EFFECTS OF PLANTING DATE AND HYBRID MATURITY ON

MOISTURE STRESS IN CORN

A Thesis

by

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Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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December 2017

Major Subject: Agronomy

ABSTRACT

A two-year (2011 and 2012) study was conducted at the Texas A&M AgriLife Research Farm near College Station, Texas, to examine the effects of planting date and hybrid maturity on moisture stress in corn (*Zea mays* L.). The objective of this research was to determine the interactive effects of these factors on corn physiological processes, development, growth and yield in southcentral Texas. Treatments consisted of two irrigation strategies (dryland and irrigated), three planting dates (25-Feb, 10-Mar, and 25-Mar), and four hybrid relative maturities (117 day, 111 day, 95 day, and 83 day). Plants were evaluated at three different growth stages (R1, R3 and R5), with several physiological parameters measured, including: photosynthetic activity, chlorophyll fluorescence, leaf temperature, and yield. Photosynthetic activity was the rate of stored carbon assimilate measured with a LI-COR 6400. Chlorophyll fluorescence was the quantum efficiency of photosystem II measured with a PAM-2100. Leaf temperature was measured with SmartCrop infrared canopy temperature sensors and data was represented as canopy temperature less ambient air temperature (canopy temperature depression). Significant differences due to treatment occurred for all the above parameters. Measurements taken at the R1 growth stage provided little insight relative to plant stress. Canopy temperature depression was more indicative of stress than actual leaf temperature. Irrigation provided greater yield, height, and photosynthetic activity. In general, later planting and longer maturing hybrids increased grain yield.

DEDICATION

This thesis is dedicated to Dr. J. Tom Cothren.

ACKNOWLEDGEMENTS

I would first like to thank Dr. J. Tom Cothren for his guidance and help. It was an amazing experience to learn from and be friends with him. I would also like to thank Dr. Frank Hons for his support and persistence. Without his passionate participation and input, this thesis could not have been successfully completed. Finally, I must express unending gratitude to my wife for providing me with unfailing support and continuous encouragement throughout my years of study and the process of researching and writing this thesis. This accomplishment would not have been possible without her. Thank you.

CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supported by a thesis committee consisting of Professors Frank Hons and James Mahan of the Department of Soil and Crop Sciences and Professor Leonardo Lombardini of the Department of Horticulture.

All work for the thesis was completed by the student, under the advisement of Frank Hons of the Department of Soil and Crop Science.

Funding Sources

There are no outside funding contributions to acknowledge related to the research and compilation of this document.

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1. INTRODUCTION AND LITERATURE REVIEW

According to the EPA, the United States is the world's largest corn (*Zea mays* L.) producer, accounting for 10 billion bushels of the world's 23 billion bushel production in 2000 (EPA, 2012). The USDA reported that US corn in 2012 was produced on 39 million hectares (USDA, 2012). Eighty percent of all corn grown in the United States is consumed by domestic and overseas livestock, poultry, and fish production according to the National Corn Growers Association (NCGA, 2012). United States national average corn yield decreased from 9,240 kg ha^{-1} in 2011 to an average of 7,746kg ha^{-1} in 2012, with the 16% decline largely attributed to widespread drought conditions in the Midwest (USDA, 2013). Corn grain yield is influenced by a host of factors including planting date, hybrid relative maturity (RM), and available soil water at critical growth stages. The objective of this research was to determine the interactive effects of these factors on corn physiological processes, development, growth and yield in southcentral Texas.

1.1 TEXAS CORN PRODUCTION

In Texas, the USDA reported that acreage planted to corn decreased from 0.93 to 0.72 million hectares in 2010 and 2012, respectively. Harvested area in Texas also decreased from 0.8 million hectares in 2010 to 0.6 million hectares in 2012 (USDA, 2013). Of the average 0.8 million hectares of corn annually planted in Texas, half the planted area is located in the Northern High Plains agricultural district. Within this district, approximately 97% of harvested acres are irrigated with the remainder being dryland. Over 0.4 million hectares of corn are also grown throughout Central and Southern Texas, with average yields below 6,277 kg grain ha^{-1}. The majority of the Central and Southern Texas production is located in the eastern part of the state within the Upper Gulf Coast (UGC) and the Blacklands agricultural districts. Of the 357,530 hectares planted to corn in 2009 in these two combined areas, 98% were non-irrigated (NASS, 2009). Approximately 94% of harvested corn acreage in these two districts is under dryland production with combined average yields of 5,800 and 2,805 kg ha^{-1} in 2010 and 2011, respectively (NASS, 2012). The yield decrease in 2011 was primarily attributed to severe drought conditions. According to the USDA 2012 Crop Report, dry soil conditions and above normal temperatures in 2011 during the critical development phases limited yield potential in many locations (USDA, 2012). Dryland corn yields in the Blacklands and UGC fluctuate due to variability in rainfall timing and amount. The rainfall pattern in these regions is bimodal, with precipitation normally peaking in May, then again in October (Nielsen-Gammon, 2011a). As such, corn establishment and early growth rely on soil water from fall-winter precipitation. Corn water demand peaks during pollination and early grain fill, which normally occurs during May in the Blacklands and UGC. Therefore, corn yield variability is often due to fluctuation in amount and timing of precipitation received during this first peak demand period.

Efficient use of available soil-water throughout the growing season can help stabilize corn yields, reducing the "crash" often associated with summer drought events.

1.2 EFFECTS OF DIFFERING PLANTING DATES

Early planting is a management strategy used to potentially avoid water deficit during corn grain fill. The diversity of climate within Texas varies the optimum planting date by geographic location. Statewide corn planting season can begin in mid-February and continue to mid-June (TCPB, 2012). The most active period of corn planting in Texas spans from March 1st through May 17th (USDA, 2013). The final insurable planting date for the Blacklands and UGC growing areas is April 15, with no limit on the earliest planting date (RMA, 2013). Little current data exists in the literature on optimal planting time for the Blacklands and UGC.

Research in the Corn Belt and the Mid-South has shown that planting corn earlier than the traditional planting date has minimal or no effect on corn yield, but planting later than optimal usually has detrimental yield effects (Pendleton and Egli, 1969: Alessi and Power, 1975; Walker and Mulvaney, 1980; Eckert 1984; Imholte and Carter, 1987; Shumway et al., 1992; Bollero et al., 1996; Mascagni and Boquet, 1996; Norwood and Currie, 1996; Lauer et al., 1999; Wiatrak et al., 2004; Bruns and Abbas, 2006; Van Roekel and Coulter, 2011). Varying factors contributed to these detrimental yield effects such as the growing season being interrupted by fall frost (Van Roekel and Coulter 2011), insect and disease pressure (Wiatrak et al., 2004), increased temperatures during grain fill (Norwood and Currie, 1996), interruption of harvest by a fall rainy season (Saunders and Johnson, 1998), and moisture stress during grain fill (Shumway et al., 1992).

In Wisconsin, Lauer et al. (1999) found that the optimum corn planting date shifted from the northern to the southern half of the state, with the southern half being the first week of May and the northern half being the second week. Yields did not change when planting was advanced one week, but grain yields across the state decreased with later planting at a rate of 0.2 to 1.7% per day over the next two weeks after the optimal date, accelerating to 1.3 to 2.2% and 2.0 to 3.8% over the following two 2-week periods. A study in West Africa concluded that delay of planting reduced yield due to drought and increased temperature (Kamara et al., 2009). A few studies determined that in their respective geographic locations, planting earlier than the given average date increased yield while planting later than average decreased yield (Arjal et al., 1978; Eckert, 1984; Imholte and Carter, 1987; Bruns and Abbas, 2006). In contrast to this research, a Kansas dryland corn trial exploring the effects of planting date found that earlier planting decreased yield and water use efficiency when compared to later plantings (Norwood, 2001).

Some studies have found, however, that planting earlier than average, as well as delayed planting, can both have negative yield effects (Nafziger, 1994; Swanson and Wilhelm, 1996; Saunders and Johnson, 1998; Staggenborg et al., 1999; Sindelar et al., 2010). Several of these studies also concluded that yield declined more rapidly when planted late compared to early (Swanson and Wilhelm, 1996; Staggenborg et al., 1999;

Sindelar et al., 2010). A Mississippi study, however, found that earlier planting had a more detrimental effect on corn yield than did later planting, with decreases of 56 to 28% and 20%, respectively (Saunders and Johnson, 1998). In Kansas, Sindelar et al. (2010) found that in a low stress environment, delayed planting reduced yield 10%, increased yield 30% with early season stress, and decreased yield 60% with full-season stress. These results suggested that situations do occur where later planting can increase dryland corn yield in select environments. Staggenborg et al. (1999) conducted a trial in Kansas in order to determine the optimum planting time in conjunction with the optimum hybrid maturity. Results indicated that delayed planting decreased yields slightly, but the yield of later planted hybrids increased at one location due to early-planting resulting in ear development during severe drought. Early and average planting dates for the full season hybrid produced higher yields. Norwood (2001) found that a later maturing hybrid used in conjunction with a later planting date resulted in increased yield. In general, many of these studies suggest a narrow window for optimal planting dates, but also acknowledge that the use of hybrids with differing relative maturities could allow for flexibility.

1.3 EFFECTS OF DIFFERING HYBRID RELATIVE MATURITIES

Hicks et al. (1991) in a study conducted in the US Corn Belt, determined that with adequate rainfall, highest yields were produced with early planting dates for all maturity groups (early is relative to geographic area). Yield reduction with delayed planting was greatest for a full-season compared to an early-season hybrid. Highest production was achieved with early planting of full-season hybrids. Likewise in Minnesota, early planting of full-season hybrids was best, followed by mid-season hybrids, followed by short-season hybrids (Hicks et al., 1991). In the southern and southeastern United States, corn grain yield was not affected by maturity differences (Hicks et al., 1991). On average in the southern United States, short- and mid-season hybrids yielded greater than full-season hybrids under irrigation, but full-season hybrids produced higher yields when planted late due to precipitation received during grain fill. Early- and mid-season hybrids, when planted early, experienced periods of no rain that lasted 4 to 6 weeks in April, May, and June. Husk coverage and grain quality were also reduced. Most importantly, when defining relative maturity as 32% grain moisture and considering all maturities, maturity occurs later when planted later. However, late planted early-maturing hybrids will mature before early-planted late maturing hybrids.

According to Nielsen at Purdue University (2002), relative maturity (RM) of corn hybrids has been interpreted several different ways. Agronomists refer to maturity with regard to physiological maturity. Physiological maturity in corn is often associated with black layer formation in the tip of a mature kernel. Another definition of maturity, harvest maturity, is that point in time after physiological maturity when a hybrid can be safely harvested with minimal loss; this is typically associated with a grain moisture content of 25%. The traditional method for rating hybrid relative maturity is based on comparisons of hybrids near harvest maturity and is based on the assumption of a loss of 0.5% moisture per day. Another method is based upon growing degree days (GDD) or growing degree units (GDU) or heat units (HU). These values represent the amount of heat accumulated over a period of time. Due to the actual measurement of thermal time, there is no need to assign a maturity value. Growing degree units can be used to estimate time to tassel, mid-pollination, and physiological maturity or black layer (Monsanto, 2010). Capristo et al. (2007) found that biomass increased positively and linearly with hybrid cycle length GDU. Long-season hybrids had highest light interception but lowest radiation use efficiency. Grain yields were lowest for short-season hybrids and equivalent for mid- and full-season hybrids. Results indicated that grain yield of short-season hybrids (lower GDU) was more limited by the capacity of the reproductive sinks during grain fill than long-season hybrids. Also, hybrids with a short developmental time from emergence to flower, but a long developmental time from flower to maturity produced the largest values for radiation interception and grain yield. This study indicated that a hybrid with a low GDU requirement to tassel and an extended GDU requirement to physiological maturity could be beneficial to yield. A study by Sutton and Stucker (1974) to determine GDD to black layer for 24 hybrids showed that GDD to black layer correlated with RM. Relative maturity was defined as a value assigned to a particular hybrid for the length of time that hybrid took to reach black layer at a given moisture content. Results showed that GDD overlapped for this ranking of RM. Basically, not all varieties with a given RM value had the same GDD requirement. In light of this confusion, the decision was made that the use of GDD to black layer was inaccurate and GDD to moisture of 30% was most accurate.

Commercial corn hybrids with RM of approximately 116 to 120 days are typically grown in the Blacklands and UGC. The general assumption is that since the area has a prolonged growing season, full-season hybrids will perform better than early-maturing corn hybrids. Results of numerous trials indicate that a late-season hybrid, when compared to an early-season hybrid planted on the same day, provided greater yield (Howell et al., 1998; Trooien et al., 1999; Norwood 2001; Capristo et al., 2007; Raymond et al., 2009; Van Roekel and Coulter, 2012). Effects of differing relative maturity hybrids on yield vary widely when associated with either a different planting date or moisture stress situation (Norwood, 2001; Larson and Clegg, 1999; Trooien et al., 1999).

In general, corn growth and physiological development can be split into two periods: germination to mid-pollination and mid-pollination to harvest. Corn hybrids planted in the Blacklands and UGC are from temperate germplasm, and their phenological development can be predicted with the Modified Growing Degree Day formula . An average commercial DEKALB 119RM corn product planted in Williamson County (central Blacklands) on March 1 would pollinate in late May, and reach physiological maturity in mid-late July. In addition to stress from potential soil water deficit, air temperatures during this time average above 95° F and often exceed 100° F. Howell et al. (1998) found that peak evapotranspiration (ET) was not affected by maturity. Water use efficiency (WUE) of grain yield and dry matter were identical for short season (98 RM) and full season hybrids (115 RM). Yield decreased 17% from full-season to short-season hybrids planted on the same day. ET rates remained the same, but due to the length of season, the short-season hybrid had a 19% lower total ET. In the Mid-South, Bruns and Abbas (2005) showed that planting corn hybrids requiring less GDU 50 to R1 than the typical hybrid selected by growers for the area provided greater yields. Therefore, corn hybrids with lower GDD requirements potentially could escape effects of water deficit and heat stress by pollinating and progressing through grain fill earlier in the growing season. Current data on optimum hybrid maturity selection for the Blacklands and UGC is lacking in the literature. In a Nebraska drought trial, Larson and Clegg (1999) found that two of three early-season hybrids did not yield comparably to late-season hybrids, but one early-maturing hybrid produced comparable yield to late-season hybrids. Results indicated that a well-adapted early-season hybrid could produce comparable or better yields to late-season hybrids when late-season water stress is prevalent.

1.4 EFFECTS OF WATER DEFICIT ON CORN YIELD

The use of either early or late planting and the choice of hybrid RM are impacted by potential abiotic stresses placed on the crop. Two abiotic stresses of concern, in regards to yield, are exposure to water deficit and thermal stress. The impact of water deficit on corn grain yield has long been understood. As many agronomic corn trials have reported, induced water deficit or measurements of irrigated crops in comparison to dryland crops has shown that moisture limiting conditions reduce yield (Denmead and Shaw, 1960; Claassen and Shaw, 1970; Lamm et al., 1994; Howell et al., 1997;

Schneider and Howell, 1998; Da Silva et al., 1999; Calvino et al., 2003; Bowman et al., 1993; Di Marco et al., 2007; Aydinsakir et al., 2013).

In a study by Trooien et al. (1999), fully irrigated crops yielded 70% greater than non-irrigated crops in the central Great Plains, but non-irrigated crops had greater water use efficiency. This difference in water use efficiency is best explained by the length of season differences that the two different water regimes experienced. The use of different planting dates and/or different hybrid RM in order to expose the crop to water deficit at different developmental stages has been commonly used (Jurgens et al., 1978; NeSmith and Ritchie, 1992; Howell et al., 1998; Larson and Clegg, 1999; Trooien et al., 1999; Norwood, 2001; Norwood and Dumler, 2002; Garcia et al., 2009). These studies showed that it is not necessarily the amount of precipitation that occurs but when that precipitation falls that is more important. Larsen et al. (1999) compared three early-maturing hybrids and three late-maturing hybrids across two locations for two years. One year experienced average rainfall and one year experienced end of season water stress. In the year with end of season stress, the yield of all three late maturing hybrids declined and the yield of two of the early hybrids declined. One early-season hybrid maintained yield. The two other early-season hybrids could not compete in yield in the average rainfall year or the end of season stress year. This study showed that the use of a well-adapted short-season hybrid could generate greater yield stability under moisture limiting conditions. In general, research using differing planting dates or hybrid maturities planted on the same day has shown that corn yield was affected the most when the crop was exposed to water deficit during reproductive growth.

Robins and Domingo (1953) found yields were equivalent when plots were irrigated at tassel and not stressed compared to plots that were stressed prior to tassel and irrigated at R1. Yields were reduced about 50% when stressed at tassel even with irrigation eight days after tassel. Yields were 30% lower for plots that were stressed at tassel and irrigated eight days after than plots that were irrigated at tassel with no subsequent irrigation. Many other studies have researched the effects of water deficit before, during, and after silking (Denmead and Shaw, 1960; Claassen and Shaw, 1970; Hall et al., 1971; NeSmith and Ritchie, 1992; Otegui et al., 1995; Norwood, 2000). In general, these studies agreed with Robins and Domingo (1953) that the effects of water stress are greatest when the deficit occurs at or around silking. The effects of water deficit that occurs during grain fill (after silking) on corn yield are somewhat less severe than at silking, and the effects of water stress on yield during the vegetative phase are much less than stress occurring during silking. Where water use was compared across growth stages by measuring soil moisture and comparing to a control, results indicated that maximum soil moisture deficit or water use occurred during the R2 (milk) growth stage (Garcia et al., 2009). Several studies suggest that stress during silking reduces yield by reducing the number of kernels, and that stress during the grain-fill period reduces kernel weight (Hall et al., 1971; Grant et al., 1989; NeSmith and Ritchie, 1992; Otegui et al., 1995; Maddonni et al., 1998). Grant et al. (1989) found that kernel number (yield) becomes most sensitive to stress 2 to 7 days after silking and ended 16 to 22 days after silking. Stress initiated prior to silking, but relieved within 2 days after silking, did not reduce yield. The fewest number of kernels (45% of control) occurred when stress was applied 7 days after silking. Kernel weight was reduced when the crop was stressed during the grain fill period. The lowest weight (51% of control) occurred 12 to 16 days after silking.

1.5 EFFECTS OF WATER DEFICIT ON PHOTOSYNTHESIS

Drought during and after the flowering period decreases seed-fill duration, leading to smaller seed size and lower yield (Frederick et al., 1991; de Souza et al., 1997; Wardlaw and Willenbrink, 2000). However, seed growth rate in soybean [*Glycine max* L. (Merr.)] has been shown to be relatively insensitive to drought stress during later reproductive development (Egli, 2004). Potential explanations for the insensitivity of grain development to drought may be attributed to the plants ability to draw upon carbohydrate reserves during later reproductive development. A trial was conducted by Jurgens et al. (1978) in which water was withheld from a corn crop during grain fill in order to determine if grain fill was dependent upon newly acquired photosynthate or stored assimilate. Results showed a decrease in leaf area after stress was imposed. As grain fill progressed, the rate of grain fill began to exceed the rate of dry matter accumulation, indicating redistribution of stored assimilates. In this study, ^{14}C was also used to study translocation in corn. Translocation was inhibited with first exposure to limited water supply 7 days after water was withheld, but was not limited during the second exposure (21 days). The continued translocation despite the lack of dry matter accumulation indicated that photosynthesis was more inhibited than translocation during dry conditions. McPherson and Boyer (1977) subjected a corn crop to water stress during the grain-fill period. Results indicated reduced photosynthesis with reduced water potential, and stressed plants had 47 to 69% lower yield, with grain development dependent on stored photosynthate. Those results agreed with Jurgen et al. (1978) in that translocation was less inhibited than photosynthesis and also that total photosynthetic accumulation for the growing season controlled yield during a drought that did not disrupt flowering. Westgate and Boyer (1985) imposed low water potential at silking, early-grain fill, or mid-grain fill, but then followed with fully irrigated conditions to maturity. Results indicated decreased yield in all cases under low water potential. Yield losses resulted from decreased seed size in mid-grain fill, decreased seed size and number in early-grain fill, and cessation of silk and ear development at silking when water restrictions were imposed at these stages. Also, inhibition of photosynthesis by low leaf water potential was recorded. The most severe yield decrease was seen from low water potential at silking. Results indicated that carbohydrate reserves were not sufficient to support anthesis at this stage of development. The effects of water deficit during early stages of flowering have also been shown to have deleterious effects on other plant processes. A reduction in plant height when plants are exposed to water deficit is well documented (NeSmith and Ritchie, 1992; Simonneau et al., 1993; Otegui et al., 1995; Da Silva et al., 1999). Other reported traits of plants subjected to drought stress include: reduced photosynthetic rate, closed stomata, and high leaf temperatures (Mittler, 2006).

Drought can influence photosynthesis by inducing stomatal closure and decreasing the flow of CO_2 into the plant (Chaves, 1991; Ort et al., 1994; Chaves et al., 2003; Flexas et al., 2004). Metabolic functions of photosynthesis are also inhibited, such as a decline in ribulose bisphosphate (RuBP) and ribulose 1,5-bisphosphate carboxylase/oxygenase (Rubisco) content (Bota et al., 2004), and decreased Rubisco activity (Parry et al., 2002). According to Cornic (2000), decreased stomatal conductance is the primary cause of the decline in photosynthesis during the initial onset of stress. Drought stress has been shown to cause increases in internal CO_2 concentration (Kicheva et al., 1994; Siddique et al., 1999), which can lead to stomatal closure (Briggs et al., 1986). Photosynthesis rate in corn during silking and early grain-fill has been well documented (Hall et al., 1971; Barnett and Pearce, 1983; Bunce, 2010). All results indicated that decreased photosynthetic rate correlated to decreased yield. In a corn trial in China, Li et al. (2013) concluded that reduced photosynthetic rate was the dominant factor affecting yield under increased temperature and reduced moisture. Researchers determined that factors reducing photosynthetic rate were drought, reduced photoperiod, lower light intensity, and higher leaf temperature.

1.6 EFFECTS OF WATER DEFICIT ON PLANT TEMPERATURE

Plant temperature has long been used as an indicator of moisture stress, being based upon the strong, inverse relationship between leaf temperature and transpirational cooling (Jackson et al., 1981). Canopy temperature measurements taken with an infrared thermometer have been used to investigate drought stress in many crops (Singh and Kanemasu, 1983; Chaudhur et al., 1986; Hatfield et al., 1987; Blum et al., 1989; Stark et al., 1991; Duffkova, 2006; Erdem et al., 2006; O'Shaughnessy et al., 2011), with several investigators using canopy temperature as a gauge for drought tolerance and yield stability (Singh and Kanemasu, 1983; Blum et al., 1989; Stark et al., 1991; Rashid et al., 1999). In these studies, a positive correlation was found between drought susceptibility and canopy temperature. The most drought resistant plants usually exhibited the lowest canopy temperatures under stressed environments. A study conducted by Wanjura et al. (2006) defined stress as when the corn crop canopy temperature exceeded 28° C (maximum). The percentage of positive canopy-air temperature differences increased with increasing stress time, with yield declining with increasing stress time. Birch et al. (1998) concluded that the optimum temperature for corn plant development was 34° C (93.2° F), with a minimum temperature of 8° C (46.4° F) and maximum temperature of 40° C (104° F). Several studies agree with the optimum temperature for corn ontogeny (Mokhtarpour et al., 2011; Bockhold et al., 2011). Bockhold et al. (2011) found that the threshold temperature for corn in humid environments may be up to 1° C higher than the findings suggested by Birch et al. (1998). Maddoni et al. (1998) reported that changes to thermal time occurring during the grain-fill period affected corn kernel weight. Lower temperatures increased fill time and kernel weight whereas higher temperatures shortened grain-fill period and decreased kernel weight. Negative correlations between canopy temperature and water use efficiency have also been found for corn (Mtui et al., 1981; Didonet et al., 2002). Gonzales-Dugo et al. (2006) determined that the use of canopy temperature to measure crop water stress was most accurate in fields with low water stress. For moderate or highly stressed crops, canopy temperature was sensitive to deviations in field characteristics and plant distribution, but had a linear relationship to field scale crop water stress index. O'Neill et al. (2006) measured leaf temperature in conjunction with chlorophyll fluorescence measurements and recorded an increase in leaf temperature (2.5° C) when deficit irrigation plots were compared to adequately irrigated plots. Results also showed a 25% decrease in quantum yield fluorescence when deficit irrigation plots were compared to adequately irrigated plots. Measurements of chlorophyll fluorescence, however, were similar among different hybrids when not under moisture stress.

1.7 EFFECTS OF WATER STRESS ON CHLOROPHYLL FLUORESENCE

The use of chlorophyll fluorescence measurements has proven useful as a method for quantifying the impact of drought stress on plants (Oukarroum et al., 2007; Ristic et al., 2007). Light energy absorbed by chlorophyll molecules drives photosynthesis, can be re-emitted as heat, and/or be re-emitted as light (fluorescence). The fluorescence signal or yield provides valuable information regarding the efficiency of photosynthesis and heat dissipation. Due to the fact that chlorophyll fluorescence is the measure of re-emitted light, ambient light has the potential to interfere with measurement. Currently, one of the most accurate methods of measuring fluorescence is with an instrument that applies light at a known frequency to induce fluorescence. This instrumentation is known as a modulating fluorometer and can induce and measure fluorescence in field conditions (Shreiber et al., 1986). Due to the ease of measurement, the light adapted fluorescence measurement of the quantum efficiency of photosystem II (PSII) has become established as an accurate indicator of operational PSII efficiency (Genty et al., 1992; Maxwell and Johnson, 2000; Baker, 2008). The operating efficiency of PSII, Fq'/Fm' (Genty et al., 1989) gives the proportion of absorbed light that is actually used in photochemistry (Genty et al., 1992). This method directly measures quantum yield of PSII electron transport and can be used to estimate the rate of electron transport through PSII and provide an indication of overall photosynthesis (Maxwell and Johnson, 2000). The relationship of chlorophyll fluorescence and moisture stress in corn has been well documented in the literature (Selmani and Wassom, 1993; Earl and Davis, 2003; O'Neill et al., 2006). Earl and Davis (2003) were able to record significantly large differences in efficiency of PSII between irrigated and moisture-stressed corn plants. Selmani and Wassom (1993) detected decreases in photosynthetic ability through use of fluorescence where variable fluorescence, F(v), increased when going from well-watered to water-stressed conditions.

