Comparing genotypic variation in wheat in response to transient waterlogging in alkaline sodic soils

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Abstract
Dispersive sodic soils are common in the cropping areas of south-eastern Australia and due to their poor water infiltration rate, transient waterlogging may occur, even following a small rainfall event. Transient waterlogging causes significant changes to soil chemistry that can severely reduce root growth and result in yield loss. To date there is limited information on the genetic variation in wheat for waterlogging tolerance in the field with sodic subsoils. The aim of this study was to 1) quantify waterlogging tolerance among wheat genotypes, and 2) identify which phenotypic traits are most closely related to waterlogging tolerance in the field. The experiments were conducted in a field at Leeton Farm Station of NSW DPI on a dispersive, sodic soil. Fifteen wheat genotypes were grown under waterlogged and control condition. Three weeks before anthesis, the area was flooded for five days and then drained. Aerial imaging and physiological and agronomic measurements at different growth stages were used to assess the response to waterlogging. Waterlogging reduced the normalized difference in vegetation index (NDVI), crop biomass, grain yield and grain protein content. Responses in NDVI and grain yield were correlated. Despite quite remarkable difference among different genotypes in their responses to waterlogging, their overall effect was statistically non-significant. Long-term evaluation of different genotypes under field conditions will help us to better understand the mechanisms of waterlogging tolerance and their phenotyping and morphological traits associated with such tolerance.

Key Words
Waterlogging tolerance, sodic subsoil, genotype screening, NDVI, biomass, yield

Introduction
Waterlogging affects about 10 - 15 million ha of wheat globally (Sayre et al., 1994), which represents 15-20% area sown to wheat each year (Setter and Waters, 2003). In Australia, waterlogging has become the key constraint for crop production especially in the high rainfall zone (Acuña et al., 2011). Dispersive sodic soils with heavy clay are common in cropping areas of south-eastern Australia and due to their poor water infiltration rate, transient waterlogging may occur even following a small rainfall event. Waterlogging causes significant changes to soil physical, chemical, electro-chemical and biological properties (Manik et al., 2019). These unfavourable conditions impede root growth and thus water and nutrient uptake from deep in the soil profile (Turner, 1992) and may result in significant yield loss (~30-40%) in an average rainfall year (Zhang et al., 2004).

Implementation of different management practices such as raised bed system, subsurface drainage, crop management and subsoil manuring have contributed to some extent yield stability in soils prone to waterlogging (Manik et al., 2019). However, for further improvements in yields or to minimise the yield gap under waterlogging conditions, development of wheat genotypes with tolerance to waterlogging is essential. To date there is limited information on the genetic variation in wheat for waterlogging tolerance and its interaction with alkaline sodic subsoils. Therefore, a field trial was conducted to characterise the agronomic and physiological responses of key wheat genotypes in response to waterlogging in an alkaline sodic subsoils. We combined the use of high-resolution, low-altitude aerial imaging for rapid phenotyping of crops with physiological and agronomic measurements to identify the traits contributing to waterlogging tolerance in the field.

Methods

The experiment was conducted in the Leeton Farm Station of NSW DPI, in NSW, Australia from May 2018 until December 2018. The soil profile was slightly alkaline in the top 10 cm (pH (1:5 water) = 8.2) and dramatically increasing with depth, reaching 9.4 at 40 cm depth and below. The changes in soil sodicity (exchangeable sodium percentage, ESP) followed a similar trend of soil pH with ESP only 2% at the topsoil increasing to 30% in the subsoil. The trial consisted of 15 wheat genotypes and two watering regimes (waterlogging and control). Wheat genotypes were nested within the watering regimes in a randomised complete block design with 3 replicates. The genotypes were selected on the basis of their waterlogging tolerance (Schilling, unpublished data). Each plot was 4m long, 1.4 m wide, and consisted of 6 rows with 0.244 m spacing. Plots were sown on 21 May 2018. Three weeks prior anthesis transient waterlogging condition was created for five days by using the irrigation facility of Yanco Agricultural Institute. The experimental plots were flooded and the water allowed to stand for five days after which it was drained. At anthesis, multispectral images were collected using drone technology to quantify the crop responses under waterlogging conditions. Quadrat samples were taken at anthesis (0.375 m^2) and physiological maturity (1 m^2) to measure plant biomass and yield and harvest index. Grain protein content was estimated non-destructively using NIR (Foss NIR systems Model 6500). Results were analysed in a linear mixed model with block/replication as a random effect.

