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EFFECT OF SOIL STRENGTH ON ROOTS AND VEGETATIVE GROWTH OF WHEAT AT SEEDLING STAGE

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Abstract

The effect of soil strength (SS) on the performance of three UK wheat genotypes i.e., Rht or Rht1 or Rht3 was studied. These genotypes were all basically the variety Mercia but containing stem dwarfing genes referred to as Rht or Rht1 or Rht3. Experiment was conducted in a controlled environment growth cabinet at Rothamsted. For the measurements of leaf area and the number of tillers per plant there was no significant genotype x SS interaction. But the Rht1 showed the greatest relative decline in the strong soil. However shoot and root weight, root number, the maximum depth of rooting all showed some genotype x SS interaction. In all cases it was only the Rht1 that showed statistically significant ($p>0.05$) difference between the two SSs. It is concluded that the stem dwarfing genes in Rht and Rht3 may have the potential to give the advantage of high productivity associated with dwarf plants, without the penalty of weaker root systems. They may therefore be useful in breeding programmes to develop wheat varieties suitable for soils with high strength.

Key words: Reduced height, Soil strength, Stem dwarfing gene, Strong and weak soil, wheat,

Introduction

Water availability is vital for productive agriculture. Approximately, 20% of the worlds' cropland receives irrigation and this water use represents a massive 70% of global freshwater use. This land produces about 40% of the world's food (Gitay *et al*., 2001) but water scarcity will constrain expansion of the irrigated area. Thus to feed the world expanding population (estimated to be *Cir*.9 billion by the middle of the twenty-first century), a 40% improvement in crop yields in rain fed (and often drought-prone) areas is needed by 2025 (Pennies, 2008).

In general, it is wheat genotypes with shorter stature that return best yields when provided with irrigated and otherwise high-input management. Such varieties have the intrinsic advantage of expending less resource on stem growth and importantly are less prone to lodging (Ahmad *et al.,* 2002). Clearly, they must have a root system extensive enough to extract from soil the necessary water and nutrients to sustain high yields. However, these varieties do not necessarily do well under adverse conditions. Indeed taller genotypes are considered to have better yield stability under adverse conditions, such as heat and/or drought stress (Reynolds *et al*., 2007).

In conditions when soils become hard (whether by compaction or dryness) root penetration to the deeper soil is more difficult (Unger & Kaspar, 1994; Wojciechowski *et al*., 2009). Under such conditions it is the degree of penetration that controls yield. Linear relationships between yield and soil strength and between yield and accumulated soil moisture have been reported in wheat (Whalley *et al*., 2006). Thus increase in root penetration of hard soils is an important breeding target to achieve stable crop production in West Asia and North Africa (Nachit 1998; Rajaram *et al*., 1996) as deep rooting may help plants to avoid drought-induced stress by extracting water from deep soil layers (Gowda *et al*., 2011; Plata *et al*., 2011; Yusaku *et al*., 2013).

The aspiration of feeding the world must involve (among many other things) an increase in world wheat grain production, particularly in developing countries and on subsistence farms. Plant breeders will need to exploit the intrinsic advantages conferred by the reduced stem height genes (Rht). However variants of this gene set that produce "fair-weather" roots must be avoided. Rather the combination of dwarf plants and a root system able to grow into and through hard soils is expected to better exploit what water is present in soil and ultimately lead to increase grain yield. Such combinations will need through evaluation in the lab and ultimately in field situations.

The aim of this study was to examine the effect of soil strength on the growth performance of three wheat genotypes, (Rht, Rht1 & Rht3), each containing a variant of the stem dwarfing gene set. The hypothesis was that, when confronted with strong soil, they would show a range of negative effects. It is expected that the replicated experiment would identify genotypes where vital plant attributes are minimally affected by soil strength.

Materials and Methods

The effect of two soil strengths on the growth performance of three reduced height lines genotypes (Rht, Rht1 & Rht3) was evaluated in experiments done in controlled environment cabinets. PVC tubes of height 45 cm and diameter 15 cm where filled with a standard sand (referred to as Red hill T summed and supplied by Sibelco UK, Brookside Hall, Sandbach, Cheshire, CW1 14FE). A steel tank accommodated six such tubes, they stood on a perforated platform immersed to a depth of 15 cm in Hoagland'snutrient solution (Table 1) Capillary action maintained the entire sand column moist. Two soil strengths were created by applying to the sand surface either: - a 17 kg steel disc to give strong soil or a similar shaped disc made from foam rubber and weighing a few grams to give the weak soil.

Table 1. Hoagland's stock solution.

