Proceedings of the 30th Annual Central Plains Irrigation Conference, Colby, Kansas, Feb. 20-21, 2018
Available from CPIA, 760 N. Thompson, Colby, Kansas

DROUGHT TOLERANT (DT) AND NON-DT CORN PRODUCTION WITH CENTER PIVOT IRRIGATION IN THE TEXAS HIGH PLAINS

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ABSTRACT

Corn (*Zea mays* L.) for feed is an important crop in the Texas High Plains region. However, it requires more water than the other major crops grown in the area to maximize grain yields. Pumping water for agriculture from the declining Ogallala Aquifer is of concern and improving irrigation water use efficiency (IWUE) using drought tolerant (DT) corn is of major interest. However, information on the performance of DT corn is limited. This paper discusses cumulative irrigation amounts, grain yields, seasonal crop evapotranspiration (ET_c) and water use efficiency for DT corn hybrids grown under various irrigation levels in Bushland, Texas over the past five years. A two-year study (2013-2014) demonstrated that a mid-season DT hybrid required less irrigation compared with a conventional (CONV) hybrid, however grain yields and WUE between the hybrids were similar. Following the 2013-2014 study, two corn hybrids with the same DT rating and relative days of maturity five days apart, were planted late in June 2015. Cumulative irrigation amounts were within 1 in. for each hybrid when compared at the same irrigation level. There was a significant difference in grain yield and WUE between hybrids at the most deficit irrigation level. In 2016, crop response between mid-season and early-maturing (EM) DT hybrids planted 30 days apart demonstrated substantial savings in irrigation water for the EM hybrid, however, grain yields were substantially reduced compared with the mid-season hybrid. Drought tolerant hybrids may be beneficial in reducing cumulative irrigation requirements and improving WUE. Mid-season DT hybrids planted in May in this region are likely to produce grain with no yield penalties compared with CONV mid-and full-season hybrids.

The mention of trade names of commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

INTRODUCTION

In the Texas High Plains region, corn remains an important grain crop for cattle feed. However, it requires more water than the other major crops grown in the area to maximize grain yields. The variability in maximum yields is large due to many factors including soil type (Tolk et al., 1998a), climatic variability and cultivar response (Howell et al., 1998). Irrigation application efficiency has improved since the conversion from furrow to sprinkler irrigation, and now more than 77% of irrigated acres in Texas is with center pivot sprinklers (USDA, 2014). Producers in the Texas High Plains region are known for using irrigation systems designed for efficiency (Amosson et al., 2014) and application methods that help minimize evaporative losses to surface evaporation, wind and high temperatures (Colaizzi et al., 2004). If DT corn is capable of producing similar yields with less water, then coupling efficient irrigation management practices with hybrids that required fewer growing degree days could aid farmers in reducing irrigation amounts while maintaining high yields. Howell et al. (1998) compared crop response of a short season hybrid (P3737) with a full-season hybrid (P3425). The WUE were similar across hybrids, but grain yield was significantly less for the short-season hybrid. There have been a number of DT hybrids released in recent years, but information on these recent hybrids performance is limited. This paper reports on crop response, grain yield, ET_c, and WUE for four different DT hybrids grown in Bushland, Texas.

MATERIALS AND METHODS

The experiments were conducted at the USDA Agricultural Research Service Conservation & Production Research Laboratory in Bushland, Texas (35° 11’ N lat., 102° 06’ W long., elevation 3, 904 ft. above mean sea level). The soils are Pullman clay loam (fine, superactive, mixed, thermic torretic Paleustoll, USDA-NRCS, 2010). A summary of corn hybrids, planting dates, planting rates and irrigation treatment is presented in Table 1.

Corn was planted under variable rate irrigation (VRI) center pivot systems outfitted with zone control (as described in O’Shaughnessy et al., 2013), which enabled randomized treatments in radial and arc-wise directions. Cultural practices were similar to those of farmers in the region practicing conventional tillage. Nitrogen and phosphorous were applied to obtain target yields of 250 bushels per acre.

Irrigation treatment levels were based on weekly neutron probe (NP) readings and replenishment of a percentage of soil water depletion to field capacity to a depth of 5 ft, i.e. within the active root zone. For example, I_{100}, I_{75} and I_{50} indicate 100%, 75% and 50% replenishment of soil water depletion to field capacity, respectively. The NP meters (model 503DR1.5, Instrotek, Campbell Pacific Nuclear) were field-calibrated using methods described by Evett et al. (2008). Neutron probe access tubes to a depth of 10 ft. were placed in the center of each plot so that profile water content changes, ΔS, could be accurately determined to 8 ft.

