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Effective Use of Soil Water Contributed to High Yield in Wheat in the U.S. Southern High Plains

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Abstract: Wheat (*Triticum aestivum* L.) is grown in a wide range of water regimes (from dryland to limited irrigation to full irrigation) and produces both grain and forage in the U.S. Southern High Plains. Due to the semi-arid environment in the area, drought stress is the single most important factor reducing grain and forage yields. Selection of drought tolerant wheat cultivars is a critical strategy for wheat management under water-limited conditions. Although wheat yield and drought tolerance have been improved over the years by the Texas A&M (TAM) Breeding Program, the physiological mechanisms of drought tolerance among the TAM cultivars have not been well understood. Our objective was to investigate the differences in soil water depletion among four TAM cultivars. A two-year field experiment was conducted at Bushland, TX, under dryland and irrigated conditions. Cultivars included TAM 105, TAM 110, TAM 111 and TAM 112, which were released from the late 1970's to early 2000's. Based on measurement of seasonal dynamics of soil water depletion, the newer cultivars (TAM 110, TAM 111 and TAM 112) extracted more water from the soil profile than the older cultivar (TAM 105), particularly from the deeper soil profile. However, only under extreme water-limited conditions, varietal differences in yields were evident and were related to measured differences in soil water content. We recommend further studies on root traits to elucidate the differential behaviors of new and old cultivars under extreme drought, moderate drought, and irrigated conditions for SWC and yield.

Key Words: Drought tolerance, Neutron probe, Soil water depletion, Water use efficiency, Wheat

1. Introduction

Wheat is grown in a wide range of water regimes and produces both grain and forage in the U.S. Southern High Plains (SHP). Wheat yield and water-use efficiency (WUE: the ratio of yield to ET) are primarily limited by drought stress from late spring to early summer in the SHP (Musick *et al*., 1994; Xue *et al*., 2006). Adoption of drought tolerant cultivars is a critical strategy for wheat management under water-limited conditions. Cultivars developed by Texas A&M AgriLife Research are grown widely in the SHP, and TAM 111 and TAM 112 were the top two cultivars in 2010-2012. A previous study showed that newer cultivars, TAM 110, TAM 111 and TAM 112, had 19-29% higher yield than an older cultivar, TAM 105 (Xue *et al*., 2014). However, the physiological mechanisms of drought tolerance among these cultivars have not been well understood.

Under water-limited conditions, extraction and effective use of soil water are important to increasing crop yield (Entz *et al*., 1992; Xue *et al*., 2003). The effective use of soil water is related to root growth and development. In the SHP, field studies have been conducted on root growth and soil water depletion (Winter and Musick, 1993; Xue *et al*., 2003). Xue *et al*. (2003) showed that a relatively deep root system and higher water uptake are important for wheat to maintain higher yield and WUE under dryland and limited irrigation conditions. However, there is little information regarding these traits among wheat cultivars. Therefore, the objective of this study was to investigate the differences in soil water depletion among four TAM wheat cultivars.

2. Materials and Methods

A two-year field experiment was conducted at Bushland, TX (Lat. 35°11'N, Long. 102°06'W; elevation 1170 m) in the 2010-2011 (2011) and 2011-2012 (2012) winter wheat growing seasons. Four hard red winter wheat cultivars (TAM 105, TAM 110, TAM 111 and TAM 112) were used in this study. These cultivars have been widely grown in the Texas High Plains and Western Kansas (TAM 105 in 1980 to early 2000's, TAM 110 in late 1990's to early 2000's, and TAM 111 and TAM 112 in the present time).

In this study, the cultivars were grown in two soil water regimes, dryland and irrigated, which were in two different fields. For each water regime, the experimental design was a randomized complete block design with three replications. The soil in both fields was a Pullman clay loam (fine, mixed,

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thermic Torrertic Paleustoll). Plot size was 5.6 m^2 for dryland and 3.7 m^2 for irrigated plots.

In both years, wheat was planted from the last week of October to the first week of November depending on the soil moisture condition for dryland. The seeding rate was 67 kg ha^{-1} for dryland and 100 kg ha^{-1} for irrigated plots. Irrigated plots generally received three to four irrigations from booting to the middle of grain filling. The seasonal rainfall (Oct.-Jun.) was 38 mm in 2011 and 191 mm in 2012, which was below the long term average (287 mm). As such, dryland plots experienced moderate (2012) to extreme drought stress (2011).

