Late, deep root development varies between wheat cultivars subjected to terminal water stress

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Abstract

Root architecture is an adaptive trait that differs markedly across wheat genotypes. Shallow and deep root growth of two wheat cultivars, Mace and Scout, were examined under well-watered and terminal water-stress conditions during late development. Variations in late deep root development are likely to affect tolerance to late season water stress in regions where crops rely on stored soil water such as sub-tropical north-eastern Australia. Plants grown in poly vinyl chloride (PVC) tubes were either well-watered or stressed in one of four water deficit treatments withholding water between, (i) early anthesis to early grain filling, (ii) early grain filling to late grain filling, (iii) mid-grain-filling to maturity and (iv) anthesis to maturity. In well-watered conditions, there was little difference in dry root biomass between the two genotypes either at heading or at maturity ($p \geq 0.05$). Under water deficit, dry biomass at maturity was higher in Scout than Mace for both shallow and deep roots when water was withheld for periods between mid-grain filling and maturity. Differences between genotypes were most apparent when water deficit was applied near anthesis or during grain filling. However, when a severe water deficit was applied from anthesis and continued to maturity, both genotypes were similarly severely affected. This suggests that applying a period of moderate water deficit may be required or at least advantageous to identify genotypes with root systems that are better adapted to late season water stress.

Keywords

Dry root biomass, drought tolerance, deep roots, late root development, phenotyping method.

Introduction

Wheat growing regions of Australia is generally rain fed rather than irrigated. This often exposes the crop to drought leading to poor harvest or crop failure.

In regions of summer dominant rainfall, such as sub-tropical north-eastern Australia, where winter cereals rely heavily on stored soil moisture from the previous summer, crops are often exposed to drought late in the season (Chenu et al. 2013). For example, in this region, deep clay soils can typically store over 200 mm of crop available water. Depletion of stored soil moisture early in the crop cycle can make crops heavily reliant on soil moisture stored in deep soil layers under late season water stress (Christopher et al. 2016; Collins et al. 2021).

Root architecture is defined as the progressive and spatial structure of the root system in the soil. Root architecture is key to the efficiency with which crops utilize nutrients and water from the soil, and could potentially be harnessed to improve yield in water-limited environments (Manschadi et al. 2006). Favourable root traits that have been reported to increase water uptake in water-stressed environments include greater root depth and root elongation rate (Lopes & Reynolds 2010), greater root distribution at depth (Manschadi et al. 2006), narrow seminal-root angle (Manschadi et al. 2008), and increased root: shoot biomass ratio (Siddique et al. 1990).

Wheat varieties with a deep root system are likely to have higher yields in rain-fed farming systems if they can access water stored deep in the soil during water stress conditions (Wasson et al. 2012). This was demonstrated in field trials and a rhizotron experiment, which were used to compare the yield and root system of a wheat variety with greater root length density at depth (SeriM82) and a standard variety (Hartog) under water deficit conditions. SeriM82 exhibited higher yield than Hartog, which was associated with increased water extraction during the grain-filling stage (Manschadi et al. 2006). Selecting for deep root development may confer a major advantage as deep soil water accessed during the grain-filling stage is more efficiently converted into grain than in-season rain measured during the entire crop cycle (Passioura & Angus 2010). In addition, deep soil water is often more predictable than in-season rainfall, which can vary in amount and timing (Liu et al. 2013). Water stored deep in the soil can also be measured before a decision is made to sow a crop (Zheng, Chapman & Chenu 2018).

Despite the potential of root architecture to improve drought tolerance and increase yield, literature on improving root architecture for breeding programs remains scarce. Instead, much effort is invested into researching shoot traits. This is likely due to difficulties in measuring root traits, especially during later stages, and a lack of efficient root screening methods (Fleury et al. 2010).

In this study, we developed a system to use poly tubes and manual washing to measure root traits to assess genotypic variations in root architecture late in the season in response to water stress. Two genotypes (Scout and Mace) were studied in five different soil-water treatments during three experiments.

Material and methods

Root growth patterns of two wheat cultivars were examined during late development using single plants cultured in 1.5-m long poly tubes. Mace and Scout have been widely grown in the west and the south of Australia, respectively. It has previously been observed that they differ in root architecture at the seedling stage (Richard et al. 2018).

Three experiments were conducted in the field using the PVC tubes. In one experiment, three water application treatments were used: well-watered during the whole crop cycle ('WW'); well-watered treatment followed by water deficit applied by withholding watering between head emergence (Zadoks decimal growth stage, Z60; (Zadoks, Chang & Konzak 1974) and early grain filling (Z71) ('WD.Z60-Z71') and; water deficit from early grain filling (Z71) to late mid grain filling (Z81) ('WD.Z71-Z81').Well-watered plants were harvested at either anthesis (Z65) or maturity (Z92) while water-stressed plants were harvested only at maturity. In a second experiment, plants were cultured as above but with water deficit applied by withholding watering slightly later, between early grain filling (Z75) and maturity ('WD.Z75-Z92'); and in a third experiment, water was withheld for the whole period from flowering to maturity ('WD.Z65-Z92').

