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Comparative Study on Leaf Gas Exchange, Growth, Grain Yield, and Water Use Efficiency under Irrigation Regimes for Two Maize Hybrids

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Abstract: Drought stress has been a great challenge for the sustainability of maize (*Zea mays* L.) production in arid and semi-arid regions. The utilization of drought-tolerant hybrids and proper irrigation regimes represent a management strategy to stabilize maize production under water-limited conditions. A two-year field experiment was conducted to assess the leaf gas exchange, growth, grain yield, and water use efficiency in two cultivars of maize, i.e., Zhengdan 958 (H1) and Zhongdan 909 (H2), under different water regimes, i.e., full irrigation (FI), reproductive irrigation (RI), and rainfed (RF). Plant samples were collected at different growth stages to measure the maize growth and development under the three irrigation regimes. The grain yield in RF was significantly reduced by 30.4% (H1) and 31.1% (H2); and the water use efficiency (WUE) by 8.5% (H1) and 9.3% (H2) compared with FI. On the other hand, irrigation application at the flowering stage was shown to significantly boost the grain yield by 40.3% (H1) and 25.5% (H2); and the WUE by 27.6% (H1) and 14.1% (H2) compared to RF. This indicated that H1 benefited more from irrigation use compared to H2. The improved grain yield through reproductive irrigation was due to the greater soil plant analysis development (SPAD), net photosynthesis, and biomass production when compared to zero irrigation. Zhengdan 958 was shown to be relatively more resistant to drought stress during flowering compared to Zhongdan 909. Thus, to achieve reliable maize production in Huaibei Plain, reproductive irrigation is recommended, combined with Zhengdan 958.

Keywords: drought stress; *Zea mays* L.; irrigation; rainfed; photosynthesis; Zhengdan 958; Zhongdan 909

1. Introduction

Increased vulnerability due to climate change may occur in many regions. Climate change will lead to more frequent or severe drought stress, resulting in more risk for crops [1]. Drought is one of the most fundamental environmental stresses that limits crop yield in many places in the world, especially in arid and semi-arid areas [2]. Huaibei Plain is an important area for food supply in China, located at south Huai-Huai-Hai, where the winter wheat (*Triticum aestivum* L.) and summer maize crops (*Zea mays* L.) are cultivated with a rotation [3]. Maize is known as one of the world's leading and most vital food security and feed crops [4]. Maize utilization has continued to grow gradually with exceeding demand in China because it serves as a valuable source of industrial material and urban nutrition products [5]. The demand for maize is expected to be doubled between now and 2050 [6]. Researchers [7,8] documented that, under vulnerable environmental change, the expending magnitudes, time periods, and the rate of droughts will intensely decrease the soil water availability for plant up-take, and maize production is susceptible to this phenomenon.

Maize plants grown in Northern China are generally affected by water deficiency, and drought stress in the early and later stages of the plant considerably diminish the grain yield [9]. All the crops suffer from drought in the summer season where the rainfall is low; however, maize plants suffer more due to a shortage of water reducing the growth and development under water deficit conditions [10]. Maize yield reduction due to water stress depends on a lot of factors including plant developmental stages, severity and duration of water limitations, hybrid susceptibility and vulnerability to soil drought [11]. Maize is sensitive to soil moisture deficiency during vegetative and reproductive growth stages. During vegetative growth period plants reduce the leaf area index, plant height, diameter of stem, number of leaves, dry matter accumulation, chlorophyll contents, net photosynthesis and transpiration rate. Nonetheless, reproductive stages under drought stress are more critical to cause greater reduction in grain yield as compared to vegetative stages [12].

The flowering stage was found to be the most sensitive stage to water shortage, leading to reductions in crop growth, biomass production, and grain yield [12–15]. Thus, the water stress two weeks before flowering had a negative effect on silk growth, the opening of anthers, and anthesis [16]. Research demonstrated that the reduction in yield shifted by 10–76% depending on the drought frequency and the sensitivity of the crop and its growth period. The highest potential yield reduction happens during the silking period. Other study provided the evidence if the deficit of water occurs before or during silking and pollination resulted to reduction in kernel number and kernel weight [17]. Water stress at pre-anthesis stage cause more reduction in number of kernels [18]. Stress during the flowering period can substantially reduce the final grain yield by 35–50% [19]. Thus, supplying supplementary irrigation at the reproductive period during maize development is fundamental to achieve high yield.

The main objectives of this study were: (i) to investigate drought impacts during flowering on maize grain yield and the yield gap between rainfed and full irrigation; (ii) to compare the effects of flowering irrigation between hybrids; and (iii) to examine the interaction between three irrigation applications and two maize hybrids on growth and grain yield.

2. Material and Methods

2.1. Experimental Site, Conditions, and Cultivars

A two-year field research study was conducted on 6 June 2017 and 9 June 2018 in the experimental farm of Mengcheng Agricultural Scientific Institute located in Huaibei plain, Anhui Province, China (33°9′44″ N, 116°32′5″ E). The typical soil type of this area has low organic matter and poor soil fertility known as lime concretion black soil which enhances cultivation barrier [20]. The cropping in semiarid Huaibei Plain mainly depends on natural rainfall and only limited irrigation may apply when severe drought occurs.

The soil of the experimental farm was a typical lime concentration black soil containing available N content at 0.97 g kg^{-1}, 52.5 mg kg^{-1} P_2O_5, 112.5 mg kg^{-1} K_2O, 25.5 g kg^{-1} organic matter, and a 4.85 pH. The maize cultivars, i.e., Zhengdan 958 and Zhongdan 909, were sown. Zhengdan 958 is a high yielding, middle maturity, and compact-type drought resistance variety [21]. Zhongdan 909 is a modern high yielding hybrid with middle maturity, that requires more water to provide a high yield [22]. Weather data of the daily temperature, total rainfall, and solar radiation for two years were collected from the meteorological department of Mengcheng Agricultural Scientific Institute (Figure 1).

