water

MDPI

Article

# Combined Effect of Different Amounts of Irrigation and Mulch Films on Physiological Indexes and Yield of Drip-Irrigated Maize (*Zea mays* L.)

**Fengjiao Wang [1,2], Zhenhua Wang [1,2,*], Jinzhu Zhang [1,2,*] and Wenhao Li [1,2]**

1 College of Water Resources and Architectural Engineering, Shihezi University, Shihezi 832000, China; sdwfj2016@163.com (F.W.); lwh8510012@163.com (W.L.)

2 Key Laboratory of Modern Water-Saving Irrigation of Xinjiang Production and Construction Corps, Shihezi University, Shihezi 832000, China

* Correspondence: wzh2002027@163.com (Z.W.); xjshzzjz@sina.cn (J.Z.)

Received: 15 January 2019; Accepted: 28 February 2019; Published: 6 March 2019

**Abstract:** Exploring the effect of irrigation on biodegradable film-covered drip-irrigated maize is essential for sustainable agricultural development in arid areas. These regions, like Xinjiang in China, are home to suitable irrigation and biodegradable films. Through field trials, four levels of irrigation, and two biodegradable films and one common polyethylene film were set up to study the effects of different treatments on the physiology, growth indicators, and yield of maize. The results showed that the effects of irrigation and biodegradable films on the photosynthetic index and fluorescence index of maize reached a very significant level ($p < 0.01$). The effect of single factor irrigation and biodegradable films on the photosynthetic index and fluorescence index of maize reached a significant level ($p < 0.05$). The photosynthesis index, fluorescence index, plant height, LAI (leaf area index) and yield of $W_3M_3$ treatment had the highest value, when compared with other treatments. The $W_1M_1$ treatment had the lowest value. The photosynthesis index, fluorescence index, plant height, LAI, and yield of the $W_3M_2$ treatment were second only to $W_3M_3$. In addition, the output was only 40 kg ha$^{-1}$ less than $W_3M_3$. $W_3M_2$ has the best treatment effect from a perspective of sustainable agricultural development and efficient water saving; the optimal irrigation amount was 5625 m$^3$ ha$^{-1}$, induction period was 60 d, and thickness was 0.01 mm. The results of this study are of guiding significance for the promotion of the use of biodegradable films, search for suitable irrigation, and development of low-carbon agriculture.

**Keywords:** biodegradable films; photosynthesis; chlorophyll fluorescence parameters; yield; arid regions in northern Xinjiang

## 1. Introduction

Mulch films have obvious functions of water retention, temperature increase, disease prevention, insect resistance, weed control, promotion of crop growth and development, improvement of crop yield, and improvement of economic benefits [1,2]. The main component of these films is polyvinyl chloride. If polyethylene remains in the soil for a long time, it will inevitably cause soil compaction, permeability deterioration, soil fertility decline, and even have serious impacts on crop growth and development, eventually leading to a decline in yield [3]. It is predicted that the global usage of agricultural plastic films, including plastic mulches, will increase—from 4.4 million tons in 2012 to 7.4 million tons in 2019—with China and the Middle East being the major markets [4].

With the increase of plastic film coverage area and usage, as well as the cost-saving reduction of film thickness in many plastic film production units, more and more plastic film debris remain in the soil. In recent years, soil structure has been seriously damaged by the increase of film residue. Soil nutrients have also changed, and the negative impact has become more significant, causing damage to not only the crop growth environment, but also to the ecological setting [5–7]. The residual film destroys the soil structure, affects the movement of soil moisture and gas, affects the growth and development of plant roots, hinders the absorption of water and nutrients by crops, and leads to the decline of yield [8]. Research on residual film in soil has indicated that the cumulative amount of residual film in a 10 years under film drip irrigation cotton field in Xinjiang could reach $259 \pm 36.78$ kg ha$^{-1}$, and the residual film volume would continue to rise with the increase of film age under the existing recycling technology. The cumulative amount of residual film in the cotton field under continuous 20 years film is more than 300 kg ha$^{-1}$. It was found that irreversible impacts on the farmland ecosystem occurred during the accumulation of residual film in the soil tillage layer, which seriously threatened the sustainable development of the local area [9]. The "white revolution" of plastic film cultivation technology has become a headache of "white pollution" [10]. Therefore, biodegradable film formulation suitable for local planting mode must be put forward taking into consideration local characteristics. In addition, planting modes of biodegradable films suitable for local planting application should be established in different regions, so as to result in breakthrough progress for the popularization and application of biodegradable films. Biodegradable films have similar effects (increasing temperature and preserving moisture) as polyethylene films, and can degrade naturally [11]. Due to new formulations, recent research has shown that biodegradable mulches can be a competitive alternative to plastic mulches in terms of improving crop yield and quality, and preventing weeds. The biodegradable films used for testing are all made from polybutyrate adipate terephthalate (PBAT), a thermoplastic biodegradable plastic synthesized from petroleum-based materials, which combines the properties of aliphatic polyesters and aromatic polyesters. It has good ductility and stretchability, good impact resistance and heat resistance, similar to the processing and mechanical properties of lower density polyethylene [12]; it also has excellent biological properties. Degradability is currently the most promising alternative to polyethylene. Water is the source of life; not only is it the lifeblood of agricultural production, but also the essence of human activity and the national economy. Xinjiang's agricultural water accounts for more than 90% of Xinjiang's total water use [13]. The study found that during the growth period, the required irrigation amount was 3570~6370 m$^3$ ha$^{-1}$, and maize yield was in the range of 13,061~14,929 kg ha$^{-1}$. With increase of the irrigation amount, maize yield first increased and then decreased [14]. Biodegradable film mulching could increase the net photosynthetic rate ($P_n$) of peanut leaves at full fruit maturity stage by 17% and 21%, and transpiration rate ($T_r$) by 15% and 52%, which was beneficial to the increase of peanut yield [15].

To solve this problem, we compared the effects of different irrigation amounts on biodegradable film drip maize in the oasis agro-ecosystem in northwestern China. The following effects of different irrigation amount on maize fields covered by biodegradable films were studied: (1) Effects of light and indicators, and fluorescence indexes; (2) growth indicators: effects of plant height and leaf area; (3) and effects of maize yield and its components. This provided technical support for the promotion of biodegradable films and efficient use of water.

## 2. Materials and Methods

### 2.1. Overview of the Test Area

The experiment was carried out from April 2018 to October 2018 at the Key Laboratory of Modern Water Saving Irrigation Corps and the Water Saving Irrigation Experimental Station of Xinjiang Shihezi University (85°59′ E, 44°19′ N, 451 m a.s.l.). The specific location is shown in Figure 1. The test station is located in the second agricultural test site of Shihezi University in the western suburb of Shihezi City. The average ground slope is 6‰, the average annual sunshine is 2865 h, the average annual precipitation is 207 mm, and the average daily temperature during maize growth is 26.61 °C (Figure 2). The evaporation is 1660 mm, the annual average temperature is 7.7 °C, of which the accumulated temperature of >10 °C is 3463.5 °C, the accumulated temperature of >15 °C is 2960.0 °C, the frost-free period is 170 d, the groundwater depth is more than 10 m, and the soil texture is medium loam, 0–100 cm soil. The average bulk density was 1.60 g $cm^{-3}$, and the field water holding capacity (mass moisture content) was 18.65%.

