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Effects of Surface Mulching on the Growth and Water Consumption of Maize

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Abstract: This study provides understandings of the effect of mulching on the growth, development, and water consumption of dry maize. Parameters including soil temperature, soil water-filled pore space (WFPS), water storage capacity, water consumption, grain yield, water-use efficiency, and biomass yields were followed and analyzed by applying straw mulching (SM), gravel mulching (GM), and plastic film mulching (FM). The results show that the soil temperature (0–20 cm) throughout the whole observation period (2011–2013) was significantly increased by applying GM and FM, while SM reduced the soil temperature. SM increased the WFPS, while FM and GM showed no significant effect. SM and FM increased the soil water storage and water-use efficiency in the early stages of maize growth (from sowing to vegetative growth) compared with using GM. With the progress of time, fewer differences between all treatments were observed. Water consumption of the three treatments was in the order of SM < FM < GM, indicating that SM was the most effective in preventing water evaporation. The resulting yields of corn also varied. Compared with the control, FM significantly increased the yields by 1.7, 0.5, and 2.2 ton/ha in the tested three years, respectively. In contrast, GM showed no significant difference in the three years, and SM showed no significant difference in 2011 and 2012 but increased the yield by 2.2 ton/ha in 2013. FM is shown to be an effective method for increasing the yields of corn for the studied region, GM is not recommended, and SM is the most effective in improving the water availability in the soil, while its effect on corn yields needs to be further explored.

Keywords: mulching measures; maize development; soil water content

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1. Introduction

The growth of crops in arid areas is largely influenced by the availability of soil water, which is mainly supplied by rainfalls in many areas. For instance, the Loess Plateau of China, an arid–semi-arid area, is a place suffering from the scarce and uneven seasonal distribution of rainfalls (578 mm/year) [1]. Such an unwanted climate is responsible for the low water-use efficiency of plants, which is considered the main challenge of growing crops in this region [2,3]. Therefore, providing appropriate management measures to improve the utilization efficiency of precipitation has become the most effective method of improving the utilization efficiency of water and fertilizers and maintaining the sustainable development of grain production in the dryland areas of the Loess Plateau.

Mulching is one of the most widely used and effective technical measures to improve the water storage capacity of soil, thus improving the availability of water to plants. There are various mulching methods which are applied in various areas [4,5]. Among these methods, straw mulching (SM), gravel mulching (GM), and film mulching (FM) are identified as the most adaptable methods for the Loess Plateau area because all these required mulching materials are locally widely available. To select the most effective mulching methods, practical studies are required to identify the merits and demerits of each method.

Previous research on applying land coverings to improve the growth of crops has demonstrated that applying surface covers can effectively suppress water transfer at the soil–gas interface, thereby providing a longer water retention time in the soil [6–8]. This can significantly increase crop yields in dry-farming systems [9,10]. However, the actual performance of mulching can vary due to differences such as different covering materials and the actual tested areas [11–13]. Identifying the most effective means must be investigated case by case. This study is thus conducted to understand the effects of different mulching measures on the soil properties, water availability, and crop yields in the dryland areas of the Loess Plateau based on 3 years of practical study, and this research aims to provide a theoretical basis for managing water resources and improving agricultural production in arid areas.

2. Materials and Methods

2.1. Site Description

The experimental data used in this work were collected between 2006 and 2011 at the Changwu Agro-Ecological Station on the Loess Plateau (35.28 N and 107.88 E) in Shaanxi Province, China. The experimental site is located at ~1206.5 m above sea level. The loess at the site is more than 100 m thick, and the soil is a Cumuli-Ustic Isohumosol [14] containing 37% clay, 59% silt, and 4% sand. The average soil pH is 8.4, and its bulk density is 1.35 g cm^{-3}. The saturated hydraulic conductivity is 240 mm d^{-1}. The soil's contents of organic matter, total nitrogen, available phosphorus, available potassium, and inorganic nitrogen are 11.8 g kg^{-1}, 0.87 g kg^{-1}, 14.4 mg kg^{-1}, 144.6 mg kg^{-1}, and 3.15 mg kg^{-1}, respectively. Most farms in the region harvest a single crop (e.g., wheat or maize) each year using rainfed agriculture.

2.2. Field Experimental Design

The spring maize experiment was conducted in 2011, 2012, and 2013, and four treatments were set up, namely, the control treatment (CK), the gravel mulching treatment (GM), the straw mulching treatment (SM), and the plastic film mulching treatment (FM). The gravel mulching treatment consisted of covering the surface of the plot with white and yellow gravel with a thickness of 2–4 cm when the plants' height was ~5 cm after the corn emerged, while the film mulching treatment consisted of covering the corn planting rows but not the space between the rows. The plastic film was colorless and transparent, 0.015 mm thick, and 90 cm wide, with a transmittance and thermal radiation rate of ~90%. In the straw mulching treatment, the corn straw was crushed into 10 cm segments with a total mulching amount of 6000 kg/hm^2 and then mulched between the corn rows after the corn's emergence on May 8. Three replicates were set for each treatment, with a cell area of 42 m^2 and a mulching amount of 6000 kg/hm^2 covering ~90% of the Plot, with N ha^{-1} N, 80 kg K ha^{-1} K, and 40 kg P ha^{-1} P. Urea with a nitrogen content of 46% was used as the nitrogen source, superphosphate with a P_2O_5 content of 12% was used as the phosphorus source, and potassium sulfate with a K_2O content of 45% was used as the potassium source. Nitrogen fertilizer was applied three times, of which base fertilizer and seed fertilizer accounted for 40% of the total amount, while the rest was applied in the jointing and silking stages each year according to the standard of 30% of the total amount, with a top-dressing amount of 67.5 kg N ha^{-1}. The experimental maize variety "Zhengdan 958" was planted at a density of 65,000 plants per hectare and a depth of 5 cm. The row spacing was 65 cm, and the plant spacing was ~25 cm.

2.3. Index Determination and Method

The sowing dates in 2011, 2012, and 2013 were 18 April, 21 April, and 23 April, respectively. The harvest dates were September 28, September 11, and September 17, respectively. All the treatments were rainfed without supplementary irrigation. The calculation standard for the corn growth period was in accordance with the corn growth period observation standard widely adopted in the Corn Belt of the United States [15]. Soil samples were taken once at pre-sowing (PT), and other samples were collected together with biomass in the six-leaf (V6), tasseling (VT), silking (R1), milking (R3), wax ripening (R5), and physiological maturity (R6) stages. The soil moisture at depths of 0–200 cm was measured in each plot. One sample was taken for every 20 cm layer, and a total of 10 samples were collected. The aboveground biomass was measured by taking 3 plant samples with uniform growth in the plot and drying them in an oven at 65–75 °C to a constant weight after finishing, and then the dried samples were weighed with a 1/1000 electronic balance.

