High chloride in subsoil: a key indicator for potential grain yield losses in southwest Queensland

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Abstract

We monitored wheat grain yields and ability to extract soil water on soils with various levels and combinations of subsoil constraints in 22 field experiments over 3 years. The effect of the complex and variable combinations of subsoil constraints was to reduce plant available water capacity as evident from increased lower limit of plant available water. Increasing Cl and Na concentrations in subsoil had a greater restricting effect on water availability than did salinity and sodicity. A relatively stronger relationship between apparent unused plant available water and/or grain yield with Cl than that with Na suggests that the presence of high concentration of Cl in these soils most likely inhibited the water extraction by wheat from the subsoil resulting in reduced grain yields. The foliar symptoms observed including leaf burning on the tips and margins of the older leaves, chlorosis and dieback were consistent with those described in literature for Cl toxicity. Increased concentration of Na and in particular Cl in young mature leaf was associated with reduced grain yields of wheat.

Key Words

Subsoil constraints, salinity, sodicity, chloride toxicity, crop lower limit

Introduction

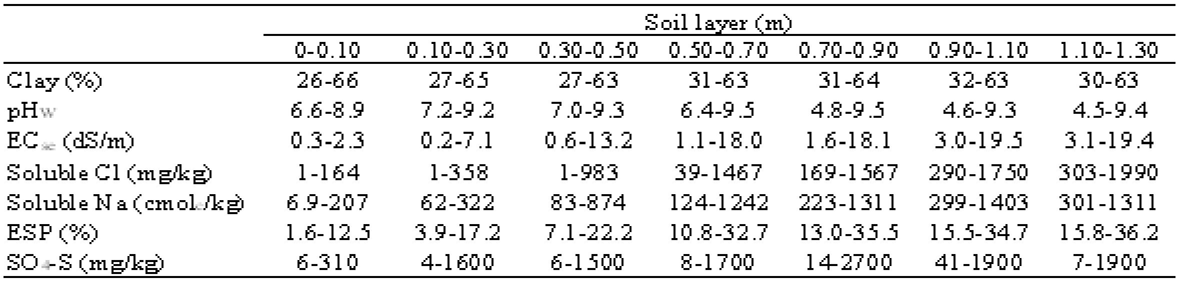
Single or multiple factors of subsoil constraints in southwest Queensland include high levels of salinity, sodicity, acidity, phytotoxic concentrations of sodium (Na) and chloride (Cl). The impact of these constraints is mainly reflected in reduced rooting depth and water extraction (Dang *et al.* 2006). These constraints alter the nutrient balance in the crop, by restricting uptake of certain nutrients but allowing other nutrients and elements to accumulate in excess of the crop's requirements, and can lead to nutrient imbalance and toxicity of some elements in the plant (Greenway and Munns 1980; Naidu and Rengasamy 1993; Bruce 1997; Xu *et al.* 2000).

Materials and Methods

The study area covered southwest of Queensland's grain-growing region, located between 26? and 29?S, and 148? and 151?E. Wheat (*Triticum aestivum cv. Baxter*) was monitored at 22 farmer's fields in the winter cropping seasons of 2003, 2004 and 2005 on soils with a range of EC_{se}, ESP, Cl and Na concentrations. All sowing and crop management operations were carried out using farmer equipment and agronomic management followed the accepted district practice. All crops were supplied with 40-50 kg mono-ammonium phosphate blended Zn fertilizer. At crop maturity, plant samples from quadrats (2 m by 1.0 m) were taken randomly from 3 places to determine total biomass and grain yield.

Soils at each site were analysed for pH, EC, Cl and Na (1:5 soil: water extracts), clay contents, sulphate-S contents and cations after alcoholic displacement (Rayment and Higginson 1992) in 0-10 cm and 20 cm depth increments thereafter. Electrical conductivity of saturated extracts (EC_{se}) was calculated from EC (1:5 soil:water extracts), Cl and clay content using the method of Shaw (1999) (Table 1). Soil water was monitored (10-130 cm) throughout the season by neutron moisture meter at sowing and at physiological maturity. The soils at all sites were characterised for bulk density, drained upper limit (DUL), crop lower limit (CLL) and plant available water capacity (PAWC=DUL-CLL) using the method of Dalgliesh and Foale (1998). For CLL, the top layer (0-0.1 m) was excluded to avoid confounding effects of evaporation and plant water uptake on minimum soil water content (Sadras *et al.* 2003). Soil water lower limits (LL15) at –1.5 MPa were calculated from the clay content (Shaw 1996), using the formula; LL15=(0.518 + 0.38 clay %)/100. Apparent unused plant available water was calculated as the difference between CLL and LL15.

