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Effect of Plastic Membrane and Geotextile Cloth Mulching on Soil Moisture and Spring Maize Growth in the Loess–Hilly Region of Yan'an, China

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Abstract: In order to study the effect of a plastic membrane and geotextile cloth mulching on soil moisture and crop growth in the loess–hilly region, a one-year continuous field monitoring experiment was carried out in Ansai District, City of Yan'an, Shaanxi Province, China. The experimentation included three treatments: plastic membrane and geotextile cloth mulching on the ridge (MB), geotextile cloth mulching on the ridge (DB), and bare soil ridge (CK). Soil moisture and water potential sensors were installed to monitor the changes in soil moisture content and water potential at 5, 15, and 30 cm below the furrow surface and meteorological data above the soil surface, and the growth traits, yield, and quality of maize were analyzed. The results showed the following: (1) The soil water-storage capacity of the three treatments dropped to a minimum in the filling stage and gradually recovered in the mature stage. The average water-storage capacity for the MB treatment was 35.5% higher than that for the DB treatment and 85.1% higher than that for the CK treatment, significant throughout the whole growth period. (2) For four types of rainfall events, namely, light, medium, heavy, and storm rainfall, significant responses were observed at 5 cm below the ground for three treatments, and the fastest response was in MB due to its best rain-collection effect. A significant response was also observed at 15 and 30 cm below the surface of the furrow during medium, heavy, and storm rainfall, while no significant difference in response time was found between the three treatments due to the restriction of the soil infiltration capacity. (3) The differences between the three treatments in the agronomic traits of maize, except for plant height and stem thickness, were insignificant ($p < 0.05$). The seed moisture content and yield for the MB treatment were the highest, with values of 40.33% and 8366 kg/hm^2, respectively, followed closely by the DB treatment, with values of 38.61% and 7780 kg/hm^2, respectively, and the smallest values were observed in the CK treatment, with values of 35.80% and 6897 kg/hm^2, respectively. Compared with those for the CK treatment, the average starch content and the average lipid content for the mulching treatments (MB, DB) decreased by 13.40% and 17.11%, respectively, while the average protein content of maize increased by 7.86%. Overall, a plastic membrane and geotextile cloth mulching could significantly increase soil moisture and spring maize yield due to their better rain-collection effect.

Keywords: loess–hilly region; soil moisture; plastic membrane and geotextile cloth mulching; spring maize

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1. Introduction

The Loess Plateau of China is bordered by the Gobi Desert in the north, the Naga Hills in the south, the Plateau of Tibet in the west, and the Taihang Mountains in the east [1,2]. In regard to topography, climate, vegetation, and agricultural activities, this region is a natural transitional zone. However, the rainfall is limited and unevenly distributed, the soil texture is loose, and the water erosion is serious, so less water is available [1,3]. Soil moisture is a constraining condition for crop growth in the region [4]. Previous studies have shown that about 70% of plant transpiration comes from precipitation and 18% from the deep unsaturated zone and rock layer [5]. Precipitation is the primary source of soil moisture recharge, and using precipitation resources has become an important method of promoting agricultural development in the region.

Mulching measures can effectively reduce soil evaporation, increase soil water storage, regulate soil temperature and structure, improve soil microorganisms, and increase crop yield [6]. A field experiment on ridge furrow micro-collection technology in the Weibei dry plateau of China showed that mulching treatments significantly increased soil water storage and spring maize yield [7]. In the Loess Plateau region, it was found that mulching on ridges could effectively improve soil organic carbon content and soil fertility [8]: field experiments in typical hilly semi-arid areas of China showed that mulching treatments could effectively reduce deep soil aridification and improve jujube plant yield and water use efficiency [9]; an exploration of different types of mulch in Iran revealed that soil moisture decreases with depth in the case of dark-colored mulch [10]; field experiments in India have shown that mulching treatments can retain soil moisture and increase water use efficiency and wheat seed yield [11]; and studies in semi-arid and arid regions of China showed that mulching is an indispensable treatment for retaining soil moisture and increasing soil temperature, which can improve fertilizer use efficiency and shorten crop maturity time [12]. As for the effect of ground cover treatments on nutrients within the crop, it has been shown that ground cover treatments increase the accumulation of assimilates in the nutrient organs of maize after spitting and also increase the transport of nitrogen and phosphorus to the maize kernels [1]. Mulching treatments reduce soil evaporation and stimulate the release of more nutrients via microorganisms, which can significantly increase soil aggregates [13,14]. As for the effect of different mulch materials on soil moisture, garlic was grown in an experimental field, and it was found that a transparent polyethylene (PE) film mulch without holes had better insulation than regular mulch and that the PE + polyethylene net (PEN) mulch could maintain higher soil moisture compared to regular PE mulch [15]. Further exploring the influence of mulching on crop quality, a field experiment conducted in the Czech Republic showed that mulching had a remarkable impact on grape quality, resulting in a 1% to 7% increase in sugar content [16].

In this study, three treatments with plastic membrane and geotextile cloth mulching on the ridge (MB), geotextile cloth mulching on the ridge (DB), and bare soil ridge (CK) were designed under "double ridge mulch and furrow planting" in the Loess Plateau region of China. Soil moisture and soil water potential were monitored at different layer depths in each treatment, and spring maize (maize varieties: Long Sheng I: LS01 $\times$ AX10) was planted on the furrows between the ridges to investigate the effect of a plastic membrane and geotextile cloth mulching on soil moisture and crop growth.

2. Materials and Methods

2.1. Measurement Site

The experiment was carried out at the Ansai Experimental Station (36°51′30″ N, 109°19′23″ E) of the Institute of Soil and Water Conservation, Chinese Academy of Sciences, and Ministry of Water Resources in Yan'an City, Shanxi Province, China (Figure 1). The region is a typical loess–hilly region of serious soil erosion affected by human activities. The climate is in the transition zone from warm–temperate and semi-humid to arid, and the vegetation type is in the transition zone from warm–temperate deciduous broad-leaved forest to dry grassland. The area has an altitude of 1068–1309 m, average annual precipitation of

500 mm, average annual temperature of 8.8 °C, annual accumulated temperature (≥10 °C) of 2866 °C, annual sunshine hour of 2375.5 h, sunshine percentage of 54%, frost-free period of 157 d, and drought index of 1.46 [17]. The soil texture is silty loam, with clay (<0.002 mm), silt (0.002–0.05 mm), and sand comprising 0.3%, 73.1%, and 26.6%, respectively. Soil bulk density (0–2 m) ranges from 1.21 to 1.39 g·cm^{-3}, with the average bulk density of 1.3 g·cm^{-3}.