The slope of the test site is small, and the groundwater depth of the Weibei dry plateau is mostly below 50 m, so the groundwater supply is negligible. Therefore, the formula for the calculation of the farmland water balance can be simplified as shown in Equation (1). The water consumption can be calculated using Equation (2). The soil water storage (W) and water-use efficiency (WUE) can be calculated using Equations (3) and (4), respectively.

$$ET = (W_1 - W_2) + P \tag{1}$$

$$W_{consumption} = W_{sowing} + P - W_{harvest} \tag{2}$$

$$W = H \times D \times B\% \times 10 \tag{3}$$

$$WUE_G = Y/ET \tag{4}$$

here, W is the soil water storage (mm), H is the soil depth (mm), D is the average soil volume mass (g/cm^3), $B\%$ is the soil moisture content; ET is the farmland evapotranspiration (mm), W_1 and W_2 are the water storage in the 0–200 cm soil layer during the two sampling periods (mm), P is the precipitation during the crop growth period (mm), $W_{consumption}$ is the water consumption (mm), W_{sowing} is the soil water storage before sowing (mm), $W_{harvest}$ is the soil water storage after the harvest (mm), WUE_G is the grain yield's water-use efficiency (kg/(hm^2.mm)), and Y is the economic output (kg/hm^2).

2.4. Statistical Analysis

SPASS 13.0 was used to analyze the data using a one-way analysis of variance (ANOVA), and the least-significant-difference (LSD) method was used to test the significance (p < 0.05), while SigmaPlot 14.0 software was used for drawing the figures.

3. Results

3.1. Effects of Surface Cover on Soil Temperature in the 0–20 cm Soil Layer

Figure 1 shows the effects of the different mulching measures on the soil temperature in the 0–20 cm layer. It can be seen that the gravel (GM) and plastic film mulching (FM) treatments significantly increased the temperature of the 0–20 cm soil layer. In 2011 and 2012, the average soil temperature under the gravel mulching treatment increased by 0.4 °C and 0.7 °C, respectively. The average soil temperature increased by 0.6 °C under the FM treatment in 2012. Compared with CK, the average soil temperature under the SM treatment in 2011 and 2012 decreased by 0.7 °C and 1.3 °C, respectively.

3.2. Effects of Surface Cover on Soil Water-Filled Pore Space in the 0–20 cm Soil Layer

Figure 2 shows that the soil water-filled pore space (WFPS) in the 0–20 cm soil layer increased sharply after the heavy rainfall event and then decreased rapidly with the effects of crop transpiration and soil evaporation. Compared with CK, the WFPS under the SM treatment increased significantly (p < 0.05), while the GM and FM treatments showed no increase in WFPS in the 0–20 cm soil layer. In 2011, the average values of WFPS under the CK, GM, SM, and FM treatments were 41.0%, 40.6%, 43.4%, and 38.1%, respectively, compared with 38.2%, 35.3%, 39.4%, and 35.0% in 2012, respectively.

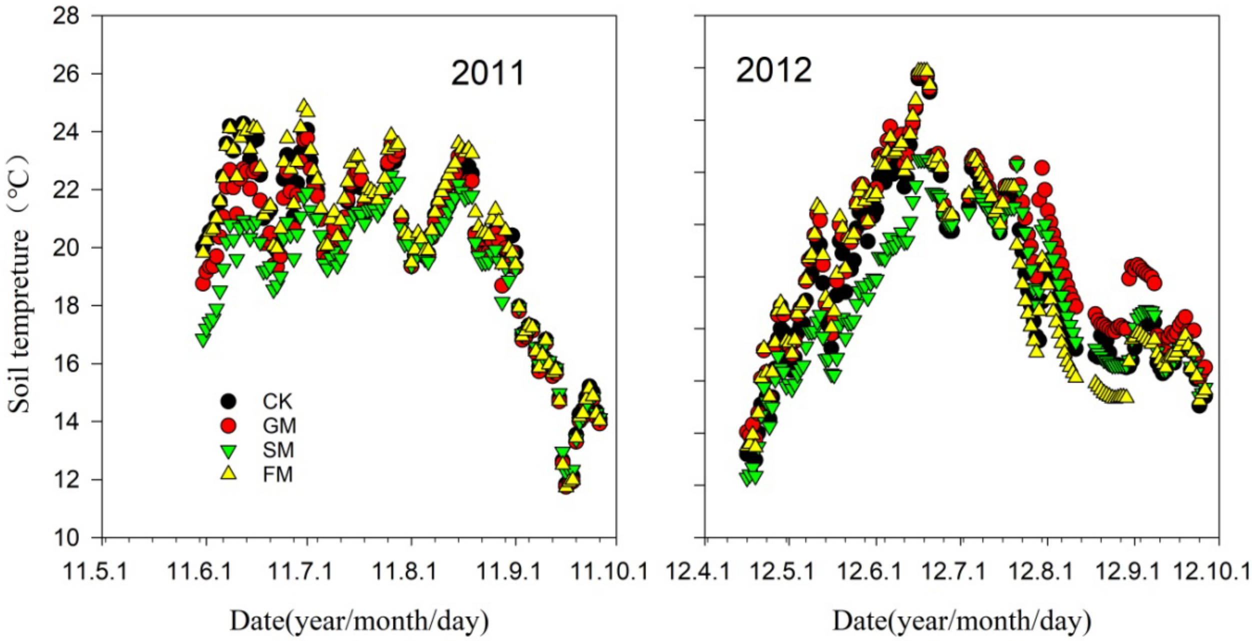

Figure 1. The mean soil temperature at a depth of 20 cm for the different mulching treatments in 2011 and 2012.

