



Effects of Different Plastic Mulching Film on Soil Hydrothermal Status and Water Utilization by Spring Maize in Northwest China

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The problem of residual film pollution in farmland caused by polyethylene mulching films is serious. The application effects of different mulching films combined with drip irrigation on maize planting in the Ili area, Xinjiang, China, were explored. In this study, four types of mulching films and non-mulching treatment were used to study the degradation properties of different plastic mulching and their effects on the dynamic changes of soil moisture, heat, and crop yields of maize under drip irrigation. The results showed that after 160 days of mulching film, only small cracks appeared in polyethylene mulching films. The degradation performance of white oxo-biodegradable film treatment was optimal than the black oxo-biodegradable film treatment. The quality loss rate of the two biodegradable films were 52.26 and 48.48%, respectively. Various mulching film treatments could increase soil moisture in the early stage of maize growth. At the 0–60 cm soil layer, the soil moisture under the white oxo-biodegradable mulching film and black oxo-biodegradable mulching film treatments were lower by 2.75 and 2.66% ($p < 0.05$) than the white polyethylene mulching film and black polyethylene mulching film treatments. The soil water consumption was highest in the non-mulching treatment, followed by biodegradable film, and the small least value was observed in the polyethylene film treatment. The average soil temperature at depth of 0–15 cm in white polyethylene mulching film, black polyethylene mulching film, white oxo-biodegradable mulching film, and black oxo-biodegradable mulching film treatments were 1.43, 1.16, 0.72 and 0.64°C higher than the non-mulching treatment, respectively. Mulching films treatment played a critical role in increasing production and improving water use efficiency. The black polyethylene mulching film treatment had the highest yield and the best water use efficiency. The black oxo-biodegradable mulching film treatment only reduces the yield by 0.33% compared to the black polyethylene mulching film treatment, and the water use efficiency was only reduced by 0.90% ($p > 0.05$). Comprehensive analysis showed that black oxo-biodegradable mulching film could be used as a substitute for polyethylene mulching film and can be applied to the production practice of drip irrigation maize in the Ili area.

Keywords: degradable mulching film, drip irrigation maize, soil moisture, soil temperature, yield, water use efficiency

INTRODUCTION

Maize (*Zea mays* L.) is one of the most extensively grown crops in China, accounting for 35.54% of total grain crops sown area in 2019 (Liu and Ye, 2020). However, scarcity of irrigation water restricts agricultural development. Maize production is critically limited by water availability in drought-prone northwestern China (Zhang et al., 2017a). Xinjiang Province is a quintessential arid-semiarid region. Especially, water shortage is a significant factor limiting crop growth and yield in the agricultural region of Xinjiang (Hao et al., 2015). In spite of the distinctive geographical position of the Ili Valley, which is characterized by heavy rainfall, high evaporation, and abundant sunlight (Xu et al., 2019), the area is dominated by oasis agriculture, which requires to increase in soil temperature and preservation of soil moisture. For this reason, plastic mulch is applied to cover the soil surface. Mulching film, which was originally introduced in Xinjiang in 1980, has been extensively practiced in farming (Bu et al., 2013; Yan et al., 2015). Plastic mulch conserves both soil heat and soil moisture, dramatically enhancing the productivity of oasis agriculture (Erenstein, 2002; Liu et al., 2010a; Fan et al., 2017). Compared to sprinkler and furrow irrigation, drip irrigation improves crop production and water use efficiency (Ibragimov et al., 2007; Hassanli et al., 2009). Therefore, combining drip irrigation with plastic mulching film was a growing technology in the area (Qin et al., 2016; Tian et al., 2017). This approach was originally invented for the production of cotton, and it was later introduced to maize and other crops (Zhang et al., 2017b). On the contrary, while the long-term adopt of sub-membrane drip irrigation had contributed significantly to crop yield, it also raised to numerous concerns (Hu et al., 2020).

Numerous scholars have studied that white polyethylene mulching film causes excessive water consumption in the early stage of crop growth, especially due to the high temperature of the soil, which is prone to dehydration and de-fertilization, also causes heavy drought in the later crop growth stage and reduce the crop yield (Zaongo et al., 1997; Zhang et al., 2008). Compared to white polyethylene mulch, black mulch not only decreases the daily variation in soil temperature, but also significantly increases maize yield and water use efficiency (Lu et al., 2016). In a study by Zhang 2017 reported that black plastic mulching films, which had a moderate temperature reduction effect and protect crops from high temperature hazards during the high temperature season, conserves moisture and increases temperature more significantly than white plastic mulching films. The phenomenon of early crop decline, which had emerged as a predominant factor affecting high maize yields in arid and semi-arid regions, was caused by white plastic mulching films (Dong et al., 2013). Plastic mulch was commonly used in increasing crop production, which was difficult to degrade under natural conditions. Residual film fragments remain in the cultivated layer for 200–400 years (Zhang et al., 2019a; Qi et al., 2021), and with the increase of the mulching film years, the negative impact becomes more serious. The annual agricultural use of mulching film about 3,000 tons and a certain degree of residual film pollution has begun to appear in the Ili River Basin in Xinjiang. The residual film stock of some cotton farms was

basically above 225 kg/hm² (Hu, 2019). The accumulation of residual film makes the permeability of the cultivated layer worse, affecting the absorption of soil nutrients and water transport by crop roots (Kasirajan and Ngouajio, 2012; Yan et al., 2014; Wang et al., 2017; He et al., 2018). Therefore, the crop yield reduction caused by polyethylene plastic mulch would gradually meet or exceed the yield increase effect brought about by it. The development and utilization of degradable mulch film was the general trend of dealing with “white pollution” (Wang et al., 2004; Liu et al., 2010b; Sintim et al., 2019).