Weather data was collected from standalone weather stations located in each center pivot field. Sensors from Campbell Scientific measured solar irradiance (model LI-200R), air temperature and relative humidity (model HC2S3), precipitation (model TE525) and wind speed (model Wind Sentry 03101). Data were sampled every 5 s and averaged and stored every 1 minute with a CR1000 datalogger. This information was used to calculate reference evapotranspiration (ASCE, 2005). The soil water balance method was used to calculate crop water use (ET_c) for each cropping season using equation (1):

$$ET_c = I + P + F - \Delta S - R \quad (1)$$

where I is the amount of irrigation water applied (in.), P is precipitation (in.), F is flux across the lower boundary of the control volume, ΔS is the change in soil water stored in the profile (surface to a depth of 8 ft., determined by the NP), and R (in.) is runoff. The value of F was set to zero since NP data at the bottom two measurement depths indicated negligible soil water flux.

A drought tolerant (DT) hybrid, Pioneer P0876HR (relative days to maturity of 108), and a conventional (CONV) hybrid, Pioneer 33Y75 (relative days to maturity of 115) were planted at the same seeding rate, in the same field on the same day of year in 2013 (May 14) and 2014 (May 15). The DT hybrid had a rating of 9 (with 10 indicating the highest drought tolerance), while the CONV hybrid had a drought tolerance rating of only 6. Hybrids were main plots, planted in a concentric pattern, with irrigation levels of I_{100}, I_{75} and I_{50} as sub-plots.

In 2015, Pioneer hybrids P0876HR and 33Y75 were planted on May 27. However, on June 13, a hailstorm and strong southwesterly winds resulted in a gradient of crop damage running from heavily damaged plants at the southwest to less-damaged plants at the northeast portion of the field. The field was replanted on June 23 using two short-season corn hybrids P0157AM (relative days to maturity of 101, DT rating of 9) and P9697AM (relative days to maturity of 96, DT rating of 9). Again, the main plots were hybrids planted in a concentric pattern, with irrigation treatment levels of I_{100}, I_{75} and I_{50} as sub-plots. In both 2013, 2014 and 2015, there were five replications of each hybrid X irrigation level treatment, and irrigations were applied using low energy precision application (LEPA drag socks) in 2013 and 2014, and low elevation spray application (LESA) in 2015.

In 2016, seed for hybrid P9697AM was unavailable, but we had enough seed left over from 2015 to plant in zones irrigated under a separate application comparison study using LESA, LEPA and mobile drip irrigation (O'Shaughnessy and Colaizzi, 2017). Water was applied weekly to replenish 100% of average soil water depletion to field capacity as determined with weekly neutron probe readings taken in each type of plot. Pioneer hybrid P0157AM was available and was planted under the remaining portion of the semi-circle and irrigated using LESA at levels I_{100}, I_{50}, I_{30}. Corn hybrid, Pioneer, P1151AM (relative days to maturity of 111 and DT rating of 9) was planted under the three-span center pivot system and irrigated using LESA at levels of I_{100}, I_{80}, I_{50}, I_{30} and I_0 in 2016 and 2017. In all experiments, furrow diking was used to minimize runoff losses ($R \approx 0$ in Eq. 1).

Crop water use efficiency (WUE) was defined as:

$$WUE = \frac{EconomicYield}{(P + I + \Delta S)} \quad (2)$$

where economic yield for grain is reported on a wet basis of 15.6% moisture, P is precipitation, I is irrigation applied, and ΔS is soil water used to eight ft depth during the growing season (Howell 2001).

Comparison of mean crop responses was made using JMP (ver. 10.0.0, SAS Institute) using ANOVA and Student's t-test for comparison of mean values.

Table 1. Summary of corn hybrids planted, planting dates, planting rates, and irrigation treatment levels for the 2013 to 2017 growing seasons in Bushland, Texas.

Year	Hybrids	Planting Dates	Planting Rate (seeds/acres)	Irrigation Levels (% replenishment soil water depletion to field capacity)
2013	Pioneer P0876HR (DT), Pioneer 33Y75 (CONV)	May 14	32,000	100%, 75%, 50%
2014	Pioneer P0876HR (DT), Pioneer 33Y75 (CONV)	May 15	32,000	100%, 75%, 50%
2015	Pioneer P0157AM, Pioneer P9697AM	May 27	32,000	100%, 75%, 50%
2016	Pioneer P1151AM; Pioneer P0157AM; P9697AM	May 13 June 16 June 16	32,000	100%, 80%, 50%, 30%, 0%; 100%, 50%, 30%; 100%
2017	Pioneer P1151AM	May 17	34,000	100%, 80%, 50%, 30%, 0%

RESULTS

Climatic Conditions

Annual and within-season precipitation (June through October) were less than average in 2013 and 2016, and greater than average in 2014, 2015 and 2017 (Table 2). Hailstorms occurred on May 28 and June 16 in 2013; on July 14, 2014; on June 13 and July 8, 2015; on June 13, 2016 and on July 2, 2017. Hail damage resulted in yield penalties, except in 2014; however, the only season that the crop was replanted was in 2015 because the storm caused spatially varying levels of damage across the field.

Table 2. Summary of annual and seasonal precipitation and growing degree-days for Bushland, Texas.