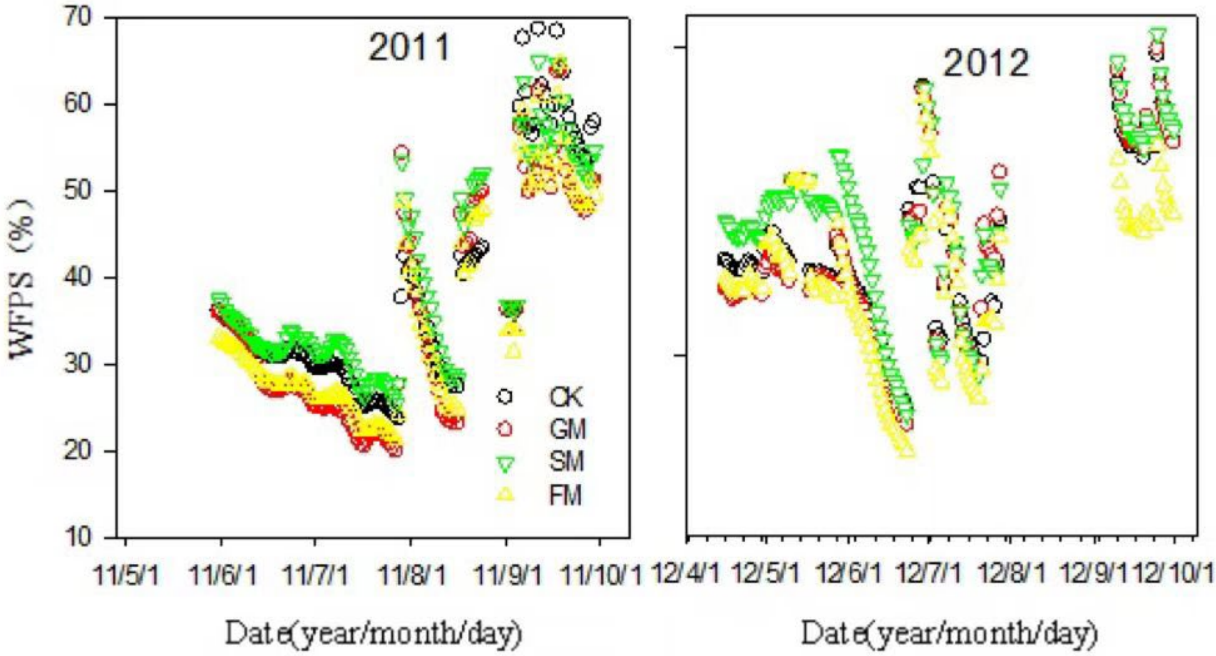

Figure 2. Soil water-filled pore space (WFPS) under the different mulching treatments in the top 20 cm of soil.

3.3. Effects of Surface Cover on Soil Water Storage Capacity

The water storage capacity of the soil at depths of 0–200 cm under the different mulching treatments is shown in Figure 3. Soil water storage shows fluctuation with the growth of the maize. Throughout the whole growth period, the SM treatment significantly increased the water storage capacity in the 0–200 cm soil layers. FM also increased soil water storage in the 0–200 cm soil layers during the early stages of maize growth. The amount of water stored in the soil under the FM treatment increased by 17.8 mm compared with that of the CK treatment in 2011, by 18.2 mm in 2012, and by 18 mm in 2013. The contribution of gravel mulching (GM) to the soil water storage was not significant. After the six-leaf stage, the soil water storage of each mulching treatment decreased noticeably in the order of FM > GM > CK > SM, while the differences between the first three treatments gradually decreased. After the silking stage, the water consumption under the straw mulching was the highest, especially in the later stages of wax ripening and maturity. Compared with the other treatments, the water consumption under the straw mulching was significantly improved. The main reasons for this were that the growth period under the straw mulching was relatively late, the wax ripening and maturity periods exhibited rapid growth, and a large amount of water was consumed for grain formation [16].

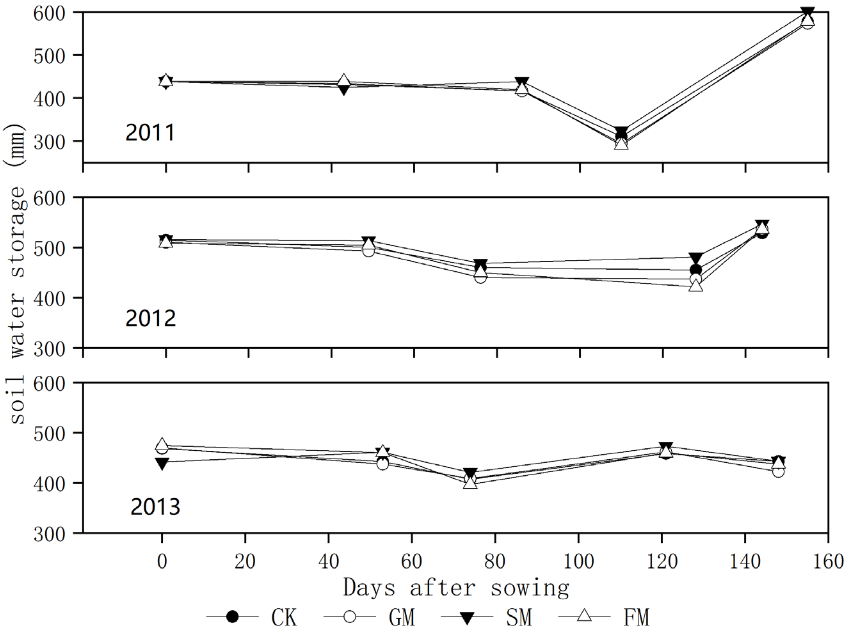

Figure 3. Soil water storage in the 0–200 cm soil layers in 2011, 2012, and 2013.

When the lowest value of soil water storage occurred (i.e., R3 in 2011, R5 in 2012, and VT in 2013), the replenishment of the water stored in the soil by rainfall gradually increased with the increase in the amount of precipitation during the late growth period of the maize. Then, the differences in soil water storage between the different treatments decreased gradually, and there were no significant differences at harvest time. The differences between the harvesting and pre-sowing soil water storage in the 0–200 cm soil layers are shown in Figure 4.

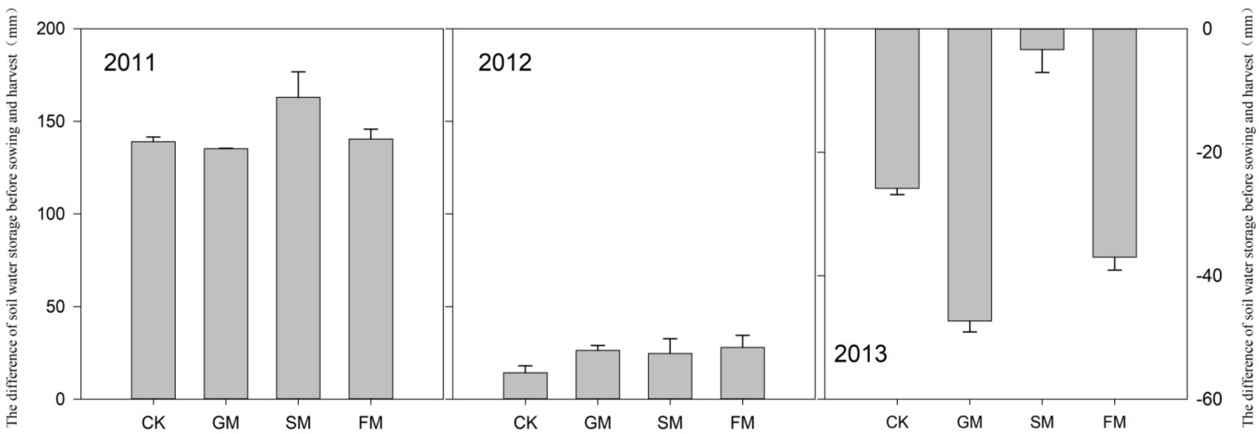

Figure 4. Changes in the water storage in the 0−200 cm soil layers under the straw mulching (SM), gravel mulching (GM), plastic film mulching (FM), and non-mulched (CK) treatments in 2011, 2012, and 2013. ※ The bar is standard error.

