

On-farm assessment of sub-soil salinity and sodicity constraints to barley production in southern Australia

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Abstract

Multiple factors contributing to subsoil constraints include salinity, sodicity, and high concentrations of chloride which are present in many rain-fed farming soils of Southern Australia. Identifying genotypes adapted to these adverse subsoil conditions and/or able to exploit subsoil water may be an option to maintain productivity of these soils. Field trials were carried out to evaluate the relative importance of high soil solution concentration of Na⁺ and Cl⁻ ions on yield reduction of barley in 4 sites over 3 years in north-west Victoria and South Australia. All soils had high concentrations of exchangeable Na⁺ and Cl⁻ in the subsoil and the variation in these levels were correlated with the spatial variation in yield. Grain yield was also greater in genotypes with the capacity to exclude Na⁺ and Cl⁻ from their leaves. Measurement of ion concentrations from the upper two leaves of the main stem at Zadoks 65 were highly correlated with yield among 10 adapted varieties of barley and may be effective as screening criteria compared with those from the lower two leaves. The maintenance of low Cl⁻ and Na⁺ concentrations in the upper two leaves offered the best guide to salt tolerance under both conditions. Potassium concentration was a poor criterion compared with the selectivity of K⁺ over Na⁺.

Key Words

Salinity, barley, abiotic stress, subsoil constraint

Introduction

Soil salinity and sodicity are two of the principal abiotic factors affecting crop yields in arid and semi-arid areas of Australia. Barley is a good target crop for breeding programs in such salt-affected areas because of its inherently high salinity tolerance (Maas and Hoffman 1977) which may offer a means for improving productivity in these environments. Since selection of tolerant germplasm based on their yield performance under saline conditions has been largely unsuccessful, partially due to the high variability of natural saline soils (Richards 1983), several authors have suggested the use of physiological traits such as the concentration of Na⁺, K⁺ and Cl⁻ in shoot tissue as alternatives to screening for yield (Flowers and Yeo 1995; Noble and Rogers 1992). Much of the recent focus has been on Na⁺ exclusion but the importance of high Cl⁻ is poorly defined for soils in southern Australia, despite some soils containing high concentrations of Cl⁻. Despite numerous reports showing variability in ion exclusion for many crops, few salt-tolerant genotypes have been released (Flowers and Yeo 1995). This lack of success may be due in part to physiologists conducting experiments under ideal, controlled conditions (e.g. hydroponics, sand cultures and greenhouse or growth chamber environments). However, genotypic differences measured under controlled conditions may not correspond to those observed under actual field conditions (Shannon 1997). Therefore, the objective of our study was to assess the value of ion exclusion to yield under in saline soils both in terms of spatial variability as well as explaining genotypic differences.

Methods

Two different sets of field experiments were conducted at five different locations in Victoria and South Australia. There were four sites in Victoria (Birchip, Walpeup, Manangatang and Werrimull) and one in South Australia (Georgetown). The Victoria sites were part of a larger program on the effects of tillage and stubble management on yield, while the SA site was part of a variety evaluation program. The barley variety Sloop was grown at the four sites in 2001-2004. The sites at Walpeup, Werrimull and

Manangatang were grown on a dunes-swale system. These experiments were designed in six rows, corresponding approximately to landscape units (e.g. face of dune, top of dune, swale) with two rows making up a replicate. Plots in these experiments were 12m wide and between 40 and 150m long. The Birchip site was on a level site with Gilgai features, and was laid out the same way as the other experiments, but with each row of identical length (55m) and wider plots (18m) to better encompass the Gilgai variation. At Georgetown, 10 genotypes of barley (Barque73, Clipper, Flagship, Fleet, Hindmarsh, Keel Mundah, Schooner, Skiff and Sloop) were grown in 2008. A randomized, complete block design was used at all locations with three replications.

Soil samples

At the four Victorian sites soil samples were collected from each plot to a depth of 1.2m. Cores were divided into 0–10, 10–25, 25–50, 50–75, 75–100 and 100–150 cm layers. Measurements of pH (H_2O), Na^+ , Cl^- and electrical conductivity (saturated paste extract) were made on each sample. At Georgetown, soil samples were taken from 0–15, 15–30, 30–60, 60–90, 90–110 cm depths with an auger to the depth of 110 cm and analysed for pH, EC, Cl^- and exchangeable Na^+ .