The volumetric soil water content (SWC, cm^3 cm^{-3}) was measured on five dates in 2011 (after emergence, early spring, jointing, anthesis and maturity) and three dates in 2012 (jointing, anthesis and maturity) with a 503 DR neutron probe (CPN International, Inc., Martinez, California, USA). The access tubes were installed at the center of each plot, and the readings were collected at 20 cm intervals from 0-240 cm profile. The neutron probe was calibrated in situ at Bushland, TX (Evett *et al*., 1993).

The amount of soil water (SW, mm) in the root zone (0-140 cm for dryland, and 0-160 cm for irrigated) was calculated by summation of the SWC multiplied by soil depth at each layer. Soil water depletion (SWD) at different stages was calculated as the difference in SW between emergence and each stage. Rooting depth was estimated indirectly by water depletion among measurement dates, which was defined as the lowest depth in which significant difference ($p < 0.05$) in SWC occurred between sampling dates (Entz *et al*., 1992). Grain yield for each plot was determined by combine harvest of the whole plot after maturity. Evapotranspiration (ET) was calculated using the soil water balance method, *i.e* ET = SWC at planting + seasonal precipitation + total amount of irrigation - SWC at maturity (Xue *et al*., 2003). Since the SWC was not measured until spring, ET was not calculated for 2012 season. WUE was determined as the ratio of yield and ET. The data were analyzed with SAS 9.2 using the PROC GLM procedure (SAS Inc., 2008). The protected Fischer LSD at p = 0.05 was used to separate means among the treatments.

3. Results and Discussion

There was a significant difference between years for grain yield under both soil water regimes. The average grain yield at 2012 was 1.6 times higher than in 2011 under both dryland and irrigated conditions. The irrigated grain yield was 4.3 - 5 times higher than the dryland grain yield in both the years (**Table 1**). Under dryland conditions, the three relatively newer cultivars (TAM 110, 111 and 112) had higher yield and WUE than TAM 105 in 2011. The yield differences among cultivars were not statistically significant in 2012. Under irrigated conditions, there were no differences among the cultivars for yield and/or WUE for either year.

Table 1. Grain yield and WUE of four wheat cultivars. Within each water regime and year, means followed by the same letters are not significantly different at p = 0.05 based on LSD test.

Cultivar	Grain yield (kg ha^{-1})		WUE (kg m^{-3})
	2011	2012	2011
Dryland			
TAM105	474b*	861a	0.36b
TAM110	756a	864a	0.58a
TAM111	696a	875a	0.56a
TAM112	676a	1048a	0.55a
Mean	651	912	0.51
cv	14.98	14.94	15.85
Irrigated			
TAM105	3267a	4569a	0.62a
TAM110	2810a	4581a	0.57a
TAM111	2922a	4665a	0.58a
TAM112	2732a	4478a	0.55a
Mean	2933	4573	0.58
cv	12.41	11.55	11.97

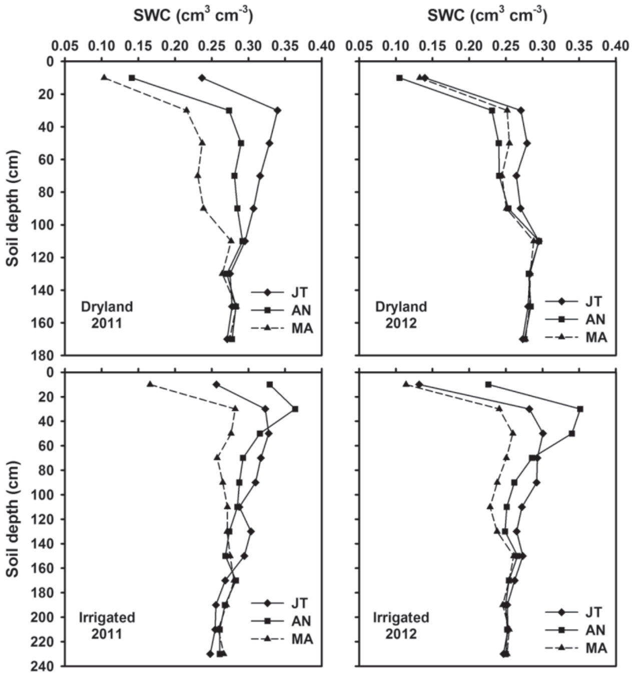

Fig. 1. Changes of SWC along soil profile at jointing (JT), anthesis (AN), and maturity (MA) in TAM 111 in two water regimes and two years.

