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The Relationship Between the Concentration of Total Soluble Salts and Osmotic Potential in Soil, Ground and Surface Waters for Several Regions of Western Australia

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Disclaimer

The contents of this report were based on the best available information at the time of publication. It is based in part on various assumptions and predictions. Conditions may change over time and conclusions should be interpreted in the light of the latest information available.

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Summary

Salinity is a problem for agriculture in Western Australia. One way in which salinity affects plant growth is by lowering the osmotic potential of water. This in turn makes it more difficult for plants to take up water, which can lead to reductions in growth. In Western Australia salinity data are commonly reported in milligrams of total soluble salts per litre of solution. Laws from solution chemistry and data on the soluble salt composition for various regions of the State were combined to derive a relationship between total soluble salt concentration (C) and osmotic potential (π_o) for each region. For the south-west of Western Australia, which contains the most productive agricultural areas in the State, this relationship is

$$\pi_o = 0.075 c$$

where π_o is in units of kPa and C is in units of mg/L. The relationships for the other regions have the same form but different coefficients.

Introduction

Salinity is a problem for agriculture in Western Australia. ~Currently there are some 315,000 ha of agricultural land in the State where plant growth is seriously affected by high salt concentrations in the soil water. At present the salt affected area is increasing at a rate of about 5% per year (Western Australian Department of Agriculture 1988). The reasons for the salinity problems in Western Australia are reviewed by Peck and Hurle (1973) and Western Australian Department of Agriculture (1988).

There are two ways in which salinity affects plant growth. Firstly, salts, or more precisely the ions of dissociated salts, can become toxic to plants if their concentration in the soil water exceeds a certain value. The concentration at which there is a toxic effect depends on the ion and plant species involved (Bernstein 1974). Secondly, salts lower the osmotic potential of soil water. This in turn lowers the total soil water potential (ψ_s), which is the sum of the matric (ψ_m), osmotic (ψ_o) and gravitational (ψ_g) potential of the soil water as given by the equation;

$$\psi_s = \psi_m + \psi_o + \psi_g \quad [1]$$

To extract water from the soil, a plant's leaf water potential (ψ_l) must be less than (ψ_s). Depending on the plant species, stomata begin to close when (ψ_l) reaches -500 to -1500 kPa. This leads to a reduction in photosynthesis. When (ψ_l) reaches -1500 to -3000 kPa, the stomata are completely closed and photosynthesis ceases (Begg and Turner 1976). Leaf enlargement and other growth processes begin to be affected at even higher (less negative) (ψ_l) values than those which affect photosynthesis. They also cease at higher values (Boyer 1970, Hsiao 1973). Hence, if the concentration of soluble salts in the soil water is high enough to lower (ψ_o) to several hundred kPa, plant growth may be reduced even if (ψ_m) is close to zero. A (ψ_m) close to zero implies that the soil water content is high. This illustrates that, apart from toxic effects, a high salt concentration has the same impact on plant growth as a low soil water content, the latter being associated with a low (ψ_m). Note that all salts in the water influence its osmotic potential, while only the concentration of salts, or more specifically ions, which are toxic to a plant is responsible for toxic effects.

In addition to the osmotic potential of soil water it is also useful to know the osmotic potential of ground and surface waters. Irrigation is practiced in several areas of Western Australia. A knowledge of the osmotic potential of ground and surface water resources helps to assess their suitability for irrigation. Also, where ground water is close to the root zone, information about its osmotic potential is useful to determine its effect on plant growth. If its osmotic potential is high (close to zero), then capillary rise of ground water into the root zone adds to the amount of water available to the plants. If its osmotic potential is low, then capillary rise of ground water is likely to retard plant growth by lowering the osmotic potential of water in the root zone. In Western Australia salinity data are commonly reported as the concentration of total soluble salts expressed in milligrams of total soluble salts per litre of solution. In this paper the relationship between total soluble salt concentration and osmotic potential

in soil, ground and surface waters will be derived for several regions of Western Australia.

Figure 1 Map showing the regions referred to in table 1



Methods

Salt concentration and osmotic potential are related by the equation

$$\pi_0 = x n \underline{M} R T \quad [2]$$

where x = osmotic coefficient, n = number of mols of ions formed by one mol of salt, \underline{M} = Molality of the solution (mols of salt/kg of water), R = gas constant

$$(8.31 \text{ kPa L mol}^{-1}\text{K}^{-1})$$

and T = absolute temperature ($^{\circ}\text{K}$). The osmotic coefficient is a factor which accounts for the interaction between ions. If there is no interaction, in which case all salts are completely dissociated, $x = 1$. Otherwise x is smaller or greater than 1, depending on the molality of the solution and the salt involved (Robinson and Stokes 1955). In dilute solutions $x = 1$. Also, in dilute solutions molality is approximately equal to molarity so that equation [2] can be simplified to

$$\pi_0 = n M R T \quad [3]$$

where M = molarity of the solution (mols of salt/L of solution). For a detailed discussion of equations [2] and [3] the reader is referred to Robinson and Stokes (1955) and Slatyer (1967).