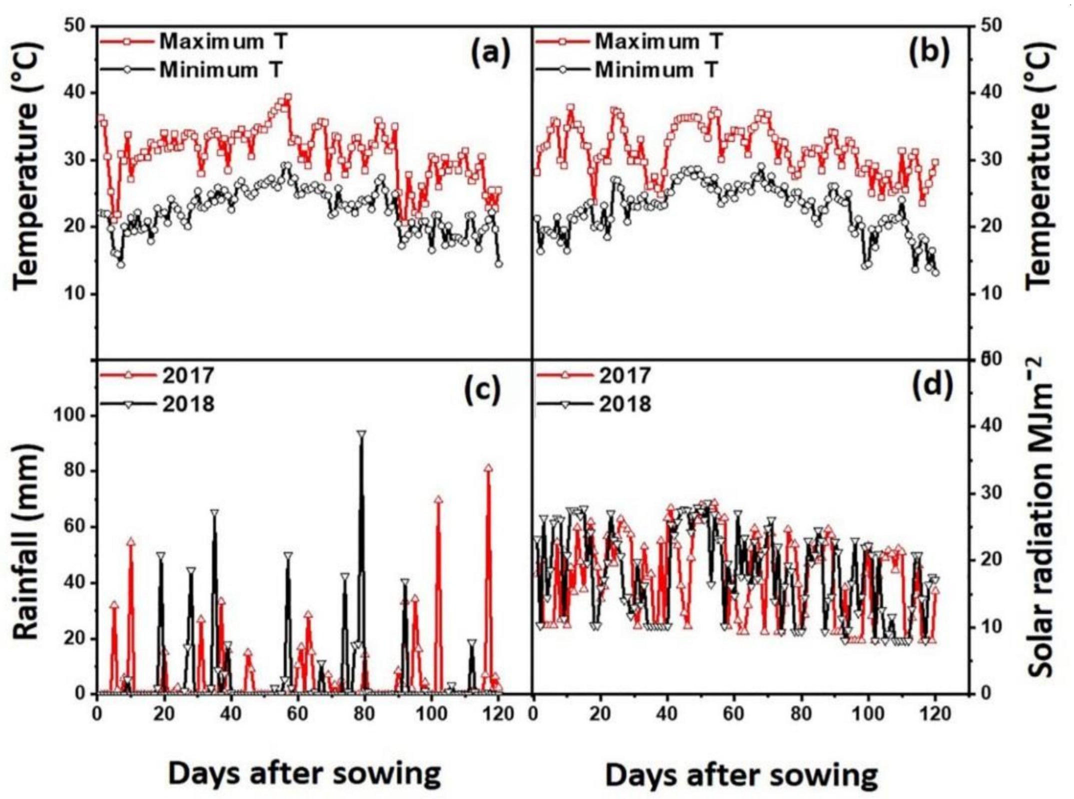

Figure 1. Weather conditions in 2017 and 2018 during the crop growing season. (**a**) Temperature (°C) in 2017, (**b**) temperature (°C) in 2018, (**c**) total rainfall (mm) of 577.1 and 540.2 in 2017–2018 respectively and (**d**) solar radiation (MJ m^{-2}) in 2017–2018.

2.2. Experimental Design, Treatments and Crop Management

A field study was designed with three irrigations using the flooded method composed of 180 mm irrigation (fully irrigated, FI), was applied at 60 mm at the big flare, flowering, and mid grain stages, respectively, 60 mm irrigation (reproductive irrigation, RI), and 0 mm irrigation (rainfed, RF), were applied at the flowering stage in a randomized complete block design (RCBD) with split arrangement along with three replicates. Two factors, i.e., irrigations and hybrids, were used in the experiment, with the main plots being hybrids and the subplots being different irrigations. A row spacing of 60 cm was used with a plant to plant space of 25 cm to achieve the desired planting population of 6.74 plants m^{-2} (66,667 plants ha^{-1}).

Maize seeds were manually sown, and the seedlings were thinned at 20 days after the emergence (DAE) of plants to maintain the required planting population. The fertilizers were applied at 300 (N), 112 (P), and 112 (K) kg ha^{-1}, respectively. The sources of fertilizers were urea (46.4% N), calcium superphosphate (12% P_2O_5), and potassium chloride (60% K_2O). The P and K were applied at the time of sowing as basal fertilizer but N fertilizer was applied at the rate of 300 kg ha^{-1} but split into two doses, 50% was applied at the time of sowing and the remaining 50% was applied on the 15 July 2017 and the 18 July 2018. All other agronomic management practices were the same during the experimental work.

2.3. Data Collection

2.3.1. Soil Moisture Contents

The soil moisture contents were determined at the jointing, big flare, flowering, initial grain filling, mid grain, and harvesting stages in growing seasons of both 2017 and 2018. The soil samples were taken at a depth of 10, 20, 30, and 40 cm, and the fresh weight of the soil was noted before placing the soil samples into the oven for drying. The moisture contents were recorded using the gravimetric method. The experiment in both years was conducted in three replicates.

2.3.2. Phenology

Ten plants were selected randomly from each treatment and tagged after emergence, and then we counted the number of days taken by plants to complete different stages [23].

2.3.3. Leaf Chlorophyll Content (Soil Plant Analysis Development (SPAD))

The SPAD-502 (Konica-Minolta Sensing, Osaka, Japan) chlorophyll meter was used to measure the leaf relative chlorophyll content [23,24]. Three plants and their two types of leaves were selected from each treatment to measure the SPAD values. During this measurement, the upper fully expanded leaf was selected at the jointing, big flare and flowering stages. The cob leaf was selected at the initial and mid grain stages. The whole leaf value was measured by calculating the average value of three points i.e., the tip, middle, and bottom.

2.3.4. Photosynthetic Attributes

Three random plants were selected from each plot to measure the photosynthesis and its attributes. A portable photosynthesis system CIRAS-3 (PP Systems, Amesbury, MA, USA) was used on a clear sunny day between 9 AM to 12 PM to record the net photosynthesis (Pn), stomatal conductance (gs), CO_2 intercellular concentration (Ci), and transpiration rate (Tr). The surge flask was used to control the environmental conditions in the leaf chamber.