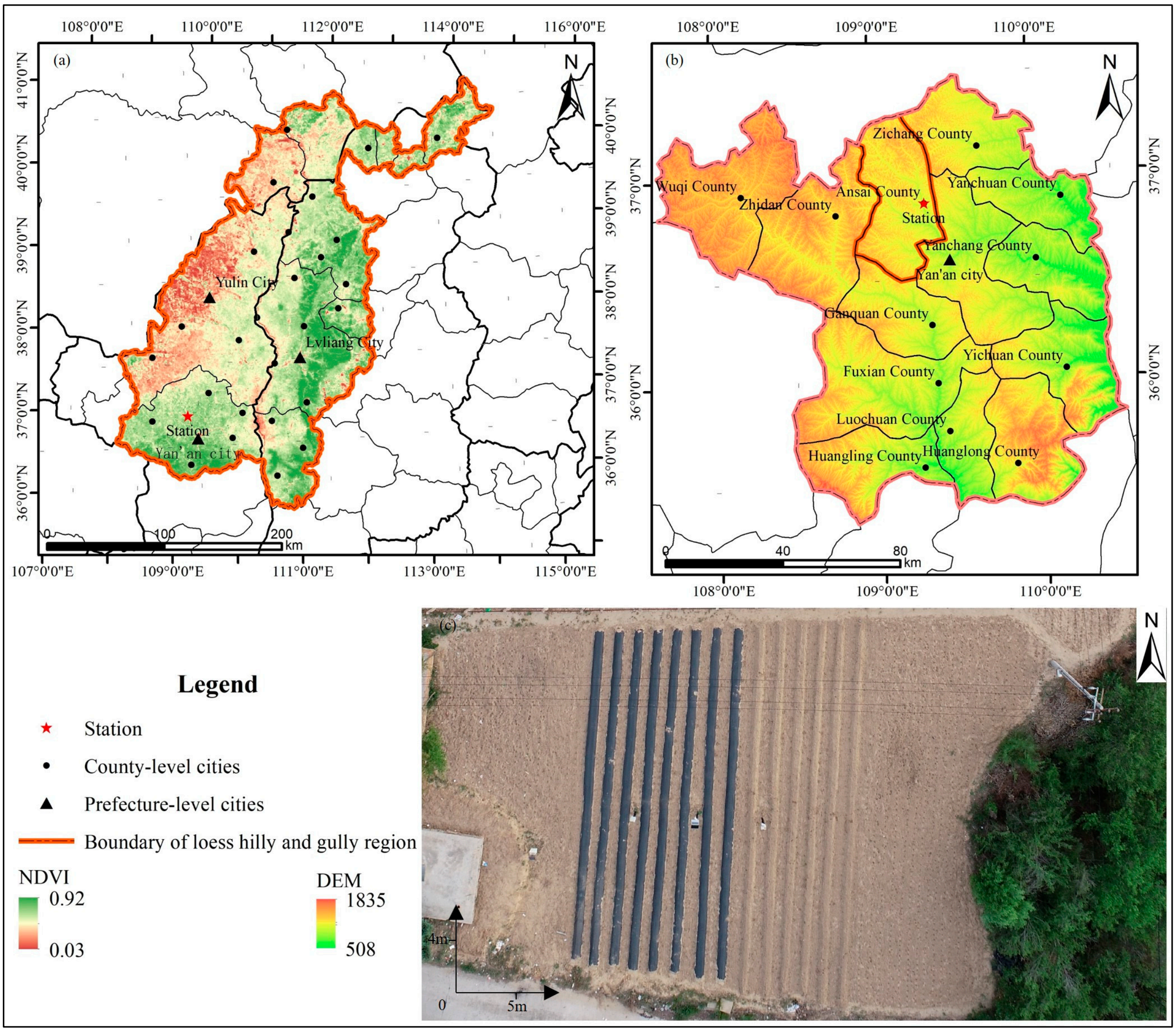

Figure 1. Geographical location of the experiment site: (**a**) Geographic location of the loess–hilly region; (**b**) Geographic location of the study area; (**c**) Aerial view of the test area.

2.2. Experimental Design

A flat field was selected at the experimental station with an area of about 360 m^2. Three sets of identical micro-ridges with a width of 50 cm, a height of 20 cm, a ridge length of 18 m, and a furrow width of 50 cm were set up. The treatments included (1) plastic membrane–geotextile cloth mulching on the ridge (MB), (2) geotextile cloth mulching on the ridge (DB), and (3) bare soil ridge (CK). Geotextile cloth has the characteristics of strong tensile strength, friction resistance, aging resistance, UV protection, and corrosion resistance. Its main component is polypropylene (PP), and its thickness is about 0.25 mm. Plastic membrane is a traditional mulch film with a thickness of about 0.008 mm, and its main component is polyethylene (PE). In this case, four replicated ridges and three corresponding furrows were laid out in MB and DB, and five replicated ridges and four corresponding furrows were laid out in CK. The test layout is shown in Figure 2. Thirty maize samples were selected in each furrow for spring maize traits and yield studies.

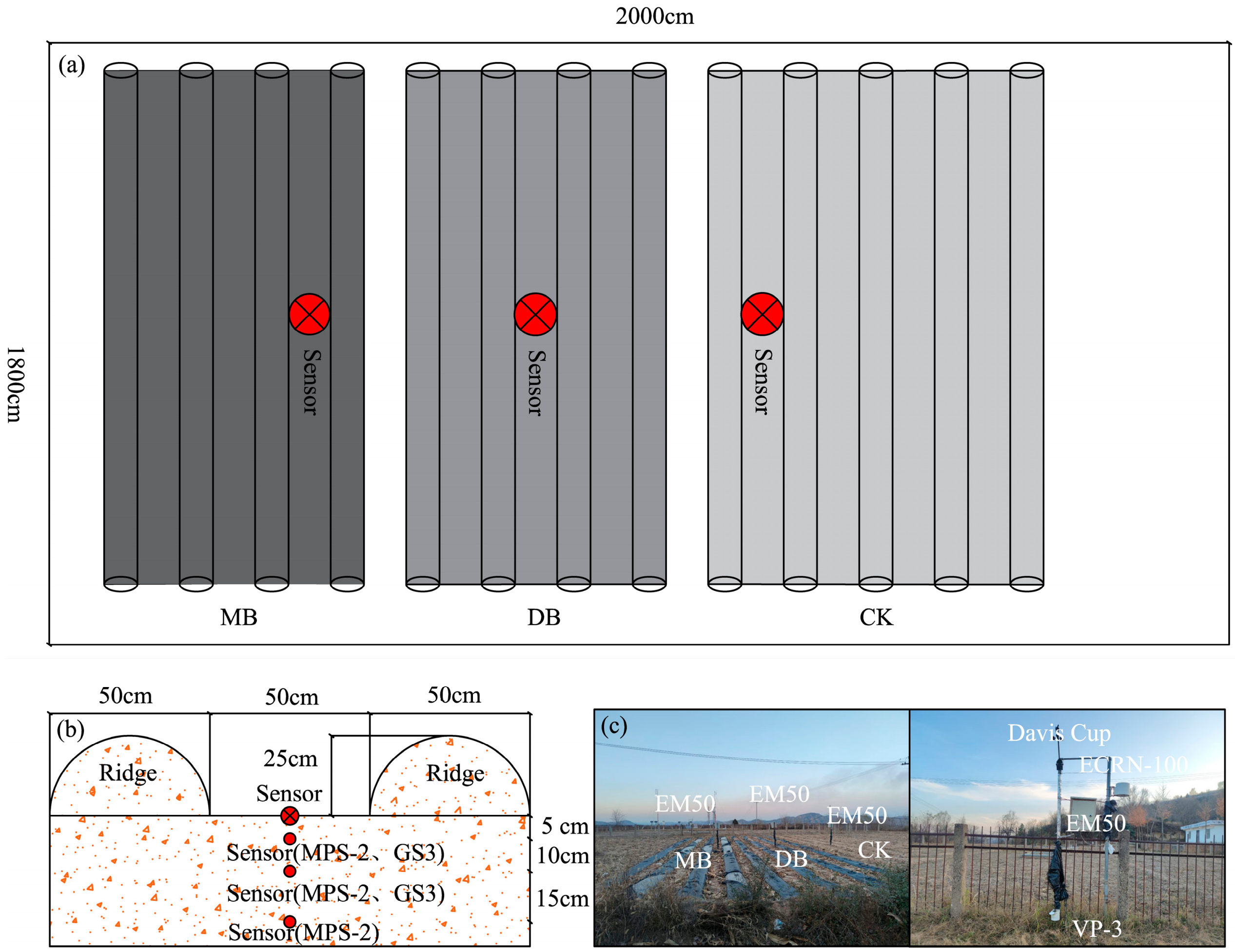

Figure 2. Field test layout: (**a**) Planar graph; (**b**) Cutaway drawing; (**c**) Photograph. MB means plastic membrane–geotextile cloth mulching on the ridge, DB means geotextile cloth mulching on the ridge, and CK means bare soil ridge. EM50 is a data logger for sensors. MPS-2 is a soil water potential and soil temperature sensor, and GS3 is a soil moisture sensor. Davis Cup is a wind speed and direction sensor. ECRN-100 is a rain gauge.