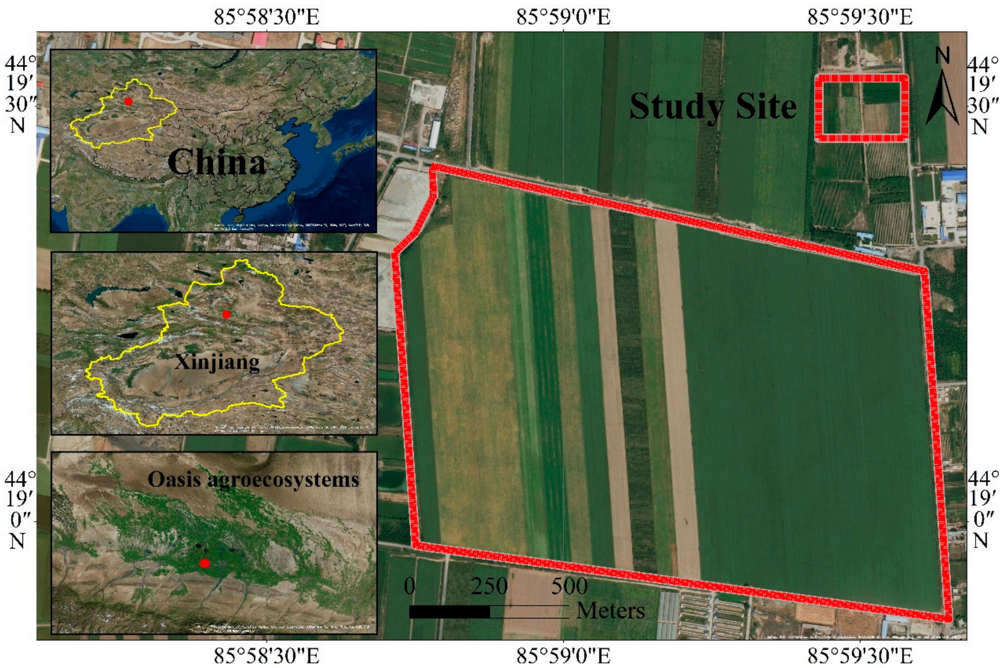


**Figure 1.** Test location area.

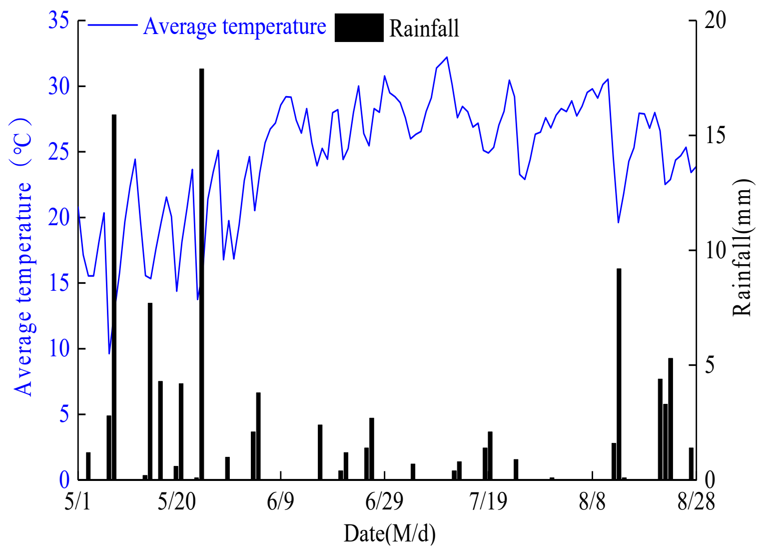


**Figure 2.** Daily average temperature and rainfall during the maize growth period.

## 2.2. Test Methods

In this experiment, the maize variety "Xinyu 66" was chosen as the research object. The sowing date was 1 May. The planting mode was a film with two tubes and four rows. The mulch film width was 1.45 m, capillary spacing was 60 cm, and row spacing was 30 cm. Plant spacing was 20 cm, the theoretical number of plants was 82,500 plants $ha^{-1}$, and seeding depth was 3 to 4 cm. The specific seeding mode is shown in Figure 3. Using the plot test, the size of each plot was 5 m × 4.5 m = 22.5 $m^2$ (length × width). The test uses a fully biodegradable film (the main component of the film is PBAT, labeled $M_1$ and $M_2$, respectively), provided by Guangzhou Kingfa Co., Ltd. (Guangdong, China).

The thickness of $M_1$ was 0.01 mm, induction period was 60 d; thickness of $M_2$ was 0.01 mm, and induction period was 80 d. Ordinary polyethylene plastic film ($M_3$) was provided by Xinjiang Tianye Co., Ltd. (Xinjiang, China) and the thickness of $M_3$ was 0.01 mm. The irrigation setting had three levels: irrigation quotas were 3625, 4625, 5625, 6625 $m^3$ $ha^{-1}$ (respectively referred to as $W_1$, $W_2$, $W_3$, $W_4$), a total of nine treatments, with three repetitions. Irrigation was done 10 times in the growth period. The number of irrigation times and irrigation quota is based on Zhai's method [14] and refers to the actual quota of the irrigation level of drip-irrigated maize in Shihezi and surrounding farms in recent years. $P_2O_5$: 120 kg $ha^{-1}$, $K_2O$: 90 kg $ha^{-1}$ was used as the base fertilizer, and urea 20% was used as the base fertilizer. The fertilizer was poured deep into the soil before sowing—the amount applied was based on the requirements of the field, and a fertilization tank that used water for the process was employed. The specific irrigation and fertilization rates for each growth period are shown in Table 1. A drip irrigation belt was one such irrigation method; it was a single-wing labyrinth drip irrigation belt (manufactured by Xinjiang Tianye Co., Ltd.) with an outer diameter of 16 mm, wall thickness of 0.3 mm, dripper spacing of 30 cm, and dripper flow of 2.6 L $h^{-1}$. Water was supplied by a power outlet, and a treatment water meter controlled the amount of irrigation.

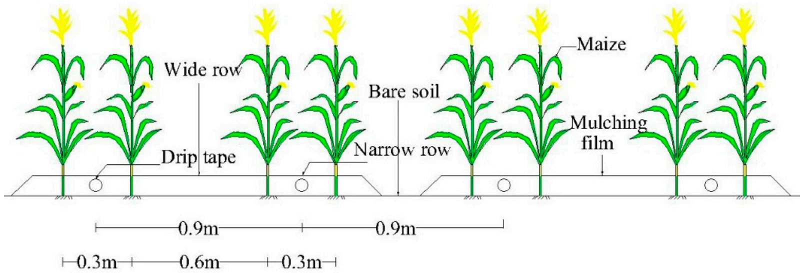


**Figure 3.** Layout of the design of mulched drip irrigation in this study. The unit of the numbers is m.

**Table 1.** Maize irrigation and fertilization treatment.

| Growth Period | Seedling Stage | Jointing Stage | Tasseling Stage | Filling Sage | Maturity Stage | Full Growth Stage |
|---|---|---|---|---|---|---|
| Irrigation and fertilization cycle/day | 30 | 10 | 7 | 10 | 15 | 123 |
| Irrigation and fertilization times | 1 | 3 | 3 | 2 | 1 | 10 |
| Irrigation and fertilization ratio/% | 10 | 20 | 45 | 15 | 10 | 100 |

### *2.3. Test Items and Methods*

#### 2.3.1. Weather Data

The test station was equipped with an automatic weather station (TRM-ZS2 type, Jinzhou Sunshine Meteorological Technology Co., Ltd., Jinzhou, China), which recorded temperature, rainfall, air humidity, solar radiation, etc. every minute.

#### 2.3.2. Photosynthetic Indicators

The photosynthetic characteristics of functional leaves were measured on 5 July (jointing stage), 24 July (tasseling stage), and 29 August (maturity stage) using a CI-340 hand-held photosynthetic apparatus made in the US. The leaves are marked. The measurements included maize transpiration rate ($T_r$), net photosynthetic rate ($P_n$), stomatal conductance ($G_s$), and intercellular $CO_2$ concentration ($C_i$) photosynthetic physiological indicators. The cotton functional leaves were selected on a clear and cloudless day in each growth period, starting from 08:00 to the end of 18:00, with a time interval of 2 h. Three samples were continuously measured for each treatment, and the test data was the average value measured throughout the day.

#### 2.3.3. Fluorescence Index

The chlorophyll fluorescence parameters of the leaves were measured using a PAM2500 fluorometer and a 2030B light-adaptive leaf clip (Walz, Nuremberg, Germany). The fluorescence parameters were measured simultaneously with the gas exchange parameters, and the leaves measured for each treatment were the same as those for the gas exchange parameters. The maximum fluorescence yield ($F_m$) and initial leaf fluorescence yield ($F_0$) of the leaves were measured before sunrise. The initial fluorescence yield ($F_0$) and the maximum fluorescence yield ($F_m$) were first determined; $F_m$ and $F_0$ of the corresponding leaves were manually input before the chlorophyll fluorescence parameters were measured. Then, using natural light as actinic light, the saturation pulse for annihilation analysis was turned on; the actual fluorescence yield ($F'$) at a random time and the maximum fluorescence yield ($F'_m$) under light adaptation was determined; and the maximum photochemical efficiency ($F_v/F_m$), PSII potential activity ($F_v/F_0$), photochemical quenching coefficient ($q^p$), non-photochemical quenching coefficient (NPQ), actual photochemical efficiency (Y(II)), and apparent electron transport rate (ETR) were calculated. The calculation formula for each fluorescence parameter uses Roháček's method [16], i.e.,

$$F_v/F_m = (F_m - F_0)/F_m \tag{1}$$

$$F_v/F_0 = (F_m - F_0)/F_0 \tag{2}$$

$$q^p = \left(F'_m - F'\right)/\left(F'_m - F'_0\right) \tag{3}$$

$$\mathrm{NPQ} = F_m/F'_m - 1 \tag{4}$$

$$\mathrm{Y(II)} = \left(F'_m - F'\right)/F'_m \tag{5}$$

$$\mathrm{ETR} = \mathrm{PAR} \times \mathrm{Y(II)} \times 0.84 \times 0.5 \tag{6}$$

Note: PAR is photosynthetically active radiation, μmol/(m$^2$·s)

#### 2.3.4. Grain Yield

During the maize crop's maturity period, random sampling was done for each plot, and five points were taken in each plot. Five maize plants were chosen continuously at each point, and the length of the panicles, the number of rows, and the length of the baldness was measured, and then the ears of the maize were threshed. The grain was air-dried and weighed (called its 1000-grain mass and total grain mass), then converted into yield per hectare.

#### 2.3.5. Determination of Growth Indicators

Plant height: Five maize plants with uniform growth were selected in each growth period, and plant height was measured and averaged, and observed every 10 days.