1.8 EFFECTS OF WATER DEFICIT ON AFLATOXIN IN CORN

Water deficit in combination with heat stress can increase the level of aflatoxins, which are detrimental to human health, in grains (Bruns and Abbas, 2005). Even though there is fluctuation with aflatoxin levels from year to year and from field to field, the

Blacklands and UGC regularly present levels above those set by the FDA as safe for human consumption. In extreme cases, these levels even surpass the animal consumption levels which are considerably greater than those for human consumption. Elevated temperature and limited rainfall during grain fill, corn ear insects, husk cover, and hybrid genetics are factors that influence the severity of aflatoxin content in grain samples. Wiatrak et al. (2004) concluded that corn hybrids containing a Bt trait may reduce aflatoxin content in grain due to insect control. This hypothesis has not been tested since the advent of new Bt traits that have superior corn ear insect control. Hence, newer Bt traits with added efficacy in controlling ear feeding Lepidopteran species could have a greater reduction in mycotoxins than those results found by Wiatrak et al. (2004).

In a research study conducted at the Texas A&M AgriLife Research Farm in Burleson County, Texas, many of the above factors influencing corn growth and yield were addressed. The physiological effects of moisture stress on corn growth and yield were studied across planting dates, irrigation amounts, and differing hybrid relative maturities.

1.9 OBJECTIVES

The objectives of this research were to:

1. Broaden the understanding of how water deficit during early grain fill might be avoided or reduced by determining the optimal planting time and corn hybrid maturity under rain-fed conditions in the Texas Blacklands and Upper Gulf Coast; and,
2. Evaluate physiological traits (e.g. leaf fluorescence, leaf photosynthetic rate, water use efficiency, etc) to explain enhanced water deficit tolerance during early grain fill.

2. MATERIALS AND METHODS

A two-year study (2011 and 2012) was conducted to determine the optimal planting time and hybrid maturity for corn grown in the Blacklands and UGC agricultural districts of Texas. Field plots were located at the Texas A&M AgriLife Research Farm in Burleson County near College Station, TX (30°32′N, 94°26′W) on a Weswood silt loam soil (fine-silty, mixed, superactive, thermic, Udifluventic Halpustepts) having a pH of 7.9.

In both years, the study was a split-split plot design with four replications. The main plot was irrigation regime (rain-fed or 80% ET replacement), the sub-plot was planting date (Feb. 25, Mar. 11, or Mar. 25, referred to hereafter as PD1, PD2, and PD3, respectively), and sub-sub plots were varieties with different relative maturities (RM). Four commercially available varieties were utilized: DKC67-21 VT3Pro, DKC61-35 VT3Pro, DKC45-51GenSS, and DKC33-53GenSS (referred to hereafter as H4, H3, H2, and H1, respectively). The relative maturities for these varieties are approximately 117 RM, 111 RM, 95 RM, and 83 RM, respectively.

Soil samples were collected in late December 2010 and early January 2012. Soil samples were delivered to the Texas A&M AgriLife Extension Service Soil, Water, and Forage Testing Lab. The nutrient requirements recommended by the Testing Lab were based on a projected 11,290 kg ha^{-1} grain yield. Plots were disked before being bedded on one meter centers. Fertilizer was applied at the recommended rate in split applications (pre-plant and V3 to V5 application). Pre-plant fertilizer was 11-37-0 and was placed within 5 cm x 5 cm of seed at 143.5 kg ha^{-1}. The V3 to V5 applications used 32-0-0 and were side-dressed at 420 kg ha^{-1}. Plots were seeded with a CASE cone plot planter at 64,220 seed ha^{-1} on the three separate planting dates. Plots consisted of four one-meter rows that were 9.75 meters in length. A linear Zimmatic® Iirrigation System was utilized to supplement water to the irrigated plots. The amount of irrigation applied was based upon ET calculated by a SmartField (Lubbock, TX) weather station. Local Texas A&M Agrilife Extension Service recommendations were utilized to prevent disease, control insects, and manage weed populations. Due to the fact that some of these hybrids were not common to this geographical area, monitoring was conducted for foliar disease from VT to R6.

Measurements to quantify stress included yield, photosynthetic rate, canopy temperature, and chlorophyll fluorescence. Canopy temperature was monitored throughout the growing season with an infrared temperature monitor (SmartCrop®, Lubbock, TX). Canopy temperature sensors were mounted on posts that were placed within the third row of each plot. Sensors and posts were installed in all plots after the final planting date had established a stand. The SmartCrop sensors recorded canopy temperature every minute and reported a 15-minute average to a corresponding base data logging station (Smartfield, Lubbock, TX) located in the field. For data analysis, an average of all 15-minute readings between the hours of 10:00 AM and 2:00 PM was used for corresponding dates that R1, R3, and R5 occurred for each relative maturity and planting date combination. Chlorophyll fluorescence was measured with a portable chlorophyll fluorometer model PAM 2100 (Heinz Walz Gmbh, Effeltrich, Germany) at growth stages R1, R3, and R5 for each hybrid RM and planting date combination. Data were collected between the hours of 10:00 AM and 2:00 PM. Measurements were collected from the third row of each plot on the uppermost fully expanded leaf. Data used for analysis represented an average of five random plants within each plot. Photosynthetic rate was measured with a LI-COR 6400 infrared gas analyzer (Lincoln, NE) at growth stages R1, R3, and R5 for each hybrid RM and planting date combination. Measurements were collected from the third row of each plot on the uppermost fully expanded leaf. Data used for analysis represented an average of three random plants within each plot. Plant heights were also measured from the soil surface to flag leaf node at growth stages R1, R3, and R5 for each hybrid and planting date combination. Measurements were collected from the third row of each plot on 10 random plants. Dates of physiological stages across hybrids and planting dates were recorded throughout both growing seasons. Weather data were obtained from a nearby USDA weather station as well as the SmartField® (Lubbock, TX) base station located within the field.

In both years, the two middle rows of each plot were machine harvested at maturity with a Gleaner two-row modified plot combine. Harvest maturity was determined by grain moisture measured using a grain moisture meter. Plots were harvested when the average moisture for each planting date was 15%. Grain yields were determined in the field by catching and weighing each plot with a hanging scale, and sub-samples collected from each plot for determination of bushel weight and moisture at harvest. Grain yield was adjusted to 15 % moisture content. Each sample was measured using a grain moisture meter for moisture content.

SAS® (version 9.3) statistical computer software was used for analysis of all data (SAS, 2009). Data were combined over years where permissible. When a significant interaction existed for years*treatment, those means were presented separately by year. Data were analyzed by analysis of variance using the General Linear Model (GLM) at the 5% level, with significant means separated using Fisher's Protected Least Significant Difference (LSD) at a significance of 5% (SAS, 2009).

3. GRAIN YIELD: RESULTS AND DISCUSSION

3.1 COMBINED RESULTS

Weather data were collected in both 2011 and 2012. The average daily maximum temperature from approximately mid-February through July in 2011 was 31.5° C, while that in 2012 was 29.5° C (Fig. 3.1). On average, the maximum temperature in 2011 was two degrees higher every day compared with 2012, and 2011 was the most severe drought year on record (Nielsen-Gammon, 2011b). In 2011, 169 mm of rain fell during the growing season, while in 2012, the amount was 522 mm. The analysis of variance for combined years is presented in Table 3.1. Due to the significant interaction of year with all main effects and all two-way interactions, the results of each of the two years will be presented separately.

Figure 3.1. Average maximum daily temperatures in degrees Celsius for the 2011 and 2012 growing seasons.

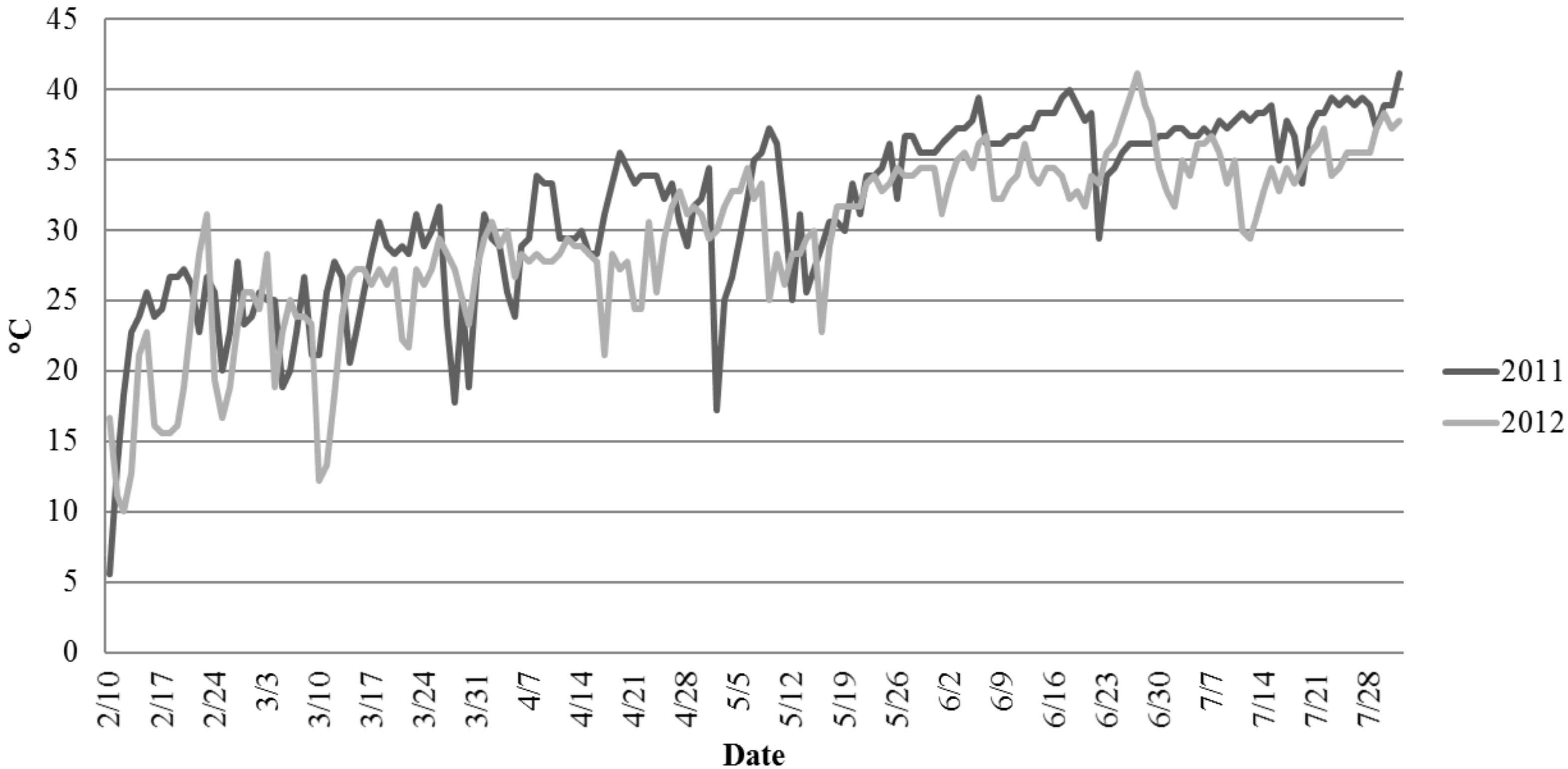


Table 3.1. Combined analysis of variance for corn grain yield.

Source	**Df**	**Grain Yield**
Year	1	***
Replication	3	ns†
Year x Rep	6	ns
Irrigation (I)	1	**
Year x I	1	***
Error a	1	
Planting Date (PD)	2	***
PD x Year	2	***
PD x I	2	**
PD x I x Year	2	***
Error b	11	
Hybrid (H)	3	***
H x Year	3	*
H x PD	6	ns
H x PD x Year	6	**
H x I	3	*
H x I x Year	3	***
H x PD x I	6	ns
H x PD x I x Year	6	ns
Error C	51	
R^2		0.88
CV %		16.37

* Significant at 0.05 probability level.

** Significant at 0.01 probability level.

*** Significant at 0.001 probability level.

† ns, Nonsignificant.

3.2 SEPARATE RESULTS: GRAIN YIELD 2011

The analysis of variance for grain yield in 2011 is presented in Table 3.2.

Table 3.2. Analysis of variance for corn grain yield in 2011.

Source	df	Grain Yield
Irrigation (I)	1	***
Replication	3	ns†
Error a	3	
Planting Date (PD)	2	***
PD x I	2	***
Error b	11	
Hybrid (H)	3	***
H x PD	6	***
H x I	3	***
H x PD x I	6	ns
Error C	51	
R^2		0.9
CV %		20.4

* Significant at 0.05 probability level.
** Significant at 0.01 probability level.
*** Significant at 0.001 probability level.
† ns, Nonsignificant.

The main effect of irrigation significantly influenced grain yield in 2011, with irrigation significantly increasing mean corn grain yield by 87% when compared to dryland plots (Table 3.3), primarily because of the extreme drought conditions that occurred that year.

Table 3.3. Irrigation effect on corn grain yield in 2011.

Treatment	Grain Yield (kg ha^{-1})	
Dryland	2190	b†
Irrigated	4103	a
Pr>f	0.0038	
R^2	0.9	
CV %	20.4	

† Means followed by the same letter are not significantly different according to LSD (0.05).

The main effect of planting date also significantly influenced grain yield in 2011 (Table 3.4). The latest planting date (3) resulted in the greatest corn grain yield, which was approximately 39% greater than the averaged yields of planting dates 1 and 2, with yield from planting date 1 was not significantly different from that of planting date 2. These results contrasted with other reported trials where planting date was a manipulated variable. Many studies concluded that planting later than the average optimal time had detrimental yield effects (Pendleton and Egli, 1969; Alessi and Power, 1975; Walker and Mulvaney, 1980; Eckert, 1984; Imholte and Carter, 1987; Shumway et al., 1992; Bollero et al., 1996; Mascagni and Boquet, 1996; Norwood and Currie, 1996; Lauer et al., 1999; Wiatrak et al., 2004; Bruns and Abbas, 2006; Van Roekel and Coulter, 2011). A Mississippi study, however, found that earlier planting had a more detrimental effect on corn yield than did later planting, with decreases of 56 to 20% (Saunders and Johnson, 1998). The most likely explanation of differences between findings of my research and that of previous reports is the range of the planting date window and the environmental conditions during grain fill in 2011. The length of time included in this planting window spanned only four weeks and most likely was not enough time to adequately describe the decreased yield from planting both before and after the optimum planting period. In 2011, planting date 3 resulted in flowering and grain fill occurring during periods of slightly lower temperatures compared to planting dates 1 and 2. Many studies have found that planting earlier than average, as well as delayed planting, can both have negative yield effects (Nafziger, 1994; Swanson and Wilhelm, 1996; Saunders and Johnson, 1998; Staggenborg et al., 1999; Sindelar et al., 2010). These results suggest that situations do occur where later planting can increase corn yield in select environments.

Table 3.4. Planting date effect on corn grain yield in 2011.

Treatment	**Grain Yield (kg ha^{-1})**	
Planting Date 1	2648	b†
Planting Date 2	2928	b
Planting Date 3	3863	a
Pr>f	<0.0001	
R^2	0.9	
CV %	20.4	

† Means followed by the same letter are not significantly different according to LSD (0.05).
Planting Dates (1: Feb. 15, 2: Mar. 1, and 3: Mar. 15)

The main effect of hybrid also significantly influenced grain yield in 2011. As hybrid relative maturity (RM) increased from shortest to longest (1 to 4), grain yield also increased (Table 3.5). Results of numerous trials indicate that a late-season hybrid, when compared to an early-season hybrid planted on the same day, provided greater yield (Howell et al., 1998; Trooien et al., 1999; Norwood, 2001; Capristo et al., 2007; Raymond et al., 2009; Van Roekel and Coulter, 2012). Hicks et al. (1991) found that full-season hybrids may produce higher yields when planted late due to increased precipitation received during grain fill. Hybrids 3 and 4 had greater yield than hybrid 1, and hybrid 3 was not significantly different from hybrid 2 in 2011. Hybrid 4 resulted in 56% greater yield than hybrid 1. Results of the literature suggested that, on average, later maturing hybrids likely avoided either heat or drought stress during grain fill, resulting in greater yield.

The interactive effect of PD x I also significantly impacted grain yield in 2011 (Fig. 3.2). Highest yield was achieved with the latest planting date (3) under irrigation, whereas in dryland plots, a change in planting date did not generate a significant difference in grain yield. The reduction in yield for planting dates 1 and 2 under irrigation was likely due to higher ambient temperature in combination with the severe drought during grain fill in 2011. Planting date 3 allowed corn grain fill to occur during a period of lower stress than planting dates 1 or 2 (Fig. 3.1). Planting dates 1 and 2 were not different from one another under irrigation, but yields for planting dates 1 and 2 under irrigation were greater than those for any planting date under dryland conditions.

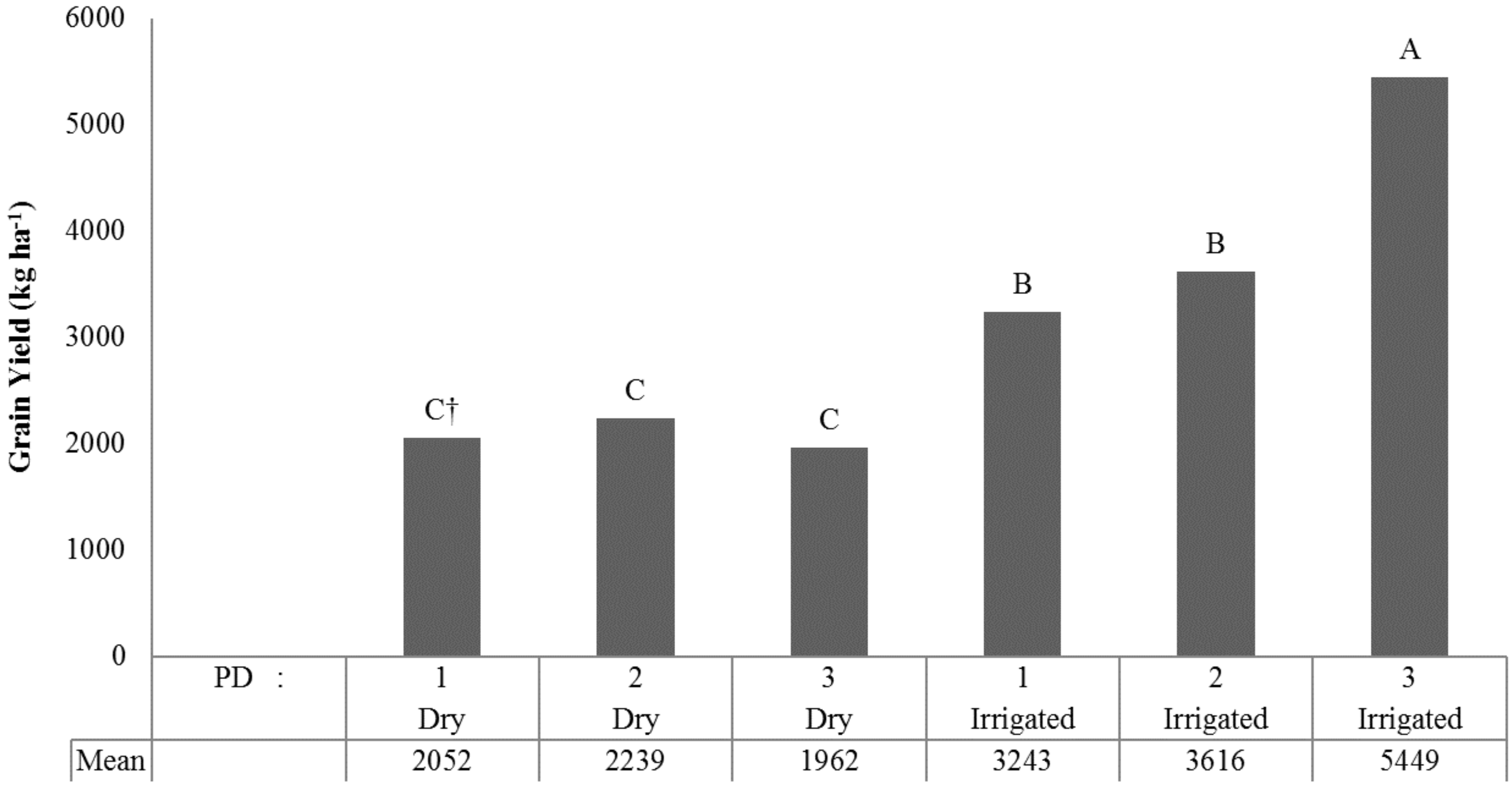
Table 3.5. Hybrid effects on corn grain yield in 2011.

Treatment	**Grain Yield (kg ha^{-1})**	
Hybrid 1	2443	c†
Hybrid 2	2874	bc
Hybrid 3	3462	ab
Hybrid 4	3806	a
Pr>f	<0.0001	
R^2	0.9	
CV %	20.4	

† Means followed by the same letter are not significantly different according to LSD (0.05).

Hybrid (1: Early, 2: Mid, 3: Mid-late, and 4: Late).

Figure 3.2. Planting date x irrigation interactive effect on corn grain yield in 2011.

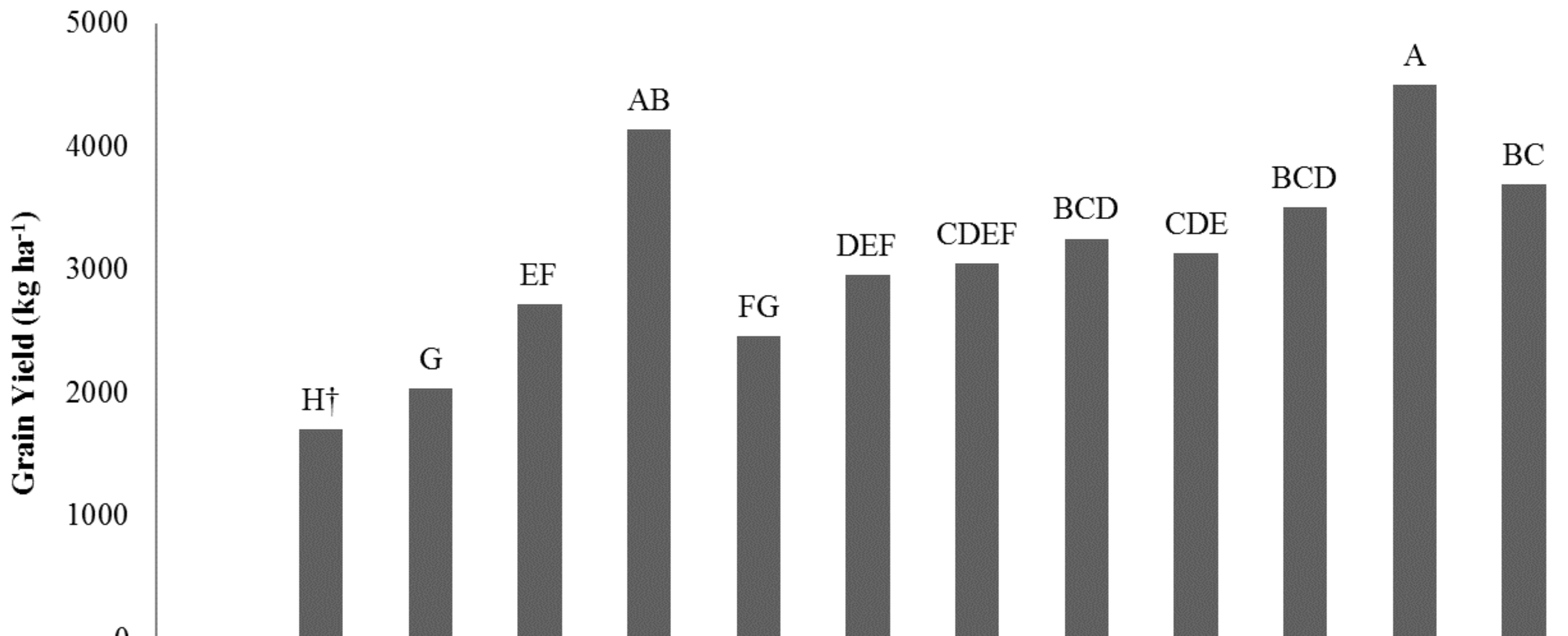


† Means followed by the same letter are not significantly different according to LSD (0.05).
PD, Planting Date (1: Feb. 15, 2: Mar. 1, and 3: Mar. 15).

The interaction of H x PD also significantly affected grain yield in 2011 (Fig. 3.3). For the two earlier planting dates, grain yield tended to increase as hybrid relative maturity increased (1 through 4). For the third planting date, a similar trend was noted with the exception of hybrid 4, in that for this planting date, hybrid 4 had a lower yield than hybrid 3 and was not significantly different from hybrids 1 or 2. For hybrids 1, 2, and 3, as planting date progressed from 1 to 3, a difference of 30 days, grain yields were significantly greater for each hybrid. Hybrid 4, with the longest RM, generated its highest yield when planted during the earliest planting date. Results agreed with Staggenborg et al. (1999) and Hicks et al. (1991) where early planting dates for full season hybrids produced higher yields. Results also agreed with Norwood (2001), who found that the use of a later maturing hybrid used in conjunction with a later planting date resulted in increased yield. The combination of hybrid relative maturities in conjunction with the three separate planting dates provided information concerning the optimum time period for grain fill in 2011. Early maturing hybrids in combination with earlier plantings resulted in ear development occurring during periods of greater stress compared to later plantings combined with later maturing hybrids.

The interactive effect of H x I also significantly affected grain yield in 2011 (Fig. 3.4). Under dryland conditions, regardless of planting date, grain yields of the various hybrids were not significantly different from each other. This result was likely due to the severity of drought stress during reproductive growth in 2011. However, with irrigation, grain yield increased with increasing hybrid RM. Hicks et al. (1991) found that full-season hybrids produce higher yields when planted late due to increased precipitation received during grain fill. Irrigation in my study lessened the effects of the drought stress and allowed the hybrids a better opportunity to express their yield potential, where later maturing hybrids had higher yield potential than shorter season hybrids. Results of numerous trials indicate that the use of a late-season hybrid, when compared to an early-season hybrid planted on the same day, provided greater yield (Howell et al., 1998; Trooien et al., 1999; Norwood 2001; Capristo et al., 2007; Raymond et al., 2009; Van Roekel and Coulter, 2012).

