

# The impact of rain water on soil pore networks following irrigation with saline-sodic water

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## Abstract

The soil pore network is an important factor affecting soil hydraulic conductivity (K<sub>sat</sub>). In this study we examine the effect on the soil pore network of a Red Ferrosol caused by irrigation with good quality irrigation water (GQW), as well as saline-sodic water with varying sodium absorption ratios (SAR; 10, 50 and 120) and constant electrical conductivity (EC; 2 dS m<sup>-1</sup>), followed by application of distilled water (simulating rain water). The K<sub>sat</sub> was measured for the different waters before and after applying the rain water to the soil. Soil samples were taken from different depths (1, 4 and 8 cm) for exchangeable cations measurement and the changes in ESP of the soil. Soil horizontal cross-sections were taken from the first 2 cm of the soil cores after drying with acetone and impregnation with polyester resin mixed with green fluorescent dye catalyst and hardener. These sections were polished and visualized under a microscope to investigate the changes in the soil pore network. By increasing the SAR of the water applied from 0.11 (GQW) to SAR 50 and 120, a significant reduction in K<sub>sat</sub> was found, alongside a significant increase in the ESP of the soil from 3 to 10 and 11, respectively; this was most evident near the soil surface. After applying rain water, the K<sub>sat</sub> reduced significantly approaching 0 mm h<sup>-1</sup> where soil was treated with water of SAR 120. Visualisation of the soil pore network of the treated soils following the application of deionised water clearly showed a reduction in soil macroporosity where water quality of SAR ≥10 was applied, even where soils were non-sodic. Where irrigation occurred with good quality, low SAR water, this reduction was not evident.

## Introduction

Saline-sodic waters are increasingly being used for irrigation in arid and semi-arid areas of the world, especially in regions where coal seam gas (CSG) is extracted. Consequent to these irrigation practices, sodium accumulates within irrigated soil as a direct relation to the sodium adsorption ratio of the applied water. This commonly results in soil structure degradation, leading to low water infiltration and limited salt leaching (Singh et al. 1992). The main mechanisms for saturated hydraulic conductivity (K<sub>sat</sub>) reduction are the processes of swelling and clay dispersion. Swelling is predominant in clay soils containing large quantities of smectitic clay minerals, while dispersion can occur regardless of clay mineral suite, leading to pore blockage, particularly when the soil is leached with low electrolyte water (Minhas et al. 1998). Abu-Sharar et al. (1987) referred to a reduction in K<sub>sat</sub> in soil leached with low electrolyte water followed by irrigation with saline-sodic water, which they attributed to a reduction in the percentage of macropores within the soil. Similarly, Sumner (1993) explains that a reduction in K<sub>sat</sub> might be expected, even in well structured soils; due to leaching with low EC permeate causing a reduction in osmotic pressure and increasing the influence of repelling forces responsible for soil structural degradation. Quirk and Schofield (1955) have also shown that soil structural decline is governed by a critical EC threshold at a given SAR; this threshold being known as the threshold electrolyte concentration (TEC). Therefore, with an increase in the incidence of saline-sodic solution irrigation practices, there are important management implications to be considered from the above research. It may well be possible to irrigate soils with high SAR irrigation solutions provided the EC is sufficiently high (above the TEC) without any apparent consequence to soil structure and K<sub>sat</sub>, initially. However, if these soils are subsequently leached with low EC water, such as rainfall, their potential to remain stable is severely reduced. In this paper we examine the impact on water with low EC and SAR on the soil pore network of a Red Ferrosol previously irrigated with saline-sodic water solutions.

## Methods

A sufficient quantity of a Red Ferrosol was collected from the top 15 cm of soil at the Agricultural Field Station Complex of the University of Southern Queensland, Toowoomba. This soil was air dried and crushed to pass a 2 mm sieve, then mixed with tap water up to 18 % gravimetric water content. The moist soil was then packed into PVC tubes (8 cm height and 5 cm internal diameter) at a bulk density of  $1 \text{ g cm}^{-3}$ . A total of 24 cores were packed to allow 6 replicates for each water quality. After packing, the lower ends of the cores were supported by cheesecloth and a 2 cm (5 cm internal diameter) ring was attached to the top of each core to enable water head application. Selected soil properties are shown in Table 1.

Saline-sodic infiltration solutions were prepared using sodium chloride and calcium chloride to achieve the desired EC and SAR. These solutions included a good quality water (GQW) with an  $\text{EC} = 0.9 \pm 0.1 \text{ dS m}^{-1}$  and  $\text{SAR} = 0.11 \pm 0.04$ ; a saline-sodic water of  $\text{EC} = 2 \pm 0.1 \text{ dS m}^{-1}$  and  $\text{SAR} = 10 \pm 0.3$  (SAR10); and two high saline-sodic waters, similar to those produced during CSG extraction procedure, with a constant EC of  $2 \pm 0.3 \text{ dS m}^{-1}$  and SARs  $50 \pm 3$  (SAR50) and  $120 \pm 5$  (SAR120).

