The effects of root angle on root growth and yield of wheat in the Australian cereal belt

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Abstract

Genetic variation in seminal root angle exists in wheat. It has been suggested that narrow root angles contribute to adaptation to summer–dominant rainfall zones and wide angles are important in the Mediterranean climates of southern Australia. This hypothesis was tested by measuring root angles in wheat and examining its relationship with yield and root distribution. Root angles of 52 genotypes, defined as the angle subtending the first pair of seminal roots of 14-day old seedlings, were measured in a root box. Field experiments were conducted in successive years to measure the depth and distribution of roots. The importance of root angle to yield over a wider range of sites was assessed by an analysis of yield variation among the 52 varieties in 12 years of breeding trials. Root angle varied significantly from 56? to 113? and there was no consistent difference between genotypes from South Australia (mean ? SEM = 82 ? 2.9?) and Queensland (82 ? 5.4?); genotypes from Western Australia had a slightly wider angle (90 ? 2.2?). In the two field trials, maximum depth of rooting did not differ significantly among the genotypes. Narrow root angle was weakly associated with more roots at 60 to 70 cm, but there was no relationship with yield. Within breeding trials, varieties with narrow root angles tended to produce slightly higher (c. 5%) yields, but this occurred in all states. The hypothesis that root angle is associated with adaptation to different parts of the cereal zone was not supported.

Key Words

Root growth, adaptation

Introduction

Acquisition of water and nutrients is a major determinant of yield and adaptation in wheat. The distribution of roots in the soil influences the pattern of water and nutrient uptake and modelling studies have indicated variation in root architecture can alter grain yields (Dreccer et al 2002, Manschadi et al 2006). One aspect of root architecture that can influence root distribution is the angle of the seminal roots. Significant variation in root angle occurs in wheat and it has been suggested that this is related to the geographical adaptation of varieties and in particular their adaptation to the patterns of soil moisture (Oyangi 1994, Manschadi et al 2006, 2008). Plants with narrow seminal roots angles tend to have deeper roots (Oyangi 1994), which has may be advantageous to the use of moisture from the subsoil. However the effect of root angle has not been examined much under field conditions and there is very little empirical data that allows its importance to be assessed.

Methods

Root angle

Seedlings were grown in unamended Mt Compass sand in Perspex root boxes. The sand was watered to 12% moisture content with deionised water. Seed was germinated in Petri dishes until the first root was just emerging. The seed was then carefully placed in the sand with the embryo facing the outer surface of the root box, 5cm below the surface of the sand. The root boxes were placed at an angle of 15? in crates and allowed to grow in the dark at a constant temperature of 20?C. The experiment was replicated in time (3 replicates, one at a time). After 10 days, each seedling was photographed with a digital camera and the root angle between the first pair of seminal roots was measured using ImagJ (Image Software and Analysis in Java http://rsb.info.nih.gov/ij/).

Field trials

The 52 genotypes of wheat were sown in field trials in 2008 and 2009. Annual rainfall in 2008 was 365 mm (281 mm April to October) and in 2009 it was 415 mm (345 mm April-October rainfall). Both sites have alkaline subsoils (pH_w>9.0) with moderate to high concentrations of B (10-20 mg B kg^{-1}) with low to moderate levels of salinity ($EC_{1:5}$ = 0.4-0.8 dS m^{-1}). In 2008 the plots were 10 m long x 8 rows with a 18 cm row spacing. Plots were sown on 5 June at a target plant population of 150 m^{-2} and with a basal fertiliser of 100 kg ha^{-1} DAP. Root growth was measured in one half of each plot and the remaining half was used to measure grain yield. In 2009, the varieties were sown on 29 May with 90 kg ha^{-1} DAP. The varieties were grown in paired plots, each 2.5 m long x 6 rows (20 cm row spacing) at 150 plants m^{-2}. One plot was destructively sampled for root growth and the other was retained to measure grain yield.

