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Root growth in field-grown winter wheat: Some effects of soil conditions, season and genotype

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ABSTRACT

This work compared root length distributions of different winter wheat genotypes with soil physical measurements, in attempting to explain the relationship between root length density and soil depth. Field experiments were set up to compare the growth of various wheat lines, including near isogenic lines (Rht-B1a Tall NIL and Rht-B1c Dwarf NIL) and wheat lines grown commercially (cv. Battalion, Hystar Hybrid, Istabraq, and Robigus). Experiments occurred in two successive years under rain fed conditions. Soil water content, temperature and penetrometer resistance profiles were measured, and soil cores taken to estimate vertical profiles of pore distribution, and root number with the core-break method and by root washing. Root length distributions differed substantially between years. Wetter soil in 2014/2015 was associated with shallower roots. Although there was no genotypic effect in 2014/2015, in 2013/2014 the dwarf wheat had the most roots at depth. In the shallower layers, some wheat lines, especially Battalion, seemed better at penetrating non-structured soil. The increase in penetrometer resistance with depth was a putative explanation for the rapid decrease in root length density with depth. Differences between the two years in root profiles were greater than those due to genotype, suggesting that comparisons of different genotypic effects need to take account of different soil conditions and seasonal differences. We also demonstrate that high yields are not necessarily linked to resource acquisition, which did not seem to be limiting in the low yielding dwarf NIL.

1. Introduction

Wheat (*Triticum aestivum* L.) is a nutritionally and economically important crop grown in countries all around the world. The 2014/15 growing season produced 729.5 million tonnes globally, making it the second most produced crop worldwide, after maize (*Zea mays* L.) (FAO, 2016). The United Kingdom (UK), while having a relatively small agricultural land area compared to the main wheat producers, has some of the highest wheat yields of all countries, reaching a new world record in 2015 of 16.5 t/ha (Guinness World Records, 2015). In contrast, the global average wheat yield is a little under 3.1 t/ha (FAO, 2016). The relatively high yields in the UK can mainly be attributed to a mild climate where rainfall is distributed evenly through the year. However, in the UK, yields of winter wheat can be restricted by water availability (Dodd et al., 2011). Even in dry summers, water is available at depths as shallow as 60 cm at relatively high matric potentials (Whalley et al., 2007, 2008), which has not been accessed by roots. Since water use (transpiration) is linearly related to crop yield (Passioura, 1977), this represents an untapped resource that might be usefully exploited to increase wheat yields.

The inability of roots to access water is commonly attributed to a low root length density at depth (Gregory et al., 1978a, 1978b). For this reason, rooting depth of wheat in the UK has been of considerable interest (e.g. Lupton et al., 1974; Gregory et al., 1978a; Barraclough and Leigh 1984; White et al., 2015). Lupton et al. (1974) found little difference between the depth of roots of tall wheats in comparison with semi-dwarf wheats which had recently been introduced to the UK. However, within wheats that are currently grown commercially in the UK, there is recent evidence that some lines are more effective at accessing deep water than others, although differences in water uptake at depth were not sufficiently large or consistent to identify extreme performers with any certainty (Ober et al., 2014). This may be partly due the impact of management on rooting depth. For example, sowing date can have a large impact on both the amount and depth of the roots, since total root mass was closely correlated with the accumulation of thermal time (Barraclough and Leigh, 1984). Early sowing led to deeper roots, especially until early spring (March), although the rooting depth was similar between early and late sown wheat thereafter. Taken

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together, these results indicate limited genetic differences in wheat root distribution with depth in the soil profile under UK conditions. Similarly, a comparison of different wheat lines at two different field sites in Australia found little effect of genotype in determining rooting depth, the amount of shallow roots or the amount of deeper roots (Wasson et al., 2014). The field sites (i.e. soil type) had the greatest effect on the distribution of roots with depth, with one of the sites encouraging a much greater root length density at depths shallower than approximately 1 m in all of the wheat lines.

In the field, deep roots are almost exclusively found in pre-existing pores (White and Kirkegaard, 2010), thus deep rooting is likely to be largely determined by the quantity of deep pores. While White and Kirkegaard studied root growth in a very different environment and soil in comparison with those found in the UK, Gao et al. (2016) have argued that their observation that deep roots are mainly found in pores is the general-case. Gao et al. (2016) suggested that increases in soil strength with depth may be responsible for confining roots to pores, especially when penetrometer resistances in the bulk soil are much greater than 2.5 MPa. In field studies, root length density decreases exponentially with depth (e.g. Gerwitz and Page, 1974; Fan et al., 2016), which contrasts to many laboratory experiments with re-packed soils (e.g. Manschadi et al., 2008; Jin et al., 2015; Gao et al., 2016), where there is relatively high root density at depth and a less noticeable exponential decrease of root length density with depth. Thus pore distribution with depth may explain the limited genetic differences in wheat root distribution with depth, but this has received little attention under UK conditions, especially with respect to deep roots.