Cores were allowed to capillary wet (-6 cm) for 24h in the solution they would be treated with. The cores were then supported in Buchner funnels on wooden stands above  $400 \text{ cm}^3$  plastic containers. Plastic bottles of  $1500 \text{ cm}^3$  were used to apply up to 10 pore volumes of each solution treatment using a constant hydraulic head. The leachate was collected and weighed to determine the  $K_{\text{sat}}$  of each treatment by use of Darcy's Equation.

**Table 1. Selected physical and chemical properties of the soil used.**

SE represent the standard errors of the mean,  $n = 5$

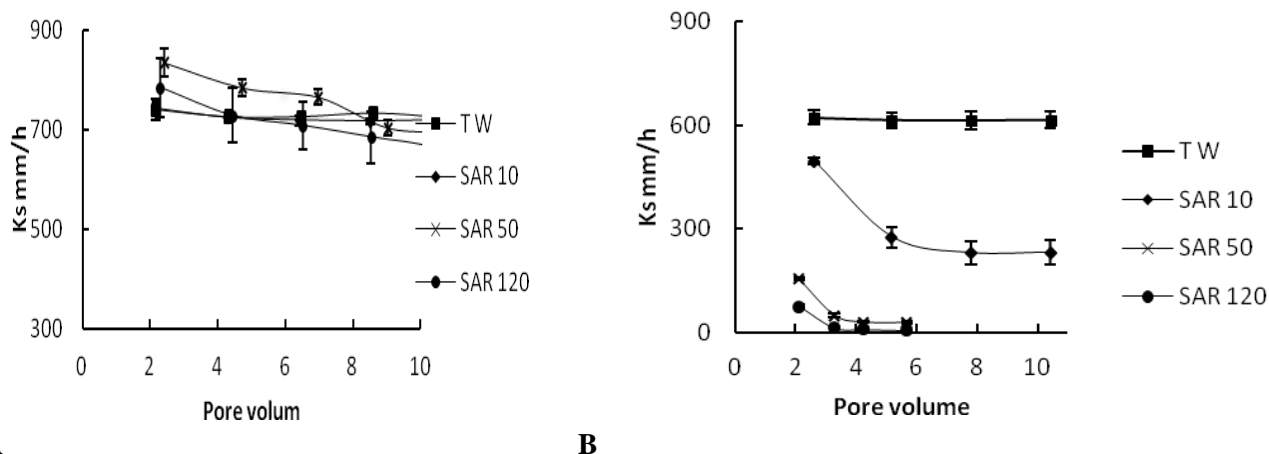
<i>Properties</i>	<i>Mean value <math>\pm</math> SE</i>
Clay %	$44.1 \pm 0.5$
Silt %	$25.5 \pm 1$
Sand %	$30.4 \pm 0.7$
pH (soil-water ratio 1:5)	$5.8 \pm 0.05$
EC (electrical conductivity, $\text{dS m}^{-1}$ )	$0.35 \pm 0.001$
Exchange sodium percentage (ESP; %)	$3 \pm 0.5$
Cation Exchange Capacity ( $\text{meq } 100 \text{ g}^{-1}$ soil)	$26 \pm 1$

After this treatment process 2 of the 6 replicates were left for three days to undergo free drainage. Exchangeable cations were measured from these cores at three depths (1, 4 and 8 cm). Distilled water ( $1500 \text{ cm}^3$ ) was applied directly to a further 3 replicates (constant hydraulic head, as per above) from each treatment in order to measure the change in  $K_{\text{sat}}$  that might be expected during a rainfall event.

One replicate of each treatment before and after treating with distilled water was dried above a bath of acetone for 15 days, with the acetone replaced every 3 days. After drying, the cores were saturated from beneath with a mixture of polyester resin and catalyst with a percent mixture of 30 and 70 %, respectively. The cores were left to dry for 2 weeks under laboratory conditions. Once dry, the soil was taken out of the core and impregnated for 24 h under vacuum in a mixture of polyester resin, catalyst, green fluorescent dye and hardener at the following percent mixture: 40, 50, 5 and 5%, respectively. The soil was left to cure for 7 weeks and was then sectioned with a domain saw into 2 cm horizontal cross-sections. The surface (2 cm) was polished and placed under the microscope to visualise the changes in the soil pore network.