Root growth was estimated using the core break method (Drew and Saker 1980). Soil cores, 4.3 cm in diameter, were taken to a maximum depth of 110 cm, the core broken at 10 cm increments and the number of root axes counted at each broken surface. Two cores, one between the rows and the other within the rows, were taken from each plot using a hydraulic soil sampler. The maximum depth of root growth was defined as the depth beyond which no further roots were detected. The method was calibrated by taking soil cores from the border plots, washing out the roots, scanning them and measuring total root length with WinRhizo software. There was a significant correlation between the number of root intercepts and total root length ($r = 0.81$, $P < 0.05$, $n= 16$) with no significant difference in the relationship between the two years. Grain yield was measured by harvesting the plots, including the outside rows. In 2009, kernel weight was measured by weighing a sample of 500 grains. Principal component analysis (PCA) was used to examine the relationships between root distribution, yield and tolerance to other soil stresses, such as zinc deficiency, boron toxicity and salinity.

Analysis of breeding trials

Grain yields of the 52 varieties were obtained from breeding trials between 1992 and 2004, a total of 233 trials. There was a continuous distribution in root angles and a variety was classified as having a narrow angle if it was less than the mean minus the SEM (< 78?) and a wide angle if it was greater than the mean plus the SEM (> 91?). Average root angles were 69 ? 1.6? and 100 ? 1.7? for the varieties with narrow and wide seminal root angles respectively. The mean yields of varieties in each category were calculated among the 233 trials.

Results

There was a significant variation in mean root angle among the 52 genotypes and it ranged from 57? in Machete to 113? in Ellison and Krichauff. There was no consistent difference in root angle in genotypes from different regional breeding programs. The mean root angle for varieties developed in SA (82 ? 2.9?) and Queensland (82 ? 5.4?) did not differ significantly, but both were significantly less than the seminal root angles of varieties released from WA (90 ? 2.2?).

In the field trial the sharp increase in bulk density at 10-20 cm suggested the presence of a compacted layer. Bulk densities increased with depth and bulk density of the subsoil was higher in 2008 than in 2009 (Fig 2). There was no significant difference among genotypes in the maximum depth of rooting and the average

