An evaluation of plant available water during reclamation of saline soils: Laboratory and field approaches

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Abstract

The amount of water available to plants in the absence of all physical restrictions except high salinity is measured for a saline soil profile. Procedures and calculations are described and examples given for the initial unreclaimed soil, which shows that when osmotic stresses are taken into account (using the EC of a saturated paste extract) the water available to plants is about 33% less than that predicted when salt is ignored.

Key Words

Plant available water, PAW, integral water capacity, IWC, reclamation of saline soils

Introduction

Plant available water in saline soils is restricted primarily by osmotic pressures but also often by poor aeration, low hydraulic conductivity and high soil strength. Reclamation through leaching, introduction of divalent cations and salt-tolerant plants produces a number of structural states because as salt concentrations drop clays tend to swell and disperse. Eventually, however, conditions improve to the point where plants can grow and thereby contribute to the reclamation process. In the process, physical conditions can sometimes get worse before they get better because swelling and dispersion lead to poor aeration and reduced hydraulic conductivity, which can reduce the amount of water plants can extract. This project tracks the incremental changes in soil structure that take place during reclamation of saline land with a view to learning how to allocate resources to maximize plant available water at each stage. The integral water capacity (IWC) model of Groenevelt *et al*. (2001, 2004) is employed to calculate plant available water and this is checked against real plant response under field conditions. The project is in its early stages so this paper describes the approach and methods employed and gives some preliminary data to evaluate the amount of plant-available water in the initial, unreclaimed, saline state.

Methods

Laboratory evaluation of plant available water in saline state

Intact soil cores (50 mm diameter x 50 mm long) were collected from nine different depths to 180 cm in a saline profile at the University of Adelaide (Roseworthy campus). We first measured pH, EC, and solution-cations on 1:5 extracts of the loose soil to enable us to prepare isotonic solutions (in terms of sodium adsorption ratio, SAR, and total cation concentration, TCC) to measure saturated hydraulic conductivity, water retention and penetration resistance curves. Saturated hydraulic conductivity was measured using a constant head until the flux did not change after several days of hourly measurements. Water retention and penetrometer resistance were measured on the same soil cores at matric suctions 1, 5, 10, 50, 100 and 150 m. Water retention data were fitted to a variation of the model proposed by Groenevelt & Grant (2004) and the differential water capacity, $d\theta/dh$, calculated for use in determining the integral water capacity (Groenevelt *et al.* 2001).

Field evaluation of plant-available water in saline state

Two areas (each 3 x 3m) in the vicinity of the soil samples taken for laboratory analysis were isolated by excavating a trench on all four sides to a depth of 1.8m. Thick plastic sheeting was placed around the excavations and the soil back-filled to stop lateral movement of water inward or outward. Five neutron access tubes were installed across each area to allow volumetric water contents to be measured down to 1.8

m. Isotonic water was applied to the areas until the soil profiles were saturated and then the surfaces covered with thick organic mulch and allowed to drain to a nominal field capacity. A neutron probe was calibrated for saline conditions and used to measure the volumetric water content of the soil profiles at the drained upper limit and as the soil profiles dried out. A salt-tolerant Kallar grass was established through the mulch and watered until its leaf area index, LAI, reached approximately 4.0 to minimize evaporation from the soil surface and to ensure that the only water losses were by transpiration. Irrigation was then stopped and the established plants were forced to extract water under increasingly dry conditions until they wilted and died (crop lower limit). The total amount of water extracted by the plants between the drained upper limit and the crop lower limit was taken as the real integral water capacity.

Results

Laboratory evaluation

The soil profile was neutral to highly-alkaline in pH, very saline and highly sodic (Table 1). As one might expect in such saline conditions, the saturated hydraulic conductivities (measured using isotonic solutions) were relatively large (ca 10^{-5} m s^{-1}) at least until the texture became more clayey below 1 m (Figure 1).

Table 1. Physical and chemical properties of the soil profile used in this study.