Loh *et al.* (1983) reported the soluble salt composition for various regions of Western Australia. The regions are shown in Figure 1 and the composition data are given in Table 1. The values are based on surface water samples but are assumed to be valid for soil and ground water, too, since most water passes through the soil and ground water system or at least across the soil surface before it enters the surface water system.

The relationship sought is one between osmotic potential and the concentration of total soluble salts in units of mg of salt/L of solution, hereafter abbreviated as C . Equation [3] requires the concentration in units of mols/L. However, C and M are related as

$$M = C / 1000 m \quad [4]$$

where m = molecular mass (g/mol) of the solute. The factor 1000 in the denominator converts from units of g to units of mg. Combining equations [3] and [4] then yields

$$\pi_0 = (n C / 1000 M) R T \quad [5]$$

For a solution containing several solutes equation [5] becomes

$$\pi_0 = \sum \pi_{oi} = R T \left(\sum [n_i c_i / 1000 m_i] \right) \quad [6]$$

where the subscript i refers to the solute component i . Equation [6] implies that the total osmotic potential of a solution is the sum of the osmotic potentials brought about by the individual components. C_i can be written as

$$C_i = C f_i \quad [7]$$

COMPONENT	MOLECULAR MASS ¹ (g/mol)	FRACTION OF TOTAL MASS					
		REGION ²					
		A	B	C	D	E	F
Cl ⁻	35.453	0.529	0.508	0.528	0.343	0.166	0.045
HCO ₃ ⁻	61.0171	0.027	0.067	0.058	0.147	0.370	0.427
SO ₄ ⁻⁻	96.0576	0.060	0.0048	0.045	0.097	0.105	0.030
NO ₃ ⁻	62.0049	0.002	0.005	0.006	0.032	0.015	0.043
Na ⁺	22.98977	0.286	0.267	0.266	0.238	0.120	0.072
K ⁺	39.0983	0.007	0.007	0.006	0.034	0.027	0.021
Mg ⁺⁺	24.305	0.039	0.045	0.048	0.033	0.034	0.042
Ca ⁺⁺	40.08	0.016	0.020	0.023	0.030	0.088	0.067
SiO ₂	60.0843	0.035	0.032	0.019	0.046	0.073	0.206

Table 1. Soluble salt composition for various regions of Western Australia (data from Loh *et al.* 1983)

¹ based on atomic mass data from Weast (1982)

² the regions are shown in Figure 1

where f_i = fraction the component i contributes to the total mass of soluble salts in the solution. Substituting this equality into equation [6] gives

$$\pi_o = CRT/1000) \quad (n_i f_i / m_i) = C \quad [8]$$

where $\pi_o = (RT/1000) \quad n_i f_i / m_i$. Equation [8] gives the desired relationship between π_o and C . Table 1 lists the values of f and m for each component. Since all components except SiO₂ are ions and SiO₂ does not dissociate into ions, $n_1 = 1$ for all components in the table.

Results and Discussion

The relationships between C and π for the various regions with the value of R given above and $T = 293.15^\circ\text{K}$ (20°C) are given in Table 2. The relationships for the regions in the south-west of the State (regions A, B and C) are the same for all practical purposes so that one relationship can be applied for all three regions. The most productive agricultural areas of Western Australia are in these regions. Table 2 further shows that the salt concentration required to lower the osmotic potential by a given amount increases towards the north of the State. The relationships in Table 2 are for 293.15°K (20°C). They could be adjusted for other temperatures by substituting the desired temperature into equation [8] or by multiplying the coefficients in Table 2 by the ratio of the desired temperature in $^\circ\text{K}$ to 293.15°K . In most cases the temperature of soil, ground and surface water is between 10 and 30°C , and in extreme cases between 0 and 40°C . At 10°C the coefficients would be 3.4% lower than those shown in Table 2, and at 0°C they would be 6.8% lower. Conversely, at 30 and 40°C the coefficients would be 3.4 and 6.8% higher, respectively. These deviations are small so that the relationships in Table 2 can be applied with sufficient accuracy over this temperature range. In deriving the relationships it was assumed that $M = \underline{M}$. These two parameters are related by the equation