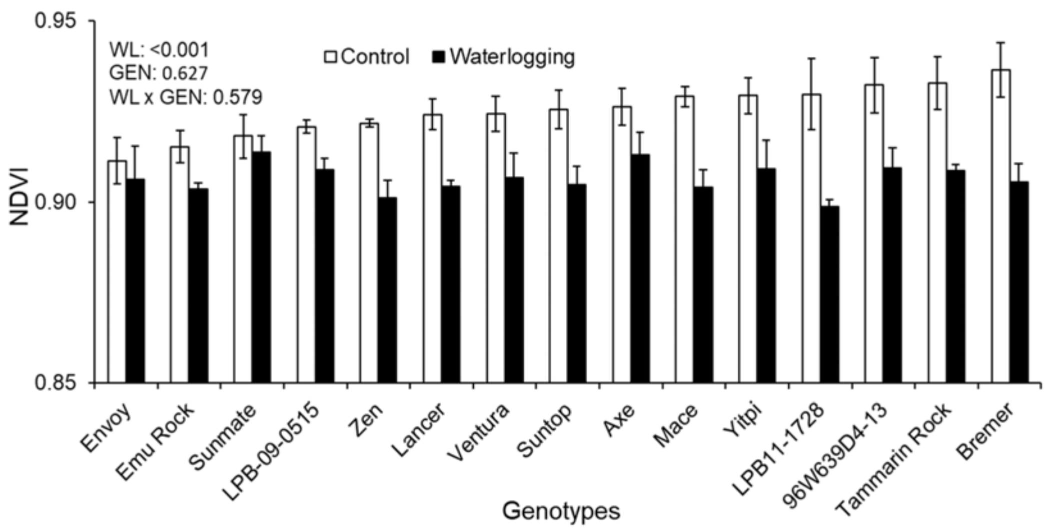

Figure 1. The effect of waterlogging (WL) on normalized difference in vegetation index (NDVI) at anthesis of different wheat genotypes (GEN) grown on a soil with a sodic subsoil in 2018 at Leeton Farm Station of SNSW in Australia. Error bars are the standard errors of the mean (n ~3).

Results

Waterlogging significantly reduced the NDVI at anthesis, however, there was no significant difference among genotypes (Figure 1). Biomass at anthesis was also reduced by waterlogging by a similar amount as NDVI (data not shown). At physiological maturity, waterlogging resulted in 11% reduction in biomass and a 10% reduction in grain yield, respectively compared to control condition (Figure 2A, B). Both biomass ($r = 0.57$; $p < 0.001$) and grain yield ($r = 0.68$; $p < 0.01$) at physiological maturity were significantly correlated with the NDVI at anthesis. Due to the similar reductions in biomass and grain yield from waterlogging, harvest index remained unaffected (Figure 2 C). Grain protein content of wheat grown under waterlogged condition was significantly lower than whet grown under control condition (Figure 3), however, there was no correlation of this parameter with grain yield (data not shown). Despite some visible difference among genotypes, none of these studied parameters were significantly affected by genotypes or waterlogging by genotypes interactions.

Discussion

The reduction of biomass and grain yield under waterlogging condition observed in our study was well below the earlier reported values for transient waterlogging before tillering stage (Zhang et al., 2004). This lower response might be attributed to the timing of waterlogging treatment. In the current study, as it was imposed just three weeks before anthesis and therefore had no effect on plant establishment and tillering, which are considered as the most important factors leading yield loss under waterlogging (Cannell et al., 1980).