This paper has two main goals. First, we compared root length density with the quantity of pores > 0.7 mm in diameter. While root length distributions of field grown wheat have been reported (e.g. Gregory et al., 1978a; Barraclough and Leigh, 1984; White et al., 2015) and they conform to the empirical root length density distribution of Gerwitz and Page (1974), they have not been compared with soil structural and physical characteristics. Indeed, Rich and Watt (2013) note that few field studies report both root and soil conditions. Second, we verify if changes in root length density with depth are genetically determined, by comparing tall and dwarf NILs (Rht-B1a Mercia (*Tall*), and Rht-B1c Mercia (*Dwarf*)) as well as wheat cultivars commercially grown in the UK. We report on measurements made in two successive seasons on adjacent fields with a similar soil. We discuss the effects of soil structure, genotype and season on the distribution of roots with depth.

2. Materials and methods

2.1. Experimental sites

Experiments were conducted on neighbouring Broadmead (2014) and Warren Field (2015) sites at Woburn Experimental Farm, Bedfordshire, UK (52°01′11.2N″0°35′30.4″W). At both sites, soil in the 0–40 cm layer was a silt-clay loam. The vertical gradient in texture, to a depth of 1 m, is negligible on Broadmead. However, on Warren Field there was sand at depths deeper than 40 cm. The differences in soil texture with depth were observed from 1 m long cores taken to measure rooting density (see below). On both sites the surface layer (approximately 30 cm) has more organic matter content and is less dense. Soil properties are summarized in Table 1. The soil profile on Broadmead is consistent with description of a soil profile by Weir et al. (1984) that should be expected to produce high yields of winter wheat.

2.2. Field management

For both experiments, the sites were prepared by cultivation with a mouldboard plough, to a depth of 23 cm, and intensive cultivation approaches (i.e. power harrow) to produce a seedbed. Both fields were drained by tile drains. The field sites were sown in the same manner in both years, with a plot drill: 96 separate 9 m x 1.8 m plots, divided into four fully randomised blocks, with each block containing 23 plots of different wheat cultivars and one fallow plot. The experiment is also described by Whalley et al. (2017). Cultivars and fallow plots were randomly arranged within each block.

Table 1
Description of the topsoil (0–40 cm below the surface) properties of Woburn Experimental Field Station, Bedfordshire, UK.

Property	Units	
Location	Latitude	5201′06″N
	Longitude	0035′30″W
Soil type	SSEW group	Typical alluvial Gley soil
	SSEW series	Eversley
	FAO	Fluvisol
Sand (2000–65 µm) Surface soil	$g\ g^{-1}$ dry soil	0.538
Silt (63–2 µm)	$g\ g^{-1}$ dry soil	0.203
Clay (< 2 µm)	$g\ g^{-1}$ dry soil	0.260
Texture	SSEW class	Sandy clay loam
Particle density	$g\ cm^{-3}$	2.587
Organic matter	$g\ g^{-1}$ dry soil	0.038

The plots were sown on 10/10/2013 in 2013/14 and 26/09/2014 in 2014/15. The field sites were rain fed with no additional irrigation. Soil moisture measurements were taken and soil cores were collected approximately 1 m from the end of each specific plot.

2.3. Wheat genotypes

Of the 23 available genotypes, five were selected for soil coring in 2014, and six in 2015, based on previous laboratory phenotyping experiments (Whalley et al., 2013). The 2014 genotypes were Battalion (*Bat*), Hystar Hybrid (*Hys*), Rht-B1c Dwarf Mercia (*Dwarf*), Rht-B1a Mercia (*Tall*), and Robigus (*Rob*). Rht-B1c Dwarf Mercia (*Dwarf*) and Rht-B1a Mercia (*Tall*) were near isogenic. The 2015 genotypes were the same as for the previous year, with the addition of Istabraq (*Ist*). We selected genotypes on the basis of contrasting rooting behaviour in laboratory experiments (unpublished data).

2.4. Field measurements

Neutron probe (CPI HydroProbe model 503TDR) readings were taken in the field at approximately monthly intervals. Aluminium access tubes were installed approximately 1 m from the end of selected plots and measurements were made at depths of 0.10, 0.25, 0.50, 0.75, 1.00, 1.25 and 1.45 m. Soil strength was measured by taking readings using a soil penetrometer, in both years (Whalley et al., 2008, 2017). Where possible penetrometer strength profiles were taken to a depth of 52.5 cm. We used a penetrometer with a cone 9.45 mm in diameter at the base with a 30° semi-angle. Atmospheric conditions and rainfall were measured and recorded by a weather station on the experimental farm. Leaf area index was periodically measured witha ceptometer (Delta-T Devices, Burwell, Cambridge, UK) during the growingseason. Crop height was measured with meter ruler. At harvest, grain yield was measuredwith a plot combine harvester.

2.5. Soil cores to estimate rooting

Cylindrical soil cores were taken from the Broadmead plots between 03/06/2014 and 13/06/2014 and from the Warren Field plots between 25/06/2015 and 03/07/2015 using a soil column cylinder auger (Van Walt Ltd, Surrey, UK). The cores were 100 cm long and 9 cm in diameter. They were extracted approximately 1 m in from the end of the wheat plots at the end opposite to the one with the neutron probe access tube. In 2014 we took one core from three of the blocks for each genotype of interest. In 2015 four cores were taken for each genotype, one from each block. Once extracted, the cores were stored inside two