At present, the research of oxo-biodegradable mulching film mainly focuses on the degradation properties and its effects on preserving soil moisture, conserving soil heat, and increasing yield. Zhou et al. (2016) reported that covering degradable mulching film transformed the water and fertilizer conditions for crop growth and promoted crop nutrient absorption. Different types of degradable mulching films impacted soil moisture preservation and corn yield (Zhang et al., 2010). The degradable mulching films, which were comparable to polyethylene mulch, could significantly increase soil temperature at the surface and 10 cm underground, and enhance soil moisture from 0 to 40 cm (Shen et al., 2011). The oxo-biodegradable mulching film is a new type of biodegradable film developed by China in recent years, which has the advantages of both oxidative degradation and biodegradation, and oxo-biodegradable mulching film has controllable degradation time, good mechanical properties, and the same effect of temperature and moisture retention as polyethylene mulching film (Sun et al., 2019). Compared to non-mulching treatments, oxo-biodegradable mulch had the most significant effect in raising temperature at depth of 0–15 cm, and increased soil water storage in the 0–60 cm soil layer, and produced 35.2% higher maize yield (Liu et al., 2017). Compared to non-mulching treatments, the soil temperatures of 5 and 25 cm soil layers of the biodegradable mulching films were 1.0–3.8°C and 0.7–2.9 °C higher, respectively (Gu et al., 2015). Although the oxo-biodegradable mulching film has preserved soil moisture and conserved soil heat effect to the regular mulch before degradation occurred, the mulch cracked extensively with weight loss of 67.7% at the end of the experiment (Yuan et al., 2014). In addition to considering its degradation characteristics, extensibility, film strength and production cost, the key question is whether degradable films could completely substitute polyethylene mulch films in agricultural practice as the preserving soil moisture, conserving soil heat, and enhancing yield.

At present, the research of degradable film mainly focuses on the degradation performance and its application effect. However, the effect of oxo-biodegradable mulching film of different colors on soil moisture, temperature and crop yield is rarely investigated and it has not been studied in the Ili region of Xinjiang, and the utilization of oxo-biodegradable mulching film can alleviate residual film pollution. Therefore, based on the research of a huge number of scholars, the objective of this study to analyze the relationship between soil moisture, temperature and yield of drip-irrigated maize under different colors of oxo-biodegradable mulching films in the Ili region. We hypothesize that different colors of oxo-biodegradable mulching films have different effects

on soil moisture, temperature and maize yield. Further, the types of the oxo-biodegradable mulching films suitable for drip-irrigated maize were screened out to alleviate residual film pollution in farmland and provided theoretical support for sustainable agricultural development in Ili area.

MATERIALS AND METHODS

Experimental Site

The field experiment was carried out during the maize-growing season in 2020 at the 67th Regiment of the Fourth Division of the Xinjiang Production and Construction Corps, where the study area (80°38'E, 43°36'N) lies in the south of Ili River Irrigation District. The multi-year average temperature, sunshine, rainfall of the test site was 9.3°C, 2,943 h, and 265.8 mm, respectively. The average bulk density of 0–40 cm soil was 1.55 g/cm³, the content of soil organic matter was 13.5 g/kg, the total nitrogen was 0.72 g/kg, and the groundwater depth was more than 6 m. The soil type was mainly calcareous soil.

Experimental Design

The tested maize was a local conventional variety “Jinguyu No. 6,” which was sown on April 25, 2020, and harvested on September 12, 2020 with a total growth period of 140 days. Polyethylene mulching films (thickness and width were 0.01 mm, and 80 cm, respectively; The tested films are provided by Ili RenJie Plastic Products Co., Ltd., Xinjiang, China.) and oxo-biodegradable mulching films (thickness and width were same with plastic mulch film, and induction period was 100 d, width 80 cm; The tested films are provided by Eco-benign Plastics Technology Co., Ltd., Shandong, China.) were selected as test mulches. The properties of oxo-biodegradable mulch film involve biodegradation, photo-oxidative degradation and thermal-oxidative degradation. These three degradation processes exist simultaneously, promote each other and mutually reinforcing. The composition of black oxo-biodegradable mulching film is 96–99% linear low-density polyethylene (LLDPE), 1–4% eco-biodegradable plastic masterbatch (EBP-1608) and 3–10% black color masterbatch. The composition of white oxo-biodegradable mulching film is 95 to 99% linear low-density polyethylene (LLDPE), 1–4% eco-biodegradable plastic masterbatch (EBP-1608).

The experiment includes five treatments, white polyethylene mulching film (WP), black polyethylene mulching film (BP), white oxo-biodegradable mulching film (WO), black oxo-biodegradable mulching film (BO), and non-mulching film (CK). Each experiment was triplicated and randomly distributed in each the plot area, and the plot area was 72 m² (12 × 6 m), the sowing method of “dry sowing and wet out” was adopted with a narrow row spacing of 30 cm and a wide row spacing of 80 cm. According to local field management methods, compound fertilizer of 400 kg/hm² (total nutrients ≥45%, N:P:K = 15:15:15) and diammonium phosphate of 300 kg/hm² were applied when maize was sowed. Maize was irrigated 9 times during the whole growth period of 140 days, and the irrigation

quota was 4,500 m³/hm². The application of top-dressing urea for the fourth irrigation and seventh irrigation were 375 kg/hm² and 400 kg/hm², respectively.

Sampling and Determination Degradation Rate and Degree

After the mulching film, three observation areas were selected randomly in each plot and the degradation degree of films were observed and recorded every 10 d in the selected areas (Yang et al., 2013). The grading standards were as follows: level 0, no cracks (including wind and man-made damage); level 1, cracks began to appear (induction period); level 2, small cracks in the 25% film; level 3, 2–2.5 cm cracks appeared; level 4, uniform network cracks appeared, film thinning, and no large film exists; level 5, the film was broken into fragments below 4 × 4 cm. The weights of tested and recorded films of 8 m² in each plot before mulching. After mulching for 160 days, we randomly select three mulching sections with a length of 1 m² in each plot. The collected mulching films were washed, dried and weighed. Film quality loss rate (QLR) in 160 d was calculated as follows:

$$QLR \text{ in } 160 \text{ d} = \frac{M_1 - M_2}{M_1} \times 100\% \quad (1)$$

where M_1 is the original weight of 1 m² film 160 d ago, and M_2 is the present weight of 1 m² film in 160 d.