As for the three treatments of MB, DB, and CK above, soil water potential and temperature at 5, 15, and 30 cm below the furrow surface between the ridges were monitored using MPS-2 sensors with 25% water potential and 1 °C temperature resolutions, respectively. Soil moisture was measured using a GS3 sensor with 2% volumetric water content resolutions at 5 and 15 cm below the furrow surface between the ridges. The treatments were isolated from each other to minimize mutual interference. Precipitation was recorded using an ECRN-100 high-resolution rain gauge with 0.2 mm resolution, placed 160 cm above the ground. Air temperature and relative humidity were measured using a VP-3 sensor with 0.1 °C and 0.1% RH resolution, respectively, placed 20 cm above the ground. Wind speed and direction were measured using a Davis Cup Anemometer with 1 mph and 1° resolution, respectively, placed 300 cm above the ground. The above sensors were produced by Decagon Devices, Pullman, WA, USA. Evaporation data were obtained from the local weather station, where an automatic evaporation pan (by Novalynx, Grass Valley, CA, USA) with an inside diameter of 120.6 cm and a depth of 25 cm was used to measure the evaporation with 0.76 mm resolutions.

The data from the above sensors were collected automatically by EM50 data loggers (by Decagon Devices, Pullman, WA, USA) at a uniform interval of 30 min, and the observation period was from 28 April 2021 to 28 September 2021. Combining local planting experience and trial maize requirements, hybrid maize (Maize varieties: Long Sheng I: LS01 × AX10) was planted in the middle of the furrow with an average spacing of 40 cm. Maize was planted on 28 April 2021 and harvested on 28 September 2021; the specific growth period is shown in Table 1.

Table 1. Growth period of spring maize.

Growth Period	Date	Duration (Days)
Seedling stage	8 April 2021–8 May 2021	30
Elongation stage	9 May 2021–30 May 2021	21
Loudspeaker stage	31 May 2021–29 June 2021	30
Male stage	30 June 2021–11 July 2021	11
Filling stage	12 July 2021–14 August 2021	33
Mature stage	15 August 2021–28 September 2021	44

2.3. Data Processing

2.3.1. Soil Water Storage

Soil water storage can reflect the soil's water-holding capacity and further reflect soil's water content change [18], which is calculated as follows:

$$W = 10H \times \theta \tag{1}$$

where W is the soil's water-storage capacity (mm), H is the soil depth (cm), and θ is the soil volumetric water content ($cm^3 \cdot cm^{-3}$).

The change in soil water storage at any given time is

$$\Delta W = W_e - W_i \tag{2}$$

where ΔW is the change in soil water storage (mm), W_e is the water storage at the end of the period (mm), and W_i is the water storage at the beginning of the period (mm).

2.3.2. Soil Moisture Conversion

In this experiment, no soil moisture data were available 30 cm below the furrow surface between the ridges for the three treatment groups of MB, DB, and CK. Soil moisture characteristic curves (Figure 3) using the van Genuchten model were obtained according to the soil moisture and water potential 5 and 15 cm below the ground. The equation used [19] was as follows:

$$\theta = \theta_r + (\theta_s - \theta_r)[1 + (\alpha|h|)^n]^{-m} \tag{3}$$

θ is the water content ($cm^3 \cdot cm^{-3}$); θ_r is the residual water content ($cm^3 \cdot cm^{-3}$); θ_s is the saturation water content ($cm^3 \cdot cm^{-3}$); α, n, m are empirical parameters, $m = 1 - \frac{1}{n}$ ($0 < m < 1$); and h is water potential (cm) and can be calculated as follows:

$$h = 100 \times \frac{p}{\gamma} \tag{4}$$

where p is the water potential measured by sensors (kPa), and $\gamma = 9.8\ kN \cdot m^{-3}$.

The data were fitted using the least squares method for θ_r, θ_s, α, n, and m: $\theta_r = 0.0345$, $\theta_s = 0.4552$, $\alpha = 0.0108$, $n = 1.62$, and $m = 0.3827$ ($NRMSD = 0.053$).

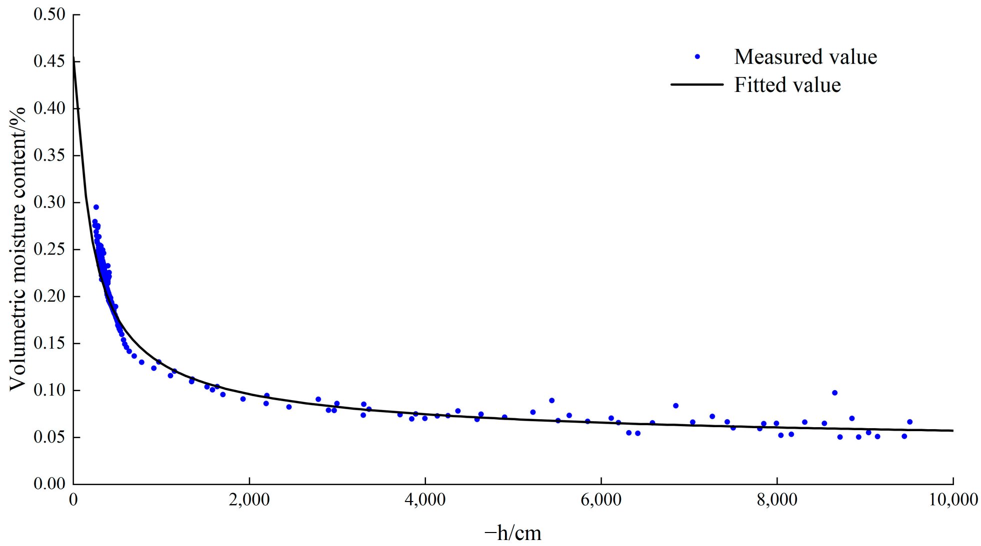

Figure 3. Soil moisture characteristic curve.

2.3.3. Determination of Maize Agronomic Traits, Yield, and Quality

1. Agronomic traits: The first complete node on the ground of maize was taken using a slide gauge, and the diameter at the middle position of the area was used as the stem thickness of the maize sample. The spikes of maize were broken off from the maize plant, the outer skin was peeled off, the spike length was measured using a slide gauge, the spike thickness was measured by taking the middle position of the spikes, and finally, the length from the maize inflorescence to the ground was measured using a tape measure as the plant height of the maize sample.
2. Yield: One hundred grains were randomly taken from the head, tail, and middle position of the corn cob; brought back to the laboratory and placed in an oven at 105 °C for 30 min; dried at 75 °C to constant weight; and weighed using an electronic balance (0.01 g). The mass of one hundred grains was transformed to obtain the yield of each treatment.
3. Quality: The dried maize samples were tested using a near-infrared rapid quality analyzer (FOSS INFRATECTM 1241 ANALYZER, by Shanghai Riphane International Trading Co. SHH, CHN) to obtain the protein, starch, and lipid content of the maize kernels in different treatments [20].

2.3.4. Data Statistics and Analysis

Data were analyzed using Microsoft Excel 2019, SPSS 25.0, and Origin 2021 software, and significance tests ($p < 0.05$) were performed using Duncan's new multiple-range test. Duncan's new multiple-range test has been described in detail by Ani et al. [21] and Duncan et al. [22].