2.3.5. Plant Dry Biomass

Three plants were selected randomly at different growth stages from each treatment, and we took the fresh weight of each plant, and then divided the vegetative and reproductive parts of each plant separately. After that, we oven-dried the separated parts of the plants at 70 °C until they reached a constant weight, and then we measured the dry weight.

2.3.6. Physiological Maturity

Before harvesting, the presence of a black layer was observed at the base of the grain, which indicated that no further accumulation of grain mass was possible [25]. The grain from the base, mid and distal end of cob was removed to check the base of the black layer. The crop was considered ready to harvest when 75% of the grain had developed a black layer.

2.3.7. Yield and Yield Components

After the physiological maturity, twenty cobs were taken from each treated plot to determine the cob length (cm), cob diameter (cm), number of lines per cob, number of kernels per cob, 1000-kernel weight (g), and grain yield (kg ha^{-1}). A Vernier caliper was used to measure the cob length (cm) and diameter (mm). The number of kernels per cob was counted manually. The weight of 1000-kernels were noted from the sample of each treatment and weighed in grams using an electronic balance. For the grain yield, the middle two rows of maize plants were cut by a small household corn thresher from each plot. The cobs were separated from harvested plants and dried in the sunshine for 10 days and then weighed.

2.3.8. Water Use Efficiency (WUE) and Harvest Index (%)

The water use efficiency (Kg ha^{-1} mm^{-1}) was computed using Equation (1) by [17].

$$WUE = \frac{Y}{ETa} \tag{1}$$

$$ETa = P + I + Cr - R - D \pm \Delta S \tag{2}$$

The WUE means that the quantity of water consumed by crops is estimated according to the total amount of water used from the plant and soil surfaces in addition to that retained within plant structures. Y is the maize grain yield (kg ha^{-1}). Where ETa is the evapotranspiration (mm), P is the seasonal cumulative rainfall (mm); I is the total seasonal irrigation (mm); Cr is the seasonal upward capillary flow into the root zone (mm), R is the surface runoff (mm), D is the downward flux below the crop root zone.

Cr, R, and D were considered to be zero because surface runoff was non-existent and negligible capillary rising from 20–30 m below the soil surface during growing season. ΔS stands for the difference between the soil water storage at seeding and at harvest (0–40 cm).

The harvest index (HI) % was computed using Equation (3) by [26].

$$\text{HI}\ (\%) = \frac{\text{Grain Yield}}{\text{Biological Yield}} \times 100 \quad (3)$$

HI is a measure of the efficiency of plants in producing seeds. It is the ratio of grain yield to total above ground biomass.

At harvest maturity, the middle two rows of maize plants were cut from each treatment, and the material was sun-dried up to a constant weight. Weighed and then converted into biological yield/biomass (kg ha^{-1}). The harvested material for biomass yield was threshed. The grains were separated and weighed, and then converted into grain yield (kg ha^{-1}).

2.4. Data Analysis

All statistical analysis was performed by using SPSS 18.0 (SPSS Inc., Chicago, IL, USA). The mean differences among treatments were calculated using LSD at ($p < 0.05$). The figures were organized using Origin 8.0 (*Origin Lab*) software.

3. Results

3.1. Soil Moisture

The soil moisture in different irrigation regimes is presented in Table 1. The soil moisture under RF was significantly reduced by 22.3% for Zhengdan 958 (H1) and 23.7% for Zhongdan 909 (H2) in 2017; and 23.1% (H1) and 24.8% (H2) in 2018 compared to the FI at the grain filling stage. However, the moisture content in the RF was significantly lower by 9.6% (H1) and 11.2% (H2) in 2017; and 12.0% (H1) and 15.2% (H2) in 2018 compared to the RI at the grain filling stage.

3.2. Maize Phenology

The phenological data of both years are presented in Table 2. Both hybrids H1 and H2 under FI took a similar number of days to complete the initial grain filling and mid grain filling stages in 2017 and 2018. H1 under RI just one day prior took to complete flowering stage and two days later to complete mid grain filling stage compared to H2 under RI in both years. However, H2 under FI took the maximum days, 115 and 111 in 2017 and 2018, respectively, to complete its maturity followed by H1 under FI to complete its maturity one day earlier in both years. H2 under RF took the least number of days 109 in 2017 and 106 days in 2018 to complete its maturity (Table 2).

Table 1. The soil profile at 0–40 cm moisture (%) as affected by different water regimes in the growing season in 2017 and 2018.

Year	Treatments	Jointing Stage	Big Flare Stage	Flowering Stage	Initial Grain Stage	Mid Grain Stage	Harvesting Stage
2017	FIH1	9.68 ± 0.02 a	12.54 ± 0.25 a	13.77 ± 0.10 a	11.11 ± 0.07 a	23.76 ± 0.13 a	15.83 ± 0.12 a
	RIH1	9.75 ± 0.01 a	12.52 ± 0.24 a	10.51 ± 0.20 c	9.55 ± 0.15 c	22.21 ± 0.12 c	14.52 ± 0.19 c
	RFH1	9.73 ± 0.02 a	12.35 ± 0.18 a	10.35 ± 0.04 cd	8.63 ± 0.06 e	20.66 ± 0.22 e	13.04 ± 0.10 e
	FIH2	9.23 ± 0.03 b	11.58 ± 0.07 b	13.18 ± 0.02 b	10.52 ± 0.18 b	22.91 ± 0.18 b	15.25 ± 0.21 b
	RIH2	9.32 ± 0.12 b	11.67 ± 0.08 b	10.18 ± 0.15 d	9.05 ± 0.05 d	21.43 ± 0.20 d	13.94 ± 0.07 d
	RFH2	9.27 ± 0.03 b	11.64 ± 0.23 b	10.33 ± 0.03 cd	8.03 ± 0.12 f	19.90 ± 0.22 f	12.62 ± 0.07 e
2018	FIH1	10.50 ± 0.08 a	11.66 ± 0.06 a	12.52 ± 0.10 a	10.92 ± 0.07 a	25.49 ± 0.08 a	15.59 ± 0.07 a
	RIH1	10.44 ± 0.06 a	11.49 ± 0.13 a	9.62 ± 0.13 cd	9.63 ± 0.08 c	23.90 ± 0.07 c	14.22 ± 0.06 b
	RFH1	10.49 ± 0.09 a	11.48 ± 0.08 a	9.67 ± 0.06 c	8.40 ± 0.08 e	21.66 ± 0.28 d	12.85 ± 0.04 c
	FIH2	10.40 ± 0.11 a	11.74 ± 0.10 a	12.01 ± 0.06 b	10.52 ± 0.18 b	25.01 ± 0.13 b	15.33 ± 0.12 a
	RIH2	10.36 ± 0.02 a	11.81 ± 0.04 a	9.29 ± 0.03 d	9.34 ± 0.05 d	23.77 ± 0.07 c	14.16 ± 0.09 b
	RFH2	10.35 ± 0.05 a	11.64 ± 0.23 a	9.44 ± 0.17 cd	7.91 ± 0.03 f	21.33 ± 0.13 d	12.57 ± 0.04 c