3.4. Effects of Surface Cover on Water Consumption, Grain Yield, and Water-Use Efficiency

During the 2011, 2012, and 2013 trial periods, the maize received 482, 399, and 418 mm of precipitation, respectively—accounting for 75%, 83%, and 73% of the total annual rainfall, respectively. As shown in Figure 5, more precipitation occurred during the grain formation stage in 2011 and during the silking stage in 2013. Table 1 shows the water consumption under the different mulching treatments. The total water consumption of the maize under the different mulching treatments in 2011, 2012, and 2013 was 319–343 mm, 371–385 mm, and 421–465 mm, respectively. In 2011 and 2013, the water consumption under the GM treatment was significantly higher than that under the other treatments, while that under the SM treatment was markedly lower than that under the other treatments. The results show that straw mulching could significantly reduce evaporation from the soil and improve the soil water storage capacity.

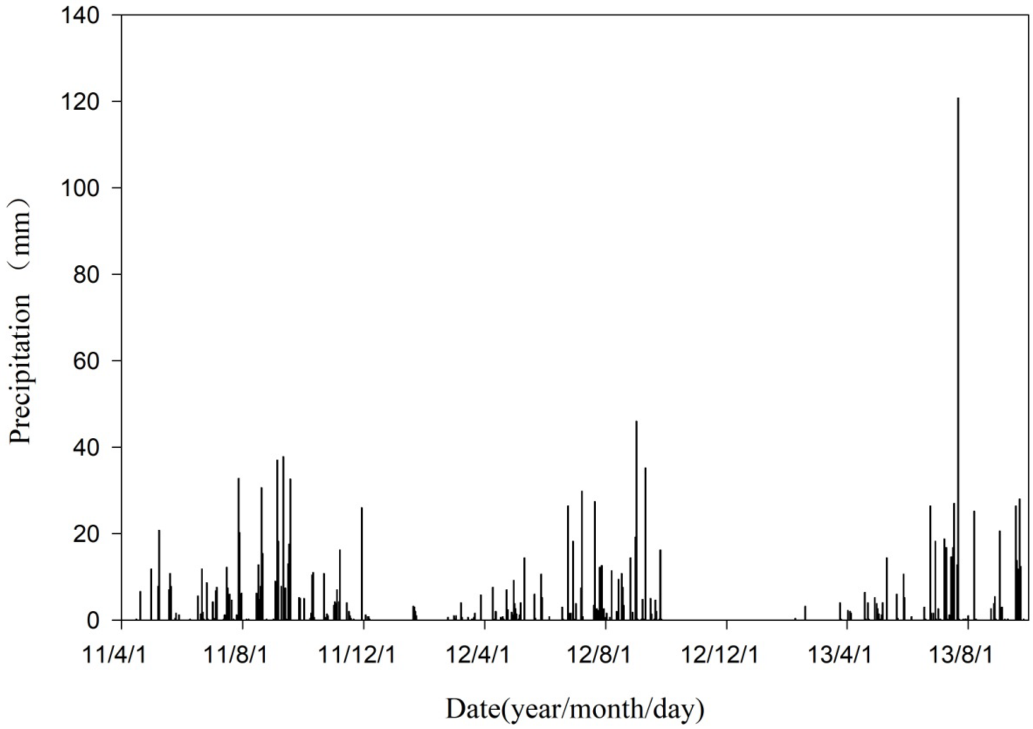

Figure 5. Daily precipitation (P) at the experimental site during 2011, 2012, and 2013.

Table 1. The water consumption (mm) of maize under the non-mulched (CK), gravel mulching (GM), straw mulching (SM), and plastic film mulching (FM) treatments in 2011, 2012, and 2013.

Year	Treatments	Whole Growth Period	before Spinning	after Spinning	before Spinning/after Spinning
2011	CK	343 ± 4.3^{ab}	167 ± 1.8^{a}	175 ± 2.3^{a}	0.95^{a}
2011	GM	347 ± 0.5^{a}	167 ± 0.8^{a}	179 ± 0.3^{a}	0.93^{a}
2011	SM	319 ± 9.3^{b}	146 ± 3.2^{b}	174 ± 7.1^{a}	0.86^{a}
2011	FM	341 ± 9.1^{ab}	165 ± 3.6^{a}	177 ± 3.2^{a}	0.94^{a}
2012	CK	385 ± 6.4^{a}	193 ± 4.0^{b}	192 ± 2.1^{a}	1.01^{b}
2012	GM	373 ± 4.7^{a}	206 ± 2.0^{a}	167 ± 1.1^{b}	1.24^{a}
2012	SM	374 ± 9.2^{a}	192 ± 1.5^{b}	182 ± 2.1^{ab}	1.06^{b}
2012	FM	371 ± 8.6^{a}	205 ± 6.0^{a}	167 ± 1.8^{b}	1.23^{a}
2013	CK	444 ± 1.7^{c}	165 ± 1.1^{c}	277 ± 0.8^{a}	0.60^{c}
2013	GM	465 ± 3.7^{a}	185 ± 3.1^{b}	281 ± 1.2^{a}	0.66^{b}
2013	SM	421 ± 6.4^{d}	145 ± 2.2^{d}	277 ± 2.1^{a}	0.52^{d}
2013	FM	455 ± 3.0^{b}	199 ± 1.0^{a}	256 ± 2.4^{b}	0.78^{a}

Note: Values with superscript letters ^{a,b,c} are significantly different across columns ($p < 0.05$).

Compared with the control, the pre-mulching water consumption increased, and, except for 2011, the ratio of water consumption after the silking stage under the GM and FM treatments was significantly higher than that under the CK treatment. Conversely, the water consumption under the straw mulching increased in the late silking period, and the ratio of water consumption before and after the straw mulching treatment was the lowest. Figure 6 shows the correlation analysis of the pre-sowing soil water storage and pre-silking water consumption in the maize. The results show that there is a significant linear relationship between the water consumption of the maize before the silking stage and the soil water storage before sowing in the different years of mulching treatment.

