

Article

Effects of Different Mulch Types on Farmland Soil Moisture in an Artificial Oasis Area

Linlin Ye ^{1,2,†} , Yuanxiao Xu ^{1,2,†}, Guofeng Zhu ^{1,2,*}, Wenhao Zhang ^{1,2} and Yinying Jiao ^{1,2}

¹ College of Geography and Environment Science, Northwest Normal University, Lanzhou 730070, China; 2021222917@nwnu.edu.cn (L.Y.); 2020212668@nwnu.edu.cn (Y.X.); 2021222902@nwnu.edu.cn (W.Z.); 201875110110@nwnu.edu.cn (Y.J.)

² Shiyang River Ecological Environment Observation Station, Northwest Normal University, Lanzhou 730070, China

* Correspondence: zhugf@nwnu.edu.cn

† These authors contributed equally to this work and should be considered co-first authors.

Abstract: Different types of mulch are often used in agricultural production to enhance soil moisture and improve crop yields. The question of which mulch provides superior water retention in arid regions, where water resources are scarce, is a major concern for agricultural production. We conducted observations and studies at a typical irrigated experimental station in an arid zone with four types of mulch, including liquid mulch (LM), biodegradable mulch (BM), ordinary black mulch (OBM), and ordinary white mulch (OWM), and plots with no mulch. Samples were collected and analyzed at 1, 3, 5, and 7 days after each rainfall or irrigation to obtain soil moisture changes and to analyze the effect of different mulches on soil moisture retention. The results showed that mulch cover was effective in retaining soil moisture compared to plots without mulch cover. Specifically, soil moisture was highest in the farmland with OWM during the observation period. OWM, OBM, and BM were all effective in reducing soil water evaporation and maintaining soil moisture. LM and BM were capable of utilizing rainfall to recharge soil water in a superior way, and polyethylene mulches (OBM and OWM) had a significant barrier impact on rainfall.

Keywords: arid area; maize field; mulch; irrigation; soil moisture



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1. Introduction

Food production is the basis for human survival and development, and global arable land accounts for about 10.9% of the land area [1]. Currently, the productivity of arable land is reduced due to climate change, inadequate water resources, declining fertility, increasing pollution of soils, and irrational cropping patterns [2,3]. Agricultural sustainability is confronted with great challenges [4]. Soil water is a considerable interface for water and energy exchange between the land surface and the atmosphere [5], playing a crucial role in plant growth [6]. Soil water acts as a substantial factor in hydrological and vegetation recovery processes in arid and semi-arid regions, controlling infiltration, evaporation, and spatiotemporal distribution patterns of vegetation [7]. Soil water is extremely vital for determining plant phenology and net primary productivity (NPP), especially in arid areas where surface water and groundwater are extraordinarily scarce [8]. In agroecosystems, rainfall and irrigation water cannot be absorbed by plants directly unless they are converted into soil water. Therefore, observing the dynamic changes of soil moisture is of particular importance, as it serves as a direct manifestation of soil moisture.

Arid areas account for approximately 40 percent of the global land surface area and more than half of the world's potential crop production area [9,10]. Water scarcity is a key constraint on effective arable land use and agricultural production in this region. With lower rainfall and higher evaporation, the water demand gap in agriculture increases [11]. Therefore, addressing how to maximize soil moisture retention is a matter of concern

for agricultural production in arid areas [12]. Many field techniques and management strategies have been developed to alleviate issues, such as water deficit and unstable crop productivity, in arid areas [13,14]. Mulches are widely used worldwide and have been shown to be effective in retaining soil moisture [15,16]. Two aspects of mulches contribute to maintaining soil moisture. One aspect involves the ability to control the surface evaporation rate using mulch covering, which favorably affects the soil moisture system by reducing water exchange between the atmospheric and soil interfaces [17]. Another aspect is their capability to stabilize soil properties by reducing surface exposure and soil disturbance. Mulches absorb solar radiation and reduce soil heat loss, thereby increasing soil moisture [18].

At the same time, mulches also bring other benefits, such as improving soil structure and enhancing weed growth [19]. Many studies have shown that mulches can significantly increase the yield of various crops [20–23]. Although the application of mulches in agriculture has achieved good economic benefits, there are concerns about the resulting environmental pollution that cannot be ignored [24,25]. Mulches in soils have become a great nuisance for farming [26]. Therefore, several types of mulches have been formulated and promoted to address the environmental issues associated with mulches [27]. Different types of mulches have been developed to play different agronomic roles [28,29].

In this study, four types of mulches were used in the experimental field of Jingtai Irrigation District, i.e., liquid mulch (LM), biodegradable mulch (BM), ordinary black mulch (OBM) and ordinary white mulch (OWM). Liquid mulch (LM) and biodegradable mulch (BM) represent innovative mulching materials. The former is composed of a blend of materials with biodegradable properties, enhancing topsoil fixation and heat and moisture retention. The latter primarily consists of biodegradable polymer materials that completely degrade within 60 to 180 days, leaving no soil pollution and producing products beneficial to crop growth.

The main component of ordinary mulch film is polyethylene. The use of polyethylene ground cover in Chinese agricultural cultivation dates back to the early 1980s [30,31]. It possesses waterproof, heat preservation, moisture retention, anti-aging, and UV resistance characteristics. However, its resistance to degradation raises environmental concerns, as it may lead to pollution after use. Therefore, it is imperative to address environmental protection issues.