Table 1. Range of soil properties over 22 experimental sites in southwest Queensland



	Soil layer (m)						
	0-0.10	0.10-0.30	0.30-0.50	0.50-0.70	0.70-0.90	0.90-1.10	1.10-1.30
Clay (%)	26-66	27-65	27-63	31-63	31-64	32-63	30-63
pH_w	6.6-8.9	7.2-9.2	7.0-9.3	6.4-9.5	4.8-9.5	4.6-9.3	4.5-9.4
EC_{se} (dS/m)	0.3-2.3	0.2-7.1	0.6-13.2	1.1-18.0	1.6-18.1	3.0-19.5	3.1-19.4
Soluble Cl (mg/kg)	1-164	1-358	1-983	39-1467	169-1567	290-1750	303-1990
Soluble Na ($cmol_c$/kg)	6.9-207	62-322	83-874	124-1242	223-1311	299-1403	301-1311
ESP (%)	1.6-12.5	3.9-17.2	7.1-22.2	10.8-32.7	13.0-35.5	15.5-34.7	15.8-36.2
SO_4-S (mg/kg)	6-310	4-1600	6-1500	8-1700	14-2700	41-1900	7-1900

At anthesis, young mature leaves (YML) were obtained, rinsed with distilled water, dried at 70^0C for 48 h and ground. Cations in plant material were determined after digesting in diacid mixture on inductively coupled plasma-optical emission spectrometer. For Cl, ground samples of YML were extracted in hot water at 80^0C for 4h (Rayment and Higginson 1992). The Cl concentration was determined on an auto-analyser (Spann and Lyons 1985).

To explain observed apparent unused water, step-wise regressions were performed with soil physiochemical properties using *all subset regression*. The regression coefficients for statistically significant independent variables were determined using multiple linear regressions on Genstat 6.1.

Results and Discussion

Relationship between CLL and subsoil constraints

Increasing concentrations of subsoil constraints including EC_{se}, ESP, Cl and Na in 6 equal depth intervals (0.20 m) linearly increased measured CLL values at these depths for wheat grown on 22 sites. This supports the hypothesis proposed by Sadras *et al.* (2003) that the primary effect of complex and variable combinations of subsoil constraints is to reduce plant available water, which was evident from increased CLL. The CLL correlated more strongly with Cl concentration than EC_{se} values (Fig 1). The poor relationships between CLL and EC_{se} was due to the presence of gypsum in some soils as evident from greatly improved relationship between EC_{se} and CLL (Y=0.022x+0.23, R^2=0.56, *P*=0.001) by excluding 4 soils containing >1000 mg SO_4-S/kg, suggesting that calculated EC_{se} would not be a good predictor of CLL in the presence of significant quantities of gypsum in the soil. Generally, evidence in the literature suggests that gypsum either has slight negative or an ameliorative effect on water extraction by plants (Marschner 1995). The strong relationship between Cl concentration and CLL remained unchanged with or without excluding gypsum-dominated soils (Y=0.0001x+0.26, R^2=0.52, *P*=0.001).

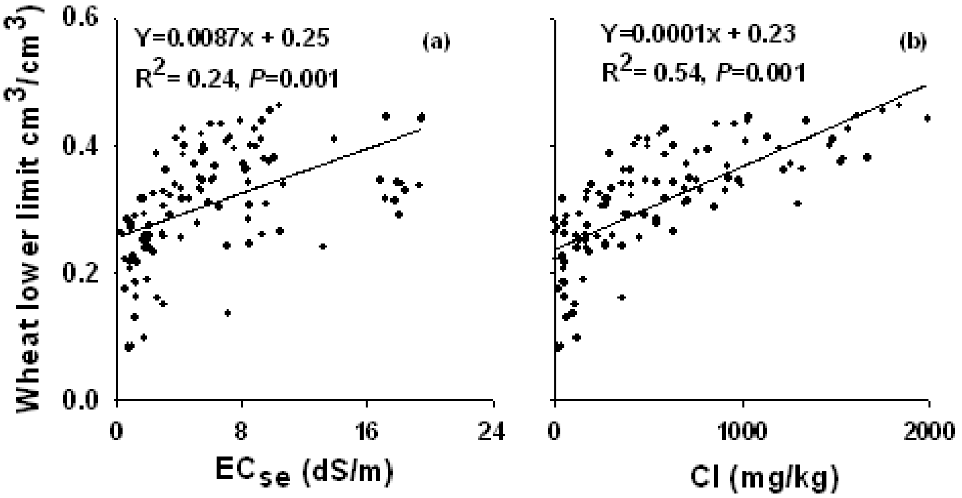


Fig.1. Relationships between wheat lower limit and (a) EC$_{se}$ and (b) Cl concentrations in 0.1-1.30 m soil depth in southwest Queensland.

