The soil specific nature of threshold electrolyte concentration analysis

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Abstract

Maintenance of soil permeability is paramount to irrigation, especially as the use of saline-sodic waters increases. While research has shown that soil permeability can be maintained under high sodicity conditions, provided the electrolyte concentration is sufficiently high, there is relatively little information depicting threshold electrolyte concentration (TEC) relationships. Furthermore, even though TEC curves have been shown to be soil specific and dependent on soil properties such as clay mineralogy, clay content and organic matter content, guidelines for irrigation management in Australia do not currently acknowledge this. The work reported in this paper provides examples of TEC relationships for a range of soils from southern Queensland. Through correlation analysis, the work also investigates the role of clay content, mineralogy and organic matter in determining these relationships. Calculation of TEC curves for 6 south-eastern Queensland soils illustrated that TEC relationships are soil specific, even within soil orders; contrary to current guidelines. Additionally, correlation analysis revealed that there were no apparent relationships between the critical EC and SAR values (those determining TEC functions) and soil properties such as clay mineralogy, clay content and organic matter content.

Introduction

Saline and sodic waters are increasingly being used for irrigation purposes. In particular, the rapid development of the coal seam gas (CSG) industry throughout eastern Australia has raised interest in the productive use of saline-sodic water. A key determinant to the sustainable use of saline and sodic water for irrigation is the maintenance of soil permeability. The application of sodic water without appropriate management has been shown to increase reactive clay swelling and dispersion (McNeal *et al.* 1968), change pore size distribution (Jayawardane and Beattie 1978) and decrease the saturated hydraulic conductivity (K_{sat}) of soils (McNeal and Coleman 1966; Quirk and Schofield 1955). However, Quirk and Schofield (1955) demonstrated that soil permeability can be maintained even under conditions of high sodicity (sodium adsorption ratio – SAR) provided the electrolyte concentration (EC) of the soil solution is greater than a critical value, known as the Threshold Electrolyte Concentration (TEC).

Quirk and Schofield (1955) suggested that the TEC could be identified on the basis of a 10% reduction in K_{sat} from the stable condition. However, McNeal and Coleman (1966) subsequently proposed using a 25% K_{sat} reduction and Cook *et al*. (2006) suggested a 20% K_{sat} reduction as the TEC value. Importantly, the TEC varies with soil type (Quirk 2001; Rengasamy and Olsson 1991), with the key soil properties known to affect the permeability being clay content (Frenkel *et al.* 1977; Goldberg *et al.* 1991; McNeal *et al.* 1966), mineralogy (Churchman *et al.* 1995) and organic matter type and content (Nelson and Oades 1998). Despite this, there are very few examples of TEC relationships found in the published literature and the ANZECC (2000) guidelines for water quality are commonly used as a guide to the appropriate selection of saline-sodic water to maintain soil permeability. However, these TEC curves (Figure 4.2.2 in ANZECC 2000) were developed from a single study (DNR 1997) conducted on only two soils and cannot be considered representative of the range of soils encountered throughout Australia. The aim of the work reported in this paper is to provide examples of TEC relationships for a range of soils from southern Queensland and to investigate the role of clay content, mineralogy and organic matter in determining these relationships.

Method

This study is reported in two parts. The first set of data provides an example of the TEC analysis for six soils only and the second set uses aggregated TEC data to investigate the relationships between TEC and selected soil properties for 36 soils from south-east Queensland.

Six soil samples were taken from Roma and the Darling Downs (Table 1). These were air-dried before being crushed to pass through a 2.36 mm sieve. Soil chemical measurements (exchangeable cations, exchangeable sodium percentage – ESP, cation exchange capacity – CEC) and organic matter content

(OMC) were calculated using standard procedures outlined in Rayment and Higginson (1992). The method for determining clay cation ratio (CCR), an indicator of clay mineralogy, was consistent with Shaw and Thorburn (1985). Clay content was obtained using particle size analysis consistent with (Gregorich *et al.* 1988).

Table 1. Selected soil properties of six south-east Queensland soils used for the TEC comparison

Soil	Soil order	Texture	Clay content (%)	OMC (%)	ESP (%)	EC1:5 (dS/m)	Ca:Mg	CEC (meq/100 g)	CCR (meq/g)
1	Grey Vertosol	Medium clay	44.3	1.7	3.7	0.05	1.14	21.40	2.07
2	Black Vertosol	Heavy clay	56.9	1.7	2.7	0.06	2.24	31.80	1.79
3	Red Chromosol	Sandy loam	12.7	0.8	1.2	0.04	3.08	5.13	2.48
4	Brown Chromosol	Silty loam	5.3	0.6	1.2	0.12	10.46	3.36	0.16
5	Brown Chromosol	Sandy loam	12.6	0.9	0.6	0.02	5.07	6.25	2.02
6	Black Vertosol	Medium clay	44.3	1.9	4.5	0.21	2.93	39.80	1.11