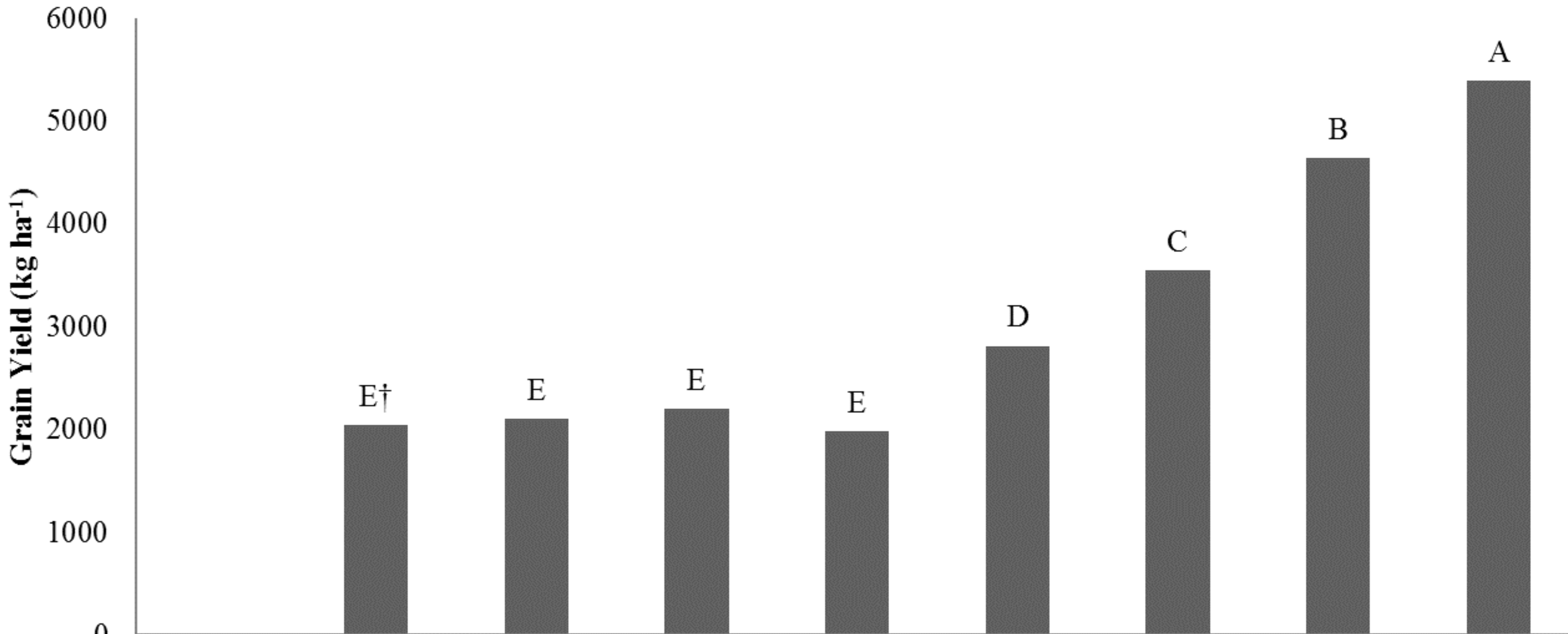
Figure 3.3. Planting date x hybrid interactive effect on corn grain yield in 2011.



	PD :	1	1	1	1	2	2	2	2	3	3	3	3
	H :	1	2	3	4	1	2	3	4	1	2	3	4
Mean		1700	2033	2721	4137	2459	2952	3050	3250	3130	3504	4500	3689

† Means followed by the same letter are not significantly different according to LSD (0.05).
PD, Planting Date (1: Feb 15, 2: Mar 1, and 3: Mar 15).
H, Hybrid (1: Early, 2: Mid, 3: Mid-late, and 4: Late).

Figure 3.4. Hybrid x irrigation interactive effect on corn grain yield in 2011.



	H :	1 Dry	2 Dry	3 Dry	4 Dry	1 Irri	2 Irri	3 Irri	4 Irri
Mean		2043	2109	2200	1986	2815	3550	4647	5398

† Means followed by the same letter are not significantly different according to LSD (0.05).
H, Hybrid (1: Early, 2: Mid, 3: Mid-late, and 4: Late).

3.3 SEPARATE RESULTS: GRAIN YIELD 2012

The analysis of variance for corn grain yield in 2012 is presented in Table 3.6.

Table 3.6. Analysis of variance for corn grain yield in 2012.

Source	df	Grain Yield
Irrigation (I)	1	**
Replication	3	ns†
Error a	3	
Planting Date (PD)	2	Ns
PD x I	2	Ns
Error b	12	
Hybrid (H)	3	***
H x PD	6	Ns
H x I	3	Ns
H x PD x I	6	Ns
Error C	33	
R^2		0.87
CV %		12.01

* Significant at 0.05 probability level.
** Significant at 0.01 probability level.
*** Significant at 0.001 probability level.
† ns, Nonsignificant.

As in 2011, irrigation again significantly influenced grain yield in 2012 (Table 3.7). Irrigation again increased grain yield when compared to dryland, although not by as much as in 2011 (Table 3.3). Irrigation increased grain yield by only 16% compared to dryland in 2012 due to the increased amount of precipitation received that year.

Table 3.7. Irrigation effects on corn grain yield in 2012.

Treatment	Grain Yield (kg ha^{-1})	
Dryland	3917	b†
Irrigated	4548	A
Pr>f	0.0106	
R^2	0.87	
CV %	12.01	

† Means followed by the same letter are not significantly different according to LSD (0.05).

Planting date did not significantly affect grain yield in 2012 (Table 3.8), likely due to the higher precipitation received and lower ambient temperature during grain fill (Fig. 3.1), but the main effect of hybrid did significantly influence grain yield (Table 3.9). Later maturing hybrids (3 and 4) yielded significantly more than earlier maturing hybrids (1 and 2). Hybrid 2 produced 26% more grain than hybrid 1, which is similar to results for 2011, while hybrids 3 and 4 on average yielded 32% more than hybrid 2. In 2012, no significant interactive effects were detected for any studied factors.

Table 3.8. Planting date effect on corn grain yield in 2012.

Treatment	Grain Yield (kg ha^{-1})	
Planting Date 1	3747	a†
Planting Date 2	3794	a
Planting Date 3	3796	a
Pr>f	0.778	
R^2	0.87	
CV %	9.3	

† Means followed by the same letter are not significantly different according to LSD (0.05).

Table 3.9. Hybrid effect on corn grain yield in 2012.

Treatment	Grain Yield (kg ha^{-1})	
Hybrid 1	3028	c†
Hybrid 2	3817	b
Hybrid 3	5068	a
Hybrid 4	5016	a
Pr>f	<0.0001	
R^2	0.87	
CV %	12.01	

† Means followed by the same letter are not significantly different according to LSD (0.05).
Hybrid (1: Early, 2: Mid, 3: Mid-late, and 4: Late).

4. PHOTOSYNTHETIC ACTIVITY: RESULTS AND DISCUSSION

4.1 COMBINED RESULTS

Photosynthesis was measured during three growth stages within the corn reproductive period (R1, R3, and R5) in 2011 and 2012. Table 4.1 contains the analysis of variance for measured photosynthetic activity for combined years. For measurements taken at any growth stage and for all main effects (irrigation, PD, and H), results could be combined across years only for the main effect of irrigation at the R1 growth stage. Irrigation effects for measurements conducted during the R3 and R5 growth stages are presented separately for the two years because of significant interactions. The main effects of PD and H are also presented separately. The interactive effect of PD x I could only be combined across years when measured at the R5 growth stage; however, results did not provide a significant difference. Results from measurements conducted during the R1 and R3 growth stages are presented separately. Neither the H x I nor H x PD interactions could be combined over years; thus, interactions are presented separately. The I x PD x H interaction was not significant for measurements conducted during R1 and R3. Data were unable to be combined for measurements collected during R5. Results of the I x PD x H interaction on photosynthesis at R5 were not significant when measured during either 2011 or 2012.

Table 4.1. Analysis of variance for corn photosynthetic activity measured during R1, R3, and R5 reproductive growth stages.

Source	df	R1	R3	R5
Year	1	ns†	ns	***
Replication	3	ns	ns	ns
Year x Rep	6	ns	***	ns
Irrigation (I)	1	**	**	**
Year x Irrigation	1	ns	***	***
Error a	1			
Planting Date (PD)	2	**	ns	***
PD x Year	2	***	***	**
PD x I	2	ns	**	ns
PD x I x Year	2	***	***	ns
Error b	11			
Hybrid (H)	3	***	ns	ns
H x Year	3	*	***	***
H x PD	6	***	ns	ns
H x PD x Year	6	**	**	**
H x I	3	ns	ns	ns
H x I x Year	3	**	***	*
H x PD x I	6	ns	ns	ns
H x PD x I x Year	6	ns	ns	***
Error C	51			
R^2		0.82	0.83	0.83
CV %		8.9	16.25	20.1

* Significant at 0.05 probability level.
** Significant at 0.01 probability level.
*** Significant at 0.001 probability level.
† ns, Nonsignificant.

The main effect of irrigation influenced photosynthesis when measured at the R1 growth stage when combined over years (Table 4.1). Corn in irrigated plots had a significantly higher rate of photosynthetic activity compared to that in dryland plots

(Table 4.2) A reduction in photosynthetic rate in response to limited moisture has been well documented (McPherson and Boyer, 1977; Jurgens et al., 1978; Chaves, 1991; Ort et al., 1994; Chaves et al., 2003; Flexas et al., 2004; Mittler, 2006).

Table 4.2. Irrigation effect on corn photosynthetic activity at R1 growth stage combined over years.

Treatment	R1	
Dryland	34.00†	b‡
Irrigated	36.63	a
Pr>f	0.0068	
R^2	0.82	
CV %	8.9	

† Units are µmol CO_2 m^{-2} s^{-1}.
‡ Means followed by the same letter are not significantly different according to LSD (0.05).

4.2 SEPARATE RESULTS: PHOTOSYNTHETIC ACITIVITY 2011

The analysis of variance for measured photosynthetic activity in 2011 is presented in Table 4.3.

Table 4.3. Analysis of variance for corn photosynthetic activity during reproductive growth stages R1, R3, and R5 in 2011.

Source	df	R1	R3	R5
Irrigation (I)	1	*	**	***
Replication	3	ns†	***	ns
Error a	3			
Planting Date (PD)	2	**	***	***
PD x I	2	*	***	ns
Error b	12			
Hybrid (H)	3	***	***	ns
H x PD	6	***	ns	***
H x I	3	***	**	*
H x PD x I	6	ns	***	***
Error C	52			
R^2		0.87	0.91	0.89
CV %		7.7	15.2	24.24

* Significant at 0.05 probability level.
** Significant at 0.01 probability level.
*** Significant at 0.001 probability level.
† ns, Nonsignificant.

The main effect of irrigation on photosynthesis was significant during R3 and R5 growth stages in 2011 and greatly increased photosynthesis compared to the dryland treatment (Table 4.4). Measurements conducted during the R5 growth stage had a greater numerical separation and percentage increase than measurements conducted during R3 or for the combined measurements of R1, though overall values were lower.

Table 4.4. Irrigation effects on corn photosynthetic activity at R3 and R5 growth stages in 2011.

Treatment	R3		R5	
Dryland	20.83†	b‡	10.40	b
Irrigated	33.62	a	26.81	a
Pr>f	0.0033		0.0005	
R^2	0.91		0.89	
CV %	15.2		24.4	

† Units are µmol CO_2 m^{-2} s^{-1}.

‡Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

The main effect of planting date influenced photosynthesis in all three growth stages in 2011 (Table 4.5). Earlier planting resulted in higher photosynthetic rates at both R1 and R3 in 2011. Photosynthetic rates associated with planting dates 1 and 2 were not significantly different when measured at R1 while corn from planting date 3 had a significantly lower photosynthetic rate than that of the two earlier dates. Photosynthetic rates during corn during silking and early grain-fill have been well documented (Hall et al., 1971; Barnett and Pearce, 1983; Bunce, 2010). All results indicated that decreased photosynthetic rate or capacity correlated to decreased yield. My data conflicted with these reports and suggested an inverse relationship between photosynthetic rate at R1 and grain yield. Grain yield results in 2011 (Table 3.4) showed the latest planting date resulted in the greatest yield when compared to planting dates 1 and 2. Photosynthetic activity at the R5 growth stage, however, was the opposite of results from earlier growth stages, with plants from the last planting date (3) having a significantly higher photosynthetic rate than those for planting dates 1 or 2.

Photosynthetic activity at planting dates 1 and 2 did not differ when measured at the R5 growth stage. It's possible that the differences in photosynthetic rate measured at R1, even though statistically significant, may not have been great enough to substantially affect yield. The differences detected at the R3 and R5 growth stages may also have had a limited effect on yield because of translocation of carbohydrates from within the plant. Potential explanations of lowered sensitivity of grain development to drought may be attributed to the plants ability to draw upon carbohydrate reserves during later reproductive development. A trial conducted by Jurgens et al. (1978) in which water was withheld from a corn crop during grain fill determined if grain fill was dependent upon newly acquired photosynthate or stored assimilate. As grain fill progressed, the rate of grain fill exceeded the rate of dry matter accumulation, indicating redistribution of stored assimilates. These authors also reported that translocation was less inhibited than photosynthesis by drought and that total photosynthetic accumulation for the growing season controlled yield during a drought that did not disrupt flowering. Reduced photosynthetic rate that does not relate to yield might also be explained by the results of Li et al. (2013). These researchers concluded that several factors could reduce corn photosynthetic rate including drought, reduced photoperiod, lower light intensity, and higher leaf temperature.

Table 4.5. Planting date effects on corn photosynthetic activity at R1, R3 and R5 growth stages in 2011.

Treatment	R1		R3		R5	
Planting Date 1	35.52 †	a‡	32.95	a	16.94	b
Planting Date 2	36.71	a	26.51	b	15.71	b
Planting Date 3	31.90	b	22.22	c	23.17	a
Pr>f	0.0004		<0.0001		<0.0001	
R^2	0.9		0.91		0.89	
CV %	8.4		15.2		24.24	

† Units are µmol CO_2 m^{-2} s^{-1}.

‡Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Planting Dates (1: Feb. 15, 2: Mar. 1, and 3: Mar. 15).

The main effect of hybrid influenced photosynthesis during R1 and R3 growth stages in 2011, but not at R5 (Table 4.3). Photosynthetic activity during the R1 and R3 growth stages decreased as hybrid relative maturity increased (1 to 4) (Table 4.6). The shortest relative maturity hybrid (1) had a significantly higher photosynthetic rate than the two longer relative maturity hybrids (3 and 4) when measured at either growth stage. Results of previous literature (Hall et al., 1971; Barnett and Pearce, 1983; Bunce, 2010) indicated that decreased photosynthetic rate or capacity correlated to decreased yield. My results disagreed and suggested an inverse relationship between photosynthetic rate at R1 and R3 growth stages and grain yield in 2011, as corn yield increased with increasing hybrid relative maturity in 2011 (Table 3.5). Again, it is possible that the differences in photosynthetic rate measured at R1 and R3, even though statistically significant, may not have been great enough to substantially influence yield. The differences detected at the R3 growth stage also may not have affected yield because of the effects of translocation as previously discussed (Jurgens et al., 1978; Westgate and Boyer, 1985). Higher grain yield of the later maturing hybrids that exhibited lower photosynthetic rates may implicate translocation capacity as an important grain yield factor. Results of numerous trials indicate that the use of a late-season hybrid, when compared to an early-season hybrid planted on the same day, resulted in greater yield due to a prolonged reproductive growth period (Howell et al., 1998; Trooien et al., 1999; Norwood 2001; Capristo et al., 2007; Raymond et al., 2009; Van Roekel and Coulter, 2012).

Table 4.6. Hybrid effects on corn photosynthetic activity at R1 and R3 growth stages in 2011.

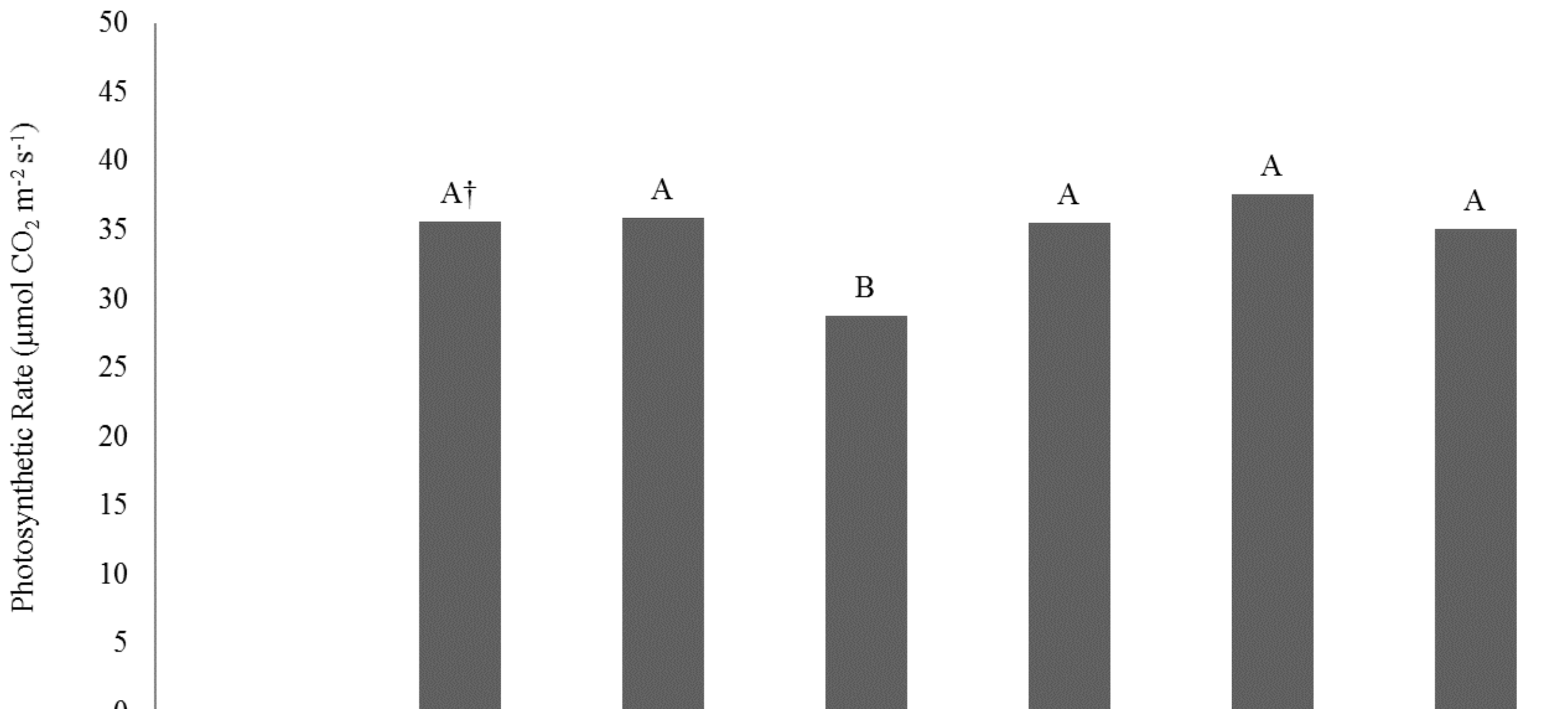
Treatment	R1		R3	
Hybrid 1	36.88†	a‡	30.10	a
Hybrid 2	36.15	ab	30.01	a
Hybrid 3	34.96	b	25.27	b
Hybrid 4	30.84	c	23.52	b
Pr>f	<0.0001		<0.0001	
R^2	0.90		0.91	
CV %	8.4		15.2	

† Units are µmol CO_2 m^{-2} s^{-1}.
‡Within columns, means followed by the same letter are not significantly different according to LSD (0.05).
Hybrid (1: Early, 2: Mid, 3: Mid-late, and 4: Late).

Since significant PD x I, H x PD, and H x I interactions existed in 2011, comparisons were made within appropriate factor combinations. The interactive effect of PD x I on photosynthesis was significant when measured during the R1 and R3 growth stages in 2011, whereas measured values during the R5 growth stage were not significantly different (Table 4.3). Photosynthetic activity measured at R1 during 2011 was only different for corn planted on the last planting date under dryland conditions and was lower than that of other treatments (Fig. 4.1). This lower rate might be attributed to increasing drought severity and temperature stress that plants in planting date 3 endured as they entered reproductive growth. Further indication of the different environment encountered by dryland plants in planting date 3 may be seen in that photosynthetic activity of plants in planting dates 1 and 2 under dryland conditions were not different from each other and also were not different from any of the three planting dates under irrigation.

When photosynthetic rate was measured at R3 in 2011, results were somewhat similar to measurements taken during the R1 growth stage (Fig. 4.2). Photosynthetic rate did not differ among planting dates when plots were irrigated; however, under dryland conditions plants from planting dates 2 and 3 had a significantly lower photosynthetic rate than those of the first planting date, and may be due to worsening drought conditions. Westgate and Boyer (1985) imposed low water potential at silking, early-grain fill, or mid-grain fill, but then followed with fully irrigated conditions to maturity. Results showed decreased yield in all cases under low water potential, and their data agreed with my results in that irrigated plots had both a higher photosynthetic rate and higher yield. The highest grain yield was achieved with the latest planting date under irrigation, whereas in dryland plots, a change in planting date did not generate a significant difference in grain yield. Again, photosynthetic rate at R1 or R3 may not be indicative of final grain yields.

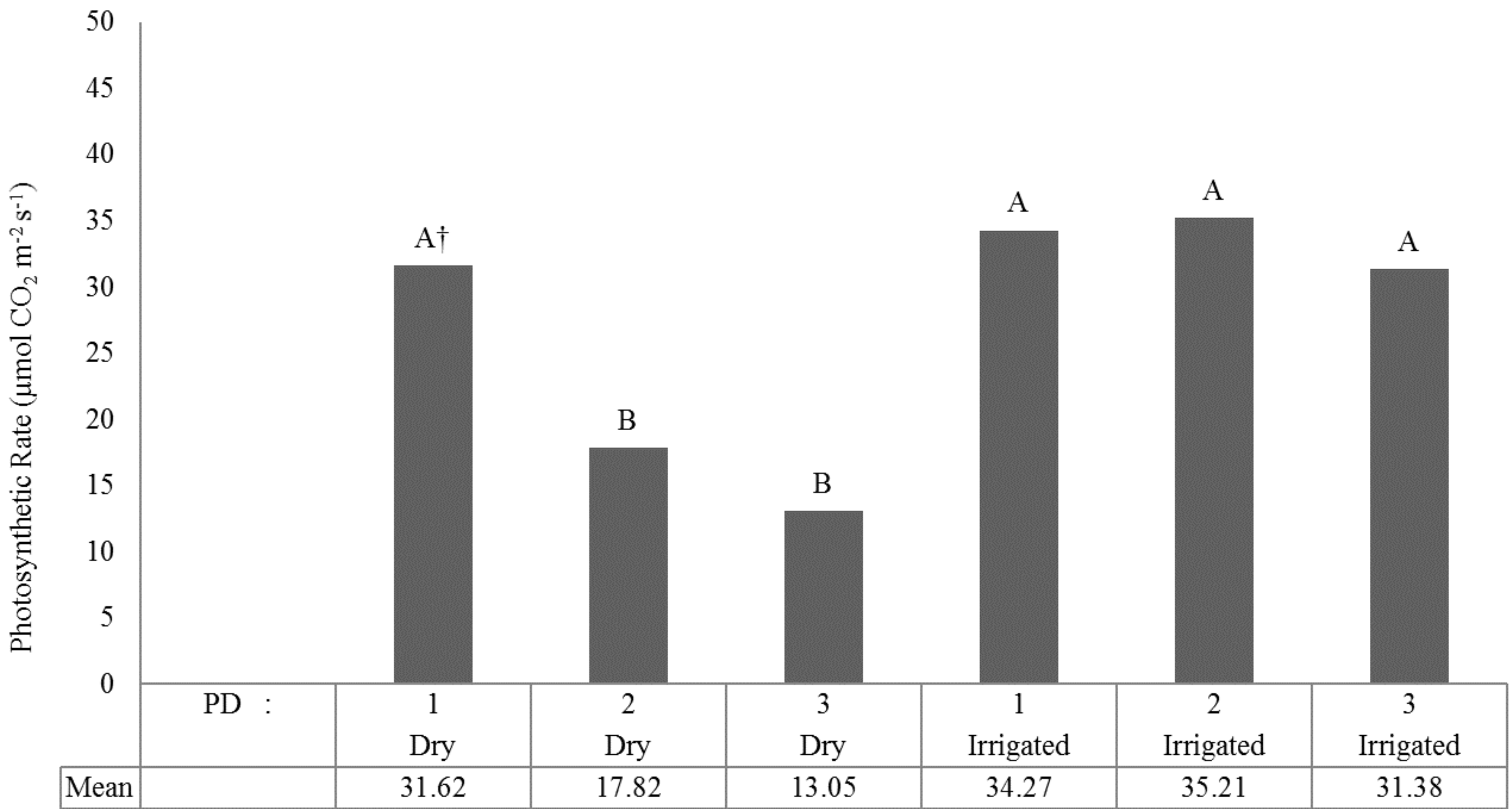
Figure 4.1. Planting date x irrigation effect on corn photosynthetic activity at R1 in 2011.



	PD :	1	2	3	1	2	3
		Dry	Dry	Dry	Irrigated	Irrigated	Irrigated
Mean		35.56	35.88	28.72	35.48	37.54	35.07

† Means followed by the same letter are not significantly different according to LSD (0.05).
PD, Planting Date (1: Feb. 15, 2: Mar. 1, and 3: Mar. 15).

Figure 4.2. Planting date x irrigation effect on corn photosynthetic activity at R3 in 2011.