Soil Temperature

The daily variation of soil temperature for different treatments was measured by curved tube geothermic meter every 2 h from 8:00 to 20:00, the curved tube geothermic meters were installed at depths of 5, 10, 15, 20, and 25 cm, respectively. Each growth period was continuously monitored for 6 days.

Soil Moisture

In each growth period of maize, soil moisture at a depth of 0–60 cm in each treatment was measured by the drying method, and a soil sample was taken from every 10 cm. We used water balance method to calculate evapotranspiration (ET) in different time periods as follows (Kresović et al., 2016; Li and Ma, 2019; Xu et al., 2019):

$$ET = P + I + \Delta W_s - Q \quad (2)$$

where ET represents the water consumption in each growth period of the crop (mm), P represents the effective rainfall (mm), I represents the effective irrigation volume (mm), ΔW_s is the change in soil water storage (mm), and Q is the groundwater replenishment and leakage (mm).

Since drip irrigation is used for irrigation, and the groundwater level in this area is greater than 6 m, thus groundwater replenishment and leakage are ignored.

The water use efficiency (WUE) is calculated as follows (Kresović et al., 2016; Du et al., 2008):

$$WUE = \frac{GY}{ET} \quad (3)$$

where GY represents maize yield (kg/hm²), and ET represents the water consumption in each growth period of the crop (mm).

TABLE 1 | Degradable rates of different mulching films.

Treatment	Days after sowing/d							
	90	100	110	120	130	140	150	160
WP	0	0	0	0	1	1	2	2
BP	0	0	0	1	1	2	2	2
WO	0	1	1	2	3	4	4	5
BO	0	1	1	2	2	3	3	4

Note: 0–5 indicate film degradation scale.

Grain Yield

After the maturity of maize, 15 plant samples were continuously selected from each plot to measure the spike length, number of ears, kernel number spike, and 1000-kernel mass. Finally, the yield of each mulching film treatment was calculated.

Statistical Analysis

Analysis of variance (ANOVA) was performed to test for differences in soil moisture, temperature and yield among various treatments. Correlation analysis was performed with SPSS 24.0 (IBM Corporation, Somers, New York). Comparison of means using the least significant difference test of $p < 0.05$ (LSD 0.05).