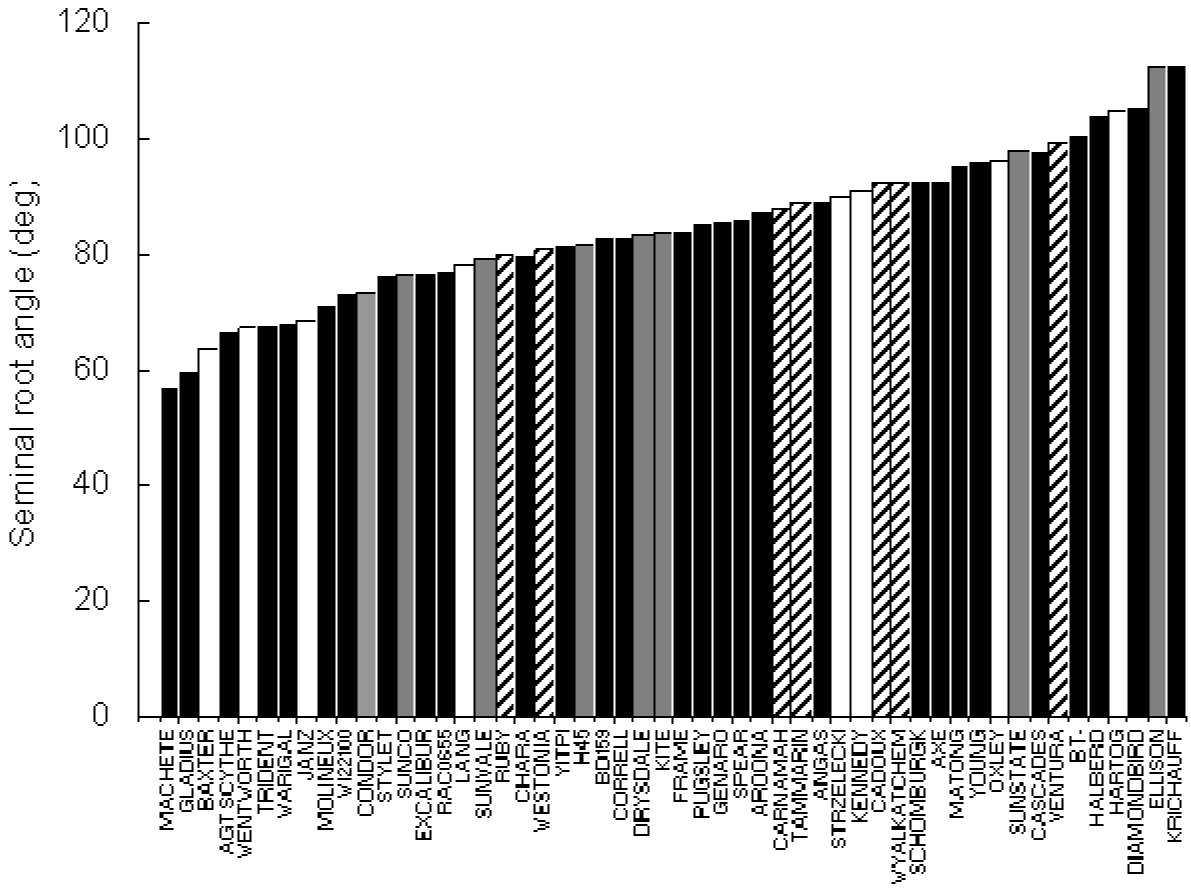

Figure 1. Variation in seminal root angle among 52 genotypes of bread wheat. The varieties originated from programs in SA and Victoria (black), Western Australia (cross hatched), NSW (grey) or Queensland (white)