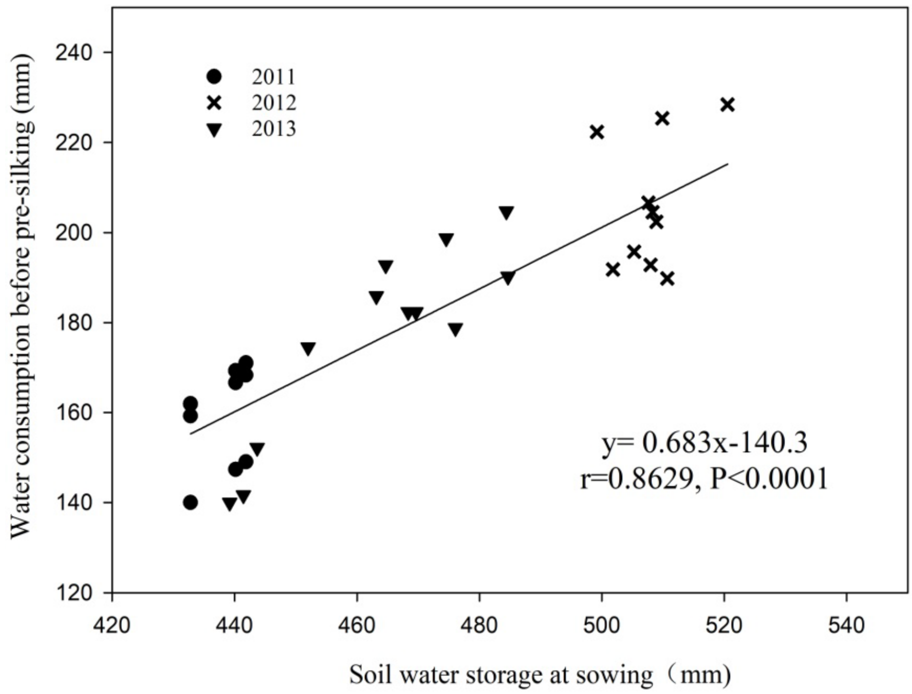

Figure 6. Correlations between the soil water storage at sowing and the average pre−silking water consumption for 3 years.

Compared with the CK treatment, the FM treatment significantly increased the maize yield, while the GM treatment did not significantly increase the yield, and the increase in the yield caused by the SM treatment was not significant in the first two years but was significant in 2013. Compared with CK, the FM treatments increased the grain yield by 15.6%, 3.85%, and 18.9% in 2011, 2012, and 2013, respectively (Table 2). The rainfall in 2012 was low, but the soil water content before sowing was higher than that in the other experimental years, ensuring the necessary moisture for the maize before silking and leading to a high grain yield. The results further indicate that soil water storage before sowing was very important to the crop growth in the following year, especially in drought years. On the other hand, the straw mulching reduced the soil temperature and affected the growth and development of the crops when the rainfall was low in 2012. Gravel mulching increased the surface temperature while reducing evaporation, thus promoting crop growth when the soil water was equal.

In addition, these results suggest that it is advisable to continue film mulching or gravel mulching of maize after harvest, which is important to capture rainfall in the fallow period and reduce evaporation from the soil. Straw mulching should be covered after sowing so as not to reduce the surface temperature, affect the early crop growth, or delay the growth period [17].

Table 2. Maize grain yield (GY) and water-use efficiency (WUE) under the non-mulched (CK), gravel mulching (GM), straw mulching (SM), and plastic film mulching (FM) treatments.

Treatments	GY (t ha^{-1})			WUE (kg ha^{-1} mm^{-1})		
	2011	2012	2013	2011	2012	2013
CK	10.9 ± 0.6 ^{b}	13.0 ± 0.5 ^{a}	11.1 ± 0.4 ^{b}	34.2 ± 2.2 ^{ab}	34.8 ± 1.5 ^{a}	26.3 ± 2.1 ^{b}
GM	11.6 ± 0.3 ^{b}	12.5 ± 1.0 ^{ab}	10.8 ± 0.5 ^{b}	33.5 ± 2.0 ^{ab}	32.6 ± 1.3 ^{ab}	24.4 ± 1.4 ^{b}
SM	10.8 ± 0.5 ^{b}	11.3 ± 0.5 ^{b}	13.3 ± 0.6 ^{a}	31.5 ± 1.0 ^{b}	30.6 ± 0.9 ^{b}	29.3 ± 2.7 ^{a}
FM	12.6 ± 0.7 ^{a}	13.5 ± 0.1 ^{a}	13.2 ± 0.6 ^{a}	36.3 ± 1.3 ^{a}	36.3 ± 1.3 ^{a}	28.5 ± 1.9 ^{a}
			Source of variation			
Treatments	***				***	
Year	***				***	
Treatments × Year	***				*	

The * and *** in the table indicate significant effects on GY and WUE at $p < 0.05$ and $p < 0.001$, respectively. Different letters indicate significant differences between treatments ($p < 0.05$).

In addition, the correlation analysis shows that there is a linear correlation between the yield of maize and the ratio of water consumption before and after the silking stage, except under the straw mulching (Figure 7). Water-use efficiency (WUE) is an important index for evaluating the efficiency of water saving. Water-use efficiency (WUE) was increased under the FM treatment. Compared with CK, the WUE under the FM treatment increased by 6.14%, 4.31%, and 8.37% in 2011, 2012, and 2013, respectively (Table 2). Compared with CK, the GM treatment reduced the WUE. The WUE under the straw mulching was the lowest in 2011 and 2012, while it was the highest in 2013, compared with the other treatments. However, the rainfall in 2011 was more distributed during the grain formation stage, while in 2013 it was more distributed during the silking stage. The water consumption was relatively high, resulting in significant differences in WUE between the different years and different treatments.

