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Full Length Article

Effects of Irrigation Quota on Photosynthetic Characteristics, Yield, and Water Utilization of Spring Maize in Semi-Arid Region

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Abstract

The response of maize yield, water utilization and photosynthetic physiological characteristics to irrigation was studied systematically, which provided an effective irrigation method for semi-arid areas in western Jilin province. The irrigation quota was set as 2500, 1700, 900 and 0 m^3/hm^2 (CK). Effects of irrigation quota on maize yield and yield formation factors, water utilization, photosynthetic and chlorophyll fluorescence characteristics on different periods were studied. The results showed that the yield, grain weight of 100 grains and ear number were all significantly increased in 2500 m^3/hm^2 and 1700 m^3/hm^2 treatment compared with CK. With the increase of irrigation quota, the water consumption of maize showed a trend of 2500 m^3/hm^2>1700 m^3/hm^2>900 m^3/hm^2>CK. The water productivity (WUE) of 1700 m^3/hm^2 treatment was the highest. The net photosynthetic rate, stomatal conductance, transpiration rate, intercellular CO_2 concentration and apparent mesophyll conductance of 2500 and 1700 m^3/hm^2 treatment significantly increased compared with CK. The stomatal limitation showed the trend of CK>900>1700>2500 m^3/hm^2. The PSII maximum photosynthetic efficiency, actual photosynthetic efficiency of PSII of 2500 m^3/hm^2, 1700 m^3/hm^2 treatment also significantly increased compared with CK. The photochemical quenching significantly increased and the non-photochemical quenching significantly decreased compared with CK. Analysis showed that when the irrigation quota of 1200 m^3/hm^2 was fixed during the growth period, its yield, water utilization and photosynthetic physiological characteristics were the best. It is concluded that the irrigation amount of 1200 m^3/hm^2 can be the best irrigation quota in the western semi-arid area of Jilin Province.

Keywords: Maize; Irrigation quota; Yield; Water utilization efficiency; Photosynthetic characteristics; Chlorophyll fluorescence characteristics

Introduction

Maize (*Zea mays* L.) as the most important food crop in China, played an essential role in the food security of Jilin Province (Xiong *et al*., 2007; Meng *et al*., 2013). Most of the western part of Jilin province is semi-arid, occasional droughts affect maize production in this region (Liu *et al*., 2012). Agricultural irrigation is one of the most important approaches to increase crop yield, but as a result, it consumes global shortage of freshwater resources (Rosegrant *et al*., 2009; Zhang *et al*., 2017). Lack of fresh water resources will have a certain impact on the growth and yield stability of crops in semi-arid regions (Peng *et al*., 2008; Zhang *et al*., 2010; Rabie *et al*., 2015). Therefore, how to make good use of the precious fresh water resources in this region to maintain and improve the maize production, an appropriate irrigation quota is very important (Fang *et al*., 2010).

Soil moisture is the key factor in the growth and development of maize playing a crucial role in the yield and formation of maize yield (Banziger *et al*., 1999; Samim *et al*., 2014; Liu *et al*., 2015; Wang *et al*., 2016). For a water shortage region, the amount of irrigation strongly affects the production of maize. Maize production had a linear increase with the increase in the amount of irrigation, water productivity decreased with the increasing of amount of irrigation (Farre *et al*., 2000). Drip irrigation just sent water to a small area to the root, but had a lot of help to water deficit in crop (Cetin and Bilgel, 2002; Ibragimov *et al*., 2007; Shareef *et al*., 2018). The number of drip irrigation cannot be increased continuously, and the appropriate number and volume can promote the growth of maize and improve the nitrogen productivity (Hokam *et al*., 2011).

Photosynthesis is an important process in the growing process of crops and an indispensable factor. When crops are under water deficit, in order to reduce water evaporation, the leaf stomata will temporarily shut down (Chaves *et al*., 2009). Proper amount of irrigation is good for maize leaf net

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photosynthetic rate, stomatal conductance and transpiration rate maintaining at a higher level (Dwyer *et al*., 1992). This is advantageous to the accumulation of plant dry matter and promotes the growth of maize (Meng *et al*., 2014). Compared with other irrigation methods, drip irrigation can enable maize to fully absorb water and improve the photosynthetic capacity of leaf mesophyll cells in maize leaves (Liang *et al*., 2014).

Chlorophyll fluorescence is a method to test whether crop leaves are affected by water deficit without destroying them (Havaux and Lannoye, 1983). Photosystem II is the main part of crops to convert light energy into chemical one. Drought stress can cause damage to plant organs due to metabolism or stomata opening and closing, and chlorophyll fluorescence technology can clearly reflect the role of plants in the conversion, transmission, dissipation and distribution of light energy, making it an ideal probe to study plants under drought stress (Bi *et al*., 2008). Irrigation can help plant leaves maintain higher photosystem II activity in order to gain higher yield. The maximum photosynthetic efficiency F_v/F_m of optical system II was one of the best indicators to judge whether the crops were being stressed or not (Winkel *et al*., 2002). Studies reported that when fully irrigated, whether F_v/F_m of quinoa was stable or not is determined by the photosynthesis on the rails. This can help evaluate quinoa development and the degree of water demand. By the ratio between maximum fluorescence F_m and leaf angle, the crop irrigation needs can be judged (Wu *et al*., 2016), which indirectly illustrates that by measuring chlorophyll fluorescence, whether the crop water shortage can be tested and the key indicators of irrigation is to be considered or not.

Water productivity is an approach to judge the efficiency of crop water utilization, especially in some semi-arid regions, where the annual evaporation is extremely high, and whether high or low in the numerical value of WUE becomes especially critical (Farooq *et al*., 2019). Some studies has illustrated that, through the straw cover and changes of different farming methods, the maize field soil moisture and WUE can be improved and increased. This improves the efficiency of the soil, but increases the cost of maize production (Hassanli *et al*., 2009). The cultivation mode was not suitable to be popularized in semi-arid areas. With the drip irrigation belt laid in the ditch, in recent years watering carried out by drop irrigation is a conventional region growing technique while planting maize in the western region of Jilin Province. The popularization of drip irrigation technology plays a crucial role in the stable improvement of maize yield, and at the same time improves the water productivity and the root soil is kept in the optimal moisture, aeration and nutrient state (Zhao *et al*., 2011).