The study is not only limited to global man-made oasis areas, including arid and desert regions, but also has broad relevance under different climatic conditions. Managing soil moisture on farmlands in different geographical areas is critical for crop growth and agricultural production. This study aims to promote the scientific management of soil moisture and effective mulch type selection to directly guide agricultural practices and provide scientific support for agricultural policies, thereby enhancing agricultural productivity and sustainability in artificial oasis regions. In the context of addressing the challenges of global climate change and resource scarcity and through an in-depth study of the effects of different mulch types on soil moisture, this research provides viable technical and management options for global agriculture and promotes sustainable agricultural development.

2. Data and Methods

2.1. Measurement Site

The experiment was conducted in July and August of 2021 at Northwest Normal University's Shiyang River Comprehensive Observation Station in the Jingdian Irrigation Area Test Field (37°23' N, 104°08' E), Jingtai County, Gansu Province, China (Figure 1). The station is located at an altitude of 2028 m and has a temperate arid continental climate with an average annual temperature of 8.4 °C, an average annual rainfall of 187.4 mm, an annual pan evaporation of 3500.6 mm, and an annual frost-free period of 184 days. The soil in this area is a sandy loam with a pH of 8.65, an organic matter content of 13.23 g/kg, a dry density of 1.61 g/cm³, and a maximum water holding capacity of 24.1% in the field.

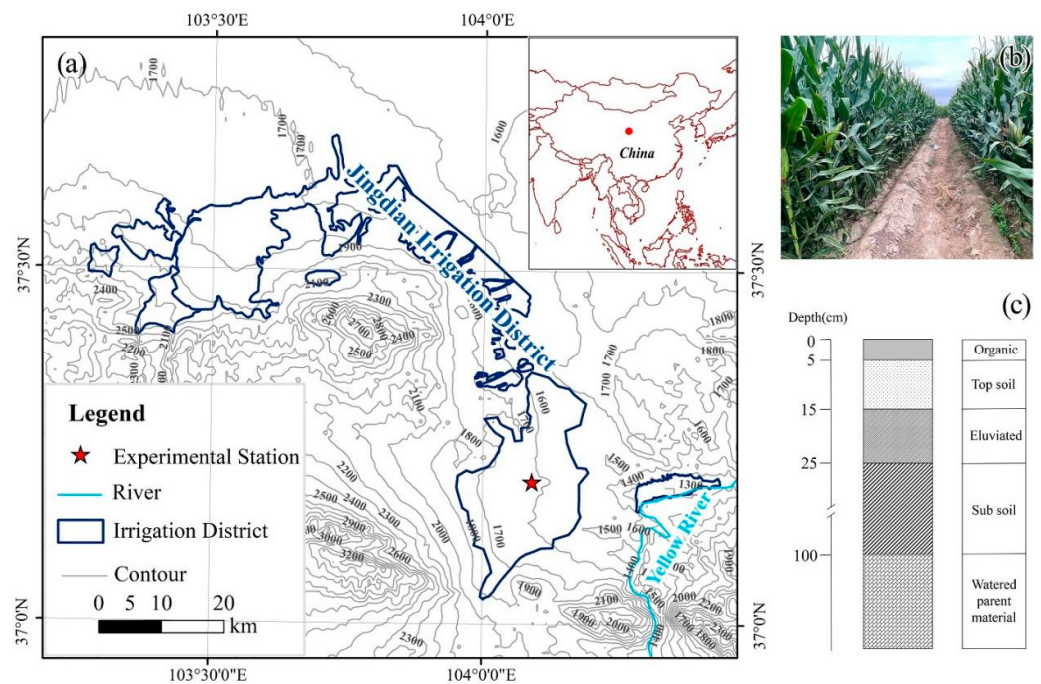


Figure 1. (a) Study area and site; (b) A photograph of the experimental field; (c) Representative soil profile.

The temperature, relative humidity, and rainfall values observed at the station during the experimental period are shown in Figure 2. The total rainfall from July to August was 24.5 mm, and the maximum cumulative daily rainfall was 9.4 mm, which occurred on August 18. Meteorological data were obtained from the China Meteorological Data Network (<http://data.cma.cn/> (accessed on 8 May 2022)).

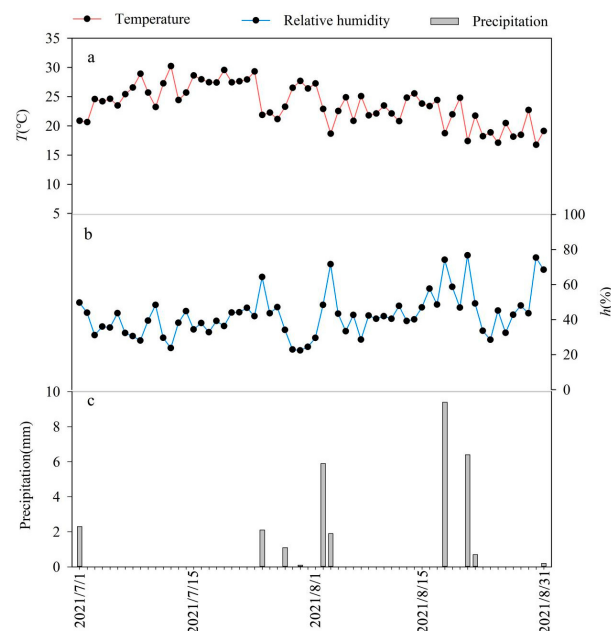


Figure 2. Meteorological conditions during the observation period. (a): Average daily temperature; (b): Average daily humidity; (c): Cumulative daily rainfall.