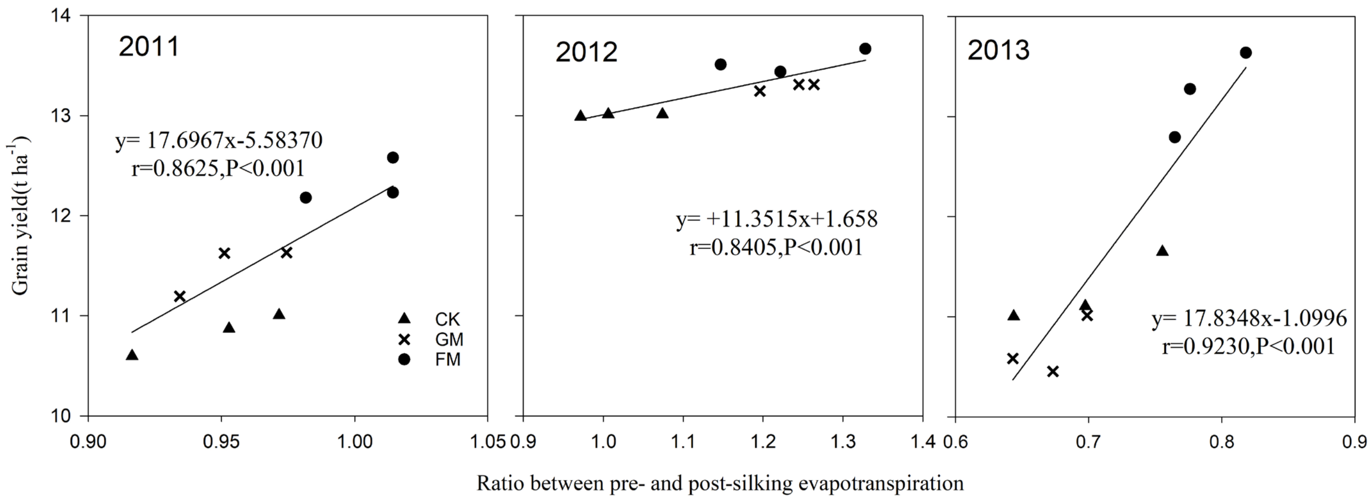

Figure 7. Correlations between grain yield and the ratio between pre−and post−silking water consumption of maize under the non−mulched (CK), gravel mulching (GM), straw mulching (SM), and plastic film mulching (FM) treatments in 2011, 2012, and 2013.

3.5. Analysis of Biomass, Grain Yield, and Yield Components

The biomass and the yield of the maize under the different mulching treatments are shown in Figure 8. Film mulching significantly increased the dry-matter production of the maize compared to CK. Gravel mulching (GM) increased the biomass during the vegetative growth period (VS), but the total biomass under GM during RS was lower compared to CK. Film mulching (FM) had the highest biomass during vegetative growth (VS) and the highest final biomass.

During the vegetative growth period (VS) of the maize, the dry-matter accumulation under the FM treatment increased by 105.8%, 73.2%, and 85.4% in 2011, 2012, and 2013, respectively, compared to the CK treatment. The GM treatment increased the biomass by 11.6%, 64.3%, and 55.6% in 2011, 2012, and 2013, respectively. The effect of the SM treatment on dry-matter accumulation during vegetative growth was not obvious except in 2013. Compared with the other treatments, in 2011, the accumulation of dry matter under SM was even reduced.

During the reproductive period (RS), the dry-matter accumulation under the SM treatment increased, and the final biomass accumulation was higher than that of the CK treatment. However, the increase did not reach a significant level during the first two years of the trial.

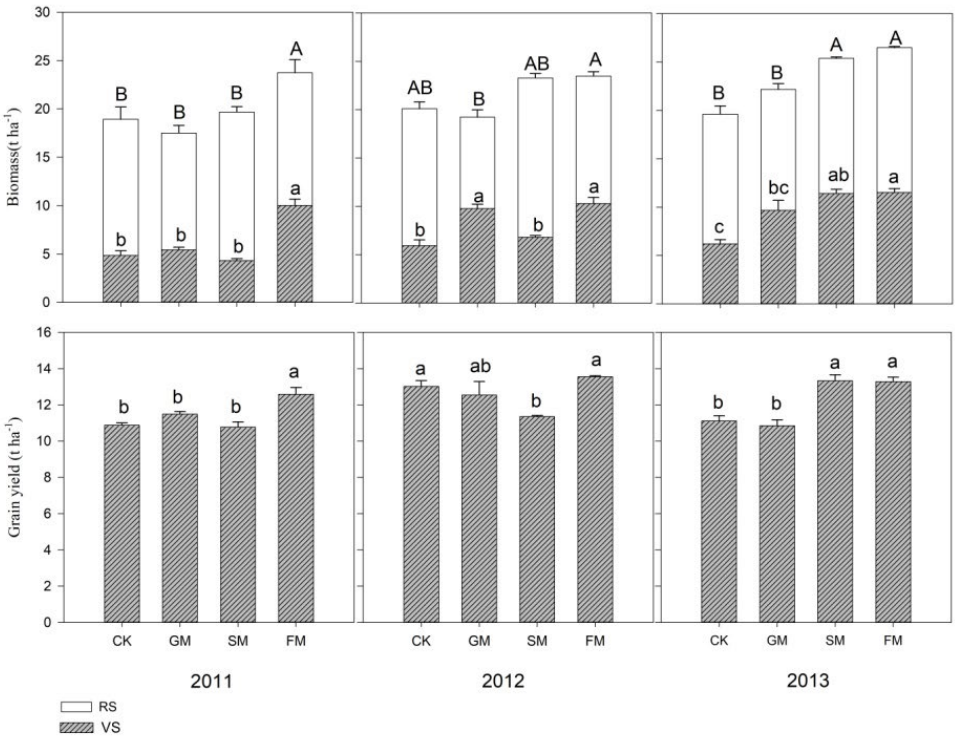

Figure 8. The aboveground biomass in the vegetative stage (VS) and reproductive stage(RS), and the grain yields under different mulching treatments, in 2011, 2012, and 2013. Note: Values with superscript letters a,b,c are significantly different of the aboveground biomass in the vegetative stage (VS) and the grain yields ($p < 0.05$). Values with letters A,B are significantly different of the aboveground biomass in the reproductive stage (RS).

Film mulching significantly increased the corn grain yield in all years except for 2012 (Figure 8). Compared with the CK treatment, the yield under the FM treatment increased by 1.7, 0.5, and 2.2 t ha^{-1} in 2011, 2012, and 2013, respectively. The effect of the GM treatment on the grain yield was not obvious in 2011, 2012, or 2013; compared with CK, the GM treatment even reduced the grain yield in the last two years, but not significantly. In the third year, the SM treatment increased the grain yield by 2.2 t ha^{-1} compared with CK, and the difference is statistically significant.

The yields under the four different treatments are shown in Table 3, with significant differences in ear number (EN) and 1000-grain weight (KW). Compared to CK, mulching did not significantly affect EN except in 2012, when the FM and GM treatments showed a significantly higher EN than the SM and CK treatments. However, the FM treatment significantly increased KN and KW. Compared with CK, the SM treatment significantly increased KN and KW in 2012 and 2013, while the GM treatment also increased KN and KW, but not significantly. In different years, the KW, EN, and KN were significantly different between the different treatments, and the interaction between treatment and year had a significant effect on KW.

Table 3. Maize ear numbers per m^2 (EN), kernel numbers (KN) per ear, and 1000-kernel weight (KW) under the different mulching treatments in 2011, 2012, and 2013.