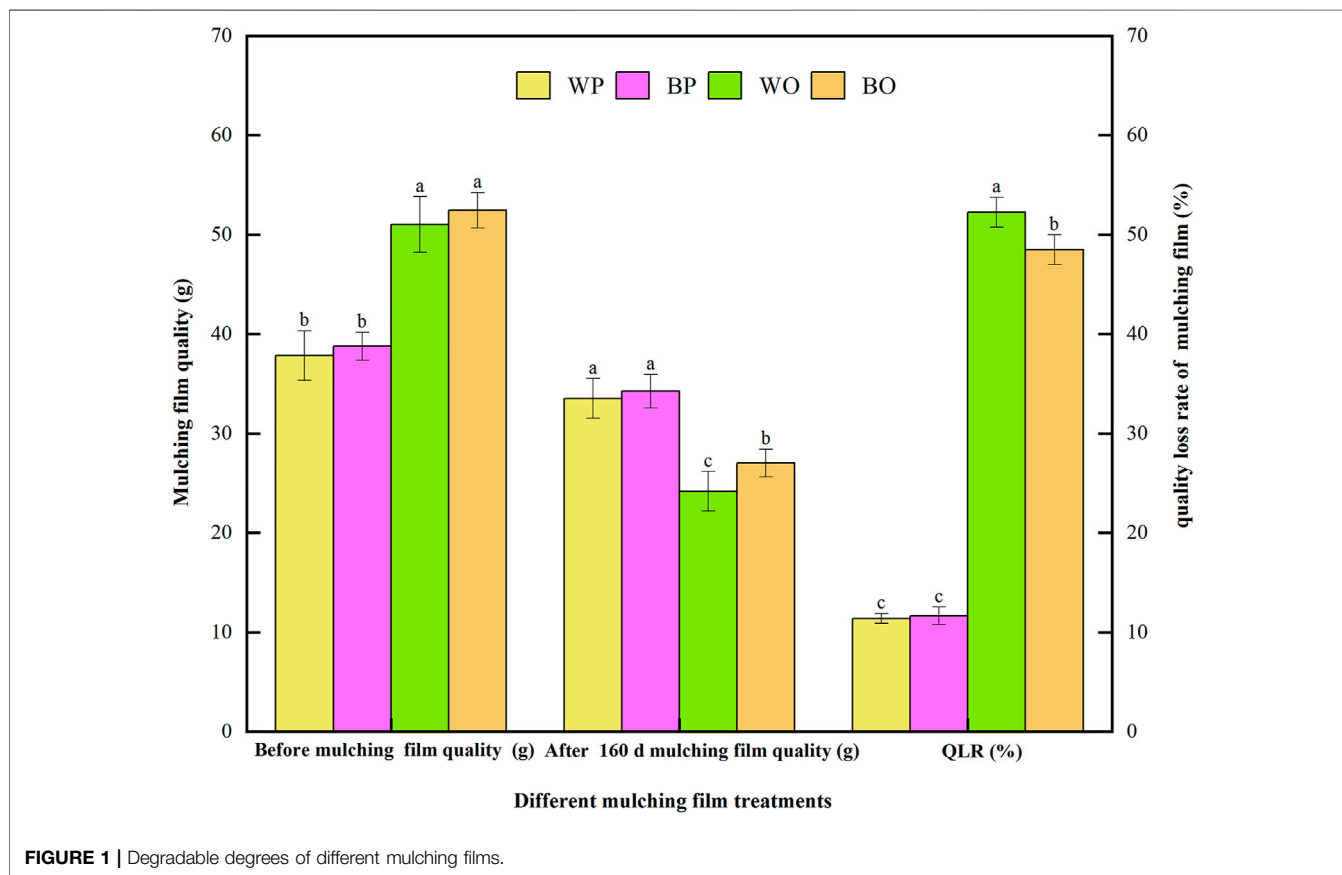
RESULTS

Degradation Characteristics of Different Mulching Films Degradation Rate

The degradation rate of different mulch films is shown in **Table 1**. Two oxo-biodegradable mulching film surface cracks began to appear (level 1) at 100 days after sowing (DAS), appeared with small cracks in the 25% film (level 2) at 120 DAS, and observed with 2–2.5 cm cracks (level 3) at 140 DAS under BO treatment. The mulch surface of BO treatment appeared uniform network cracks and film thinning (level 4) at 160 DAS. However, Compared to BO treatment, the WO treatment mulching film surface appeared 2–2.5 cm cracks (level 3) 10 days ahead of time, the mulching film surface appeared uniform network cracks, film thinning and no large film exists (level 4) 20 days ahead of time. Until the end of the experiment, the WO treatment was broken into fragments below 4×4 cm (level 5). In both WP and BP treatments, surface cracks began to appear (level 1) at 130 DAS and 120 DAS, respectively and appeared small cracks in the 25% film (level 2) at 160 DAS.

Degradation Degrees

The quality loss rate of the mulch film is shown in **Figure 1**. After mulching film for 160 days, there was a significant difference in the QLR between polyethylene mulching film and oxo-

**FIGURE 1** | Degradable degrees of different mulching films.

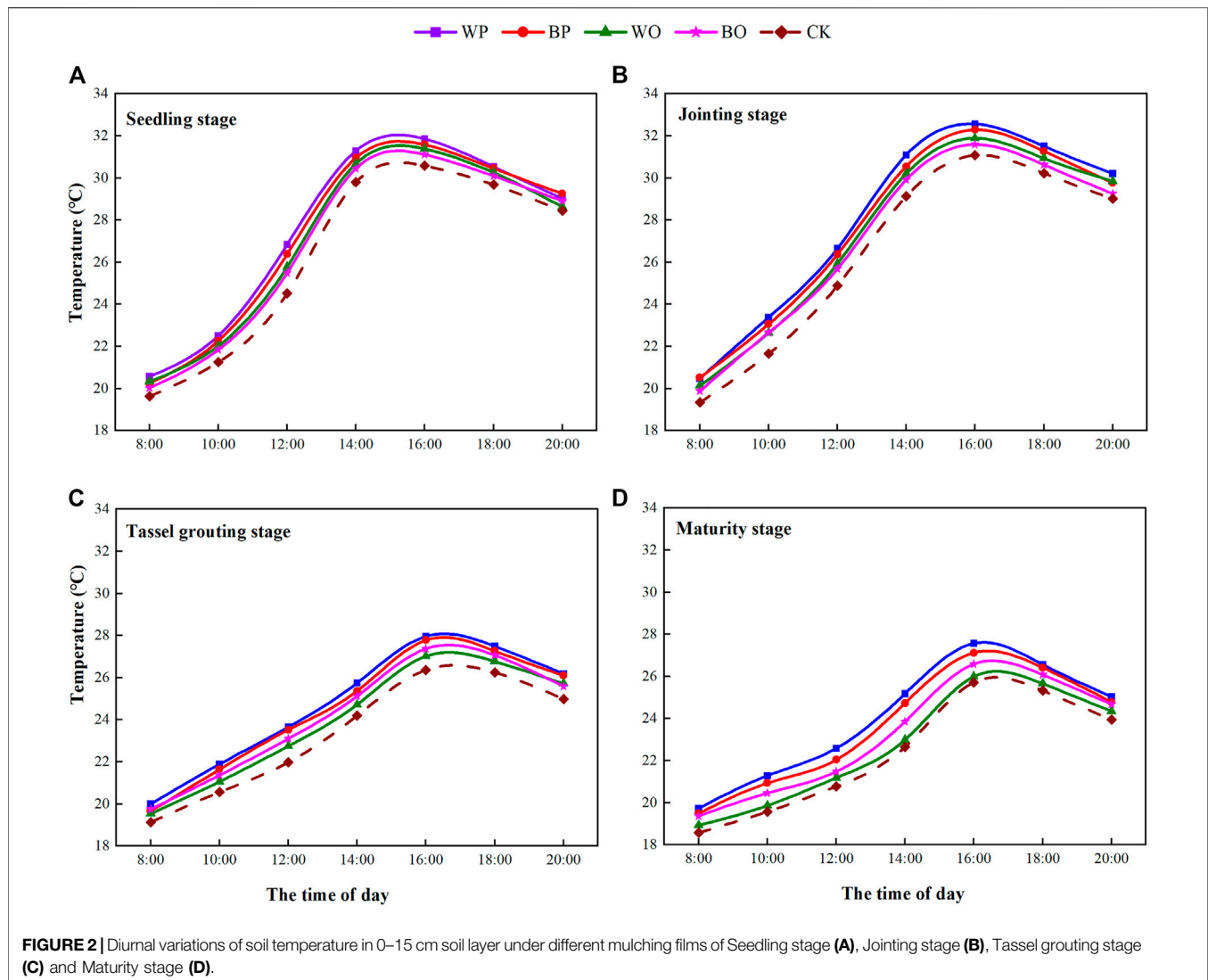


FIGURE 2 | Diurnal variations of soil temperature in 0–15 cm soil layer under different mulching films of Seedling stage (A), Jointing stage (B), Tassel grouting stage (C) and Maturity stage (D).

biodegradable mulching film, the QLR of BO and WO treatments were reported 48.48 and 52.26%, respectively. However, the QLR of WP and BP treatments were only 11.39 and 11.66%, respectively. Under the same condition, the QLR of BO treatment was 3.78% lower than WO treatment ($p < 0.05$), which was consistent with the change of the degradation rate.