Leaf area: For maize plants with high plant height, the length and width of the leaves were measured with a tape measure to ensure normal growth; the leaf area and leaf area index were calculated separately. The formula was calculated with reference to Wang's method [17].

$$\text{Leaf area per plant of maize (cm}^2\text{)} = \text{Leaf length (cm)} \times \text{Leaf width (cm)} \times 0.7 \tag{7}$$

$$\text{LAI} = \text{Leaf area per plant} \times \text{Number of maize plants per unit of land area/Unit land area} \tag{8}$$

### *2.4. Data Processing*

Data was calculated using Microsoft Excel 2016, plotted by Origin 2017; two-way ANOVA and Duncan ($p$ = 0.05) method were used for multiple comparisons between treatments using IBM SPSS Statistics 22.

## 3. Results and Discussion

### *3.1. Effect of Irrigation Amount on Light and Index of Degradable Film Covering Drip-Irrigated Maize*

#### 3.1.1. Effect of Irrigation Amount on $P_n$ and $T_r$ of Degradable Film-Covered Drip-Irrigated Maize

The way in which future crop yields will increase will depend mainly on increased conversion by photosynthesis [18]. Changes in net photosynthetic rate ($P_n$) and transpiration rate ($T_r$) of dewatering film coverage on de-irrigated maize were noted at the jointing stage (5 July), tasseling stage (24 July), and maturity stage (29 August). The regularity and variance analysis are shown in Table 2. It can be seen from Table 2 that the $P_n$ of drip-irrigated maize reached maximum at the tasseling stage, and the average value of each treatment was 30.45 µmol m$^{-2}$ s$^{-1}$; the average value of $P_n$ in the jointing stage was 23.28 µmol m$^{-2}$ s$^{-1}$; the average value of $P_n$ treatment at maturity was 22.33 µmol m$^{-2}$ s$^{-1}$, and the $P_n$ value of the treatment from the jointing stage to the maturity stage increased first and then decreased. Owing to different water treatments, $P_n$ value increased with the extension of the film induction period. At the $W_1$ irrigation stage, $M_3$ was 11.73% and 8.88% higher than $M_1$ and $M_2$, respectively. At the $W_2$ irrigation level, $M_3$ was 9.46% and 7.54% higher than $M_1$ and $M_2$, respectively. Under the $W_3$ irrigation level, the $M_3$ ratio was higher. $M_1$ and $M_2$ were 12.31% and 6.56% higher, respectively. Under the $W_4$ irrigation level, $M_3$ was 11.46% and 7.17% higher than $M_1$ and $M_2$, respectively. The film can regulate soil temperature, improve soil moisture, and promote crop photosynthesis. Ordinary plastic film mulching has the strongest effect on maize $P_n$, which is characterized by ordinary plastic mulch >biodegradable mulch film. $W_3M_2$ treatment is best for degradable films' coverage, second only to $W_3M_3$ treatment, showing obvious interaction between irrigation and mulch film. This is mainly because the water retention and warming performance of the common plastic film is better than that of the biodegradable film, and water can regulate the photosynthetic rate of the crop. Previous studies have shown that PE films and biodegradable films can increase soil temperature and soil water content, thereby promoting crop growth [19–21]. Moisture is an important factor affecting the photosynthetic, physiological characteristics of plants [22]. Soil moisture affects crop photosynthetic rate [23]. The amount of irrigation and mulching will affect soil moisture content, affecting the water absorption of crops, and ultimately impacting the photosynthesis of crops. The analysis of variance showed that the effects of irrigation and film mulching and single factor irrigation on the $P_n$ of the maize growth period reached a very significant level ($p < 0.01$); the single factor mulch factor did not reach the significant level of $P_n$ ($p > 0.05$).

**Table 2.** Effect of irrigation amount on $P_n$ and $T_r$ of degradable film-covered drip-irrigated maize.

| Treatments | $P_n$/(µmol m$^{-2}$ s$^{-1}$) | | | $T_r$/(mmol m$^{-2}$ s$^{-1}$) | | |
|---|---|---|---|---|---|---|
| | Jointing Stage | Tasseling Stage | Maturity Stage | Jointing Stage | Tasseling Stage | Maturity Stage |
| $W_1M_1$ | 17.43 ± 0.47e | 25.58 ± 0.56f | 18.67 ± 0.52d | 2.57 ± 0.03e | 3.86 ± 0.04e | 1.96 ± 0.07e |
| $W_1M_2$ | 18.28 ± 0.25e | 26.25 ± 0.27f | 19.16 ± 0.35d | 2.68 ± 0.02d | 4.82 ± 0.05d | 2.56 ± 0.06d |
| $W_1M_3$ | 20.79 ± 0.56d | 28.58 ± 0.62e | 20.96 ± 0.65c | 3.38 ± 0.04c | 5.57 ± 0.04c | 2.97 ± 0.05c |
| $W_2M_1$ | 21.46 ± 0.12d | 28.65 ± 0.53e | 21.26 ± 0.43c | 2.70 ± 0.01d | 4.75 ± 0.03d | 2.49 ± 0.03d |
| $W_2M_2$ | 23.97 ± 0.69c | 29.16 ± 0.18d | 21.48 ± 0.26c | 3.41 ± 0.02c | 5.63 ± 0.02c | 3.04 ± 0.02c |
| $W_2M_3$ | 25.46 ± 0.27b | 31.36 ± 0.72c | 23.47 ± 0.76b | 4.25 ± 0.05b | 6.38 ± 0.02b | 3.59 ± 0.05b |
| $W_3M_1$ | 24.88 ± 0.58b | 31.68 ± 0.23c | 23.86 ± 0.58b | 3.40 ± 0.01c | 5.56 ± 0.04c | 2.98 ± 0.05c |
| $W_3M_2$ | 25.39 ± 0.39b | 33.39 ± 0.37b | 24.19 ± 0.20b | 4.31 ± 0.02b | 6.29 ± 0.04b | 3.61 ± 0.03b |
| $W_3M_3$ | 27.78 ± 0.36a | 35.58 ± 0.48a | 25.78 ± 0.36a | 5.21 ± 0.06a | 6.86 ± 0.08a | 4.27 ± 0.06a |
| $W_4M_1$ | 23.76 ± 0.79c | 30.18 ± 0.06d | 21.59 ± 0.21c | 3.42 ± 0.03c | 5.57 ± 0.04c | 2.93 ± 0.09c |
| $W_4M_2$ | 24.76 ± 0.69b | 31.39 ± 0.64c | 23.55 ± 0.70b | 4.28 ± 0.03b | 5.65 ± 0.01c | 3.06 ± 0.02c |
| $W_4M_3$ | 25.36 ± 0.43b | 33.64 ± 0.27b | 23.96 ± 0.52b | 4.35 ± 0.01b | 6.27 ± 0.05b | 3.58 ± 0.05b |
| W | 5.217 ** | 8.639 ** | 6.893 ** | 4.529 ** | 8.437 ** | 10.315 ** |
| M | 6.027 | 5.625 | 7.378 | 6.218 * | 5.365 * | 3.157 * |
| W*M | 98.176 ** | 47.528 ** | 26.751 ** | 154.68 ** | 215.28 ** | 326.37 ** |

Note: W for single factor irrigation, M for single factor mulch, and W*M for interaction between irrigation and mulch; The data is mean value ± standard error, different letters indicate significant difference between treatments ($p < 0.05$). * and ** in significance test represent reached significant value under $p < 0.05$ and $p < 0.01$, respectively. The letter identifiers in Tables 3–6 are the same as Table 2.

Transpiration rate is an important physiological indicator reflecting the strength of leaf transpiration. Irrigation amount and plastic film mulching are the main factors affecting the change. The change of corn transpiration rate can reflect the growth of maize. It can be seen from Table 2 that the transpiration rate ($T_r$) of each treatment is consistent with the changing trend of $P_n$, and the single-peak curve is first increased and then decreased from the jointing stage to the maturing stage, and the tasseling stage reaches the maximum value. At the same irrigation level, the $T_r$ value increases with the extension of the mulch induction period. The range of $T_r$ in the tasseling stage is 3.86 mmol·m$^{-2}$ s$^{-1}$ to 6.86 mmol m$^{-2}$ s$^{-1}$. The analysis of variance showed that the effects of irrigation and film mulching and single factor irrigation on the growth period of maize $T_r$ reached a very significant level ($p < 0.01$); the single factor mulch factor reached a significant level in maize $T_r$ ($p < 0.05$). This indicated that suitable irrigation amount and film combination could reduce the content of abscisic acid (ABA) and increase the content of cytokinin and auxin in cotton leaves, thus increasing the net photosynthetic rate and transpiration rate.

### 3.1.2. Effect of Irrigation Amount on $G_s$ and $C_i$ of Degradable Film-Covered Drip-Irrigated Maize

This study shows the stomatal amount of the degradable film covering the stomatal maize jointing stage (5 July), the tasseling stage (24 July), the maturity stage (29 August), stomatal conductance ($G_s$) and intercellular $CO_2$ concentration ($C_i$). The change law and variance analysis are shown in Table 3. From the jointing stage to the maturity stage of maize, $G_s$ showed a single peak curve, which increased first and then decreased, and the maximum appeared during the tasseling stage; $C_i$ showed a trend of decreasing first and then increasing, and the minimum value was found during the tasseling stage. The effects of single factor irrigation, irrigation and film interaction on $G_s$ and $C_i$ of maize leaves reached a significant level ($p < 0.01$). The influence of single factor factors on $G_s$ and $C_i$ of maize leaves reached a significant level ($p < 0.05$).