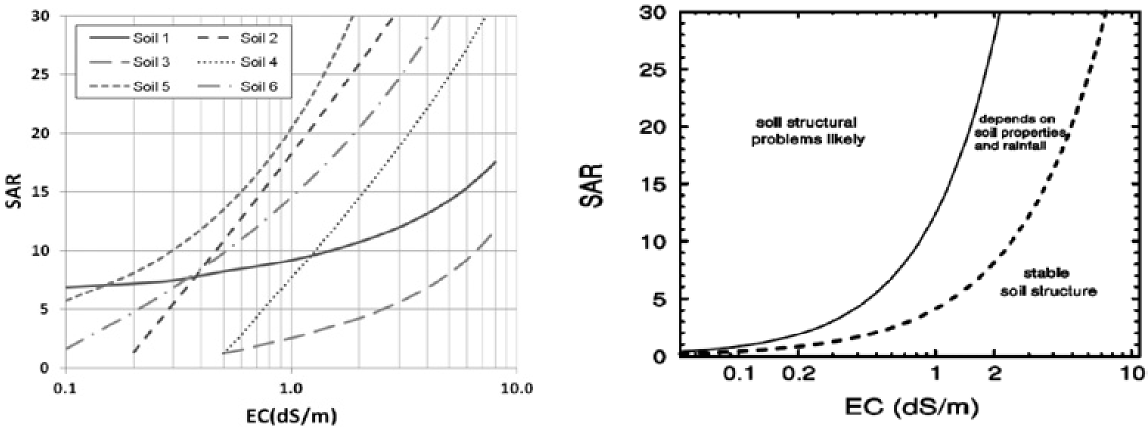
Five short soil columns (internal diameter 87.5 mm, length 50 mm) were prepared within stormwater pipe (75 mm length, 90 mm external diameter). A fast (Whatman No. 4) filter paper was placed beneath the soil and the soil samples were settled by dropping the core from a height of 50 mm, three times. The average bulk density of the settled soil samples was determined and all cores were subsequently re-packed to this bulk density. Two filter papers were placed on top of the soil column. The columns were placed into a pre-treatment calcium chloride (EC 2.0 dS/m) solution bath and allowed to capillary wet (-4 cm) for a minimum of 12 hours. The columns were then removed from the bath and 1000 cm^3 of calcium chloride pre-treatment solution was applied (head ~20 mm) to the top of each column which was placed in a Bucher funnel and open to the atmosphere at the bottom interface. The pre-treatment was allowed to drain for 2 h after the last of the pre-treatment solution had infiltrated and then a second pre-treatment calcium chloride (EC 2 dS/m) solution was applied with a constant hydraulic head (~20 mm measured from the upper surface of the soil column) to each column. The discharge (i.e. flux) from the base of each column was measured at contiguous time intervals until a constant flux was recorded. The hydraulic conductivity was then calculated using Darcy's equation.

A range of up to ten sequentially increasing SAR treatments (0 to ∞) were then applied to each of the five columns where each column was subjected to SAR treatments at a single EC (0.5, 1, 2, 4 and 8 dS/m). The SAR 0 treatment was applied first to each column. In each case, the hydraulic conductivity was measured with a constant head of ~20 mm as for the pre-treatment after a minimum of 1000 cm^3 of solution had infiltrated. The relative hydraulic conductivity (rK_{sat}) of the column was then calculated by dividing the hydraulic conductivity of the SAR>0 water quality treatments by the hydraulic conductivity measured when the SAR 0 water treatment was applied. The relative hydraulic conductivity data was then used to create a three dimensional response surface (in the form used by Ezlit 2009) for rK_{sat} against solution SAR and EC. The 20% reduction in K_{sat} ($0.8rK_{sat}$) contour was then calculated and represents the soil specific TEC relationship.

A correlation analysis was conducted using 36 soil samples from across south-east Queensland. The SAR required to produce a $0.8rK_{sat}$ was calculated for water with an EC of 1, 2 or 4 dS/m. This critical SAR was then correlated with the CCR, clay content and OMC.

Results and Discussion

The six soil samples compared were all either Vertosols or Chromsols. While the soil properties were generally similar within each order (Table 1), the TEC curves obtained for these soils were not similar (Figure 1a). For example, where a solution EC of 1 dS/m was applied, the critical SAR resulting in a $0.8rK_{sat}$ ranged between 9 and 17 for the Vertosols and between 3 and 20 for the Chromosols (Figure 1a). These TEC functions clearly show soil specific responses. More importantly, the TEC curves (Figure 1a) within each soil order were not similar and confirm that the two TEC curves shown in the ANZECC (2000) guidelines (Figure 1b) are not appropriate for all soils. According to the ANZECC guidelines, the structural response for all soils when water with a specific SAR and EC is applied can be obtained directly from Figure 1b. However, considering as an example Soil 3 (Figure 1a) where water with an EC 3 dS/m and SAR 7 is applied, soil instability would be expected to occur, but according to the ANZECC diagram (Figure 1b) the soil would remain stable. This has important implications for irrigation management, especially as the incidence of irrigation with saline-sodic water increases.