3. Results

3.1. Analysis of Meteorological Factors

Changes in rainfall and evaporation during the growing period are shown in Figure 4. The total accumulated rainfall was 469.4 mm, with a monthly maximum of 183.2 mm (September) and a minimum of 21.4 mm (June). The seasonal distribution of rainfall was uneven, mainly concentrated in August–September, accounting for 63.7% of the total rainfall, while the rainfall in May–June was relatively small, accounting for 19.0% of the total rainfall. The accumulated evaporation during the monitoring period was 744.8 mm, with a monthly maximum of 169.2 mm (June) and a minimum of 106.3 mm (September).

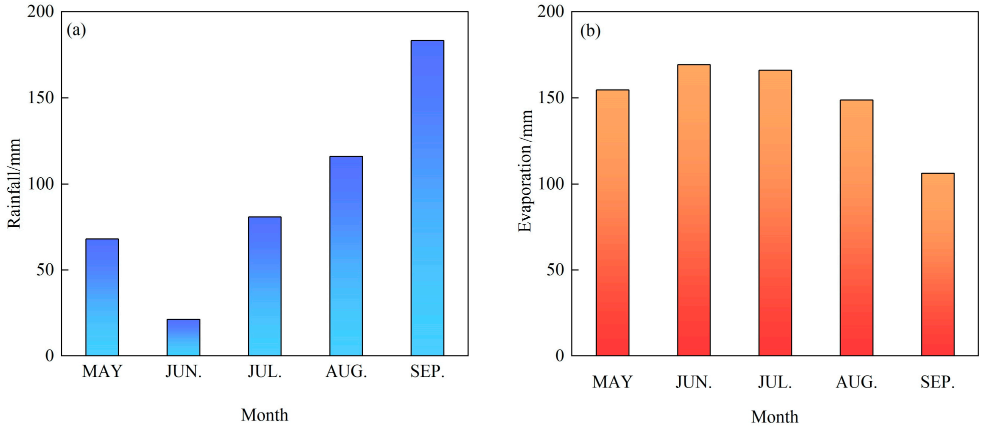

Figure 4. Monthly rainfall and evapotranspiration during the growing period: (**a**) Monthly rainfall; (**b**) Monthly evaporation.

The changes in air temperature and relative humidity near the surface during the monitoring period are shown in Figure 5. The average air temperature during the monitoring period was 19.7 °C, the highest was 27.0 °C (July 15), and the lowest was 8.8 °C (April 28). The relative humidity fluctuated greatly, and the average value during the monitoring period was 69.8%, with a maximum of 98.2% (September 26) and a minimum of 31.44% (May 7).

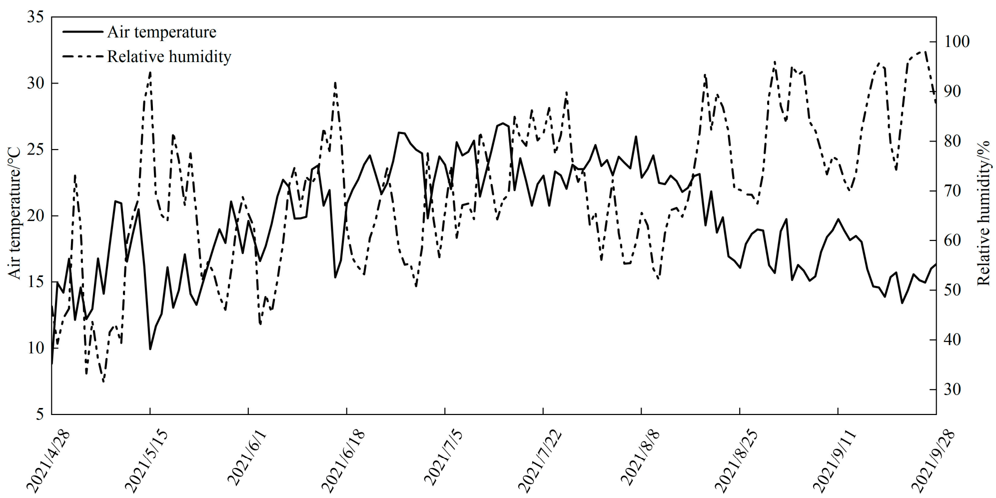

Figure 5. Variation in air temperature and relative humidity during the growing period.

The wind speed and wind direction frequency during the monitoring period are shown in Figure 6; the maximum average wind speed was 0.9 m·s^{-1} (in May), the minimum was 0.1 m·s^{-1} (in July), and the wind speed variation was characterized by "large in spring, small in summer and autumn", according to the statistics of the test station during the study period. The frequency of still wind accounted for 1.6%, easterly wind accounted for 19.2%, southerly wind accounted for 20.5%, westerly wind accounted for 35.1%, and northerly wind accounted for 23.6%, which shows that the study area is dominated by northwest and southeast winds.

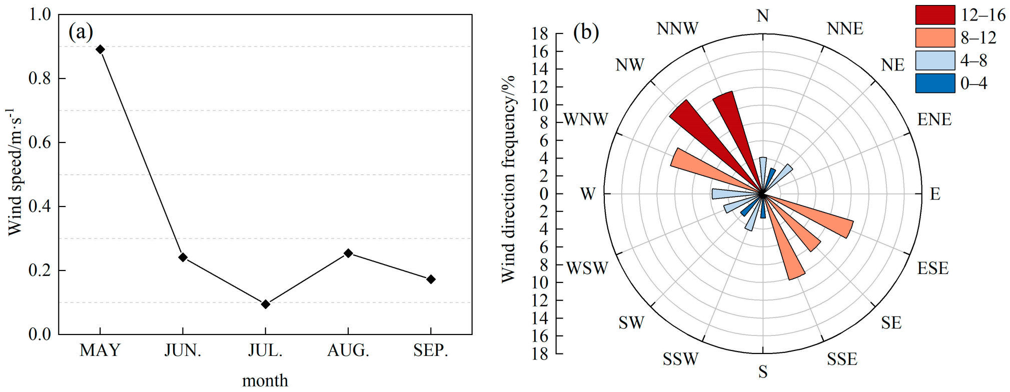

Figure 6. Wind speed (**a**) and wind direction frequency (**b**) characteristic diagram.

3.2. Dynamic Changes in Soil Moisture

Soil wetting and drying have obvious seasonality because the distribution of the rainfall season is uneven, mostly distributed in late summer and early autumn, and there is less rainfall in spring in the Loess Plateau hilly region [23]. Figure 7 shows the soil water content at 5, 15, and 30 cm below the furrow surface between the ridges in different treatments. The soil water content for the same layer among the three groups showed MB > DB > CK, MB treatment was better in preserving soil water, and CK treatment was the worst. Figure 8 reflects the dynamic changes in soil water content in each layer of different treatments. The variation in soil water content decreases with the increase in depth. Over time, the soil water content shows a decreasing–rising trend under the alternating effect of evaporation and rainfall during the monitoring period. Starting from sowing, the water consumption gradually increases, and the soil water content decreases with the growth of crops and the gradual increase in evaporation intensity. Subsequently, the soil water content began to increase when supplemented by rainfall in late summer.