In the treatment column: FI is showing full irrigation (180 mm), RI is showing reproductive irrigation (60 mm), RF is showing rainfed, H1 is showing hybrid (Zhengdan 958), and H2 is showing hybrid (Zhongdan 909). In data table ± indicates standard deviation, and different letters indicate significant differences among treatments ($p < 0.05$).

Table 2. Maize phenology and growth periods taken from irrigation frequencies.

		Growing Period (days)					
Year	**Treatments**	**Jointing Stage**	**Big Flare Stage**	**Anthesis Stage**	**Initial Grain Stage**	**Mid Grain Stage**	**Physiological Maturity**
2017	FIH1	28.27 a	42.80 a	62.55 b	76.01 a	89.62 a	114.14 ab
	RIH1	28.15 a	43.04 a	62.83 ab	75.99 a	88.20 a	113.64 ab
	RFH1	28.11 a	43.03 a	64.05 ab	75.04 ab	85.34a	110.77 cd
	FIH2	28.43 a	42.83 a	62.65 ab	76.03 a	89.60 b	115.36 a
	RIH2	28.14 a	43.03 a	63.32 ab	75.52 ab	86.07 b	112.57 bc
	RFH2	28.17 a	43.06 a	64.49 b	73.70 b	84.66 b	109.00 d
2018	FIH1	27.09 a	41.10 a	60.14 c	73.18 ab	86.22 a	110.18 ab
	RIH1	27.03 a	41.32 a	60.39 c	73.05 ab	85.18 b	109.13 b
	RFH1	27.08 a	41.34 a	62.27 ab	72.02 c	82.96 c	107.29 c
	FIH2	27.15 a	41.15 a	60.19 c	73.4 a	86.38 a	111.00 a
	RIH2	27.13 a	41.36 a	61.09 bc	72.97 b	83.40 c	108.95 b
	RFH2	27.11 a	41.38 a	63.12 a	70.2 d	82.14 d	106.28 b

In the treatment column: FI is showing full irrigation (180 mm), RI is showing reproductive irrigation (60 mm), RF is showing rainfed, H1 is showing hybrid (Zhengdan 958), and H2 is showing hybrid (Zhongdan 909). In data table ± indicates standard deviation, and different letters indicate significant differences among treatments ($p < 0.05$).

3.3. Leaf Chlorophyll Contents

At the big flare stage, the SPAD values in RF were significantly reduced by 6.5% (H1) and 7.4% (H2) in 2017; and 7.3% (H1) and 8.6% (H2) in 2018, compared to FI. SPAD in H2 was clearly reduced more compared to H1. At the flowering stage, the SPAD values in RF were reduced by 8.9% (H1) and 8.8% (H2) in 2017 and 7.8% (H1) and 9.1% (H2) in 2018 compared with FI. However, the SPAD values in RI were significantly improved by 8.1% (H1) and 7.4% (H2) in 2017 and 5.3% (H1) and 7.9% (H2) in 2018 compared to RF due to irrigation at the flowering stage (Figure 2).

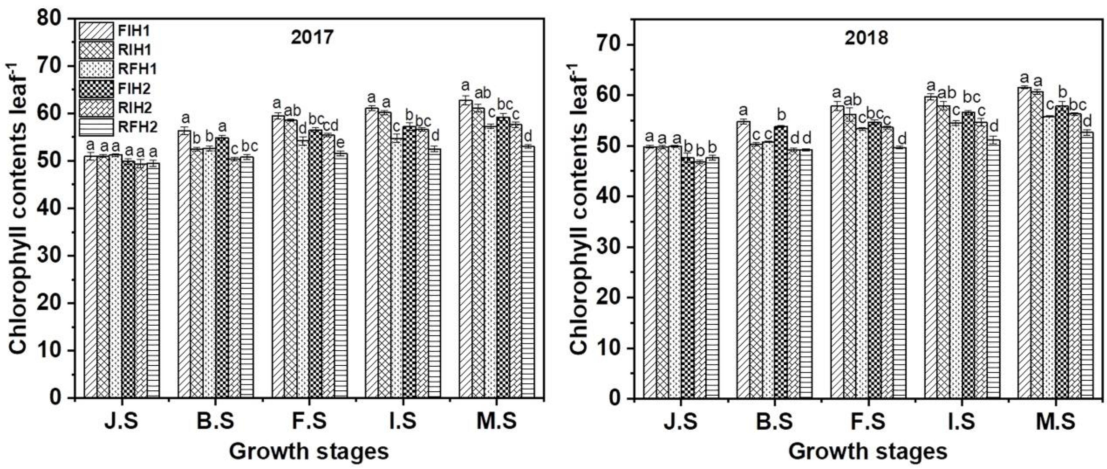

Figure 2. The leaf chlorophyll contents at different growth stages in the years 2017–2018. In treatments: J.S is the jointing stage, B.S is the big flare stage, F.S is the flowering stage, I.S is the initial grain stage, and M.S is the mid grain stage. FI is the full irrigation (180 mm), RI is reproductive irrigation (60 mm), RF is rainfed, H1 is hybrid Zhengdan 958, and H2 is hybrid Zhongdan 909. Different letters indicate significant differences among treatments ($p < 0.05$).