Effects of Different Plastic Mulching Film on Soil Temperature

The diurnal changes of soil temperature during the maize growth period under different mulching films are shown in Figures 2, 3. The daily variation of soil temperature in the 0–15 cm soil layer of different mulching film treatments showed a trend of first increasing and then decreasing. The soil temperature under different mulching film treatments were higher than non-mulching film treatment. Due to the influence of natural environmental temperature and sunlight, the average soil temperature of the 0–15 cm soil layer is higher than the 15–25 cm soil layer. As shown in Figure 2, the average soil

temperature of BO, WO, WP and BP treatments were 0.72, 0.64, 1.43 and 1.16°C higher than that of CK treatment ($p < 0.05$), respectively in 0–15 cm soil layer. As shown in Figure 3, there was no significant difference among different mulching film treatments in the 15–25 cm soil layer. In the 0–15 cm soil layer, the average soil temperature of WP treatment was 1.21°C higher than that of BP treatment ($p < 0.05$), respectively, and the corresponding WO treatment was 1.16°C higher than BO treatment ($p < 0.05$). From the tassel grouting stage to the maturity of maize, the degradation of the oxo-biodegradable mulching film showed poor thermal insulation effects, resulting in the average soil temperature of the 0–15 cm soil layer in WO treatment was 1.29°C lower than WP treatment ($p < 0.05$), and BO treatment was 0.43°C lower than BP treatment ($p > 0.05$).

Effects of Different Plastic Mulching Film on Soil Moisture

The vertical changes of soil water content in 0–60 cm soil layer under different mulching films are shown in Figure 4. Under

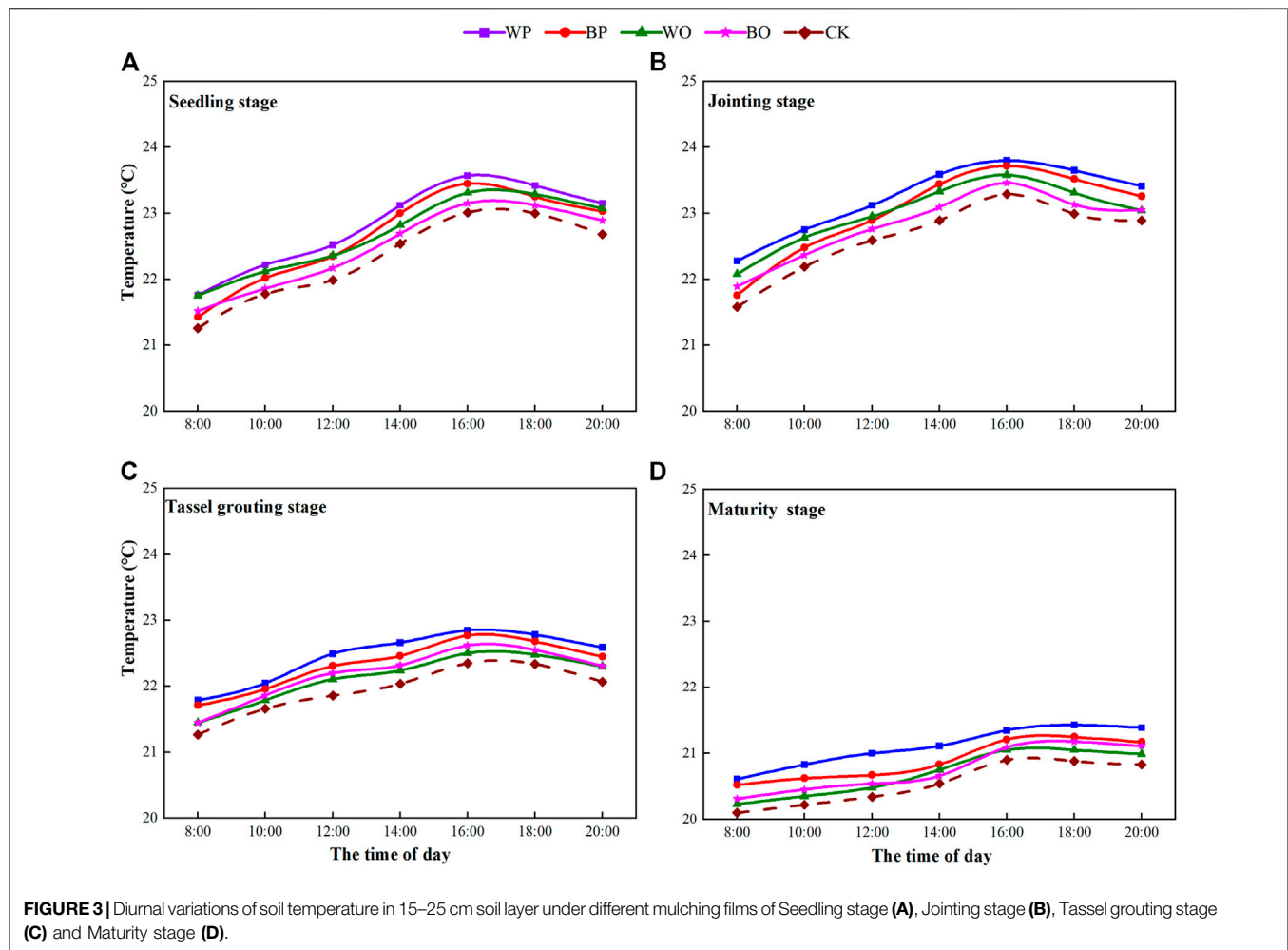


FIGURE 3 | Diurnal variations of soil temperature in 15–25 cm soil layer under different mulching films of Seedling stage (A), Jointing stage (B), Tassel grouting stage (C) and Maturity stage (D).

