Report to the California Wheat Commission: Glasshouse and Field Experiments 2012-2013
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Title: Determination of optimum root and shoot size in bread wheat for increased water and nutrient-use efficiency and grain yield.

Introduction: Environmental stresses are major threats to California and global food security in the twenty-first century. Improving production of grain yield per unit area of bread wheat (*Triticum aestivum* L.) has become critical. Wheat provides more than 20% of the calories and the protein for the world human population (Braun et al. 2010).

Wheat grain yield is a function of the crop biomass (B) multiplied by the harvest index (HI), that is Y = B × HI. During the green revolution, yield increased dramatically following the introduction of reduced height alleles, these not only increased the HI, but also allowed the application of more nitrogen fertilizer without crop lodging. In the most high-yielding wheat crop, HI already approaches 0.6 (60%) and further improvement is improbable given that leaves and stems are necessary to both produce and support the grain. Further increase in grain yield potential will therefore require increases in total biomass. Increase in biomass will require improvements in water and nutrient uptake efficiency (Ehdaie et al. 2010, Reynolds et al. 2012), which depends on root architecture (Ehdaie et al. 2010). Many scientists are starting to see roots as central to their efforts to produce crops with better grain yield under both non-stressed and stressed environments.

Water and nutrient uptake are among the most important roles of roots in plant growth and development. Our studies indicated that a larger root system improves water and nutrient uptake in wheat (Ehdaie et al. 2003, Ehdaie et al. 2010). Therefore, genetic manipulation of the root system holds the potential to increase plant yield. However, breeding for root characteristics has been seldom considered, principally because of the difficulty of scoring root phenotypes directly and the absence of suitable proxy measurements. Phenotying and genotyping of root characteristics of recombinant inbred lines (RILs) derived from contrasting parents for root traits would identify molecular markers associated with genes (QTL) influencing the root system. Using these QTL in a marker assisted selection (MAS) breeding program might produce wheat plants with desirable root system and higher grain yield.

Experiment 1. ***To determine the relationship between root and shoot biomass and grain yield of bread wheat grown in long (1.5 m) root tubes in a cooled glasshouse.***

The long sand-tube experiment conducted in 2012 was repeated this year to explore the relationship between grain yield and root biomass using a slightly different set of RILs of '# 49' and 'Yecora Rojo' to reduce differences in plant height among the 12 RILs observed in 2012. Plant characteristics measured in 2013 are presented in Table1. The range in plant height in the second year (2012-2013) (34 cm) was reduced by 13 cm compared to the first year (2011-12) (47 cm). The range in days to maturity was the same in both years (27 days). The relationship between root biomass and shoot biomass (excluding grains) with grain yield in 2013 and in 2012 is represented in Fig. 1. In both years, a hyperbolic curve could explain these relationships. However, in 2013 maximum grain yield was produced when root biomass reached 7.5 g, whereas in 2012 when it reached 9.0 g (Fig. 1). Our results indicate that depending on the genotypes used, the optimum root biomass to maximize grain yield might change. In both years, maximum grain yield was reached when shoot biomass (excluding grains) approached 23 g plant^{-1}. In both years, optimum root biomass to maximize grain yield was significantly greater than root biomass of the standard varieties, namely 'Blanca Fuerte', 'Joaquin', and 'Yecora Rojo', grown commercially in California.

Table 1. Mean plant height (PH), days to maturity (DM), shallow root weight (SRW), deep root weight (DRW), root biomass (RB), shoot biomass excluding grains (SBEG), grain yield (GY), shoot biomass (SB), and harvest index (HI) for spring wheat genotypes grown under well-watered conditions in a 1.5 m sand-tube experiment in glasshouse in 2013.

Genotype	PH cm	DM no.	SRW g plant^{-1}	DRW g plant^{-1}	RB g plant^{-1}	SBEG g plant^{-1}	GY g plant^{-1}	SB g plant^{-1}	HI %
Blanca Fuerte	69	120	2.58	0.37	2.95	17.04	19.53	36.57	49.6
Joaquin	70	118	2.34	0.37	2.71	16.02	16.51	32.52	47.1
# 49	107	136	9.84	1.37	11.21	32.45	19.02	51.47	30.3
Yecora Rojo	62	117	2.06	0.16	2.21	15.45	17.95	33.40	50.6
L 8	88	120	3.22	0.63	3.85	18.87	18.64	37.51	45.3
L 22	82	112	2.30	0.36	2.66	17.09	15.11	32.20	43.5
L 23	93	115	2.03	0.34	2.36	15.74	9.34	25.07	34.2
L 28	77	120	3.61	0.83	4.43	16.71	16.57	33.28	44.0
L 31	59	136	5.72	1.19	6.90	22.50	18.28	40.77	38.2
L 49	65	121	2.03	0.73	2.77	14.97	13.76	28.73	43.9
L 55	65	118	1.97	0.21	2.17	15.14	15.37	30.51	47.6
L 57	68	139	2.44	0.81	6.25	33.23	6.91	40.14	15.2
L 122	79	123	3.78	0.83	4.61	21.12	21.10	42.22	45.0
L 128	81	118	2.01	0.23	2.25	16.69	16.16	32.85	46.1
L 136	84	116	1.54	0.32	1.86	15.48	12.92	28.41	42.9
L152	84	125	5.21	1.22	6.43	21.07	20.36	41.43	42.5

