Cultivar-irrigation interactions in shoot/root traits of 15 wheat varieties in the Wintergarden region

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Introduction

Breeding to improve crop water use efficiency requires a better understanding of how crop traits interact with farm management practices and the environment to bring about improved yield performance. Using a diverse collection of crop cultivars, field eco-physiology holds promise for clarifying linkages among crop traits influencing plant resource capture and yield. In this work, we used 15 winter wheat varieties to investigate how photosynthetic and root water use traits are linked to grain yield under different irrigation regimes. The traits we considered include specific leaf area (a surrogate for leaf photosynthetic capacity), leaf area index, root length density and root distribution pattern. In southwest Texas, the humid and warm climate during booting and flowering stages of winter wheat encourages leaf rust infection, which in turn strongly affects leaf photosynthesis. Thus a major focus of our research is to look for scenarios whereby different traits interact with irrigation management to affect grain yield. Specifically, we wanted to find out (a) if some varieties perform better under limited irrigation through developing deeper roots; and (b) to what extent the rust infection rate is linked to specific leaf area?

Materials and methods

The experiment was conducted in 2014 and 2015 using fifteen wheat varieties ('Armour', 'Billings', 'Cedar', 'Coronado', 'Doans', 'Duster', 'Fuller', 'Gallagher', 'Santa Fe', 'Shocker', 'TAM 112', 'TAM 304', 'TAM 305', 'TAM 401') planted in small plots (dimension 15 ft × 5 ft) in a conventionally tilled silty clay soil under three levels of irrigation management: Full irrigation (100% evapotranspiration replenishment), 70% and 50% of full irrigation (Table 1). The irrigation was replicated twice. There were 90 plots in total. Management practices commonly used in the region were adopted for weeds and disease control. In particular, at boot sage, a mixture of Tilt (4 oz/ac), Tubistar (4 oz/ac) and Dynamic (4 oz/ac) was spayed by airplane to control leaf rust. At flowering stage, leaf area index was measured using a LI-2000C Canopy Analyzer and specific leaf area was measured on selected flag leaves (five from each plot). Sustained rainfall in May and June in 2015 prevented whole plot harvesting; so only a 50 cm segment of row of each plot was harvested to measure yield. In 2014, root length density at harvest were measured based on collected soil sample from top 0-120 cm soil depth. In each plot, two soil cores, one in the row and one in the furrow, were collected at 20 cm depth intervals. In 2015, the severity of leaf rust infection on the flag leaves was surveyed in early April on five randomly chosen leaves from each plot. Once the leaves were severed from plants, they were immediately impressed on contact papers to preserve leaf area and promptly scanned into the computer as digital images. The total leaf area and rust-infected percentages were measured by the `SigmaScan Pro` software based on color thresholding. The effects of cultivar, or cultivar grouping, and irrigation on yield were analyzed by balanced ANOVA, analysis of means (ANOM), as well as exploratory data analysis.

Table 1: Monthly precipitation and irrigation amounts during the 2013-2014 and 2014-2015 growing seasons in comparison to the long-term averages in Uvalde, Texas.

	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Total (mm)
12-year average†	224.5	158.5	98.6	32.0	79.5	61.7	109.7	95.0	859.5
2013-2014 precipitation	**83.8**	**99.1**	**50.5**	**13.2**	**3.6**	**11.2**	**19.1**	**37.3**	**317.7**
Irrigation (100%)‡	-	-	25.4	25.4	38.1	25.4	63.5	50.8	228.6
(75%)	-	-	25.4	25.4	31.8	19.1	47.8	38.1	187.5
(50%)	-	-	25.4	25.4	25.4	12.7	31.8	25.4	146.1
2014-2015 precipitation	**93.7**	**1.8**	**64.5**	**5.6**	**34.3**	**19.6**	**47.8**	**69.3**	**336.6**
Irrigation (100%)	-	-	25.4	50.8	-	25.4	-	25.4	127.0
(75%)	-	-	25.4	38.1	-	19.1	-	19.1	101.6
(50%)	-	-	25.4	25.4	-	12.7	-	12.7	76.2

†Based on daily weather data measured from 2001 to 2012 at Texas A&M AgriLife Research - Uvalde, TX.
‡i.e., 100% crop evapotranspiration replenishment.