different mulching film treatments, soil moisture changes in the 0–60 cm soil layer during each growth period of maize showed a trend of first increasing and then decreasing. In the seedling stage and jointing stage, there were no significant differences in the soil moisture content between various mulching film treatments. Under different mulching film treatments, soil moisture was significantly different in the 10–30 cm soil layer. Compared to WP, WO, BO and CK in the seedling stage, the soil moisture content of BP treatment increased by 2.62, 10.03, 5.99 and 18.29% ($p < 0.05$), and the jointing stage was increased to 2.63, 10.03, 5.99 and 18.29% ($p < 0.05$), respectively. With the deepening of the soil layer, the soil moisture content of each mulching film treatment showed a downward trend and the difference gradually became smaller in the 30–50 cm soil layer. The tassel grouting stage was the critical period of crop water demand and the oxo-biodegradable mulching films began to degrade. Under different mulch treatments, the difference gradually became larger in soil moisture. The soil moisture of the BO treatment was 2.48% lower than the BP treatment, and the WO treatment was 3.02% lower than the WP treatment ($p < 0.05$) in the 0–30 cm soil layer. Meanwhile, soil moisture of BP treatment was 1.09% higher than WP treatment, and soil moisture of BO treatment was 1.66% higher than WO treatment ($p < 0.05$). The soil moisture

content of BO treatment was significantly lower than WP and BP treatments by 3.35 and 5.88%, respectively, however it was significantly increased by 20.66% than the CK treatment ($p < 0.05$). The soil moisture content of WO treatment was significantly lower than WP and BP treatment by 7.72 and 10.13%, respectively. However, it was significantly higher than CK treatment by 15.21% ($p < 0.05$) in the 0–30 cm soil layer at the maturity stage.

The dynamic changes of soil water consumption in 0–60 cm soil layer under different mulching films are shown in **Figure 5**. The soil water consumption during the growth period of maize was lower than the CK treatment. The order of total soil water consumption of each mulching film treatment was BP < WP < BO < WO < CK. There was no significant difference in the water consumption under same color mulching films during the seedling stage and the jointing stage. And there was also no significant difference in soil water consumption between BO treatment and BP treatment at the tassel grouting stage. However, the soil water consumption of WO treatment was 1.84% less than WP treatment ($p < 0.05$). The water consumption of BO treatment was significantly increased by 4.93% compared to BP treatment ($p < 0.05$), and the corresponding WO treatment was significantly increased by

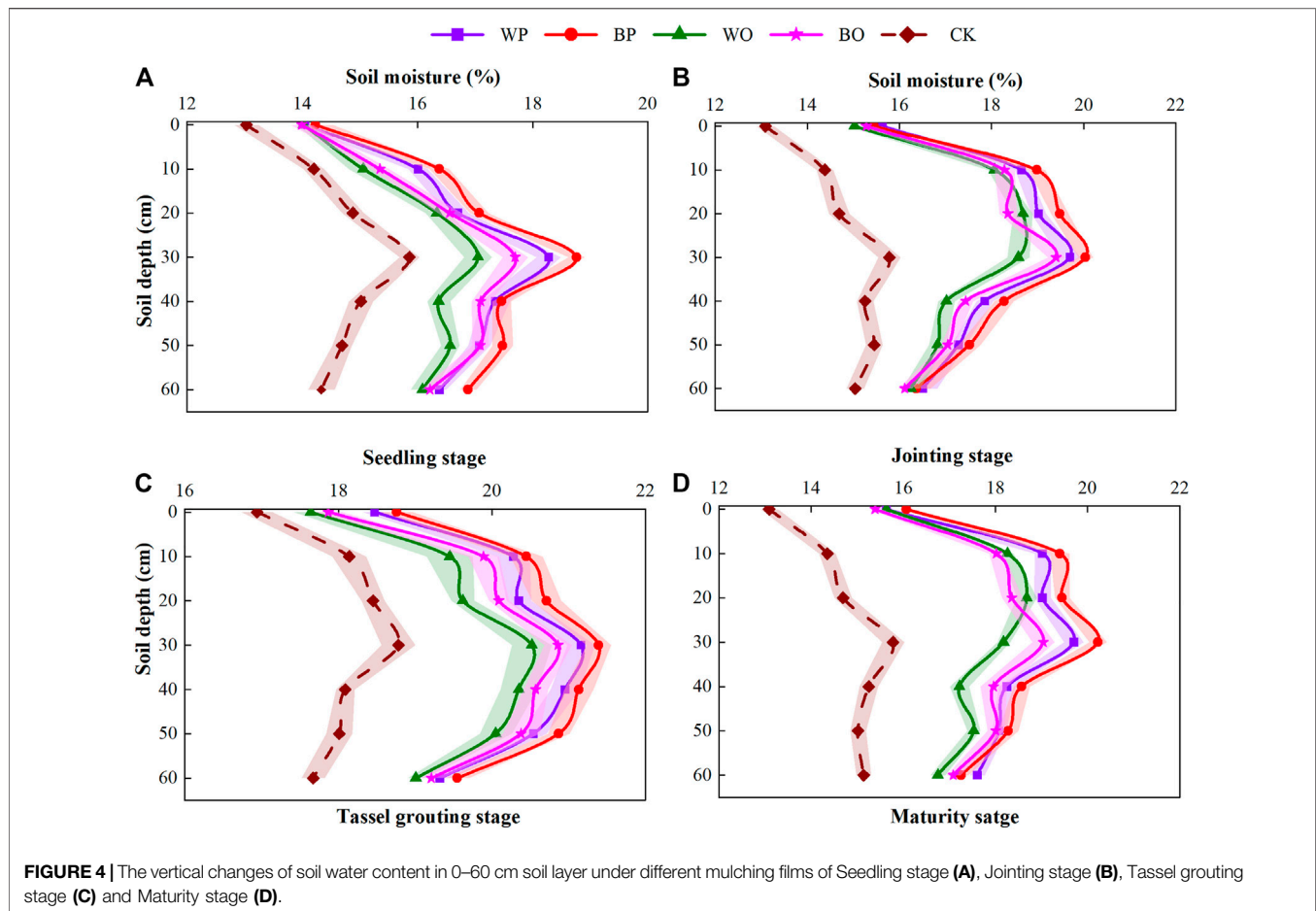


FIGURE 4 | The vertical changes of soil water content in 0–60 cm soil layer under different mulching films of Seedling stage (A), Jointing stage (B), Tassel grouting stage (C) and Maturity stage (D).