3.4. Leaf Photosynthetic Attributes

Different irrigation regimes and hybrids were significantly affected by the net photosynthesis (Pn) values of the upper fully expanded leaf in maize as shown (Figure 3). At the jointing stage, the Pn values were not significantly affected by irrigation. In contrast, the Pn values were found to be significantly different between hybrids. At the big flare stage, the Pn values in RF were considerably reduced by 21.8% (H1) and 32.9% (H2) in 2017; and 29.3% (H1) and 27.3% (H2) in 2018, compared to FI. At the flowering stage, the Pn values in RF were significantly decreased by 25.0% (H1) and 26.2% (H2) in 2017; and 25.4% (H1) and 24.4% (H2) in 2018, compared to FI. However, the Pn values in RI were also significantly increased by 30.7% (H1) and 21.0% (H2) in 2017 and 31.4% (H1) and 20.8% (H2) in 2018, compared to RF (Figure 3).

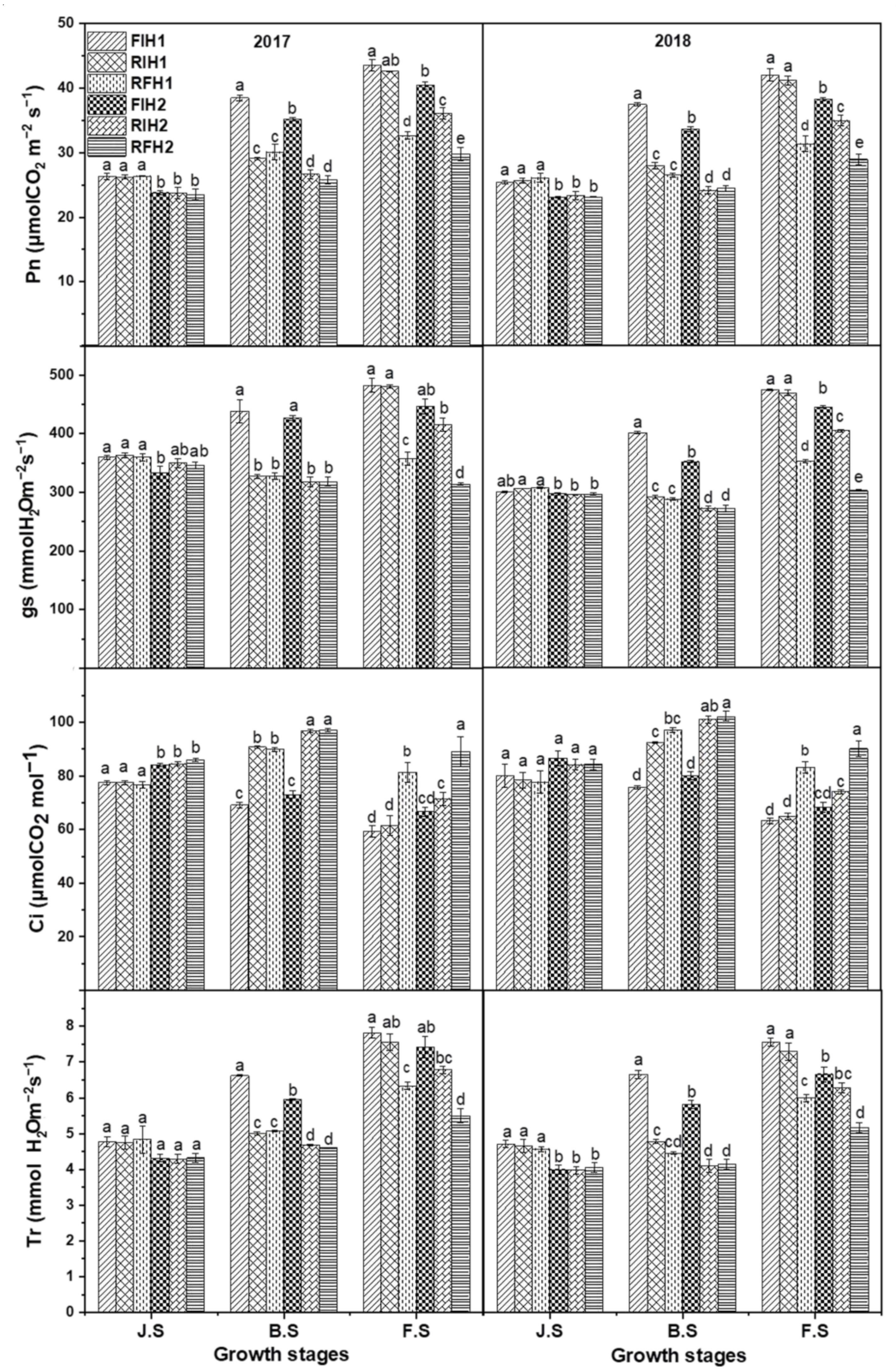

Figure 3. The net photosynthetic rate and leaf gas exchange of maize at different growth stages in the years 2017–2018. In treatments: J.S is the jointing stage, B.S is the big flare stage, and F.S is the flowering stage. FI is full irrigation (180 mm), RI is reproductive irrigation (60 mm), RF is rainfed, H1 is the hybrid Zhengdan 958, and H2 is the hybrid Zhongdan 909. Different letters indicate significant differences among treatments ($p < 0.05$).

3.5. Dry Matter Accumulation

The whole plant dry matter accumulation under different water applications and maize hybrids is presented in Table 3. The results elucidated that H1 acquired significantly higher biomass accumulation compared with H2 at the big flare stage. In contrast, at this stage, the dry biomass accumulation in RF was significantly decreased by 16.1% (H1) and 18.0% (H2) in 2017; and 18.6% (H1) and 18.4% (H2) in 2018, compared with FI. At the flowering stage, the dry biomass accumulation under RF was significantly reduced by 23.9% (H1) and 25.3% (H2) in 2017; and 25.0% (H1) and 25.8% (H2) in 2018, compared to FI. However, the dry biomass accumulation was also significantly declined in RF by 19.9% (H1) and 15.0% (H2) in 2017; and 21.5% (H1) and 15.7% (H2) in 2018, compared with RI. The results illuminated that H1 produced greater dry biomass accumulation compared with H2 at all growth stages in both years of study (Table 3).

