Field Crops Research 216 (2018) 1–9

Contents lists available at ScienceDirect

Field Crops Research

journal homepage: www.elsevier.com/locate/fcr

# Yield and water use of drought-tolerant maize hybrids in a semiarid environment

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## ARTICLE INFO

*Keywords:*
Drought-tolerant hybrid
Soil water extraction
Deficit irrigation
Evapotranspiration

## ABSTRACT

Water shortage has been a challenge to sustainability of maize (*Zea mays* L.) production in many irrigated agriculture regions. Adoption of drought-tolerant (DT) hybrids could be a management strategy for maize production under water-limited conditions. The objective of this study was to investigate the differences in soil profile water extraction patterns at vegetative and grain filling stages, dynamics of evapotranspiration (ET), yield, and water use efficiency (WUE) in maize hybrids differing in drought tolerance characteristics in a semiarid environment. Field experiments were conducted in 2014 and 2015 in two conventional (33D53AM and N74R) and two DT hybrids (P1151AM and N75H). The hybrids were grown under two water regimes ($I_{100}$ and $I_{50}$, referring to meet 100% and 50% of ET requirement, respectively). Comparing the well-watered plants at $I_{100}$, water stress at $I_{50}$ reduced seasonal ET by 22–41%, grain yield by 30–48% and yield components by 6–41%; however, water stress only reduced WUE by 8%. Although the DT hybrids did not always provide yield benefit, the Pioneer AQUAmax® hybrid P1151AM had about 30% greater grain yield and WUE than the conventional hybrid 33D53AM. Regardless of year, water regime and hybrid, greater maize yield was related to greater biomass at maturity, harvest index, kernel weight and kernel number. Under water-limited conditions, two DT hybrids consistently had 3–6% lower seasonal ET than the two conventional hybrids. Compared with the conventional hybrids, the two DT hybrids extracted less soil water along the profile at vegetative stage. However, there were no significant differences in soil water extraction among hybrids during the reproductive stage. The results of this study demonstrated that effective use of soil water during grain filling is important for maintaining high yield under water limited conditions.

## 1. Introduction

Maize (*Zea mays* L.) is an extremely important cereal crop grown worldwide. In 2014, there were $2.22 \times 10^8$ ha of harvest area and $1.25 \times 10^9$ Mg of production around the world (FAO, 2015). The demand for maize is projected to double between now and 2050 (CIMMYT, 2011). However, drought stress has been a main constraint to maize production globally. Under climate change, increasing magnitude, duration, and frequency of droughts will profoundly reduce soil water available for plant uptake (Rurinda et al., 2015), and maize production is threatened by this phenomenon (Žalud et al., 2017). Therefore, much breeding and agronomic research has been designed to improve maize performance under drought conditions (Campos et al., 2004).

Maintaining high yields with less water for irrigation is critical to sustaining maize production. Drought-tolerant (DT) maize hybrids could help to maintain high yield under water-limited conditions (Mounce et al., 2016) and it is expected that yield stability will be achieved through improved drought tolerance (Boomsma and Vyn, 2008; Cooper et al., 2014; Sammons et al., 2014). As the hybrids' rapid turnover, studies have been focused on DT maize hybrids with the investigations of germplasm, genetics, and physiological processes. Cooper et al. (2014) investigated the yield performance in DuPont Pioneer's AQUAmax® hybrids as compared to conventional hybrids throughout the US maize-belt from 2008 to 2013. The results showed that AQUAmax® hybrids generally yielded ~45% more than conventional hybrids under drought. In another Pioneer on-farm study, grain yields from the AQUAmax® hybrids were 6.5% larger under water-