Water is an important factor restricting crop growth and yield formation in the semi-arid area of Jilin Province, and the effects of irrigation quota on maize yield, water use and photosynthetic physiological characteristics are not clear. In this study, two conventional maize varieties were selected from the western semi-arid area of Jilin province. The factors of maize yield and yield formation, water utilization efficiency and photosynthetic characteristics under different irrigation quota conditions were studied. The effects of irrigation quota on maize yield formation and photosynthetic physiological characteristics were investigated, which provides an effective irrigation quota and theoretical basis for the efficient production of maize in the western semi-arid area of Jilin Province, China.

Materials and Methods

Site Description

The experimental field is located in Taonan Agricultural Extension Center Test Station, Taonan, Jilin Province, China (Latitude: 45°20'N; Longitude: 122°49' E). In 2016 and 2017, the effective accumulated temperature of 10ºC or higher was 3292.4ºC and 3296.8ºC and for the whole growth period, the average temperature was 20.26ºC and 20.52ºC. Respectively, precipitation in the whole stages was 273.7 mm and 197.7 mm, the reproductive period of rainfall distribution was mainly concentrated in July to August. It accounts for 61.91% and 68.42% of precipitation in the whole growth period respectively. The soil of the test site is characterized in sandy with 0–20 cm bulk density of soil layer is 1.49 g/cm^3, with 18% field moisture capacity, soil organic matter content of 12.46 g/kg, available N, 65.47 mg/kg, available P 21.65 mg/kg, and rapidly-available potassium content of 103.56 mg/kg including pH 7.8.

Characteristics of Maize Cultivars y

The maize variety tested, was chosen from Huanong 887(H887) and Xianyu 335(X335) in the western region of Jilin Province in recent years by a large number of expanding cultivation, provided by the Germplasm Resource Lab., Agricultural Resources and Environmental Research Center in Jilin Academy of Agricultural Sciences.

Experimental Design and Treatments

The experiment was conducted from April 2016 to October 2017. The planting dates were May 2, 2016 and May 4, 2017 respectively and the harvest dates were on September 29, 2016 and October 2, 2017 respectively. The seeding density was 65000 plants /hm^2, and compound fertilizer was applied as the base fertilizer (15–15–15) 750 kg/hm^2, and urea 277.2 kg/hm^2 was applied at the V8 stage.

Irrigation Treatments

Before the test, an investigation was made on the irrigation quota of the farmers in Taonan area. The local farmers had the irrigation quota of 500 m^3/hm^2, before sowing. During the whole maize growing period, average irrigation quota was 2000 m^3/hm^2. Irrigative treatment schemes of the detailed test were shown in Table 1. Irrigation was carried out by manual drop irrigation tape, placed in the furrow. Water meter was used to record irrigation water in each community. The plot area was set as 30 m^2, with ridge width of 65 cm, and the length of 7.7 m. Each treatment was repeated three times. In order to guarantee the realization of irrigation norm, 0.5 meters conservation area was set within each plot.

Measurement of Plant Gas Exchange Traits

The net photosynthetic rate (P_n), stomatal conductance (G_s), intercellular CO_2 concentration (C_i) and transpiration rate (T_r) of maize leaves were determined by Li-6800 portable photosynthesis measuring system from Li-Cor company at V8, V12, R1 and R3 stages while, choosing the cloudless weather, at 8:30–11:30 am. Apparent mesophyll conductance (A.M.C.) was obtained through the calculation of ratio of P_n and C_i. The stomatal limitation (L_s) was calculated according to the formula $L_s = (1–C_i /C_a) \times 100\%$, where the C_a was the environmental CO_2 concentration (*i.e.*, the CO_2 concentration of the instrument inlet). The optical quantum density of instrument was set as 1800 $mol \cdot m^{-2} \cdot s^{-1}$. In order to avoid the influence of the change of ambient CO_2 concentration on the numerical results, the CO_2 inlet of the instrument was connected with a small CO_2 cylinder, and the concentration was set as 375 plus or minus 5 $mol \cdot mol^{-1}$. Three representative plants of maize were selected randomly in each community for determination.

Chlorophyll Fluorescence

The determination of chlorophyll fluorescence was carried out by applying the Li-6800 portable photosynthetic measurement system at R1, R3 and R4 stage. The detecting light intensity was set to 1800 $\mu mol \cdot m^{-2} \cdot s^{-1}$, and the intensity of the saturated pulse light at 7200 $\mu mol \cdot m^{-2} \cdot s^{-1}$. The plants were kept in darkness for at least two hours and the maximum photosynthetic efficiency of *PSII* (F_v/F_m) of the maize leaves was measured under dark conditions. The plants were placed in light for 2 h after the indicators measured in the dark. The actual photosynthetic efficiency of *PSII* ($\Phi PSII$) were then measured. Again, after 2 h of dark adaptation treatment, the plants were fully activated under light, photochemical quenching (*qP*) and non-photochemical quenching (NPQ) were calculated after the measurements were taken. Three representative plants were randomly selected from each community for measurement. In order to reduce the impact of environmental changes, 2–3 d was determined in each period.

Yield and Yield Formation Factors

At the R6 stage of maize, the whole area was tested for yield, and 10 consecutive ears of fruit in the community were selected for indoor seed testing. The grain moisture content was determined by grain moisture meter, and the yield was calculated according to 15.5% water.

Soil Moisture

Before sowing and after harvest, by using soil drill to obtain soil, up to 120 cm soil water content was determined, at 20 cm as a layer distance, water content of soil quality was calculated by drying method (%).

Water Consumption Rate

The water consumption of crops (ET) was calculated according to the water balance equation of farmland, and the factors of soil water infiltration and groundwater recharge were ignored. The precipitation data in the experimental area during the growth period of maize were obtained by the automatic weather station in the experimental station. Crop water consumption ET (mm) = soil water storage capacity of 120 cm before sowing-soil water storage capacity of 120 cm –after harvest + rainfall in the growth period + irrigation water in the growth period.