3.6. Yield, Yield Components, and Harvest Index

The maize cob length, cob diameter, number of lines per cob, number of kernels per cob, and 1000-kernel weight was considerably influenced by the irrigation regimes and hybrids (Table 4). The non-significant differences were noted between the number of kernels per cob and the 1000-kernel weight in FI and RI; however, a significant difference in the hybrids was found in these two yield components (Table 5). In comparative study, we observed that the number of kernels per cob and the 1000-kernel weight significantly decreased in RF by 19.8% and 8.9% (H1) and 19.0% and 9.9% (H2) in 2017; and 25.4% and 8.4% (H1) and 24.7% and 8.2% (H2) in 2018; respectively, proportionate to FI.

Similarly, RF caused a huge reduction by 18.9% and 6.8% (H1) and 15.8% and 6.7% (H2) in 2017; and 23.9% and 7.9% (H1) and 18.0% and 6.4% (H2) in 2018; respectively compared with RI (Table 5). On the basis of the yield components, we concluded that the grain yield in RF was significantly reduced by 29.1% (H1) and 29.3% (H2) in 2017; and 31.7% (H1) and 32.9% (H2) in 2018, compared to FI. On the other hand, a huge reduction of grain yield was also noted in RF by 27.4% (H1) and 19.1% (H2) in 2017; and 30.0% (H1) and 21.4% (H2) in 2018, compared to RI. The reduction of grain yield in RF was more in 2018 as compared to 2017 (Table 5). The harvest index between the water irrigation regimes and hybrids are shown in Tables 4 and 5. The highest harvest index was noted under the treatment of RF with H2 in both years.

Table 3. The whole plant dry matter accumulation (kg ha^{-1}) at jointing, big flare, flowering, initial grain, mid grain and physiological maturity stages during the growing season in 2017 and 2018.

Year	Treatments	Jointing Stage	Big flare Stage	Flowering Stage	Initial grain Stage	Mid grain Stage	Physiological Maturity
2017	**Irrigations**						
	FI	1869.98 ± 94.87 a	8011.15 ± 311.11 a	11255.61 ± 344.45 a	18048.36 ± 841.61 a	22407.81 ± 1002.37 a	23586.64 ± 880.22 a
	RI	1874.33 ± 75.47 a	6766.70 ± 344.44 b	10311.16 ± 711.11 b	16645.40 ± 1491.10 b	20403.27 ± 1996.15 b	21519.50 ± 2414.04 b
	RF	1880.96 ± 88.64 a	6644.47 ± 333.33 b	8488.93 ± 333.34 c	12611.67 ± 900.50 c	15262.52 ± 1135.16 c	15668.84 ± 885.37 c
	Hybrids						
	H1	1961.42 ± 43.61 a	7470.40 ± 61.72 a	10481.53 ± 187.38 a	16846.22 ± 239.69 a	20735.76 ± 412.80 a	21651.55 ± 247.90 a
	H2	1788.76 ± 31.23 b	6811.14 ± 108.42 b	9555.60 ± 155.75 b	14690.74 ± 245.57 b	17979.97 ± 270.20 b	18865.12 ± 241.80 b
	Interactions						
	FIH1	1964.86 ± 47.30 a	8322.26 ± 67.58 a	11600.05 ± 173.20 a	18889.98 ± 346.22 a	23410.17 ± 372.97 a	24466.86 ± 315.07 a
	RIH1	1949.81 ± 37.80 a	7111.14 ± 58.79 c	11022.27 ± 292.07 ab	18136.51 ± 160.04 a	22399.42 ± 462.49 ab	23933.55 ± 230.28 a
	RFH1	1969.60 ± 45.72 a	6977.81 ± 58.81 c	8822.26 ± 96.86 d	13512.17 ± 212.82 d	16397.68 ± 402.95 d	16554.22 ± 198.26 d
	FIH2	1775.11 ± 39.54 b	7700.03 ± 83.88 b	10911.16 ± 117.58 b	17206.75 ± 97.60 b	21405.44 ± 219.25 b	22706.42 ± 104.67 b
	RIH2	1798.85 ± 27.97 b	6422.25 ± 145.72 d	9600.04 ± 195.31 c	15154.29 ± 270.78 c	18407.11 ± 356.23 c	19105.45 ± 112.39 c
	RFH2	1792.32 ± 26.19 b	6311.14 ± 96.86 d	8155.59 ± 154.36 e	11711.16 ± 368.34 e	14127.36 ± 235.13 e	14783.47 ± 508.34 e
2018	**Irrigations**						
	FI	1816.58 ± 97.63 a	7909.51 ± 310.67 a	11041.72 ± 413.11 a	17752.27 ± 725.90 a	22161.86 ± 936.29 a	23254.56 ± 731.55 a
	RI	1828.44 ± 105.10 a	6569.86 ± 314.91 b	10146.52 ± 789.81 b	16468.33 ± 1601.81 b	20189.04 ± 1992.13 b	21045.44 ± 2366.26 b
	RF	1812.79 ± 97.77 a	6447.13 ± 247.28 b	8237.41 ± 348.75 c	12261.47 ± 869.31 c	14971.56 ± 1057.95 c	15164.66 ± 1214.09 c
	Hybrids						
	H1	1919.44 ± 44.40 a	7266.46 ± 64.58 a	10325.78 ± 170.50 a	16559.71 ± 135.50 a	20436.28 ± 143.49 a	21258.81 ± 241.28 a
	H2	1719.10 ± 45.42 b	6684.54 ± 70.69 b	9291.32 ± 144.61 b	14428.34 ± 168.34 b	17778.69 ± 142.90 b	18384.25 ± 257.68 b
	Interactions						
	FIH1	1914.22 ± 34.27 a	8220.18 ± 76.89 a	11454.83 ± 202.31 a	18478.17 ± 121.80 a	23098.15 ± 144.63 a	23986.11 ± 159.76 a
	RIH1	1933.54 ± 39.73 a	6884.78 ± 16.36 c	10936.33 ± 177.02 ab	18070.14 ± 153.90 a	22181.17 ± 153.35 a	23411.70 ± 402.74 ab
	RFH1	1910.56 ± 29.93 a	6694.41 ± 100.52 c	8586.17 ± 132.17 d	13130.78 ± 130.82 d	16029.50 ± 132.51 d	16378.76 ± 161.35 d
	FIH2	1718.95 ± 58.79 b	7598.84 ± 61.81 b	10628.60 ± 157.35 b	17026.35 ± 249.78 b	21225.57 ± 172.64 b	22523.00 ± 379.39 b
	RIH2	1723.33 ± 48.67 b	6254.94 ± 64.41 d	9356.71 ± 197.42 c	14866.51 ± 102.79 c	18196.90 ± 134.44 c	18679.18 ± 109.99 c
	RFH2	1715.02 ± 25.75 b	6199.84 ± 85.82 d	7888.66 ± 79.05 e	11392.15 ± 152.45 e	13913.60 ± 121.62 e	13950.56 ± 283.66 e

