Path Analysis of Root/Shoot Traits and Grain Yield in Winter Wheat in the Wintergarden and High Plains of Texas

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Introduction

The yield of agricultural crops is strongly influenced by shoot and root traits and their interactions, yet shoot traits have received more attention than do root traits in past studies. This imbalance hampers crop breeding in the appropriate selection of crop growth indicators. The focus of this study is on winter wheat (*Triticum aestivum* L.) growing in the Wintergarden and the High Plains of Texas – the third largest wheat producer in the United States. The correlations established between grain yield and specific shoot/root traits for selected wheat varieties will help to address potential ecophysiological mechanisms underlying drought adaptations of some of the widely planted wheat varieties in the Southern Great Plains, and thus will assist wheat breeding to target selected shoot/root traits for improving crop drought-resistance under water limited conditions in Texas and beyond.

Materials and methods

We tested ten wheat varieties in 2016, namely 'Duster', 'Fannin', 'Fuller', 'Gallagher', 'TAM 112', 'TAM 114', 'TAM 304', 'TAM 305', 'TAM 401', 'WB Cedar'. The testing was done two irrigation regimes, full irrigation and deficit irrigation, in two semi-arid regions-Uvalde (Wintergarden) and Bushland (High Plains) in Texas. Winter wheat was planted in a two-acre field and irrigated using a center pivot irrigation system on a clay soil site in Uvalde. The field was divided into six sections for two irrigation levels with three replicates. A field on a silty clay loam soil in Bushland was divided into two subplots for the two irrigation treatments applied by flooding irrigation and the same ten wheat varieties were planted in a random arrangement in the subplots with three replications. In both locations, each variety was planted in a 4.6 m × 1.5 m plot with 40 g seeds each. There were 60 plots in total in each location. A local winter wheat variety was planted around the plots to minimize the border effects. The detailed information of irrigation schedule and precipitation received are shown in Table 1.

Leaf and root samples were taken at the end of the flowering stage (April 4 in Uvalde and May 19 in Bushland). Ten flag leaves were selected randomly in each of the plots to measure leaf area (cm^2) and leaf weight (g). Root samples were taken by a hydraulic soil corer to 1 m depth in 20 cm intervals. The soil cores containing roots (300 each location) were stored at -20 °C freezer awaiting for washing and processing. Washed root samples were stored in plastic bottles with 20% of ethanol inside and then clean roots were scanned on a flatbed scanner and analyzed by the WinRhizo software ver. 2003b (Reagent Instruments Inc., Quebec, Canada). Root weight was recorded after oven-dried at 75°C for 72 hs. Three combined trait indicators-specific leaf area (SLA), specific root length (SRL) and root/shoot ratio (RS) were chosen to represent above-ground characters, below-ground characters and their relations, respectively. Multiple linear regression and path analysis were used to analyze the relationships of SLA, SRL, and RS with grain yield. Bootstrap analysis (with 1000 resamples) was used to test the statistical significance.

Table 1 Precipitation (mm) and irrigation (mm) received during the 2015-2016 season in Uvalde and Bushland

Location	Treatment	Sowing to flowering	Flowering to harvest	Total (mm)
Uvalde	Full irrigation	127.0	0	127.0
	Deficit irrigation	87.8	0	87.8
	Precipitation	114.5	192.8	307.3
Bushland	Full irrigation	51	127	178
	Deficit irrigation	51	0	51
	Precipitation	72	101	173

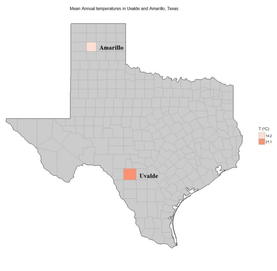
Much more rainfall during vegetation growing stage in Bushland than in Uvalde.

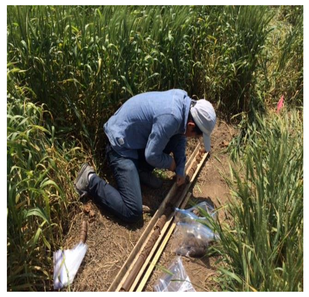
Results: Regression analysis of SLA, SRL and RS with grain yield

Table 2 Multiple linear regression of crop traits and grain yield of winter wheat

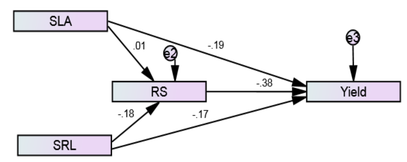
Location	Treatment	SLA	SRL	RS
Uvalde	Full irrigation	-0.187	-0.173	-0.386*
	Deficit irrigation	0.001	0.160	0.501*
Bushland	Full irrigation	0.423*	-0.083	-0.103
	Deficit irrigation	0.431**	0.195	-0.392*

Values in the table mean standardized coefficients; and ** mean significance at P=0.05 and P=0.01, respectively. RS was significantly related to grain yield in Uvalde; SLA was highly associated with grain yield in Bushland.*