Results: Yield in relation to variety × irrigation

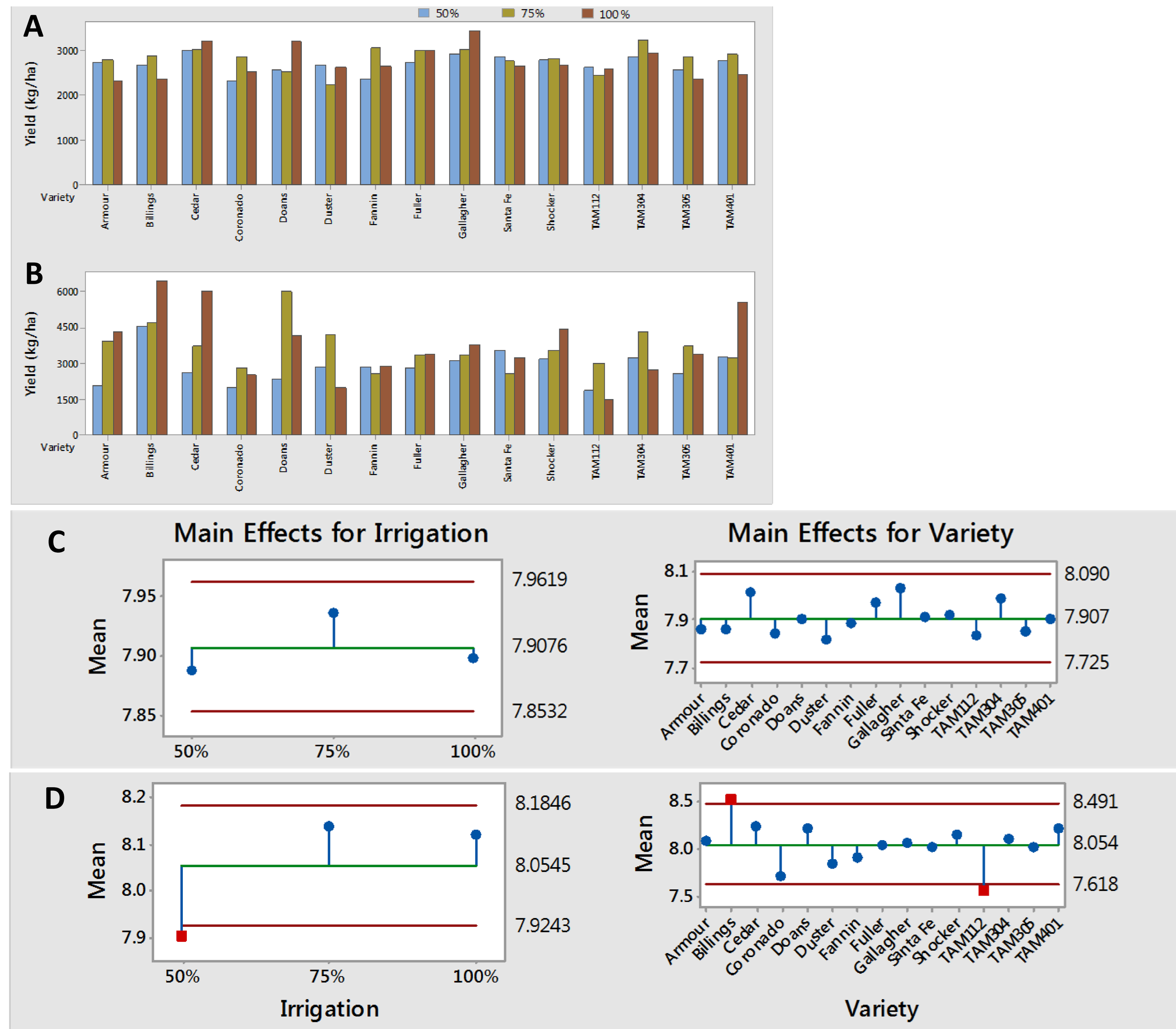

*Figure 1. Yields of the 15 wheat varieties under three different irrigation regimes in 2014 (**A**) and 2015 (**B**). Overall grain yields in 2015 were higher than those in 2014, partly due to the difference in rainfall pattern (Table 1). (**C**) In 2014 none of Irrigation or Variety had significant effect on yield, as seen from the main effect charts. (**D**) In 2015, yields under 50% ETc was significantly lower than the grand mean for Irrigation; 'Billings' yielded higher, and 'TAM 112' yielded lower than the grand average of varieties ($p \leq 0.05$). Yield data were log-transformed to run analysis of means (ANOM).*

Are thin leaves more prone to rust infection?