Water Productivity

Water productivity (W.U.E) was calculated as:

W.U.E. ($kg \cdot hm^{-2} \cdot mm^{-1}$) = Crop grain yield/Water consumption

Results

Yield and Yield Contributing Factors

The results showed that years, varieties and irrigation quotas had significant influence on maize yield, while year and variety had no significant influence on yield indicating that irrigation quota in different years had the same trend on yield. The regulatory response of different varieties to irrigation quota was consistent. The responses of hundred-grain weight and ear number to years, varieties and irrigation quota were the same. Different years and irrigation quotas had significant effects on hundred-grain weight and ear number of maize, but the differences among varieties were not significant. There was no significant difference in years and varieties irrigation quotas, indicating that the influence trend of different years, irrigation quota and varieties on hundred-grain weight and ear number was consistent (Table 2). Irrigation is one of the essential factors to maintain the high yield and stable yield of maize in the western semi-arid area of Jilin Province. The yield and its component factors under different irrigation quotas in 2016 and 2017 showed that the yield of both varieties increased with the increase of irrigation quantity compared with CK (Table 3). There was no significant difference between 2500 m^3/hm^2 and 1700

Table 1: Irrigation quota treatments scheme in 2016 and 2017

Treatment (m^3/hm^2)	Before sowing (m^3/hm^2)	Leaf age				Total irrigation quota (m^3/hm^2)
		V8 (m^3/hm^2)	V12 (m^3/hm^2)	R1 (m^3/hm^2)	R3 (m^3/hm^2)	
Control (0)	500	0	0	0	0	500
900	500	100	100	100	100	900
1700	500	300	300	300	300	1700
2500	500	500	500	500	500	2500

Table 2: The yield and its component factors of two varieties in different sampling dates under four irrigation quota in 2016 and 2017

Treatments		Yield (kg/hm^2)	Hundred grain weight (g)	Ear number
Year	2016	10135.7a	30.5a	581.4a
	2017	8939.6b	29.6b	546.5b
Variety	H887	9831.1a	30.1a	567.9a
	X335	9244.2b	29.9a	560.0a
Irrigation quota	2000	10878.4a	32.8a	595.8a
	1200	10683.0a	32.0a	580.3ab
	400	9329.6b	29.9b	557.1b
	0	7259.6c	25.4c	522.6c
Source of variation				
Year (Y)		**	*	**
Variety (V)		**	NS	NS
Irrigation quota (I)		**	**	**
Y×V		NS	NS	NS
Y×I		NS	NS	NS
V×I		NS	NS	NS
Y×V×I		NS	NS	NS

Note: The different lowercase letters showed significant differences between varieties, sampling periods, or years ($P < 0.05$). NS: not significant ($P > 0.05$). * Significant at $P < 0.05$. ** Significant at $P < 0.01$

Table 3: The yield and its component factors under different irrigation quotas in 2016 and 2017

Yield characteristics	Year	Varieties	2500 m^3/hm^2	1700 m^3/hm^2	900 m^3/hm^2	Control
Yield (kg/hm^2)	2016	H887	11574 ± 490a	11560 ± 283a	10255 ± 809b	8062 ± 567c
		X335	11371 ± 607a	11207 ± 505a	9365 ± 992b	7692 ± 509c
	2017	H887	10620 ± 555a	10355 ± 600a	9399 ± 247b	6824 ± 388c
		X335	9949 ± 308a	9610 ± 402a	8300 ± 168b	6461 ± 363c
Ear number	2016	H887	620.37 ± 28.01a	598.00 ± 34.31ab	590.40 ± 45.37ab	542.13 ± 13.42b
		X335	605.80 ± 44.24a	594.33 ± 57.50ab	567.33 ± 27.04ab	532.87 ± 13.61b
	2017	H887	564.60 ± 50.60a	538.33 ± 10.58a	520.93 ± 45.08a	505.27 ± 9.70a
		X335	592.33 ± 29.29a	590.33 ± 34.77a	549.77 ± 47.86ab	510.13 ± 13.60b
Hundred grain weight (g)	2016	H887	32.20 ± 0.79a	31.63 ± 0.99ab	30.53 ± 0.68c	24.53 ± 1.09c
		X335	31.44 ± 1.12a	31.26 ± 1.65a	29.38 ± 0.96a	25.45 ± 1.25b
	2017	H887	33.11 ± 0.45a	32.50 ± 2.54a	29.30 ± 0.95ab	25.69 ± 3.64b
		X335	34.27 ± 1.04a	32.60 ± 1.67ab	30.27 ± 0.85b	25.96 ± 1.75c

Note: The different lowercase letters showed significant difference at the 5% level between different irrigation treatments in the same varieties at the same leaf age

m^3/hm^2 treatments, but both of them were significantly higher than 900 m^3/hm^2 treatment in 2016 and 2017. Therefore, it can be inferred that a reduction of 800 m^3/hm^2 according to local farmers' practice of irrigation, can achieve both high yield and water saving. Both the 100 grains-weight and the number of grains in ears of 2500 m^3/hm^2 and 1700 m^3/hm^2 treatments showed an increasing trend with the increase of irrigation water irrigation quantity compared with CK. The percentage increase of 2500 m^3/hm^2 treatment was higher, but there was no significant difference compared with 1700 m^3/hm^2 treatment. This indicates that the irrigation quota can increase the grain weight and grain number of ears of maize, thus increasing the yield.

Photosynthetic Traits

Year and variety had no significant effect on P_n, G_s and C_i from V8 to R1 leaf age. This indicated that the two varieties had the same trend on P_n, G_s and C_i under different irrigation quota conditions in different years, the response to T_r is significant. The effects of irrigation quota and year on G_s and T_r were not significant, indicating that the different trends of G_s and T_r of H887 and X335 with different irrigation quota were fixed in different years. The maize leaves maintaining higher photosynthesis is one of the main factors for the formation of high yield in maize. The changes in the photosynthetic parameters of maize during the key growth periods of 2016 and 2017 demonstrated that P_n, G_s, T_r and C_i of 2500 m^3/hm^2 and 1700 m^3/hm^2 treatments significantly increased in four periods compared with CK in 2016 and 2017 (Table 4 and 5). The percentage increase of 2500 m^3/hm^2 treatment was higher, but there was no significant difference compared with 1700 m^3/hm^2 treatment. This suggests that the appropriate irrigation can

Table 4: The photosynthetic characteristics in maize leaves under different irrigation quotas in 2016