The CLL was better correlated with Na concentration in the soil profile than with ESP (Fig. 2). However, relatively high correlation between CLL and ESP makes it difficult to conclude whether sodicity or Na and/or Cl *per se* resulted in reduced uptake of water. However, given the presence of high salt contents in the subsoils, there is sufficient salt concentration to maintain flocculation (Sumner 1993). The effect of sodicity could be due to high Na concentrations in soil resulting in reduced uptake of water largely due to gradual build up of Na in plants (Sheldon *et al.* 2004).

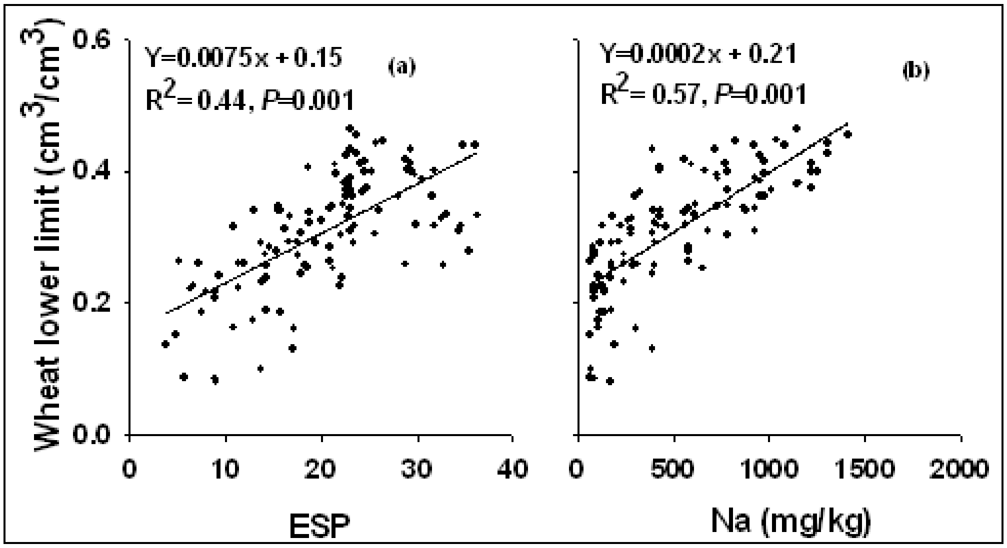


Fig.2. Relationships between wheat lower limit and (a) ESP and (b) Na concentrations in 0.1-1.30 m soil depth in southwest Queensland.

Cl and/or Na

The multiple effects of high concentrations of Cl and Na on plants could be due to (i) increased osmotic potential, resulting in reduced ability of roots to obtain soil water, (ii) impaired root growth and functions due to toxicity of Na and/or Cl, and (iii) nutrient imbalance by depression in uptake of other mineral nutrients (Marschner 1995).

Apparent unused water by wheat showed positive relationships with both Cl and Na concentrations (Fig. 3). Individually, Na accounted for 32% variation in apparent unused plant available water by wheat and Cl accounting for 58% of the variation. However, in step-wise regression, Cl was the principal determinant of the apparent unused water with Na as secondary determinant both together accounted for 67% of the variation: Apparent unused water =0.057 + 0.000063Cl + 0.00011Na, R^2 =0.67, P=0.001, SE = 0.04.