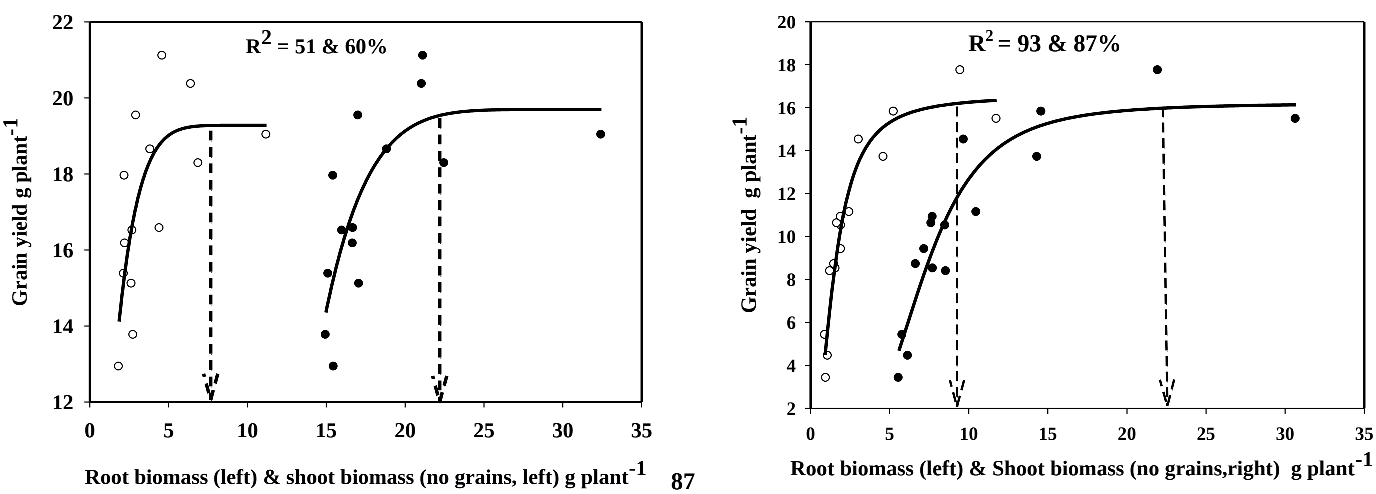

Fig.1. Relationship between root biomass (left) and shoot biomass (excluding grains, right) with grain yield in 2013 (left) and in 2012 (right).

In Table 1, grain yield of L 122 (21.1 g plant^{-1}) and L 152 (20.36 g plant^{-1}) with root biomass of 4.61 and 6.43 g plant^{-1}, respectively, were greater than those of Joaquin (GY = 16.51, RB = 2.71 g plant^{-1}) and Yecora Rojo (GY = 17.95, RB = 2.21 g plant^{-1}) (Table 1). However, Blanca Fuerte with root biomass of 2.95 g plant^{-1} had similar grain yield (19.53 g plant^{-1}) as those of L 122 and L 152.

Experiment 2. Preliminary Field Experiment.

In a preliminary field experiment, we evaluated grain yield of five RILS with different root biomass as quantified under well-watered glasshouse experiments in long tubes. Yecora Rojo, a variety still cultivated in CA and one parent of the RILs, was included as a check. The root biomass among these genotypes ranged from 1.2 to 7.9 g plant^{-1}. These six genotypes were evaluated for agronomic traits including grain yield under well-watered and droughted field conditions using a split-plot design with six replicates.

Plant height among the five RILs ranged from 69 to 87 cm and days from sowing to physiological maturity ranged from 114 to 119 days in the field experiment. Plant height and days to maturity for Yecora Rojo was 56 cm and 114 days, respectively. These observations indicated that differences in grain yield among the RILs were not confounded by days to maturity, but to some extent by plant height.

Main effect of irrigation regime and that of genotype was significant for grain yield. Genotype × irrigation regime was also significant for grain yield. Differences among the genotypes for grain yield were not significant under droughted field conditions; grain yield ranged from 2.886 (L 136) to 2.187 t ha^{-1} (L 8) and grain yield of Yecora Rojo was 2.714 t ha^{-1}. Significant differences were found among the genotypes under well-watered field conditions. Maximum grain yield belonged to L122 (7.534 t ha^{-1}) with root biomass of 4.0 g plant^{-1}. Minimum grain yield belonged to L 115 (5.689 t ha^{-1}) with root biomass of 1.5 g plant^{-1}. Line 57 with maximum root biomass (7.9 g plant^{-1}) had grain yield similar to that of L 122, but was greater than that of Yecora Rojo (6.464 t ha^{-1}) with relatively small root biomass (1.8 g plant^{-1}). A quadratic curve could explain 92% of variation in grain yield under well-watered field conditions based on variation in root biomass measured in well-watered glasshouse conditions, excluding L 136 (see Fig. 2). As root biomass increased from 1.5 to 4.0 g plant^{-1}, grain yield increased from 5.689 to 7.534 t ha^{-1}. The quadratic curve indicated an increase in grain yield as root biomass increased from 4.0 to 5.2 g plant^{-1}, then grain yield decreased progressively as root biomass reached 7.9 g plant^{-1}. This reduction in grain yield was most probably due to competition between root biomass and grain for assimilates. As root biomass increases in growth and development, it competes for more assimilates, then the availability of assimilates to fill the grains become less which results in reduced grain yield.