Leaf age	Treatment (m^3/hm^2)	P_n ($\mu mol \cdot m^{-2} \cdot s^{-1}$) H887	P_n X335	G_s ($mol \cdot m^{-2} \cdot s^{-1}$) H887	G_s X335	C_i ($\mu mol \cdot mol^{-1}$) H887	C_i X335	T_r ($mol \cdot m^{-2} \cdot s^{-1}$) H887	T_r X335
V8	2500	36.03 ± 1.31a	36.46 ± 3.85a	0.46 ± 0.06a	0.62 ± 0.07a	191.67 ± 10.83a	188.29 ± 5.27a	4.07 ± 0.13a	4.99 ± 0.41a
	1700	31.88 ± 2.55a	33.66 ± 1.52ab	0.46 ± 0.01a	0.56 ± 0.05b	187.51 ± 7.27a	182.73 ± 11.02a	3.71 ± 1.28a	4.89 ± 0.13a
	900	26.08 ± 3.23b	31.62 ± 3.59b	0.38 ± 0.01b	0.41 ± 0.08b	178.41 ± 10.33ab	168.65 ± 15.54ab	3.50 ± 0.28a	4.79 ± 1.11a
	Control	24.81 ± 0.41b	26.19 ± 1.79c	0.32 ± 0.05b	0.40 ± 0.07b	173.61 ± 1.75b	167.54 ± 14.32b	3.35 ± 0.48a	4.65 ± 0.68a
V12	2500	40.10 ± 5.04a	37.38 ± 3.08a	0.56 ± 0.03a	0.50 ± 0.04a	141.37 ± 2.17a	133.01 ± 29.39a	7.12 ± 0.86a	10.72 ± 0.80a
	1700	36.06 ± 0.29ab	33.12 ± 2.96a	0.49 ± 0.06ab	0.47 ± 0.05a	142.37 ± 11.47a	126.67 ± 16.33a	6.80 ± 0.65ab	9.03 ± 0.88ab
	900	25.54 ± 1.85b	25.57 ± 2.21b	0.46 ± 0.02b	0.43 ± 0.04ab	133.25 ± 12.14a	127.84 ± 26.14a	6.32 ± 0.17ab	8.27 ± 1.23b
	Control	21.48 ± 1.47c	21.49 ± 2.79b	0.43 ± 0.02b	0.38 ± 0.03b	111.25 ± 11.68b	100.98 ± 8.98b	5.76 ± 0.15b	6.26 ± 0.69c
R1	2500	31.15 ± 0.48a	27.52 ± 0.59a	0.46 ± 0.10a	0.37 ± 0.15a	198.43 ± 14.83a	167.29 ± 2.05a	3.36 ± 0.31ab	3.94 ± 0.66a
	1700	26.48 ± 1.21ab	24.66 ± 2.11a	0.36 ± 0.08ab	0.31 ± 0.04ab	187.80 ± 13.24a	156.76 ± 14.62ab	3.93 ± 0.39a	3.55 ± 0.12a
	900	25.63 ± 3.05bc	25.16 ± 1.12a	0.24 ± 0.05bc	0.34 ± 0.04ab	172.30 ± 9.42a	156.85 ± 21.81ab	3.04 ± 0.43b	3.75 ± 0.13a
	Control	21.56 ± 3.35c	18.05 ± 1.95b	0.18 ± 0.04c	0.18 ± 0.05b	147.57 ± 16.00b	138.96 ± 20.25b	2.74 ± 0.28b	2.60 ± 0.30a
R3	2500	30.87 ± 1.75a	30.47 ± 2.01a	0.32 ± 0.09a	0.28 ± 0.07a	183.46 ± 29.71a	166.00 ± 11.66a	5.49 ± 1.01a	5.11 ± 0.78a
	1700	28.22 ± 2.16a	28.76 ± 2.17a	0.27 ± 0.04ab	0.24 ± 0.04a	149.65 ± 18.03ab	145.98 ± 18.61a	4.38 ± 0.48ab	4.55 ± 0.57a
	900	20.63 ± 1.07b	23.95 ± 1.06b	0.20 ± 0.02bc	0.16 ± 0.02b	136.23 ± 17.92ab	129.09 ± 12.26ab	3.44 ± 1.15bc	2.83 ± 0.23b
	Control	16.67 ± 1.15c	16.09 ± 2.90c	0.14 ± 0.04c	0.08 ± 0.03c	124.50 ± 18.86b	100.06 ± 15.85b	2.46 ± 0.11c	1.53 ± 0.42c

Note: The different lowercase letters showed significant difference at the 5% level between different irrigation treatments in the same varieties at the same leaf age

Table 5: The photosynthetic characteristics in maize leaves under different irrigation quotas in 2017

Leaf age	Treatment (m^3/hm^2)	P_n ($\mu mol \cdot m^{-2} \cdot s^{-1}$) H887	P_n X335	G_s ($mol \cdot m^{-2} \cdot s^{-1}$) H887	G_s X335	C_i ($\mu mol \cdot mol^{-1}$) H887	C_i X335	T_r ($mol \cdot m^{-2} \cdot s^{-1}$) H887	T_r X335
V8	2500	33.34 ± 1.66a	37.07 ± 2.59a	0.45 ± 0.05a	0.48 ± 0.05a	309.80 ± 19.50a	347.19 ± 9.71a	3.74 ± 0.08a	4.14 ± 0.21a
	1700	30.97 ± 0.28ab	32.88 ± 3.92ab	0.37 ± 0.08ab	0.45 ± 0.04ab	296.83 ± 7.56a	326.00 ± 30.14a	3.69 ± 0.10a	3.62 ± 0.24ab
	900	29.44 ± 1.89bc	27.81 ± 3.65b	0.36 ± 0.06b	0.45 ± 0.03ab	296.99 ± 13.48a	310.19 ± 12.41a	3.32 ± 0.04b	3.60 ± 0.17ab
	Control	27.74 ± 0.43c	24.84 ± 3.09b	0.30 ± 0.05b	0.42 ± 0.06b	284.30 ± 14.23a	303.05 ± 29.37a	3.23 ± 0.14b	3.37 ± 0.30b
V12	2500	35.48 ± 3.33a	37.28 ± 4.89a	0.53 ± 0.06a	0.54 ± 0.04a	248.37 ± 15.10a	232.83 ± 20.68a	3.78 ± 0.46a	3.84 ± 0.38a
	1700	31.07 ± 2.15ab	30.24 ± 4.59ab	0.45 ± 0.07ab	0.48 ± 0.01ab	229.28 ± 25.63ab	218.36 ± 17.65a	2.93 ± 0.39a	2.87 ± 0.37a
	900	28.33 ± 0.48b	27.62 ± 3.33b	0.40 ± 0.03ab	0.42 ± 0.05bc	228.21 ± 16.53ab	206.47 ± 9.92ab	2.64 ± 0.46ab	2.36 ± 0.28a
	Control	26.13 ± 3.45b	25.14 ± 2.51b	0.38 ± 0.01b	0.38 ± 0.01c	194.56 ± 8.50b	190.23 ± 11.40b	2.39 ± 0.08b	2.34 ± 0.19a
R1	2500	32.11 ± 3.11a	32.75 ± 2.33a	0.34 ± 0.04a	0.35 ± 0.02a	238.64 ± 15.78a	247.18 ± 19.76a	3.98 ± 0.37a	3.90 ± 0.41a
	1700	31.33 ± 0.30a	30.00 ± 3.37a	0.31 ± 0.04ab	0.34 ± 0.01a	220.83 ± 13.81ab	216.07 ± 23.94ab	3.23 ± 0.32ab	3.07 ± 0.37ab
	900	24.99 ± 3.78a	26.25 ± 5.13b	0.27 ± 0.02b	0.23 ± 0.03b	202.54 ± 8.23bc	200.15 ± 18.61bc	2.84 ± 0.14b	2.66 ± 0.22b
	Control	22.06 ± 2.52b	22.94 ± 3.49c	0.19 ± 0.01c	0.19 ± 0.02b	185.82 ± 6.68c	176.86 ± 9.80c	2.20 ± 0.17c	2.18 ± 0.14c
R3	2500	25.77 ± 3.92a	24.09 ± 4.25a	0.19 ± 0.05a	0.25 ± 0.01a	129.22 ± 42.72a	180.29 ± 26.63a	2.93 ± 0.57a	3.10 ± 0.18a
	1700	21.31 ± 0.31ab	23.34 ± 3.65a	0.13 ± 0.01ab	0.17 ± 0.06ab	128.92 ± 14.83a	140.07 ± 26.80ab	2.26 ± 0.07ab	2.60 ± 0.10ab
	900	18.00 ± 2.41bc	20.59 ± 1.36ab	0.13 ± 0.02b	0.13 ± 0.01b	117.14 ± 17.76a	125.81 ± 19.71ab	2.14 ± 0.28b	2.43 ± 0.07b
	Control	14.81 ± 2.78c	16.10 ± 4.09b	0.10 ± 0.02b	0.12 ± 0.02b	96.88 ± 7.52a	100.15 ± 18.61b	1.90 ± 0.27b	2.20 ± 0.33b