	Annual Precipitation (in.)	Seasonal Precipitation (in.)	Seasonal GDD† (°F)
2013	11.2	9.4	3211
2014	20.7	13.2	2998
2015	38.1	21.53	3059
2016	16.2	10.1	3497
2017	25.6	18.7	3061

†GDD= $(T_{max}+T_{min})/2-50$

Yield, Water Use (ET_c) and Water Use Efficiency

A Two Year Comparison of Mid-season DT and Conventional Corn Hybrids

In 2013 and 2014, cumulative irrigation amounts required for the DT hybrid were, on average, 2 inches less than applied to the CONV hybrid (Figure 1). Irrigation was terminated on Sept. 1 (DOY 244) for the DT hybrid and on Sept. 6 (DOY 249) for the CONV hybrid in 2013. In 2014, irrigations to both hybrids were terminated after Aug. 31 (DOY 243). Mean grain yields in 2014 were significantly greater than in 2013, likely due to optimal climatic conditions, i.e. cooler maximum daily air temperatures and plentiful precipitation during the reproductive stages, and perhaps less severe hail damage (Table 3).

Comparing crop response between hybrids in both years, overall grain yield was similar, but seasonal ET_c was significantly greater for the CONV hybrid. Importantly in the drier year of 2013, WUE was significantly greater for the DT hybrids across all irrigation treatment levels as compared with the CONV hybrid (Fig. 1). In 2014, WUE was similar for all hybrids and all irrigation treatment levels due to the amount of precipitation received during the growing season. Hao et al. (2016) reported that DT hybrid, Pioneer P1151HR, grown alongside the CONV hybrid, Pioneer 33D49 in Etter, Texas (approximately 100 miles north of Bushland) produced significantly greater grain yields and WUE at irrigation treatment levels of 100%, 75% and 50% replenishment of ET_c. Those studies were conducted in 2012 and 2013.

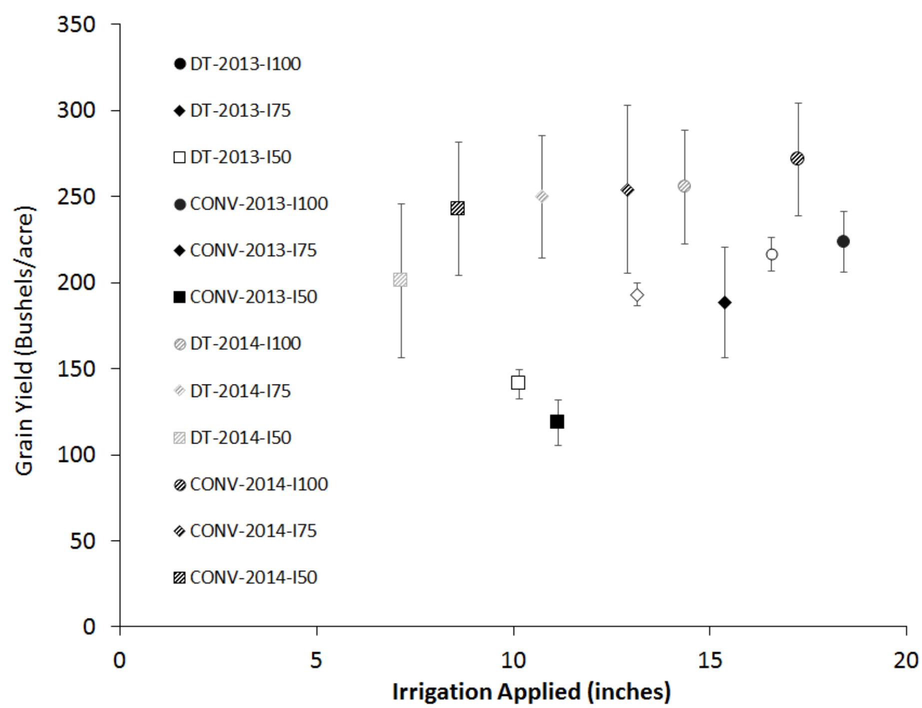

Figure 1. Grain yield plotted against irrigation water applied to the drought tolerant (DT) and conventional (CONV) corn hybrid grown in 2013 and 2014 at Bushland, Texas. Error bars represent standard deviations in grain yield.

In the relatively dry growing season of 2013, irrigation treatments significantly influenced grain yields. Although there was no significant difference in grain yield and WUE between hybrids at the same irrigation level, grain yield and WUE were numerically greater for the DT hybrid at the deficit irrigation levels. In 2014, irrigation treatments did not significantly affect grain yields or WUE, because of the relatively high amount of precipitation received throughout the growing season. At the same irrigation level, grain yield, ET_c and WUE were similar between hybrids.

Table 3. Mean crop response between Pioneer P0876HR, drought tolerant (DT), and Pioneer 33Y75, conventional (CONV) corn hybrid grown in 2013 and 2014 at Bushland, Texas. Mean values followed by the same letter are not significantly different at $p < 0.05$. Grain yield is reported on wet basis of 15.6%.