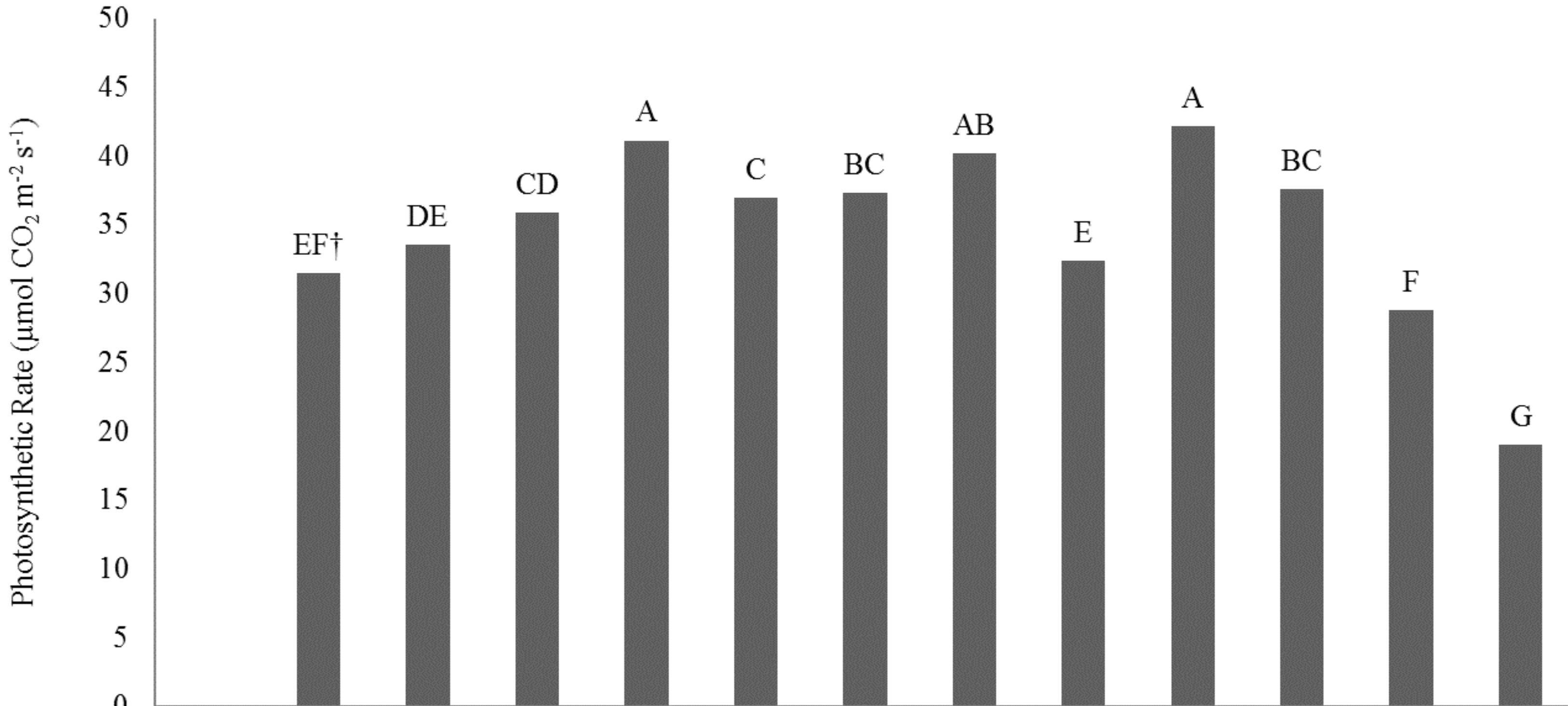
† Means followed by the same letter are not significantly different according to LSD (0.05).
PD, Planting Date (1: Feb. 15, 2: Mar. 1, and 3: Mar. 15).

The interactive effect of H x PD on photosynthesis was significant during the R1 and R5 growth stages in 2011 (Table 4.3 and Figs. 4.3 and 4.4, respectively). When photosynthetic rate was measured during the R1 growth stage, within the first planting date, photosynthetic rate increased with increasing hybrid maturity (Fig. 4.3). Within the second planting date, hybrids 1 through 3 tended to follow a similar trend as observed for the first date, but hybrid 4 now showed the lowest photosynthetic activity, and in the last planting date (3), a pattern opposite to that for planting date 1 occurred, in that photosynthetic activity now decreased with increasing hybrid maturity. The results suggested a possible overlap in the optimum timing for R1 to occur during the 2011 growing season, and potentially an opposite trend for effects of corn hybrid maturity on photosynthetic rate when corn was planted on dates one month apart.

When photosynthetic rate was measured at R5 in 2011 (Fig. 4.4), the trend was similar to the R1 data for hybrid maturity within the last planting (Fig. 4.3), but few obvious trends were noted for the first two dates. The latest planting date generated the greatest photosynthetic rate in hybrids 1, 2, and 3, but hybrid 4 had a lower rate indicating this planting date resulted in a more photosynthetically active crop during this time period with the exception of hybrid 4. These results also indicated an optimum window for ear development in 2011 where the highest photosynthetic rates were achieved with either earlier maturing hybrids planted later or later maturing hybrids planted earlier.

When photosynthetic activity was measured at R1 (Fig. 4.3), results corresponded to grain yield in 2011 for planting dates 1 and 2 but not for date 3 (Table 3.4), possibly because of inhibition of photosynthesis by drought in later maturing hybrids (Chaves, 1991; Ort et al., 1994; Chaves et al., 2003; Flexas et al., 2004) and the insensitivity of grain yield to reduced photosynthetic activity because of its dependence on the translocation of stored carbohydrates (Jurgens et al., 1978). Results of numerous trials indicate that a late-season hybrid will usually produce greater yield compared to an early-season hybrid planted on the same day (Howell et al., 1998; Trooien et al., 1999; Norwood, 2001; Capristo et al., 2007; Raymond et al., 2009; Van Roekel and Coulter, 2012). Capristo et al. (2007) found that biomass increased positively and linearly with hybrid cycle length and that long-season hybrids had higher light interception but lower radiation use efficiency. Grain yields were lowest for short-season hybrids and equivalent for mid- and full-season hybrids. Results indicated that grain yield of short-season hybrids (lower GDU) would likely be more limited by the capacity of the reproductive sinks during grain fill than long-season hybrids.

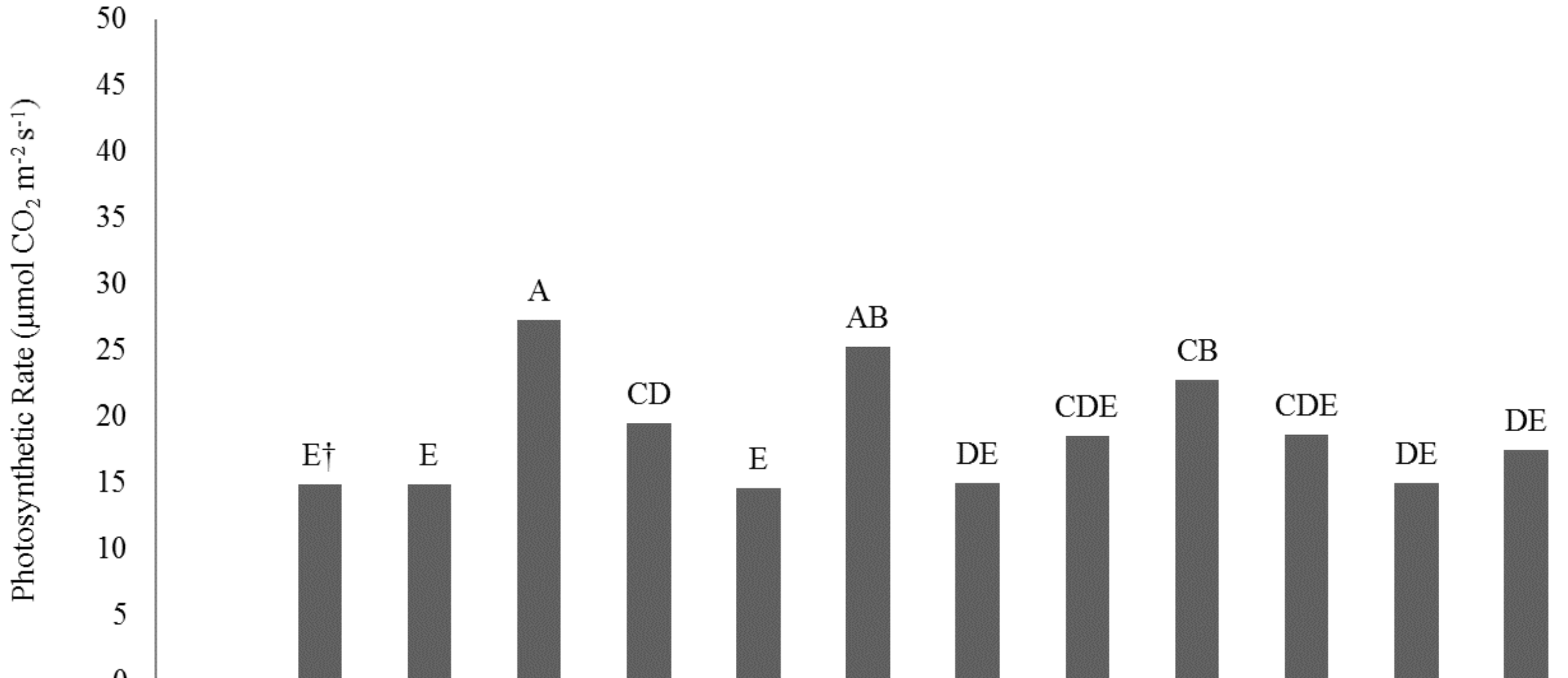
Figure 4.3. Hybrid x planting date effect on corn photosynthetic activity at R1 in 2011.



	PD :	1	1	1	1	2	2	2	2	3	3	3	3
	H :	1	2	3	4	1	2	3	4	1	2	3	4
Mean		31.48	33.54	35.90	41.14	36.98	37.34	40.16	32.37	42.18	37.56	28.82	19.02

† Means followed by the same letter are not significantly different according to LSD (0.05).
H, Hybrid (1: Early, 2: Mid, 3: Mid-late, and 4: Late).
PD, Planting Date (1: Feb. 15, 2: Mar. 1, and 3: Mar. 15).

Figure 4.4. Hybrid x planting date effect on corn photosynthetic activity at R5 in 2011.



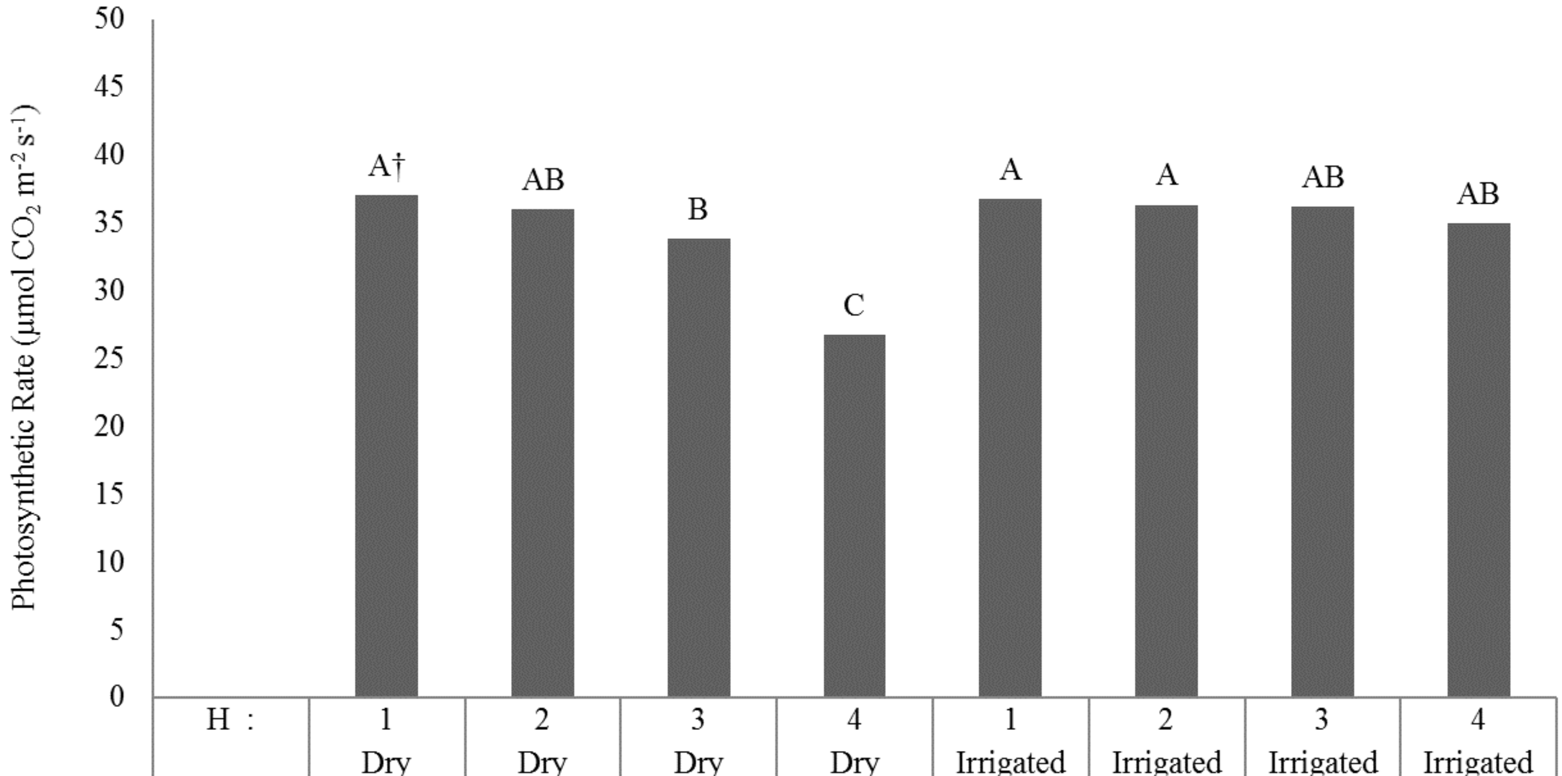
	PD :	1	2	3	1	2	3	1	2	3	1	2	3
	H :	1	1	1	2	2	2	3	3	3	4	4	4
Mean		14.82	14.81	27.28	19.43	14.56	25.22	14.94	18.49	22.73	18.58	14.96	17.45

† Means followed by the same letter are not significantly different according to LSD (0.05).
H, Hybrid (1: Early, 2: Mid, 3: Mid-late, and 4: Late).
PD, Planting Date (1: Feb. 15, 2: Mar. 1, and 3: Mar. 15).

The interactive effect of H x I significantly influenced photosynthesis during all three growth stages in 2011 (Table 4.3). Photosynthetic activity under dryland conditions during R1 was greatest for the earliest maturity hybrid and lowest for the latest maturing hybrid (Fig. 4.5). Hybrid 4 generally exhibited the lowest photosynthetic rate of all hybrids regardless of water treatment. Photosynthetic rate did not differ among hybrids under irrigated conditions. These results may indicate that the later maturing hybrids entered into the R1 growth stage during a more stressed period in 2011, with more limited soil water and elevated temperatures (Fig. 3.1).

Results from the R3 growth stage were similar to those of the R1 growth stage (Fig. 4.6 and 4.5, respectively). Photosynthetic rate during R3 also declined with increasing hybrid maturity (Fig. 4.6). Although the trend for irrigated data mirrored that for dryland during R3, photosynthetic rate for irrigated plots did not diminish as much as those for dryland, although the rates for the two later maturing hybrids (3 and 4) were statistically lower than that for hybrid 2. Later maturing hybrids likely entered into the R3 growth stage under increased stress. By this stage of development, photosynthetic rates were reduced by 20%, 35%, 54%, and 52% for hybrids 1, 2, 3 and 4, respectively, in the dryland compared to the irrigated plots. Photosynthetic activity during R5 was drastically reduced under dryland conditions compared to those measured at R3 (Fig. 4.7). Rates under irrigation also declined, but not as much. In dryland plots, photosynthetic rates were again lower for later maturing hybrids.

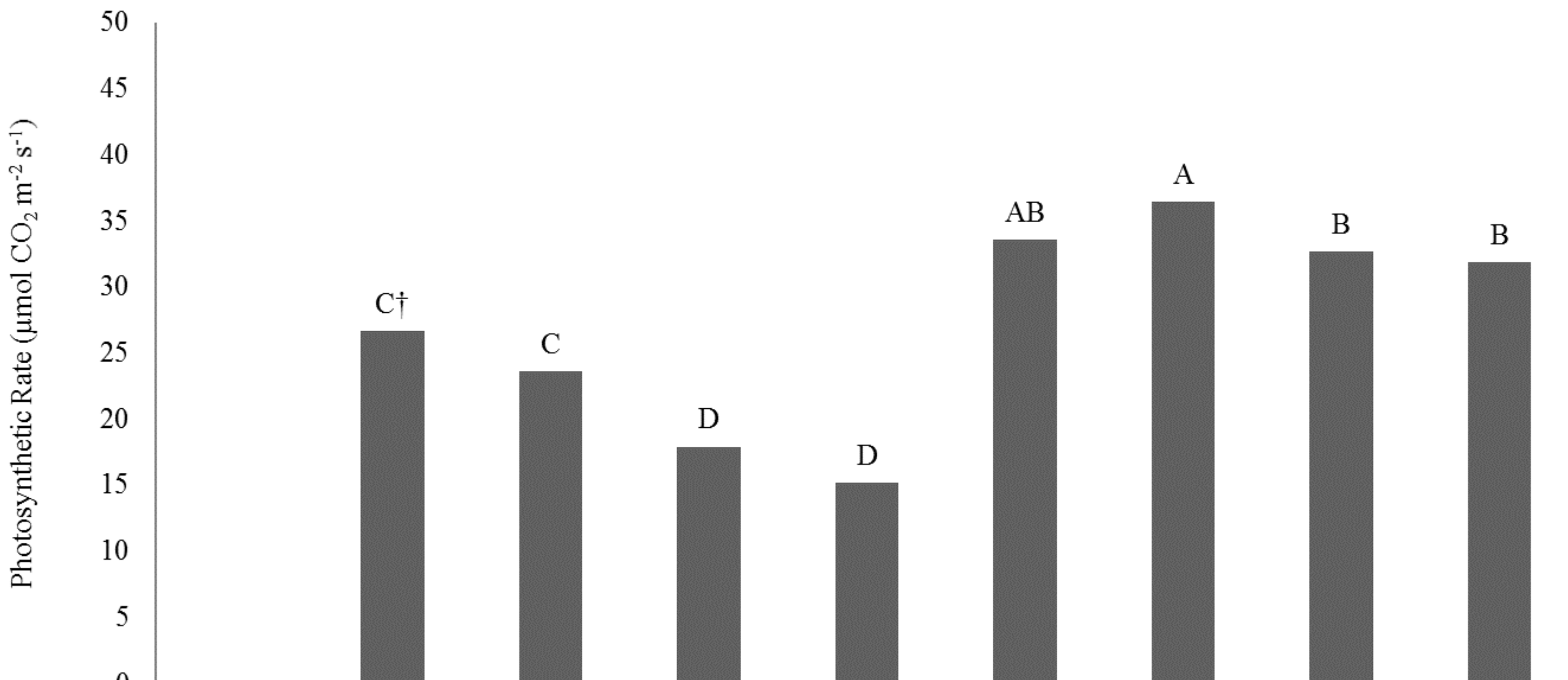
Figure 4.5. Hybrid x irrigation effect on corn photosynthetic activity at R1 in 2011.



H :	1 Dry	2 Dry	3 Dry	4 Dry	1 Irrigated	2 Irrigated	3 Irrigated	4 Irrigated
Mean	37.05	35.96	33.78	26.75	36.72	36.33	36.14	34.93

† Means followed by the same letter are not significantly different according to LSD (0.05).
H, Hybrid (1: Early, 2: Mid, 3: Mid-late, and 4: Late).

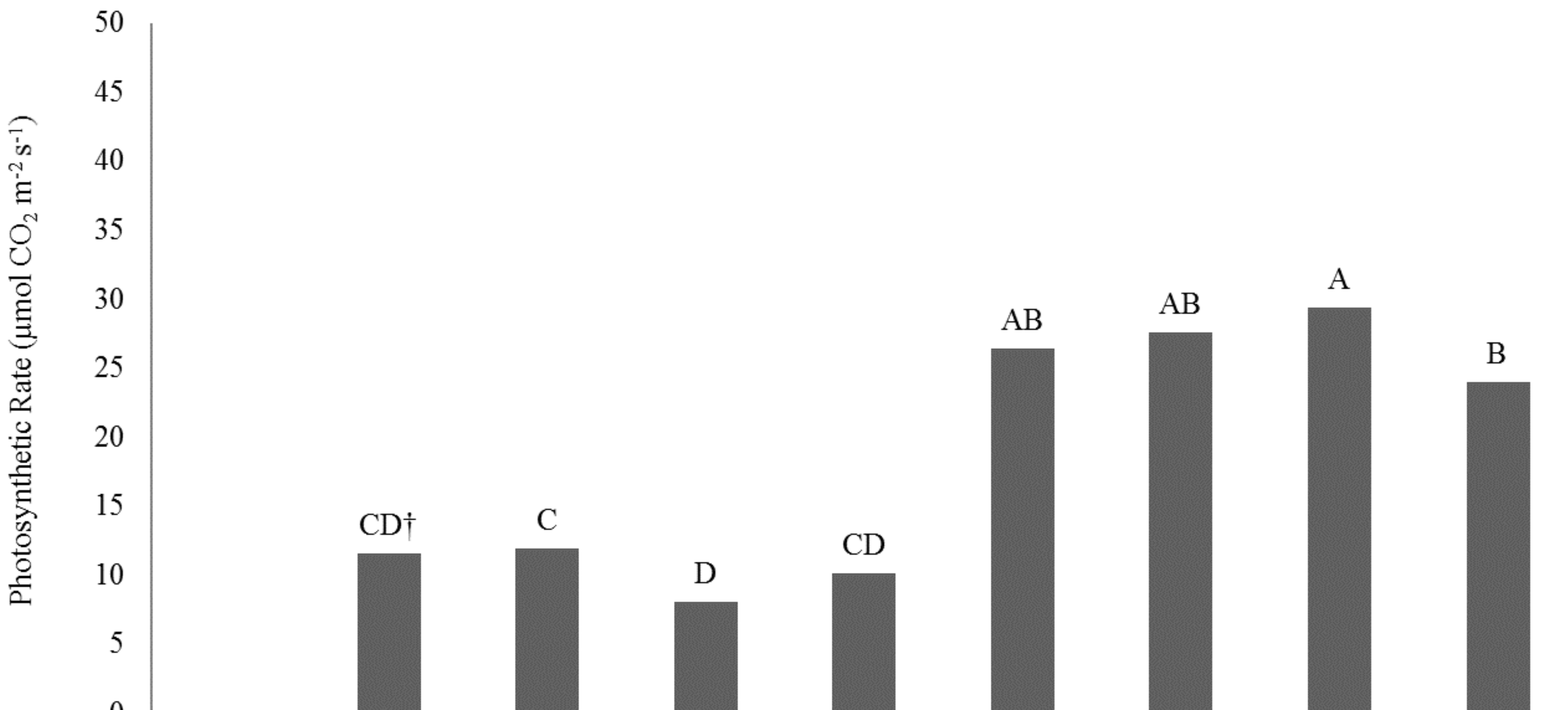
Figure 4.6. Hybrid x irrigation effect on corn photosynthetic activity at R3 in 2011.



	H :	1 Dry	2 Dry	3 Dry	4 Dry	1 Irrigated	2 Irrigated	3 Irrigated	4 Irrigated
Mean		26.63	23.60	17.90	15.19	33.57	36.41	32.65	31.86

† Means followed by the same letter are not significantly different according to LSD (0.05).
H, Hybrid (1: Early, 2: Mid, 3: Mid-late, and 4: Late).

Figure 4.7. Hybrid x irrigation effect on corn photosynthetic activity at R5 in 2011.



H :	1	2	3	4	1	2	3	4
	Dry	Dry	Dry	Dry	Irrigated	Irrigated	Irrigated	Irrigated
Mean	11.57	11.92	8.06	10.07	26.36	27.55	29.38	23.93

† Means followed by the same letter are not significantly different according to LSD (0.05).
H, Hybrid (1: Early, 2: Mid, 3: Mid-late, and 4: Late).

4.3 SEPARATE RESULTS: PHOTOSYNTHETIC ACTIVITY 2012

The analysis of variance for corn photosynthetic activity in 2012 is presented in Table 4.7.

Table 4.7. Analysis of variance for corn photosynthetic activity measured during reproductive growth stages R1, R3, and R5 in 2012.

Source	df	R1	R3	R5
Irrigation (I)	1	*	*	ns†
Replication	3	ns	ns	ns
Error a	3			
Planting Date (PD)	2	***	***	***
PD x I	2	ns	ns	ns
Error b	12			
Hybrid (H)	3	***	***	***
H x PD	6	***	***	*
H x I	3	ns	*	ns
H x PD x I	6	ns	ns	ns
Error C	48			
R^2		0.8	0.84	0.78
CV %		8.6	14.85	15.8

* Significant at 0.05 probability level.
** Significant at 0.01 probability level.
*** Significant at 0.001 probability level.
† ns, nonsignificant.

Photosynthetic activity during the R3 growth stage was increased by irrigation in 2012 (Table 4.8), but the main effect of irrigation was not significant for photosynthetic activity at the R5 growth stage in 2012, possibly because of the wetter growing season compared to 2011. Since year x irrigation was not significant for photosynthesis at R1 (Table 4.1), effects were previously combined over years (Table 4.7).

Table 4.8. Irrigation effect on corn photosynthetic activity at growth stages R3 and R5 in 2012.

Treatment	R3		R5	
Dryland	33.71†	b‡	23.62	a
Irrigated	37.76	a	28.29	a
Pr>f	0.0121		ns	
R^2	0.84		0.78	
CV %	14.85		15.8	

† Units are µmol CO_2 m^{-2} s^{-1}.
‡Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

The main effect of planting date influenced photosynthesis at all three growth stages in 2012 (Table 4.7). Regardless of growth stage, plants from later planting dates had higher photosynthetic rates than those from earlier planting dates (Table 4.9). Photosynthetic rate decreased as plants aged regardless of planting date. In 2012, planting date 3 produced plants with the highest photosynthetic rate at all growth stages, except R1 where plants from planting dates 2 and 3 had statistically equal rates. The year

2012 differed from 2011 in the amount of precipitation received during reproductive growth, with 2012 receiving over 50.8 cm of precipitation while 2011 received only 15.2 cm. Corn planted on dates 2 and 3 in 2011 had lower photosynthetic rates than those planted on date 1 indicating increasing stress with time in 2011, but not 2012.

Table 4.9. Planting date effect on corn photosynthetic activity in 2012.

Treatment	R1		R3		R5	
Planting Date 1	32.37†	b‡	22.84	c	21.87	c
Planting Date 2	37.52	a	28.99	b	26.01	b
Planting Date 3	37.32	a	32.03	a	29.98	a
Pr>f	0.0002		<0.0001		<0.0001	
R^2	0.8		0.84		0.78	
CV %	8.6		14.85		15.81	

† Units are µmol CO_2 m^{-2} s^{-1}.
‡Within columns, means followed by the same letter are not significantly different according to LSD (0.05).
Planting Date (1: Feb. 15, 2: Mar. 1, and 3: Mar. 15).

The main effect of hybrid also influenced photosynthesis during all corn growth stages in 2012 (Table 4.10). Results for the R1 growth stage were similar to those for 2011, in that as hybrid relative maturity (1 to 4) increased, photosynthetic rate decreased. In contrast to 2011, however, measurements collected during the R3 and R5 growth stages showed that as hybrid maturity (1 to 4) increased, photosynthetic rate also increased. This contrast may be representative of the difference between the growing seasons of 2011 and 2012, where 2011 was a very hot, extremely dry growing season and 2012 had a reasonable amount of rainfall and cooler temperatures. In a growing season where rainfall is not a limiting factor, it is reasonable to assume that the longer maturing hybrids would have an elevated photosynthetic rate compared to shorter season hybrids due to the extended grain fill characteristics of a longer season hybrid. Capristo et al. (2007) found that hybrids with a short developmental time from emergence to flower, but a long developmental time from flower to maturity, resulted in the greatest radiation interception and grain yield.