$$\underline{M} = 1000 M / [\rho - (\text{mM})] \quad [9]$$

given by Weast (1982), where ρ = density of the solution (g/cm^3). The factor 1000 in the numerator converts from units of g to units of kg and the factor 1000 in the denominator converts from units of cm^3 to units of L. The salt composition in the waters of south-west Western Australia (regions A-C) is very similar to that of sea water (Loh *et al.*, 1983) so that a 1 molar solution has practically the same salt content as sea water, namely about $33,000 \text{ mg/L}$. The density of such a solution is therefore about the same as that of sea water, which is $1.025 \text{ g}/\text{cm}^3$ (Weast 1982). The density of solutions at other concentrations can thus be calculated as

$$\rho_{\text{sn}} = \rho_{\text{sw}} M + \rho_{\text{pw}} (1 - m) \quad [10]$$

Table 2. The relationship between salt concentration (C) and osmotic potential (π) for various regions of Western Australia.

REGION ¹	RELATIONSHIP ²
A	$\pi = 0.076 C$
B	$\pi = 0.075 C$
C	$\pi = 0.076 C$
A-C	$\pi = 0.075 C$
D	$\pi = 0.067 C$
E	$\pi = 0.056 C$
F	$\pi = 0.050 C$

- ¹ the regions are shown in Figure 1
² for π in units of kPa and C in units of mg/L

where the subscripts sln, sw and pw refer to solution, sea water and pure water, respectively. A comparison of equations [5] and [8] shows that for a mixture of solutes

$$m = (m^i / f^i)^{-1} \quad [11]$$

which yields $m = 32.29$ g/mol for the solute composition of regions A-C. Using this information in equation [9] it can be shown that, for the salt composition typical for south-west Western Australia, M is within 1% of \underline{M} for concentrations up to 1.4 mol/L (45,160 mg/L). Making the assumption $M = \underline{M}$ therefore does not introduce a significant error. It is not possible to do the same computations for the other regions since the density of solutions with a salt composition typical for these regions is not known. However, in light of the results for the south-west of the State, it appears unlikely that this assumption would cause an appreciable error.

In deriving the relationships in Table 2 it was further assumed that $X = 1$. Values of X presented by Robinson and Stokes (1955) suggest that this is a good approximation for salt concentrations below 0.001 mol/L, which in south-west Western Australia corresponds to about 32 mg total soluble salts per litre of solution. (The conversion between mol/L and mg/L is given by equation [4]). Such a low concentration rarely occurs. The lowest salinities are typically around 100 to 200 mg/L. Salinities are frequently above 1000 mg/L and concentrations in excess of 10,000 mg/L are not uncommon. These concentrations are equivalent to 0.003 to 0.006, 0.03 and 0.3 mol/L, respectively. For such concentrations x can be expected to be different from 1. Its exact value for a solution with the mix of components shown in Table 1 would have to be experimentally determined. However, some idea about its value can be gained from values of x published by Robinson and Stokes (1955). These suggest that for a concentration of 0.006 mol/L (200 mg/L), $x = 0.96$, and for concentrations between 0.03 and 1 mol/L (1,000 to 32,260 mg/L), $x = 0.93$. For most practical applications this is still close enough to $x = 1$ to make a correction of the relationships in Table 2 unnecessary. Note that the salt concentrations in mg/L which correspond to the concentrations in mol/L quoted above are higher for the other parts of Western Australia.

Another reason why a correction of the relationships in Table 2 for the above deviations is not warranted is that the salt concentration in soil water varies. The concentration is higher around plant roots than in the bulk soil (Dalton *et al.* 1975, Fiscus 1975, Sinha and Singh 1976). Water flowing to the roots carries salt with it, but when the water is taken up by the plants most of the salts are left behind. Salts therefore accumulate around the roots. Also, water uptake by plants reduces the soil water content which increases the salt concentration. The change in salt concentration brought about this way is given as

$$C_t = C_i (\theta_i / \theta_t) \quad [12]$$

where θ = soil water content, and the subscripts i and t refer to the initial value of C and θ , and their value at time t , respectively. Addition of water to the soil also results a change in the salt concentration if the concentration of the water added is different from that already in the soil. The new concentration (C_t) will then be

$$C_t = [C_i + C_n (t - i)] / t \quad [13]$$

where C_n = salt concentration of the water added. Note that in equations [12] and [13] the choice of units for t is immaterial since it only appears in a ratio of t values.

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