Plant samples

Whole shoot samples at anthesis were taken from the four Victorian sites, dried to a constant weight and ground to a fine powder. At Georgetown at Zadoks growth stages (ZGS) 45, 65 and 92 two randomly-selected plants from each plot were sampled. The plants were washed and separated into the upper and lower two leaves of the main stem for dry weight measurements and ionic analysis. All the samples were digested in 4% w/v nitric acid. The concentration of Na^+ and K^+ in the digested samples was determined using a flame photometer. Chloride concentrations of the digested extracts were determined using a chloride analyser. Grain yield was determined by hand harvesting from each plot.

Statistical analysis

All data were analysed by ANOVA. The relationship between soil chemical properties, plant ion composition and yield were investigated by using simple correlations and regressions.

Results

All soils showed increasing pH and E_{ce} with depth but there was marked variation among the five sites in the extent of these changes. The concentrations of Na^+ , Cl^- , and the E_{ce} and ESP of the soil at Georgetown and Birchip were higher than those at other locations (Fig 1). Within each of the Victorian sites, variation in grain yield of Sloop barley was significantly correlated to soil Na^+ and Cl^- concentrations (0–100cm, weighted by depth) except at Walpeup where soil Na^+ concentration was not correlated with grain yield (Fig 2).

There were significant differences in yield among the 10 genotypes at Georgetown and these were correlated with the ion composition of the leaves, but the strength of the association differed with growth stage (Fig 3). The highest correlation between grain yield and the concentrations of Na^+ , Cl^- and K^+ in the leaves was found at ZGS 65 whereas earlier or later sampling time did not indicate a significant relationship. Although the upper leaves had lower concentrations of Na^+ and Cl^- and higher K^+ than the lower leaves, these were more strongly correlated with yield compared with the concentrations in the lower leaves (Fig 4). The ratios of K^+/Na^+ in the upper and lower leaves of the main stem showed significant genotypic differences under field conditions.

Discussion

The level of subsoil salinity affected the variation in yield at each of the sites. The spatial variation in yield within each of the Victorian sites was related to the concentrations of Na^+ and Cl^- in the subsoil and this influenced the concentrations of Na^+ and Cl^- in the plant. This provides evidence of the importance of ion

exclusion as a potential means of improving yield on the saline-sodic soils of the region. This is supported by the results from Georgetown that showed that differences in yield among 10 adapted varieties of barley were strongly associated with the ability to exclude Na^+ and Cl^- .

After anthesis, the upper leaves, and especially the flag leaf, make a major contribution in terms of the photosynthetic supply towards the grain yield. By contrast, the salt taken up by the plant tends to concentrate in the older, lower leaves; where over an extended period of time this produces high concentrations of Na^+ and Cl^- , causing the leaves to die (Munns *et al.* 2006). The maintenance of low Na^+ and Cl^- in actively growing tissues such as young leaf blades and sheaths could be an important mechanism contributing to the enhanced salt tolerance of some genotypes (Hasegawa *et al.* 2000). According to Boursier *et al.* (1987) the salt tolerance of different barley genotypes has been associated with their respective abilities to selectively partition Na^+ and Cl^- into old leaves and sheaths and K^+ into growing tissues. In the present work, the order of genotypes for Na^+ and Cl^- concentrations in the upper two leaves of the main stem were closer with their rankings in terms of their salt tolerance (on the basis of grain yield) than were those derived using the concentrations of these ions in the lower two leaves. Furthermore, the high-yielding genotypes accumulated less Na^+ and Cl^- in the upper two leaves than did the low-yielding or moderate genotypes. Consequently, grain yield from salt-affected soils was highly significantly correlated with Na^+ and Cl^- concentrations in the upper two leaves (Figure 3), but generally not in the lower, two leaves under field conditions. Thus, measurement of Na^+ and Cl^- in young leaves under field conditions might be an effective selection criterion for salinity tolerance, more so than the concentration of Na^+ and Cl^- in the entire plant, which does not correlate well with the salt tolerance in some genotypes.