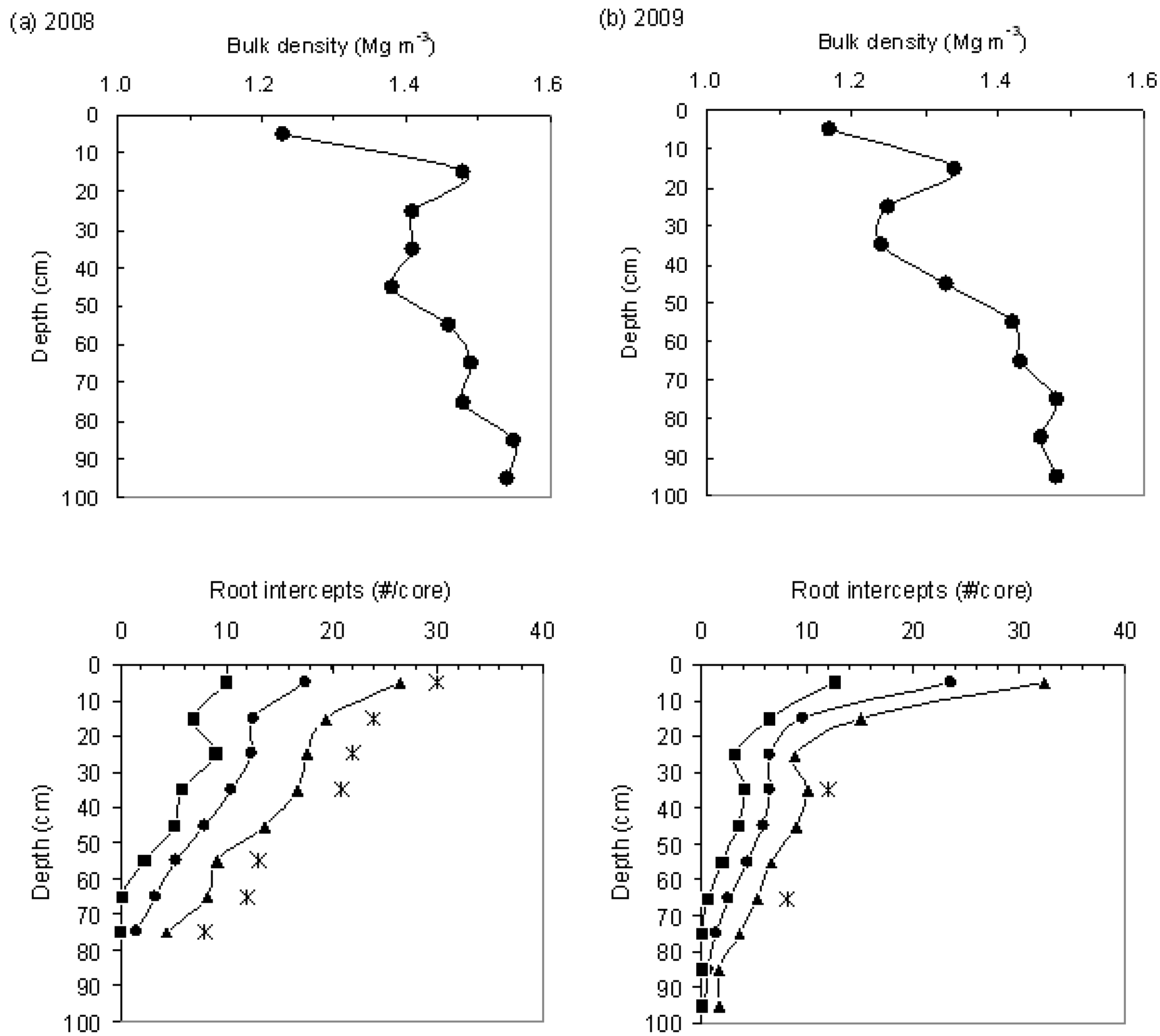

Fig 2 The changes in bulk density and the distribution of roots in the profile in (a) 2008 and (b) 2009 Root data are shown as the mean (●), the minimum (■) and maximum (▲) values. Depths at which significant differences among varieties occurred are indicated with an asterisk.