We are aware of the possible changes in soil evapotranspiration that may occur as a result of variations in sunlight and wind, either decreasing or increasing. During the study period, considering the diversity of weather conditions, we chose the same time points

and sampled from soils with different cover types for a comparative moisture study. It is reasonable to believe that evapotranspiration must be higher in soils without mulch than in soils with mulch under the same meteorological conditions. This is the central question of our study. The aim of our study was to gain insights into the effects of different types of mulch on soil moisture under actual farm conditions. In the comparison samples obtained during the same period, we ignored the effect of climatic conditions because we focused on comparing soils with different mulch cover types and did not make a longitudinal comparison between the first and second irrigation events.

2.2. Continuous Measurements

The selected crop type for the experiment was maize, a cash crop with a significant presence in arid areas and a relatively large planted area. The experiment included five treatments: no mulch (NM), liquid mulch (LM), biodegradable mulch (BM), ordinary black mulch (OBM), and ordinary white mulch (OWM) (Figure 3).

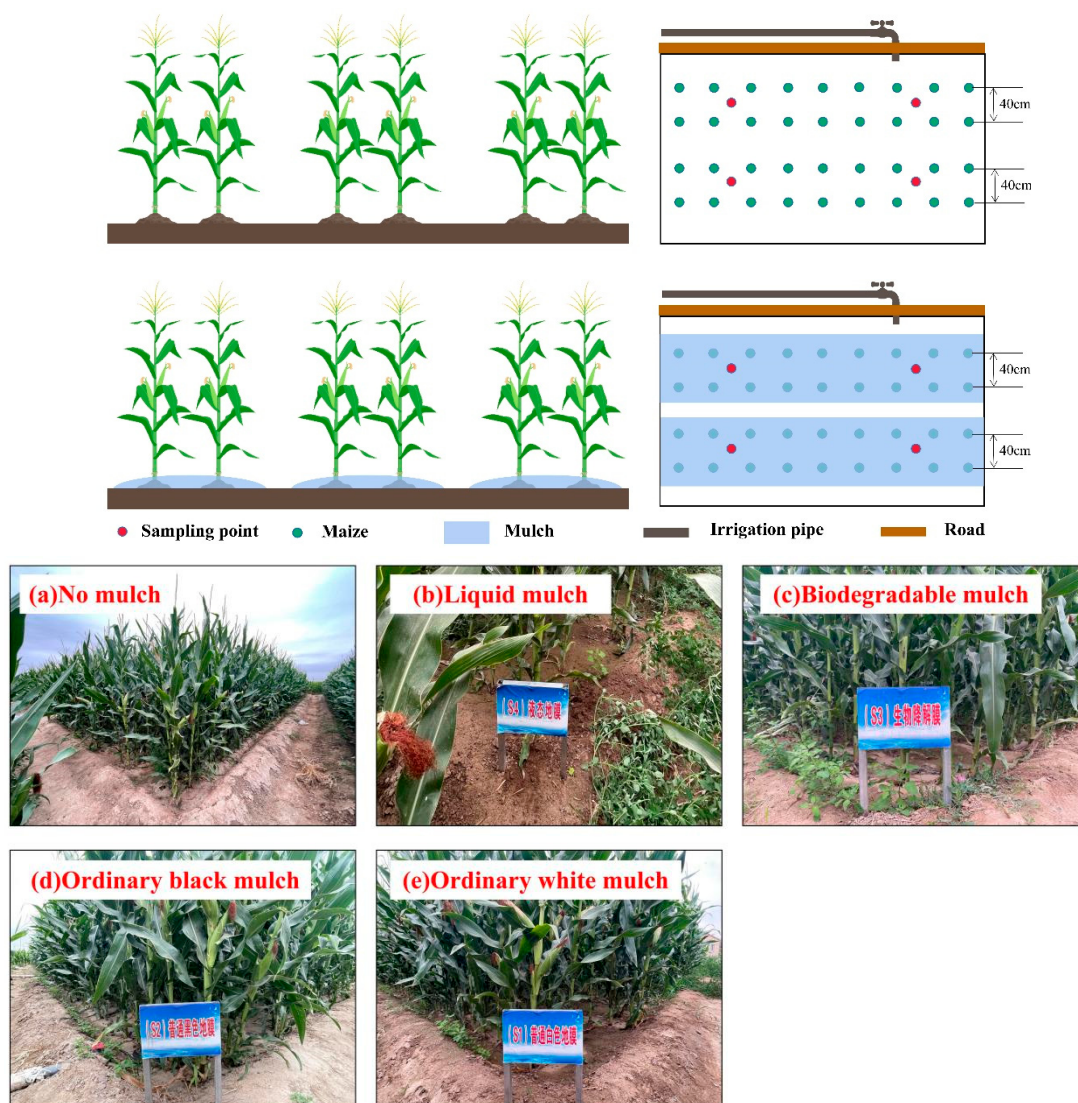


Figure 3. Schematic diagram of the observation system and photos of the experimental field.