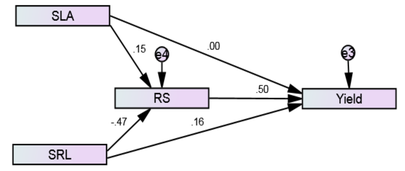




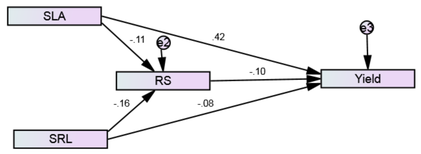
Path analysis of SLA, SRL and RS with grain yield



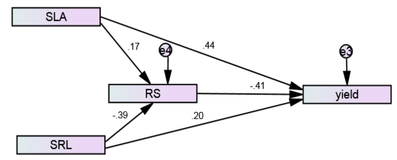
Uvalde-full irrigation



Uvalde-deficit irrigation



Bushland-full irrigation



Bushland-deficit irrigation

Fig. 1 Path model describing the effects of shoot/root traits on grain yield in winter wheat. Model indices showed no significant difference between this path model and default model (P>0.05). RS had the highest direct effects on grain yield in Uvalde. SLA had the highest direct effects on grain yield in Bushland.

Bootstrap resampling to test statistical significance for the effects of SLA, SRL and RS on grain yield

Table 3 Bootstrap analysis of direct effects of crop traits on grain yield of winter wheat

Location	Treatment	SLA	SRL	RS	SLA-RS	SRL-RS
Uvalde	Full irrigation	-0.185	-0.171	-0.383*	0.012	-0.181
	Deficit irrigation	0.001	0.160	0.499*	0.148	-0.47**
Bushland	Full irrigation	0.419	-0.083	-0.102	-0.106	-0.161
	Deficit irrigation	0.441**	0.199	-0.409	0.172	-0.392

Values in the table mean standardized coefficients; and ** means significance at P=0.05 and P=0.01, respectively. Blue shade represents direct effects on yield; green shade means direct effects on RS.*

Root traits in Uvalde and Bushland

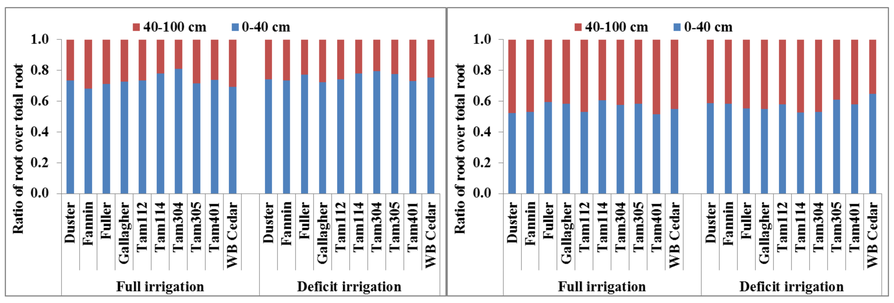


Fig.2 Root length ratios over total root length (Left-Uvalde; right-Bushland). More than 70% of roots were concentrated in the 0-40 cm in Uvalde and around 55% of roots in the surface layer in Bushland.

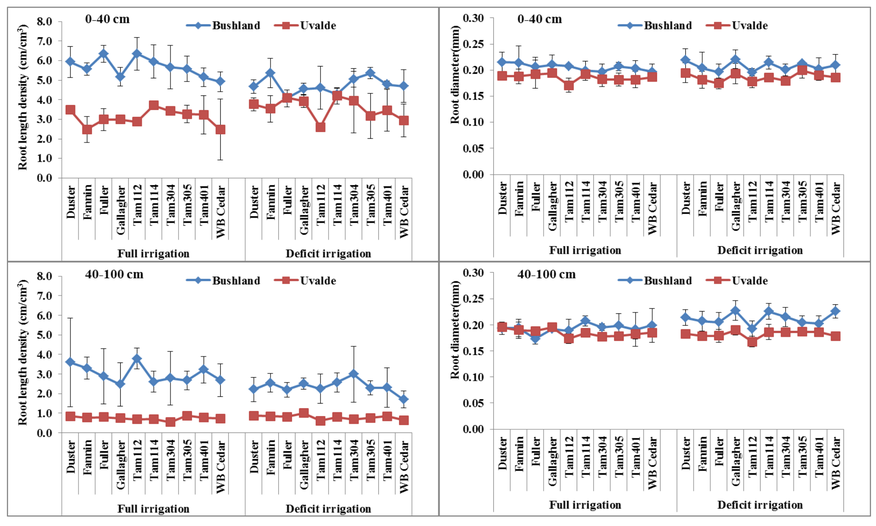


Fig.3 Root length density and root diameter in Uvalde and Bushland. Bushland not only had more roots per unit soil volume, but also thicker roots than Uvalde.

Discussion and conclusions

- Both regression analysis and path analysis showed RS played more important roles in determining grain yield of winter wheat in Uvalde (Table 2), while path analysis also identified the importance of indirect effects of SRL on grain yield.
- Regression analysis showed SLA was significantly related to crop production in Bushland (Table 2 and 3). A possible reason why this result was only verified by path analysis under deficit irrigation may be that SLA had a slightly negative effect on RS. It indicates that choosing a variety with a larger SLA is beneficial for crop production under deficit irrigation.
- Denser and deeper roots were found in Bushland than in Uvalde. The underlying mechanisms leading to the observed differences in root traits need to be further studied (Fig. 2 and Fig. 3).