**Table 3.** Effect of irrigation amount on $G_s$ and $C_i$ of degradable film-covered drip-irrigated maize.

| Treatments | $G_s$/(mmol m$^{-2}$ s$^{-1}$) | | | $C_i$/(µmol mol$^{-1}$) | | |
|---|---|---|---|---|---|---|
| | Jointing Stage | Tasseling Stage | Maturity Stage | Jointing Stage | Tasseling Stage | Maturity Stage |
| $W_1M_1$ | 306.45 ± 3.48f | 458.92 ± 3.28e | 189.16 ± 2.18f | 248.65 ± 4.18a | 181.29 ± 4.23a | 279.96 ± 1.89a |
| $W_1M_2$ | 328.36 ± 4.52e | 482.16 ± 2.16d | 212.59 ± 3.25e | 223.79 ± 2.93b | 161.38 ± 4.39b | 261.38 ± 4.39b |
| $W_1M_3$ | 352.28 ± 3.59d | 503.65 ± 3.35c | 231.35 ± 2.34d | 205.98 ± 4.86c | 143.72 ± 4.71c | 245.62 ± 5.56c |
| $W_2M_1$ | 331.86 ± 2.85e | 476.58 ± 1.59d | 215.27 ± 3.36e | 225.46 ± 2.65b | 160.32 ± 4.64b | 258.78 ± 4.62b |
| $W_2M_2$ | 357.42 ± 3.17d | 501.29 ± 3.26c | 228.59 ± 2.29d | 206.36 ± 4.62c | 141.57 ± 5.48c | 241.89 ± 6.13c |
| $W_2M_3$ | 384.37 ± 4.15c | 528.65 ± 2.25b | 251.86 ± 3.16c | 192.24 ± 4.69d | 138.85 ± 5.62c | 238.58 ± 6.48c |
| $W_3M_1$ | 382.79 ± 4.31c | 497.21 ± 3.68c | 249.52 ± 3.21c | 191.21 ± 5.27d | 139.78 ± 5.86c | 221.29 ± 3.25d |
| $W_3M_2$ | 403.58 ± 3.36b | 525.35 ± 2.17b | 265.71 ± 2.13b | 168.37 ± 4.28e | 119.52 ± 3.27d | 198.52 ± 4.13e |
| $W_3M_3$ | 427.31 ± 1.96a | 551.38 ± 3.36a | 287.53 ± 3.26a | 146.29 ± 3.41f | 101.63 ± 2.39e | 183.59 ± 5.41f |
| $W_4M_1$ | 361.67 ± 2.43d | 501.63 ± 3.25c | 226.92 ± 2.24d | 208.58 ± 4.39c | 163.27 ± 4.15b | 243.51 ± 5.82c |
| $W_4M_2$ | 385.59 ± 4.06c | 505.26 ± 3.16c | 248.31 ± 3.26c | 189.39 ± 5.71d | 142.34 ± 5.03c | 220.38 ± 3.69d |
| $W_4M_3$ | 398.26 ± 5.28b | 526.58 ± 2.19b | 264.25 ± 2.18b | 171.19 ± 3.86e | 121.25 ± 3.02d | 197.76 ± 4.26e |
| W | 4.629 ** | 5.138 ** | 7.216 ** | 6.297 ** | 21.473 ** | 8.965 ** |
| M | 6.528 * | 3.275 * | 8.763 * | 5.137 * | 9.268 * | 5.682 * |
| W*M | 245.781 ** | 136.328 ** | 217.572 ** | 25.361 ** | 23.785 ** | 29.872 ** |

Stomatal conductance reflects the degree of stomatal opening of plant leaves, which directly affects photosynthesis and transpiration of crops. It can be seen from Table 3 that the treatment of maize $G_s$ from the jointing stage to the maturity stage $W_1M_1$ treatment obtained the minimum value, $W_3M_3$ treatment obtained the maximum value; the $W_3M_2$ treatment was found to be the best in the biodegradable film coverage, second only to $W_3M_3$ treatment. The value of maize $G_s$ increased from 14.48% to 40.47% in the $W_3M_2$ treatment from the jointing stage to the maturity stage. The same irrigation level and $G_s$ increased with the mulching stage. In the stage of maize tasseling, $M_3$ was increased by 9.75% and 4.46%, respectively, compared with $M_1$ and $M_2$ at the $W_1$ irrigation level; $M_3$ was increased by 10.93% and 5.46%, respectively, at the $W_2$ irrigation level; $M_3$ was higher than $M_1$ and $M_2$ under $W_3$ irrigation level, respectively, by 10.89%, 4.95%; $M_3$ increased by 4.97% and 4.22% compared with $M_1$ and $M_2$ at the $W_4$ irrigation level. At the maturity stage of maize, the value of $C_i$ reached the maximum. Under the $W_1$ irrigation level, $M_1$ increased by 7.11% and 13.98%, respectively, compared with $M_2$ and $M_3$. Under the $W_2$ irrigation level, $M_1$ increased by 6.89% and 8.47%, respectively, and $M_1$ ratio under $W_3$ irrigation level. $M_2$ and $M_3$ increased by 11.47% and 20.53%, respectively. Under the $W_4$ irrigation level, $M_1$ increased by 10.50% and 23.13%, respectively, compared with $M_2$ and $M_3$. A reasonable irrigation amount and mulch can reduce the activity of nitrate reductase, increase the chlorophyll content of leaves, accumulate carbohydrates of vascular bundle sheath cells, and enhance the gas exchange capacity of maize leaves, and finally improve the photosynthetic carbonization ability of maize. Previous studies have found that too much or too little water is not conducive to photosynthesis [24]. Appropriate irrigation and biodegradable film coverage keep the soil moisture at an appropriate level, which is conducive to photosynthesis. In this study, the net photosynthetic rate of leaves under biodegradable film coverage treatment was improved to some extent. It can be seen that biodegradable film coverings can produce more photosynthetic products in leaves, which may be related to the heat preservation and moisturizing effect of agricultural film coverings.

### *3.2. Effect of Irrigation Amount on Chlorophyll Fluorescence Parameters of Degradable Film-Covered Drip-Irrigated Maize*

The initial fluorescence ($F_0$) value in the chlorophyll fluorescence parameter is the fluorescence yield when the PSII reaction center is completely open; a decrease indicates that the antenna pigment heat dissipation increases, and an increase indicates that the PSII reaction center suffers severe damage, and the maximum photochemical efficiency ($F_v/F_m$) is closely related to the plant photosynthetic rate [25]. Chlorophyll fluorescence analysis can reflect plant PSII function under environmental stress change of energy [26].

#### 3.2.1. Effect of Irrigation Amount on $F_v/F_m$ and $F_v/F_0$ of Biodegradable Film-Covered Drip-Irrigated Maize

Table 4 shows the variation and variance of $F_v/F_m$ and $F_v/F_0$ in the jointing stage of drip-irrigated maize (5 July), the tasseling stage (24 July), and the maturity stage (29 August). It can be seen that both $F_v/F_m$ and $F_v/F_0$ change first and then decrease with advancement of the maize growth period, and the tasseling stage reaches the maximum value and reaches the minimum value at maturity. Among them, the effects of single factor irrigation and film mulch on $F_v/F_m$ and $F_v/F_0$ of maize growth stages reached significant levels ($p < 0.05$). The effect of amount of irrigation and film interaction on maize leaf $F_v/F_m$ and $F_v/F_0$ reached a very significant level ($p < 0.01$).