	Grain Yield (bu/acre)		ET_c (inches)		WUE (bu/acre-in)	
Year/Hybrid	2013	2014	2013	2014	2013	2014
P0876HR	182a	242a	22.7b	22.8b	8.0a	10.6a
33Y75	176a	256a	24.9a	25.6a	7.1b	10.0a
Hybrid X Irrigation	Grain Yield (bu/acre)		ET_c (inches)		WUE (bu/acre-in)	
	2013	2014	2013	2014	2013	2014
DT X I_{100}	212a	265a	25.2b	25.4a	8.4a	10.4a
CONV X I_{100}	223a	271a	28.1a	29.5a	7.9ab	9.2a
DT X I_{75}	192b	245b	22.8b	22.7a	8.4a	10.8a
CONV X I_{75}	189b	253b	25.1b	25.6a	7.5ab	9.9a
DT X I_{50}	139c	212c	20.0c	20.4a	7.0b	10.4a
CONV X I_{50}	123c	240bc	21.7c	21.6a	5.7c	11.1a

Comparison of Two Early-maturing DT Corn Hybrids

In 2015, 50% (10.4 in.) of total precipitation for the growing season occurred in the vegetative growth stage, while 16% (3.5 in.) occurred in the reproductive stages and 27% of precipitation occurred after physiological maturity. Harvest was delayed until early November because of difficulty entering the fields.

Cumulative irrigation amounts were 10.0, 7.4 and 5.0 in. for the P0157AM hybrid, and 11.4, 8.5 and 5.6 in. for the P9697AM hybrid in the I_{100}, I_{75} and I_{50} irrigation treatment levels, respectively. Grain yield response to irrigation was best represented by a quadratic equation, while for the P9697AM hybrid, grain yield response to irrigation was linear (Fig. 2). The first irrigation event was applied in the 10-leaf stage, and then two weeks later at tassel and then every 3-5 days throughout the reproductive stages. Irrigations were terminated after Sept. 23 (DOY 266), when the P0157AM hybrid was in the early dent stage and the P9697AM was in the late dent stage. Average plant available water in the 5-ft profile at the time of termination was approximately 5 in.

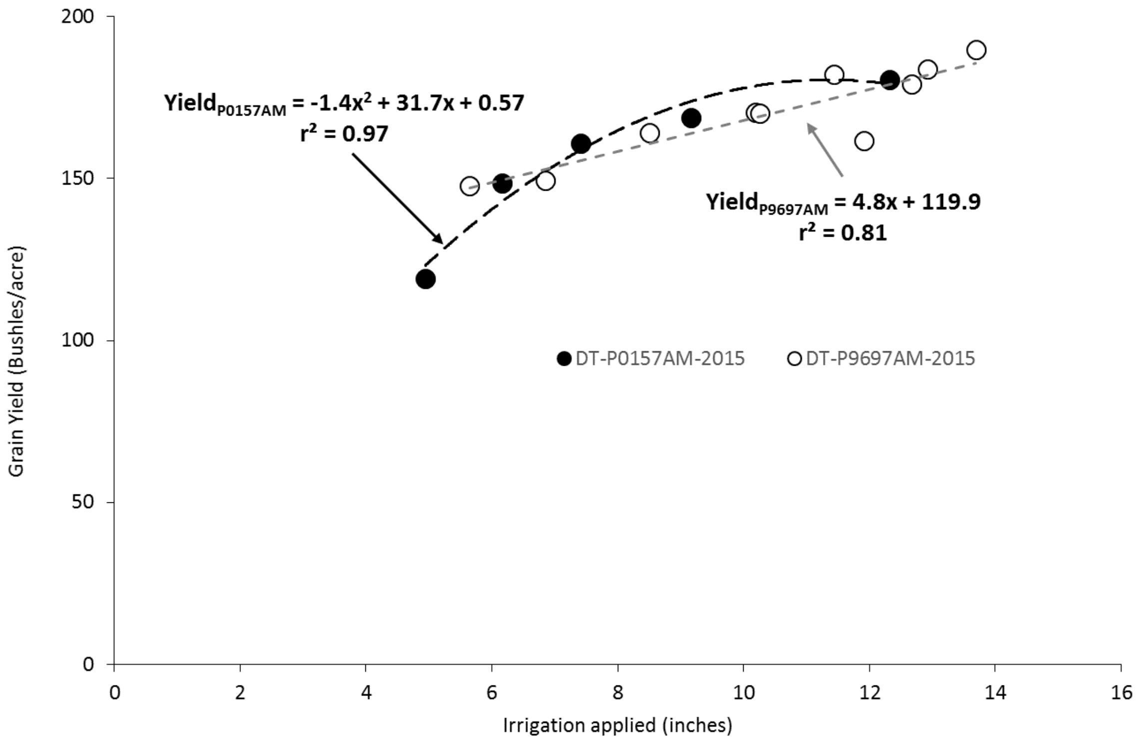

Figure 2. Grain yield (adjusted to wet basis of 15.6%) plotted against applied irrigation amounts for DT corn hybrids P0157AM and P9697AM grown in Bushland, Texas in 2015.

