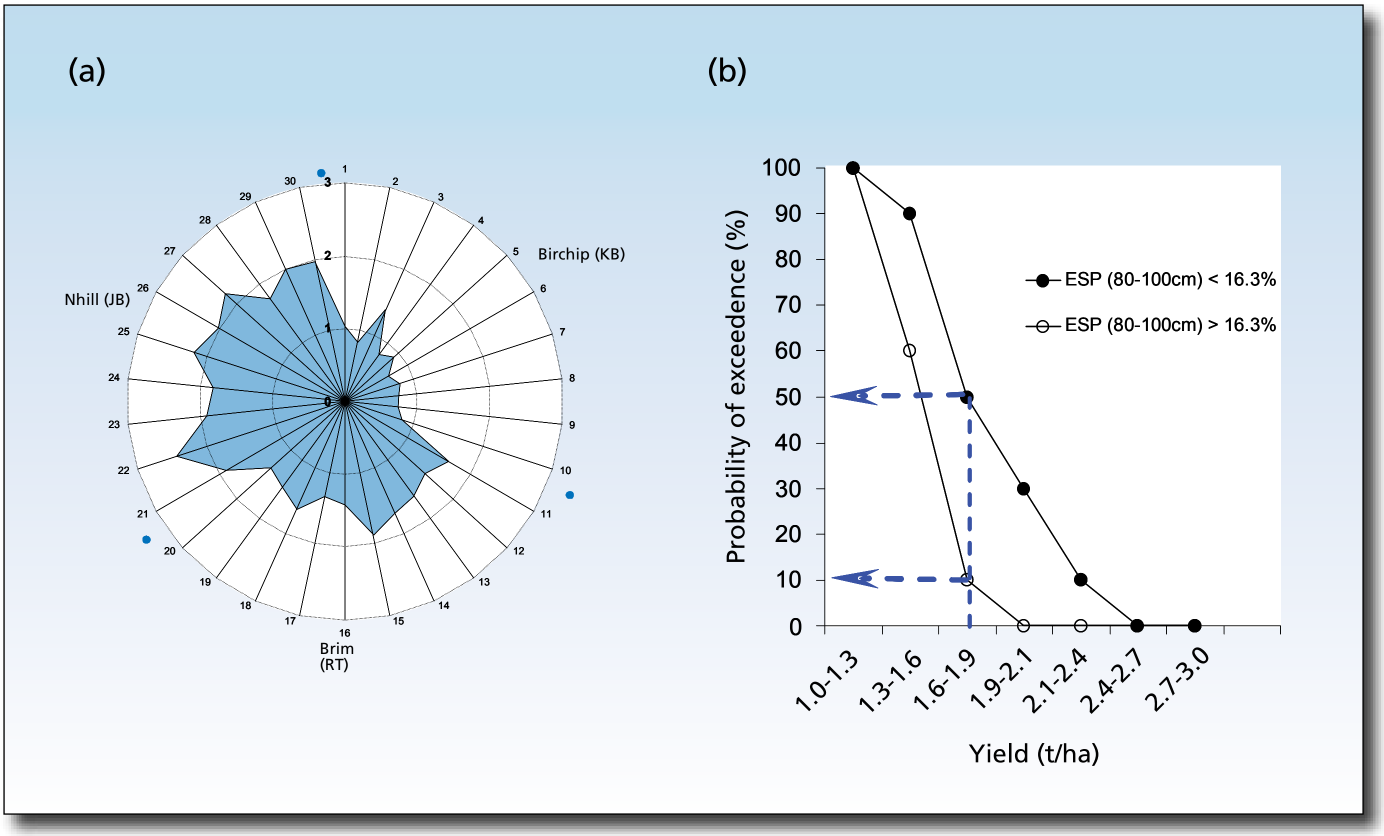

Figure 4.10 a: Variation in canola yield (t/ha) across 3 paddocks for 2003. For this radar graph, distance from the centre is yield and numbers on the circumference are the survey points within and across paddocks.

Figure 4.10 b: Probability of exceedence for canola yield given subsoil (80 – 100 cm) ESP (%) (sodicity). Data was restricted to where grain number was greater than 50000 grains/m^2.

(Nuttal and Armstrong 2008)

Conclusions

Most soil used for cropping in Victoria are sodic, and even if the topsoil is not saline, there is a very high probability that the subsoil will contain high and potentially limiting levels of salinity and sodicity to crop growth. Field research in Victoria/South Australia indicates that soil salinity and sodicity can substantially reduce crop yields. It was estimated that wheat yield was reduced when ESP (60-100 cm) > 19 %, for lentil EC_e (10-40 cm) > 2.2 dS/m, and for canola - ESP (80-100 cm).

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