Table 4.10. Hybrid effect on corn photosynthetic activity in 2012.

Treatment	**R1**		**R3**		**R5**	
Hybrid 1	38.72	a	25.06	b	23.26	b
Hybrid 2	36.24	b	23.58	b	22.76	b
Hybrid 3	34.93	bc	31.34	a	28.66	a
Hybrid 4	33.05	c	31.83	a	29.14	a
Pr>f	<0.0001		<0.0001		<0.0001	
R^2	0.8		0.84		0.78	
CV %	8.6		14.85		15.81	

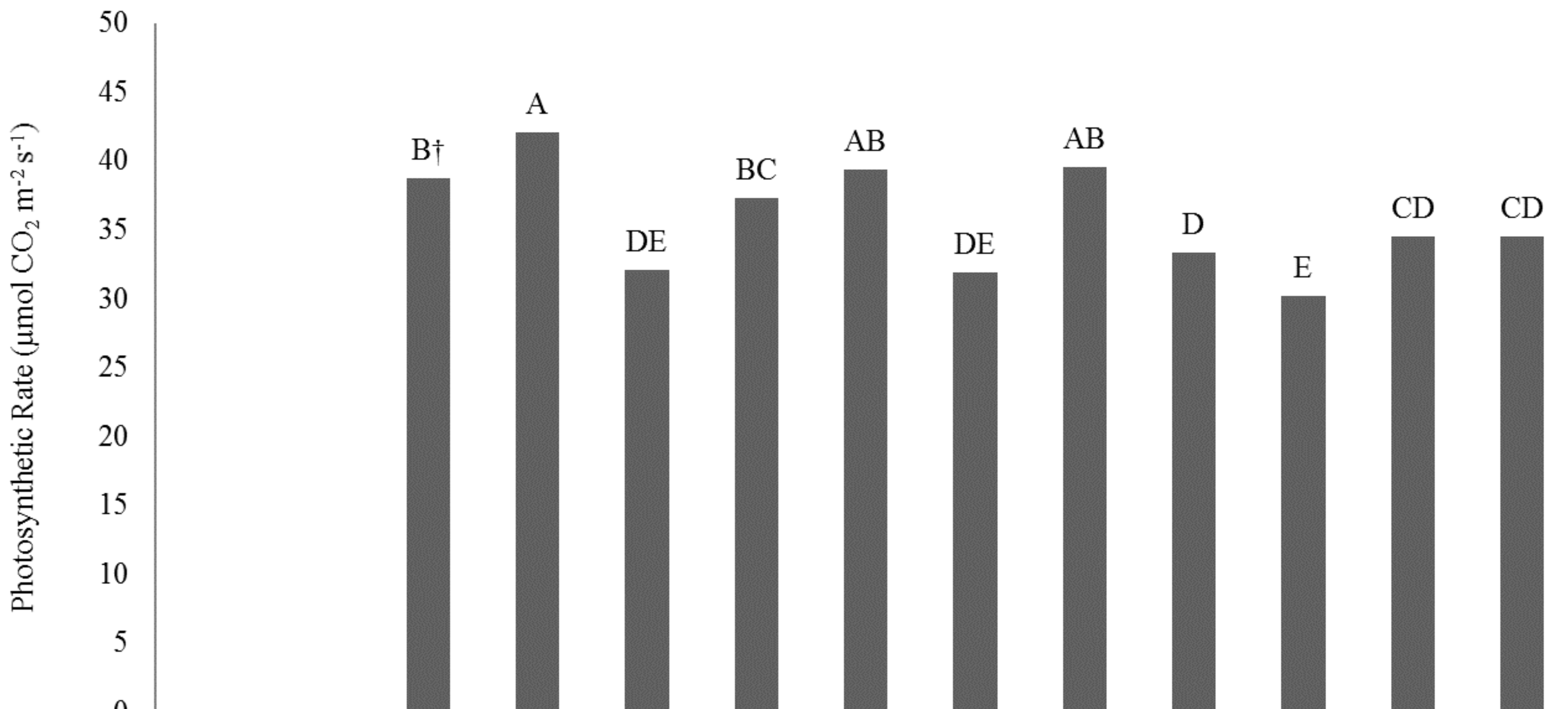
† Units are µmol CO_2 m^{-2} s^{-1}.
‡Within columns, means followed by the same letter are not significantly different according to LSD (0.05).
Hybrid (1: Early, 2: Mid, 3: Mid-late, and 4: Late).

Since significant H x PD and H x I interactions existed, comparisons were also made within appropriate factor combinations. The interactive effect of PD x I was not significant for photosynthetic activity during any growth stage in 2012 (Table 4.7). This result was more than likely due to increased rainfall amount received and cooler temperatures during the 2012 growing season. Approximately 523 mm of rain fell during the 2012 growing season as opposed to 169 mm in 2011. The interactive effect of H x PD, however, significantly influenced photosynthesis during all three growth stages in 2012 (Table 4.7). When measurements were taken during the R1 growth stage in 2012, earlier maturity group hybrids 1 and 2 responded with an increased photosynthetic rate to delayed planting (Fig. 4.8). Hybrids 3 and 4 had limited response to a change in planting date, with hybrid 3 increasing photosynthetic rate from PD 1 to 2 and then decreasing from PD 2 to 3.

Similar to the results of corn photosynthetic rates during R1, results from the R3 growth stage also showed that hybrid photosynthetic rate increased in response to delayed planting (Fig. 4.9). In contrast to R1 data, however, R3 results showed this trend across all maturity groups, although hybrids 3 and 4 had elevated photosynthetic rates during all planting dates when compared to hybrids 1 and 2. The trend of increased photosynthetic rate among hybrids in response to delayed planting also continued during R5 (Fig. 4.10). However, photosynthetic rate decreased from R1 to R3 to R5 (Figs. 4.8, 4.9, and 4.10, respectively). This trend contrasted with the 2011 data, likely because hybrids planted during the 2012 growing season did not incur the severity of stress as they did during the 2011 season.

The interactive effect of H x I on photosynthesis was only significant at the R3 growth stage, represented in Figure 4.11. Regardless of irrigation level, the later maturing hybrids (3 and 4) had a higher photosynthetic rate when compared to the earlier hybrids (1 and 2). Photosynthetic rates were higher for all hybrids when plots were irrigated, but the increase in photosynthetic rate for hybrids 1 and 2 was greatest.

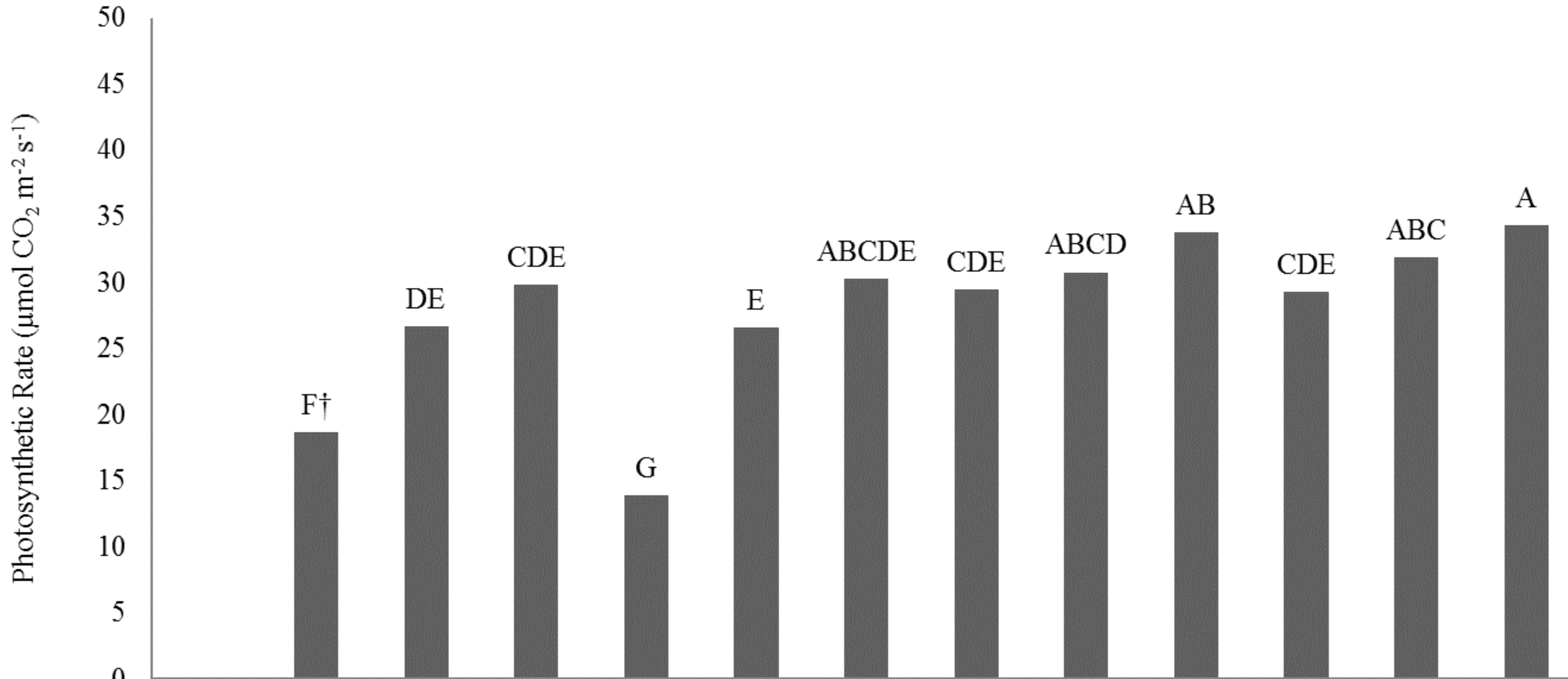
Figure 4.8. Hybrid x planting date effect on corn photosynthetic activity at R1 in 2012.



	PD :	1	2	3	1	2	3	1	2	3	1	2	3
	H :	1	1	1	2	2	2	3	3	3	4	4	4
Mean			38.75	42.07	32.07	37.26	39.39	31.90	39.56	33.33	30.16	34.50	34.49

† Means followed by the same letter are not significantly different according to LSD (0.05).
H, Hybrid (1: Early, 2: Mid, 3: Mid-late, and 4: Late).
PD, Planting Date (1: Feb. 15, 2: Mar. 1, and 3: Mar. 15).

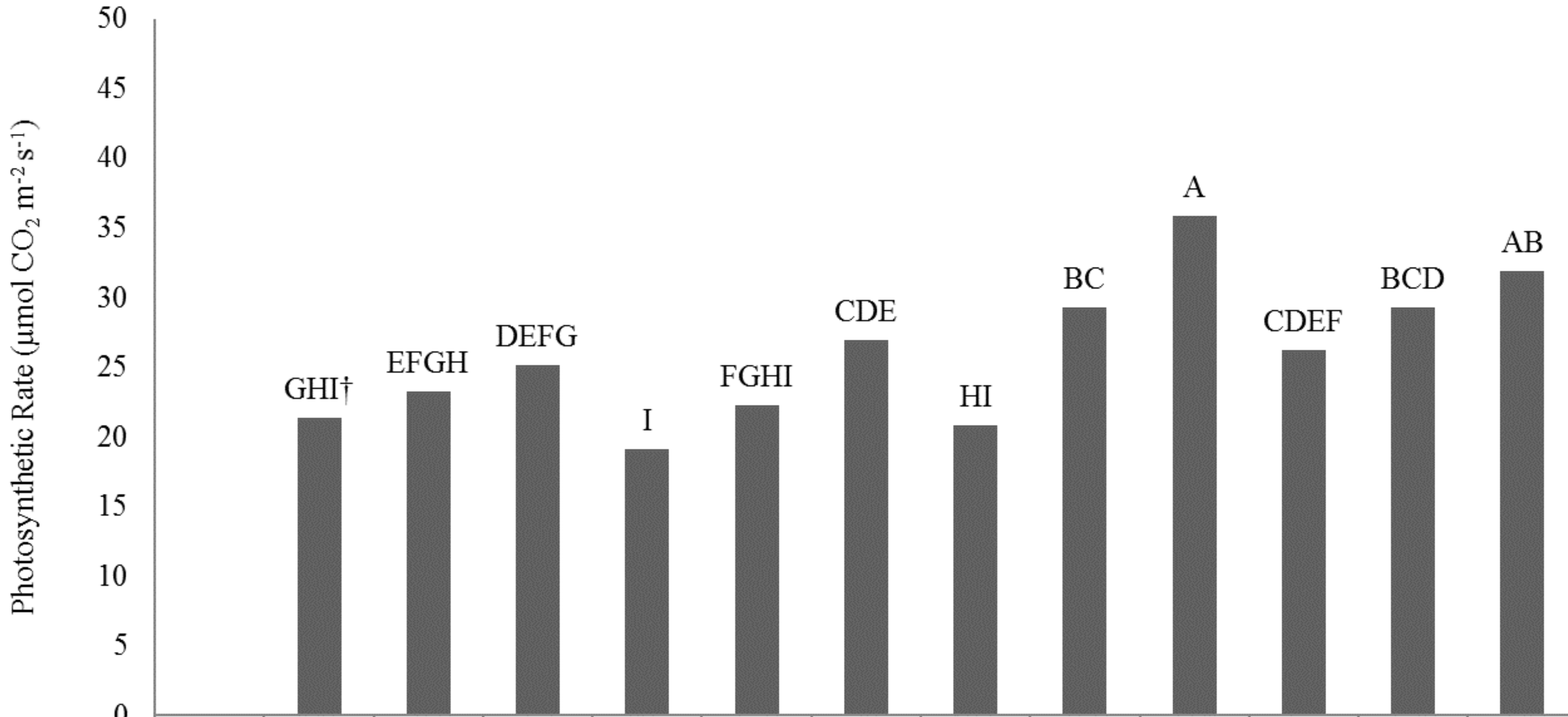
Figure 4.9. Hybrid x planting date effect on corn photosynthetic activity at R3 in 2012.



PD :	1	2	3	1	2	3	1	2	3	1	2	3
H :	1	1	1	2	2	2	3	3	3	4	4	4
Mean	18.68	26.68	29.81	13.90	26.60	30.24	29.49	30.76	33.78	29.29	31.91	34.29

†Means followed by the same letter are not significantly different according to LSD (0.05).
H, Hybrid (1: Early, 2: Mid, 3: Mid-late, and 4: Late).
PD, Planting Date (1: Feb. 15, 2: Mar. 1, and 3: Mar. 15.

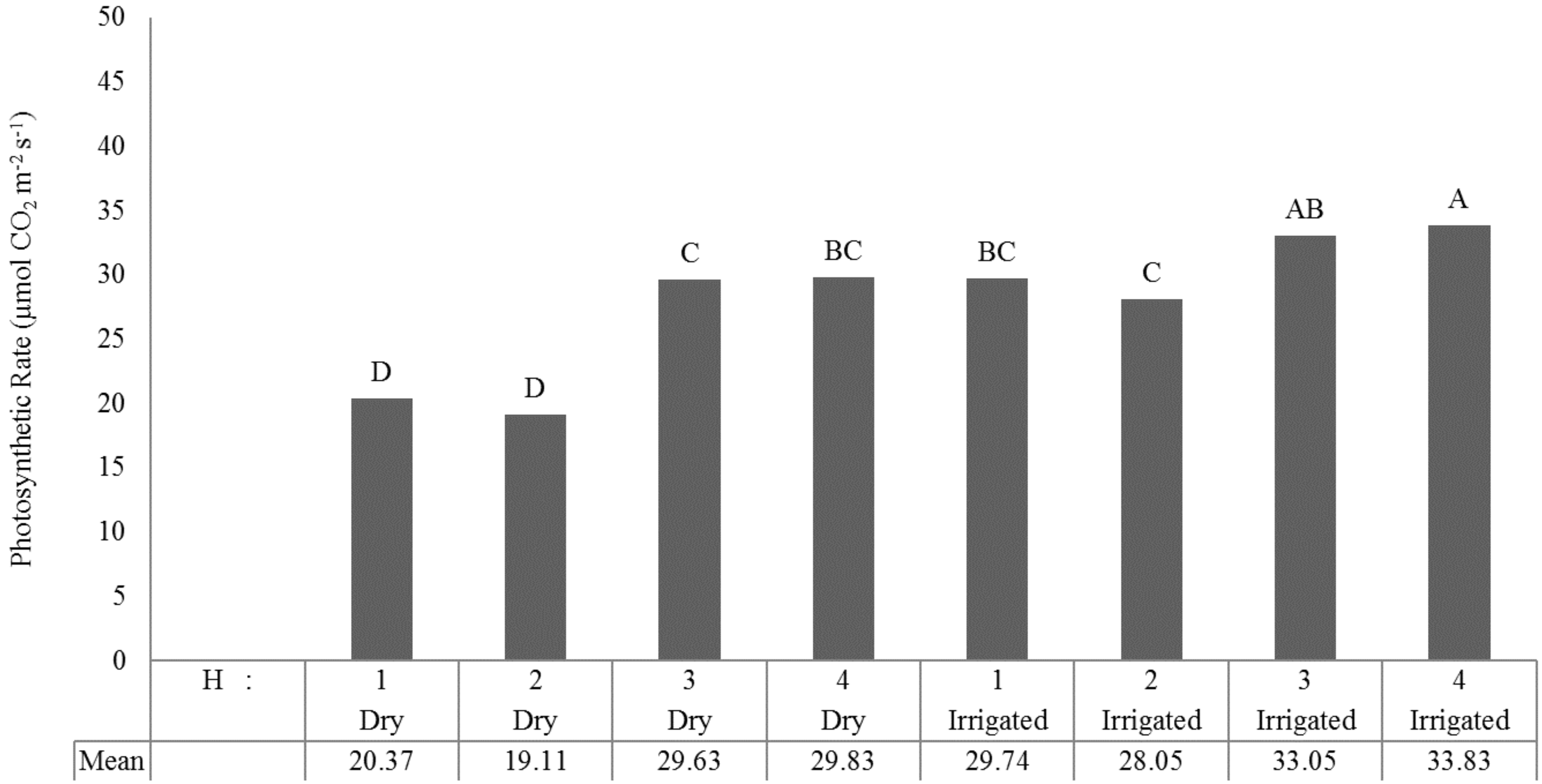
Figure 4.10. Hybrid x planting date effect on corn photosynthetic activity at R5 in 2012.



PD :	1	2	3	1	2	3	1	2	3	1	2	3
H :	1	1	1	2	2	2	3	3	3	4	4	4
Mean	21.39	23.26	25.14	19.09	22.22	26.98	20.78	29.31	35.89	26.24	29.24	31.93

† Means followed by the same letter are not significantly different according to LSD (0.05).
H, Hybrid (1: Early, 2: Mid, 3: Mid-late, and 4: Late).
PD, Planting Date (1: Feb. 15, 2: Mar. 1, and 3: Mar. 15.

Figure 4.11. Hybrid x irrigation effect on corn photosynthetic activity at R3 in 2012.



† Means followed by the same letter are not significantly different according to LSD (0.05).
H, Hybrid (1: Early, 2: Mid, 3: Mid-late, and 4: Late).

5. CHLOROPHYLL FLUORESCENCE: RESULTS AND DISCUSSION

5.1 COMBINED RESULTS: CHLOROPHYLL FLUORESCENCE

Chlorophyll fluorescence indicates the quantum efficiency of photosystem II by measuring the excess energy being re-emitted as light (Maxwell and Johnson, 2000). Quantum yield of photosystem II (ϕPS_{II}) was measured using the saturation pulse method in light adapted leaves and calculated as $Y = (F_m – F_t) / F_m$, where F_m is maximum fluorescence and F_t is fluorescence at given time. As long as there is no chlorophyll containing object, the F_t parameter field shows values close to 0.0. With a healthy leaf, Y amounts to approximately 0.8 (Maxwell and Johnson, 2000). ϕPS_{II} was measured during three growth stages (R1, R3, and R5) within the corn reproductive period. The analysis of variance for combined years is presented in Table 5.1.

Table 5.1. Analysis of variance for the quantum yield of photosystem II (ϕPS_{II}) measured during corn reproductive growth stages R1, R3, and R5.

Source	**df**	**R1**	**R3**	**R5**
Year	1	***	***	***
Replication	3	ns†	ns	ns
Year x Rep	6	ns	ns	ns
Irrigation (I)	1	ns	ns	ns
Year x Irrigation	1	***	*	ns
Error a	1			
Planting Date (PD)	2	***	*	***
PD x Year	2	ns	ns	***
PD x I	2	ns	ns	ns
PD x I x Year	2	ns	ns	ns
Error b	11			
Hybrid (H)	3	***	***	***
H x Year	3	**	ns	***
H x PD	6	***	***	***
H x PD x Year	6	ns	***	***
H x I	3	ns	ns	ns
H x I x Year	3	ns	**	*
H x PD x I	6	ns	ns	ns
H x PD x I x Year	6	ns	***	ns
Error C	51			
R^2		0.69	0.76	0.74
CV %		13.81	16.41	15.14

* Significant at 0.05 probability level.
** Significant at 0.01 probability level.
*** Significant at 0.001 probability level.
† ns, nonsignificant.

The main effect of irrigation on ϕPS_{II} was not significant at any of the measured reproductive growth stages nor were any of the interactions involving irrigation at R5, except H x I x year (Table 5.1). Effects of irrigation on ϕPS_{II} at R1 and R3 could not be combined across years because of significant year x irrigation interactions. The main effect of planting date significantly influenced ϕPS_{II} at all measured reproductive stages, but could not be combined across years for R5 because of a significant planting date x year interaction for that stage. When ϕPS_{II} was measured at R1, planting dates 1 and 3 had greater ϕPS_{II} rates than planting date 2 (Table 5.2). At R3, the third planting date generated the greatest ϕPS_{II} rate, while planting dates 1 and 2 were lower and not significantly different from each other. This trend is likely due to the higher temperatures and limited available moisture during that period.

Table 5.2. Planting date effects on quantum yield of corn photosystem II (ϕPS_{II}) combined across years and measured during reproductive growth stages R1 and R3.

Treatment	R1		R3	
Planting Date 1	0.57	a†	0.47	b
Planting Date 2	0.48	b	0.49	b
Planting Date 3	0.54	a	0.53	a
Pr>f	<0.0001		0.0164	
R^2	0.69		0.76	
CV %	13.8		16.4	

† Within columns, means followed by the same letter are not significantly different according to LSD (0.05).
Planting Date (1: Feb. 15, 2: Mar. 1, and 3: Mar. 15).
ϕPS_{II}, calculated as $Y = (F_m - F_t) / F_m$, where F_m = maximum fluorescence and F_t = fluorescence at given time.

The main effect of hybrid relative maturity on ϕPS_{II} could not be combined over years at the R1 and R5 growth stages because of significant hybrid x year interactions, but could be combined during R3 (Table 5.1). Hybrid 4, the longest RM hybrid, had the highest ϕPS_{II} rate at R3, with all other hybrids not significantly different from each other (Table 5.3). Variability of ϕPS_{II} among different hybrids was previously documented by Selmani and Wassom (1993) where ϕPS_{II} was measured for different hybrids in order to test the measurement as an indicator of drought tolerance. Results showed that the measurement could be used to identify more drought tolerant hybrids if used under moisture limiting conditions.

Table 5.3. Corn hybrid effects on quantum yield of photosystem II (ϕPS_{II}) measured during the R3 reproductive growth stage and combined across years.

Treatment	R3	
Hybrid 1	0.46	b†
Hybrid 2	0.47	b
Hybrid 3	0.47	b
Hybrid 4	0.61	a
Pr>f	<.0001	
R^2	0.76	
CV %	16.4	

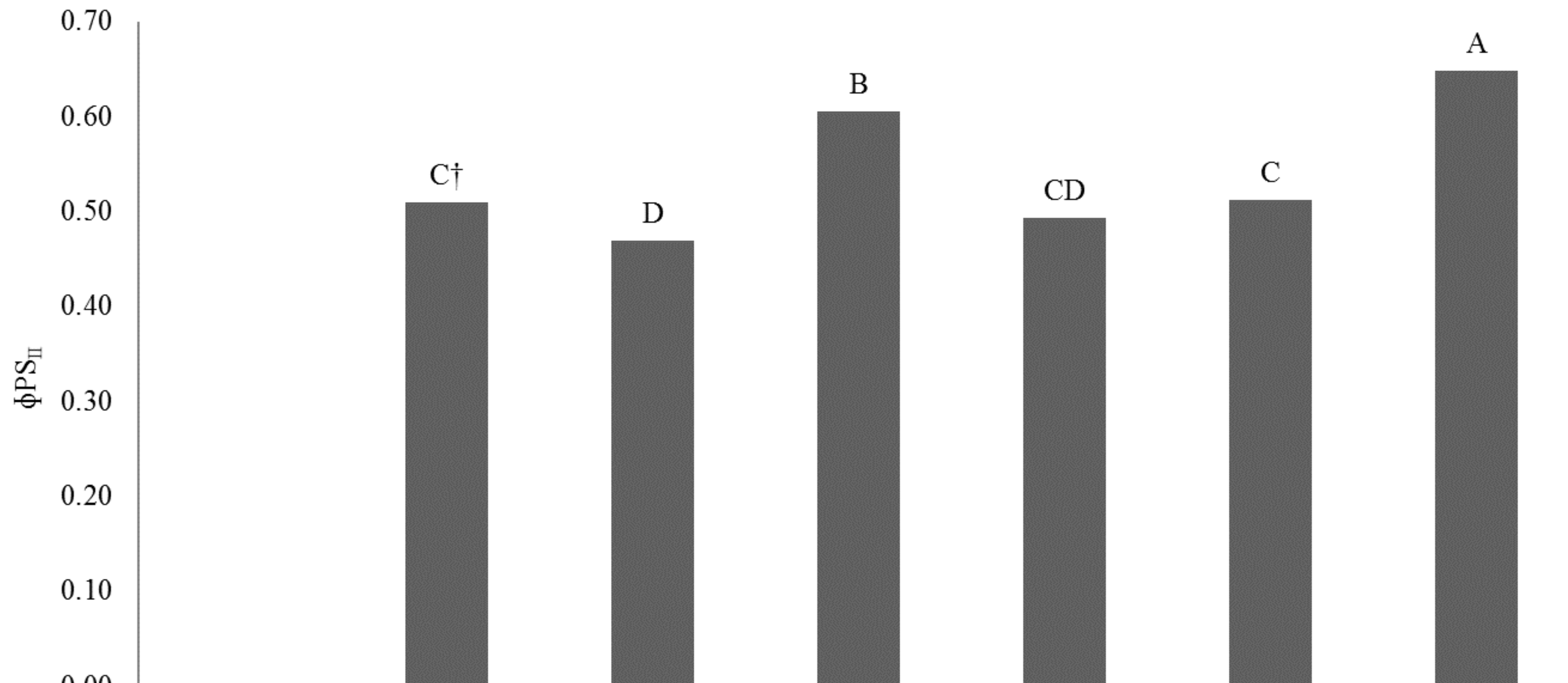
† Means followed by the same letter are not significantly different according to LSD (0.05).