Comparing grain response among hybrids by irrigation level, the P9697AM hybrid responded with greater yields and WUE at the I_{50} treatment level compared with the P0157AM hybrid. However, grain yields and WUE were similar between hybrids at the greater irrigation levels (Table 4). Seasonal ET_c was significantly greater at the I_{100} and I_{75} levels for the P9697AM hybrid. Water use efficiencies were significantly less in this year compared with previous studies due to the large amounts of precipitation received after the crop had reached physiological maturity.

Table 4. Mean crop response between drought tolerant hybrids Pioneer P0157AM and P9697AM grown in 2015 at Bushland, Texas. Mean values followed by the same letter are not significantly different at $p < 0.05$. Grain yields are adjusted to 15.6% moisture.

Year/Hybrid	Grain Yield (bu/acre)	ET_c (inches)	WUE (bu/acre-in)
P0157AM	154b	29.8b	5.15a
P9697AM	165a	30.5a	5.39a
Hybrid X Irrigation	Grain Yield (bu/acre)	ET_c (inches)	WUE (bu/acre-in)
P0157AM X I_{100}	183a	31.6b	5.78a
P9697AM X I_{100}	182a	32.5a	5.60a
P0157AM X I_{75}	161b	29.9d	5.38a
P9697AM X I_{75}	164ab	31.0c	5.30a
P0157AM X I_{50}	119c	27.8e	4.29b
P9697AM X I_{50}	148b	28.0e	5.27a

In 2016, the non-availability of Pioneer P9697AM seed required a reduction in total planting area for this hybrid; and the irrigation treatment was limited to the I_{100} level. More than 69% of precipitation occurred in August at the start of corn tassel and tapered off at the early dough stage. Irrigation amounts between the two hybrids at the I_{100} level were similar with 13.5 in. and 14.5 in. applied to the P9697AM and P0157AM, respectively. Mean adjusted grain yields and WUE were 194 bu/acre and 7.9 bu/acre-in for the P9697AM hybrid, similar to the P0157AM hybrid at 198 bu/acre and 7.8 bu/acre-in, respectively.

Comparison of Crop Response between a Mid-season and an Early-Maturing (EM) DT Hybrid

In 2016, the mid-season hybrid (P1151AM) was planted 30 days earlier than the EM hybrid (P0157AM). Mean cumulative irrigation amounts of 17.5, 15.6, 10.0, 6.2 and 0.40 in. were applied to the I_{100}, I_{80}, I_{50}, I_{30} and I_0 irrigation treatments, respectively. Mean cumulative irrigation amounts for the P0157AM were 14.5, 9.0 and 7.0 inches for the I_{100}, I_{50} and I_{30} in. irrigation treatment levels, respectively. The grain yield response function was linear for both hybrids (Fig. 3). It should be noted that cumulative irrigations of approximately 6 in. resulted in 146 bushels/acre for the EM hybrid but only 80 bushels/acre for the mid-season hybrid. At 10 inches of water, grain yields were similar, while at 14 inches, irrigation resulted in nearly 200 bushels/acre for the EM hybrid, and almost 255 bushels/acre for the mid-season hybrid.

A statistical analysis of crop response was made separately for each hybrid (Table 5). For both hybrids, crop response was significantly influenced by irrigation treatment level. Deficit irrigation at the I_{50} and I_{30} levels for the EM hybrid resulted in a significant reduction in grain yield and ET_c, while WUE was significantly less at the I_{30} level. For the mid-season hybrid, a significant reduction in grain yield and WUE occurred at irrigation levels < $I_{80.}$ These results are similar to those reported by Howell et al., (1998) for a study comparing crop response between an EM corn hybrid (P3737) and a full-season corn hybrid (P3245). The hybrids were planted on the same day in mid-April of 1994. Cumulative irrigation amounts were 18.3 and 22.7 in. for the EM and full-season hybrid, respectively. Grain yields (adjusted to a wet basis of 15.6%) were 204 and 242 bushels/acre and WUE were 11.1 and 10.7 bushels/acre-in for the EM and full-season hybrid, respectively.