Note: The different lowercase letters showed significant difference at the 5% level between different irrigation treatments in the same varieties at the same leaf age

maintain the maize leaf photosynthesis and keep the degree of stomatal opening and closing. Without irrigation, due to the effect of limitation of the porosity, the P_n and G_s of CK leaf are lower. By shutting down the stomata, maize suppress stress is caused by the shortage of water in the body. Along with the advancement of growth period, the P_n, T_r and G_s of CK attained the lowest value at the R3 stage. This shows that as the maize growth and development process of continuous, long-term water deficit may cause a certain impact on the maize leaf stomatal opening and closing and maize leaves do not photosynthesize properly.

L_s is an important index to determine the degree of stomatal opening and closing of crop leaves. The L_s of H887 and X335 showed a CK>900 m^3/hm^2>1700 m^3/hm^2>2500 m^3/hm^2 trend and it can also be seen that with the advancement of maize growth, the limiting functions of stomatal are increasing, combined with the change of C_i (Fig. 1; Table 4–5). The decreased factors of photosynthesis may come from the limitation of stomatal nature and suitable irrigation (2500 m^3/hm^2, 1700 m^3/hm^2) is favorable to maintain higher photosynthesis ability of maize leaves.

The changes of leaf AMC under different irrigation quota showed that the changeable trend of AMC is similar to P_n, G_s, T_r and C_i (Fig. 2.). Compared with CK, 2500 m^3/hm^2 and 1700 m^3/hm^2 treatments were significantly increased. This shows that the fixed irrigation in the key growth period of maize is the way to effectively maintain the activity of RuBP in maize, thus reducing the stress caused by the drought.

Chlorophyll Fluorescence

Year and variety had no significant effect on F_v/F_m, *ΦPSII*, *qP* and NPQ from R1 to R4 leaf age. This indicated that the two varieties had the same response on F_v/F_m, *ΦPSII*, *qP* and NPQ under different irrigation quota conditions in different years. There was no significant effect on F_v/F_m, *ΦPSII*, *qP* and NPQ in years, varieties and irrigation quotas,

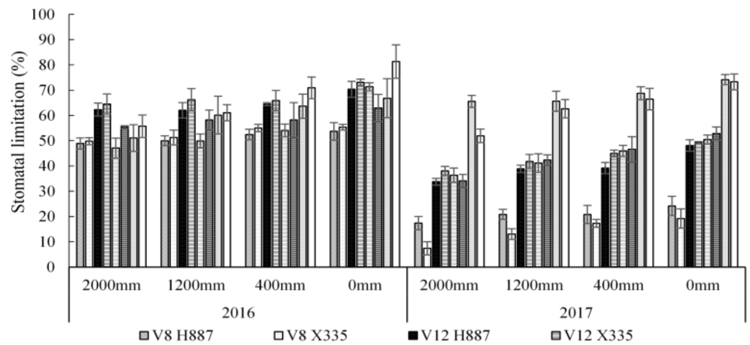

Fig. 1: The stomatal limitation in maize leaves under different irrigation quotas in 2016 and 2017

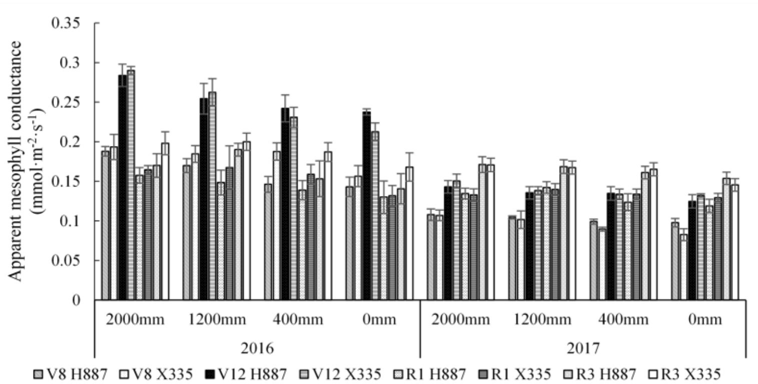

Fig. 2: The apparent mesophyll conductance in maize leaves under different irrigation quotas in 2016 and 2017

indicating that the difference in trends of F_v/F_m, *ΦPSII*, *qP* and NPQ of two varieties was fixed on different irrigation quotas in different years. The F_v/F_m and *ΦPSII* are the key indexes to determine whether the light system II of crop leaves is damaged or not. As can be observed from Table 6 and 7, the F_v/F_m and *ΦPSII* of 2500 m^3/hm^2, 1700 m^3/hm^2 treatment showed a significant increase in the tendency of change compared with CK in 2016 and 2017, without any significant differences between the 2500 m^3/hm^2 and 1700 m^3/hm^2 treatments. Each treatment of F_v/F_m and *ΦPSII* in 2016 and 2017 illustrated a R1 stage > R3 stage > R4 stage trend. It can be seen that from the changes of F_v/F_m and *ΦPSII*, with the advancement of the growth period, without CK processing irrigation, the damage to the light System II is gradually on the rise, while 2500 m^3/hm^2 and 1700 m^3/hm^2 treatments are still maintaining a higher activity of light System II on account of the suitable irrigation ration.