Note: Different letters indicate significant differences among treatments ($p < 0.05$).

Table 4. Effects of irrigation regimes and maize hybrids on yield and yield components, harvest index and water use efficiency in growing season 2017 and 2018.

Source	SOV	Cob Length	Cob Diameter	No. of Lines per cob	No. of Kernels per cob	1000-Kernel Weight	Grain Yield	Harvest Index	Water Use Efficiency
Water (W)	2	199.11 **	181.83 **	95.84 **	163.25 **	40.18 *	1940.63 **	13.50 *	847.08 **
Hybrid (H)	1	53.75 **	19.22 **	437.85 **	148.07 **	15.79 *	267.76 **	50.50 **	244.06 **
W×H	2	0.53	0.23	23.01 **	7.35 *	0.22	50.49 **	11.18 *	49.36 **
Year (Y)	1	190.63 **	643.06 **	15.85 **	7.86 *	18.04 **	57.15 **	0.85 *	6.01 *
Y×W	2	0.27	0.30	0.84	2.42	0.46	2.06	1.11	2.56
Y×H	1	0.34	0.32	0.52	0.59	2.06	0.02	0.62	0.48
Y×W×H	2	0.14	0.21	0.69	0.30	0.09	0.18	0.46	0.36

In the columns; SOV indicates the source of variation. ** and * indicate significance at $p < 0.01$ and < 0.05, respectively.

Table 5. Effects of different irrigation and maize hybrids on grain yield and yield components in season 2017 and 2018.

Year	Treatments	No. of Kernel cob^{-1}	1000-Kernel Weight (g)	Grain Yield (kg ha^{-1})	WUE (kg ha^{-1} mm^{-1})	Harvest Index (%)
2017	**Irrigations**					
	FI	522.97 ± 25.91 a	333.86 ± 2.76 a	11950.68 ± 337.67 a	15.92 ± 0.45 b	54.08 ± 0.33 b
	RI	510.51 ± 31.91 a	324.72 ± 4.97 a	11085.28 ± 928.13 b	17.58 ± 1.47 a	55.12 ± 1.62 ab
	RF	421.40 ± 18.15 b	302.36 ± 4.18 b	8465.61 ± 251.32 c	14.72 ± 0.43 c	57.42 ± 1.21 a
	Hybrids					
	H1	510.28 ± 11.53 a	324.29 ± 4.21 a	11006.23 ± 116.11 a	16.86 ± 0.18 a	54.48 ± 0.46 a
	H2	459.64 ± 8.62 b	316.34 ± 6.11 b	9994.81 ± 108.11 b	15.29 ± 0.17 b	56.61 ± 1.22 a
	Interactions					
	FIH1	548.87 ± 10.94 a	336.62 ±2.98 a	12288.28 ± 96.45 a	16.38 ± 0.13 b	53.74 ± 0.27 b
	RIH1	542.42 ± 9.28 a	329.07 ± 5.01 a	12013.42 ± 98.44 a	19.06 ± 0.16 a	53.49 ± 0.68 b
	RFH1	439.66 ± 14.29 c	306.55 ± 4.64 b	8716.93 ± 153.44 d	15.15 ± 0.27 c	56.21 ± 0.42 ab
	FIH2	497.07 ± 8.61 b	331.10 ± 6.70 a	11613.02 ± 57.97 b	15.48 ± 0.08 c	54.42 ± 0.40 b
	RIH2	478.33 ± 12.74 bc	319.74 ± 2.09 ab	10157.14 ± 161.29 c	16.12 ± 0.26 b	56.75 ± 0.74 ab
	RFH2	402.66 ± 4.63 d	298.17 ± 9.41 b	8214.23 ± 104.99 e	14.29 ± 0.18 d	58.63 ± 2.53 a
2018	**Irrigations**					
	FI	521.88 ± 18.11 a	319.67 ± 7.15 a	11651.35 ± 300.33 a	16.31 ± 0.42 b	53.22 ± 0.11 b
	RI	496.14 ± 33.47 b	315.86 ± 9.34 b	10672.74 ± 974.26 b	17.96 ± 1.63 a	54.12 ± 1.21 ab
	RF	391.21 ± 11.79 c	293.16 ± 6.31 c	7884.61 ± 266.98 c	14.65 ± 0.49 c	55.32 ± 2.24 a
	Hybrids					
	H1	490.85 ± 6.91 a	317.17 ± 3.67 a	10583.43 ± 130.15 a	17.16 ± 0.21 a	53.13 ± 0.91 b
	H2	448.62 ± 7.26 b	301.96 ± 2.99 b	9555.71 ± 112.11 b	14.45 ± 0.17 b	55.37 ± 0.91 a
	Interactions					
	FIH1	539.95 ± 3.45 a	326.84 ± 4.03 a	11951.69 ± 194.09 a	16.74 ± 0.27 b	53.32 ± 0.66 b
	RIH1	529.62 ± 7.71 a	325.21 ± 3.27 a	11647.34 ± 70.51 ab	19.60 ± 0.12 a	52.99 ± 1.34 b
	RFH1	403.00 ± 9.29 d	299.48 ± 3.40 cd	8151.60 ± 125.86 d	15.14 ± 0.23 d	53.07 ± 0.70 b
	FIH2	503.81 ± 6.58 b	312.50 ± 1.50 ab	11351.02 ± 161.20 b	15.90 ± 0.23 c	53.12 ± 0.93 b
	RIH2	462.67 ± 10.33 c	306.52 ± 4.35 bc	9698.48 ± 72.21 c	16.32 ± 0.12 bc	55.43 ± 0.29 ab
	RFH2	379.40 ± 4.89 e	286.85 ± 4.14 d	7617.62 ± 102.71 e	14.16 ± 0.19 e	57.57 ± 1.56 a