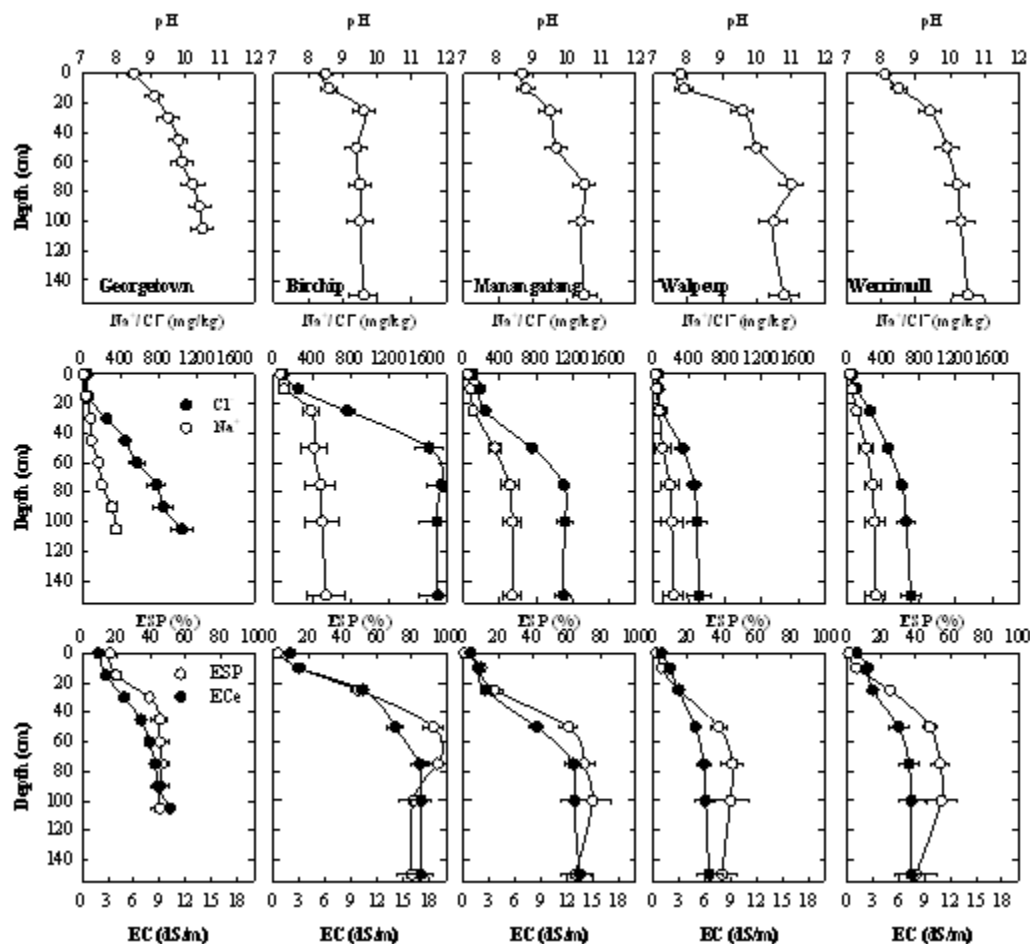


Figure 1. Selected characteristics of saline-sodic soils used in this study. Georgetown is the South Australian site and the rest are in Victoria. Error bars are standard errors of the means (n=3).

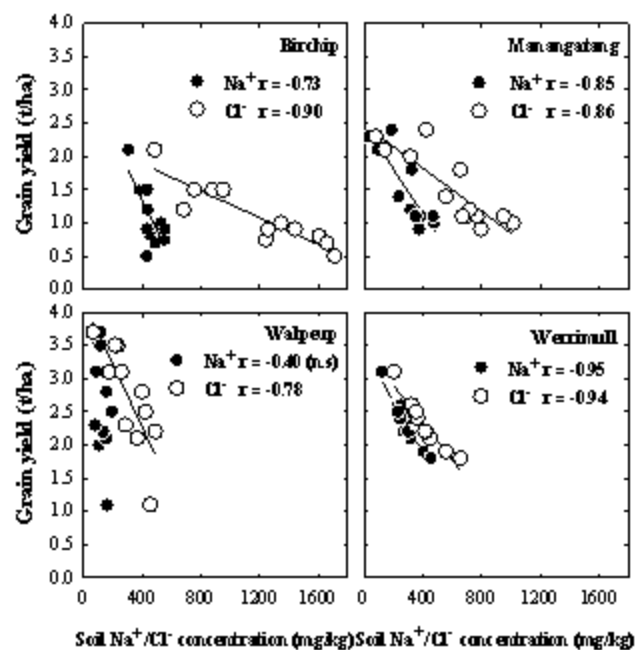


Figure 2. The relationships between variations in grain yield of barley variety Sloop, and variations in soil Na^+ and Cl^- concentrations in four saline-sodic sites in Southern Australia.