The *qP* and NPQ respectively reflect the energy transferred by photochemical electron and the energy that can't be used in photochemical electron transfer in the form of heat dissipation. The *qP* showed a significant increase in three periods compared with CK, while NPQ, on the contrary, displayed an apparent decline in the trend of change (Table 6 and 7). There is no obvious difference in *qP* and NPQ between 2500 m^3/hm^2 and 1700 m^3/hm^2 treatment. Each treatment of *qP* in 2016 and 2017 showed a R1 > R3 > R4 stages tendency. The change trend of NPQ was opposite to *qP*. As can be seen from the changes of *qP* and NPQ, with the development of the growth period, suitable irrigation (2500 m^3/hm^2, 1700 m^3/hm^2) can promote the energy consumption of the maize leaves in the way of heat dissipation, thus resisting the stress caused by the drought.

Water Consumption and Water Productivity of Maize

The Table 8 showed that the ET of 2500 m^3/hm^2 and 1700 m^3/hm^2 treatment increased significantly, compared with CK. With the increase of irrigation quota, ET showed an increasing trend. This indicates that with the increase of irrigation quota, soil moisture increases, so does the demand for water. The W.U.E. of 2500 m^3/hm^2, 1700 m^3/hm^2 and 900 m^3/hm^2 treatments of the two were significantly higher than CK. The W.U.E. of 1700 m^3/hm^2 treatment was the highest in both varieties. From the point of view of

Table 6: The chlorophyll fluorescence parameters in maize leaves under different irrigation quotas in 2016

Leaf age	Treatment (m^3/hm^2)	F_v/F_m		*ΦPSII*		*qP*		NPQ	
		H887	X335	H887	X335	H887	X335	H887	X335
R1	2500	0.84 ± 0.03a	0.82 ± 0.05a	0.75 ± 0.04a	0.72 ± 0.01a	0.83 ± 0.04a	0.76 ± 0.05a	1.45 ± 0.04a	1.63 ± 0.05b
	1700	0.80 ± 0.02a	0.78 ± 0.07ab	0.72 ± 0.04ab	0.70 ± 0.05a	0.78 ± 0.04ab	0.73 ± 0.05a	1.46 ± 0.06a	1.68 ± 0.10b
	900	0.74 ± 0.02b	0.72 ± 0.02bc	0.71 ± 0.01ab	0.70 ± 0.01a	0.72 ± 0.05b	0.60 ± 0.02b	1.57 ± 0.10a	1.78 ± 0.44a
	Control	0.70 ± 0.01b	0.69 ± 0.02c	0.67 ± 0.04b	0.68 ± 0.01a	0.70 ± 0.05b	0.58 ± 0.08b	1.59 ± 0.11a	1.81 ± 0.18a
R3	2500	0.60 ± 0.02a	0.58 ± 0.03a	0.57 ± 0.03a	0.55 ± 0.05a	0.64 ± 0.01a	0.59 ± 0.02a	1.67 ± 0.05b	1.69 ± 0.09b
	1700	0.56 ± 0.05a	0.57 ± 0.05a	0.51 ± 0.05ab	0.47 ± 0.05ab	0.59 ± 0.02a	0.53 ± 0.04ab	1.73 ± 0.10b	1.78 ± 0.17b
	900	0.49 ± 0.02b	0.50 ± 0.05b	0.47 ± 0.05ab	0.44 ± 0.04b	0.51 ± 0.02b	0.45 ± 0.03b	1.80 ± 0.07b	1.84 ± 0.11b
	Control	0.44 ± 0.04b	0.41 ± 0.01c	0.43 ± 0.07b	0.38 ± 0.03c	0.42 ± 0.07c	0.30 ± 0.06c	1.98 ± 0.09a	2.00 ± 0.06a
R4	2500	0.46 ± 0.06a	0.48 ± 0.04a	0.47 ± 0.05a	0.45 ± 0.03a	0.47 ± 0.04a	0.48 ± 0.08a	1.82 ± 0.04c	1.80 ± 0.03b
	1700	0.37 ± 0.05ab	0.39 ± 0.05ab	0.41 ± 0.04a	0.40 ± 0.02ab	0.46 ± 0.06a	0.46 ± 0.05a	1.95 ± 0.06bc	1.90 ± 0.21ab
	900	0.29 ± 0.02bc	0.33 ± 0.03b	0.37 ± 0.06ab	0.37 ± 0.03b	0.37 ± 0.06ab	0.43 ± 0.03ab	2.01 ± 0.05b	1.99 ± 0.13ab
	Control	0.23 ± 0.02c	0.25 ± 0.01c	0.31 ± 0.07b	0.30 ± 0.02c	0.30 ± 0.07b	0.36 ± 0.04b	2.28 ± 0.15a	2.09 ± 0.24a

Note: The different lowercase letters showed significant difference at the 5% level between different irrigation treatments in the same varieties at the same leaf age

Table 7: The chlorophyll fluorescence parameters in maize leaves under different irrigation quotas in 2017