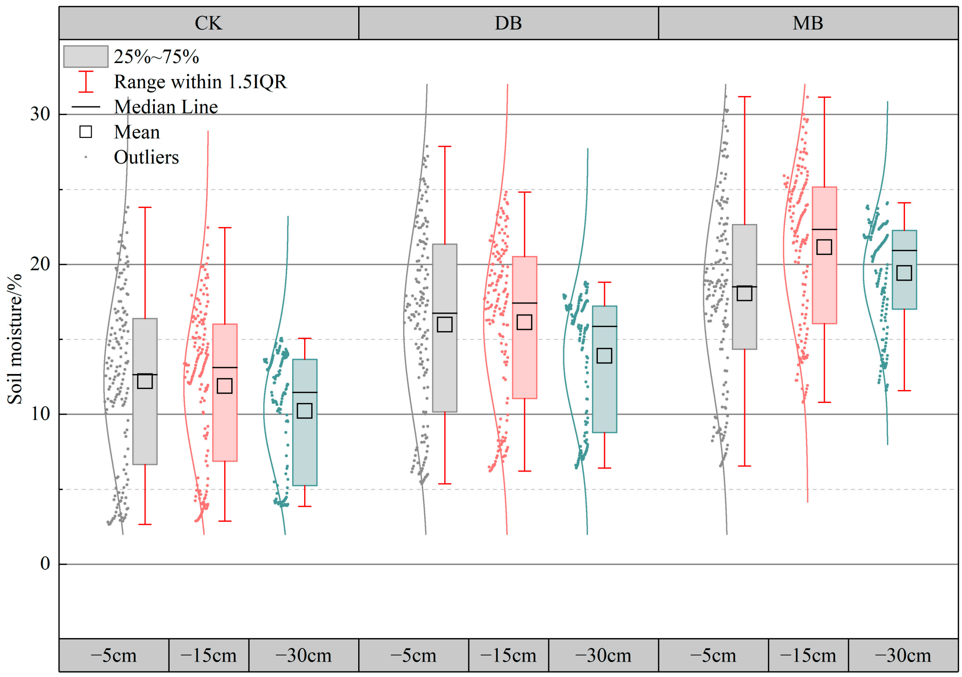

Figure 7. Differences in soil moisture content at each layer under different treatments. MB: Plastic membrane–geotextile cloth mulching on the ridge; DB: Geotextile cloth mulching on the ridge; CK: Bare soil ridge.

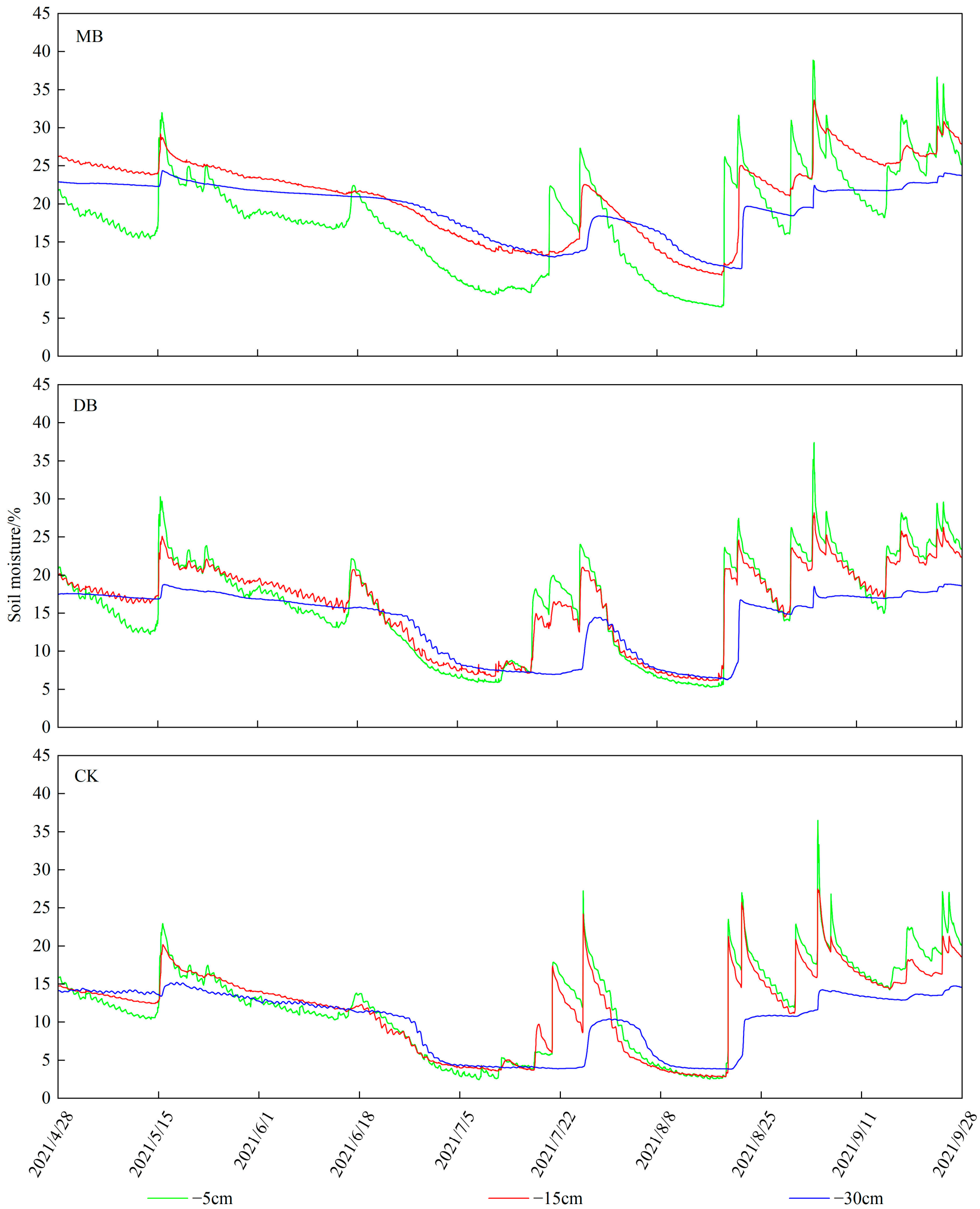

Figure 8. Dynamic soil moisture changes from 0 to 30 cm during the growth period. MB: Plastic membrane–geotextile cloth mulching on the ridge; DB: Geotextile cloth mulching on the ridge; CK: Bare soil ridge.

Figure 9 reflects the variation in soil water storage during the maize growth period. It can be seen that the soil water storage of MB treatment was significantly higher than DB and CK at each period. As the consumption of soil water by the crop increased, the soil water storage of each treatment gradually decreased, with the minimum value appearing in the filling stage, and the soil water storage gradually began to recover in the mature stage. The average water-storage capacity of MB treatment was significantly higher than DB by 35.5% and CK by 85.1% throughout the growth period. The average soil water storage of MB was 71.06 mm at the seedling stage and 55.60 mm at the mature stage, with a rate of decrease of 21.75%. That of DB was 53.70 mm at the seedling stage and 42.06 mm at the mature stage, with a rate of decrease of 21.68%. That of CK was 41.87 mm at the seedling stage and 29.80 mm at the maturity stage, with a rate of decrease of 28.83%. The rate of decrease in MB was significantly lower than DB and CK, which means MB treatment slows down soil water consumption.

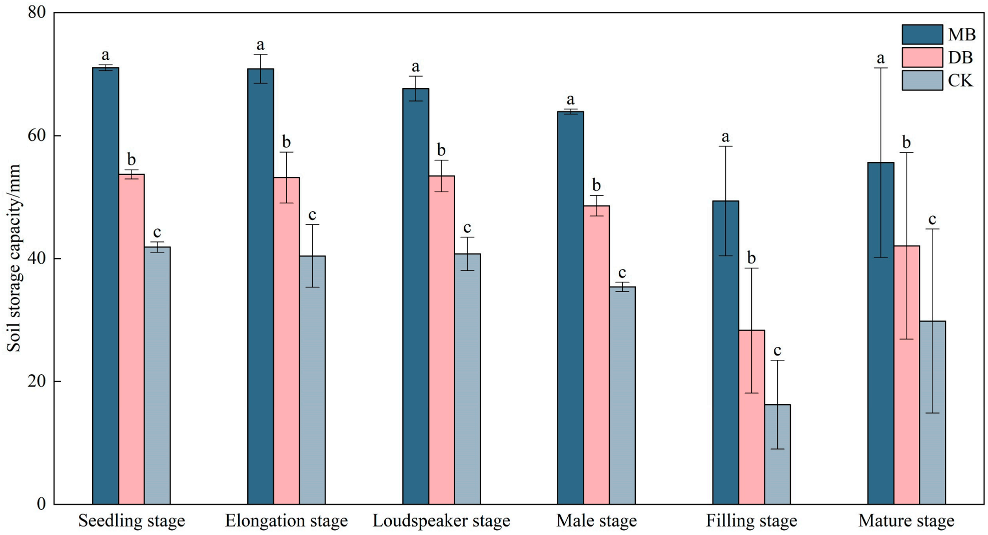

Figure 9. The average soil water storage from 0 to 30 cm in three treatments during the maize growth period. MB: Plastic membrane–geotextile cloth mulching on the ridge; DB: Geotextile cloth mulching on the ridge; CK: Bare soil ridge. Different letters mean significant differences according to LSD test at $p < 0.05$.