(a) **(b)**

Figure 1. Comparison of (a) the TEC (i.e. 20% reduction in Ksat) curves for the six soils in Table 1; and (b) the relationship between SAR and EC for soil structural stability (TEC) as it appears in ANZECC (2000), modified from DNR (1997).

Soil properties that affect the permeability of soils include clay mineralogy, clay content and organic matter content. Hence, it could be expected that these properties should provide a relationship with soil specific TEC responses. However, no significant relationship was found between these properties and the SAR required to produce a $0.8rK_{sat}$ (Figure 2). In all cases the r^2 values were <0.1 for the relationships between the critical SAR and CCR, clay content, or OMC.

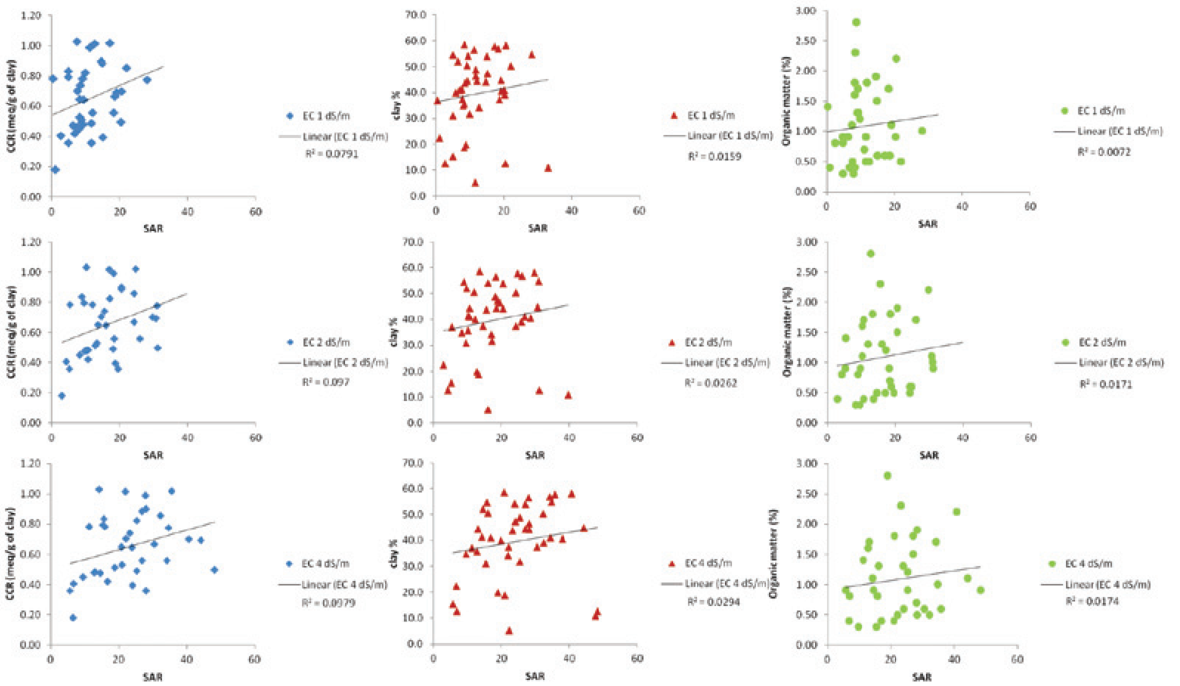


Figure 2. Correlation analysis between clay cation ratio, clay content and organic matter content against the critical SAR at three threshold EC values for 36 soil samples. These threshold values represent a 20% reduction in saturated hydraulic conductivity ($0.8rK_{sat}$).

The original depiction (DNR 1997) of the SAR/EC relationship diagram in ANZECC (2000) suggests that the CCR and clay content may be soil properties that are related to the TEC curves. In reference to Figure 1b, the hashed line is defined by a clay content of 55–65% and CCR of 0.55–0.75, while the solid line is defined by a clay content of 25–35% and CCR of 0.35–0.55 (DNR 1997). However, the results in Figure 2 suggest that while there is a weak trend consistent with the DNR (1997) observations, there is not a relationship that would enable the prediction of soil structural responses based on the CCR, clay content or OMC individually.

The CCR is only an indicator used for clay mineralogy, so a relationship between clay mineralogy and TEC cannot be ruled out. Future work could endeavour to broaden the range of soils, evaluate interactions between these soil properties and/or compare quantitative clay mineralogy with TEC values. Furthermore, the results presented in this paper refer to relative changes in K_{sat}, rather than actual hydraulic conductivity. Hence, the relationships between CCR, clay content, organic matter and absolute hydraulic conductivity should be investigated.

Conclusion

This work illustrates that there are significant differences between soil TEC curves for soils, even within the same soil order. There is therefore a need to reconsider current guidelines used for irrigation management, especially as the requirement to irrigate with saline-sodic water increases. Furthermore, the results suggest that there is no apparent relationship between CCR, clay content or OMC and the critical SAR required to produce a $0.8rK_{sat}$. This means that a useful prediction of soil structural responses is unlikely to be obtained using these soil properties alone.

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