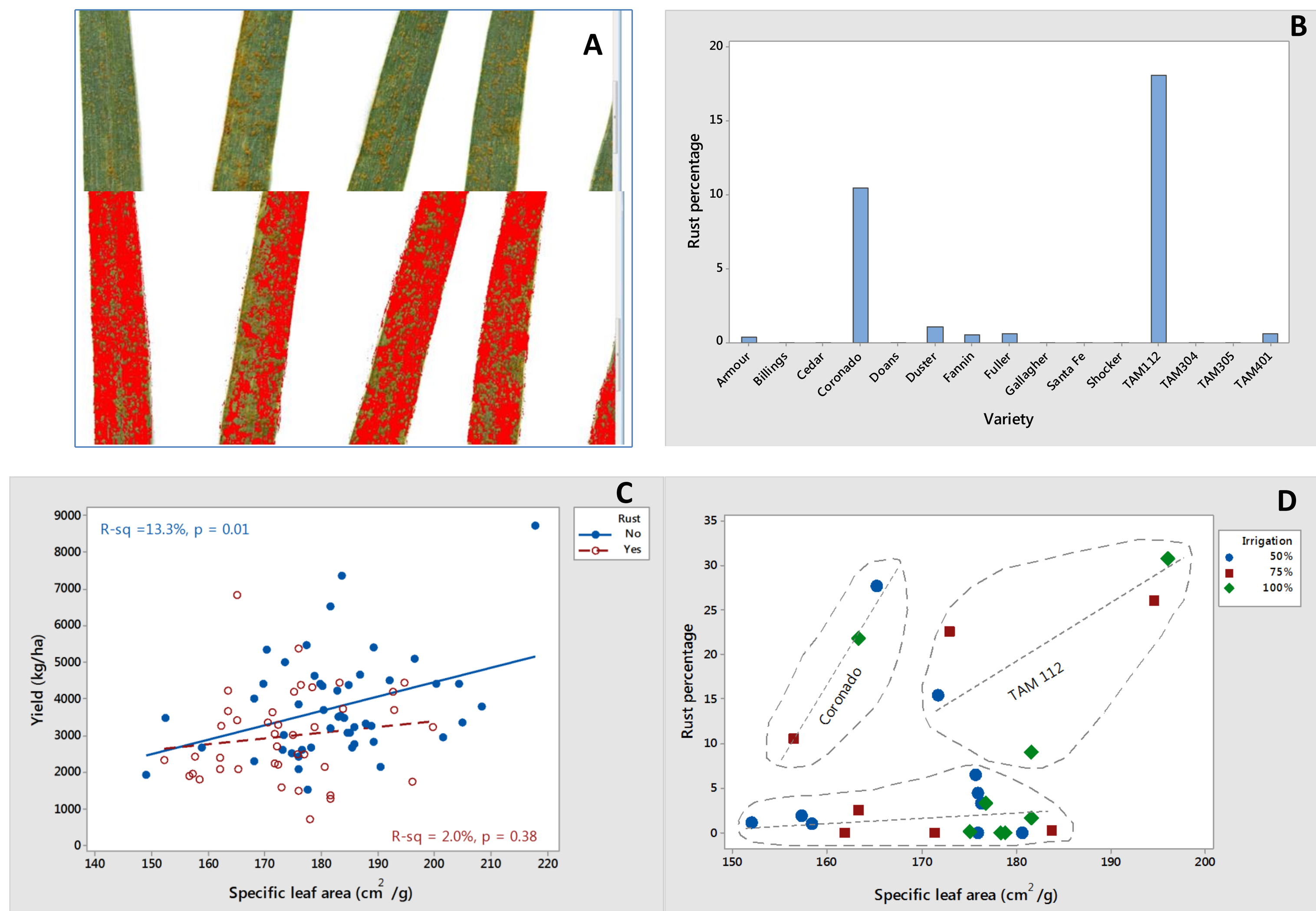

*Figure 2. (**A**) Flag leaf samples from 'TAM 112' showing how rust infection was quantified using SigmaScan Pro software. (**B**) Out of the 15 varieties, seven had rust infection on flag leaves while eight others did not. (**C**) Grain yields in rust-affected varieties tended less responsive to increased photosynthetic potential (shown as a higher SLA) when compared with no-rust group. (**D**) In both rust-susceptible varieties ('TAM 112' and 'Coronado') rust infection occurred more seriously in more photosynthetically capable leaves (i.e., those with higher SLA).*

Table 2: Effects of leaf rust infection and irrigation on grain yield, leaf area index (LAI) and specific leaf area (SLA) of 15 winter wheat varieties as measured in 2015.

Irrigation	Rust status	Yield (kg/ha)†	Leaf area index	Specific leaf area (cm²/g)
100%‡	No	4261.8 ± 1483.0	5.5 ± 1.1	180.8 ± 11.5
	Yes	3159.6 ± 1596.5	5.2 ± 1.0	178.0 ± 10.6
75%	No	3680.7 ± 1008.7	4.6 ± 0.7	179.2 ± 11.0
	Yes	3286.6 ± 1088.8	4.5 ± 1.1	174.7 ± 12.3
50%	No	3219.8 ± 1015.4	4.1 ± 0.8	181.3 ± 13.5
	Yes	2518.4 ± 761.5	4.0 ± 1.1	168.8 ± 10.1
Effect of	Irrigation§	*	***	NS
Effect of	Rust	**	NS	*
Interactions	Irrigation × Rust	NS	NS	NS

†Data are shown as means and standard deviations ($n = 14$).
‡i.e., 100% crop evapotranspiration replenishment.
§Definition of statistical significance from ANOVA test:
"NS" – "$p \geq 0.05$"; "*" – "$0.01 \leq p < 0.05$"; "**" – "$0.001 \leq p < 0.01$"; "***" – "$p < 0.001$"