**Table 4.** Effect of irrigation amount on $F_v/F_m$ and $F_v/F_0$ of degradable film-covered drip-irrigated maize.

| Treatments | $F_v/F_m$ | | | $F_v/F_0$ | | |
|---|---|---|---|---|---|---|
| | Jointing Stage | Tasseling Stage | Maturity Stage | Jointing Stage | Tasseling Stage | Maturity Stage |
| $W_1M_1$ | 0.715 ± 0.01e | 0.751 ± 0.01f | 0.708 ± 0.02f | 2.756 ± 0.05f | 3.157 ± 0.17e | 2.435 ± 0.07f |
| $W_1M_2$ | 0.736 ± 0.02d | 0.778 ± 0.02e | 0.723 ± 0.01e | 3.065 ± 0.06e | 3.462 ± 0.14d | 2.762 ± 0.06e |
| $W_1M_3$ | 0.763 ± 0.03c | 0.796 ± 0.02d | 0.739 ± 0.03d | 3.322 ± 0.14d | 3.803 ± 0.19c | 3.046 ± 0.19d |
| $W_2M_1$ | 0.735 ± 0.03d | 0.776 ± 0.03e | 0.721 ± 0.02e | 3.059 ± 0.12e | 3.436 ± 0.18d | 2.756 ± 0.11e |
| $W_2M_2$ | 0.765 ± 0.01c | 0.797 ± 0.01d | 0.742 ± 0.01d | 3.326 ± 0.11d | 3.806 ± 0.14c | 3.061 ± 0.07d |
| $W_2M_3$ | 0.789 ± 0.01b | 0.819 ± 0.01c | 0.768 ± 0.01c | 3.705 ± 0.21c | 4.215 ± 0.24b | 3.407 ± 0.16c |
| $W_3M_1$ | 0.764 ± 0.02c | 0.816 ± 0.04c | 0.765 ± 0.02c | 3.708 ± 0.17c | 3.811 ± 0.09c | 3.405 ± 0.16c |
| $W_3M_2$ | 0.786 ± 0.02b | 0.838 ± 0.03b | 0.786 ± 0.02b | 4.126 ± 0.05b | 4.259 ± 0.18b | 3.736 ± 0.07b |
| $W_3M_3$ | 0.806 ± 0.03a | 0.861 ± 0.03a | 0.807 ± 0.03a | 4.437 ± 0.16a | 4.613 ± 0.16a | 4.059 ± 0.16a |
| $W_4M_1$ | 0.760 ± 0.04c | 0.795 ± 0.03d | 0.743 ± 0.01d | 3.346 ± 0.08d | 3.452 ± 0.14d | 3.058 ± 0.13d |
| $W_4M_2$ | 0.767 ± 0.01c | 0.817 ± 0.03c | 0.764 ± 0.02c | 3.712 ± 0.09c | 3.849 ± 0.05c | 3.339 ± 0.20c |
| $W_4M_3$ | 0.785 ± 0.02b | 0.840 ± 0.01b | 0.787 ± 0.02b | 4.123 ± 0.09b | 4.261 ± 0.13b | 3.768 ± 0.04b |
| W | 1.569 * | 5.716 * | 2.362 * | 5.278 * | 3.637 * | 1.962 * |
| M | 4.739 * | 12.475 * | 8.326 * | 12.276 * | 14.537 * | 9.316 * |
| W*M | 24.561 ** | 18.923 ** | 31.284 ** | 23.158 ** | 32.471 ** | 18.895 ** |

$F_v/F_m$ reflects the maximum photosynthetic quantum yield of maize photosystem II. It can be seen from Table 4 that the $F_v/F_m$ of drip-irrigated maize functional leaves reached the maximum level at the tasseling stage, with an average of 0.81 for each treatment; the jointing stage decreased, the average value of each treatment was 0.76; the maturity period was reduced to the lowest, and the average value of each treatment was 0.75. The value of $F_v/F_m$ in each treatment from the jointing stage to the maturity stage showed a trend of increasing first and then decreasing. Under the same irrigation level, the $F_v/F_m$ value of the functional leaves of maize growth period rose with increase of the film induction period. The $W_3M_2$ treatment was found to be best in degradable film coverage, and the minimum value was obtained at $W_1M_1$. At the $W_1$ level, $M_3$ was 9.23% and 1.57% higher than $M_1$ and $M_2$, respectively. This indicates that proper irrigation and biodegradable film coverage can improve the photosynthetic performance of corn and improve the conversion efficiency of light energy in the PSII reaction center. At the $W_3$ level, $M_3$ was 5.60% and 0.47% higher than $M_1$ and $M_2$, respectively.

$F_v/F_0$ reflects the original light energy conversion efficiency of maize photosystem II. It can be seen from Table 4 that the functional leaf $F_v/F_0$ of drip irrigation reached the maximum level during the tasseling stage, and the average value of each treatment was 3.84; the jointing stage decreased, the average value of each treatment was 3.56. The maturity stage was reduced to the lowest, and the average value of each treatment was 3.24. From the jointing stage to the maturity stage, the $F_v/F_0$ values of the treatments increased first and then decreased. Under the same irrigation level, the $F_v/F_0$ value of the maize growth period increased with the increase of the mulch induction period; the $W_3M_2$ treatment was found to best in degradable film coverage and $W_1M_1$ obtained the minimum value. At the $W_1$ level, $M_3$ was higher than $M_1$ and $M_2$ treatments by 20.46% and 9.85%, respectively. At the $W_2$ level, $M_3$ was higher than $M_1$ and $M_2$ treatments by 22.67% and 10.75% respectively. At the $W_3$ level, the $M_3$ ratio at the tassel stage was higher. The $M_1$ and $M_2$ treatments were 21.04% and 8.31% higher, respectively. At the $W_4$ level, $M_3$ was 23.44% and 10.70% higher than the $M_1$ and $M_2$ treatments, respectively. It indicated that reasonable irrigation and biodegradable films could enhance the activity of RUBP carboxylase in the photosynthetic leaf of maize, and increase the chlorophyll fluorescence kinetic parameters $F_v/F_m$ and $F_v/F_0$, thus increasing the accumulation of photosynthetic products in maize.

### 3.2.2. Effect of Irrigation Amount on $q^p$ and NPQ of Biodegradable Film-Covered Drip-Irrigated Maize

Table 5 shows the variation of $q^p$ and NPQ and the analysis of variance of the amount of irrigation on the de-irrigation film covering the drip-irrigated maize jointing stage (5 July), the tasseling stage (24 July), and the maturity stage (29 August). It can be seen that the $q^p$ value from the jointing stage to the maturity stage increased first and then decreased. The tasseling stage reached the maximum and the maturity stage reached the minimum. The NPQ decreased first and then increased with the growth of the maize growth period. The minimum is reached and the maturity stage reaches a maximum. Among them, the effects of single factor irrigation and film mulch on $q^p$ and NPQ of maize growth stages reached significant levels ($p < 0.05$). The effect of amount of irrigation and film interaction on maize leaf $q^p$ and NPQ reached a very significant level ($p < 0.01$).

$q^p$ represents the reduction state of QA of the original electron acceptor. $q^p$ indicates the degree of openness of the PSII reaction center [16]. It can be seen from Table 5 that the $q^p$ of drip-irrigated maize functional leaves reached the maximum at the tasseling stage, and the average value of each treatment was 0.87; the jointing stage decreased, the average value of each treatment was 0.74; the maturity stage was reduced to the lowest, and the average value of each treatment was 0.59. The $q^p$ value of each treatment from the jointing stage to the maturity stage increased first and then decreased. At the $W_1$ level, $M_3$ was 13.88% and 6.16% higher than the $M_1$ and $M_2$ treatments, respectively. At the $W_2$ level, $M_3$ was 12.99% and 5.79% higher than the $M_1$ and $M_2$ treatments, respectively. At the $W_3$ level, $M_3$ at the tasseling stage was higher than the $M_1$ and $M_2$ treatments by 11.02% and 5.06%, respectively. At the $W_4$ level, $M_3$ was 12.29% and 6.15% higher than the $M_1$ and $M_2$ treatments, respectively. This shows that reasonable irrigation volume and biodegradable film coverage can enhance the utilization of light energy and improve photosynthetic electron transport ability.

**Table 5.** Effect of irrigation amount on $q^p$ and NPQ of degradable film-covered drip-irrigated maize.

| Treatments | $q^p$ | | | NPQ | | |
|---|---|---|---|---|---|---|
| | Jointing Stage | Tasseling Stage | Maturity Stage | Jointing Stage | Tasseling Stage | Maturity Stage |
| $W_1M_1$ | 0.635 ± 0.02e | 0.742 ± 0.03f | 0.461 ± 0.03f | 1.647 ± 0.12a | 1.479 ± 0.11a | 2.034 ± 0.05a |
| $W_1M_2$ | 0.682 ± 0.01d | 0.796 ± 0.01e | 0.508 ± 0.02e | 1.389 ± 0.03b | 1.219 ± 0.09b | 1.805 ± 0.11b |
| $W_1M_3$ | 0.736 ± 0.04c | 0.845 ± 0.03d | 0.562 ± 0.01d | 1.118 ± 0.07c | 0.981 ± 0.06c | 1.561 ± 0.09c |
| $W_2M_1$ | 0.681 ± 0.01d | 0.793 ± 0.03e | 0.510 ± 0.01e | 1.358 ± 0.05b | 1.235 ± 0.07b | 1.592 ± 0.06c |
| $W_2M_2$ | 0.738 ± 0.03c | 0.847 ± 0.02d | 0.561 ± 0.01d | 1.109 ± 0.09c | 0.993 ± 0.04c | 1.346 ± 0.08d |
| $W_2M_3$ | 0.791 ± 0.02b | 0.896 ± 0.03c | 0.615 ± 0.02c | 0.837 ± 0.06d | 0.718 ± 0.11d | 1.021 ± 0.04 |
| $W_3M_1$ | 0.740 ± 0.01c | 0.898 ± 0.02c | 0.613 ± 0.03c | 1.116 ± 0.07c | 0.987 ± 0.06c | 1.327 ± 0.12d |
| $W_3M_2$ | 0.792 ± 0.02b | 0.949 ± 0.01b | 0.669 ± 0.03b | 0.815 ± 0.12d | 0.726 ± 0.08d | 0.995 ± 0.07e |
| $W_3M_3$ | 0.846 ± 0.02a | 0.997 ± 0.02a | 0.726 ± 0.02a | 0.692 ± 0.03e | 0.598 ± 0.06e | 0.765 ± 0.08f |
| $W_4M_1$ | 0.735 ± 0.04c | 0.846 ± 0.02d | 0.612 ± 0.03c | 1.327 ± 0.08b | 1.246 ± 0.04b | 1.562 ± 0.09c |
| $W_4M_2$ | 0.739 ± 0.03c | 0.895 ± 0.03c | 0.618 ± 0.01c | 1.165 ± 0.05c | 0.995 ± 0.04c | 1.375 ± 0.06d |
| $W_4M_3$ | 0.793 ± 0.01b | 0.950 ± 0.01b | 0.671 ± 0.01b | 0.824 ± 0.09d | 0.731 ± 0.05d | 1.043 ± 0.04e |
| W | 1.749 * | 5.371 * | 3.623 * | 7.218 * | 8.217 * | 5.629 * |
| M | 15.378 * | 9.632 * | 17.359 * | 21.673 * | 18.675 * | 25.826 * |
| W*M | 22.318 ** | 16.618 ** | 25.781 ** | 31.264 ** | 22.531 ** | 26.728 ** |

