Hardpan penetration ability of wheat roots

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Abstract

This paper builds on current and past research undertaken in WA that has described the pattern of root growth of wheat crops in a range of soils with chemical and/or physical barriers to growth, including hard soils and drought. It is not known whether genetic diversity exists for root growth in hostile soils among the currently-available wheat cultivars and breeding lines. Genotypic variation in root penetration ability has been reported in other cereals, and we have validated it in wheat using a pot technique where a thin disc of wax and petroleum jelly is placed in a soil column to simulate a hardpan. Partitioning of the soil column by the wax layer makes it possible to examine the interaction between hardpan strength and soil moisture stress. Our pot experiments have revealed differences in root penetration ability under drought among 24 wheat cultivars and breeding lines. These results are compared with observations on their rooting depths in two contrasting soil types in field experiments undertaken in the WA wheatbelt. This technique will have application in identifying promising lines for wheat breeding programs and in the interpretation of field performance of wheat grown in hostile soils.

Key Words

Wheat, hardpans, wax layer, drought, roots

Introduction

Of the 18 million hectares of cropping land in the Western Australian wheatbelt, 24% has high susceptibility subsoil compaction and 43% moderate susceptibility (pers. comm. D Van Gool, Department of Agriculture WA). Soils that compact easily or that have a high clay content that set hard on drying, or abruptly change in bulk density at depth constrain root growth and water movement. Roots are instead distorted and thickened radially (Bengough and Mullins 1990; Watt et al. 2005). Without penetration, root growth is then restricted to the soil layer above the hardpan or clay subsoil, and rapid depletion of soil nitrogen (N) and water there promotes the early onset of drought, poor shoot growth and reduced grain yield.

Deep roots that are capable of penetrating hard soils are important for drought avoidance and nutrient-scavenging. Despite that little research attention has been place as it is difficult to study, especially in the field. Root growth in unploughed soil has been shown to differ between the wheat cultivar, Janz, and a line bred for greater early vigour (Watt et al. 2005). However, it is not known whether genetic diversity exists for root growth in soils specifically containing a hardpan among the currently-available wheat cultivars and breeding lines. Genotypic variation in root penetration ability has been reported in other cereals (Yu *et al.* 1995; Kubo *et al.* 2004), and validated in our own research, using a pot technique where a thin disc of wax and petroleum jelly is placed in a soil column to simulate a hardpan (Botwright Acuna and Wade 2005).

The maximum wax-layer strength that wheat roots could penetrate was about 1.0 MPa (Botwright Acuna and Wade 2005), which is slightly higher than previous studies using durum wheat grown in pots containing wax-layers (Kubo *et al.* 2004), but was around half that of rice grown in pots with a wax-layer (Yu *et al.* 1995). Partitioning of the soil column by the wax layer made it possible to examine the interaction between hardpan strength and soil moisture stress (Botwright Acuna and Wade 2005). Our results indicated that a 35:65 ratio of wax to petroleum jelly would provide sufficient resistance to root growth to quantify root penetration ability of wheat among cultivars. Here we report on root penetration ability and root distribution among 24 wheat cultivars and breeding lines. An experiment was undertaken in controlled environment in pots, using the thin wax layer technique under contrasting water regimes. These results are compared with rooting depth of the cultivars and breeding lines in preliminary field trials undertaken at Merredin in Western Australia.

Methods

Measurement of root penetration ability in pots

Twenty four wheat cultivars (Table 1) were grown in PVC pots (0.10 m diameter ? 0.50 m tall) that were split in half length ways for easy access to roots. Plants were grown in a controlled environment room (CER) with a 20/15 ?C day/night temperature, with a 10 h day length and 70% relative humidity. The pots were filled with Richgro commercial soil mix and contained a wax layer (35:65 ratio of paraffin wax: petroleum jelly, 3 mm thick; equivalent to 1.00 MPa) placed at a depth of 0.24 m in soil. The pots were well-watered until 14 days after sowing (DAS), when two contrasting water regimes (WW, well-watered; and DS, drought stress) were applied in two replications. Water-use was measured weighing the pots every two to three days. The soil surface was mulched using gravel to minimise soil evaporation. Plants were harvested at approximately 6 expanded main-stem leaves, at 36 DAS in WW and 52 DAS in DS treatments. The numbers of seminal and nodal root axes were counted. Root dry mass was measured after drying in an oven at 70 ?C for 24 hrs.