Depth (cm)	Texture	$pH_{1:5}$	EC* (dS m^{-1})	TCC** (mmol+/L)	SAR	K_s (± std error), 5 reps (m s^{-1})	
0 - 10	Loamy sand	7.42	5	60	2	6×10^{-5}	(3×10^{-5})
10 - 25	Sandy clay loam	8.24	4	45	6	3×10^{-5}	(8×10^{-6})
25 - 35	Light clay	8.30	4	39	7	4×10^{-5}	(6×10^{-6})
35 - 55	Light clay	8.47	3	38	9	3×10^{-5}	(4×10^{-6})
55 - 75	Light clay	8.91	3	34	15	2×10^{-5}	(7×10^{-6})
75 - 100	Light clay	9.51	3	41	41	2×10^{-5}	(3×10^{-6})
100 - 115	Medium clay	9.48	4	52	58	7×10^{-7}	(2×10^{-7})
115 - 150	Medium clay	9.34	5	65	64	2×10^{-7}	(6×10^{-8})
> 150	Heavy clay	8.86	8	96	94	8×10^{-9}	(1×10^{-9})

* 1:5 EC multiplied by 5 was very close to the sum of ICP-cation concentrations divided by 10.

** TCC total cation concentration, calculated as sum of ICP-cation concentrations: (2 x (Ca+Mg) + Na+ K).

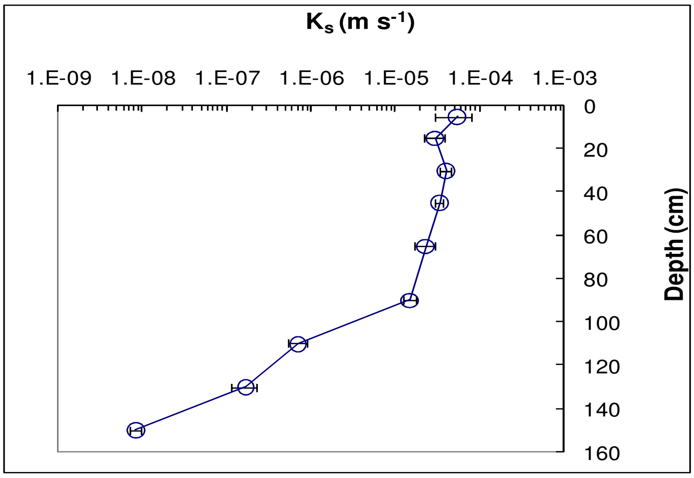

Figure 1. Profile of saturated hydraulic conductivity; horizontal bars indicate standard errors in K_s.

An example of the water retention curves produced in this work is shown in Figure 2 for the first soil horizon. The water retention curve was fitted to the model of Groenevelt et al. (2004):

$$\theta(h) = \theta_{wp} + k_1 \left\{ \exp\left(-\left(\frac{k_0}{150} \right) \right)^n - \exp\left(-\left(\frac{k_0}{h} \right)^n \right) \right\}, \qquad [1]$$

where θ_{wp} is the water content at matric head h = 150 m, k_1, k_0 and n are adjustable fitting parameters.

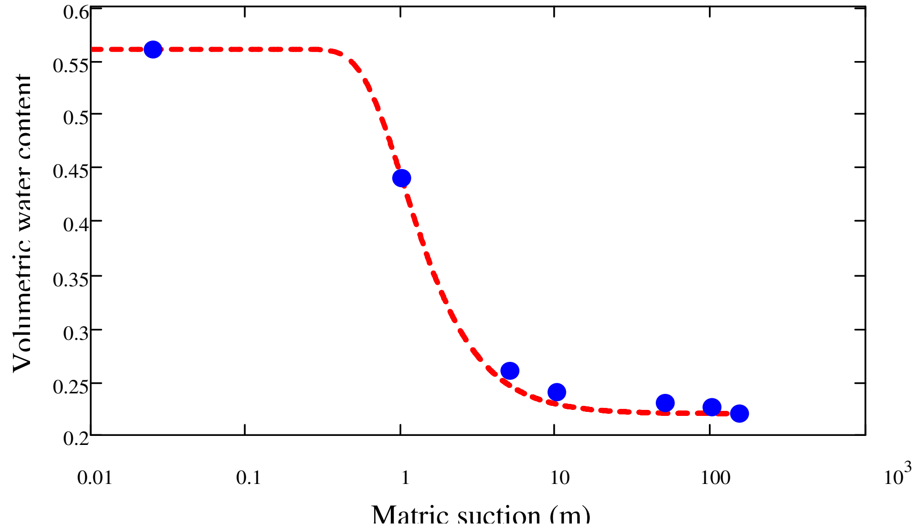

Figure 2. Water retention curve for the loamy sand in the top horizon (0 to 10 cm).