3.3. Response of Soil Moisture to Different Rainfalls

In order to analyze the response of soil moisture to different rainfall amounts, all rainfall events during the monitoring period were classified into four rainfall classes according to the Grade of Precipitation issued by the Standardization Administration of China (SAC), namely, light rain of 0.1–9.9 mm (recorded as LR events), medium rain of 10–24.9 mm (recorded as MR events), heavy rain of 25–49.9 mm (recorded as HR events), and storm rain of 50–99.9 mm (recorded as S events), according to the total rainfall over 24 h [24]. According to the monitoring information, there were 94 light rainfall events, 13 moderate rainfall events, 5 heavy rainfall events, and 1 storm rain event. Typical rainfall events for the four rainfall levels above were selected from the monitoring period to explore their effects on soil moisture in each layer under different cover conditions, as shown in Figure 10.

The total rainfall of light rain (LR) was 7.40 mm, lasting about 7 h. It can be seen that the light rain event had a more obvious effect on the 5 cm soil layer below the furrow surface of the three treatments, and there was an increasing trend of soil water content in this layer when the continuous rainfall lasted for 1 h. Soil water content at the 5 cm soil layer in MB, DB, and CK had a rate of increase of 10.75%, 10.05%, and 8.39%, respectively. After 12 h, it began to gradually decrease. For the 15 cm soil layer, soil water content also showed an increasing trend with a lagging effect compared with the 5 cm soil layer. Soil water content at the 15 cm soil layer in MB, DB, and CK lagged about 2, 4, and 7 h and had a rate of increase of 4.60%, 3.82%, and 1.61%, respectively. Then, it decreased almost simultaneously with the 5 cm soil layer. Additionally, soil water content in the 30 cm soil layer for the three treatments was unaffected. As for the soil water content in the 5 and 15 cm soil layers of each treatment, the 5 cm soil layer responded more strongly than the 15 cm soil layer, and the response time in MB was faster than that in DB and CK. Due to the lack of continuous rainfall, the water at the 5 cm soil layer began to replenish the 15 cm soil layer before it reached saturation.

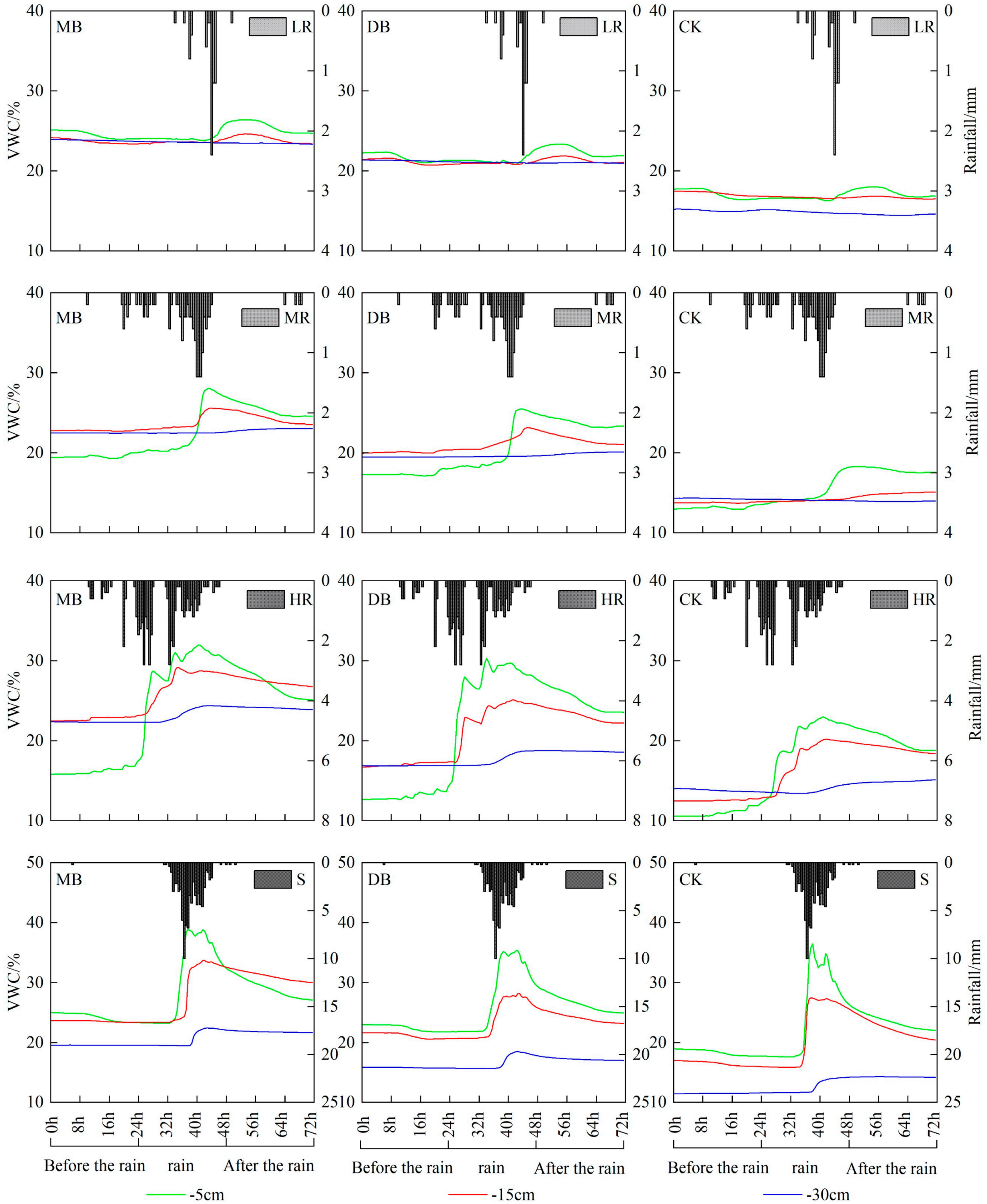

Figure 10. Effect of different types of rainfall on soil moisture. MB: Plastic membrane–geotextile cloth mulching on the ridge; DB: Geotextile cloth mulching on the ridge; CK: Bare soil ridge. VWC refers to the volumetric water content of the soil. LR, MR, HR, and S stand for light rain, medium rain, heavy rain, and storm rain, respectively.

The total rainfall of medium rain (MR) was 17.40 mm, lasting about 12 h. Soil water content in the 5 cm soil layer in MB, DB, and CK increased almost simultaneously and had a rate of increase of 34.54%, 33.00%, and 27.25%, respectively, at the beginning of rainfall. The 15 cm soil layer in MB, DB, and CK maintained a minimally increasing trend after the rainfall event was over, while there was a rapidly increasing trend after 1, 3, and 8 h of rainfall, with a rate of increase of 10.57% in MB, 8.30% in DB, and 4.40% in CK, respectively. The 30 cm soil layer was less influenced by the medium rainfall event. The medium rain event increased water content in the 0–15 cm layer significantly more compared with the light rain event.