Hybrid (1: Early, 2: Mid, 3: Mid-late, and 4: Late)

Since significant PD x I, H x PD, and H x I interactions existed (Table 5.1), comparisons were also made within appropriate factor combinations. The interactive effect of PD x I on ϕPS_{II} was only significant when measured at the R5 growth stage. Regardless of moisture treatment, the third planting date exhibited the greatest ϕPS_{II} (Fig. 5.1), and was likely due to the narrow range of the planting window and the environmental conditions during grain fill. The length of time included in the planting window spanned only four weeks, and likely was not enough time to adequately describe the extremes of higher and lower ϕPS_{II} measurements from planting both before and after the optimum planting period. Planting date 3 resulted in flowering and grain fill occurring during periods of slightly lower temperatures compared to planting dates 1 and 2. Also, irrigation increased ϕPS_{II} within the second and third planting dates compared to dryland, while irrigation had no effect for the first planting date.

The interactive effect of H x PD on ϕPS_{II} could not be combined over years for measurements at the R3 and R5 growth stage because of a significant year interaction (Table 5.1). Measurements during the R1 growth stage were able to be combined and were significantly influenced by the interactive effect of H x PD (Fig. 5.2).

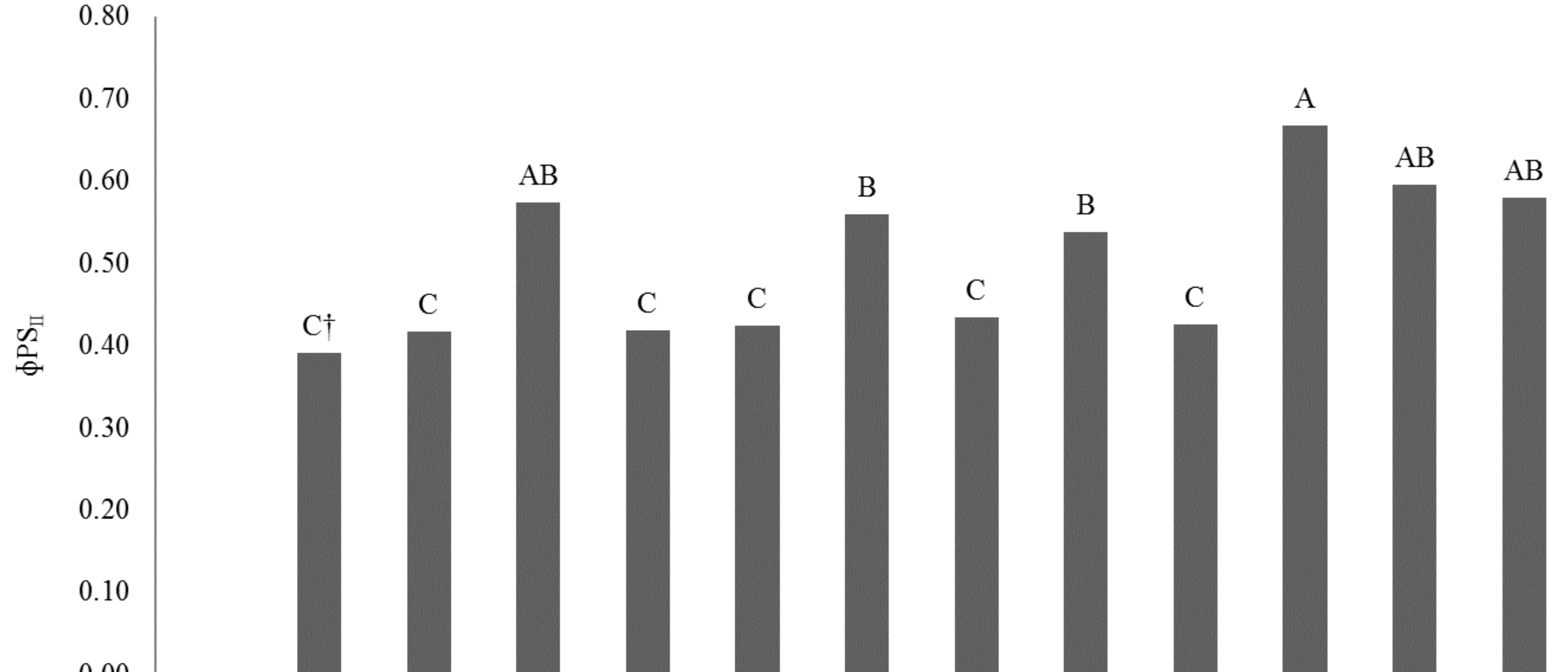
Figure 5.1. Planting date x irrigation effect on quantum yield of photosystem II (ϕPSII) at corn R5 growth stage across years.



	PD :	1 Dry	2 Dry	3 Dry	1 Irrigated	2 Irrigated	3 Irrigated
Mean		0.51	0.47	0.61	0.49	0.51	0.65

† Means followed by the same letter are not significantly different according to LSD (0.05).
PD, Planting Date (1: Feb. 15, 2: Mar. 1, and 3: Mar. 15).
ϕPS_{II}, calculated as $Y = (F_m - F_t) / F_m$, where F_m = maximum fluorescence and F_t = fluorescence at given time.

Figure 5.2. Hybrid x planting date effect on quantum yield of photosystem II (ϕPSII) at corn R1 growth stage across years.



PD :	1	2	3	1	2	3	1	2	3	1	2	3
H :	1	1	1	2	2	2	3	3	3	4	4	4
Mean	0.39	0.42	0.57	0.42	0.42	0.56	0.43	0.54	0.43	0.67	0.60	0.58

† Means followed by the same letter are not significantly different according to LSD (0.05).
PD, Planting Date (1: Feb. 15, 2: Mar. 1, and 3: Mar. 15).
H, Hybrid (1: Early, 2: Mid, 3: Mid-late, and 4: Late).
ϕPS_{II}, calculated as $Y = (F_m - F_t) / F_m$, where F_m = maximum fluorescence and F_t = fluorescence at given time.

For hybrids 1 and 2, the latest planting date resulted in the highest ϕPS_{II} at R1 (Fig. 5.2). The highest ϕPS_{II} observed for hybrid 3 was at planting date 2, while hybrid 4 exhibited the largest ϕPS_{II} with the earliest planting date. Within the first two planting dates, the highest ϕPS_{II} occurred with later maturing hybrids (3 and 4), while the third planting date resulted in a decreased ϕPS_{II} for the hybrid 3 with others being not significantly different. These results indicated that for earlier maturing hybrids, later planting resulted in a higher ϕPS_{II}, and the later maturing hybrids achieved the highest ϕPS_{II} when planted earlier.

The interactive effect of H x I on ϕPS_{II} was not significant during any measured corn growth stages (Table 5.1). The H x I x year interaction, however, was significant for ϕPS_{II} during R3 and R5; therefore, ϕPS_{II} results from the R3 and R5 growth stages could not be combined across years. The H x PD x I interaction was not significant for ϕPS_{II} when measurements were conducted at any of the three growth stages. This interaction could not be combined over years for measurements collected during R3, however, because of a significant H x PD x I x year interaction at this growth stage.

5.2 SEPARATE RESULTS: CHLOROPHYLL FLUORESENCE 2011

Analysis of variance for ϕPS_{II} measured during the reproductive period for 2011 are presented in Table 5.4. The main effect of planting date significantly influenced ϕPS_{II} when measured at R5 in 2011, with no other planting date interactions being significant for this growth stage (Table 5.4).

Table 5.4. Analysis of variance for quantum yield of photosystem II (ϕPS_{II}) measured during corn reproductive growth stages R1, R3, and R5 in 2011.

Source	df	R1	R3	R5
Irrigation (I)	1	ns	ns	ns
Replication	3	ns	*	ns
Error a	3			
Planting Date (PD)	2	*	**	***
PD x I	2	ns	ns	ns
Error b	12			
Hybrid (H)	3	***	***	ns
H x PD	5	***	**	ns
H x I	3	ns	**	ns
H x PD x I	5	ns	ns	ns
Error C	48			
R^2		0.76	0.75	0.54
CV %		10.6	10.8	16.98

* Significant at 0.05 probability level.
** Significant at 0.01 probability level.
*** Significant at 0.001 probability level.
† ns, nonsignificant.

Results for measured ϕPS_{II} for growth stages R1 and R3 were combined over years (Table 5.1). The third planting date resulted in the greatest ϕPS_{II} at R5 in 2011, followed by the first planting date, with the second planting date resulting in the lowest ϕPS_{II} (Table 5.5). This result may indicate that the second planting date was under the most stress during R5 (Fig. 3.1). Combined 2011 and 2012 results from measurements collected during R1 and R3 (Table 5.2) showed a similar trend where the third planting date had the greatest ϕPS_{II}. Again, this is likely due to the range of the planting dates and the environmental conditions during grain fill. The length of time included in this planting window spanned only four weeks and likely was not enough time to adequately describe the extremes of ϕPS_{II} from planting both before and after the optimum planting period.

Table 5.5. Planting date effects on quantum yield of corn photosystem II (ϕPS_{II}) at growth stage R5 in 2011.

Treatment	R5	
Planting Date 1	0.56	b†
Planting Date 2	0.50	c
Planting Date 3	0.64	a
Pr>f	<0.0001	
R^2	0.54	
CV %	16.98	

† Means followed by the same letter are not significantly different according to LSD (0.05).
Planting Date (1: Feb. 15, 2: Mar. 1, and 3: Mar. 15).
ϕPS_{II}, calculated as $Y = (F_m – F_t) / F_m$, where F_m = maximum fluorescence and F_t = fluorescence at given time.

The main effect of hybrid also significantly influenced ϕPS_{II} at R1 in 2011 (Table 5.4). Results for measurements conducted during the R3 growth stage were previously combined over years (Table 5.1). Measurements collected during the R5 growth stage were not significantly different (Table 5.4). Results for hybrid effect at R1 in 2011 showed that later maturing hybrids (3 and 4) achieved higher rates of ϕPS_{II} when compared to hybrids 1 and 2 (Table 5.6). Hybrid 4 also had a higher rate of ϕPS_{II} than hybrid 3. Results of numerous trials indicate that the use of a late-season hybrid, when compared to an early-season hybrid planted on the same day, resulted in greater yield due to an elongated reproductive growth period (Howell et al., 1998; Trooien et al., 1999; Norwood, 2001; Capristo et al., 2007; Raymond et al., 2009; Van Roekel and Coulter, 2012). The combined 2011 and 2012 results for measurements collected during R3 showed a similar trend in that hybrid 4 had the highest ϕPS_{II} and hybrids 1-3 were lower and not statistically different (Table 5.3).

Table 5.6. Hybrid effects on quantum yield of corn photosystem II (ϕPS_{II}) at R1 growth stage in 2011.

Treatment	R1	
Hybrid 1	0.50	c†
Hybrid 2	0.53	c
Hybrid 3	0.58	b
Hybrid 4	0.62	a
Pr>f	<0.0001	
R^2	0.76	
CV %	10.60	

† Means followed by the same letter are not significantly different according to LSD (0.05).

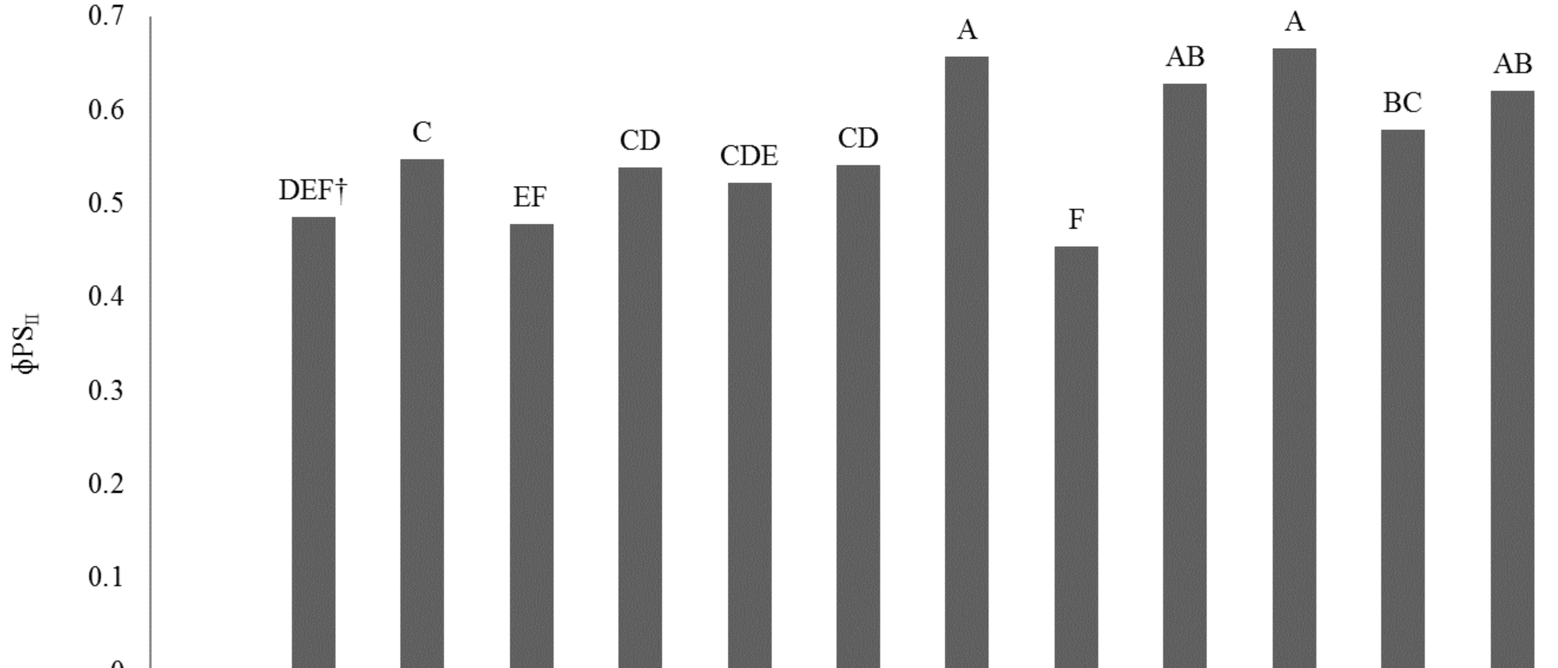
Hybrid (1: Early, 2: Mid, 3: Mid-late, and 4: Late).

ϕPS_{II}, calculated as $Y = (F_m – F_t) / F_m$, where F_m = maximum fluorescence and F_t = fluorescence at given time.

Because significant H x PD and H x I interactions existed (Table 5.4), comparisons were made within appropriate factor combinations. The interactive effect of H x PD significantly influenced ϕPS_{II} at R1 and R3 in 2011. Results for the R1 growth period were able to be combined over years (Table 5.1). The interaction of H x PD during R5 in 2011 was not statistically significant (Table 5.4). Means for ϕPS_{II} at R3 as influenced by the H x PD interaction are presented in Figure 5.3. For all hybrids, the first and last planting date resulted in ϕPS_{II} values that were not significantly different within a hybrid. For hybrids 3, and 4, the second planting date tended to result in lower ϕPS_{II} values when compared to the first and third. Results for hybrid 2 showed no effect of planting date, while for hybrid 1, the second planting date resulted in ϕPS_{II} values that were greater than the first and third dates. The general trend was for greater ϕPS_{II} with longer maturing hybrids. Higher ϕPS_{II} in more drought tolerant hybrids has been well documented (O'Neill et al., 2006; Selmani and Wassom 1993). Numerous studies indicate a late-season hybrid, when compared to an early-season hybrid planted on the same day, provided greater yield (Howell et al., 1998; Trooien et al., 1999; Norwood, 2001; Capristo et al., 2007; Raymond et al., 2009; Van Roekel and Coulter, 2012).

The interactive effect of H x I also significantly influenced ϕPS_{II} at the R3 growth stage in 2011 (Table 5.4). Regardless of irrigation, hybrid 4 achieved the highest ϕPS_{II} values (Fig. 5.4). When irrigation was applied, as hybrid maturity increased, ϕPS_{II} values also increased. Irrigation did not increase ϕPS_{II} in hybrids 1 or 2 compared to dryland, but did in hybrids 3 and 4, likely due to differences in hybrid ϕPS_{II} (O'Neill et al., 2006) and the yield characteristics of a longer season hybrid. Quantum yield decreased under dryland conditions with increased maturity for hybrids 1 through 3, but not for hybrid 4.

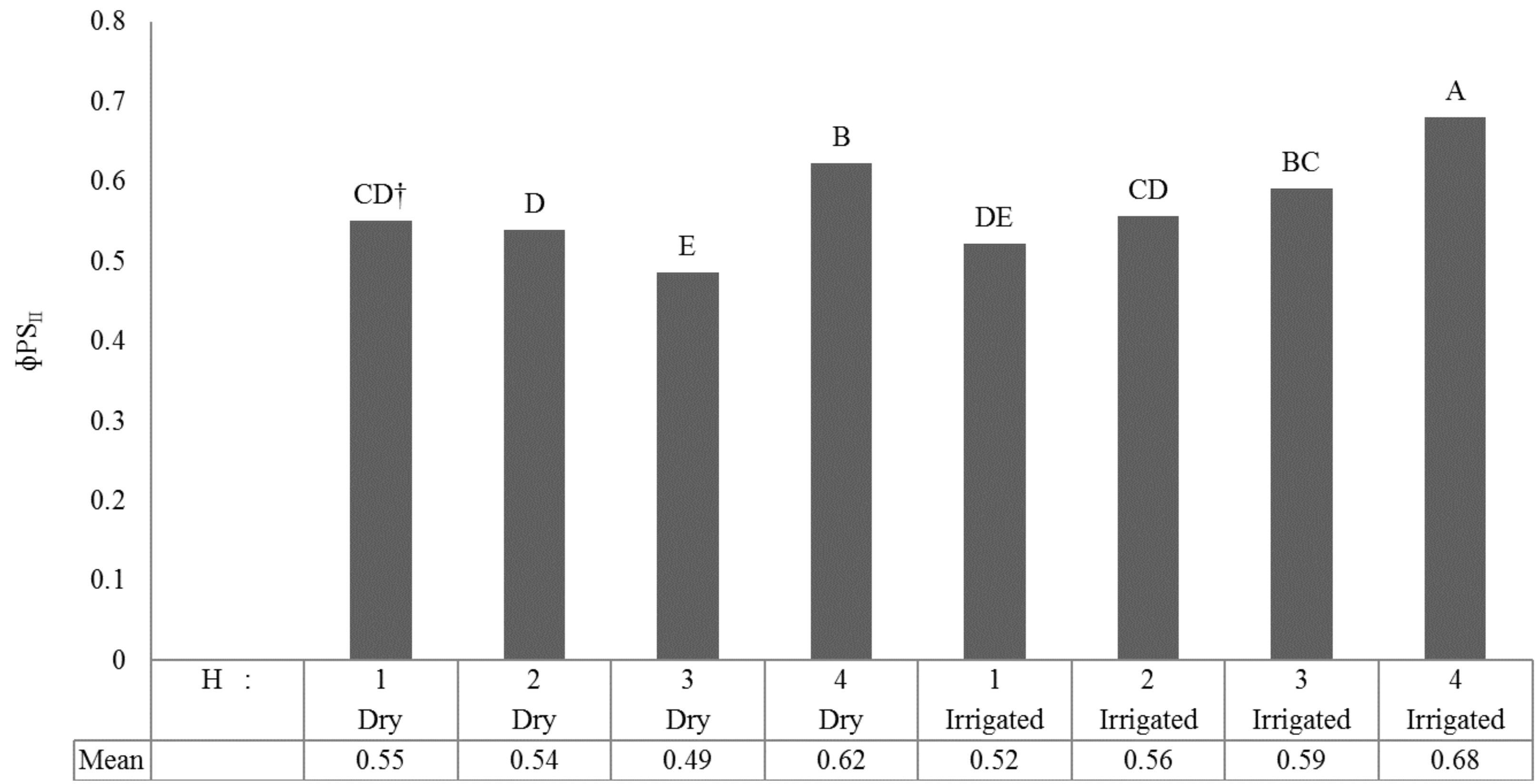
Figure 5.3. Hybrid x planting date effects on quantum yield of photosystem II (ϕPSII) at corn R3 growth stage in 2011.



PD :	1	2	3	1	2	3	1	2	3	1	2	3
H :	1	1	1	2	2	2	3	3	3	4	4	4
Mean	0.49	0.55	0.48	0.54	0.52	0.54	0.66	0.45	0.63	0.67	0.58	0.62

† Means followed by the same letter are not significantly different according to LSD (0.05).
PD, Planting Date (1: Feb. 15, 2: Mar. 1, and 3: Mar. 15).
H, Hybrid (1: Early, 2: Mid, 3: Mid-late, and 4: Late).
ϕPS_{II}, calculated as $Y = (F_m – F_t) / F_m$, where F_m = maximum fluorescence and F_t = fluorescence at given time.

Figure 5.4. Hybrid x irrigation effects on quantum yield of photosystem II (ϕPSII) at corn R3 growth stage in 2011.



† Means followed by the same letter are not significantly different according to LSD (0.05).
H, Hybrid (1: Early, 2: Mid, 3: Mid-late, and 4: Late).
ϕPS$_{II}$, calculated as $Y = (F_m - F_t) / F_m$, where F_m = maximum fluorescence and F_t = fluorescence at given time.

5.3 SEPERATE RESULTS: CHLOROPHYLL FLUORESCENSE 2012

Analysis of variance for ϕPS_{II} measured during the respective corn reproductive periods in 2012 are presented in Table 5.7.

Table 5.7. Analysis of variance for quantum yield of photosystem II (ϕPS_{II}) measured during corn reproductive growth stages R1, R3, and R5 in 2012.

Source	**df**	**R1**	**R3**	**R5**
Irrigation (I)	1	ns†	ns	ns
Replication	3	ns	ns	ns
Error a	3	-	-	-
Planting Date (PD)	2	*	**	***
PD x I	2	ns	ns	**
Error b	12	-	-	-
Hybrid (H)	3	ns	**	***
H x PD	5	ns	***	ns
H x I	3	ns	ns	ns
H x PD x I	5	ns	ns	ns
Error C	48	-	-	-
R^2		0.78	0.74	0.86
CV %		17.48	23.45	15.05

* Significant at 0.05 probability level.
** Significant at 0.01 probability level.
*** Significant at 0.001 probability level.
† ns, nonsignificant.

The main effect of irrigation on ϕPS_{II} was not statistically significant at any growth stage in either year (Tables 5.4 and 5.7). The main effect of planting date, however, significantly influenced ϕPS_{II} at all three growth stages in 2012 (Table 5.7). However, results at R1 and R3 were able to be previously combined over years (Table 5.1). As planting date was delayed in 2012, ϕPS_{II} at R5 increased (Table 5.8). The combined results from measurements collected at R1 and R3 showed the same trend (Table 5.2). Quantum yield results during R5 in 2011 also exhibited a similar pattern as those in 2012 (Tables 5.5 and 5.8). Again, this was likely due to the range of the planting window and the environmental conditions during grain fill. The length of time included in this planting window spanned only four weeks and likely was not wide enough to result in extremes of ϕPS_{II} from planting both before and after the optimum planting period.

Table 5.8. Planting date effects on quantum yield of photosystem II (ϕPS_{II}) at corn growth stage R5 in 2012.

Treatment	R5	
Planting Date 1	0.44	c†
Planting Date 2	0.48	b
Planting Date 3	0.62	a
Pr>f	0.0186	
R^2	0.78	
CV %	17.48	

† Means followed by the same letter are not significantly different according to LSD (0.05).
Planting Date (1: Feb. 15, 2: Mar. 1, and 3: Mar. 15).
ϕPS_{II}, calculated as $Y = (F_m - F_t) / F_m$, where F_m = maximum fluorescence and F_t = fluorescence at given time.

The main effect of hybrid significantly influenced ϕPS_{II} in 2012 at R3 and R5, but not at R1 (Table 5.7). Measurements collected during R3, however, were able to be combined over years and were previously presented in Table 5.3. The two later maturing hybrids (3 and 4) had significantly greater ϕPS_{II} values at R5 in 2012 compared to shorter maturity hybrids (1 and 2) (Table 5.9). These results were similar to those for R1 in 2011 (Table 5.6) and combined results over years for R3 (Table 5.3).

Table 5.9. Hybrid effects on quantum yield of photosystem II (ϕPS_{II}) at corn R5 growth stage in 2012.