Macro-nutrients	MW	Working Conc	
$Ca(NO_3)_2.4H_2O$	236.15	2	mM
KH_2PO_4	136.09	1	mM
KCl	74.55	4	mM
$CaCl_2.2H_2O$	147.02	4.0	mM
$MgSO_47H_2O$	246.48	2.0	mM
$[CH_2.N(CH_2.COO)_2]2FeNa$	367.05	50	µM
$NaSiO_3.5H_2O$	212.4	60.0	µM
Micronutrients:			
H_3BO_3	61.85	50.0	µM
$MnCl_2.4H_2O$	223.06	15.0	µM
$ZnSO_4.7H_2O$	287.54	0.8	µM
$CuSO_4.5H_2O$	249.68	0.30	µM
$(NH_4)_8Mo_7O_{24}.4H_2O$	1235.9	0.100	µM

Table 2. Total leaf area (cm^2) of three wheat genotypes under weak and strong soil strength from day 5^{th} to day 23^{rd} after sowing.

Day	Rht		Rht1		Rht3	
	Weak	Strong	Weak	Strong	Weak	Strong
5	1.33	1.59	2.76	1.59	0.77	0.89
6	2.14	2.20	3.27	2.12	1.36	1.42
7	3.30	2.74	4.14	2.84	1.80	1.79
8	5.31	4.95	6.23	3.66	2.79	2.45
9	6.49	6.71	8.34	5.16	4.12	4.22
12	12.41	11.93	14.78	9.39	8.40	8.06
13	15.2	15.15	18.63	12.3	10.78	10.97
14	16.86	16.74	20.16	12.83	10.66	10.2
15	23.22	21.18	28.35	16.89	13.52	12.63
16	28.85	26.79	31.64	19.99	15.52	14.14
19	39.54	36.81	38.8	26.84	21.35	20.19
20	44.47	41.8	41.11	28.25	22.11	22.22
21	44.05	44.87	41.54	30.37	25.24	25.4
23	45.58	45.41	40.88	32.54	25.43	25.83

Six tanks were used and each contained a set of the 6 treatments and these were arranged in random order, i.e., the experiment contained 6 replicates.A single germinated seed was planted in each tube during the first week of June 2011. Weights (17 kg and foam) were put into position immediately after planting the seeds. De-ionized water was used to maintain the required level of solution in each tank during the experiment, but after 4 weeks 20 L of old solution was removed and replaced with the same volume of fresh Hoagland's solution. The controlled environment room had a 14 hour 'day' with a light intensity of 450µmole photons m^{-2} s^{-1} and a 10 hour night. Day temperature and humidity were 22°C and 70% respectively and for the night it was 18°C and 80%.

The leaf area of just the first five leaves that grew from the plants was recorded from day 5 until day 23 (when these leaves grew no more). Area was assumed to equal the product length multiplied by width multiplied by a factor of 0.7 (reference required). After 6 weeks the plants were harvested. For each plant the recorded was:- number of tillers, number of primary roots, maximum depth of rooting and the dry weight (80°C for 24 hours) of shoots, roots 0-5 cm depth and roots deeper than 5 cm.. Data were analysed using ANOVA by Genstat (2011).

Results

The combined area of leaves 1-5, (i.e. the first 5 leaves on a plant), of all genotypes reach a maximum by day 23 (Table 2). For Rht and Rht3, the soil strength had almost similar effect on leaf area. However for Rht1, the leaf area was clearly lower on the strong soil. The genotype Rht3 had less leaf area and this gave less shoot DM.

Analysis of variance of genotypes, stress and genotype x stress interaction for a variety of parameters (leaf area on day 23, number of tillers per plant, shoot dry weight, maximum roots depth, number of primary roots, dry weight of roots to 5 cm depth, dry weight of roots deeper than 5 cm and dry weight of all roots) are given in Table 3. Statistical significant differences ($p>0.05$) were found among genotypes for all the studied parameters except the number of tillers per plant and the maximum root depth. Similarly, there were statistically significant ($p>0.05$) differences between strong and weak soils for all the recorded parameters with the exception of leaf area on day 23. Statistical significant ($p>0.05$) interaction between genotype x stress was observed for shoots dry weight, maximum roots depth, number of primary roots, and for all the root measurements. Rht1 was by far the most sensitive to strong soil (Table 3).