The total rainfall of heavy rain (HR) was 43.2 mm, lasting about 20 h. The soil water content in the 5 cm soil layer in the three treatments showed an increasing trend immediately after the rainfall occurred, with a rate of increase of 94.82%, 87.75%, and 84.78%, respectively. The 15 cm soil layer in the three treatments also showed an increasing trend. MB increased almost simultaneously with the 5 cm soil layer and had a rate of increase of 29.87%. DB and CK lagged relatively with a time of 0.5–1 h and had a rate of increase of 29.31% and 25.92%, respectively. The 30 cm soil layer also showed an increasing trend, and all treatments had a lagging effect. MB had the shortest lagging time, with a rate of increase of 9.26%, and that in CK was the longest, with a rate of increase of 7.56%.

The total rainfall of storm rain (S) was 82.00 mm, lasting about 11 h. Soil water content in the 5 cm and 15 cm soil layers in MB, DB, and CK showed the same trend as that in heavy rain events and maintained saturation for a short time. The 30 cm soil layer in MB, DB, and CK showed a more rapid response than that in heavy rain events and increased simultaneously due to the limitations of the soil infiltration capacity.

3.4. Effect of Plastic Membrane–Geotextile Cloth on Traits and Quality of Spring Maize

The height of plants for each treatment is shown in Figure 11. The average plant height among the three groups was in the order of MB > DB > CK. The difference was statistically significant ($p < 0.05$). The mean plant height in MB and DB was 22.81% and 10.79%, respectively, higher than in CK in five monitoring sessions.

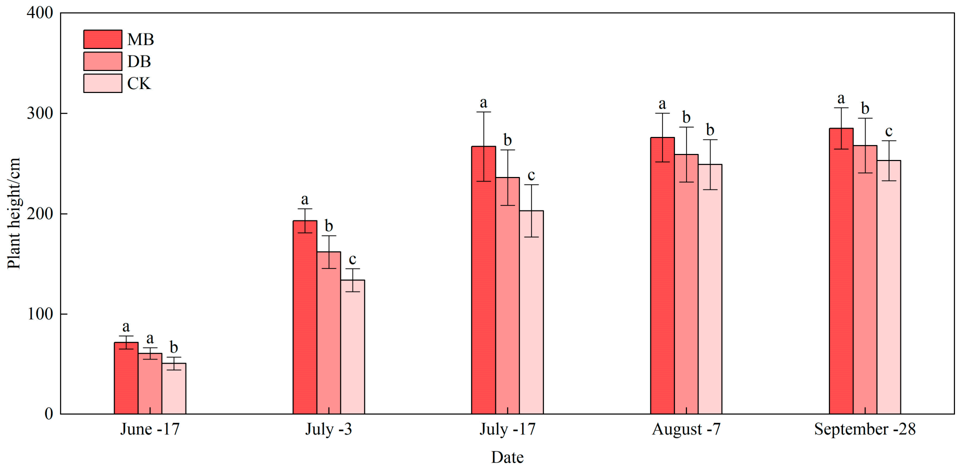

Figure 11. Spring maize height in each treatment. MB: Plastic membrane–geotextile cloth mulching on the ridge; DB: Geotextile cloth mulching on the ridge; CK: Bare soil ridge. Different letters mean significant differences according to LSD test at $p < 0.05$.

One-way ANOVA was conducted to determine stem thickness, spike thickness, spike length, and the number of grains per plant, and the results are shown in Table 2. The average plant stem thickness among the three groups was in the order of MB > DB > CK. Thickness in MB and DB was 12.2% and 11.2%, respectively, larger than that in CK, and there was a significant difference in stem thickness among the three groups ($p < 0.05$). The values for the spike thickness and the number of grains per plant in different treatments also showed the same as the stem thickness, while that for the spike length showed DB > MB > CK. There was no significant difference in spike thickness, spike length, or the number of grains per plant among the three groups ($p > 0.05$).

Table 2. Agronomic traits of spring maize under different treatments.

Characters	Measure	Statistic		Homogeneity Test for Variance	ANOVA	
		Mean	SD	*p*	F	*p*
Stem Thick	MB	2.39	0.30	0.368	6.62	0.002
	DB	2.37	0.30			
	CK	2.13	0.34			
Spike thickness	MB	5.37	0.41	0.179	0.203	0.817
	DB	5.32	0.34			
	CK	5.31	0.37			
Spike length	MB	19.85	3.92	0.728	2.114	0.127
	DB	20.34	3.52			
	CK	18.43	3.80			
Number of grains per plant	MB	561	132.5	0.229	2.150	0.123
	DB	525	137.0			
	CK	482	170.6			

Note—MB: Plastic membrane–geotextile cloth mulching on the ridge; DB: Geotextile cloth mulching on the ridge; CK: Bare soil ridge.

The results of maize seed moisture content and yield are shown in Table 3, where the seed moisture content showed MB > DB > CK, with MB 4.45% higher than DB and DB 7.85% higher than CK. The maize yield showed the same as the seed moisture content, with MB 7.53% higher than DB and DB 12.80% higher than CK. Therefore, MB is most effective and has the effect of preserving moisture and increasing yields.

Table 3. Water content and yield of spring maize under different treatments.

Measure	Moisture Content (%)	Yield per Plant (kg/Plant)	Cell Output (kg/m^2)	Equivalent to Production (kg/hm^2)
MB	40.33 ± 0.28a	0.21 ± 0.06a	0.84 ± 0.24a	8366 ± 2419a
DB	38.61 ± 0.32b	0.18 ± 0.05b	0.78 ± 0.23b	7780 ± 2337b
CK	35.80 ± 0.34c	0.17 ± 0.05c	0.69 ± 0.20c	6897 ± 2031c

Note—MB: Plastic membrane–geotextile cloth mulching on the ridge; DB: Geotextile cloth mulching on the ridge; CK: Bare soil ridge. Different letters mean significant differences according to LSD test at $p < 0.05$.

The quality of spring maize under different groups is shown in Table 4. The starch content showed CK > MB > DB, with the former being 11.62% and 19.60% higher than the latter two, respectively, and MB being 7.15% higher than DB. The decrease in starch content of MB and DB treatments is probably due to better water harvesting, which increased their soluble sugar content. The protein content showed DB > CK > MB, with the former being 25.77% and 39.83% higher than the latter two, respectively, and CK being 11.17% higher than MB. The lipid content showed CK > MB > DB, with the former being 5.56% and 40.74% higher than the latter two, respectively, and MB being 33.33% higher than DB. Overall, compared with CK, the average starch content and the average lipid content of mulching treatment obtained from the averaged value between the MB and DB decreased by 13.40% and 17.11%, respectively, while the average protein content of maize increased by 7.86%.

Table 4. Quality of spring maize under different treatments.

Measure	Starch Content (%)	Protein Content (%)	Lipid Content (%)
MB	74.90 ± 0.24b	6.98 ± 0.30c	3.60 ± 0.27b
DB	69.90 ± 0.29c	9.76 ± 0.28a	2.70 ± 0.29c
CK	83.60 ± 0.31a	7.76 ± 0.30b	3.80 ± 0.27a

Note—MB: Plastic membrane–geotextile cloth mulching on the ridge; DB: Geotextile cloth mulching on the ridge; CK: Bare soil ridge. Different letters mean significant differences according to LSD test at $p < 0.05$.