NPQ reflects the heat dissipation of plant photosystem II and can indicate the degree of stress on plants. It can be seen from Table 5 that the NPQ value of functional leaf of drip-irrigated maize reached the maximum at maturity stage, and the average value of each treatment was 1.37; it decreased in the jointing stage—the average value of each treatment was 1.11; the tasseling stage was reduced to the lowest, and the average value of each treatment was 0.98; the NPQ value of each treatment from the jointing stage to the maturity stage decreased first and then increased. At the same irrigation level, the NPQ value decreased gradually with increase of the mulching period. At the $W_1$ level, $M_1$ increased by 21.33% and 50.76%, respectively, when compared with $M_2$ and $M_3$. At the $W_2$ level, $M_1$ increased by 24.37% and 72.0%, when compared to $M_2$ and $M_3$; at the $W_3$ level, $M_1$ increased by 35.95% and 65.05%, when compared to $M_2$ and $M_3$, respectively. At the $W_4$ level, $M_1$ increased by 25.23% and 70.45%, respectively, when compared to $M_2$ and $M_3$. This indicates that reasonable irrigation and biodegradable films can improve the photochemical quenching coefficient and photochemical activity of the PSII reaction center, thus improving the photosynthetic capacity of maize plants.

#### 3.2.3. Effect of Irrigation Amount on Biodegradable Films Covering Drip-Irrigated Maize Y(II) and ETR

Table 6 shows the variation law and variance analysis of irrigation amount on biodegradable films coverage on drip-irrigated maize jointing stage (5 July), tasseling stage (24 July), maturity stage (29 August) Y(II) and ETR. It can be seen that the values of Y(II) and ETR both increase first and then decrease with the growth of the maize growth period. The tasseling stage reaches the maximum and the maturity stage reaches the minimum. Among them, the effects of single factor irrigation and film mulch on Y(II) and ETR of maize growth stages reached significant levels ($p < 0.05$). The effect of amount of irrigation and film interaction on maize leaf Y(II) and ETR reached a very significant level ($p < 0.01$).

Y(II) and ETR represent the actual photosynthetic quantum yield and relative electron transport rate of plant photosystem II, respectively. Plant PSII reaction center activity can be used for table-viewing and quantum transfer efficiency (ETR) to reflect that it is an effective parameter to characterize photosynthetic capacity [27]. It can be seen from Table 6 that the mean value of the functional leaf Y(II) of the drip-irrigated maize at the jointing stage is 0.54; the maximum length of the maize is reached, the average value of each treatment is 0.72; the maturity stage reaches the minimum value, and the average value of each treatment is 0.45. At the $W_1$ level, $M_3$ was 17.71% and 8.22% higher than the $M_1$ and $M_2$ treatments, respectively. At the $W_2$ level, $M_3$ was 17.26% and 7.56% higher than the $M_1$ and $M_2$ treatments, respectively. At the $W_3$ level, the $M_3$ ratio at the tasseling stage of the

$M_1$ and $M_2$ treatments was 12.93% and 6.41% higher, respectively. At the $W_4$ level, $M_3$ was 13.09% and 5.72% higher than the $M_1$ and $M_2$ treatments, respectively. The trend of ETR is similar to that of Y(II): the maximal stage of maize is reached, the minimum value of maturity stage is reached, the same level of irrigation, and the ETR value increases with the increase of mulch induction period. This indicates that reasonable irrigation amount and biodegradable films may enhance the antioxidant capacity of cotton leaves, slow down the oxidation rate of film lipids, increase the utilization rate of light energy of plants, improve their photosynthetic electron capacity and enhance photosynthetic capacity.

**Table 6.** Effect of irrigation amount on degradable film covering drip-irrigated maize Y(II) and ETR.

| Treatments | Y(II) | | | ETR | | |
|---|---|---|---|---|---|---|
| | Jointing Stage | Tasseling Stage | Maturity Stage | Jointing Stage | Tasseling Stage | Maturity Stage |
| $W_1M_1$ | 0.425 ± 0.01e | 0.593 ± 0.01f | 0.356 ± 0.01e | 231.526 ± 2.65e | 286.791 ± 5.38f | 185.625 ± 3.75f |
| $W_1M_2$ | 0.481 ± 0.01d | 0.645 ± 0.02e | 0.398 ± 0.01d | 258.317 ± 3.27d | 317.258 ± 6.14e | 216.729 ± 6.87e |
| $W_1M_3$ | 0.536 ± 0.01c | 0.698 ± 0.03d | 0.451 ± 0.02c | 293.156 ± 4.98c | 356.159 ± 7.13d | 254.648 ± 8.61d |
| $W_2M_1$ | 0.478 ± 0.02d | 0.643 ± 0.02e | 0.400 ± 0.01d | 253.869 ± 4.36d | 315.437 ± 6.38e | 213.852 ± 7.28e |
| $W_2M_2$ | 0.532 ± 0.02c | 0.701 ± 0.02d | 0.453 ± 0.02c | 296.425 ± 4.65c | 359.536 ± 5.93d | 258.365 ± 7.34d |
| $W_2M_3$ | 0.586 ± 0.02b | 0.754 ± 0.02c | 0.498 ± 0.03b | 336.268 ± 6.31b | 397.628 ± 7.31c | 296.753 ± 4.36c |
| $W_3M_1$ | 0.538 ± 0.01c | 0.750 ± 0.02c | 0.455 ± 0.01c | 300.516 ± 3.58c | 394.315 ± 9.16c | 298.894 ± 4.17c |
| $W_3M_2$ | 0.590 ± 0.01b | 0.796 ± 0.01b | 0.501 ± 0.02b | 339.249 ± 5.22b | 435.739 ± 4.38b | 326.318 ± 6.83b |
| $W_3M_3$ | 0.643 ± 0.02a | 0.847 ± 0.01a | 0.556 ± 0.02a | 375.826 ± 2.47a | 478.926 ± 3.54a | 357.576 ± 4.12a |
| $W_4M_1$ | 0.531 ± 0.02c | 0.703 ± 0.01d | 0.399 ± 0.01d | 291.415 ± 5.29c | 352.549 ± 8.62d | 261.427 ± 6.23d |
| $W_4M_2$ | 0.537 ± 0.01c | 0.752 ± 0.02c | 0.456 ± 0.01c | 302.637 ± 3.21c | 398.538 ± 7.05c | 295.532 ± 4.51c |
| $W_4M_3$ | 0.589 ± 0.01b | 0.795 ± 0.01b | 0.503 ± 0.01b | 341.459 ± 4.96b | 437.612 ± 4.14b | 328.851 ± 6.35b |
| W | 3.768 * | 4.316 * | 6.529 * | 3.823 * | 5.916 * | 6.195 * |
| M | 6.842 * | 9.785 * | 5.741 * | 7.526 * | 6.425 * | 8.982 * |
| W*M | 12.217 ** | 7.153 ** | 16.856 ** | 10.735 ** | 11.894 ** | 7.315 ** |

### *3.3. Effect of Irrigation Amount on Plant Height and Leaf Area Index (LAI) of Biodegradable Film-Covered Drip-Irrigated Maize*

#### 3.3.1. Effect of Irrigation Amount on Plant Height of Biodegradable Film-Covered Drip-Irrigated Maize

Figure 4 shows the variation of irrigation yield on the plant height of biodegradable films covered with drip irrigation. The variation trend of maize plant height is as follows: it first increases rapidly, then remains stable; the effects of different treatment plant heights vary. The overall trend of plant height in the whole growth period was as follows: the growth rate in the seedling stage was slower, and the difference of different treatments was small. The growth of plants in the jointing stage was rapid, and plant height increased significantly. The difference of different treatments is significant; the growth of maize from vegetative to reproduction changes—morphological indicators change slowly, and plant height growth is slow. At maturity, plant height tends to be stable, and is not significantly increased. It can be seen from Figure 4 that the plant height of maize at the $W_4$ level is significantly higher than that of other levels. Among them, the $W_4M_3$ treatment resulted in the highest plant height—average plant height was 187.4 cm; the $W_1M_1$ treatment had the smallest plant height—average plant height was 154.2 cm. Maize is a high-water crop. Moisture is very important for corn growth. Film mulching will affect soil moisture. Biodegradable film water retention performance is weaker than ordinary plastic mulch, and biodegradable films in different induction periods will follow the filming time. Different degrees of degradation occur, and water retention performance will decrease, resulting in a decrease in plant height. This indicates that the appropriate amount of water and degradable film can increase the maize plant's height.

