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Salt tolerance, date of flowering and rain affect the productivity of wheat and barley on rainfed saline land

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ABSTRACT

Over two growing seasons, we examined the effects of natural field salinity on grain production by a range of wheat and barley genotypes on rainfed (i.e. non-irrigated) land with a Mediterranean climate. Blocks of wheat and barley were grown at adjacent locations, on saline and non-saline sites. The two growing seasons differed in the amount of rain that fell in late Spring during grain filling, which strongly affected soil moisture, and in the salinity of the soil solution during grain filling. On the non-saline site in 2009 (less rain in Spring) there were similar ranges of grain yield between the 27 barley and 90 wheat genotypes; the 5th–95th percentile ranges of grain yield for the two crops were 0.9–2.1 t ha^{-1} and 0.9–1.9 t ha^{-1} respectively. However on the saline site in this year, the average salinity of the soil solution during grain filling was ~0.4 M, and the earlier flowering barley genotypes had higher grain yields (5th–95th percentile 1.5–3.1 t ha^{-1}) than the later flowering wheat genotypes (0.8–2.3 t ha^{-1}). By contrast, in 2011 (dry early Spring, rain in late Spring), on the saline site the average salinity of the soil solution was less than 0.2 M during grain filling, and the 320 wheat and 14 barley genotypes had similar 5th to 95th percentile ranges in grain yield to each other under saline conditions (barley 1.1–3.1 t ha^{-1}; wheat 1.3–2.9 t ha^{-1}). Comparisons of genotypes common to both sites showed that there were wheat (e.g. Mace, Tammarin Rock, Binnu) and barley cultivars (e.g. Mundah, Parent 19) with consistently higher yields under saline conditions. We conclude that grain yield by cereals on saltland is associated with the severity of salinity, the adaptation of genotypes to local conditions, their salt tolerance, and (in seasons with a dry spring) early flowering.

1. Introduction

Salinity is a major constraint to agriculture in many arid and semi-arid regions of the world (Ghassemi et al., 1995), and is one of the major soil constraints in the Australian wheatbelt (Dang et al., 2006; McDonald et al., 2012). This paper focuses on factors affecting the productivity of wheat and barley genotypes on soils affected by dryland salinity in south-western Australia.[1] In Australia, two kinds of salinity are recognised: 'dryland salinity' caused by the presence of a saline shallow watertable, and 'transient salinity' caused by the accumulation of salts from rain (c.f. Hingston and Gailitis, 1975) over many hundreds of years in sodic soils (Rengasamy, 2002); both occur on rainfed (non-irrigated) land. It is estimated that 16% of Australia's rainfed cropping area has the potential for dryland salinity, but 67% of the cropping area has the potential for transient salinity (Rengasamy, 2002).

One of the major challenges in determining differences in production between crop genotypes in response to salinity under dryland conditions in the field is that the severity of salinity can be highly temporally variable during the growing season and highly spatially variable over short distances. Temporal variation is caused by the fact that plant growth responds to the salinity of the soil solution, which is proportional to the salt concentration of the soil (of which EC_e and $EC_{1:5}$ are measures) and inversely proportional to the water concentration of the soil (Bennett et al., 2009). On

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[1] Definitions

Production on salt affected soils refers to grain yield or biomass production in a

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non-irrigated saltland soils in Mediterranean environments, we might therefore expect the salinity of the soil solution to be initially high at the start of winter (the growing season for annual plants) because salt has risen to the soil surface by capillarity from deeper in the soil profile over the preceding summer and autumn, and this salt becomes dissolved in the relatively small amounts of water that are available at the start of the growing season. Later in the growing season we might expect the salinity of the soil solution to decrease because the increasingly abundant winter rains leach salt and also hydrate the soil. Then towards the end of Spring and the start of summer, we might expect the salinity of the soil solution to increase again as the soil dries out. Spatial variation is inherent in salt affected landscapes. Within one field salinities may vary from being negligible to being so high that even halophytes will not grow (Richards, 1983; Barrett-Lennard et al., 2013). Many researchers now use electromagnetic induction to estimate and map spatial variation in soil salinity (e.g. Huang et al., 2016).

A range of physiological studies suggest that barley has greater tolerance to internal Na^+ ions than wheat and is therefore more salt tolerant than wheat (see review by Colmer et al., 2005). Reflecting this physiological understanding, agronomic studies conducted under conditions of controlled salinity have shown greater persistence of leaves and higher grain yields in barley than in wheat. For example, Rawson et al. (1988) grew 5 barley cultivars and 6 bread wheats in irrigated gravel cultures with ~4 weeks exposure to salinities of 0–250 mM NaCl. With an external salinity of 175 mM NaCl, the proportion of the total shoot DM that died was ~13 and 24% for the barley and wheat respectively, whereas at 250 mM NaCl, these proportions had increased to ~34 and 57% of shoot DM respectively (calculated from data of Rawson et al., 1988). In a longer-term trial, Ayers et al. (1952) grew 4 barley and 2 wheat cultivars in 18.2 m^2 plots irrigated with water salinised to 10,000 ppm with equal parts of NaCl and $CaCl_2$ to produce soils with an average EC_e (0–30 cm) of 8.7 dS m^{-1}. Under saline conditions, the barley cultivars had final grain yields of 1.9–4.0 t ha^{-1}, whereas the wheat cultivars had average grain yields of ~1.9 t ha^{-1}.