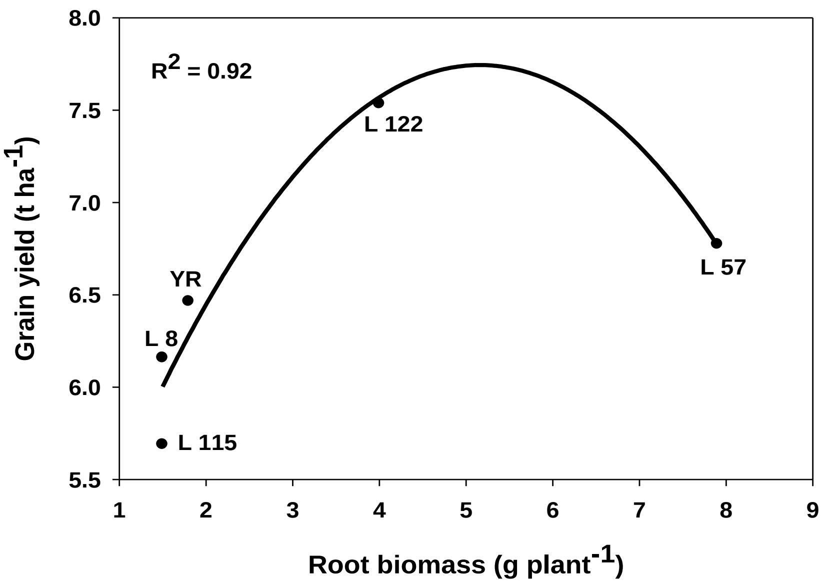

Figure 2. Relationship between grain yield measured in well-watered field conditions and root biomass measured in well-watered glasshouse conditions in long tubes.

Harvest index (the ratio of grain yield to above ground biomass) of Yecora Rojo (48.6%) was the highest under well-watered field conditions followed by L 136 (43.3%) and L 8 (43.2%). Harvest index of L 122 with highest grain yield was relatively low (37.3%). However, it is the grains that are harvested by the farmers and not HI. Drought significantly reduced HI. Three RILs, including L 122, had HI similar to that of Yecora Rojo (32.7%) under drought treatment.

A stress index (STI) was used to characterize relative response of each genotype to stressed fields conditions (Fernandez 1992). The index was calculated from genotype means using the generalized formula

STI = ( ))

Where and are the yield of a given genotype in well-watered treatment (yield potential) and drought treatment, respectively, and and are mean yield in well-watered treatment and drought treatment, respectively. Therefore, STI is a function of relative performance of a genotype in well-watered (and drought treatments and the stress intensity Greater values of STI for a genotype indicate greater stress tolerance and yield potential. The greatest value for STI belong to L 136 (0.46) followed by L 122 (0.41) and Yecora Rojo (0.40). Therefore, L 136 showed greater yield potential and drought tolerance than Yecora Rojo.

Conclusions from research in 2012-2103 season:

The fact that a wide range of wheat plants with different root-system traits was obtained among the 104 RILs we assayed, derived by crossing Iran # 49 (a landrace genotype) and Yecora Rojo, was encouraging, especially as two RILs had higher grain yield than Yecora Rojo under well-watered field conditions. In general root system biomass and grain yield are positively associated, but optimum root size and maximum grain yield varied with year and genotype.

We expected RILs with larger root-system biomass than Yecora Rojo to perform better in terms of grain production under droughted field conditions. That this did not occur, most probably was due to initiation of the drought treatment at a late stage of plant growth (early heading). This was due to miscommunication between a graduate student and the field irrigator. Yecora Rojo was about 7 to 9 days earlier than L 122 to reach booting, heading, and anthesis. Therefore it was under less environmental stress than L 122. However, all the genotypes examined had similar grain yield under droughted field conditions.

Publications:

Ehdaie B, Maheepala DC, Bektas H, Waines JG. Phenotyping and genetic analysis of root and shoot traits in bread wheat using RILs. (Submitted to Plant Breeding, July 2013).

Ehdaie B, Waines JG. 2013. Stem reserves and grain growth in goatgrass *Aegilops tauschii* and wheat. Cereal Research Communications. (In press). *DOI: 10.1556/CRC.2013.0027.*

Maheepala DC. 2013. Yield performance of wheat isolines with different dosages of the short arm of rye chromosome 1. Master of Science thesis in Plant Biology. UC Riverside. August 2013.