Leaf age	Treatment (m^3/hm^2)	F_v/F_m		*ΦPSII*		*qP*		NPQ	
		H887	X335	H887	X335	H887	X335	H887	X335
R1	2500	0.81 ± 0.03a	0.78 ± 0.06a	0.69 ± 0.05a	0.73 ± 0.02a	0.88 ± 0.03a	0.85 ± 0.05a	1.45 ± 0.08a	1.52 ± 0.04a
	1700	0.79 ± 0.04a	0.76 ± 0.03a	0.66 ± 0.09a	0.71 ± 0.03a	0.83 ± 0.05ab	0.82 ± 0.05a	1.47 ± 0.10a	1.53 ± 0.07a
	900	0.76 ± 0.02ab	0.74 ± 0.04a	0.64 ± 0.04a	0.70 ± 0.05ab	0.81 ± 0.05ab	0.80 ± 0.01ab	1.50 ± 0.13a	1.54 ± 0.09a
	Control	0.72 ± 0.02b	0.72 ± 0.03a	0.61 ± 0.03a	0.66 ± 0.02b	0.75 ± 0.05b	0.77 ± 0.05b	1.53 ± 0.12a	1.56 ± 0.18a
R3	2500	0.62 ± 0.02a	0.59 ± 0.03a	0.68 ± 0.04a	0.67 ± 0.08a	0.64 ± 0.05a	0.59 ± 0.02a	1.59 ± 0.08b	1.57 ± 0.16b
	1700	0.57 ± 0.05a	0.57 ± 0.05a	0.61 ± 0.05ab	0.58 ± 0.02ab	0.59 ± 0.06a	0.53 ± 0.04a	1.67 ± 0.12ab	1.66 ± 0.07b
	900	0.51 ± 0.02b	0.52 ± 0.04a	0.54 ± 0.04b	0.55 ± 0.03b	0.49 ± 0.02b	0.47 ± 0.02ab	1.74 ± 0.04ab	1.75 ± 0.28ab
	Control	0.45 ± 0.04b	0.43 ± 0.03b	0.48 ± 0.02b	0.48 ± 0.05b	0.42 ± 0.06b	0.39 ± 0.04b	1.88 ± 0.11a	1.91 ± 0.08a
R4	2500	0.53 ± 0.02a	0.51 ± 0.05a	0.48 ± 0.03a	0.49 ± 0.03a	0.47 ± 0.04a	0.49 ± 0.05a	1.75 ± 0.05b	1.80 ± 0.15c
	1700	0.48 ± 0.05a	0.46 ± 0.05a	0.43 ± 0.04ab	0.43 ± 0.02a	0.43 ± 0.06a	0.43 ± 0.04a	1.83 ± 0.10ab	1.88 ± 0.12bc
	900	0.42 ± 0.05ab	0.39 ± 0.03a	0.35 ± 0.02b	0.37 ± 0.03b	0.37 ± 0.05ab	0.37 ± 0.04ab	1.99 ± 0.08a	1.99 ± 0.08b
	Control	0.31 ± 0.01b	0.31 ± 0.02b	0.29 ± 0.01c	0.30 ± 0.05b	0.30 ± 0.06b	0.29 ± 0.06b	2.15 ± 0.19a	2.24 ± 0.17a

Note: The different lowercase letters showed significant difference at the 5% level between different irrigation treatments in the same varieties at the same leaf age

Table 8: The water consumption and water productivity of maize under different irrigation quotas

Year	Varieties	Treatment (m^3/hm^2)	Reservoir capacity before sowing (mm)	Reservoir capacity after harvest (mm)	Irrigation quota (mm)	Rainfall (mm)	ET (mm)	W.U.E. ($kg/mm{\cdot}hm^2$)
2016	H887	2500	292.45	288.36	200	273.70	477.79a	24.22a
		1700	292.45	253.12	120	273.70	433.03a	26.69a
		900	292.45	212.27	40	273.70	393.88ab	26.03a
		Control	292.45	210.76	0	273.70	355.39b	22.28b
	X335	2500	292.45	360.73	200	273.70	405.43a	28.04a
		1700	292.45	301.18	120	273.70	384.97a	29.11a
		900	292.45	238.26	40	273.70	357.89b	26.17a
		Control	292.45	216.58	0	273.70	349.58b	22.00b
2017	H887	2500	239.26	269.90	200	197.70	367.05a	28.93a
		1700	239.26	245.89	120	197.70	311.07ab	33.29a
		900	239.26	191.54	40	197.70	285.42ab	32.93a
		Control	239.26	176.23	0	197.70	260.72b	26.17b
	X335	2500	239.26	252.27	200	197.70	384.69a	25.86a
		1700	239.26	223.10	120	197.70	363.86a	26.41a
		900	239.26	176.23	40	197.70	333.86b	24.86ab
		Control	239.26	159.94	0	197.70	277.02b	23.32b

Note: The different lowercase letters showed significant difference at the 5% level between different irrigation treatments in the same varieties at the same leaf age

increasing production and saving water, the irrigation quota treated with 1700 m^3/hm^2 is more appropriate.

Discussion

Agricultural water is often in short supply in semi-arid areas, which affects the formation and improvement of crop yield (Kang *et al*., 2000; Sun *et al*., 2006). Irrigation has become an essential way to ensure the normal growth of crops in these areas (Zotarelli *et al*., 2009). Zwart and Bastiaanssen (2004) reported that the water productivity of maize remains at 1.1–2.7 kg/m^3, which can greatly help increase agricultural production and reduce water waste. This research also improves the water production efficiency of maize and uses appropriate water quota for irrigation that should be reduced as much as possible on the premise of ensuring production. The results of this study showed that different years, varieties and irrigation quotas had significant effects on the yield of maize, but there was no significant difference in the yield of maize after the interaction of the three factors, indicating that the trend of difference in yield of maize under different years (different rainfall in 2016 and 2017) and different varieties (H887 and X335) is consistent. Through the comparison and analysis of physiological indexes, this paper looks for the irrigation quota suitable for the semi-arid area in the west of Jilin Province to ensure the premise of maize yield and improve the water productivity of maize. In the current study, the yield of 2500 m^3/hm^2, 1700 m^3/hm^2 and 900 m^3/hm^2 treatment showed a significant increase but without no significant difference between 2500 m^3/hm^2 and 1700 m^3/hm^2 treatment. This shows that irrigation is the most important way to ensure the increase of maize yield in this area. Compared with 1700 m^3/hm^2 treatment, the irrigation quota of 2500 m^3/hm^2 treatment increased by 800 m^3/hm^2 during the whole growth period, the yield of both varieties did not increase significantly. According to the local water and electricity standards, the cost input of 2500 m^3/hm^2 treatment increased by 120 yuan /hm^2 compared with the 1700 m^3/hm^2 treatment. The Table 3 showed that the average yield of 2500 m^3/hm^2 treatment was 195.4 kg/hm^2 higher than 1700 m^3/hm^2 treatment. The purchase price of maize in Jilin Province was about 1.5 kg/ yuan during 2016 and 2017. The income of 2500 m^3/hm^2 treatment was 293.1 yuan /hm^2 higher than 1700 m^3/hm^2 and the net benefit of 2500 m^3/hm^2 treatment was only 173.1 yuan /hm^2 higher than 1700 m^3/hm^2 treatment. Therefore, from the perspective of comprehensive economic benefits and environmental benefits, the irrigation quota with 1700 m^3/hm^2 treatment is more suitable for large-scale promotion and application in Jilin Province. This study showed that suitable irrigation quota suitable for semi-arid area in western Jilin was screened by photosynthetic trait index to ensure the premise of maize yield and improve the water production efficiency of maize.