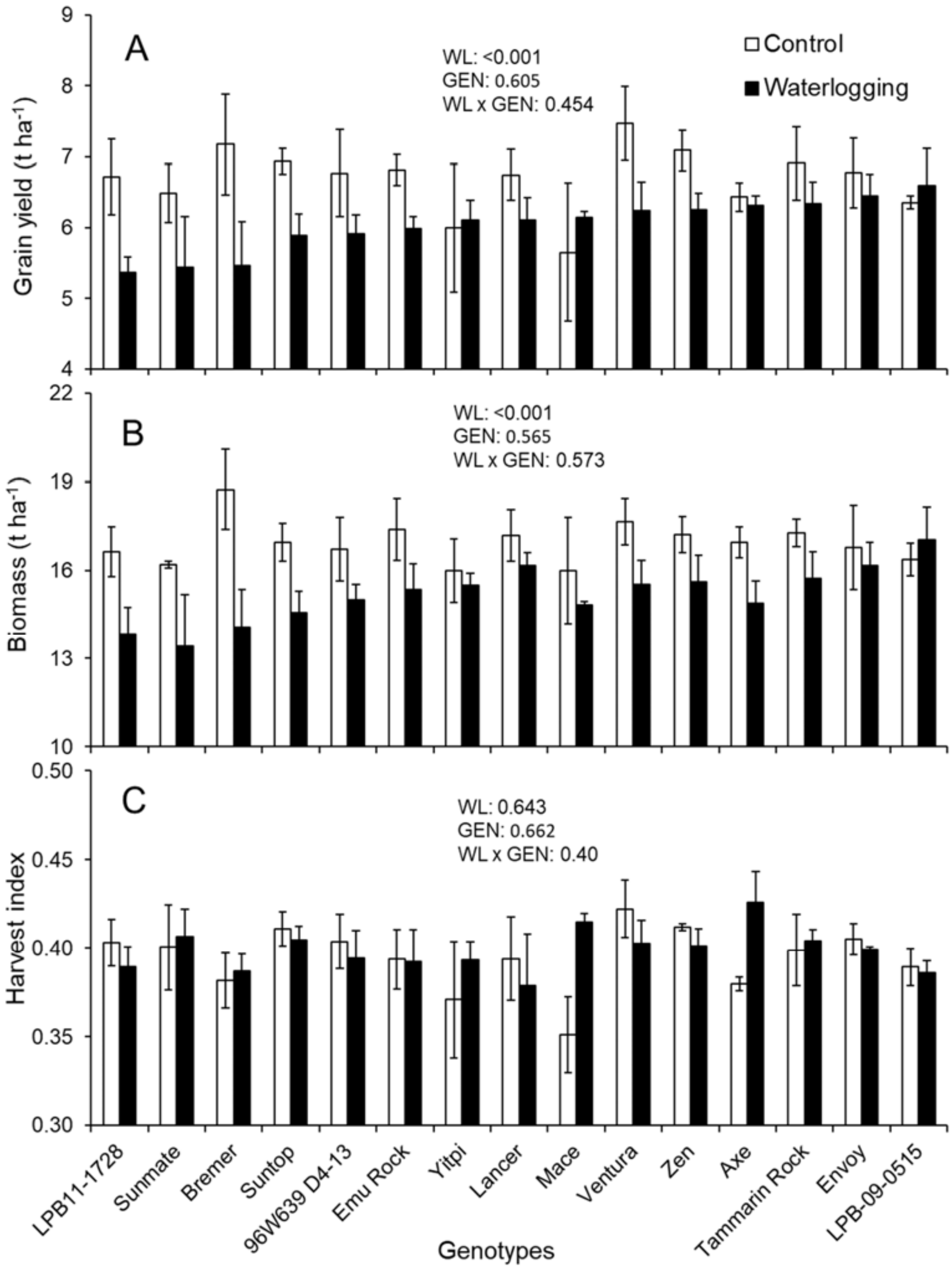

Figure 2. The effect of waterlogging (WL) on grain yield (A), biomass (B) and harvest index (C) at physiological maturity of different wheat genotypes (GEN) grown on a soil with a sodic subsoil in 2018 at Leeton Farm Station of SNSW in Australia. Error bars are the standard errors of the mean (n ~3).