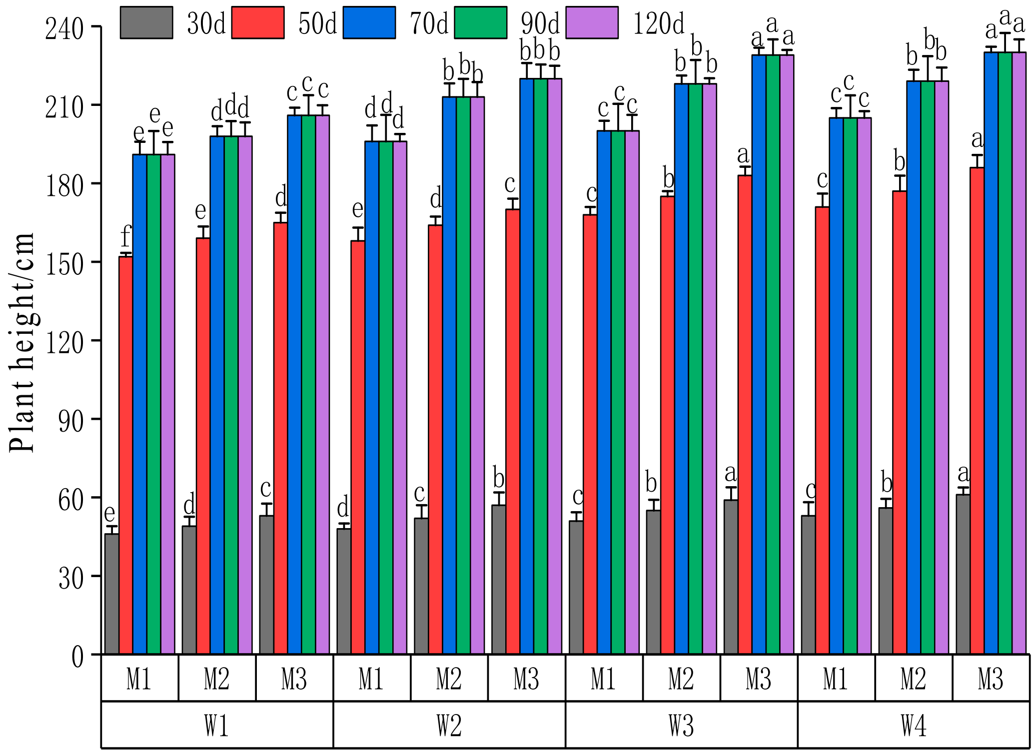


**Figure 4.** Variation of irrigation amount on plant height of degradable film-covered drip-irrigated maize. Note: 30 d, 50 d, 70 d, 90 d, 120 d represent the number of days after emergence of corn; different lowercase letters, respectively, indicate $p < 0.05$ difference, and the error line in the figure indicates standard deviation; the same below.

### 3.3.2. Effect of Irrigation Amount on LAI of Biodegradable Film-Covered Drip-Irrigated Maize

The leaf is the main organ for crop photosynthesis, and the size of the leaf area directly determines the strength of photosynthesis [28]. The size of the leaf area index directly determines the interception ability and light energy utilization rate of the crop group, and ultimately affects crop yield. Figure 5 shows the change of LAI in the treatment of drip-irrigated maize with different irrigation water content. The change trend of maize LAI is: the seedling stage is small, but has produced significant difference; the jointing stage increases rapidly, then growth is slow, and the tasseling stage reaches the maximum value; after the tasseling stage, the vegetative growth is gradually replaced by reproductive growth, and the number of yellow leaves begins to increase until the maturity period decreases. Biodegradable films can significantly promote the growth of maize in the early stage of growth, and its effect is equivalent to that of common mulch; however, with the advancement of the growth process, its promoting effect is gradually weakened. The $W_3M_3$ treatment of LAI is the largest, the tasseling stage is 5.89; the $W_3M_2$ treatment has a LAI value of 5.58, which is second only to the $W_3M_3$ treatment. the $W_1M_1$ treatment's LAI is the smallest, and the tasseling stage is 3.57. This shows that suitable irrigation amount and biodegradable film can promote maize LAI, which can promote maize growth.

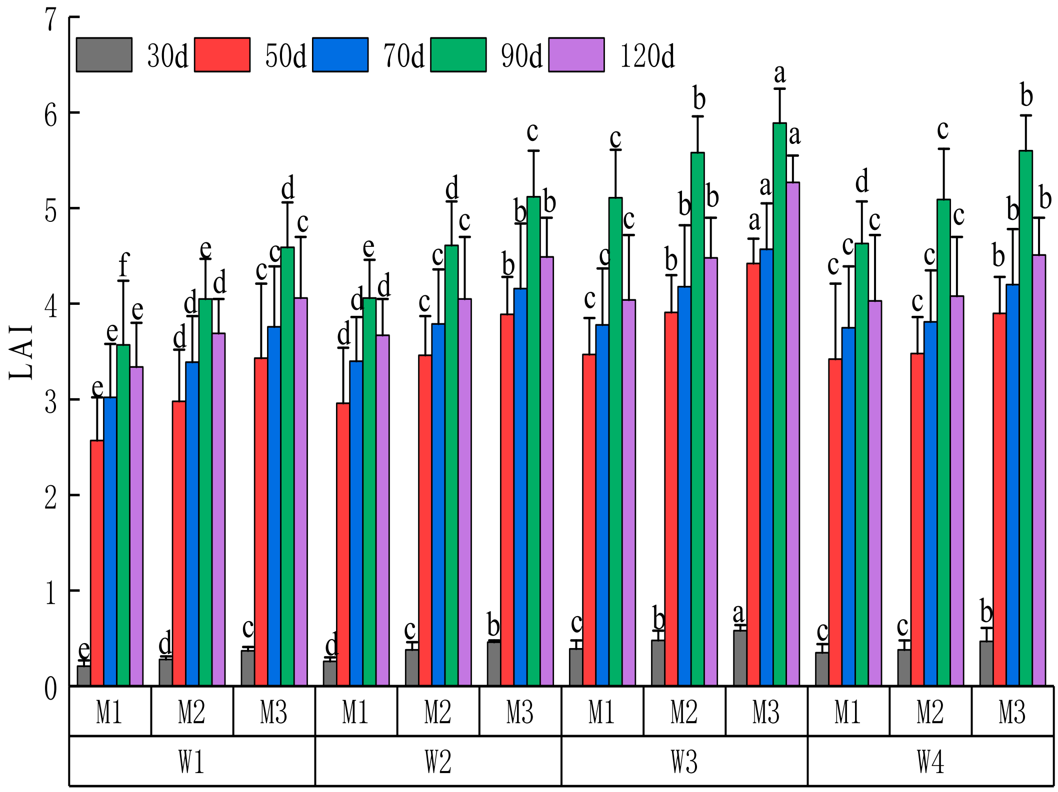


**Figure 5.** Changes of irrigation amount on the LAI of degradable film-covered drip-irrigated maize.

### *3.4. Effect of Irrigation Amount on Yield and Its Components of Biodegradable Films Covered with Drip-Irrigated Maize*

The amount of water and biodegradable film not only affects the growth index of corn, but also has a great impact on the yield of maize. Table 7 shows the effect of irrigation volume on the yield and composition of biodegradable films covered with drip-irrigated maize. At the same irrigation level, maize stalk length, bald tip length, grain number and 1000-grain weight were significantly different ($p < 0.05$). The ear length, grain number and 1000-grain weight of maize increased with increase of the mulch induction period, and the length of the cusp decreased with the increase of the mulch induction period. $W_3M_3$ treatment yielded the highest, $W_3M_2$ processing second, $W_1M_1$ treatment yield was the lowest; the $W_3M_2$ treatment increased by 18.02% compared to the $W_1M_1$ treatment under the $W_3$ irrigation level; $W_3M_3$ grain yield increased by 2.64% and 0.31%, respectively, when compared with $W_3M_1$ and $W_3M_2$. The $W_3M_2$ treatment only reduced the yield of the $W_3M_3$ treatment by 40 kg ha$^{-1}$, which did not reach significant difference. This indicates that the $W_3M_2$ treatment has the same effect as the $W_3M_3$ treatment, which shows that reasonable irrigation amount and biodegradable film can reduce soil residual film pollution. It can effectively improve soil environment and play a role in the preservation and water retention of common mulch films. Therefore, it is of great significance to use biodegradable films instead of ordinary plastic mulch films for agricultural production.