For each experiment, a randomized complete block design was used with eight replicates per genotype for each watering treatment. The tube experiment was conducted in an open area (Figure 1a) in the winter growing season in Toowoomba, Queensland, Australia (27º31'58''S, 151 º 56'8''E). Poly tubes (90 mm diameter by 1500 mm long) were cut vertically and reassembled using general-purpose cloth tape 50 mm.

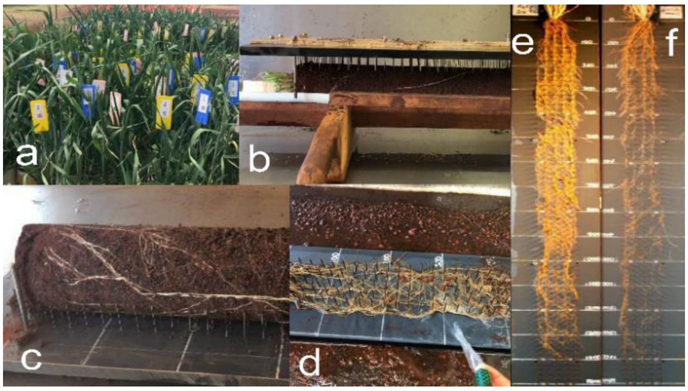

Figure 1. **Plants grown in an open area (a); soil from split tubes mounted on the nail board prior to root washing (b) and (c); removal of soil from the nail board by washing (d); root images from Scout (e) and Mace (f) root systems at maturity (Z92) after withholding water between mid-grain filling and maturity (WD.Z75-Z92 treatment). Horizontal bars in (e-f) are separated by 100 mm.**

A 1:1 mixture of two soils was used (black and red soil) with added Osmocote fertilizer containing trace elements at 2 g L^{-1} (N 15.3%, P 1.96%, K 12.6%). Three seeds of each genotype were placed in each tube at a depth of 2 cm. Seedlings were thinned to one per tube following emergence and water was added until drainage was observed from the bottom of the poly tubes.

Plants were harvested for each target harvest stage after splitting the tube along the taped line and the roots were extracted after washing the soil away on a purpose built nail board (Figure 1b-c). Dry root biomass was measured for shallow (30-40 cm) and deep roots (110-120 cm) after drying in an oven at 65ºC for 72 h.

Analysis of variance (ANOVA) using a linear mixed model was conducted in R software (v3.2.5; R Core Team 2019).

Results and discussion

In well-watered conditions, no significant differences were observed between Scout and Mace for either shallow or deep root dry biomass (Figure 2a). However, the root biomass of both genotypes declined with depth, both at heading and at maturity (Figure 2a).

In contrast to the well-watered treatment, dry root biomass significantly differed between genotypes for the short-term water deficit treatment WD. Z75-Z92 (Figure 2b ii and v). Shallow dry root biomass differed significantly for water deficit treatment WD.Z60-Z71 (Figure 2b i). A similar pattern was observed for the other two intermediate drought treatments although the differences between genotypes were not statistically significant in all cases (WD.Z60-Z71, WD.Z71-Z81; Figure 2b i and 2b iv). In contrast, root growth was severely reduced in both genotypes under severe water stress when water was withheld from flowering through to maturity (WD. Z65-Z92, Figure 2b ii and 2b vi).

In each case, there was a similar pattern for shallow (30-40 cm) and deep roots (110-120 cm). Root biomass was reduced more in Mace than Scout for well-watered (non-significant differences) and intermediate water-stress treatments (generally significant differences), while similar in both Mace and Scout for the most severe treatment.

The difference in shallow and deep root development between these two wheat genotypes was, thus, most apparent when exposed to periods of moderate water-stress near anthesis or during grain filling but less so when plants are either well-watered or severely water-stressed from anthesis onward. This suggests that the imposition of water-stress from the time of anthesis may accentuate differences making it easier to distinguish genotypes that are able to maintain late, deep root growth in the face of water-stress.