## Result and discussion

Fig. 1 shows the variation in  $K_{\text{sat}}$  of the Red Ferrosol treated with varying saline-sodic water (A) and the changes in  $K_{\text{sat}}$  after distilled water was applied (B). The changes in  $K_{\text{sat}}$  of the soil treated with GQW (TW) were generally similar to those irrigated with SAR solutions of 10, 50 and 120 (Fig. 1 A). However, when the distilled water was applied, a significant reduction in  $K_{\text{sat}}$  was found in all treatments except that treated with GQW (TW) (Fig. 1B), which maintained a  $K_{\text{sat}}$  similar to that in Fig.1A. After applying the distilled water to the soils treated with high saline sodic solutions (SARs 50 and 120) the  $K_{\text{sat}}$  decreased to  $30 \text{ mm h}^{-1}$  and  $5 \text{ mm h}^{-1}$ , respectively, which likely resulted from the reduction of macropores within the soil pore network (Sumner 1993; Minhas *et al.* 1999).



**Fig. 1.** Changes in Ksat by pore volume of a Ferrosol soil when water of (A) varying SARs was applied (B) followed by application of distilled water. Intervals represent the standard error.

The change in exchangeable sodium percentage (ESP) with soil depth for all treatments is shown in Table 2. Soil treated with GQW showed a general decrease in ESP throughout the measured depths, which is consistent with application of water containing low ionic concentrations. Given the initial soil properties and the ionic composition of the GQW treatment, the observed decrease in sodicity could be expected. Similarly, application of SAR 10 treatment generally resulted in non-sodic conditions, although a slight increase in sodicity is observed and the ESP at depth 4 cm is considered sodic by definition of Northcott and Skene (1972). On the other hand, where SAR 50 and 120 treatments were applied, significant increases in sodicity that would enhance the potential for clay dispersion were observed at all depths. Furthermore, increases were greatest in the surface depth, suggesting that this is initially the zone of greatest importance for soil permeability management.

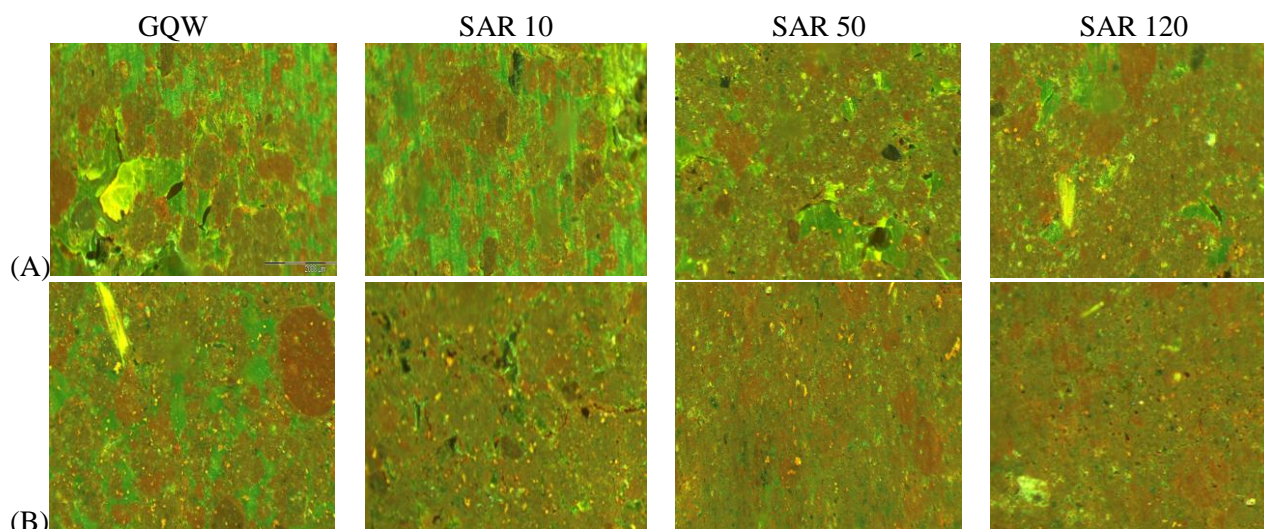
**Table 2.** Changes in exchangeable cation concentrations and ESP of the soil with depth after treatment with water with varying SAR.