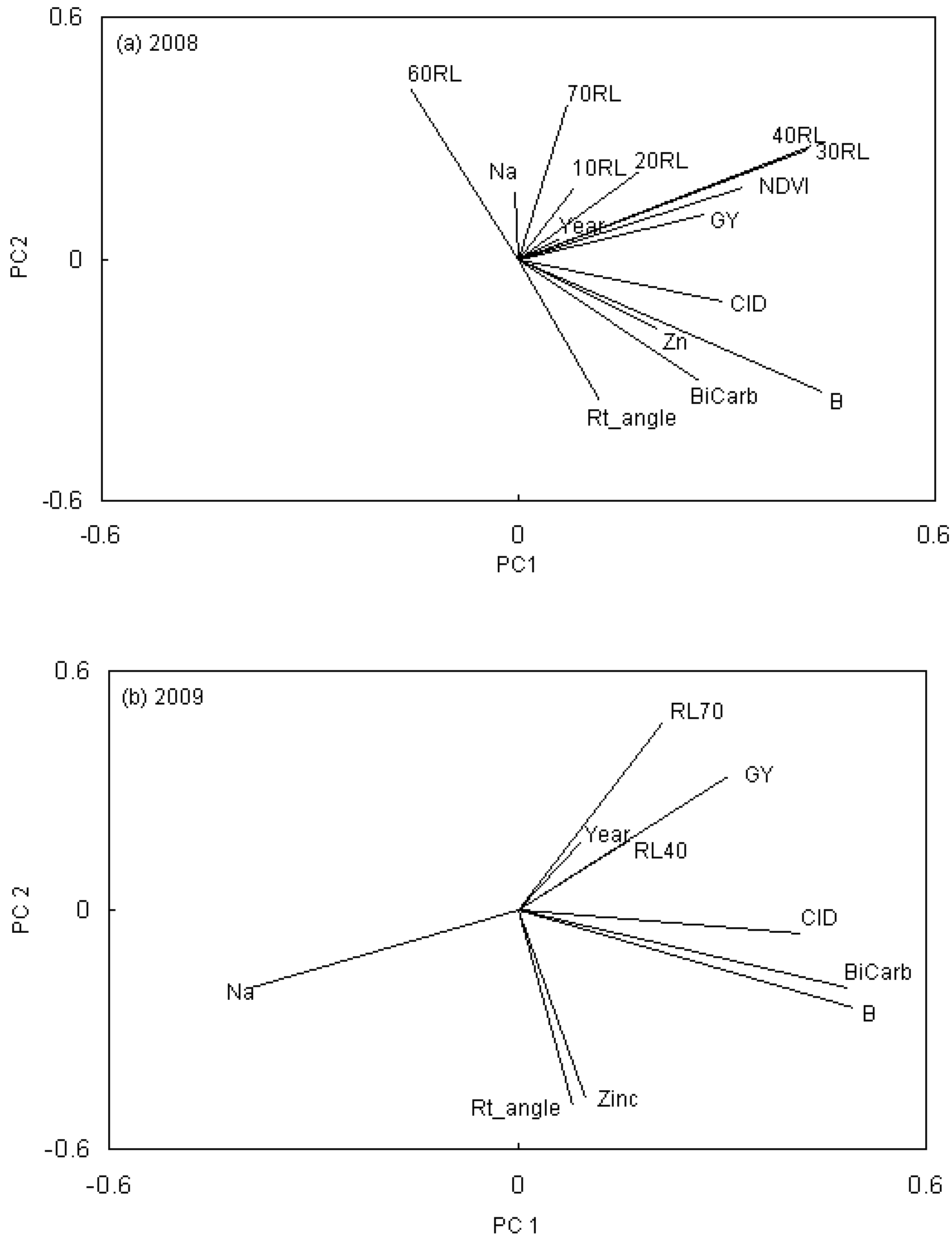

Fig 3 Principal component analysis for experiments in (a) 2008 and (b) 2009. The variables included in the analysis are the number of root axes at depth (10RL = 5-10cm, 20RL = 10-20 cm, 30RL = 20-30 cm etc), grain yield (GY), boron tolerance (B), tolerance to high pH (BiCarb), tolerance to low Zn (Zn), the ability to exclude Na^+ (Na), root angle (Rt_angle), year of release (Year) and NDVI. In 2008 the first two PCs accounted for 31% of the variation and in 2009 they accounted for 40% of the variation.

values were (mean ? SEM) 65 ? 2 cm in 2008 and 80 ? 1 cm in 2009. There was greater variation among the genotypes in 2008 (Fig 2) and significant differences occurred at most depths, but in 2009 significant differences among the genotypes only occurred at 30 – 40 cm (P<0.001) and 60 – 70 cm (P<0.05). While significant differences occurred in root growth no single variety had consistently high root growth through the profile. Differences in total root growth in the full profile among the genotypes were not significant. Principal component analysis based on the variation among the 52 genotypes indicated that grain yield was most strongly associated with root growth in the 20-30 cm and 30-40 cm depths in 2008 and the 30-40 cm depth and more weakly with the 60-70 cm depth in 2009. Genotypes with narrow root angles tended to be associated with more roots in the 50-60 cm layer in 2008 and to a lesser extent in the 60-70 cm layer in 2008 and 2009. While the subsoils were highly alkaline, tolerance to high pH and to B were unrelated to yield. The ability to exclude Na^+ from the leaves contributed to yield in 2009 but not in 2008.

Table 1. The mean grain yields (t ha^{-1}) of wheat varieties, classified according to their seminal root angles, in plant breeding trials between 1992 and 2004. The number of trials are shown and data are presented as mean ? SEM

Root angle	All sites (N = 233)	WA (N = 65)	SA (N = 113)	VIC (N=31)	NSW (N=22)	QLD (N=2)
Narrow (69?)	2.43 ? 0.08	2.54 ? 0.13	2.33 ? 0.12	2.24 ? 0.18	2.86 ? 0.27	3.04 ?0.19
Intermediate (84?)	2.40 ? 0.08	2.54 ? 0.13	2.31 ? 0.12	2.14 ? 0.18	2.73 ? 0.26	3.05 ? 0.15
Wide (100?)	2.30 ? 0.07	2.44 ? 0.13	2.22 ? 0.11	2.03 ? 0.17	2.65 ? 0.25	3.03 ? 0.22

Analysis of the yields from the breeding trial showed that in each State grain yields tended to be greater in the varieties with narrow root angles (Table 1) but the differences were small (≤ 5%) and not significant.

Discussion

Within a group of 52 varieties of wheat derived from different breeding programs within Australia no systematic difference in root angle was detected (Fig 1). There was also no evidence of regional differences in the effect of root angle in yield within 12 years of breeding trails (Table 1). Therefore, the suggestion that varieties bred for and/or adapted to Mediterranean environments have wider roots angles, which may lead to shallower rooting, was not supported.

When the root distribution of these varieties was assessed in the field significant genetic variation was measured throughout the profile, but especially in 2008. PCA suggested grain yield was most consistently associated with root growth in the 30-40 cm layer of the profile, but this was unrelated to root angle. On the soils used in the experiments, the 30-40 cm region corresponds to the transition into the heavier textured, more alkaline and sodic subsoil as well as being the layer below the compaction layer. The ability to penetrate the hard layer may be important to the development of roots deeper in the profile. Root growth at 60-70 cm was more important in 2009, which may be related either to the lower bulk density or the higher amount of rainfall. Varieties with narrow root angles tended to produce more roots in the deeper layers but this was not related to the variation in yield in the two years, although when the effect of root angle was examined in plant breeding trials across the cereal belt there was a tendency for varieties with narrow root angles to yield slightly more than those with wide angles. Any effect of root angle on differences in yield among the varieties seems to be small and not strongly associated with the seasonality of rainfall.

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