The growing season of maize is mainly in summer, so the selected continuous observation time is from July to August 2021. Continuous sampling was conducted on the 1st, 3rd, 5th, 7th, and 9th days after rainfall or irrigation to observe the dynamics of soil moisture. The experimental fields are equipped with pipelines to transport irrigation

water, and the irrigation method is flood irrigation, which is commonly used in arid areas. All pipes were equipped with intelligent water meters, and the irrigation quota of each experimental field was realized through the water meter readings. Two irrigation events and one rainfall event were observed consecutively during the experimental observation period. The first irrigation was carried out on 2 August with 6.3 cubic meters of water, and the second irrigation was carried out on 13 August with 7.8 cubic meters of water. The rainfall event occurred on 18 August. In addition, there were unexpected rainfall events during the study period (2 August, 3 August, 18 August, 21 August, and 22 August). To increase the confidence of the data, on the day of the unexpected rainfall, we used soil samples collected before the rainfall and excluded some of the parallel samples, which were subject to large data errors because the soil moisture in these samples originated from both irrigation and precipitation.

The dimensions of each experimental field were 6 m × 7.5 m. Soil samples were collected every 10 cm with a hand-held auger, ranging from 0–10 cm, 10–20 cm, 20–30 cm, 30–40 cm, 40–50 cm, 50–60 cm, 60–70 cm, 70–80 cm, 80–90 cm, and 90–100 cm. To mitigate the potential impact of irrigation on soil moisture in the same experimental field, four sampling points were set up in each experimental field, and soil moisture was measured and averaged after sample collection. In total, an extensive set of 2600 soil samples was systematically collected.

2.3. Experimental Analysis

The collected soil samples were placed in sealable plastic bags to weigh the wet weight (M) on site. After bringing the samples back to the laboratory, they were removed from the plastic bags, placed in pre-weighed aluminum boxes, and then dried in an oven at 105 °C for 24 h. The dry weight (Ms) of each sample was measured again. Subsequently, the soil moisture was calculated as follows:

$$\text{Soil moisture} = [(M - Ms)/Ms] \times 100\%$$

Soil moisture was averaged for four soil samples measured in each soil layer of the same experimental field to obtain soil moisture from 0–100 cm under different mulch covers (Table 1). However, due to a major error in the preservation process of the samples taken on the third day after the rainfall, the values of this batch of samples deviated from the error interval. In light of this, to ensure the scientific validity and rigor of the study, upon careful consideration, we have thus decided not to use the data collected on the same day and, consequently, not to present the data obtained on the third day after the rainfall in the table.

Table 1. Soil moisture at 0–100 cm under different mulch covers (I₀: before irrigation; I₁: 1st day after irrigation; I₃: 3rd day after irrigation; I₅: 5th day after irrigation; I₇: 7th day after irrigation; R₁: 1st day after rainfall; R₅: 5th day after rainfall; R₇: 7th day after rainfall; R₉: 9th day after rainfall).

Date		No Mulch (%)	Liquid Mulch (%)	Biodegradable Mulch (%)	Ordinary Black Mulch (%)	Ordinary White Mulch (%)
8.1	I ₀	7.80	8.20	11.3	13.0	13.0
8.3	I ₁	20.9	23.1	24.7	21.2	21.0
8.5	I ₃	15.0	21.1	19.5	20.4	20.3
8.7	I ₅	14.6	18.0	22.7	18.9	20.3
8.9	I ₇	13.8	17.0	22.3	20.7	20.9
8.11	I ₀	10.9	13.3	18.3	21.1	21.3
8.14	I ₁	27.4	27.6	26.6	21.1	27.7
8.16	I ₃	23.8	23.3	25.1	19.5	26.9
8.18	I ₅ /R ₀	20.6	23.0	21.7	19.0	25.8
8.19	R ₁	21.4	26.3	24.3	19.3	25.3
8.23	R ₅	16.9	21.1	22.0	17.1	20.9
8.25	R ₇	16.4	20.1	20.0	18.3	23.3
8.27	R ₉	15.1	19.9	19.6	16.6	21.4

3. Results

3.1. Soil Moisture Variation with and without Mulch

The soil moisture in the fields with mulch (20.9%) was higher than that in the fields without mulch (17.6%) during the experimental observation period. There were two irrigation events and one rainfall event of more than 8 mm during the observation, and after each irrigation or rainfall event, there was a noticeable increase in soil moisture. After the second irrigation, the soil moisture content of the fields with and without mulch reached a maximum. It is worth noting that the water content of the soil without film cover was 20.9% one day after the first irrigation and increased to 27.4% one day after the second irrigation, which is related to the difference in the amount of water between the two irrigations; moreover, the difference in the soil water content before irrigation further affects the water content of the soil after irrigation (Table 1). Except for August 14, the soil moisture in fields with mulch was consistently higher than that without mulch. After irrigation and rainfall, soil moisture decreased faster in fields without mulch, while soil moisture maintained a lower decline rate in fields with mulch. Mulch could reduce evaporation and retain soil moisture better. Meanwhile, mulch blocks the external input water from entering the soil to a certain extent, thus more water infiltrates into the bare surface without mulch. Therefore, after each irrigation or rainfall, the difference in soil moisture between the fields with and without mulch (Figure 4) was reduced.