SE represents the standard error of the mean

Parameters	Initial exchangeable cation concentration	Water applied	Mean value of measured properties after treatment		
			Depth		
			1 cm	4 cm	8 cm
			<i>GQW</i>		
Na (mg Kg <sup>-1</sup> )	190 ± 10		129 ± 8	184 ± 11	156 ± 10
Ca (mg Kg <sup>-1</sup> )	1420 ± 50		1760 ± 78	1620 ± 70	1490 ± 12
Mg (mg Kg <sup>-1</sup> )	487 ± 28		91 ± 5	215 ± 15	490 ± 9
K (mg Kg <sup>-1</sup> )	119 ± 23		73 ± 6	105 ± 7	130 ± 5
ESP	3.12 ± 0.1		2.11 ± 0.02	3.02 ± 0.01	2.56 ± 0.01
			<i>SAR 10</i>		
Na (mg Kg <sup>-1</sup> )	190 ± 10		241 ± 11	318 ± 14	229 ± 19
Ca (mg Kg <sup>-1</sup> )	1420 ± 50		1700 ± 25	1530 ± 20	1360 ± 50
Mg (mg Kg <sup>-1</sup> )	487 ± 28		172 ± 4	405 ± 9	440 ± 17
K (mg Kg <sup>-1</sup> )	119 ± 23		50 ± 3	57 ± 5	92 ± 7
ESP	3.12 ± 0.1		3.69 ± 0.04	5.22 ± 0.07	3.76 ± 0.17
			<i>SAR 50</i>		
Na (mg Kg <sup>-1</sup> )	190 ± 10		599 ± 20	414 ± 15	334 ± 7
Ca (mg Kg <sup>-1</sup> )	1420 ± 50		1200 ± 71	1470 ± 95	1350 ± 73
Mg (mg Kg <sup>-1</sup> )	487 ± 28		240 ± 11	420 ± 5	437 ± 13
K (mg Kg <sup>-1</sup> )	119 ± 23		42 ± 7	89 ± 9	91 ± 6
ESP	3.12 ± 0.1		9.84 ± 0.17	6.80 ± 0.14	5.48 ± 0.01
			<i>SAR 120</i>		
Na (mg Kg <sup>-1</sup> )	190 ± 10		679 ± 25	462 ± 33	384 ± 10
Ca (mg Kg <sup>-1</sup> )	1420 ± 50		1000 ± 38	1260 ± 16	1286 ± 42
Mg (mg Kg <sup>-1</sup> )	487 ± 28		277 ± 12	390 ± 21	420 ± 25
K (mg Kg <sup>-1</sup> )	119 ± 23		46 ± 4	85 ± 8	92 ± 5
ESP	3.12 ± 0.1		11.15 ± 0.2	7.59 ± 0.24	6.3 ± 0.1

The soil horizontal cross-sections taken after treatment with SAR solutions and those following the application of distilled water are shown in Figure 2A and 2B, respectively. There is an apparent decrease in soil macroporosity with increasing solution SAR application (Fig. 2A). These results support those observed in Fig. 1A, while the Ksat was not reduced severely by the SAR 50 and 120 treatments, presumably due to an EC effect (Sumner 1993), a slight decline in Ksat was observed. This is attributable to a decrease in

macroporosity (Fig. 2A). When distilled water was applied to cores previously treated with SAR solutions, there was an obvious decrease in all treatments, except for the GQW treatment (Fig. 2B). Soils treated with high SAR solutions (SAR 50 and 120) exhibited a reduced soil pore network, which can be attributed to pore blockages from clay dispersion under sodic conditions (Table 2); hence, the observed Ksat reduction in Fig 2B. Importantly, the results for the SAR 10 treatment (Fig. 2A and B) show that an obvious reduction in the macroscopic soil pore network has occurred in the top 2 cm, even in the absence of sodic conditions (Table 2), which has resulted in a significant reduction in Ksat (Fig. 1B). This illustrates that a solution sufficiently low in EC is capable of causing soil dispersion and subsequent pore blockage in non-sodic soils (Sumner 1993) and highlights the importance of managing soil EC.



**Figure 2.** Microscope images of the 2 cm horizontal cross-sections of the Red Ferrosol pore networks after treatment with (A) solutions of varying SAR; and (B) SAR solutions followed by distilled water. The green and yellow portions of the image represent fluorescent dyed resin filled pores; black portions represent pore space that was not impregnated; and red/brown portions are soil particles.

## Conclusion

The results of our experiment on using varying saline-sodic water followed by rain water to irrigate a Red Ferrosol soil indicate that the soil pore network can be maintained in a reasonable condition even where solutions of high sodicity are applied, provided the solution EC is sufficiently high. However, the pore network is adversely affected by the SAR of water applied when low EC solution is allowed to percolate these soils, such as rainfall. This effect was greatest when the SAR of the applied water exceeded 10; but was significant even at SAR 10. Furthermore, visualisation of pore networks show that even soils with non-sodic conditions undergo substantial reduction in macroporosity when low EC solution is allowed to percolate through soil. This highlights the importance of managing soil EC in order to maintain soil pore networks.

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