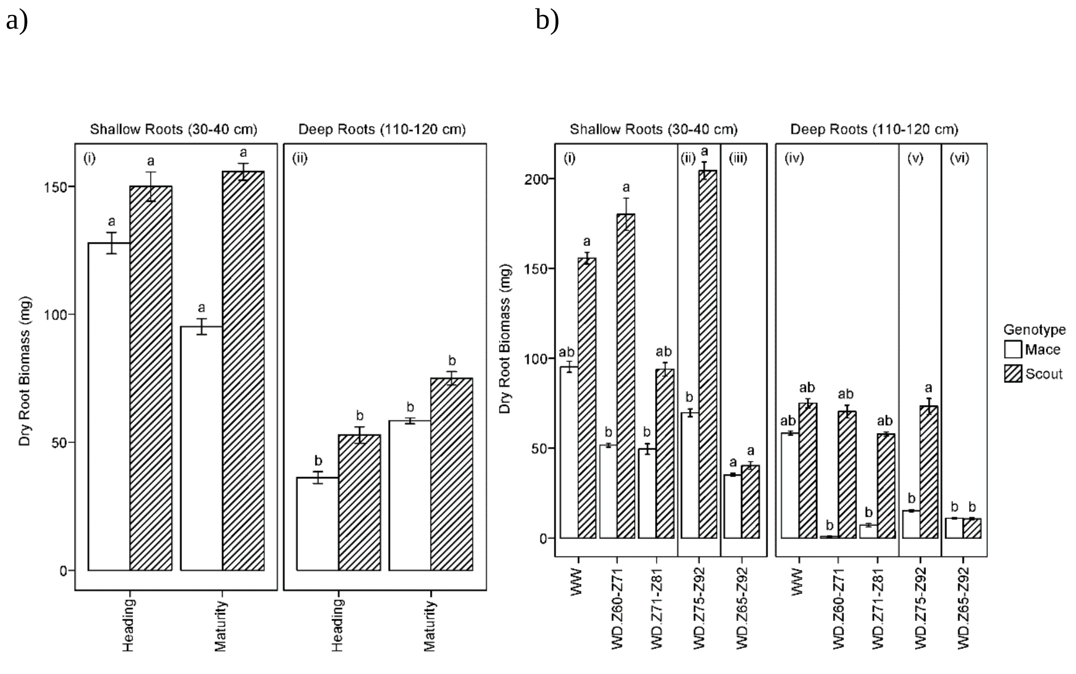

Figure 2. Dry biomass of shallow (30-40 cm) and deep (110-120 cm) roots from wheat genotypes Mace (white) and Scout (shaded) for (i) well-watered plants at heading and maturity and (b) plants subjected to different soil water treatments and harvested at maturity. In (b), three separate experiments are presented (i, ii, iii)). The first experiment had three water treatments (i, iv), the second experiment had a single intermediate water deficit treatment (ii, v), while the third had a single long and severe water-deficit treatment (iii, vi). Error bars represent the standard error of the mean (n=8). Means indicated with the same letter do not differ significantly within each experiment and within each depth ($p > 0.05$).

Conclusion

Two wheat cultivars, Mace and Scout, differed in late deep root architecture when periods of water-stress were applied near anthesis or during the grain filling period, but less so when well-watered or severely stressed. Thus, genotypic differences may be enhanced by imposition of intermediate levels of water-stress at appropriate developmental stages. Taken together, these results suggest a possible method to select for increased late, deep root development in response to late season water deficit. To achieve this in breeding programs, further work will be required to develop high-throughput screening methods and/or molecular genetic selection strategies.

References

Chenu K, Deihimfard R and Chapman SC (2013) Large-scale characterization of drought pattern: a continent-wide modelling approach applied to the Australian wheatbelt–spatial and temporal trends', *New Phytologist*, vol. 198, no. 3, pp. 801-20.

Christopher JT, Christopher MJ, Borrell AK, Fletcher S and Chenu K (2016) Stay-green traits to improve wheat adaptation in well-watered and water-limited environments, *Journal of Experimental botany* 67:5159-72.

Fleury D, Jefferies S, Kuchel H and Langridge P (2010) Genetic and genomic tools to improve drought tolerance in wheat, *Journal of experimental botany* 61:3211-22.

Liu X, Li R, Chang X and Jing R (2013) Mapping QTLs for seedling root traits in a doubled haploid wheat population under different water regimes, *Euphytica* 189:51-66.

Lopes MS and Reynolds MP (2010) Partitioning of assimilates to deeper roots is associated with cooler canopies and increased yield under drought in wheat, *Functional Plant Biology* 37:147-56.

Manschadi AM, Christopher J, deVoil P and Hammer GL (2006) The role of root architectural traits in adaptation of wheat to water-limited environments, *Functional Plant Biology*, 33:823-37.

Manschadi AM, Hammer GL, Christopher JT and Devoil P (2008) Genotypic variation in seedling root architectural traits and implications for drought adaptation in wheat (*Triticum aestivum* L.), *Plant and soil* 303:115-29.

Passioura J and Angus J (2010) Improving productivity of crops in water-limited environments, *Advances in agronomy*, 106:37-75.

R Core Team (2019). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Richard C, Christopher J, Chenu K, Borrell A, Christopher M and Hickey L (2018) Selection in early generations to shift allele frequency for seminal root angle in wheat. *The Plant Genome* 11.

Siddique K, Tennant D, Perry M and Belford R (1990) Water use and water use efficiency of old and modern wheat cultivars in a Mediterranean-type environment, *Australian Journal of Agricultural Research* 41:431-47.

Wasson AP, Richards R, Chatrath R, Misra S, Prasad SS, Rebetzke G, Kirkegaard J, Christopher J and Watt M (2012) Traits and selection strategies to improve root systems and water uptake in water-limited wheat crops, *Journal of experimental botany* 63:3485-98.

Zadoks JC, Chang TT and Konzak CF (1974) A decimal code for the growth stages of cereals, *Weed research* 14:415-21.

Zheng B, Chapman S and Chenu K (2018) The value of tactical adaptation to El Niño–Southern Oscillation for East Australian wheat, *Climate* 6:77.

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