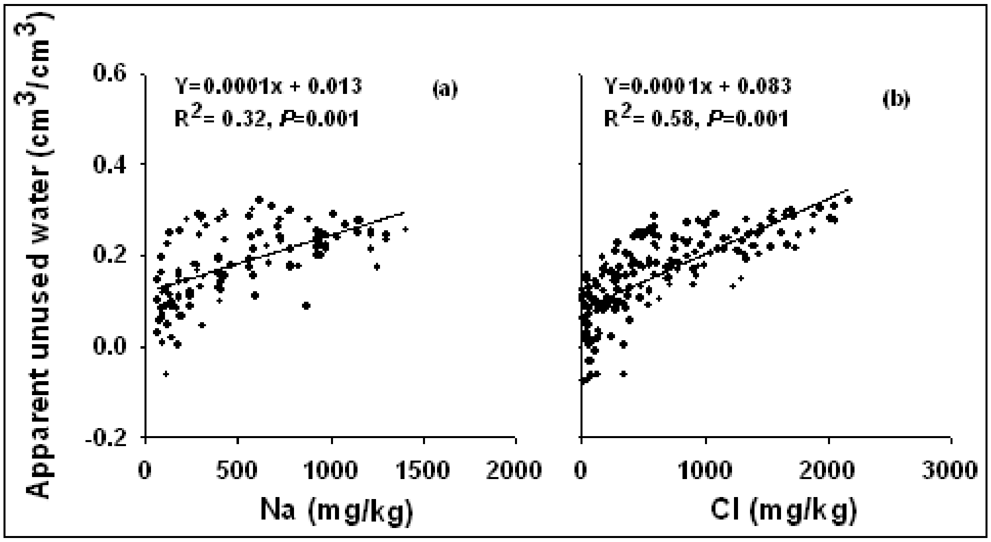


Fig. 3. Relationships between apparently unused plant available water for wheat and (a) soluble Na (b) soluble Cl in the soil profile in southwest Queensland.

At the few sites, high in Cl concentration, wheat crops were water stressed initially, with chlorosis on tips and margins of older leaves. The chlorosis developed to necrosis and affected younger leaves. At maturity, plants were stunted and heads had few grains. These foliar symptoms observed were more consistent with those described earlier for Cl toxicity (Marschner 1995; Xu *et al.* 2000).

The wheat grain yield reduction corresponded well with increased Cl concentrations in the YML of wheat. However, there was an increasing trend in grain yield up to Na concentration <0.01 mM/g in YML (Fig. 4). This could be due to low K concentrations in many soils of the region and Na substituting for K for plant functions (Marschner 1995). In the present study, Cl concentrations in the YML appear to be a better predictor of the impact of subsoil constraints on crop yield.

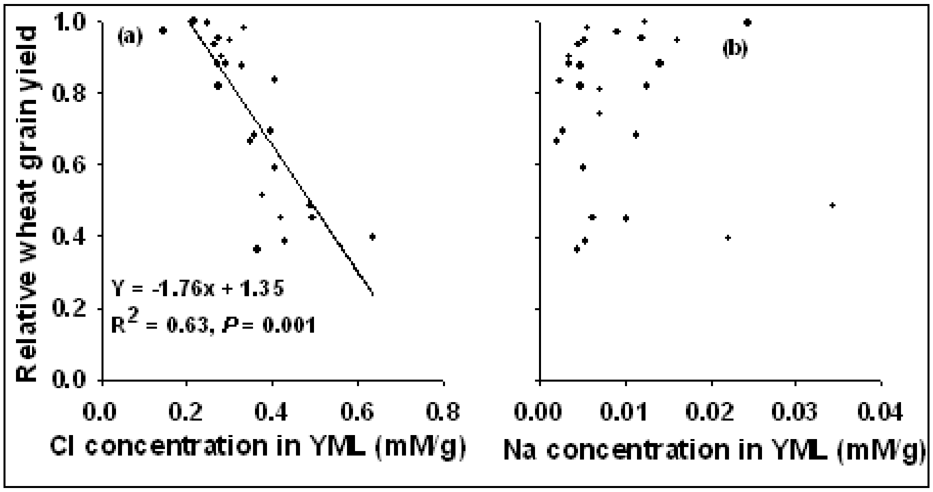


Fig. 4. Relationships between relative wheat grain yield with (a) Cl concentration, and (b) Na concentration in YML of wheat.

Increasing concentrations of Cl and Na in YML decreased the uptake of essential nutrients such as K and in particular Ca through the effect of ion selectivity and more so due to former than the latter (data not shown). Maintenance of higher K and Ca concentrations in salt-tolerant genotypes has been shown to be one of the mechanisms underlying their superior salt tolerance (Marschner 1995).

Acknowledgements

The Grains R&D Corporation funded this research. The generous support of our collaborative growers and their families in providing sites and managing the trials is greatly appreciated.

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