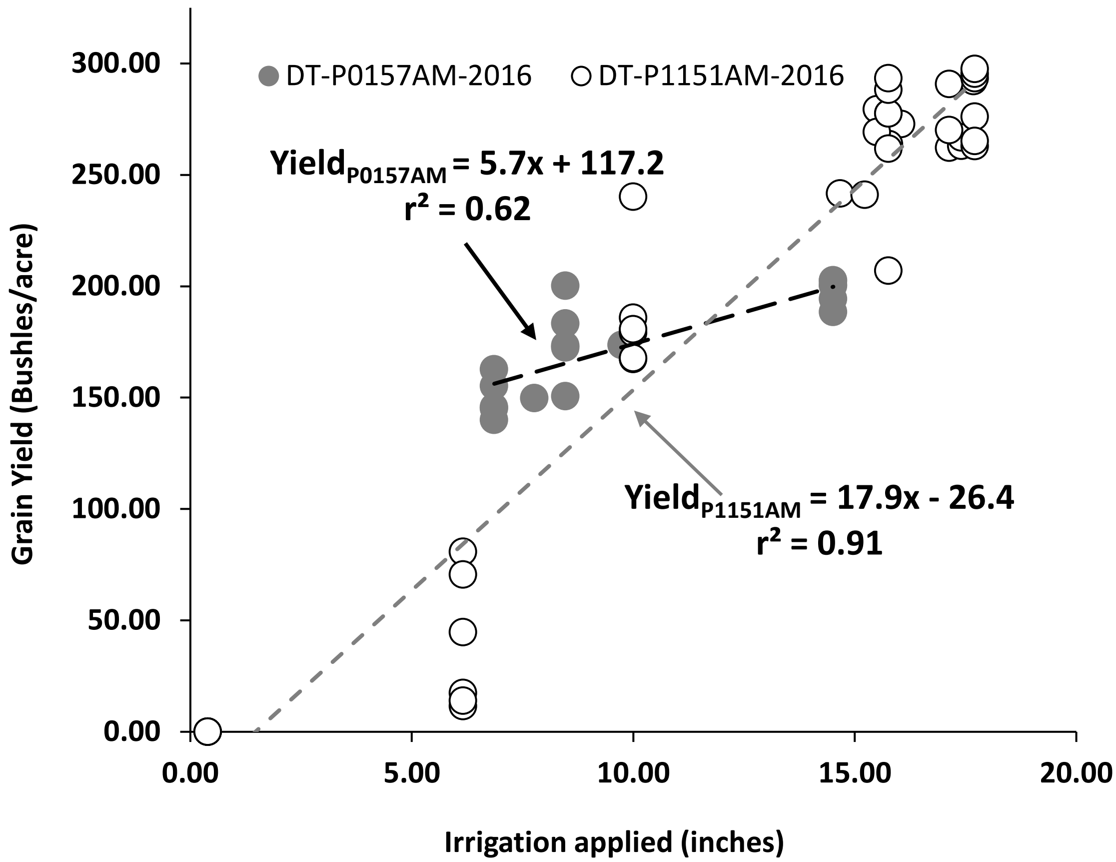

Figure 3. Grain yield plotted again irrigation amount applied for the early-maturing hybrid P0157AM and the mid-season hybrid P1151AM, grown in 2016 in Bushland, Texas.

At the I_{100} treatment level, 3 in. of water was saved by cultivating the EM hybrid P0157AM as compared with the mid-season hybrid, yet grain yield per acre was 38% less for the P0157AM hybrid compared with the mid-season hybrid. Grain yields and WUE for P1151AM were comparable to those of the CONV hybrid grown in 2014. Precipitation and cooler air temperatures occurring during the reproductive stages of the crop likely influenced the positive crop response.

Table 5. Mean crop response between drought tolerant hybrids Pioneer P0157AM grown in 2016 at Bushland, Texas. Mean values followed by the same letter are not significantly different at $p < 0.05$. Grain yields are adjusted to 15.6% moisture.

Hybrid X Irrigation	Grain Yield (bu/acre)	ET_c (inches)	WUE (bu/acre-in)
P0157AM X I_{100}	198a	25.4a	7.8ab
P0157AM X I_{50}	176b	21.1b	8.3a
P0157AM X I_{30}	150c	19.9c	7.5b
P1151AM X I_{100}	274.0a	27.1a	10.2a
P1151AM X I_{80}	265.0a	26.0b	10.2a
P1151AM X I_{50}	187.0b	21.6c	8.7b
P1151AM X I_{30}	40.0c	17.6d	2.3c
P1151AM X I_0	0.0d	9.9e	0.0d

Crop Response of Mid-Season Hybrid P1151AM Over Two Years

For confirmation of the 2016 results for corn hybrid P1151AM, in 2017, this hybrid was planted in mid-May following a relatively mild spring. After planting, minimal rainfall occurred during the next 22 days and a total of four 1-inch irrigations were applied uniformly across all plots, approximately every fifth day; maximum and minimum daily air temperatures reached their highest in this part of the growing season. A hailstorm hit on July 2 and damaged leaves and corn stalks throughout the field. The corn was in the 7th leaf stage. The damage from the storm slowed crop maturity by approximately two weeks and resulted in an estimated 20% yield penalty. Irrigations resumed 7 days after the hailstorm until precipitation events returned on August 5. Irrigation was terminated on August 7. Total rainfall received from May through October was 80% of seasonal crop water use. Grain yields for the mid-season DT hybrid as a function of irrigation applied demonstrated similar slopes between 2016 and 2017.