Note: Different letters indicate significant differences among treatments ($p < 0.05$).

3.7. Water Use Efficiency

The water use efficiency (WUE) was found to be lower in RF compared to FI and RI (Tables 4 and 5). However, the H1 hybrids had greater water use efficiency compared to H2 in 2017–2018. In this study, the WUE under rainfed was significantly reduced by 7.50% (H1) and 7.68% (H2) in 2017; and 9.55% (H1) and 10.94% (H2) in 2018 compared with FI. Similarly, it was also decreased significantly by 20.51% (H1) and 11.35% (H2) in 2017; and 22.75% (H1) and 13.23% (H2) in 2018 compared with RI (Tables 4 and 5).

4. Discussion

Rainfed treated maize plants have an enormous compromise of grain yield as compared to those in fully irrigated conditions. However, there was less difference found in the grain yield at reproductive irrigation compared to the grain yield at fully irrigated frequencies. We found a substantial difference in the grain yield under rainfed conditions due to the increased anthesis-silking interval (ASI) due to flowering drought stress.

Flowering time is a key event as plants shift from vegetative to reproductive growth, moving toward harvestable yield. In our study, under rainfed conditions, the number of kernels decreased by 17.7% in 2017 and 21.1% in 2018, compared with RI. Other studies observed a significant decrease in number of kernels by 31.13% [27], and 19% [28] under drought stress during flowering period. Maize crops were found to be particularly susceptible to drought at the flowering stage [29]. In addition, the grain yield decreased by 23.6% in 2017 and 26.1% in 2018 under rainfed conditions, compared with RI. Other studies also observed significant reduction in grain yield by 53% [17], 50% [30], and 34.28 to 66.15% susceptible to drought and 38.48 to 55.95% in drought-tolerant hybrids particularly severe when drought stress occurs at the flowering stage [31].

Source activity and sink capacity can be affected by water deficits by reducing the leaf area accelerating leaf senescence [32]. Our results showed that, under rainfed conditions, dry biomass accumulation, and Pn decreased by 17.7%, and 20.7% in 2017 and 18.8%, and 20.9% in 2018, respectively, compared with RI. Our results were supported by another study, where dry matter loss during tasseling stage were recorded as 25% and 19.2% under water deficit condition [13]. Another research study reported that a 55.1% reduction in photosynthetic rate was observed at flowering stage [33]. Another researcher demonstrated reduced net photosynthesis to a comparable extent at both pre- and post-pollination stages under water deficit condition, to less than 10% of controls [34]. We found similar results in our study where irrigation at the flowering stage and rainfed decreased the Pn rate as compared to full irrigation.

We observed that the application of reproductive irrigation at the flowering stage was more important as it led to the synchronous process of anthesis and silking, which, in turn, favored good pollination and resulted in more kernel setting, ultimately increasing the grain yield with lower amounts of water. In addition, we applied 60 mm irrigation at the flowering stage using the flooded method to obtain the maximum grain yield; however, a large water loss occurred through seepage.

While the future is difficult to predict, available freshwater resources will certainly decrease in the coming years due to the increasing demands of a growing world population. Many areas of the world are already experiencing a shortage of water resources. In this study, 60 mm irrigation was applied during the flowering stage. Whether this is optimal remains to be determined. Crop models can assist to optimize the irrigation amount. For example, the APSIM-Maize model [35] was used to predict drought impacts on maize production [36]. Thus, APSIM-Maize may be helpful in assessing the optimal irrigation during flowering.

In this study, we observed the performance of maize hybrids in the grain yield and water use efficiency. Across the irrigation, Zhongdan 909 (H2) expressed lower grain yield and WUE as compared to Zhengdan 958 (H1). In our observations, H1 was more drought-tolerant at the flowering stage compared to H2. Our results are line with a study showing that drought resistant maize hybrids performed very well under water-limited conditions [37]. Drought tolerance was characterized by having a shorter anthesis-silking interval (ASI) [38], and a higher number of kernels/ear [39,40].

The proper selection of drought hybrids can increase the grain yield with a greater biomass and harvest index (HI), greater kernel weight, and higher water use efficiency under water-limited conditions [41–43].

Maintaining favorable plant–soil–water relations throughout the entire growing season is important to stabilize plant growth and development for high yield under water-limited conditions [44,45]. However, few previous studies focused on the difference in soil water extraction patterns and evapotranspiration (ET) between conventional and drought-tolerant hybrids at different growing stages under water-limited conditions [46–49].

5. Conclusions

In this study, we compared the responses of leaf gas exchange, growth, grain yield, and water use efficiency of maize hybrids to different irrigation regimes. Results of this study showed that irrigation regimes significantly influenced maize hybrids, growth and development by altering leaf gas exchange and source to sink relationship. Results of this study revealed that the grain yield in rainfed conditions demonstrated a huge compromise compared with the potential yield achieved under fully irrigated conditions due to the loss of kernels caused by water stress during flowering. Irrigation during flowering (60 mm) had a considerable increase in the grain yield and almost reached 93.0% of the fully irrigated (180 mm) results. The WUE also showed an increase. Thus, the application of irrigation during flowering should be recommended, combined with the use of Zhengdan 958 for greater maize grain yield and efficiency of resource utilization in Huaibei plain or in similar conditions.

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