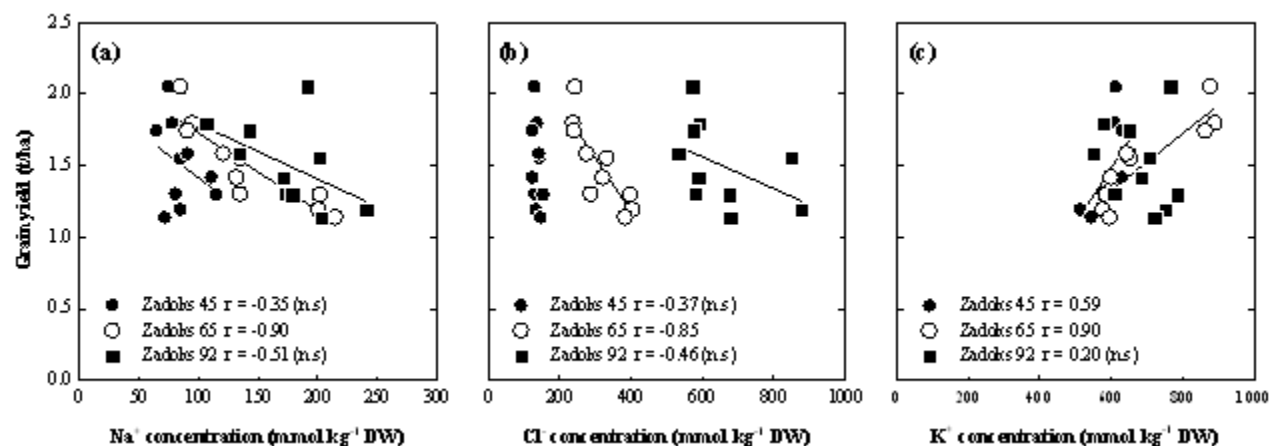


Figure 3. The relationships between grain yield and a) Na^+ , b) Cl^- and c) K^+ concentration of the youngest fully expanded leaf of 10 genotypes of barley at three different growth stages grown at Georgetown.

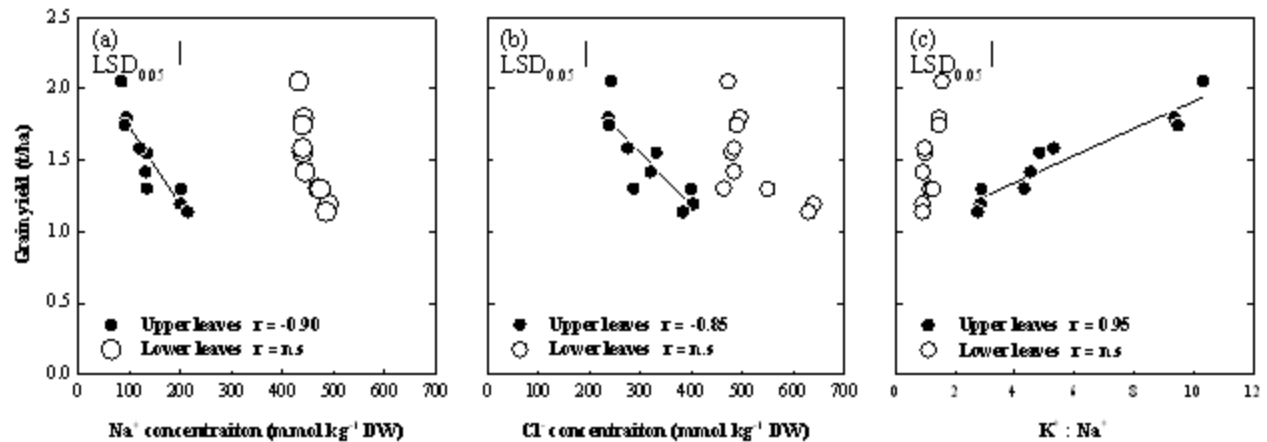


Figure 4. The relationships between grain yield and (a) Na^+ , (b) Cl^- concentration and (c) $\text{K}^+:\text{Na}^+$ concentration of the lower leaves (\circ) and upper fully expanded leaf (\bullet) of 10 genotypes of barley at ZGS 65 grown at Georgetown.

Conclusion

For selecting barley cultivars with salinity tolerance, measurement of the upper two leaves of the main stem at ZGS 65, including a simple measurement of dry weight, Cl^- , Na^+ and K^+ concentrations appears to provide a reliable criterion to evaluate the tolerance of genotypes under field conditions.

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