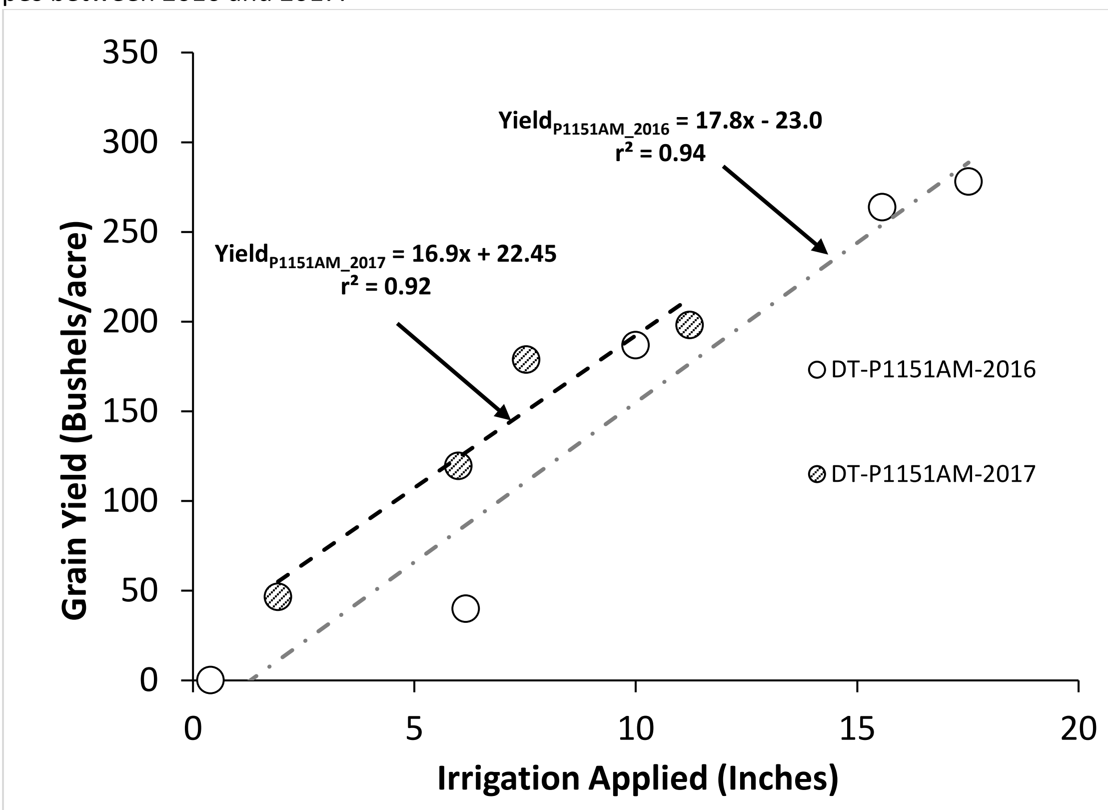

Figure 4. Grain yields adjusted to 15.6% moisture were plotted against irrigation applied for the DT hybrid P1151AM grown at Bushland in 2016 and 2017. Data points are averages for each treatment level.

In 2017, grain yield and WUE were similar for the I_{100}, I_{80} and I_{50} treatment levels, while the lower irrigation treatments, I_{30} and I_0, significantly reduced grain yield and WUE (Table 6). Grain in the lower irrigation treatments had a higher susceptibility to disease (corn smut).

Compared with grain yields in 2016, yields in the I_{100} and I_{80} treatments were much less because of hail damage. However, grain yields and WUE in the I_{30} and I_0 treatments were greater in 2017. The additional seasonal rainfall and cooler air temperatures during the reproductive stages of crop development in 2017 helped to alleviate water stress at these lesser irrigation treatment levels.

Table 6. Mean crop response for drought tolerant hybrid P1151AM grown in 2017 at Bushland, Texas. Mean values followed by the same letter are not significantly different at $p < 0.05$.

Hybrid X Irrigation	Grain Yield (bu/acre)	ET_c (inches)	WUE (bu/acre-in)
P1151AM X I_{100}	196.1a	27.0a	7.27a
P1151AM X I_{80}	188.4a	25.1b	7.50a
P1151AM X I_{50}	180.8a	23.5c	7.68a
P1151AM X I_{30}	119.5b	22.6cd	5.29b
P1151AM X I_0	21.1c	21.4d	1.14c

Historical Corn Response

Seasonal crop water use for 200-bushel corn or greater grown in Bushland, Texas since the late 1980's under sprinkler irrigation systems varied from 19.5 in. to 33.0 in. and WUE for the larger irrigation treatment levels was 9.05 bushels/acre-in. (Fig. 5). Maximum grain yields and WUE occurred in growing season 2014, when precipitation during the growing season was greater than normal and air temperatures were moderate. Minimum WUE for the larger irrigation treatment levels occurred in 1994 and 1995. Precipitation during these growing seasons was less than normal (Schneider and Howell, 1998). Rainfed plots in 1994, 1995 and 2016 resulted in no grain production. With the exception of the EM corn grown in 2015 and the hail damaged corn in 201, WUE of the different DT corn hybrids were greater than WUE for CONV corn grown in Bushland in 1994, 1995 and 2012.