There is limited consistent evidence for higher grain yields in barley compared with wheat on saline sites in the field. In one study by Bole and Wells (1979), 7 cultivars of bread wheat, 7 cultivars of 2-row barley and 7 cultivars of 6-row barley were grown under conditions of dryland salinity (average EC_e at 0–30 cm of 9.2 dS m^{-1}) and ~320 mm of seasonal rainfall in Alberta Canada. At harvest, the wheat cultivars had lower grain yields than the 2-row and 6-row barleys, but there were overlapping yield ranges between the three groups of cultivars (wheat 0.8–1.5 t ha^{-1}, 2-row barley 1.2–1.8 t ha^{-1}, 6-row barley 1.8–2.6 t ha^{-1}). By contrast, in another study on an irrigated field site in the San Joaquin Valley of California, at an EC_e of ~20 dS m^{-1}, 17 wheat cultivars had virtually the same range of grain yields (5th–95th percentile; 1.5–4.1 t ha^{-1}) as 16 barley cultivars (~0.8–3.9 t ha^{-1}) (Richards et al., 1987). Clearly, the extrapolation of results from simple physiological experiments conducted under controlled conditions to plant performance on saline land in the field should be questioned.

One reason physiological experiments under controlled conditions may be a poor mimic of the field situation is that such experiments are usually conducted with a constant salinity of the soil solution. However this approach removes the interaction between increasing water stress and differences in the rate of plant development at the end of the growth cycle from considerations of adaptation. One difference between barley and wheat is that barley often flowers and ripens earlier than wheat (Rawson et al., 1988). This means that in situations of declining water availability towards the end of the growing season, early-flowering barley cultivars might be able to fill their seed with carbohydrates before the soil gets too dry and the salinity of the soil solution increases to unacceptable levels, whereas later-flowering wheat cultivars might not be able to do this. Early flowering date associated with escape from salinity could therefore be a critical attribute in explaining differences in yield between barley and wheat on saltland. An extensive survey of wheat yields on land with subsoil constraints across Australia showed that date of maturity was the trait most frequently associated with yield variation (McDonald et al., 2012). The relative importance of early and late flowering varied across the country, but in Western Australia, yield variation was more associated with early flowering (48% of sites examined) than any other factor (McDonald et al., 2012).

This paper describes comparisons of the relative performance of wheat and barley genotypes to non-irrigated (dryland) salinity in two years 2009 and 2011 at a location in Western Australia (Ballidu) with a Mediterranean climate and an annual average rainfall of 335 mm. In each year we planted the wheat and barley genotypes at a non-saline site (enabling us to determine the local adaptation of each genotype) and at a nearby saline site (enabling us to determine the salt tolerance of each genotype).

We focus on three issues. Firstly, in situations of moisture constraint or high salinity of the soil solution at the end of the growing season, barley may have higher yields than wheat, but this could be at least partly associated with early flowering. Secondly, on saline sites, the salinity of the soil solution varies seasonally and spatially, and measurement of this variation is important in accounting for the apparent relative differences in tolerance between wheat and barley genotypes. Thirdly, high production on saline field sites is associated with traits associated with both local adaptation and salt tolerance.

2. Materials and methods

2.1. Location of trials and experimental design

Field trials to evaluate the salinity tolerance of wheat and barley accessions under rain fed conditions were conducted in the 2009 and 2011 growing seasons on saline and non-saline sites near Ballidu, Western Australia. The trials were located on the farm of Mr David Hood, in an area that had been used for cereal cropping over the prior 80 years. In 2009, the saline (S30.5699° E116.8142°) and non-saline (S30.5721° E116.8142°) trial locations were approximately 100 m apart. In 2011, the saline (S30.5700° E116.8148°) and non-saline (S30.6102° E116.8673°) trial locations were ~6.7 km apart.

At each site, the blocks of wheat and barley were planted immediately adjacent to each other, i.e. separated by only two rows of buffer plots. A spatial row-column design with replication in two directions (along rows and columns) was generated using DiGGer

saline environment. It is affected by the plant's 'local adaptation' and 'salt tolerance'. 'Local adaptation' refers to the suitability of a plant to its local environment. The range of grain yields on a non-saline soil is a useful index of variation in local adaption.

Salt tolerance/salt sensitivity refers to the increment of gain or loss in growth, grain yield or biomass production in a saline environment relative to a control grown in a non-saline environment. For cereal crops the difference in grain yield between plants grown under saline and non-saline conditions is a useful index of variation in salt tolerance.

The electrical conductivity of the soil saturation extract (EC_e) and 1:5 extract ($EC_{1:5}$) are measures of the salt concentration in the soil. These affect plant growth by influencing the salinity of the soil solution.

The salinity of the soil solution is the causal factor that decreases plant growth on saline soils and is the ratio of salt concentration in the soil to water concentration in the soil. For soils affected by NaCl, the salinity of the soil solution (moles L^{-1}) can be estimated from the $EC_{1:5}$ (dS/m) and percent soil moisture (% DM) using the following formula:

Salinity of soil solution = $EC_{1:5} \times 5$/Soil moisture