Table 3. Analysis of variance of three wheat genotypes for leaf area on day 23rd , number of tillers, shoot dry matter, maximum root depth, number of primary roots and all roots dry weight evaluated at weak (W) and strong (S) soil strengths under controlled environment

Parameter	Significance		Mean values					
			Stress		Genotype		Genotype x Stress	
							Strong	Weak
Leaf area on day 23rd (cm^2)	Genotype	***	Strong	34.6	Rht	45.5	45.4	45.6
	Stress	ns	Weak	37.3	Rht1	36.7	32.5	40.9
	Interaction	ns	-	-	Rht3	25.6	25.8	25.4
	LSD (5%)	-	-	-	-	6.30	-	
Number of tillers per plant	Genotype	ns	Strong	13.6	Rht	17.9	15.2	20.7
	Stress	***	Weak	21.6	Rht1	17.8	12.7	23.0
	Interaction	ns	-	-	Rht3	17.2	13.0	21.3
	LSD (5%)	-	-	2.67	-	-	-	
Shoots dry weight (g)	Genotype	***	Strong	4.19	Rht	6.60	6.24	6.96
	Stress	***	Weak	6.48	Rht1	5.78	3.49	8.07
	Interaction	*	-	-	Rht3	3.63	2.84	4.42
	LSD (5%)	-	-	1.05	-	1.29	1.82	
Maximum roots depth (cm)	Genotype	ns	Strong	16.1	Rht	20.7	20.2	21.2
	Stress	***	Weak	21.9	Rht1	18.2	13.3	23.0
	Interaction	*	-	-	Rht3	18.2	14.8	21.5
	LSD (5%)	-	-	2.35	-	-	4.12	
Number of primary roots	Genotype	***	Strong	25.9	Rht	39.4	33.7	45.2
	Stress	***	Weak	42.4	Rht1	33.6	21.2	46.0
	Interaction	*	-	-	Rht3	29.4	22.8	36.0
	LSD (5%)	-	-	4.0	-	4.9	6.9	
Dry weight of roots cut at 5cm length (g)	Genotype	**	Strong	1.2	Rht	2.00	1.52	2.49
	Stress	***	Weak	2.2	Rht1	1.87	1.04	2.71
	Interaction	*	-	-	Rht3	1.16	0.92	1.40
	LSD (5%)	-	-	0.38		0.47	0.66	
Dry weight of roots (g) remaining after cut at 5cm length	Genotype	*	Strong	1.14	Rht	1.83	1.48	2.19
	Stress	***	Weak	2.41	Rht1	2.18	1.03	3.32
	Interaction	*	-	-	Rht3	1.32	0.92	1.71
	LSD (5%)	-	-	0.48	-	0.59	0.83	
Dry weight of all roots (g)	Genotype	**	Strong	2.3	Rht	3.84	3.01	4.67
	Stress	***	Weak	4.6	Rht1	4.05	2.06	6.03
	Interaction	*		-	Rht3	2.47	1.84	3.11
	LSD (5%)	-		0.77		0.95	1.34	

Discussion

The ability of a plant to grow a canopy of leaves is a vital component of its yield potential. The current experimental results clearly showed that for Rht1, strong soil significantly reduced the area of initial leaf growth and this resulted in a lower yield of shoots and roots. These suggest that had the plants grown to maturity under these conditions; grain yield would also be lower. In contrast for the other two genotypes in this study (Rht and Rht3); soil strength had little impact on initial leaf area, although at harvest some of the attributes we measured were affected. Other studies have shown that soil strength is an important stress that limits leaf area and crop productivity in wheat irrespective of whether it is due to water stress (drying) or physical impedance (compaction) (Whalley *et al.*, 2008; Bai *et al*., 2013; Khakwani *et al*., 2013). Genotypes with stem dwarfing genes i.e., Rht2 and Rht3 have also been reported with lower stomatal conductance under normal growth conditions under control environment (Khattak *et al*., 2014).

The statistically significant differences ($p>0.05$) among the three genotypes for the parameters studied in this project clearly indicates that these genotypes exhibit variation in genetic makeup which play an important role in expressing tolerance/sensitivity under strong soil strength. Thang *et al*., (2010) have investigated the effects of dwarfing genes Rht-B1b, Rht-D1b and Rht8 on agronomic traits of wheat. They reported that the dwarfing genes Rht-B1b and Rht-D1b shorten the flag leaf length significantly while also reducing plant height. The dwarfing gene Rht8 had much little negative effects on yield but it did reduce plant height and increase grain number per spike. Their findings recommend Rht8 as an ideal dwarfing gene for wheat improvement. Similarly, in current study the genotypes with stem dwarfing gene Rht and Rht3 showed that they were robust when confronted with strong soil, the genotype with the Rht1genes did not.

Further evaluation of the stem dwarfing genes i.e., Rht, Rht1 and Rht3 is required under field conditions for comparison with laboratory screen to investigate the genetic effects of these dwarfing genes on the studied parameters prior to their utilization in wheat breeding programs.

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