Table 1. List of wheat breeding lines and cultivars used in controlled environment experiments and field trials.

Name	Release date	Name	Release date
Ajana	1998	Halberd	1969
Amery	1993	Janz	1989
Bonnie Rock	2002	Kalannie	1996
Brookton	1998	Karlgarin	1999
Camm	1998	Machete	1985
Carmanah	1996	Perenjori	1996
Cascades	1994	Spear	1983
Castle Rock	2003	Stiletto	1993
Chuan Mai 18	*	Vigour 18	*
Cranbrook	1984	Westonia	1997

Cunderdin	1996	Wilgoyne	
Gamenya	1960	Wyalkatchem	2001

*Denotes breeding line

Root depth in the field

Field experiments were undertaken in 2005 at the DAWA Merredin Dryland Research Station (31?30'S, 118?12'E) on two soil types, a red clay (Calcic Haploxeralf, USDA (1992) and sandy duplex (Lichic Haplumbrept, USDA (1992). Seed of the 24 wheat cultivars and breeding lines were sown in early June in 1 m single rows with 0.5 m row spacing, and 2 replicates. Maximum root depth was measured at anthesis by soil coring, using a soil auger. Soil hardness was measured to a depth of 0.6 m using a Rimik Cone Penetrometer and soil water content measured at 0.2 m depth intervals in three plots per site.

Results and Discussion

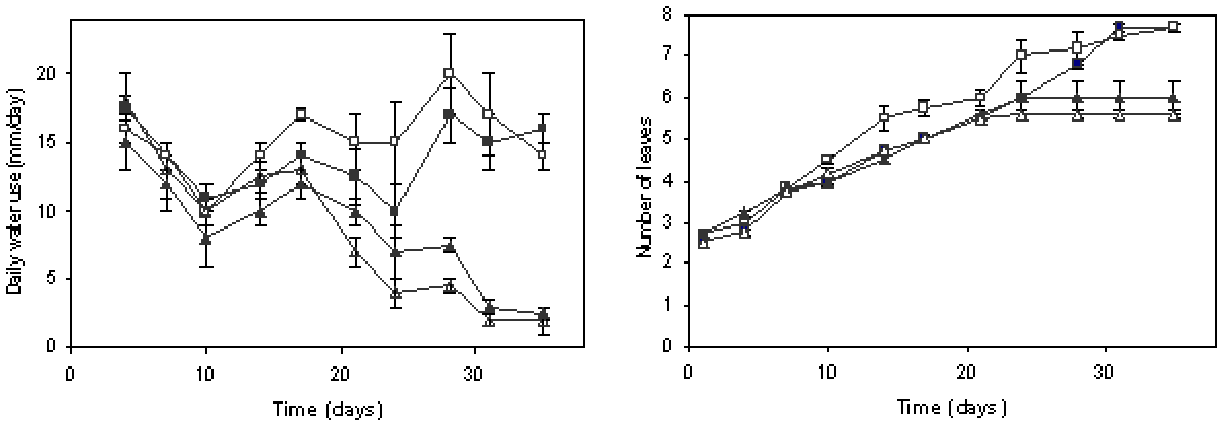
Root penetration ability of wheat grown in pots

The water regimes had a large effect on shoot and root biomass . For instance, plants grown under DS conditions had fewer tillers, and less leaf area and above-ground dry matter compared to WW (data not shown). A seed produced on average five seminal roots. Fewer seminal roots penetrated the wax layer under DS than WW conditions ($P < 0.05$), but those that did were considerably longer and had much greater dry matter (Table 2). An average of 28 nodal roots per plant were produced under WW conditions, consistent with our previous experiments (Botwright Acuna and Wade 2005) and the observations of Richards and Passioura (1989) in moist soil.

Table 2. Effect of water regime on the number and dry matter of seminal roots below the wax layer in selected wheat cultivars grown in pots in a CER. l.s,d$_A$ = 1; l.s.d$_B$ = 160 mg.