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https://doi.org/10.1016/j.fcr.2017.11.001
Received 4 June 2017; Received in revised form 29 October 2017; Accepted 1 November 2017

limited conditions and 1.9% larger under favorable conditions (Gaffney et al., 2015). Besides, grain yield advantages were also found in DT maize hybrids in many other studies (Tollefson, 2011; Sammons et al., 2014; Hao et al., 2015a; Mounce et al., 2016). In addition to yield, other traits were also investigated in previous studies. Proper selection of DT hybrids can increase maize yield with greater biomass and harvest index (HI), heavier kernel weight, and higher resources use efficiency (e.g., water and radiation) under water-limited conditions (Boomsma and Vyn, 2008; Hao et al., 2015a, b; Hao et al., 2016). Furthermore, maintaining more favorable plant-soil-water relations throughout the whole growing season is important for maintaining plant growth and development for high yield under water-limited conditions (Campos et al., 2004; Cooper et al., 2014). Soil water use and extraction in maize hybrids have been reported in previous studies (Hao et al., 2015b; Tolk et al., 2016). However, few studies had been focused on the differences in soil water extraction patterns and ET between conventional and DT hybrids at different growing stages under water-limited conditions.

As a typical semiarid region, the Texas high Plains produced almost two times maize as much as those in the other regions of Texas (Farfan et al., 2013). In this region, approximately 90% of the irrigation water withdrawals were provided by the Ogallala Aquifer (Colaizzi et al., 2009). However, water for agriculture continues to decline where the water source is the non-replenishing in the Ogallala Aquifer (Scanlon et al., 2010; Ziolkowska, 2015). Increased gap between seasonal evapotranspiration (ET) and water input (rain and irrigation) could decrease grain yield and quality (Campos et al., 2004; Aydinsakir et al., 2013; Ali et al., 2016; Avramova et al., 2016). This is particularly true in the Texas High Plains because the average rainfall (~233 mm) during the maize growing season is only 31% of ET requirement (~745 mm) for the maximum production of maize grain (Kapanigowda et al., 2010). In this study, we investigated the differences in soil profile water extraction patterns at vegetative and grain filling stages and dynamics of water use among two conventional and two DT hybrids in a semiarid environment in the Texas High Plains. In addition, yield, yield components, and water use efficiency (WUE) were also compared among the hybrids under two water regimes.

## 2. Materials and methods

### 2.1. Locations and experimental design

Two-year field experiments were conducted at the Texas A&M AgriLife Research Station near Etter, Texas (35° 52’ N, 101° 58’ W; elevation 1114 m above mean sea level) in 2014 and at Bushland, Texas (35° 13’ N, 102° 04’ W; elevation 1161 m above mean sea level) in 2015. In 2014, the soil was a Sherm silty clay loam soil (fine, mixed, mesic Torrertic Paleustolls). The field capacity ($0.38\ m^3\ m^{-3}$) (Undersander and Regier, 1988) and permanent wilting point ($0.22\ m^3\ m^{-3}$) (Unger and Pringle, 1986) water contents were assumed uniform across the field. In 2015, the soil was a Pullman silty clay loam soil (fine, mixed, superactive, thermic Torrertic Paleustolls). The field capacity ($0.33\ m^3\ m^{-3}$) and wilting point ($0.18\ m^3\ m^{-3}$) water contents were uniform across the field (Mounce et al., 2016). The daily temperature and precipitation data during the maize growing seasons in 2014 and 2015 were obtained from agro-meteorological stations located at the experimental sites. The monthly average temperature and total rainfall during the maize growing seasons (May–October) at Etter in 2014, Bushland in 2015 and the 30-year (1981–2010) averages at both sites were from National Centers for environmental information in National Oceanic and Atmospheric Administration (NOAA: http://www.ncdc.noaa.gov).