5.49% than the WP treatment ($p < 0.05$), and compared to non-mulching treatment, it only increased by 0.58% ($p > 0.05$).

Effects of Different Plastic Mulching Film on Maize Yield and WUE in Drip Irrigation

Table 2 showed the spring maize yield, yield components and water use efficiency under different mulching films. There was no significant difference in spike length and kernel number spike among WP, WO and BO treatments, and the BP treatment had the highest yield. Compared to BP treatment, the 1000-kernel mass of BO treatment decreased by 0.43% ($p > 0.05$), while BO treatment was 2.32, 8.56 and 14.58% lower than WP, WO and CK treatment ($p < 0.05$), respectively. The yield of BO treatment was 0.33% lower than BP treatment ($p > 0.05$). Similarly, the yield of WO treatment was 2.44% lower than WP treatment ($p < 0.05$). However, the BO treatment and WO treatment were 29.39 and 22.88% higher than CK treatment ($p < 0.05$), respectively.

The order of water use efficiency of spring maize was: BP > BO > WP > WO > CK. The BO treatment was 0.90% lower than the BP treatment ($p > 0.05$), while the WO treatment was 3.84% lower than the WP treatment ($p < 0.05$). Compared to CK, the WUE of WP, BP, BO and WO treatments increased significantly by 31.89, 35.53, 34.32 and 26.82%, respectively ($p < 0.05$).

DISCUSSION

In our study, compare to black oxo-biodegradable mulching film white oxo-biodegradable mulching film degraded rate the best over time, The reason of phenomenon is that black oxo-biodegradable mulching film has lower thermal radiation and light transmission than white oxo-biodegradable mulching film, and white oxo-biodegradable mulching film has better than environment black oxo-biodegradable mulching film which promoted the photo and thermal oxidative degradation (Lu et al., 2016; Yan et al., 2020). Therefore, the degradation of white oxo-biodegradable mulch is faster. It was similar to the results of Ding et al. (2021) who found that white oxo-biodegradable mulching film entered the disintegration period after 150 d in the extreme arid zone of Xinjiang. The oxo-biodegradable mulching film with different degradation formulations degraded into small fragments, the QLR of oxo-biodegradable mulching film was 74.5% (Yuan et al., 2016). Similar conclusion were found in this study. However, the overall degree of degradation was relatively small, and the possible reasons for this phenomenon are as follows: The scarce rainfall and dry climate have given rise to weaken of soil microbial activity in 2020, and the relatively high number of surface boulders and flakes led to reducing the contact area between soil and mulching films, which slowed down the

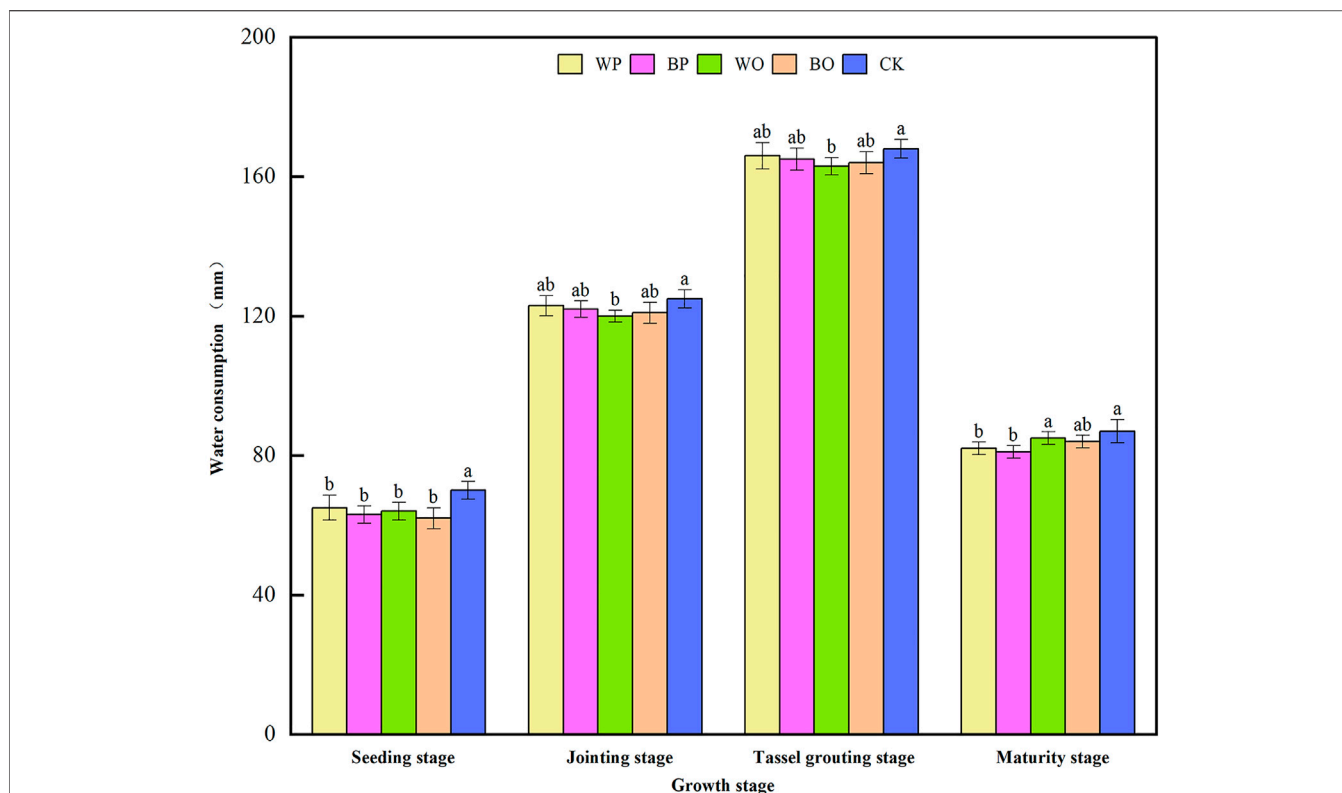


FIGURE 5 | The dynamic changes of soil water consumption in 0–60 cm soil layer under different mulching films. Note: Different lowercase letters indicate significant differences among treatments at 0.05 level.