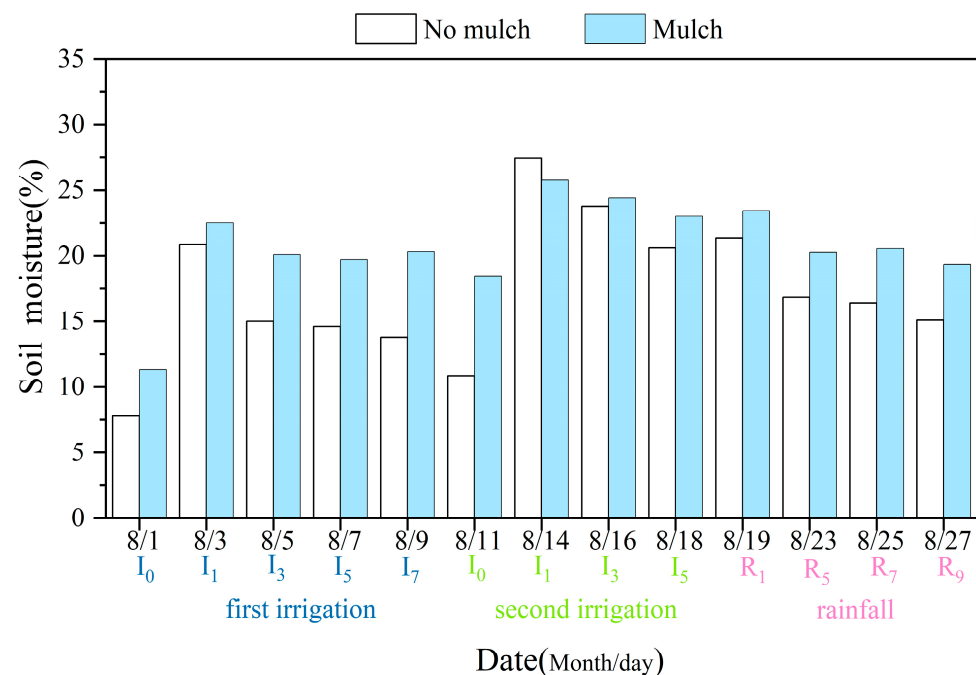


Figure 4. Soil moisture content variation with and without mulching during the observation period was examined through distinct intervals. I₀: before irrigation; I₁: 1st day after irrigation; I₃: 3rd day after irrigation; I₅: 5th day after irrigation; I₇: 7th day after irrigation; R₁: 1st day after rainfall; R₅: 5th day after rainfall; R₇: 7th day after rainfall; R₉: 9th day after rainfall.

There were differences in soil moisture in different soil layers due to the influence of irrigation, rainfall, and mulch. During periods without irrigation and rainfall, soil moisture levels were generally lower in fields without mulch than in those with mulch, especially at the soil layer of 60–100 cm with a soil moisture of 8.7% without mulch and 14.4% with mulch. During the irrigation period, the maximum difference of 5.0% in soil moisture emerged in the fields with and without mulch occurred at the soil layer of 0–30 cm. During the rainfall period, the difference in soil moisture was greatest in the soil layer of 60–100 cm (5.3%) and the smallest in the soil layer of 30–60 cm (1.0%) (Table 2).

Table 2. Variations in soil moisture at different soil layers under irrigation and rainfall with and without mulch. The data in this table examine the effect of different types of mulch on soil moisture, focusing on whether mulch cover was used. We calculated the average soil moisture content under four different types of mulch cover.

	Depth	No Mulch (%)	Mulch (%)
No irrigation and Rainfall	0–30 cm	6.30	9.00
	30–60 cm	8.10	9.70
	60–100 cm	8.70	14.4
During irrigation	0–30 cm	14.0	19.1
	30–60 cm	16.7	20.4
	60–100 cm	22.9	24.4
During rainfall	0–30 cm	12.8	16.5
	30–60 cm	17.6	18.6
	60–100 cm	20.8	26.1

3.2. Soil Moisture Characteristics of Farmland under Different Mulches

There were differences in soil moisture in maize fields covered by different mulches, with OWM exhibiting the highest moisture content (22.3%) followed by BM (21.7%), LM (19.7%), OBM (19.6%), and NM (17.6%). Throughout the experimental period, OWM consistently maintained the highest soil moisture with BM following closely behind. No significant difference was observed between LM and OBM.

The box represents the interquartile range (IQR), spanning the 25th–75th percentiles. Additionally, the required line indicates the extent of data distribution at the 95th and 5th percentiles, and the point indicates outliers. The line in the box represents the median (50th percentile), while the square in the box represents the average value.

The spatiotemporal variation of soil moisture was compared among different mulches (Figure 5). Since soil water at the surface layer is more susceptible to evaporation than at the deep layer, the soil moisture at the 0–50 cm soil layer (17.0%) was lower than that at the 50–100 cm soil layer (22.9%) throughout the experimental observation period. Moreover, in addition, long periods of no irrigation and no rainfall lead to lower soil moisture, especially in fields without mulch, where soil moisture decreases to 7.8%. Soil moisture at the soil layer of 0–100 cm increased significantly once irrigation was completed and showed a gradual decrease as time progressed. There was less rainfall in the arid area, and there was a significant larger rainfall event with 9.4 mm during the experimental period. The rainfall significantly increased the soil moisture in the 0–10 cm soil layer of NM, LM, and BM, but had less effect on the soil moisture at the soil layer below 10 cm (Figure 6).