4. Discussion

The variation in soil moisture during the growth period was mainly affected by rainfall and evaporation. As for the soil moisture content at the 5 and 15 cm soil layer, the fluctuation in CK was larger, and that in MB and DB was close, because the shallow soil in CK is more affected by evaporation and rainfall. At the same time, the fluctuation at the 30 cm soil layer in CK was lower than that in MB and DB due to its weak ability to collect rainwater and inhibit evaporation. For the entire growth period, the average soil water content of the 0–30 cm soil layer in MB was 27.4% higher than that in DB and 70.8% higher than that in CK, indicating that MB treatment has a better water-retention effect, which is in agreement with the findings of Zhang et al. [25] and Zhao et al. [26]. Different organic mulching materials (newspaper, bran, and grass) used in cold regions of China by Zhang et al. [25] showed that soil water content in newspaper mulching increased by 14.1% compared with bare land. Ridge furrows with plastic film mulching (RP) and flat soil surfaces with plastic film mulching (FP) conducted in the Loess Plateau of China by Zhao et al. [26] showed that deep soil moisture was better transferred to topsoil, making the topsoil moisture higher in the FP and RP treatments than the bare land.

The soil water-storage capacity of each treatment reached the maximum in the seeding stage. With the growth of spring maize and the strengthening of evapotranspiration, the soil water-storage capacity was gradually reduced, and the minimum value for the three treatments appeared in the filling stage. The soil water-storage capacity was gradually recovered with the strengthening of rainfall and the weakening of evapotranspiration. The average water-storage capacity of MB treatment was 35.5% higher than DB and 85.1% higher than CK significantly throughout the whole growth period. It can be seen that the MB treatment maintained good water storage and moisture retention throughout the growing period. A full amount of plastic film with flat mulching throughout the whole season (FLW) was used in semi-arid areas of northwest China by Wu et al. [27], who showed that FLW was more beneficial for reducing soil water losses and soil water storage at harvest under FLW, which were 9.13 mm higher than the flat planting without mulching. Straw mulching (SM), gravel mulching (GM), and plastic film mulching (FM) were applied at the Changwu Agro-Ecological Station on the Loess Plateau in China by Wang et al., who showed that SM and FM increased the soil water storage in the early stages of maize growth (from sowing to vegetative growth) compared with using GM [28]. A location-fixed field experiment using two soil mulching treatments (plastic mulch and planting legume) by He et al. [29] showed that plastic mulching resulted in a 13% increase in soil water storage compared to planting legumes. In addition, the variation in soil water storage during seedling, elongation, and loudspeaker stages was small, while the soil moisture content decreased significantly in the filling stage. Additionally, the soil water content gradually recovered during the mature stage as the rainfall increased and the consumption of soil water by spring maize decreased. This is in agreement with the findings in the Loess Plateau of northwestern China by Ding et al. [30]. There was a strong relationship between the variation in soil moisture and the distribution characteristics of rainfall and evaporation.

Regarding the impact of rainfall on soil moisture, the soil moisture content at the 5 cm soil layer had an obvious response to the four types of rainfall event, while that at the 15 and 30 cm soil layer had a lessened response to light and medium rainfall events than to heavy and storm rainfall events. As for the heavy and storm rainfall events, the rate of increase in soil moisture content at the 30 cm soil layer showed MB > DB > CK, indicating that MB and DB have a better rainwater-collection effect; more rainwater falling on the ridge is gathered in the ditch, and the accumulation of rainfall is larger. The results further verified that the rain-harvesting effect of the mulching film is significant, which was also reflected in previous studies. For example, four treatments with no mulching on ridges and furrows (NMCK), ridge–furrow planting without plastic film mulching after flat planting (RFAF), half mulching only on ridges (RFHM), and soil covering after plastic film mulching only on the ridges but not on furrows (RFSM) conducted by Liang et al. [31] showed that RFHM had the best rainwater-harvesting effect, increasing the surface soil moisture and causing seedling emergence 14–32 days earlier than NMCK. Film fully mulched ridge–furrow (FMRF) water harvesting and film mulched with conventional flat planting in one-half (FMCF) and two-thirds (FTMCF) applied by Fan et al. [32] showed that FMRF had a rain-harvesting efficiency of 65.7–82.7%, which caused rain to infiltrate deep soil and soil moisture to increase by double in the furrow root zone.

Regarding the traits of spring maize, the average plant height of MB and DB treatment was higher than CK, especially in the trumpet stage and male spike stage. The stem thickness among the three groups showed MB > DB > CK, with a significant difference ($p < 0.05$). No significant differences were found in spike thickness, spike length, and the number of grains per plant. The yield and the moisture content of maize showed MB > DB > CK. It may be that MB treatment has the effect of increasing temperature and preserving moisture, coupled with the better rainfall-collection effect of the plastic membrane–geotextile cloth mulching, which can provide sufficient moisture during the critical growth period and increase its yield [30,33]. In addition, the mulching treatment can inhibit the growth of weeds, so that soil nutrients can be better absorbed by crops, thus increasing yields [34–36]. In terms of quality, the mulching treatment reduced the starch and lipid content and increased the protein content of spring maize. The reason for this may be that the mulching treatment enhanced the absorption and conversion of soil nutrients [37–39], especially for the nitrogen reuse capacity, and nitrogen is a major component of protein, thus increasing the protein content of maize kernels [40]. Meanwhile, mulching treatment increased the water content of mature maize, resulting in an increase in soluble carbohydrate content and a decrease in starch content [41].

The geotextile cloth applied in the experiment was mainly composed of polypropylene (PP), while the traditional covering film was mainly composed of polyethylene (PE) and more susceptible to weathering than geotextile cloth. The weathering debris materials (microplastics) produced by pure PE materials will reduce the crop yield and have a relatively large impact on the soil structure and soil environment [42–44]. The strong tensile strength, friction-resistant, aging-resistant, UV-protection, and corrosion-resistant characteristics of the geotextile cloth made it possible to be reused for 5 years, which is recyclable and ecologically sound. According to a market investigation, the annual cost of laying film per mu of farmland is about 640 RMB, the service life of geotextile cloth is 5 years, and the average annual cost of geotextile cloth is 4.5 times that of traditional film. Plastic membrane–geotextile cloth can be carried out in the field and used for years. It can save a lot of manpower, reduce costs, and has good ecological and economic benefits. Plastic membrane–geotextile cloth mulching on the ridge (MB) is a good method that can be used in rain-fed agricultural production.

Although plastic membrane–geotextile cloth mulching on a ridge (MB) is a good method in rain-fed agricultural production, the soil environmental pollution caused by plastic film residue in the mulching treatment has not been researched. The monitoring period should be lengthened to 3–5 years in subsequent research, and soil environmental pollution monitoring could be carried out year by year throughout the service life of the plastic membrane–geotextile cloth to explore the suitable service life of the mulching treatment and soil environmental pollution caused by the various years. In addition, more indicators can be monitored and systematically analyzed in accordance with the corresponding standards for the actual use of the crop, so as to give reasonable suggestions that are more in line with the industry's production practice, which is also more conducive to the promotion of plastic film mulching.

5. Conclusions

A one-year in situ monitoring experiment was carried out to analyze the dynamics of soil moisture and its effect on maize at different depths in plastic membrane–geotextile cloth mulching on a ridge (MB), geotextile cloth mulching on a ridge (DB), and bare soil ridge (CK). The results were as follows:

1. The soil water storage in the MB, DB, and CK treatments decreased to a minimum in the filling stage and gradually recovered in the mature stage, and the soil water storage was maximum in MB, followed by DB, and the worst in CK, indicating that MB treatment had a good rainwater-harvesting effect.
2. Significant responses of soil moisture to light, medium, heavy, and storm events were observed at 5 cm below the surface of the furrow in all three treatments. However, MB demonstrated the fastest response time and the greatest increase in soil moisture. The soil moisture at 15 and 30 cm below the surface had a significant response to medium, heavy, and storm rainfall, and no significant difference was found in the response time among the three treatments due to the restriction of the soil-infiltration capacity. This further illustrated that the MB treatment responded better to micro-rainfall due to its strong ability to collect rain.
3. Seed moisture content and yield showed MB > DB > CK, and MB treatment had a better moisture-retention and yield-increasing effect. Mulching treatment reduced starch and lipid content and increased the protein content of maize.

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