TABLE 2 | Grain yield and yield components of maize and water use efficiency under different mulching films.

Treatment	Spike length/cm	Kernel number spike	1000-Kernel mass	Yield/(kg·hm ⁻²)	WUE/[kg·(mm·hm ⁻²) ⁻¹]
WP	20.00 ± 1.00 ab	646.33 ± 20.03 ab	359.75 ± 4.82 b	14013.67 ± 251 ab	32.55 ± 0.46 a
BP	21.17 ± 1.26 a	664.33 ± 24.54 a	368.14 ± 1.95 a	14443.67 ± 117 a	33.45 ± 0.23 a
WO	20.10 ± 0.53 ab	636.67 ± 21.93 ab	339.10 ± 0.99 c	13671.45 ± 232 b	31.30 ± 0.55 b
BO	19.93 ± 0.40 ab	620.00 ± 14.93 ab	366.58 ± 2.57 a	14395.80 ± 214 a	33.15 ± 0.41 a
CK	18.83 ± 0.29 b	610.67 ± 42.10 c	321.30 ± 1.10 d	11125.84 ± 318 c	24.68 ± 0.68 c

Note: The data are presented as mean ± standard deviation, and different lowercase letter safter value within the same column indicate a significant level at $p < 0.05$ among various treatments.

erosive effect of soil microorganisms on the mulching films and improved the optical catalytic reaction in the region.

The suitable soil water and heat condition were the key factors to promote crop growth (Ni et al., 2016; Wang et al., 2021). The mulching film not only affected soil water evaporation but also improved the field soil environment (Touchaleaume et al., 2016). The results showed that the soil moisture of BP treatment was higher than WP treatment, and soil moisture of BO treatment was higher than WO treatment. In fact, due to black mulching film which has lower light transmission, did not raise the temperature as much as white mulch film under sunlight, and black mulch film has slower moisture loss (Zhang et al., 2019b). Consequently, it has higher than white mulch film in moisture retention capacity. In this experiment, white oxo-biodegradable mulching film

degraded better than black oxo-biodegradable mulching film due to light transmission and thermal radiation. Hence, it has higher moisture retention capacity than white mulch film. Although oxo-biodegradable mulching film surface began to cracks and the moisture retention gradually weakened after the tassel grouting stage, the degradation did not affect the normal growth of crops. Therefore, the obvious moisture-preserving effect of early and mid-term maize growth was equivalent to the polyethylene mulching film (Shen et al., 2019; Gu et al., 2021).

This experiment showed that due to the small plant canopy cover, white mulching film intercepts more solar radiation and has better light transmission than black mulching film. As a result, the cumulative temperature of the soil tillage layer of white

mulching film is significantly higher than with black mulching film (Lu et al., 2016; Zhang et al., 2017a; Li et al., 2018a; Sun et al., 2018; Amare and Desta, 2021). The highest soil temperature period of the white mulching film was significantly higher than black mulching film at 16:00, during the maize seedling stage and jointing stage. Li et al. (2018b) also revealed that compared to white mulching film, black mulching film was beneficial to plant growth and development could effectively reduce the ground temperature in the 0–15 cm soil layer, during the highest temperature of the day. Therefore, the black mulching film had a certainly effect on lowering the temperature, avoided the effect of high temperature on the maize seedlings, which was beneficial to the growth and development of the plants (Chen et al., 2017; Sun et al., 2018). From the perspective of the degradation of oxo-biodegradable mulching film in this experiment, the black oxo-biodegradable mulching film had a better thermal insulation effect. Therefore, between WO treatment and WP treatment, BO treatment and BP treatment showed significant differences in the soil temperature of 0–15 cm.

Meng et al. (2021) showed that compared to polyethylene mulching film, the black oxo-biodegradable mulching film reduced yield by only 0.43% and water use efficiency by only 1.09%. This study also showed a similar result. Black mulch film increased soil moisture content, stabilized and regulated soil temperature, caused faster growth in the early stages of maize and slower aging in the later stages, promoted root activity and absorption of soil nutrients, and enhanced grain yield (Zhang et al., 2019a). The effect of black oxo-biodegradable mulching film is better than white oxo-biodegradable mulching film in moisture retention and heat preservation. Black oxo-biodegradable mulching film is comparable to polyethylene mulch film. Therefore, there is no significant difference in yield between black oxo-biodegradable mulching film and polyethylene mulch film.

CONCLUSION

There is no degradation of polyethylene mulching film during the whole growth period. The degradation rate of white oxo-biodegradable mulching film is higher than the black oxo-biodegradable mulching film.

BP treatment has better moisture retention than WP treatment. Meanwhile, BO treatment has better moisture retention than WO treatment during the growth period of maize in the 0–60 cm soil layer; WO treatment has better heat

retention than BO treatment, due to different degrees of degradation of oxo-biodegradable mulching film, BO treatment has better heat retention than WO treatment in the middle and late growth periods at depth of 0–15 cm.

Compared to the black polyethylene mulching film, there are no significant differences in yield and water use efficiency of the black oxo-biodegradable mulching film. This study indicates that the black oxo-biodegradable mulching film application is better, and it can replace the polyethylene mulching film. Our findings suggest considering it for promotion and use in the production in the Ili River area of Xinjiang.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication. RL: Investigation, experiment, data analysis, writing-original draft and revise; ZW: Conceptualization, methodology, supervision and project administration; HY, WL, RZ, and XT: Investigation, supervision and editing.

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