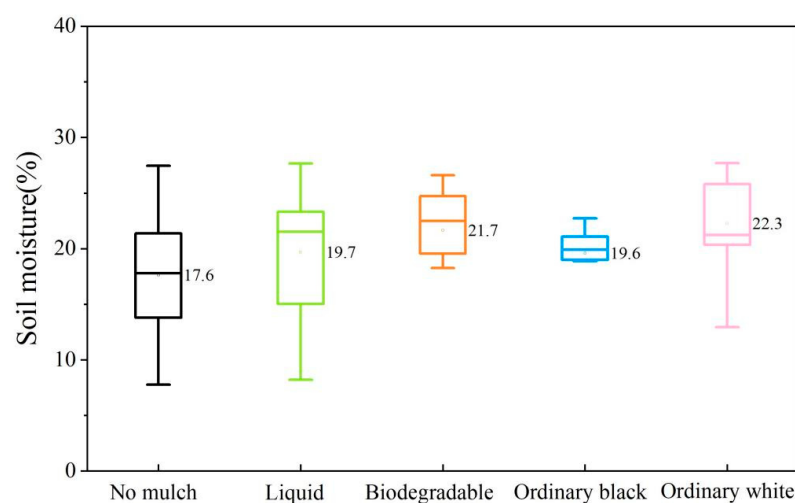


Figure 5. Soil moisture content characteristics of farmland with different types of mulch.

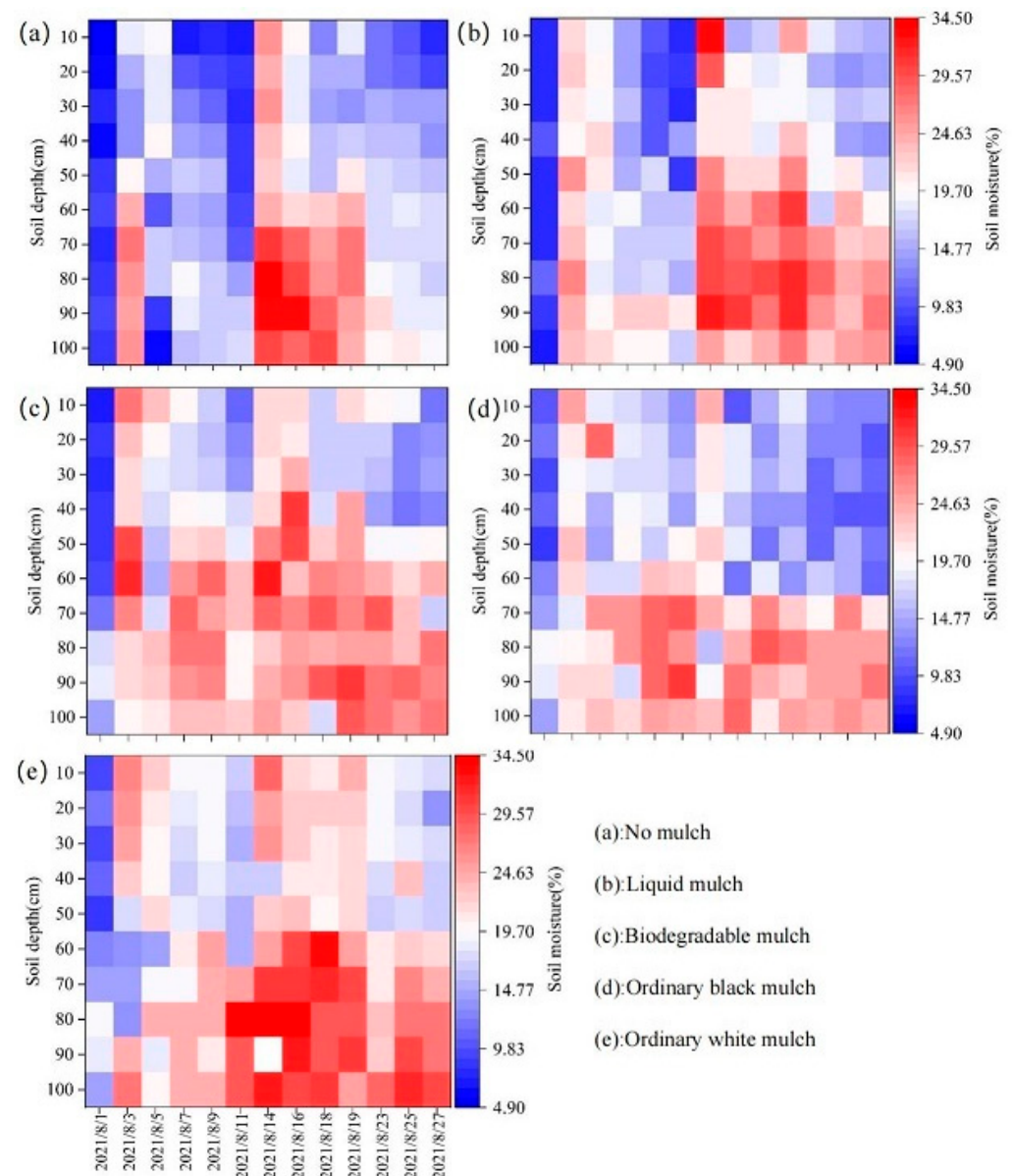


Figure 6. Spatial and temporal variation of soil moisture in maize fields with different mulching.