Eqn [1] was differentiated to produce the so-called 'water' capacity, C(h), which is actually the 'soil solution' capacity (green line in Figure 3):

$$C(h) = n\, k_0\, k_1\, h^{-(n+1)} \left\{ \exp\left(-\left(\frac{k_0}{h} \right)^n \right) \right\}. \qquad [2]$$

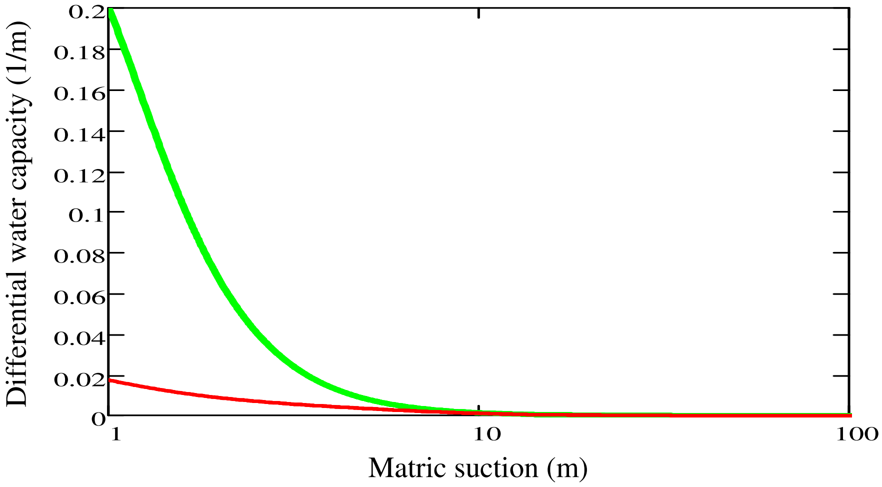

Figure 3. Differential water capacity, $C_{om}(h)$, for soil in horizon 1 unweighted (green) and weighted for soluble salts (red).

Eqn [2] was then weighted for osmotic limitations to produce an effective water capacity (red line in Figure 3). The IWC was then calculated as a function of the osmotic head (h_{os}, as measured in a saturated paste extract) as well as the matric head, h, according to the model of Groenevelt et al. (2004):

$$\mathrm{IWC}(h_{os}) = \int_0^\infty C_{om}(h, h_{os})\,dh \ , \qquad [3]$$

where $h_{os} \sim 3.6\ EC_e$. In this way, if one has knowledge of the amount of salt in the saturated soil, the osmotic head can be calculated as well as the amount of water available to plants in the absence of other physical limitations. Integration of the two lines shown in Figure 3 produced values for IWC for the unweighted water capacity (classical value of plant available water) = 220 mm/m and for the weighted water capacity = 66 mm/m. The calculations for the other 8 horizons in this profile are shown in Table 2.

Table 2. Amount of plant available water in each horizon (and whole profile) when salt is ignored (PAW) and when salt is accounted for in the integral water capacity (IWC).

Depth (cm)	PAW (mm/m)	PAW total (mm)	IWC (mm/m)	IWC total (mm)
0 - 10	220	22	66	7
10 - 25	314	47	172	26
25 - 35	339	34	199	20
35 - 55	172	34	74	15
55 - 75	188	38	109	22
75 - 100	190	48	135	34
100 - 115	158	24	133	20
115 - 150	137	48	111	39
> 150	195	98	161	81
Total for profile		392		262

Field evaluation of plant-available water

Experimental work for the field component of this work is only just beginning and progress will be reported at the Congress.

Conclusions

The real amount of plant-available water in the un-reclaimed soil profile (i.e. IWC shown in Table 2) is at least 33% lower than the classical PAW that ignores osmotic stresses. In the reclamation process (yet to occur in this project), it is expected that the IWC will decrease in the first instance (because of swelling and dispersion processes) and then gradually increase toward the classical PAW as calcium replaces sodium, as the concentration of salt is decreased, and as salt-tolerant plants are introduced.

References

Groenevelt PH, Grant CD and Semetsa S 2001. A new procedure to determine soil water availability. *Australian Journal of Soil Research* **39**, 577-598.

Groenevelt PH and Grant CD 2004. A new model for the soil-water retention curve that solves the problem of residual water contents. *European Journal of Soil Science* **55**, 479-485.

Groenevelt PH, Grant CD and Murray RS 2004. On water availability in saline soils. *Australian Journal of Soil Research* **42**, 833-840.