**Table 7.** Effect of irrigation amount on yield and components of biodegradable film covered with drip-irrigated maize.

| Treatments | Ear Length (cm) | Bald Tip Length (cm) | Row Grain Number | Kernel Weight (g) | Yield (kg·hm$^{-2}$) |
|---|---|---|---|---|---|
| $W_1M_1$ | 18.06f | 1.38a | 38.98f | 247.36e | 10,820e |
| $W_1M_2$ | 18.51e | 1.27b | 39.05f | 263.68d | 11,070e |
| $W_1M_3$ | 18.98d | 1.16c | 39.97e | 286.53c | 10,960e |
| $W_2M_1$ | 19.01d | 1.13c | 39.08f | 265.72d | 11,600d |
| $W_2M_2$ | 19.42c | 1.04d | 39.95e | 283.37c | 11,810d |
| $W_2M_3$ | 20.04b | 0.95e | 40.87d | 304.52b | 11,760d |
| $W_3M_1$ | 19.48c | 1.02d | 41.79c | 306.86b | 12,480bc |
| $W_3M_2$ | 20.05b | 0.93e | 42.76b | 316.19a | 12,770a |
| $W_3M_3$ | 20.56a | 0.85f | 43.89a | 319.68a | 12,810a |
| $W_4M_1$ | 19.03d | 1.15c | 40.84d | 301.16b | 12,360c |
| $W_4M_2$ | 19.46c | 1.03d | 41.83c | 305.71b | 12,510b |
| $W_4M_3$ | 20.03b | 0.94e | 42.78b | 315.38a | 12,590b |

## 4. Conclusions

This study evaluated the effects of different irrigation amounts on the physiological growth indicators and yield of biodegradable films covered with drip-irrigated maize in the Xinjiang Oasis Agro-ecosystem in northwestern China. The study found that single factor irrigation amount and biodegradable films had significant effects on most of the physiological growth indexes of maize. When the irrigation amount and biodegradable films interacted, the effect on the physiological growth index of maize reached a very significant level. Inappropriate irrigation and biodegradable film coverage can have a negative impact on maize growth physiology, resulting in reduced maize production. The results of this study found that the appropriate amount of irrigation and biodegradable film is the best choice—that is, a combination of biodegradable film with a water filling amount of 5625 m$^3$ ha$^{-1}$, induction period of 60 d, and thickness of 0.01 mm. We also advocate continuing efforts to test the effects of biodegradable mulch on agricultural production and soil and still require long-term practice. This study can provide local farmers with reasonable maize irrigation capacity and suitable biodegradable films, reduce low crop yield and soil pollution caused by residual films pollution, and promote the development of high-efficiency water and biodegradable films. Low carbon agriculture provides the basis for the same.

**Author Contributions:** Z.W. and J.Z. provided the idea of the study and writing of the manuscript, F.W. conducted the data analysis, W.L. provided important advice on the concept of the methodology.

**Funding:** This research received no external funding.

**Acknowledgments:** We acknowledge the financial support from Study on Development Strategy of Field Drip Irrigation in China (2018-XY-36) and Study on Corn Crop Coefficient (Kc) and Irrigation System in Shihezi Reclamation Area (DTJSSY-201808).

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. Tian, Y. Functional Polyolefin Agriculture Films in China. *China Plast.* **2004**, *18*, 1–8.
2. Kasirajan, S.; Ngouajio, M. Polyethylene and biodegradable mulches for agricultural applications: A review. *Agron. Sustain.* **2012**, *32*, 501–529. [CrossRef]
3. He, W.Q.; Yan, C.R.; Zhao, C.X.; Chang, R.Q.; Liu, Q.; Liu, S. Study on the pollution by plastic mulch film and its countermeasures in China. *J. Agro-Environ. Sci.* **2009**, *28*, 533–538.
4. Sintim, H.Y.; Flury, M. Is biodegradable plastic mulch the solution to agriculture's plastic problem? *Environ. Sci. Technol.* **2017**, *51*, 1068–1069. [CrossRef] [PubMed]
5. Xie, H.E.; Li, Y.S.; Yang, S.Q.; Wang, J.J.; Wu, X.F.; Wu, Z.X. Influence of Residual Plastic Film on Soil Structure, Crop Growth and Development in Fields. *J. Agro-Environ. Sci.* **2007**, *26*, 153–156.

6. Zhang, J.J.; Guo, T.W.; Fan, T.L.; Zhao, G.; Dang, Y.; Wang, L.; Li, S.Z. The effect of the agricultural residual plastic film on maize growth and development and soil moisture movement. *J. Irrig. Drain.* **2014**, *33*, 100–102.
7. Xu, G.; Du, X.M.; Cao, Y.Z. Residue levels and morphology of agricultural plastic film in representative area of China. *J. Agro-Environ. Sci.* **2005**, *24*, 79–83.
8. Liu, M.; Huang, Z.B.; Yang, Y.J. A study on status and developmental trend of biodegradable plastic film. *Chin. Agric. Sci. Bull.* **2008**, *24*, 439–443.
9. Xin, J.J.; Shi, H.B.; Li, X.Y.; Liang, J.C.; Liu, R.M.; Wang, Z.C. Effects of plastic film residue on growth and yield of maize. *J. Irrig. Drain.* **2014**, *33*, 52–54.
10. Roy, P.; Surekha, P.; Rajagopal, C. Surface oxidation of low-density polyethylene films to improve their susceptibility toward environmental degradation. *J. Appl. Polym. Sci.* **2011**, *122*, 2765–2773. [CrossRef]
11. Wang, X.; Lv, J.L.; Sun, B.H. Effects of covering degradable films on corn growth and soil environment. *J. Agro-Environ. Sci.* **2003**, 397–401.
12. Ohkoshi, I.; Abe, H.; Doi, Y. Miscibility and solid-state structures for blends of poly [(S)-lactide] with atacticpoly [(R,S)-3-hydroxybutyrate]. *Polymer* **2000**, *41*, 5985–5992. [CrossRef]
13. Xie, W.B.; Chen, T.; Liu, Y.G. Decoupling relationship and effect decomposition of agricultural water resources utilization and economic growth in Xinjiang. *Water Sav. Irrig.* **2018**, *4*, 69–72.
14. Zhai, C.; Zhou, H.P.; Zhao, J. Experimental Study on Inter-Annual Water Requirement and Water Consumption of Drip Irrigation Maize in North of Xinjiang. *Sci. Agric. Sin.* **2017**, *50*, 2769–2780.
15. Yin, G.H.; Tong, N.; Hao, L.; Gu, J.; Liu, Z.X. Effects of mulching with film of different materials on soil temperature and photosynthesis of peanut leaf. *Agric. Res. Arid Areas* **2012**, *30*, 44–49.
16. Roháček, K. Chlorophyll fluorescence parameters: The definitions, photosynthetic meaning, and mutual relationships. *Photosynthetica* **2002**, *40*, 13–29. [CrossRef]
17. Wang, Q.; Ma, S.Q.; Guo, J.P.; Zhang, T.L.; Yu, H.; Xu, L.P. Effect of air temperature on maize growth and its yield. *Chin. J. Ecol.* **2009**, *28*, 255–260.
18. Zhu, X.G.; Long, S.P.; Ort, D.R. Improving photosynthetic efficiency for greater yield. *Annu. Rev. Plant Biol.* **2010**, *61*, 235–261. [CrossRef] [PubMed]
19. Li, X.Y.; Gong, J.D.; Gao, Q.Z.; Li, F.R. Incorporation of ridge and furrow method of rainfall harvesting with mulching for crop production under semiarid conditions. *Agric. Water Manag.* **2001**, *50*, 173–183. [CrossRef]
20. Duan, X.M.; Wu, P.T.; Bai, X.M. Micro-rainwater catchment and planting technique of ridge film mulching and furrow seeding of corn in dryland. *J. Soil Water Conserv.* **2006**, *20*, 143–146.
21. Wang, X.; Xu, G.B.; Ren, Z.G.; Zhang, Z.J.; Jian, Y.F.; Zhang, Y.M. Effects of environment-friendly degradable films on maize growth and soil environment. *Chin. J. Eco-Agric.* **2007**, *15*, 78–81.
22. Chu, J.M.; Meng, P.; Zhang, J.S. Effects of soil water stress on the photosynthesis characteristics and chlorophyll fluorescence parameters of Cerasus humilis seeding. *For. Res.* **2008**, *121*, 409–420.
23. Selzer, L.J.; Busso, C.A. Pigments and photosynthesis of understory grasses: Light irradiance and soil moisture effects. *Russ. J. Plant Physiol.* **2016**, *63*, 224–234. [CrossRef]
24. Gao, S.; Su, P.X.; Yan, Q.D.; Ding, S.S. Canopy and leaf gas exchange of Haloxylon ammodendron under different soil moisture regimes. *Sci. China Life Sci.* **2010**, *53*, 718–728. [CrossRef] [PubMed]
25. Singh, S.K.; Reddy, K.R. Regulation of photosynthesis, fluorescence, stomatal conductance and water-use efficiency of cowpea (*Vigna unguiculate*(L.)Walp.)under drought. *J. Photochem. Photobiol. B Biol.* **2011**, *105*, 40–50. [CrossRef] [PubMed]
26. Krause, G.H.; Weis, E. Chlorophyll fluorescence and photosynthesis: The basics. *Annu. Rev. Plant Physiol. Plant Mol. Biol.* **1991**, *42*, 319–359. [CrossRef]
27. Clavel, D.; Diouf, O.; Khalfaoui, J.L.; Braconnier, S. Genotypes variations in fluorescence parameters among closely related groundnut (*Arachis hypogaea* L.) lines and their potential for drought screening programs. *Field Crop. Res.* **2006**, *96*, 296–306. [CrossRef]
28. Yang, Y.J.; Huang, Z.B.; Yan, Y.M.; Liu, M.; Zhu, Q. Effects on temperature and moisture of soil and seeding of maize to biodegradable film coverage. *J. Agro-Environ. Sci.* **2010**, *29*, 10–14.