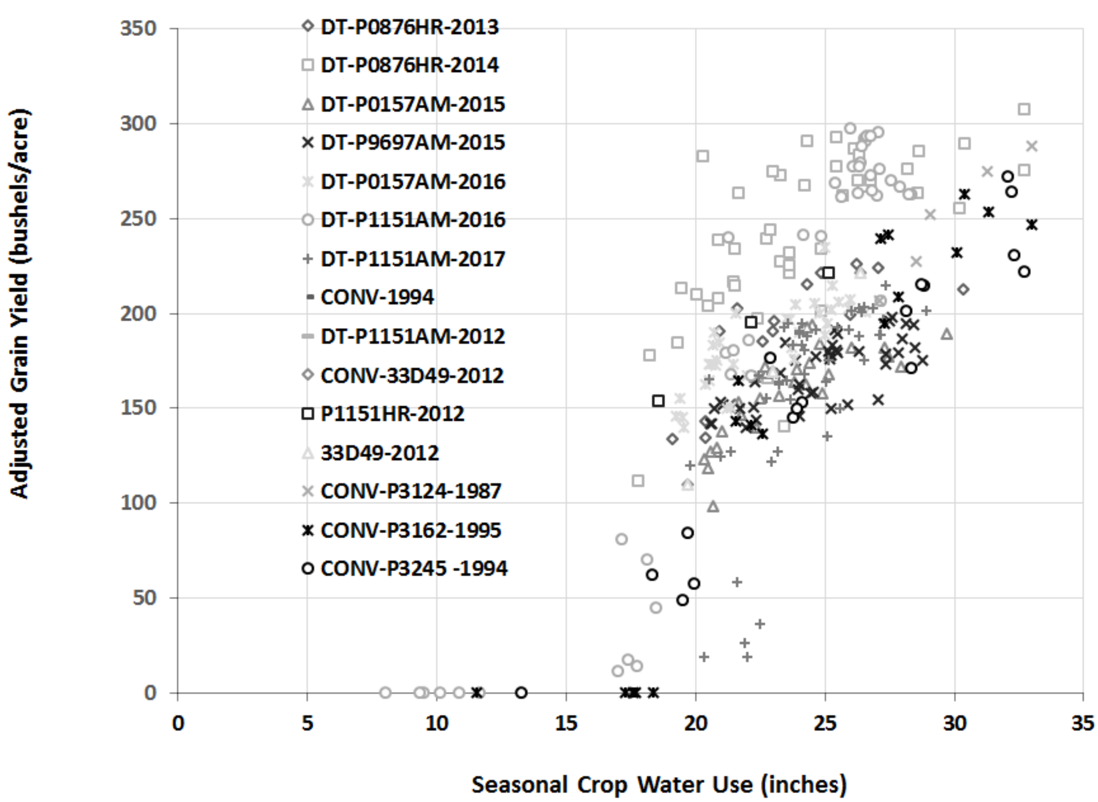

Figure 5. Grain yield adjusted to 15.6% wet moisture plotted against seasonal crop water use for corn grown in Bushland, Texas under sprinkler irrigation systems.

With the exception of 2015, WUE was maximized for hybrids at the mild deficit irrigation treatments I_{80} and I_{75}. Howell (2001) also discussed this outcome of mild irrigation deficit, and explained that it may have a tendency to promote deeper root penetration, enabling the crop to make better use of both stored soil water and within-season rainfall.

CONCLUSIONS

Data reported from these five growing seasons in Bushland, Texas demonstrate that crop production functions for yield versus irrigation applied, and crop responses for DT corn hybrids are influenced by climate variability and corn varieties. Drought tolerant hybrids may be beneficial in reducing cumulative irrigation requirements for corn in the Texas High Plains region. At smaller irrigation amounts, yields can be greater for EM corn hybrids compared with mid-season and CONV hybrids. However, maximum yields (larger irrigation amounts) for EM hybrids were less than for mid-season and CONV corn hybrids grown at Bushland. On the other hand, mid-season DT hybrids planted in mid-May in this region allowed 1-2 inches of water savings compared with a CONV mid-season hybrid without significant yield penalty. Grain WUE was generally maximized at mild deficit irrigation levels.

ACKNOWLEDGEMENTS

Research reported in this paper is funded by the Ogallala Aquifer Program (OAP), a consortium between USDA-Agricultural Research Service, Kansas State University, Texas AgriLife Extension Service & Research, Texas Tech University, and West Texas A&M University. This paper is also part of the OAP Center Pivot Technology Transfer effort. This material is based in part upon work that is supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, under award number 2016-67021-24420.

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