Many studies have shown that the lack of soil moisture is the main factor leading to the decrease of photosynthetic rate of crop leaves, which eventually lead to the decrease of crop yield (Farooq *et al*., 2017; Souza and Montenegro, 2011; Roth *et al*., 2013). The main reason of it is the joint action of stomatal and non-stomatal restriction (Heber *et al*., 1986; Komeili, 2006; Farooq *et al*., 2009). Our results showed that the P_n, G_s, T_r and C_i of 2500 m^3/hm^2 and 1700 m^3/hm^2 treatments showed a significant increase in 4 periods compared with the control. There was no significant difference between 2500 m^3/hm^2 and 1700 m^3/hm^2 treatments in all four periods. This indicates that effective irrigation can keep normal photosynthetic physiological metabolism of maize leaves. Due to low soil moisture and lack of water in the plant, the photosynthetic physiological metabolism in its leaves was inhibited. The P_n, G_s and T_r of the control all reached the lowest during the R3 stage. This indicates that with the continuous growth and development of maize, the long-term water deficit may have some influence on the opening and closing of the stomata of maize leaves, making it impossible for maize leaves to carry out photosynthesis normally. The L_s of both varieties showed the change trend of CK > 900 m^3/hm^2 > 1700 m^3/hm^2 > 2500 m^3/hm^2 in two years. With the increase of irrigation quota, the limiting factor of stomata is increasing, the decrease in photosynthetic capacity may be due to stomatal restriction. Suitable irrigation (2500 m^3/hm^2 and 1700 m^3/hm^2 treatments) is beneficial to maintain high photosynthetic capacity of maize leaves. The change trend of AMC is similar to P_n, G_s, T_r and C_i. This indicates that the quota of irrigation during the key growth period of maize is an effective way to maintain the activity of RuBP carboxylase in maize which reduces stress caused by drought (Du *et al*., 2013).

Chlorophyll fluorescence is another manifestation of photosynthesis. The effects of any environmental factors on photosynthesis can be reflected by chlorophyll fluorescence parameters (Baker, 2008; Mashilo *et al*., 2018). The relationship between fluorescence dynamics and photosynthesis is very complex. Through chlorophyll fluorescence, biophysical process of crop photosynthesis can be understood (Sayed, 2003). Some researchers have studied the relationship between chlorophyll fluorescence and yield in wheat under different irrigation conditions, which found that different soil moisture conditions strongly influenced changes in chlorophyll fluorescence, and is a good way to determine whether plant leaves were damaged or not (Araus *et al*., 1998). These results showed that the F_v/F_m and $\Phi PSII$ of 2500 m^3/hm^2 and 1700 m^3/hm^2 treatments significantly increased compared with CK in 2016 and 2017, there was no immense significant difference between 2500 m^3/hm^2 and 1700 m^3/hm^2 treatments. The F_v/F_m and $\Phi PSII$ showed the change trend from R1 > R3 > R4 stage in two years. This indicates that the photosystem II of 2500 m^3/hm^2 and 1700 m^3/hm^2 treatments still maintains high activity and light energy conversion efficiency with the development of the growth period. Chlorophyll in leaves can still complete the synthesis acceleration, which provides favorable conditions for the improvement and stable production of maize (Sotiropoulos *et al*., 2010). The PSII activity of leaves demonstrated a decreasing trend without considering water abundance in the later growth stages of maize. This indicates that the conversion rate of light energy is decreasing. At this time, if soil water is deficient and irrigation is not timely, it will have a greater impact on maize yield (Earl and Davis, 2003).

Photochemical quenching reflects the energy of maize used for photochemical electron transfer, while non-photochemical quenching reflects the energy emitted in the form of heat dissipation which can't be applied for photochemical electron transfer (Estrada *et al*., 2015). The results in present research showed that qP of 2500 m^3/hm^2 and 1700 m^3/hm^2 treatments showed a significant increase in three periods, while NPQ showed a significant decline, compared with CK however, with no significant difference between 2500 m^3/hm^2 and 1700 m^3/hm^2 treatments. The *qP* showed the change trend from R1 > R3 > R4 stages in two years, while the NPQ showed the change trend from R4 > R3 > R1 stage. This indicated that appropriate irrigation (2500 and 1700 m^3/hm^2) can promote the consumption of energy by heat dissipation by maize leaves as the growth period progresses and maintains conversion and transmission efficiency of light energy, as to resist the drought stress caused by water deficit (Colom and Vazzana, 2003).

Water productivity is an important index to measure whether the maize can get enough water from soil which mainly depends on the precipitation and yield of maize during the whole growth period. Some studies have shown that large and sufficient irrigation can improve crop yield, however, moderate water deficit can improve the water productivity of crops to achieve the purpose of energy saving and increase production (Chai *et al*., 2011). The present study results showed that the water consumption of 2500 m^3/hm^2 and 1700 m^3/hm^2 treatments and the WUE of 2500 m^3/hm^2, 1700 m^3/hm^2 and 900 m^3/hm^2 treatments increased significantly, compared with the CK. This indicates that the WUE value depends largely on the crop yield. Although the yield of 1700 m^3/hm^2 treatment slightly decreased compared with 2500 m^3/hm^2 treatment, the change was not significant. Due to the different irrigation quota, 1700 m^3/hm^2 treatment can be used as the reference value of maize irrigation quota in the western semi-arid area of Jilin Province.

Conclusion

Water is an important factor limiting maize yield in semi-arid areas. When the irrigation quota is 1200 m^3/hm^2 in the growth period of maize in the semi-arid region of western Jilin Province, its yield, water productivity, photosynthetic and physiological characteristics all perform better. It not only ensures the water demand of maize, but also gives consideration to environmental benefits and economic benefits. The irrigation amount of 1200m^3/hm^2 is the optimal irrigation quota in the western semi-arid area of Jilin Province, which has important theoretical and practical importance for the efficient production of maize in the western semi-arid area of Jilin Province.

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