Treatments	EN			KN			KW (g)		
	2011	2012	2013	2011	2012	2013	2011	2012	2013
CK	7.3 ± 0.7 ^{a}	7.6 ± 0.3 ^{b}	8.1 ± 0.9 ^{a}	536 ± 1.6 b	549 ± 7.7 ^{a}	546 ± 1.3 ^{c}	284 ± 1.8 ^{b}	305 ± 5.0 ^{ab}	290 ± 5.2 ^{b}
GM	7.5 ± 0.4 ^{a}	8.0 ± 0.8 ^{ab}	7.5 ± 0.1 ^{a}	550 ± 2.1 ^{ab}	543 ± 4.6 ^{a}	555 ± 3.1 ^{bc}	274 ± 42 ^{b}	297 ± 3.6 ^{ab}	289 ± 4.6 ^{b}
SM	7.2 ± 0.4 ^{a}	7.7 ± 0.4 ^{b}	7.8 ± 0.4 ^{a}	547 ± 5.6 ^{ab}	517 ± 6.0 ^{a}	584 ± 2.6 ^{ab}	247 ± 3.8 ^{c}	281 ± 1.8 ^{b}	319 ± 3.6 ^{a}
FM	7.4 ± 0.3 ^{a}	8.4 ± 0.6 ^{a}	7.8 ± 0.7 ^{a}	563 ± 4.6 ^{a}	504 ± 0.9 ^{a}	608 ± 6.6 ^{a}	305 ± 5.4 ^{a}	315 ± 3.1 ^{a}	344 ± 1.4 ^{a}
				Source of variation					
Treatments		ns			*			***	
Year		***			***			***	
Treatments × Year		ns			ns			*	

The * and *** in the table indicate significant effects on GY and WUE at $p < 0.05$ and $p < 0.001$, respectively. Values with superscript letters ^{a,b,c} are significantly different across columns($p < 0.05$); ns: not significant.

3.6. Discussion

Some studies have found that mulching can encourage crops to make full use of solar radiation energy, increase the surface and tillage soil temperature, and increase the effective cumulative temperature [18,19]. Mulching has the functions of moisture conservation, evaporation suppression, rainwater collection, and precipitation infiltration, enabling the full and efficient utilization of natural precipitation, and it is of great practical significance to promote crop yield improvement in dry cropping areas [20,21].

The gravel mulching treatment had no significant effect on the increase in soil water storage and seed yield during the reproductive period, and it even reduced the seed yield in the latter two years. This may have been related to the amount of mulch as well as the mulching method.

Although the majority of the data show that straw mulching significantly improved the soil moisture conditions and the crop yield, the increase in the crop yield under mulching conditions was slow to manifest and even showed a reduced yield on occasion, which should not be ignored. Our results are consistent with the findings of Yin et al., who showed that the average soil temperature under SMP (i.e., plastic mulching on the surface with straw mulching) treatment in the 0~10 cm soil layer during the early growth stage of maize (i.e., April–May) was 3.2 °C higher than that under SM (straw mulching) [20]. Additionally, the effects of soil temperature on the growth of crops have been shown to be more important in the earlier stages than in the middle and late stages [22]. Some studies have shown that, although no-till straw mulching can improve soil moisture conditions and increase soil carbon storage in some areas, it also leads to a decrease in soil surface temperature—especially when the temperature rises in the spring when the soil temperature under no-till straw mulching is slow to rise, which is not conducive to the increase in maize seedlings or the yield [23]. In contrast, film mulching is highly light-transmissive, isolating the soil from external moisture exchange, eliminating latent heat exchange, and weakening sensible heat exchange, making the warming effect obvious [24,25]. This may explain why the crop grew better in the early growth stages under film mulching than under straw mulching. After the tassel stage, as the temperature rose in the summer and the mulch was shredded, low temperatures were no longer a constraint on plant growth, and the straw mulch was effective in regulating the soil temperature, storing rainwater, and inhibiting evaporation. However, at this time, the plants had moved from nutritional growth to reproductive growth, so the plant growth's LAI, yield, composition, and WUE were essentially stable and were higher than the ground cover treatment. Straw mulching reduces the soil temperature and affects crop growth and development, hence the low yield under straw mulching in dry years [26,27].

The year 2012 was a drought year with a lower rainfall, but due to the high pre-sowing soil water content in 2012—which ensured the required moisture conditions for the maize before silking—the seed yield of each treatment in 2012 was higher and was not significantly different from that of the other test years. This result further indicates that pre-sowing soil water storage is critical for the following year's crop growth, and this effect is particularly pronounced in drought years. According to Fang [28], the soil water contents at the time of maize sowing played an important role in determining the final maize yield. The yield of maize under the deficit irrigation schedule was reduced by 22–32% compared to the maize following the full irrigation schedule.

In addition, these results also suggest that it is desirable to continue the gravel mulching and straw mulching treatment of maize after harvest, which is important to intercept rainfall on the soil during the recreational period as well as to reduce soil evaporation. Straw mulching should be carried out after sowing to avoid lowering the surface temperature, affecting the pre-growth of the crop, and delaying the growth period.

4. Conclusions

The effect of different mulching methods on the properties of soil (water content, temperature, and water distribution) and the growth of maize in an arid area (the Loess Plateau) is investigated. In the tested three years (2011 to 2013), SM was the most effective method for maintaining water content in the soil with a water storage that was ~40 mm higher than the control in each year, while FM showed less improvement at ~18 mm higher than the control, and GM showed no significant difference. Applying FM achieved the most significant improvement in the production of corn, with yields that were 15.7%, 4.0%, and 19.5% higher than the control in 2011, 2012 and 2013, respectively. GM showed no significant increase in the yields of corn. Although SM was the most effective method in maintaining water in the soil, the yield was not increased in 2011 but rather was followed by a decrease of 13% in 2012 and an increase of 19.8% in 2013 compared with that of the control. This interesting observation is likely due to the fact that SM achieved no improvement to the growth of the maize in its early stage (from the sowing to the vegetative stage) in 2011–2012. More in-depth insights into the causes of this phenomenon are encouraged to be provided in future studies. Furthermore, conducting a longer testing period (>3 years) is recommended to provide further understandings into the long-term effect of biomass mulching (such as SM) on the growth of maize.