Physiologically, waterlogging tolerance is defined as the survival or maintenance of high growth rates under waterlogged than control conditions. However, agronomically it is defined as the maintenance of relatively high grain yield under waterlogged relative to control conditions (Setter and Waters, 2003). This contrast in definitions is due to the strong correlation between biomass and grain yield in waterlogging conditions (Sayre et al., 1994). We also observed similar correlation ($r = 0.87$; $P < 0.001$) between biomass and grain yield in the current study.

Genotypic variabilities in wheat for waterlogging tolerance is associated with different morphological, physiological and biochemical processes (Manik et al., 2019). NDVI measured as a surrogate of canopy cover was correlated with biomass and grain yield and can be used as a non-destructive tool for estimating the effect of waterlogging. This parameter will be further accompanied with the more sensitive vegetation indices like green NDVI (GNDVI), normalized difference red edge (NDRE) and green red vegetation index (GRVI) to identify the best possible indices associated with the waterlogging tolerance of wheat genotypes.

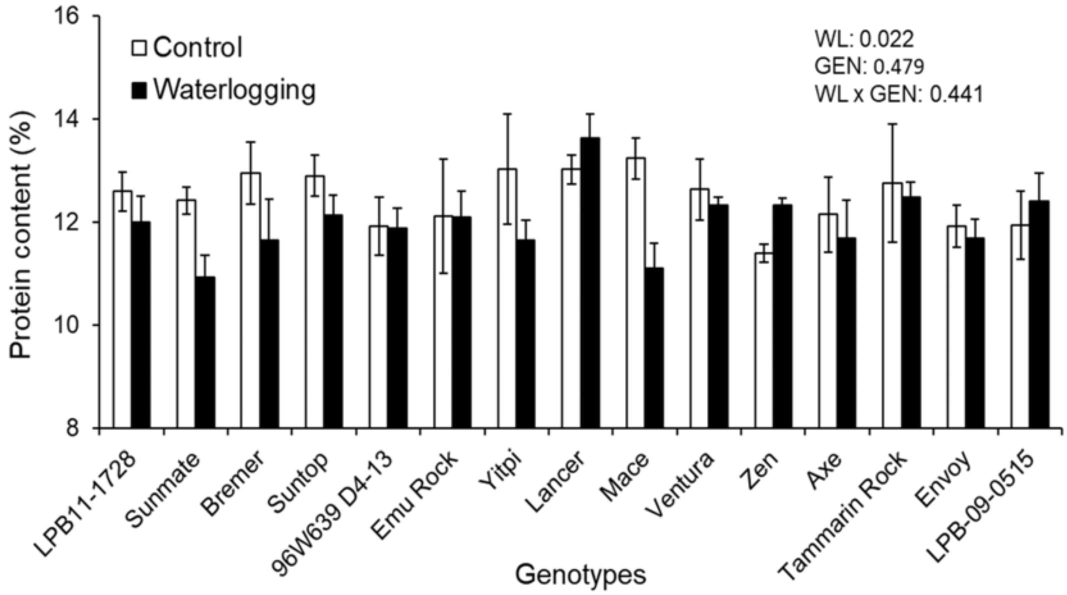

Figure 3. The effect of waterlogging (WL) on grain protein content of different wheat genotypes (GEN) at physiological maturity grown on a soil with a sodic subsoil in 2018 at Leeton Farm Station of SNSW in Australia. Error bars are the standard errors of the mean (n ~3).

The reduction of grain protein under waterlogging might be attributed to the nitrogen loss by denitrification, which resulted in approximately 30 ~ 40% reduction of total N uptake (Zhang et al., 2004). This lower N uptake under waterlogging condition can affect the remobilisation processes and therefore deteriorated the grain protein content.

Acknowledgements

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