The experimental design was a split-plot design with four replications. Irrigation level was the main plot factor with hybrid as the subplot factor. Irrigation levels were consisted of 100% ($I_{100}$) and 50% ($I_{50}$) of expected ET requirement. In 2014, irrigation was applied with a center pivot irrigation system using low elevation spray application (LESA) method. Irrigation scheduling was determined by reference evapotranspiration ($ET_0$), crop coefficient, and plant available soil water (PAW) at the root zone on daily basis for $I_{100}$ (Marek et al., 2011). The daily $ET_0$ was calculated according to the FAO Penman-Monteith equation (Allen et al., 1998). Actual maize water requirements ($ET_c$) were determined based on the relation to $ET_0$. The equations were as follow:

$$ET_0 = \frac{0.408\Delta(R_n - G) + 900\gamma\cdot u_2(e_s - e_a)/(T + 273)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

$$ET_c = K_c \times ET_0 \quad (2)$$

where $ET_0$ and $ET_c$ are the daily reference evapotranspiration and actual maize water requirement in mm $day^{-1}$; Δ is the slope of the saturation vapor pressure temperature relationship in kPa °C; $R_n$ is the daily solar radiation in $MJ\cdot m^{-2}\ day^{-1}$; G is the daily ground heat flux in $MJ\cdot m^{-2}\ day^{-1}$; γ is the psychrometric constant in kPa °C; $u_2$ is the average wind speed at 2 m height in m $s^{-1}$; $e_s$ and $e_a$ are the saturation and actual vapor pressures in kPa; T is the daily mean air temperature in °C; $K_c$ is the crop coefficient for maize.

Daily $ET_0$ was calculated based on the climatic data from the meteorological station of TXHPET. Crop coefficient for maize was previously determined using lysimeter from TXHPET. The daily PAW (mm) was calculated as the difference between current root zone soil water and that at wilting point. The initial soil water at root zone was measured by taking soil cores at 0–15, 15–30, 30–60, 60–90, and 90–120 cm deep at planting. Then, the daily soil water was calculated by using soil water in previous day subtracting ET and adding precipitation and irrigation. Irrigation events were initiated when root zone soil PAW reached to 50%. For $I_{50}$ treatments, irrigation frequency was the same as that of $I_{100}$ but the irrigation amount was 50% to that of $I_{100}$ by changing the nozzles. In 2015, water was applied by furrow irrigation, and soil moisture targets for the 100% ET were maintained by utilizing regular measurements of soil water content at root zone (0–1.6 m) using a neutron moisture meter. In each season, no irrigation was applied before planting. The total irrigation amounts for $I_{100}$ and $I_{50}$ treatments were 651 and 325 mm in 2014, 274 and 105 mm in 2015, respectively (Fig. 1). In 2014, water treatment with the first irrigation started right after planting due to dry conditions at planting. In 2015, rainfall was sufficient up to 68 days after planting (DAP) when plants reached to early grain filling ($R_2$ stage). As a result, no irrigation was applied until after 68 DAP and the two water treatment levels were only imposed during grain filling stage.

Four maize hybrids that differed in their DT characteristics were planted in two seasons: two conventional hybrids (Pioneer 33D53AM and Syngenta N74R) and two DT hybrids (Pioneer P1151AM and Syngenta N75H). 33D53AM (Relative maturity 115 d) was rated as poorly suitable for Drought-Prone soil by DuPont Pioneer. However, drought score for AQUAmax® hybrid P1151AM (Relative maturity 111 d) determined by DuPont Pioneer was 9 on a 9-point scale (9 = Excellent, 1 = Poor). Although N74R (Relative maturity 114 d) is a conventional hybrid, the drought score of N74R determined by Syngenta on a 9-point scale (1 = Excellent, 9 = Poor) was 3 and it was proved strong yield performance in an excellent agronomic package. Meanwhile, the drought score of N75H (Relative maturity 115 d) with Agrisure Artesian technology was 1.

The four hybrids were planted on May 15, 2014 and June 4, 2015. In both years, hybrids were planted by a John Deere Max-Emerge planter and the planting density was 74,000 plants $ha^{-1}$; 290 kg $ha^{-1}$ of N, 109 kg $ha^{-1}$ of $P_2O_5$ and 11 kg $ha^{-1}$ of S were applied before planting; weeds were controlled using a combination of hand-hoeing and herbicide application at pre-plant and post-emergence.