Treatment	R5	
Hybrid 1	0.41	b†
Hybrid 2	0.41	b
Hybrid 3	0.63	a
Hybrid 4	0.59	a
Pr>f	<0.0001	
R^2	0.86	
CV %	15.05	

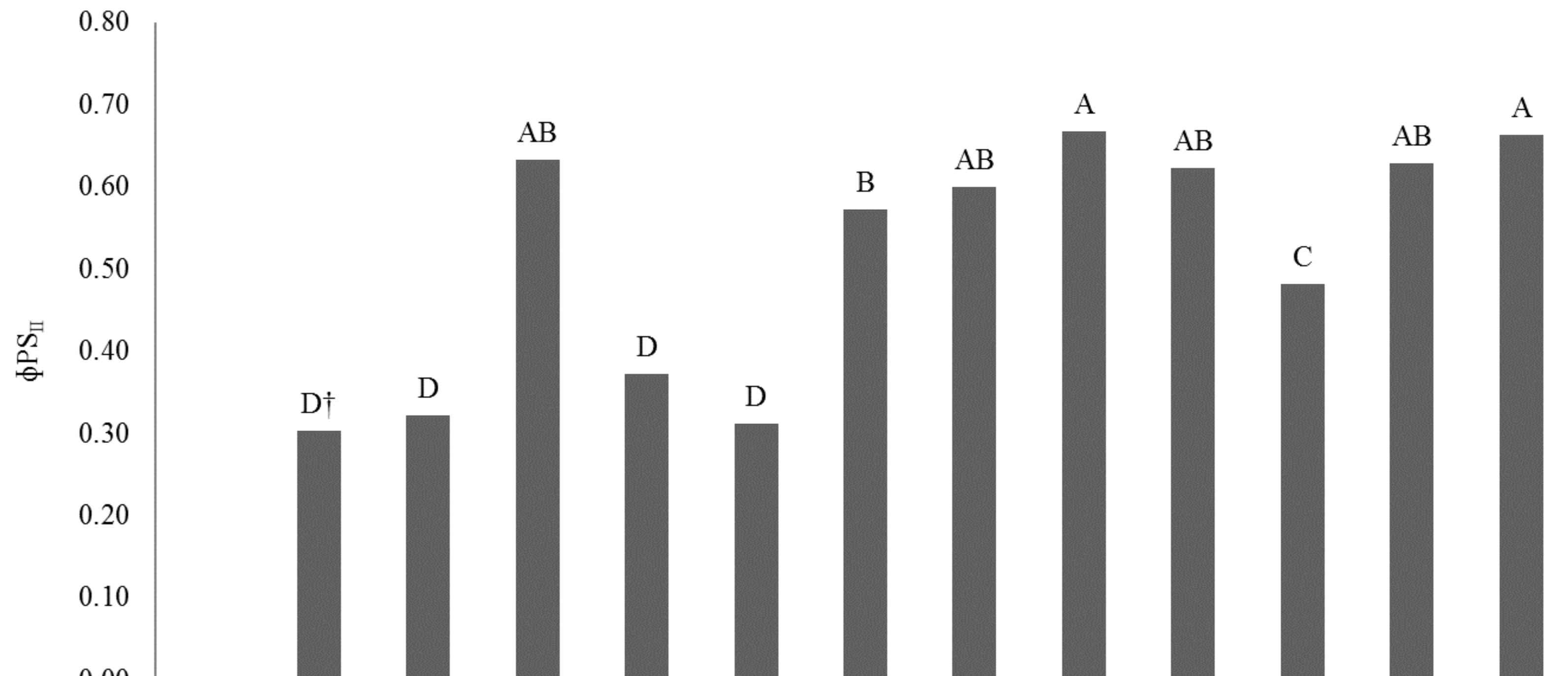
† Means followed by the same letter are not significantly different according to LSD (0.05).

Hybrid (1: Early, 2: Mid, 3: Mid-late, and 4: Late).

ϕPS_{II}, calculated as $Y = (F_m - F_t) / F_m$, where F_m = maximum fluorescence and F_t = fluorescence at given time.

Since a highly significant H x PD interaction existed at R3 (Table 5.7), comparisons were made within appropriate factor combinations. Results for the R1 growth stage were able to previously be combined over years (Table 5.1). For hybrids 1 and 2, planting date 3 resulted in the highest value in 2012 (Fig. 5.5). Planting date had no effect on ϕPS_{II} for hybrid 3 in 2012, while the greatest values for hybrid 4 were associated with planting dates 2 and 3. Within planting date, the later maturing hybrids (3 and 4) generally exhibited higher ϕPS_{II} values than the earlier maturing hybrids (1 and 2). Planting date 3 tended to result in increased ϕPS_{II} when compared to earlier planting dates.

Figure 5.5. Hybrid x planting date effect on quantum yield of photosystem II (ϕPSII) at corn growth stage R3 in 2012.



	PD :	1	2	3	1	2	3	1	2	3	1	2	3
	H :	1	1	1	2	2	2	3	3	3	4	4	4
Mean		0.30	0.32	0.63	0.37	0.31	0.57	0.60	0.67	0.62	0.48	0.63	0.66

† Means followed by the same letter are not significantly different according to LSD (0.05).

PD, Planting Date (1: Feb 15, 2: Mar 1, and 3: Mar 15).

H, Hybrid (1: Early, 2: Mid, 3: Mid-late, and 4: Late).

ϕPS_{II}, calculated as $Y = (F_m - F_t) / F_m$, where F_m = maximum fluorescence and F_t = fluorescence at given time.

6. CANOPY TEMPERATURE DEPRESSION: RESULTS AND DISCUSSION

Canopy temperature was measured throughout the growing season. However, canopy temperature depression (CTD) was only calculated for three growth stages, R1, R3, and R5, within the corn reproductive period during 2011 and 2012.

6.1 COMBINED RESULTS: CANOPY TEMPERATURE DEPRESSION

The analysis of variance for CTD for combined years is presented in Table 6.1. The main effect of irrigation on CTD was not significant combined over years when measured at R1, but was significant at R3 and R5. Differences between canopy temperature and air temperature increased with irrigation when measured during either R3 or R5 growth stages (Table 6.2). When comparing measurements across growth stages, decreased CTD was observed at R5 compared to R3 and was likely due to the transition by the corn plant to draw upon carbohydrate reserves as opposed to photosynthetic gain, also known as “drying down”. Both irrigated and dryland plots had a canopy temperature that was significantly cooler than ambient temperature, with irrigated plots having a greater CTD.

Table 6.1. Analysis of variance for canopy temperature depression measured during three corn reproductive growth stages R1, R2, and R3 and combined over years.

Source	df	R1	R3	R5
Year	1	***	ns†	***
Replication	3	ns	ns	*
Year x Rep	6	ns	ns	***
Irrigation (I)	1	ns	**	*
Year x Irrigation	1	**	ns	ns
Error a	1			
Planting Date (PD)	2	***	***	**
PD x Year	2	**	***	***
PD x I	2	*	ns	ns
PD x I x Year	2	ns	**	**
Error b	11			
Hybrid (H)	3	***	**	ns
H x Year	3	**	***	***
H x PD	6	ns	***	ns
H x PD x Year	6	ns	***	***
H x I	3	***	ns	ns
H x I x Year	3	ns	ns	*
H x PD x I	6	ns	ns	ns
H x PD x I x Year	6	ns	ns	ns
Error C	51			
R^2		0.87	0.83	0.70
CV %		58.40	26.06	32.08

* Significant at 0.05 probability level.
** Significant at 0.01 probability level.
*** Significant at 0.001 probability level.
† ns, nonsignificant.

Table 6.2. Irrigation effects on corn canopy temperature depression combined over years at growth stages R3 and R5.

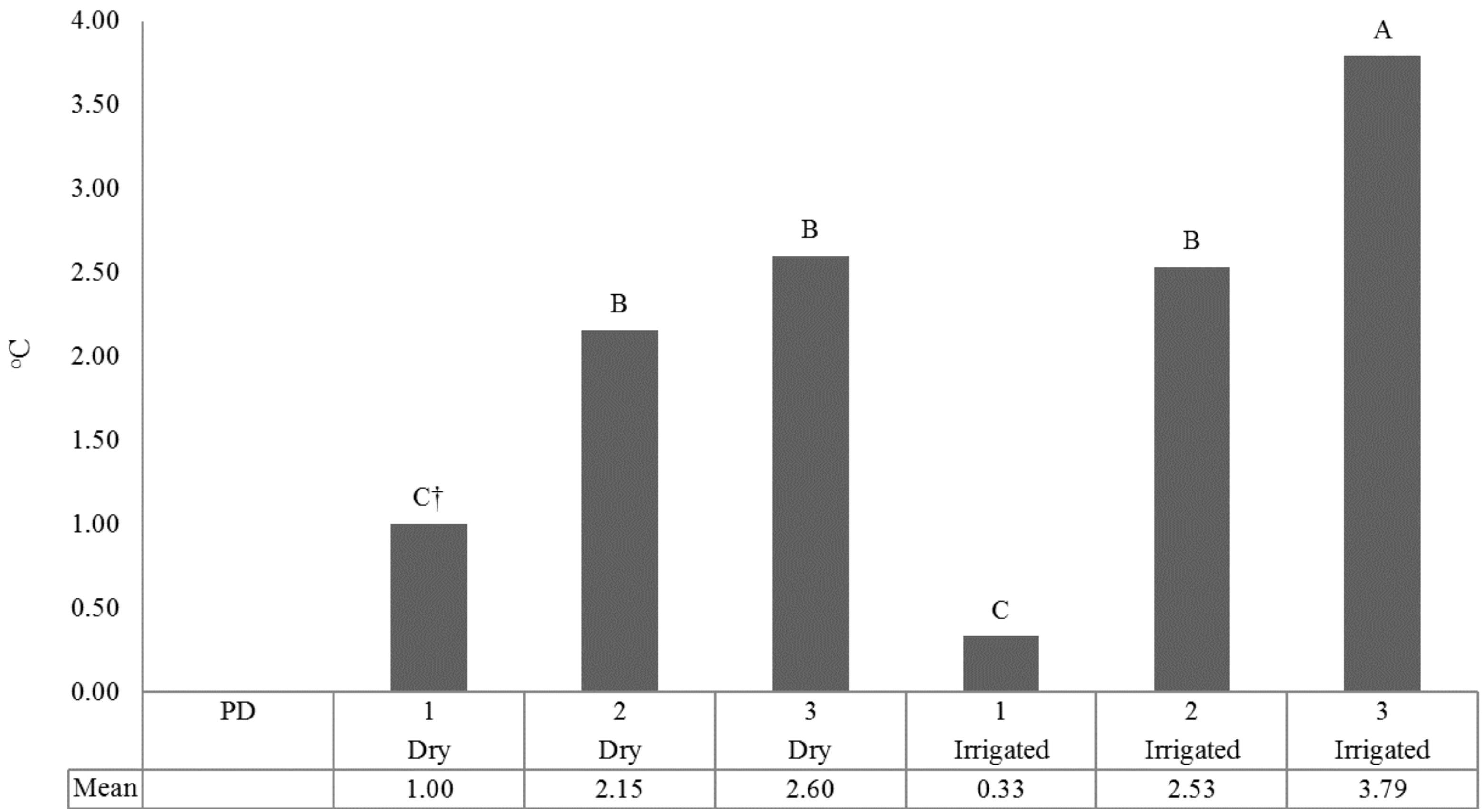
Treatment	R3		R5	
Dryland	4.42†	b‡	3.75	b
Irrigated	6.54	a	4.95	a
Pr>f	0.0046		0.0313	
R^2	0.52		0.32	
CV %	43.05		46.6	

† Units are degrees Celsius.
‡Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

The main effects of planting date and hybrid on CTD could not be combined over years for any of the three growth stages because of significant treatment interactions with year (Table 6.1). The interactive effect of PD x I significantly affected CTD when measured at R1, but not at R3 and R5. The interactive effect of PD x I involved a significantly greater temperature depression for the latest planting date when coupled with irrigation (Fig. 6.1). Regardless of irrigation, canopy temperatures were closer to ambient for the first planting date, with greater separation as planting dates progressed. This data suggested that corn from the second and third planting dates was under less stress than that from the first planting date. Several investigators have used canopy temperature as a gauge for drought tolerance and yield stability (Singh and Kanemasu, 1983; Blum et al., 1989; Stark et al., 1991; Rashid et al., 1999). In these studies, a positive correlation was found between drought susceptibility and canopy temperature. The most drought resistant plants usually exhibited the lowest canopy temperatures under stressed environments. Planting date results are likely somewhat limited due to the narrow range of the planting window (four weeks) and the environmental conditions during grain fill. This range most likely was not long enough to adequately describe extremes of higher and lower CTD from planting both before and after the optimum planting period. A greater separation for CTD was generally also observed for irrigated plots across planting dates than for dryland plots.

The interactive effect of H x PD on CTD was not significant when measured at R1 and R5 (Table 6.1). The interaction of H x PD x year was significant at R3 and R5 and effects, therefore, could not be combined over years. The interactive effect of H x I on CTD was significant when measured at R1, but not at R3 and R5. Measurements taken at R5 were unable to be combined over years because of a significant H x I x year interaction.

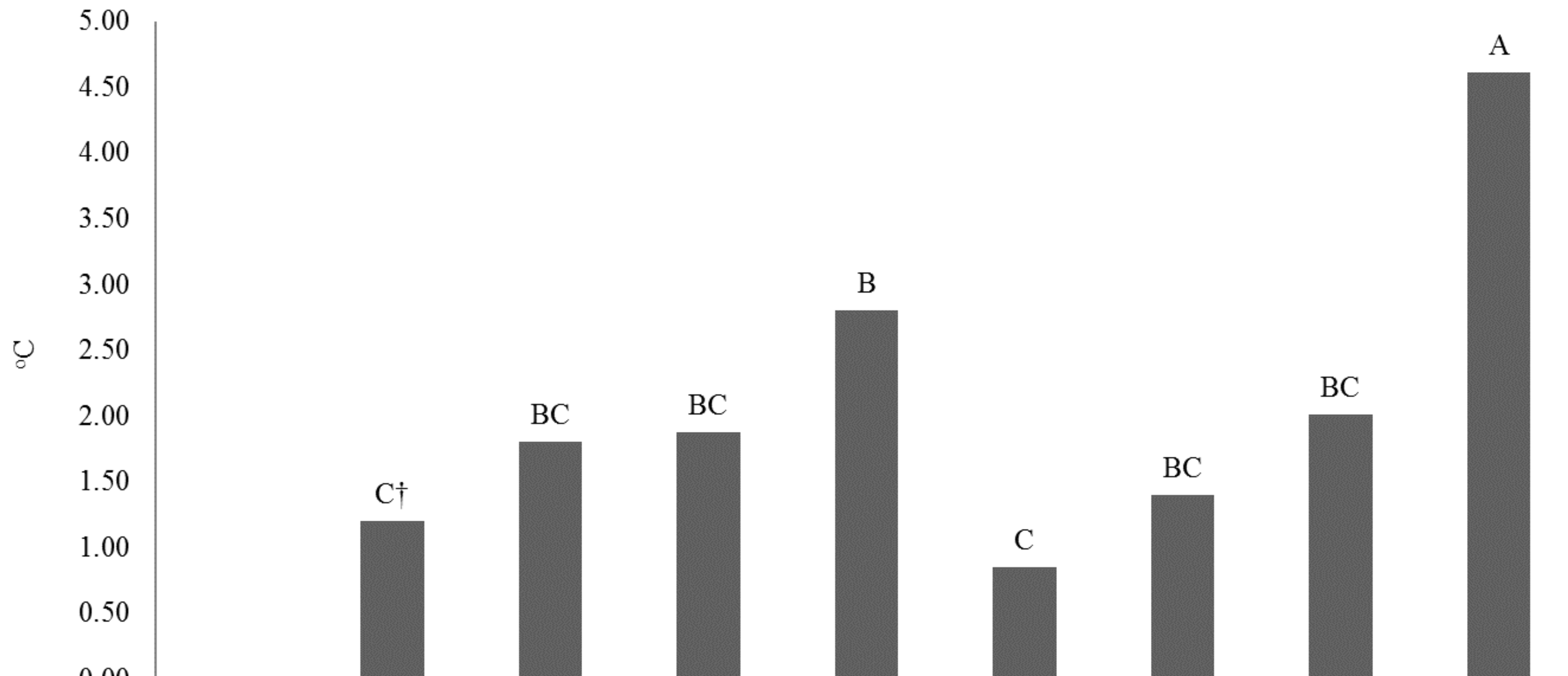
Figure 6.1. Planting date x irrigation effect on corn canopy temperature depression at R1 combined over years.



† Means followed by the same letter are not significantly different according to LSD (0.05).
PD, Planting Date (1: Feb. 15, 2: Mar. 1, and 3: Mar. 15)

Results of the H x I interaction indicated that CTD was greater for hybrid 4, regardless of irrigation level, when compared to hybrid 1 (Fig. 6.2). Irrigation also significantly increased CTD in hybrid 4, but did not significantly influence CTD for the other hybrids. A numerical trend worth noting is the increase in CTD with increasing hybrid maturity; however, these results were not statistically significant. Capristo et al. (2007) found that biomass increased positively and linearly with hybrid cycle length growing degree units (GDU). Long-season hybrids had highest light interception but the lowest radiation use efficiency. Grain yields were lowest for short-season hybrids and equivalent for mid-season and full-season hybrids. Also, hybrids with a short developmental time from emergence to flower, but a long developmental time from flower to maturity produced the greatest radiation interception and grain yield. The H x PD x I interaction was not significant for CTD during any growth stage (Table 6.1).

Figure 6.2. **Hybrid x irrigation effect on corn canopy temperature depression at R1 combined over years.**



H :	1 Dry	2 Dry	3 Dry	4 Dry	1 Irrigated	2 Irrigated	3 Irrigated	4 Irrigated
Mean	1.20	1.80	1.88	2.80	0.85	1.40	2.01	4.61

† Means followed by the same letter are not significantly different according to LSD (0.05).
H, Hybrid (1: Early, 2: Mid, 3: Mid-late, and 4: Late

6.2 SEPARATE RESULTS: CANOPY TEMPERATURE DEPRESSION 2011

The analysis of variance for canopy temperature depression (CTD) measured during the 2011 reproductive period is presented in Table 6.3.

Table 6.3. Analysis of variance for corn canopy temperature depression measured during reproductive growth stages R1, R3, and R5 in 2011.

ource	df	R1	R3	R5
Irrigation (I)	1	ns†	*	ns
Replication	3	ns	ns	**
Error a	1			
Planting Date (PD)	2	***	***	***
PD x I	2	ns	ns	ns
Error b	11			
Hybrid (H)	3	***	***	ns
H x PD	6	ns	***	***
H x I	3	***	ns	*
H x PD x I	6	ns	**	ns
Error c	51			
R^2		0.82	0.89	0.78
CV %		26.03	28.07	33.8

* Significant at 0.05 probability level.
** Significant at 0.01 probability level.
*** Significant at 0.001 probability level.
† ns, nonsignificant.

The main effect of irrigation on CTD at R1 and R5 was not significant in 2011 (Table 6.3). Results for CTD during the R3 and R5 growth stages were able to be combined over years because the year x irrigation effect at these stages was not significant (Table 6.1). The main effect of planting date significantly affected CTD at all growth stages in 2011 (Table 6.3). For CTD measurements at the R1 growth stage, the earliest planting date resulted in canopy temperatures that were warmer than ambient temperatures, indicating a very stressed crop (Table 6.4). For measurements during R3 and R5, however, the earliest planting date produced plants with significantly greater CTD than the latest planting date, indicating that plants from the latest planting date were under more stress than those from the earliest planting date.

Table 6.4. Planting date effects on corn canopy temperature depression at growth stages R1, R3, and R5 in 2011.

Treatment	R1		R3		R5	
Planting Date 1	-1.65†	b‡	6.16	a	6.53	a
Planting Date 2	0.68	a	6.48	a	3.18	b
Planting Date 3	1.03	a	3.64	b	4.42	b
Pr>f	0.0003		<0.0001		0.0004	
R^2	0.82		0.89		0.78	
CV %	26.03		28.07		33.8	

† Units are degrees Celsius.
‡Within columns, means followed by the same letter are not significantly different according to LSD (0.05).
Planting Date (1: Feb. 15, 2: Mar. 1, and 3: Mar. 15).

The main effect of hybrid on CTD was significant when measured at R1 and R3 in 2011 (Tables 6.3 and 6.5). Canopy temperatures during the R1 growth stage were closer to ambient temperatures than at R3 for all hybrids, and was likely due to the moisture stress in 2011 (169 mm rainfall) and the elevated maximum temperature at that time (Fig. 3.1). Hybrid 4 exhibited the greatest CTD at R1 and equivalent to the greatest CTD at the R3 growth stage.

Table 6.5. Hybrid effects on corn canopy temperature depression at growth stages R1 and R3 in 2011.

Treatment	R1		R3	
Hybrid 1	-0.62†	b‡	5.05	b
Hybrid 2	-0.38	b	6.30	a
Hybrid 3	-0.74	b	4.39	b
Hybrid 4	1.82	a	5.98	a
Pr>f	<.0001		0.0002	
R^2	0.82		0.89	
CV %	26.03		28.07	

† Units are degrees Celsius.
‡Within columns, means followed by the same letter are not significantly different according to LSD (0.05).
Hybrid (1: Early, 2: Mid, 3: Mid-late, and 4: Late).

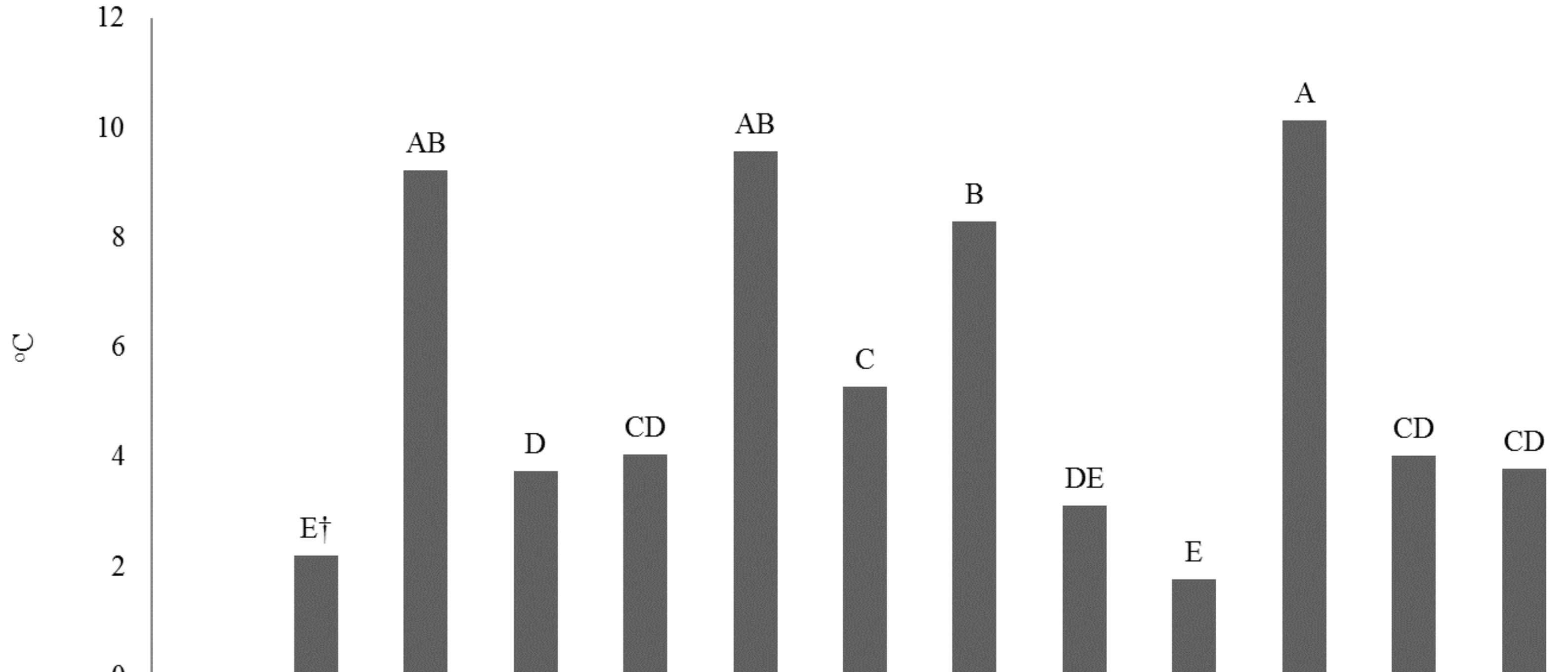
Since highly significant H x PD and H x I interactions existed (Table 6.3), comparisons were made within appropriate factor combinations. The interactive effect of PD x I was not significant for CTD at any growth stage in 2011, but H x PD was significant when measured at R3 and R5. Results for the latter interaction at R3 are shown in Fig. 6.3 while those at R5 are presented in Fig. 6.4. For R3, within the first planting date, as hybrid maturity increased, CTD also significantly increased (Fig. 6.3).

Within the second planting date, however, a large separation was observed, with the two earlier maturing hybrids having greater CTD than the two later maturing hybrids. The third planting date had mixed results, with hybrid 3 exhibiting the lowest CTD. With the focus on hybrid, the two earlier maturing hybrids had the greatest CTD for planting date 2, while the two later maturing hybrids achieved the greatest CTD with the first planting date.

At R5, all four hybrids showed the greatest CTD with the earliest planting date (Fig. 6.4). The lowest CTD was observed with the second planting date for the later maturing hybrids 3 and 4. O'Neill et al. (2006) measured leaf temperature in conjunction with chlorophyll fluorescence measurements and recorded an increase in leaf temperature (2.5 °C) when deficit irrigation plots were compared to adequately irrigated plots. Results also demonstrated that under stress, leaf temperature was 2.8°C cooler for tolerant vs. susceptible hybrids, while all hybrids produced similar leaf temperatures under no stress.

The interactive effect of H x I significantly affected CTD at R1 and R5 in 2011 (Table 6.3). Measurements for R1 were able to be previously combined over years and measurements for R3 were not significant (Table 6.1). For R5, hybrid 3 had the least CTD than all other hybrids under dryland conditions, but CTD for all hybrids was similar with irrigation (Fig. 6.5).

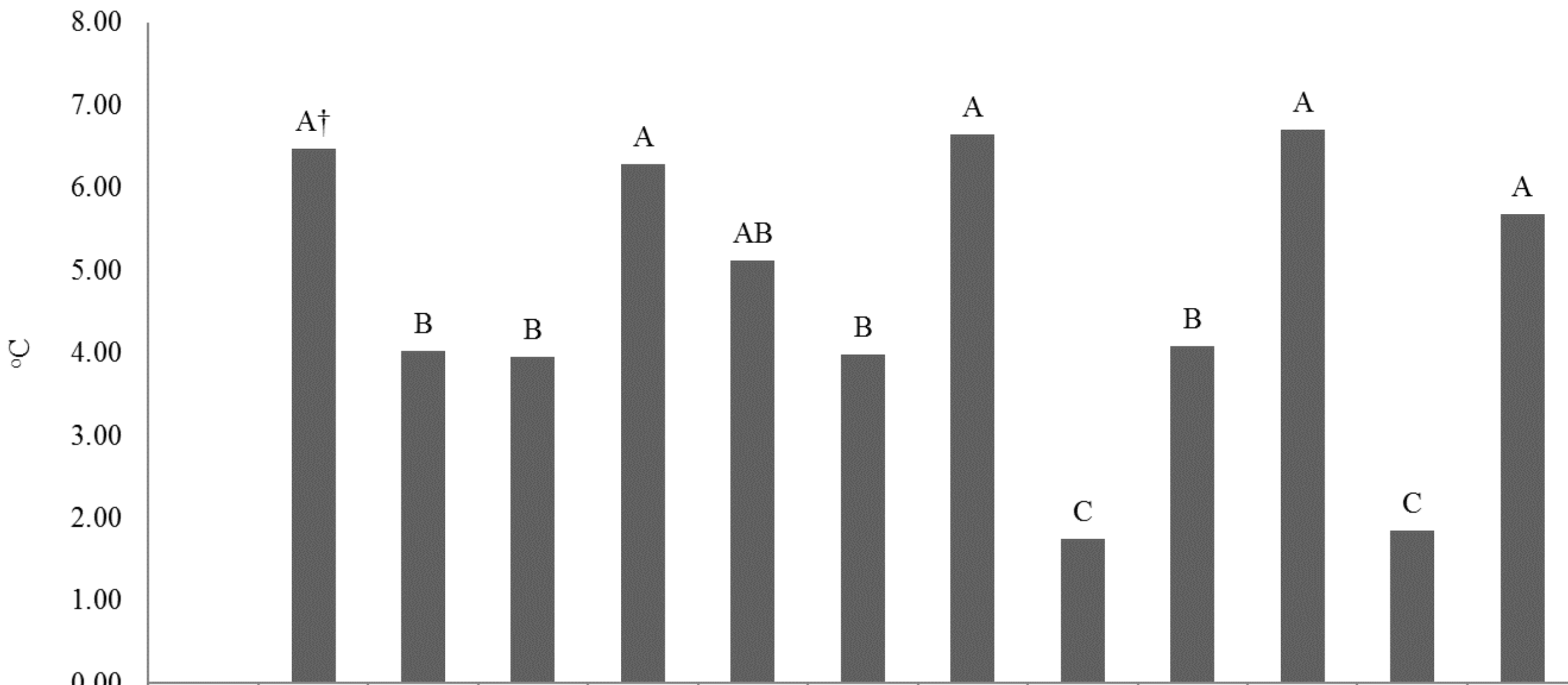
Figure 6.3. Hybrid x planting date effects on corn canopy temperature depression at R3 in 2011.