Figure 1 shows the SWC along the profile at jointing (JT), anthesis (AN) and maturity (MA) in TAM 111, in two years and two water regimes. The changes of SWC over the season reflected the rooting depth. For dryland plots, rooting depth was 110 cm in 2011 and 90 cm in 2012. For irrigated plots, the rooting depth was down to 140 cm in both years. The changes of SWC along the profile in the other three cultivars were similar to TAM 111 (data not shown). The rooting

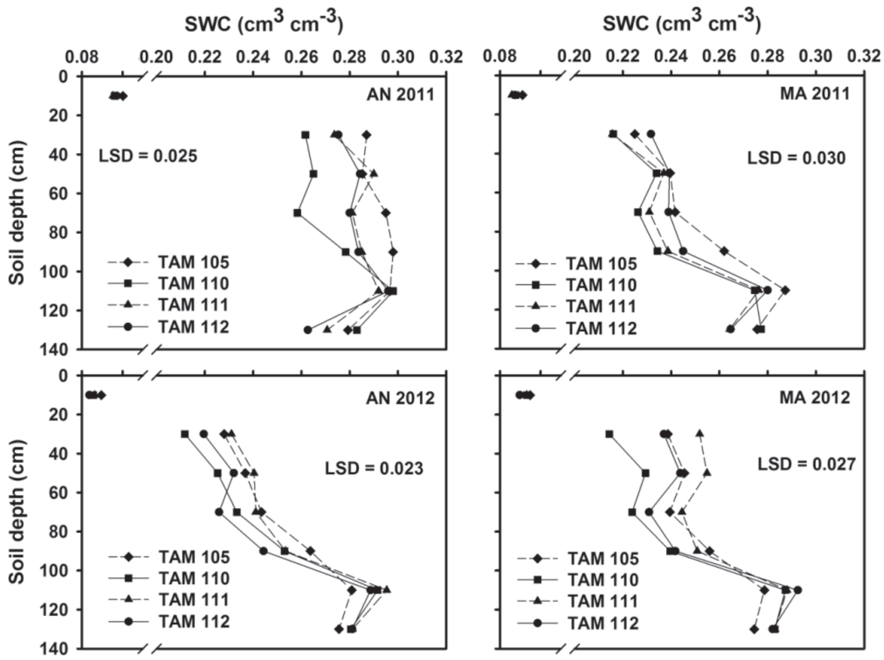

Fig. 2. Soil water content along the profile in four cultivars at anthesis (AN) and maturity (MA) in two years under dryland conditions.

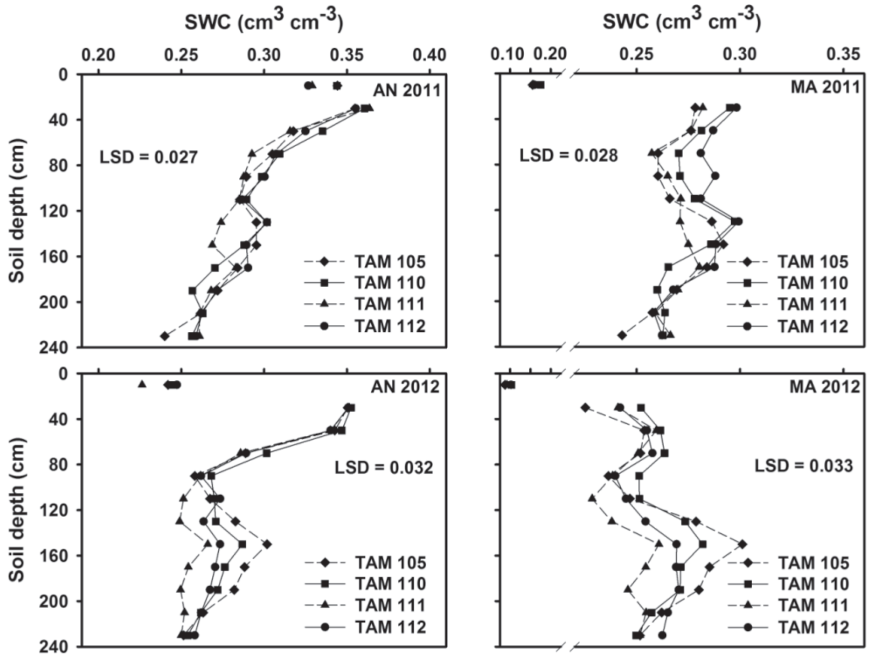

Fig. 3. Soil water content along the profile in four cultivars at anthesis (AN) and maturity (MA) in two years under irrigated conditions.

depth in this study was shallower than that in a previous study (160 cm, Xue *et al*., 2003).