Cultivar	Number of seminal roots penetrating wax layer[A]		Seminal DM below wax layer[B] (mg)	
	WW	DS	WW	DS
Bonnie Rock	4	2	39	312
Carnamah	6	2	58	409
Karlgarin	5	0	17	0
Perenjori	4	0	22	0

One or more seminal roots in 12 of the 24 wheat cultivars or breeding lines penetrated the wax layer. Few nodal roots penetrated the wax layer (data not shown). Under DS, seminal roots of wheat cultivars which penetrated the wax layer, such as Bonnie Rock and Carnamah, produced more DM in DS than WW conditions (Table 2). Extensive exploration by seminal roots of the soil below the wax layer contributed to greater daily water use (Figure 1a), which maintained plant growth beyond 24 days after water deficits was induced (Figure 1b). This was consistent with our previous findings that nodal roots of wheat ceased growth under early soil water deficit, and water uptake was instead dependant on seminal roots (Botwright Acuna and Wade 2005). Cultivars whose seminal roots failed to penetrate the wax layer, such as Karlgarin and Perenjori, died prematurely (Figure 1b) under DS.



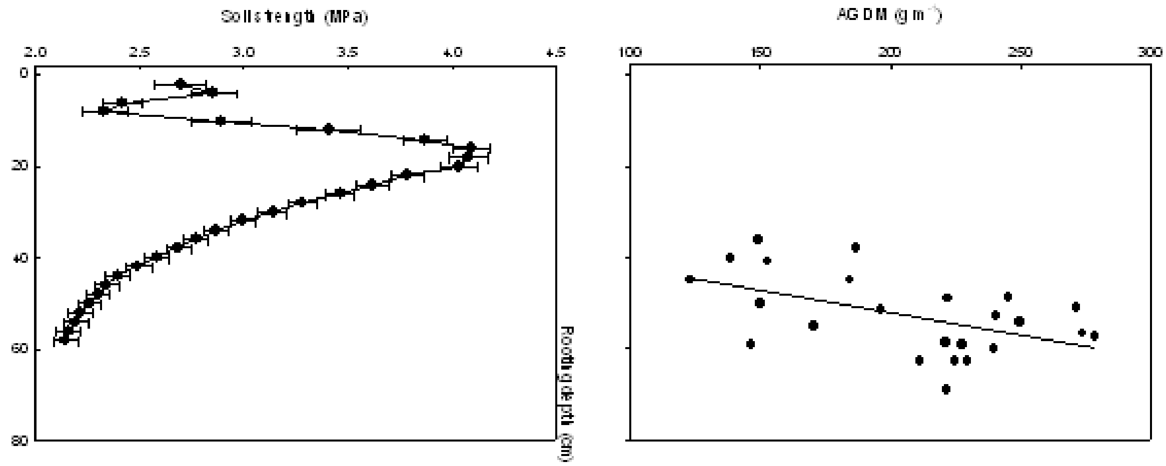
B

A

Figure 1. Effect of wax-layer strength on A) daily water use; and B) number of leaves of selected cultivars. Symbols: ?, Carnamah; ?, Bonnie Rock; ▼, Karlgarin; and s, Perenjori. Time is days after stress imposition. Bars represent the s.e.

Rooting depth in the field

Field trials at Merredin indicated promising and consistent differences in rooting depth among cultivars at the two sites (Figure 2b). Soil strength of the red clay increased with depth, reaching a maximum of 4 MPa at 0.6 m (data not shown). In contrast, soil on the duplex site contained a hardpan of 4 MPa at a depth of approximately 0.2 m (Figure 2a). Soil strengths of 2.5 MPa in the hardpan zone of a loamy sand caused a severe reduction in root growth of wheat (Hamblin *et al.* 1982). Values of penetrometer resistance in the field can vary with soil water content, structure and texture and it is likely that resistance to root elongation is experienced at much lower soil strengths. Soil was approximately 3-fold drier at all depths on the sandy duplex compared with the red clay, which was wettest at a depth of 0.4 m (data not shown). Roots growing into drying soil would experience an increase in soil hardness (Barley and Greacen 1967), which slows root growth and reduces the diameter of seminal root axes (Belford *et al.* 1987).



A) **B)**

Figure 2. Relationship between A) soil depth and soil strength; and B) rooting depth and above-ground dry matter (AGDM) of wheat cultivars grown at Merredin, WA on a sandy duplex in 2005. Bars represent the s.e.

Conclusion

This study has demonstrated the promise of the wax-layer technique for pot studies of hardpan penetration ability in wheat and its interaction with soil water deficit . Further research is needed, however, to validate the response in the field. While there is evidence of soil water being available below a hardpan in field environments, it remains to be demonstrated whether deep roots reliant on soil water below the hardpan alone are fully effective in extracting soil water and maintaining transpiration. Further research is needed to examine root signals and their effects on stomatal conductance, water extraction and growth under the influence of water stress and soil physical constraints.

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