Yield in relation to root distribution × irrigation

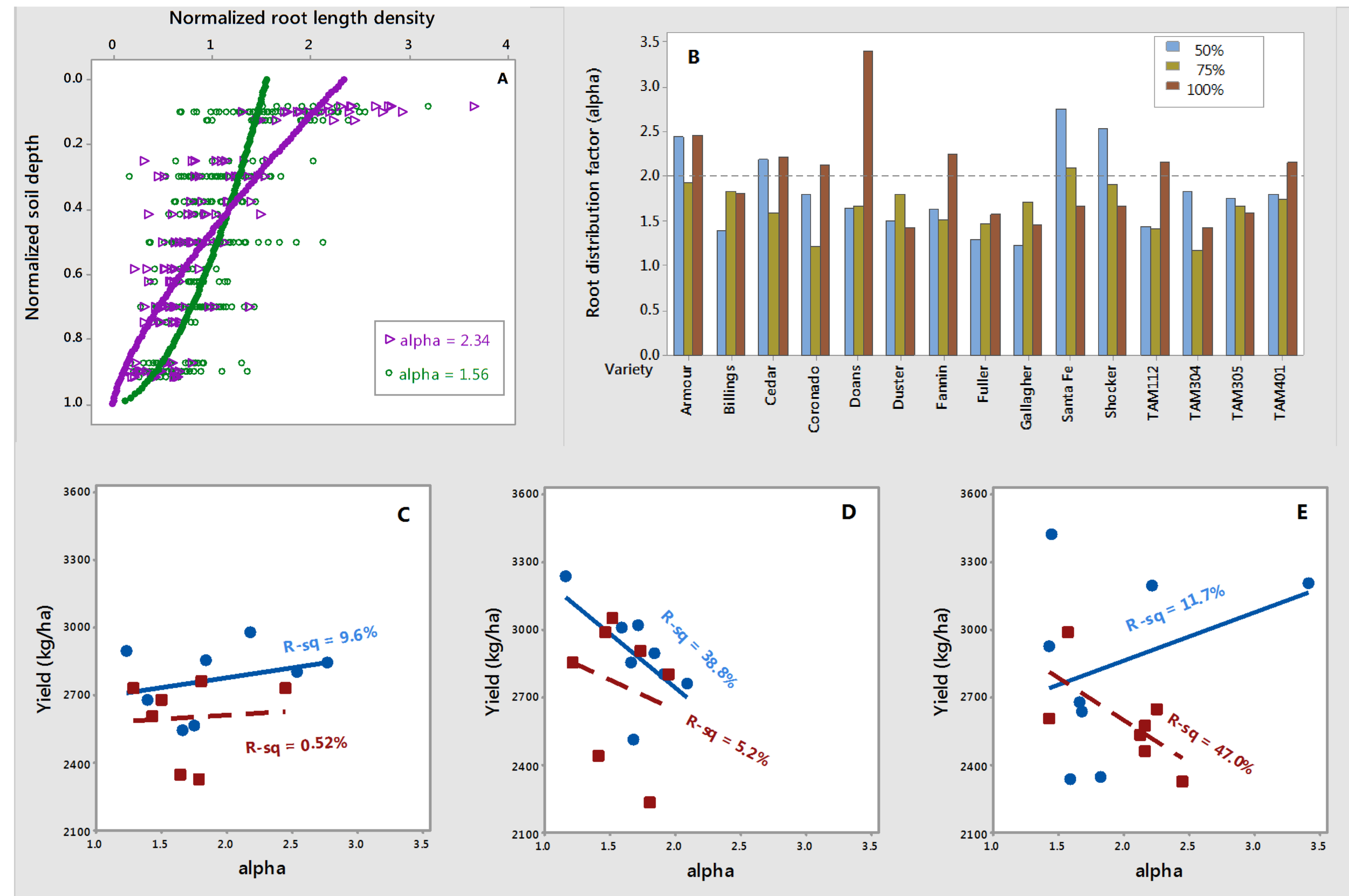

*Figure 3. (**A**) Two types of root distribution as revealed by fitting a normalized root density function, $L_{nrd} = \alpha(1 - z_r)^{(\alpha-1)}$, to the measured root data (Ojha and Ray, 1996; Zuo, et al. 2013). (**B**) Root distribution factor α for different varieties of wheat under three irrigation regimes. A L_{nrd} of 2.0 represents a linear distribution with soil depth; a value lower than 2.0 represents deep distribution, while a value larger than 2.0 is for shallow root dominance. Grain yields in relation to α are shown under 50% (**C**), 75% (**D**) and 100% (**E**) irrigation regimes. The blue dots in (**C**), (**D**) and (**E**) represent rust-resistant varieties and red squares for rust-sensitive varieties.*

Discussion and conclusions

- The 2013-2014 growing season was dry compared with the long-term average precipitation received (Table 1). However, grain yield was similar under different irrigation regimes (2739 kg/ha). Thus production under 50% irrigation is preferred. The 2014-2015 growing season was also dry but had more precipitation during the wheat growing period than the previous one. Limited irrigation again seems to be preferred as 40% reduction in water input resulted in only 24% reduction in grain yield.
- Under intermediate level of irrigation (75% ETc), a lower α, thus deeper root growth, was associated with high yield (Figure 3). The trend was not clear under drier (50 % ETc) or wetter (100% ETc) conditions, with high yield occurring at both shallower and deeper root distribution. Leaf rust resistance appeared to be a factor interacting with irrigation.
- Leaf rust infection tended to reduce both specific leaf area (SLA) and grain yield, while irrigation tended to influence leaf area index and yield. This pattern was similar under different irrigation regimes (Table 2). One suggestion for future breeding efforts related to rust resistance selection perhaps is to dissociate the linkage of rust infection rate and specific leaf area as seen in Figure 2D, so that the most photosynthetically capable population of leaves (having a higher SLA) are less infected by rust, thus preventing significant loss in plant carbon gain.