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References

1. Wang, X.X.; Wang, Q.J.; Fan, J.; Fu, Q.P. Evaluation of the AquaCrop model for simulating the impact of water deficits and different irrigation regimes on the biomass and yield of winter wheat grown on China's Loess Plateau. *Agric. Water Manag.* **2013**, *129*, 95–104.
2. Deng, X.P.; Shan, L.; Zhang, H.; Turner, N.C. Improving agricultural water use efficiency in arid and semiarid areas of China. *Agric. Water Manag.* **2006**, *80*, 23–40. [CrossRef]

3. Wang, H.; Wang, C.; Zhao, X.; Wang, F. Mulching increases water-use efficiency of peach production on the rainfed semiarid Loess Plateau of China. *Agric. Water Manag.* **2015**, *154*, 20–28. [CrossRef]
4. Xie, Z.; Wang, Y.; Li, F. Effect of plastic mulching on soil water use and spring wheat yield in arid region of northwest China. *Agric. Water Manag.* **2005**, *75*, 71–83. [CrossRef]
5. Juan, H.A.; Jia, Z.K.; Han, Q.F.; Zhang, J. Application of mulching materials of rainfall harvesting system for improving soil water and corn growth in northwest of China. *J. Integr. Agric.* **2013**, *12*, 1712–1721.
6. Nachtergaele, J.; Poesen, J.; Van Wesemael, B. Gravel mulching in vineyards of southern Switzerland. *Soil Tillage Res.* **1998**, *46*, 51–59. [CrossRef]
7. Li, X.Y. Effects of gravel and sand mulches on dew deposition in the semiarid region of China. *J. Hydrol.* **2002**, *260*, 151–160. [CrossRef]
8. Zong, R.; Han, H.; Li, Q. Grain yield and water-use efficiency of summer maize in response to mulching with different plastic films in the North China Plain. *Exp. Agric.* **2021**, *57*, 33–44. [CrossRef]
9. Alothman, A.A.; Mattar, M.A.; Alsamhan, M.A. Effect of mulching and subsurface drip irrigation on soil water status under arid environment. *Span. J. Agric. Res.* **2020**, *18*, e1201. [CrossRef]
10. Li, Q.; Gan, Z.; Sun, M.; Zhao, W.; Deng, Y.; Deng, L. Effect of Mulching and Fertilizer Application in Summer Fallow Period on Yield and Soil Water Use of Winter Wheat in Dryland. *J. Triticeae Crops* **2011**, *31*, 519–523.
11. Bhardwaj, R.L. Effect of mulching on crop production under rainfed condition -A review. *Agric. Rev.* **2013**, *34*, 188. [CrossRef]
12. Lu, X.; Li, Z.; Bu, Q.; Cheng, D.; Duan, W.; Sun, Z. Effects of Rainfall Harvesting and Mulching on Corn Yield and Water Use in the Corn Belt of Northeast China. *Agron. J.* **2014**, *106*, 2175. [CrossRef]
13. Luo, S.; Wang, S.; Zhang, H.; Zhang, J.; Tian, C. Plastic film mulching reduces microbial interactions in black soil of northeastern China. *Appl. Soil Ecol.* **2022**, *169*, 104187. [CrossRef]
14. Machery, E. *Pedogenesis and Soil Taxonomy: Concepts and Interactions: Concepts and Interactions*; Oxford University Press: Oxford, UK, 2013.
15. Ritchie, S.W.; Hanway, J.J.; Benson, G.O. *How a Corn Plant Develops*; Iowa State University of Science and Technology Cooperative Extension Service: Ames, IA, USA, 1993.
16. Dong, Q.; Dang, T.; Guo, S.; Hao, M. Effects of mulching measures on soil moisture and N leaching potential in a spring maize planting system in the southern Loess Plateau. *Agric. Water Manag.* **2019**, *213*, 803–808. [CrossRef]
17. Li, R.; Hou, X.Q.; Jia Zh, K. Effects on soil temperature, moisture, and maize yield of cultivation with ridge and furrow mulching in the rainfed area of the Loess Plateau, China. *Agric. Water Manag.* **2013**, *116*, 101–109. [CrossRef]
18. Li, Q.; Li, H.; Zhang, L.; Zhang, S.; Chen, Y. Mulching improves yield and water-use efficiency of potato cropping in China: A meta-analysis. *Field Crops Res.* **2018**, *221*, 50–60. [CrossRef]
19. Bonachela, S.; López, J.C.; Hernández, J.; Granados, M.R.; Magán, J.J.; Cabrera-Corral, F.J.; Bonachela-Guhmann, P.; Baille, A. How mulching and canopy architecture interact in trapping solar radiation inside a Mediterranean greenhouse. *Agric. For. Meteorol.* **2020**, *294*, 108132. [CrossRef]
20. Yin, T.; He, W.; Yan, C.; Liu, S.; Liu, E. Effects of plastic mulching on surface of no-till straw mulching on soil water and temperature. *Trans. Chin. Soc. Agric. Eng.* **2014**, *30*, 78–87.
21. Sun, T.; Li, G.; Ning, T.Y.; Zhang, Z.M.; Mi, Q.H.; Lal, R. Suitability of mulching with biodegradable film to moderate soil temperature and moisture and to increase photosynthesis and yield in peanut. *Agric. Water Manag.* **2018**, *208*, 214–223. [CrossRef]
22. Wang, S.; Wang, H.; Zhang, Y.; Wang, R.; Zhang, Y.; Xu, Z.; Jia, G.; Wang, X.; Li, J. The influence of rotational tillage on soil water storage, water use efficiency and maize yield in semi-arid areas under varied rainfall conditions. *Agric. Water Manag.* **2018**, *203*, 376–384. [CrossRef]
23. Chen, J.; Zheng, X.; Qin, Z.; Liu, P.; Zang, H.; Sun, M. Effects of maize straw mulch on spatiotemporal variation of soil profile moisture and temperature during freeze-thaw period. *Trans. Chin. Soc. Agric. Eng.* **2013**, *29*, 102–110.
24. Li, R.; Wang, M.; Jia, Z.; Hou, X.; Yang, B.; Han, Q.; Nie, J.; Zhang, R. Effects of different mulching patterns on soil temperature, moisture water and yield of spring maize in Weibei Highland. *Trans. Chin. Soc. Agric. Eng.* **2012**, *28*, 106–113.
25. Zhou, L.; Zhao, W.; He, J.; Flerchinger, G.N.; Feng, H. Simulating soil surface temperature under plastic film mulching during seedling emergence of spring maize with the RZ–SHAW and DNDC models. *Soil Tillage Res.* **2020**, *197*, 104517. [CrossRef]
26. Qin, X.; Huang, T.; Lu, C.; Dang, P.; Zhang, M.; Guan, X.K.; Wen, P.F.; Wang, T.C.; Chen, Y.; Siddique, K.H. Benefits and limitations of straw mulching and incorporation on maize yield, water use efficiency, and nitrogen use efficiency. *Agric. Water Manag.* **2021**, *256*, 107128. [CrossRef]
27. Liu, X.; Ren, Y.; Gao, C.; Yan, Z.; Li, Q. Compensation effect of winter wheat grain yield reduction under straw mulching in wide-precision planting in the North China Plain. *Sci. Rep.* **2017**, *7*, 213. [CrossRef]
28. Fang, Q.; Wang, Y.; Uwimpaye, F.; Yan, Z.; Li, L.; Liu, X.; Shao, L. Pre-sowing soil water conditions and water conservation measures affecting the yield and water productivity of summer maize. *Agric. Water Manag.* **2021**, *245*, 106628. [CrossRef]