4. Discussion

4.1. Soil Moisture with and without Mulch

Mulch is effective at reducing evaporation because it heightens the resistance to water vapor flow between the soil surface and the atmosphere, and using plastic mulch can enhance water use efficiency and crop yield [32]. Compared to the fields with mulch, there are higher evapotranspiration losses in the fields without mulch [33]. This study demonstrates that mulch was effective in increasing soil moisture during the dominating growing season of the crop, and soil moisture was consistently higher in all types of mulch than in fields without mulch (Figure 4). However, there are differences in soil moisture retention at different soil layers, with mulch being effective in increasing soil moisture in the soil layer from 0–80 cm, especially at 30–80 cm, which is the main range of soil moisture used by crops. In soil layers below 80 cm, the difference in soil moisture between fields with and without mulch diminished, and it was not meaningful to use mulch for soil moisture retention at deeper layers (Figure 6).

Mulch made a significant contribution to retaining soil moisture. Following input water to the soil on the 1st day, 3rd day, 5th day, and 7th day after irrigation or rainfall; the

mulch, in reducing evaporation of soil water and retaining soil moisture, showed good performance (Figure 3). Li [34] found that the use of plastic mulch in maize cropping systems resulted in a significant increase in soil water content and an increase in water use efficiency of maize crops by approximately 10% compared to no mulch. Other studies in the same region have reported similar results [35–37]. Likewise, mulch can also improve water use efficiency and rainfall use efficiency for other crops (e.g., winter wheat, tomato, pumpkin) [38–40]. Studies on increased soil water content under plastic films have been conducted in other parts of the world [41,42], and mulch is considered an effective agricultural practice to increase soil moisture and water use efficiency.

4.2. Effect of Mulch Type on Soil Moisture after Irrigation

In arid areas, irrigation serves as the primary method for supplying water to support crop growth given the limited rainfall that fails to meet the plants' growth requirements. Evaporation depletes most of the soil water after irrigation [12], and mulch is considered to be a vital agricultural practice to effectively reduce its impact. After irrigation, differences in mulch materials led to differences in soil moisture dynamics. Comparatively, NM, LM, and BM exhibited notable increases in soil moisture, with increases of 13.1%, 14.9%, and 13.4%, respectively. Furthermore, OBM experienced an 8.3% increase, and OWM exhibited an 8.1% increase (Figure 7). Soil moisture in LM increased by 2.8 times on the 1st day after irrigation compared to that before irrigation. Prominent water infiltration is caused by the impermeability of LM material; however, minimized water evaporation was noted in comparison with bare ground [43].

Significant differences arise due to the impermeable polyethylene composition of OBM and OWM, causing the accumulation of a substantial volume of irrigation water in the permeable monopole. This hinders irrigation water infiltration into the soil [44], resulting in a 1.7-fold increase in soil moisture on the 1st day post-irrigation compared to pre-irrigation levels. On the 7th day after irrigation, soil moisture in the fields with different mulch types changed by −7.1% (NM), −6.1% (LM), −2.5% (BM), −0.48% (OBM), and −0.14% (OWM) compared to the 1st day after irrigation. OWM and OBM had the best ability to retain soil moisture, and then BM and LM performed worse but better than NM. LM is an emulsion suspension that is sprayed onto the surface of loose sand grains to form a film that agglomerates the dispersed grains, thereby improving the physical properties of the grains. LM can form a thin film on irregular ground and is easy to decompose and dispose of. Its disadvantage is that the ability to retain soil moisture and soil temperature is open to discussion due to its non-full coverage of the soil surface [40].

BM, comprising polysaccharides, such as cellulose and starch, is easily decomposed by microorganisms and is thinner than OBM and OWM. However, it is susceptible to weathering and breakage during crop growth, resulting in increased water infiltration but offering effective reduction of soil water evaporation [40]. Previous research by Ashrafuz-zaman [45] also identified significant variations in soil moisture due to different mulches, with transparent plastic mulch providing the highest soil moisture (21.1%), followed by black plastic mulch (20.4%) and blue plastic mulch (19.2%), while uncovered soil exhibited the lowest soil moisture (14.6%).