The main reason for this could be due to the relatively late planting date (late Oct. to early Nov.) in this study as compared to Oct. 1 in the Xue *et al*. (2003) study. Winter and Musick (1993) showed that late planting (Nov.) reduced rooting depth and soil water depletion in wheat in the SHP. Lower soil water content at planting might also have contributed to the shallower root system in this study, particularly in the 2012 season.

There were significant differences in SWC among the four cultivars along the profile at AN and MA in two years under both dryland and irrigated conditions (**Figs. 2** and **3**). For dryland wheat, in 2011, TAM 105 had higher SWC than other cultivars at both AN and MA, and TAM 110 had the lowest SWC particularly at deeper soil layers; (Fig. 2). Further, the TAM 105 had the highest (1.5 cm^3 cm^{-3}) and TAM 110 the lowest (1.4 cm^3 cm^{-3}) averaged [(AN + MA)/2] summed root zone water content (SrjWC). In 2012, TAM 105 and TAM 111 had higher SWC along the profile and also higher

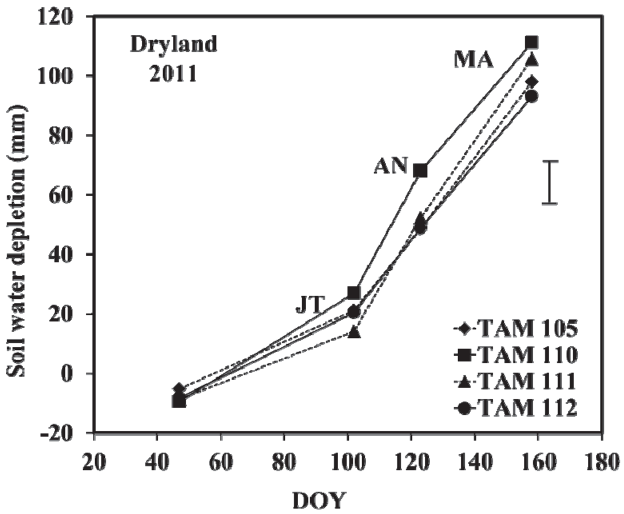

Fig. 4. Soil water depletion under dryland condition in four cultivars at different growth stages (spring; jointing, JT; anthesis, AN; maturity, MA). The vertical bar is a LSD at $p = 0.05$.

averaged SrjWC (1.1 cm^3 cm^{-3}) content than TAM 110 and TAM 112 (1.03 cm^3 cm^{-3}). For irrigated wheat, the differences in SWC among the cultivars were more significant at deeper soil layers (*e.g.*, below 120 cm) as compared to upper layers (0-120 cm). In 2011, TAM 110 and TAM 111 had lower SWC than TAM 105 and TAM 112. In 2012, the ranking of SWC at 120-200 cm profile was TAM 105 > TAM 110 > TAM 112 > TAM 111, suggesting that newer cultivars were able to extract more water than older cultivars from deeper soil (Fig. 3). It is to be noted here that the rooting depth of irrigated wheat at Bushland is generally about 140 cm. However, wheat plants can still extract water from deeper soil by means of hydraulic conductivity (Xue *et al*., 2003). Based on a greenhouse study (Zhang *et al*., 2012), the ability of newer cultivars to extract more water from deeper soil than TAM 105 could be related to their higher aboveground and root biomass at early stages.

Figure 4 shows the soil water depletion (SWD) under the dryland conditions in four cultivars at early spring, jointing (JT), anthesis (AN) and maturity in 2011. The cultivar TAM 110 had higher SWD than the other three from JT to MA, and TAM 111 had higher SWD than TAM 105 and TAM 112 at maturity. The high SWD (Fig. 4) and low SWC at anthesis and maturity (Fig. 2), and also the lowest average SrjWC indicated that TAM 110 used soil water more effectively than the other three cultivars under the extreme dry condition. The better performance of a somewhat older cultivar (TAM 110) as compared to the newest ones (TAM 111 and TAM 112) under the extreme drought condition may be due to the presence of rye translocation gene in it (Xue *et al*., 2014). However, as the cultivar TAM 112, with the same translocation gene, performed differently, a further study is warranted.

4. Summary

There were significant differences in SWC along the soil profile, among four TAM cultivars in both years and under both soil regimes. The study showed that the new cultivars were able to extract more water from the deeper soil profile than the older one. However, only under extreme drought condition (*i.e.* under dryland condition in 2011), significant differences in cultivars for grain yields and their relation to measured differences in SWC were evident. Since the effective use of soil water is highly related to root growth and development, we recommend further studies on root traits to elucidate the differential behavior of old and new cultivars under extreme drought, mild drought and irrigated conditions.

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