PD	:	1	2	3	1	2	3	1	2	3	1	2	3
H	:	1	1	1	2	2	2	3	3	3	4	4	4
Mean		2.20	9.22	3.74	4.04	9.56	5.28	8.29	3.12	1.77	10.13	4.02	3.79

† Means followed by the same letter are not significantly different according to LSD (0.05).
PD, Planting Date (1: Feb. 15, 2: Mar. 1, and 3: Mar. 15).
H, Hybrid (1: Early, 2: Mid, 3: Mid-late, and 4: Late).

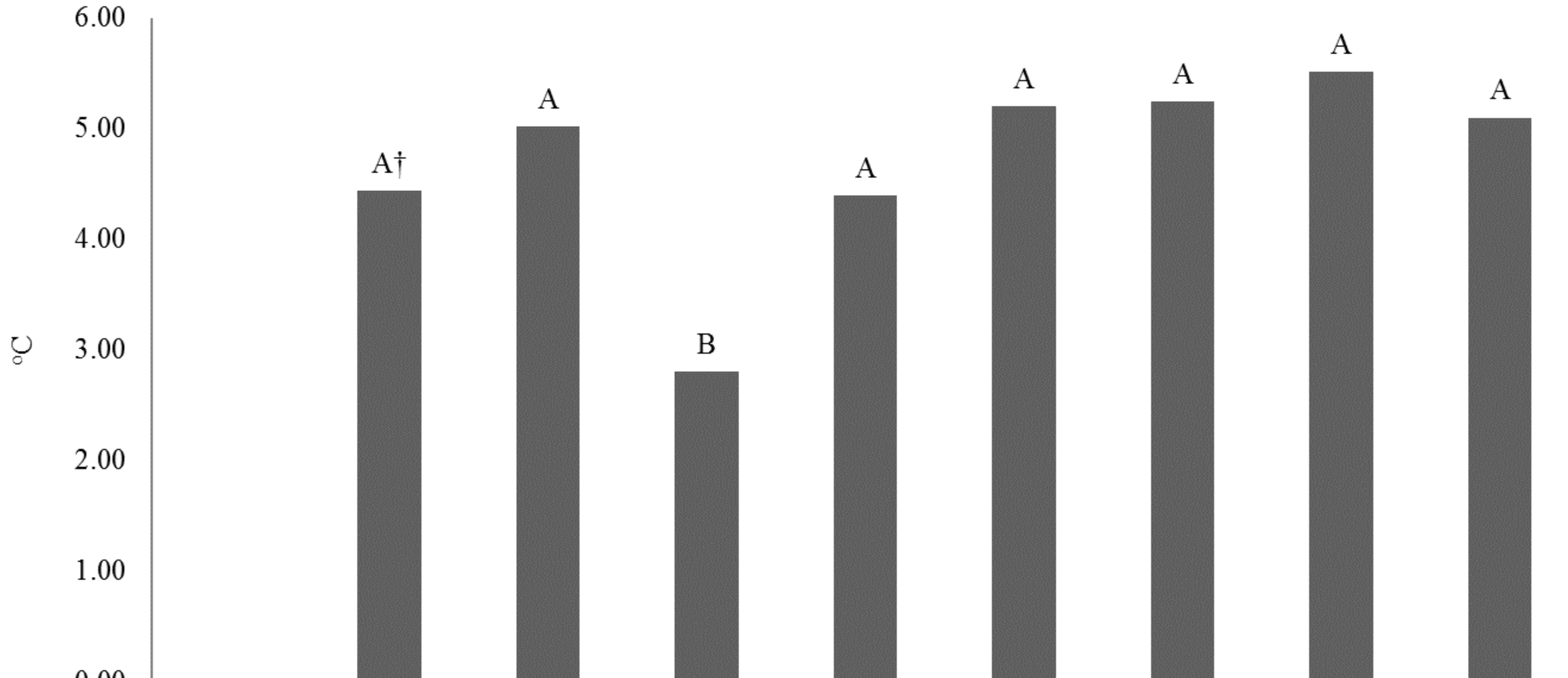
Figure 6.4. Hybrid x planting date effects on corn canopy temperature depression at R5 in 2011.



PD :	1	2	3	1	2	3	1	2	3	1	2	3
H :	1	1	1	2	2	2	3	3	3	4	4	4
Mean	6.48	4.03	3.96	6.28	5.12	3.98	6.65	1.74	4.08	6.71	1.85	5.68

† Means followed by the same letter are not significantly different according to LSD (0.05).
PD, Planting Date (1: Feb. 15, 2: Mar. 1, and 3: Mar. 15).
H, Hybrid (1: Early, 2: Mid, 3: Mid-late, and 4: Late).

Figure 6.5. Hybrid x irrigation effects on corn canopy temperature depression at R5 in 2011.



	H :	1 Dry	2 Dry	3 Dry	4 Dry	1 Irrigated	2 Irrigated	3 Irrigated	4 Irrigated
Mean		4.44	5.01	2.80	4.39	5.20	5.24	5.51	5.10

† Means followed by the same letter are not significantly different according to LSD (0.05).
H, Hybrid (1: Early, 2: Mid, 3: Mid-late, and 4: Late)

6.3 SEPARATE RESULTS: CANOPY TEMPERATURE DEPRESSION 2012

The analysis of variance for CTD measured during the reproductive period for 2012 is presented in Table 6.6. The main effect of irrigation when measured at all measured reproductive stages significantly affected CTD in 2012. Measurements collected during the R3 and R5 growth stages were previously combined over years (Table 6.1).

Table 6.6. Analysis of variance for corn canopy temperature depression measured during three reproductive growth stages in 2012.

Source	df	R1	R3	R5
Irrigation (I)	1	**	*	**
Replication	3	ns†	**	**
Error a	3			
Planting Date (PD)	2	***	***	***
PD x I	2	ns	*	ns
Error b	12			
Hybrid (H)	3	***	***	***
H x PD	6	ns	***	***
H x I	3	*	ns	ns
H x PD x I	6	*	**	ns
Error C	52			
R^2		0.85	0.88	0.86
CV %		22.5	19.27	20.3

* Significant at 0.05 probability level.
** Significant at 0.01 probability level.
*** Significant at 0.001 probability level.
† ns, nonsignificant.

The difference between corn canopy and air temperatures at R1increased with irrigation in 2012, with irrigated plants having significantly greater CTD than dryland plants (Table 6.7). Results were similar to the results combined over years for the R3 and R5 growth stages (Tables 6.2 and 6.7).

Table 6.7. Irrigation effects on corn canopy temperature depression at R1 in 2012.

Treatment	**R1**	
Dryland	3.72†	b‡
Irrigated	4.61	a
Pr>f	0.003	
R^2	0.85	
CV %	22.52	

† Units are degrees Celsius.
‡Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

The main effect of planting date also significantly affected CTD when measured at all reproductive stages in 2012 (Table 6.6). When CTD was measured at any growth stage in 2012, the third planting date resulted in the greatest difference between canopy and ambient air temperatures when compared to the earliest planting date (Table 6.8). Results for R1 in 2012 were similar to those measured in 2011 (Table 6.4) in that the third planting date also had the greatest CTD and the first planting date had the lowest CTD. Results for R3 and R5 in 2012 also showed that the third planting date had the greatest CTD and the first planting date had the lowest CTD (Table 6.8). These results contrast with R3 and R5 results for 2011 where the inverse was true (Table 6.4). Although there were CTD differences for planting date in 2012, planting date did not result in a significant difference in grain yield in 2012 (Table 3.6).

Table 6.8. Planting date effects on corn canopy temperature depression at three growth stages in 2012.

Treatment	R1		R3		R5	
Planting Date 1	3.11†	c‡	4.44	b	3.35	c
Planting Date 2	4.04	b	6.04	a	3.84	b
Planting Date 3	5.36	a	6.14	a	4.80	a
Pr>f	<0.0001		0.0001		<0.0001	
R^2	0.85		0.88		0.86	
CV %	22.52		19.27		20.33	

† Units are degrees Celsius.
‡Within columns, means followed by the same letter are not significantly different according to LSD (0.05).
Planting Date (1: Feb. 15, 2: Mar. 1, and 3: Mar. 15).

The main effect of hybrid on CTD was significant at all reproductive stages in 2012 (Table 6.6). When CTD was measured at the three growth stages, later maturing hybrids (3 and 4) had significantly greater canopy temperature depressions than the earliest maturing hybrids (1 and 2), indicating that the longer RM hybrids were better suited for ambient conditions and stressed less than earlier maturing hybrids during the 2012 cropping season (Table 6.9). Hybrid 4 also exhibited significantly greater CTD than hybrid 3 at R1 and R5. O'Neill et al. (2006) reported a 2.8 °C cooler leaf temperature for drought tolerant hybrids compared to susceptible hybrids.

Table 6.9. Hybrid effects on corn canopy temperature depression at three growth stages in 2012.

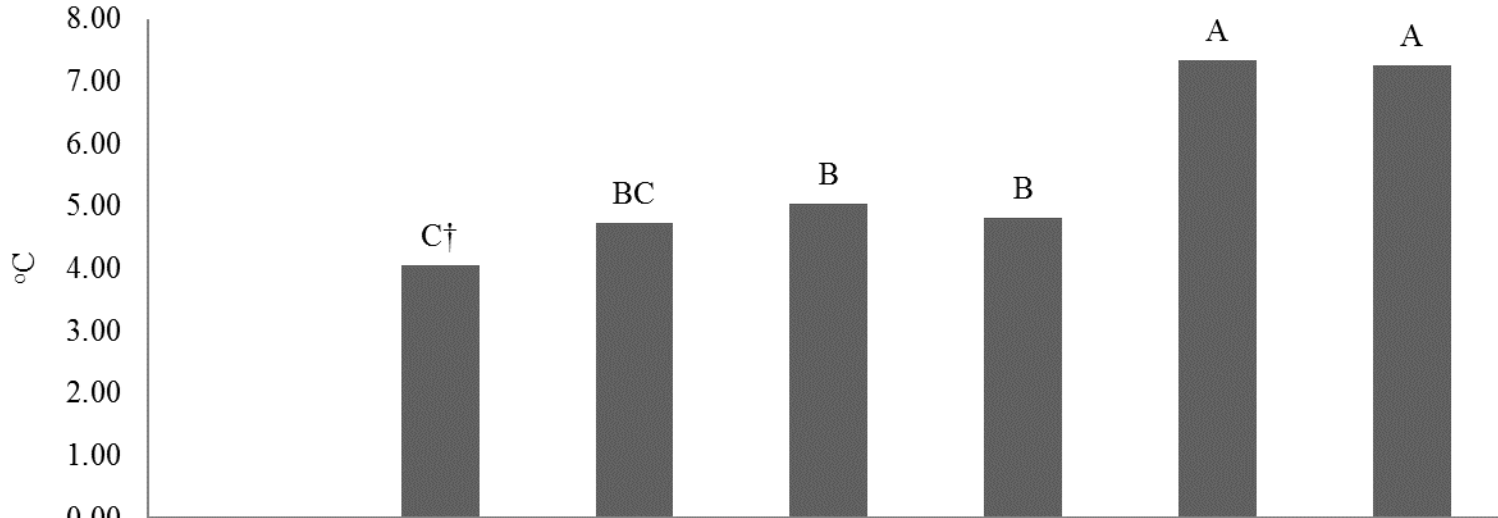
Treatment	R1		R3		R5	
Hybrid 1	2.71†	d‡	3.93	c	3.48	c
Hybrid 2	3.58	c	5.04	b	3.17	c
Hybrid 3	4.80	b	6.58	a	4.40	b
Hybrid 4	5.59	a	6.61	a	4.94	a
Pr>f	<0.0001		<0.0001		<0.0001	
R^2	0.85		0.88		0.86	
CV %	22.52		19.27		20.33	

† Units are degrees Celsius.
‡Within columns, means followed by the same letter are not significantly different according to LSD (0.05).
Hybrid (1: Early, 2: Mid, 3: Mid-late, and 4: Late).

Significant PD x I, H x PD, and H x I interactions existed for some reproductive stages, so comparisons were made within appropriate factor combinations (Table 6.6). The interactive effect of PD x I measured at R3 significantly affected CTD in 2012 (Fig. 6.6). Later planting dates resulted in a greater CTD at R3, indicating a lower stress environment for later planting dates during this growth stage. Irrigation enhanced CTD for all planting dates, especially the latter two dates. The PD x I interaction results for the R3 growth stage in 2012 were similar to those at the R1 growth stage combined over years (Fig. 6.1).

The interactive effect of H x PD for CTD was significant at R3 and R5 in 2012 (Table 6.6). Within the first planting date, as hybrid maturity increased, CTD at R3 also increased (Fig. 6.7). Results are consistent with 2011 where later maturing hybrids combined with early planting dates resulted in the greatest CTD (Fig. 6.3). Within the second planting date, a large separation was noted between hybrids 1, 2, and 3 and hybrid 4, with hybrid 4 having a greater CTD than the other three hybrids (Fig. 6.7). Results conflicted with 2011 findings for the second planting date where hybrids 1 and 2 had significantly greater CTD compared to hybrids 3 and 4 (Fig. 6.3). The conflicting results are likely due to the lower rainfall (Fig. 3.1) and elevated temperatures in 2011 and could indicate a stress event in 2011 that limited the yield potential of the later maturing hybrids for the second planting date. The third planting date had mixed results with hybrid 3 having the greatest CTD and a decline seen with hybrid 4 (Fig. 6.7). Results again conflicted with 2011 where hybrids 1 and 2 exhibited greater CTD than hybrids 3 and 4 (Fig. 6.3). For hybrids 1, 2, and 3, the greatest CTD resulted with the later planting dates (Fig. 6.7). For hybrid 4, however, the greatest CTD was achieved with the first and second planting date.

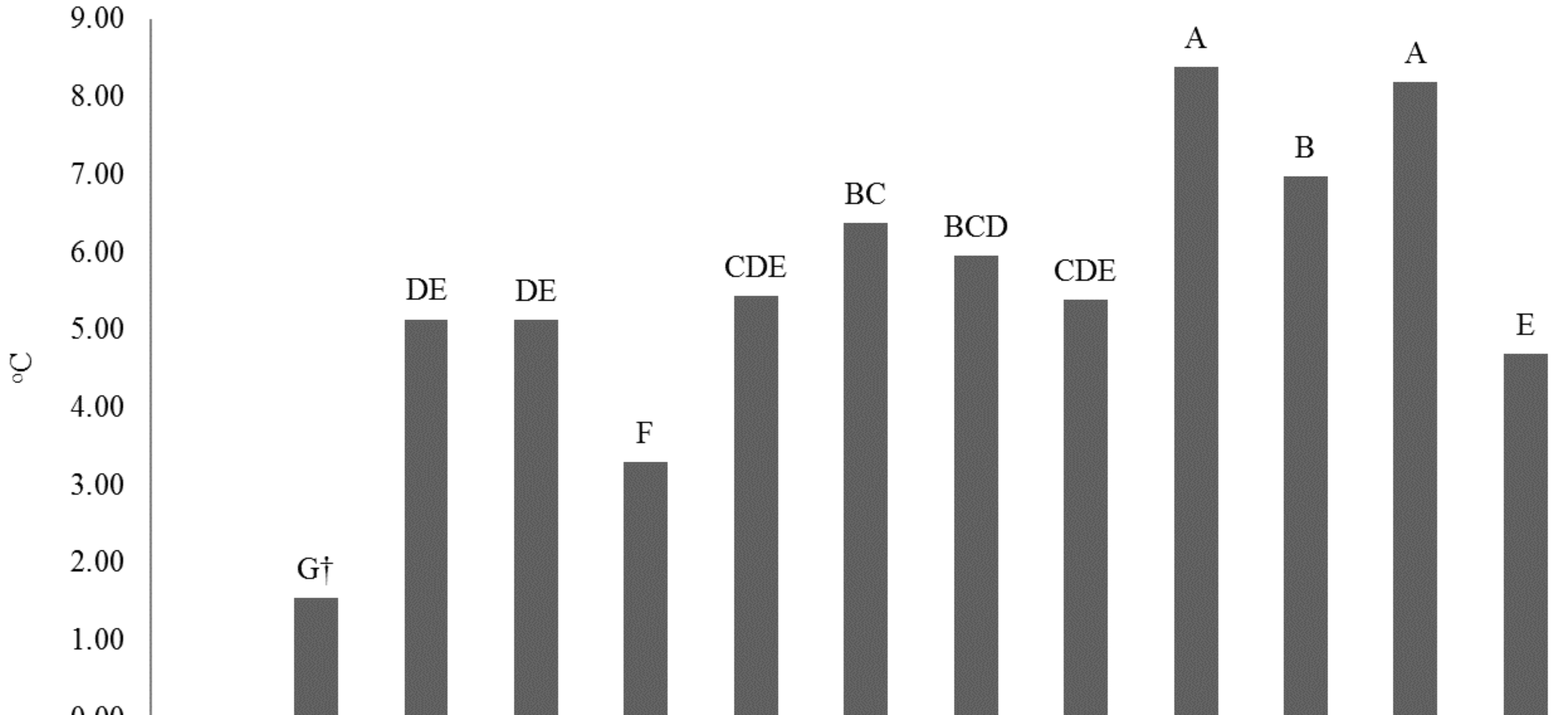
Figure 6.6. Planting date x irrigation effect on corn canopy temperature depression at R3 in 2012.



	PD :	1	2	3	1	2	3
		Dry	Dry	Dry	Irrigated	Irrigated	Irrigated
Mean		4.06	4.72	5.03	4.82	7.35	7.25

† Means followed by the same letter are not significantly different according to LSD (0.05).
PD, Planting Date (1: Feb. 15, 2: Mar. 1, and 3: Mar. 15).
H, Hybrid (1: Early, 2: Mid, 3: Mid-late, and 4: Late).

Figure 6.7. Hybrid x planting date effect on corn canopy temperature depression at R3 in 2012.

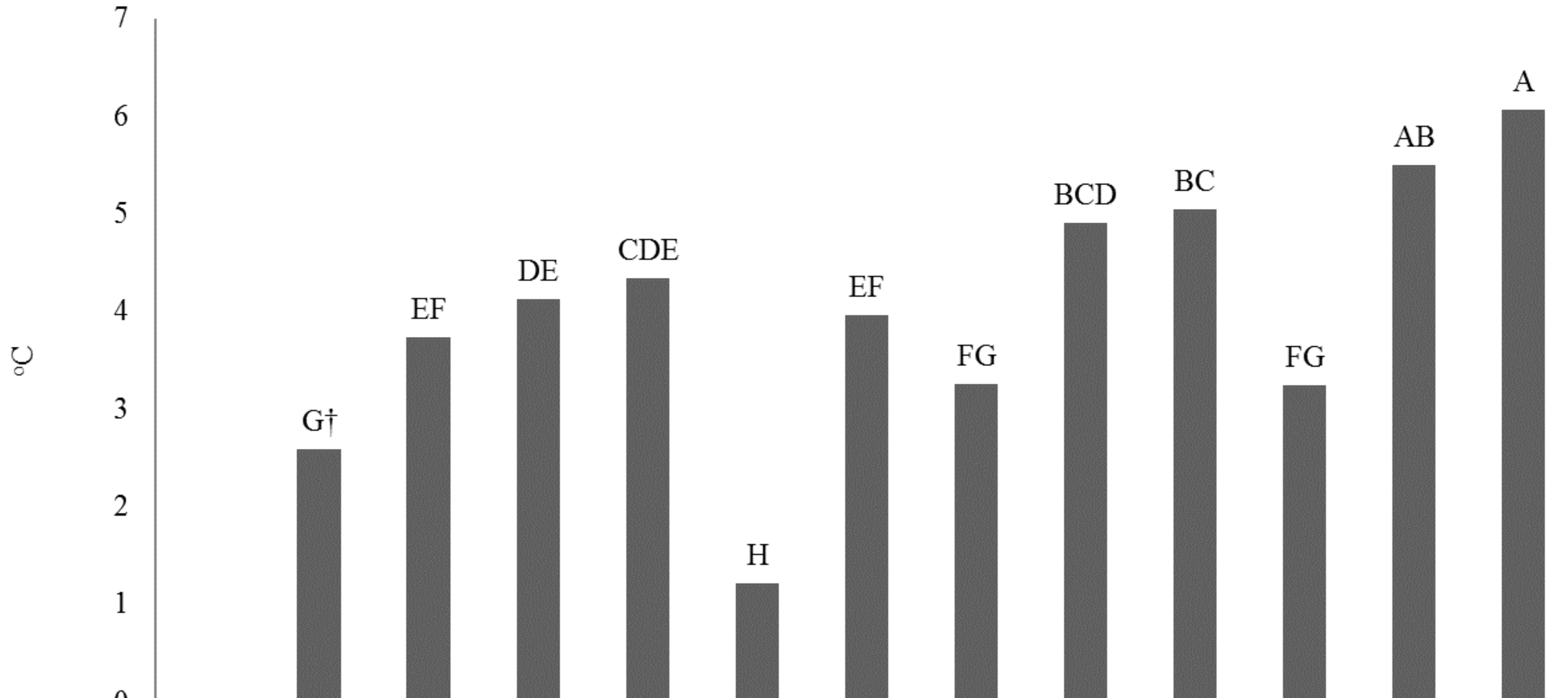


PD :	1	2	3	1	2	3	1	2	3	1	2	3
H :	1	1	1	2	2	2	3	3	3	4	4	4
Mean	1.54	5.13	5.12	3.29	5.44	6.38	5.95	5.39	8.39	6.97	8.18	4.68

† Means followed by the same letter are not significantly different according to LSD (0.05).
PD, Planting Date (1: Feb. 15, 2: Mar. 1, and 3: Mar. 15).
H, Hybrid (1: Early, 2: Mid, 3: Mid-late, and 4: Late).

Results for the H x PD effect on canopy temperature depression at R5 are given in Fig. 6.8. For hybrids 1, 3, and 4, greater CTD resulted from the later planting dates. Results conflicted with those of 2011 where the greatest CTD was seen within the first planting date by all hybrids (Fig. 6.4). However, the lowest CTD was seen for the second planting date and hybrid 2 in 2012 but not in 2011 (Figs. 6.4 and 6.8). In 2012, the greatest CTD resulted from a combination of later planting dates and later maturing hybrids (Fig. 6.8). Results of numerous trials indicate that the use of a late-season hybrid, when compared to an early-season hybrid planted on the same day, resulted in greater yield due to a prolonged reproductive growth period (Howell et al., 1998; Trooien et al., 1999; Norwood, 2001; Capristo et al., 2007; Raymond et al., 2009; Van Roekel and Coulter, 2012).

Figure 6.8. Hybrid x planting date effect on corn canopy temperature depression at R5 in 2012.



	PD :	1	2	3	1	2	3	1	2	3	1	2	3
	H :	1	1	1	2	2	2	3	3	3	4	4	4
Mean		2.58	3.73	4.13	4.34	1.21	3.96	3.25	4.91	5.05	3.24	5.50	6.07

† Means followed by the same letter are not significantly different according to LSD (0.05).
PD, Planting Date (1: Feb. 15, 2: Mar. 1, and 3: Mar. 15).
H, Hybrid (1: Early, 2: Mid, 3: Mid-late, and 4: Late).

7. CONCLUSION

The 2011 and 2012 growing seasons contrasted dramatically. Dryland and irrigated treatments during a drought in 2011 and good growing conditions in 2012 provided essentially four vastly different environments. Reduced photosynthetic rate, chlorophyll fluorescence, and canopy temperature depression indicated moisture stress and generally resulted in lower corn grain yield. In general, within the 2011 growing season, later planting and longer maturing hybrids produced greater grain yields, lower photosynthetic rates at R1, greater ϕPS_{II}, and greater CTD at R1. In the 2012 growing season, planting date did not significantly influence grain yield but longer maturing hybrids did increase grain yield. Also in 2012 longer maturing hybrids and later planting resulted in lower photosynthetic rates at R1, greater ϕPS_{II}, and greater CTD at all growth stages. This research demonstrated, as many others have shown, that the growing environment during pollination tends to have the greatest effect on corn grain yield. Information regarding general timing of rainfall is important for optimizing planting date. For example, in College Station, TX, significant rainfall is historically received in late March through mid-April with a potential dry period between that and a rainy period in September. Thus, corn hybrid maturity should be selected to target pollination occurring during a period of more likely precipitation.

In the College Station example, a planting date 45 to 55 days prior to mid-April with a 105-day corn hybrid would target pollination occurring during a likely wet period.

The same hybrid could also potentially be planted 45 to 55 days prior to the rainy period in September. The later planting would allow for pollination to occur during the September rainy period but would require planting during probable dry conditions. Understanding weather patterns in a given production region along with historic freeze dates may be the best management practice available to identify possible planting dates and hybrid relative maturities. The combination of those two choices coupled with regional weather patterns could help avoid moisture stress.

To provide specific recommendations regarding planting date and hybrid choice, further research should possibly narrow its focus to the bimodal rain pattern. Relevant data should include GDD and growth stage dates in order to understand temperatures effect when trying to target the pollination window.

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