After irrigation, the different mulches made a significant difference in soil moisture at different soil layers. On the 1st day after irrigation, there was a dramatic improvement in soil moisture at 0–100 cm for both NM and LM, at 0–80 cm depth for BM, at 0–70 cm depth for OBM, and at 0–80 cm for OWM (Figure 8). The coverage of OWM, OBM, and BM on the surface impedes the infiltration of irrigation water. In contrast, LM and NM allow a large amount of irrigation water to infiltrate, and the irrigation water infiltrates deeper. Since evaporation and infiltration of irrigation water are simultaneous and soil water is transported downward [18], soil moisture at 0–40 cm is lower in NM than at 40–100 cm, and LM reduces surface evaporation. Thus, there is no significant difference in soil moisture at 0–100 cm. Irrigation is subject to economic development, which makes flood irrigation superior to other methods in arid areas and allows more irrigation water to

enter the soil to replenish soil moisture when there is no mulch or when the mulch material is highly permeable. However, soil moisture evaporation was more pronounced in NM and LM in the days after irrigation. On the 3rd day after irrigation, soil moisture in the surface 0–10 cm layer decreased by 12.2%, 4.4%, 6.6%, and 3.7% with NM, BM, OBM, and OWM, respectively. BM and OWM have made a great contribution to directly reducing the evaporation of the surface soil layer, which is in contact with the atmosphere. On 5th and 7th day after irrigation, OWM and BM soil moisture decreased slightly and stabilized throughout the 0–100 cm soil profile. It has been demonstrated that both biodegradable paper and biodegradable film exhibit the same water use dynamics as polyethylene film mulch [46]. This study further demonstrated that biodegradable plastic mulch exhibited good performance in retaining soil moisture after irrigation.

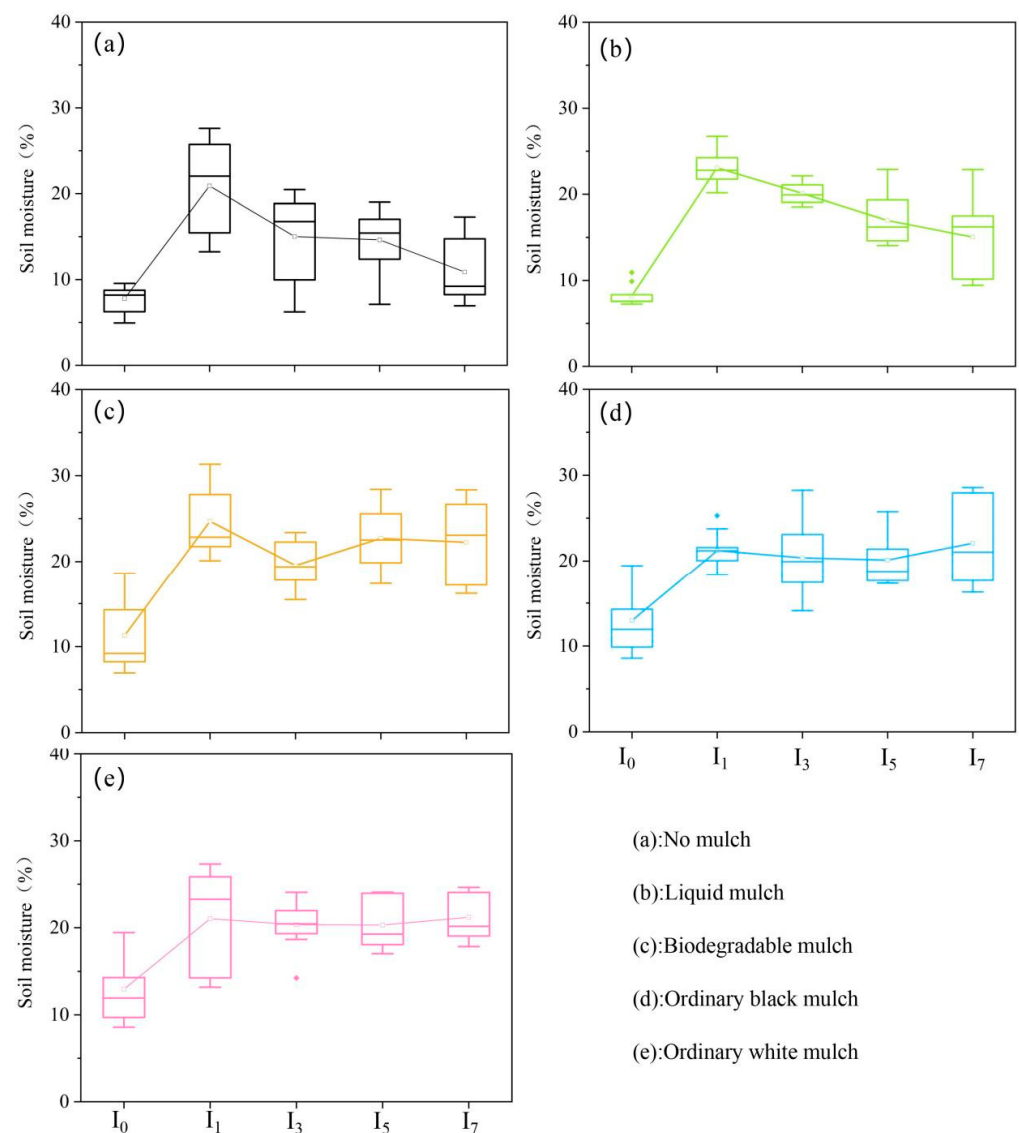


Figure 7. Variation in soil moisture content with irrigation time in different mulched farmlands. The study investigated changes in soil moisture content over time in various mulched farmlands. (The box represents the 25th–75th percentiles, the line indicates the 95th and 5th percentiles, and the point indicates outliers. The line in the box represents the median (50th percentile), the square in the box represents the average value, and the polyline between the boxes connects the averages.) I₀: before irrigation; I₁: 1st day after irrigation; I₃: 3rd day after irrigation; I₅: 5th day after irrigation; I₇: 7th day after irrigation.

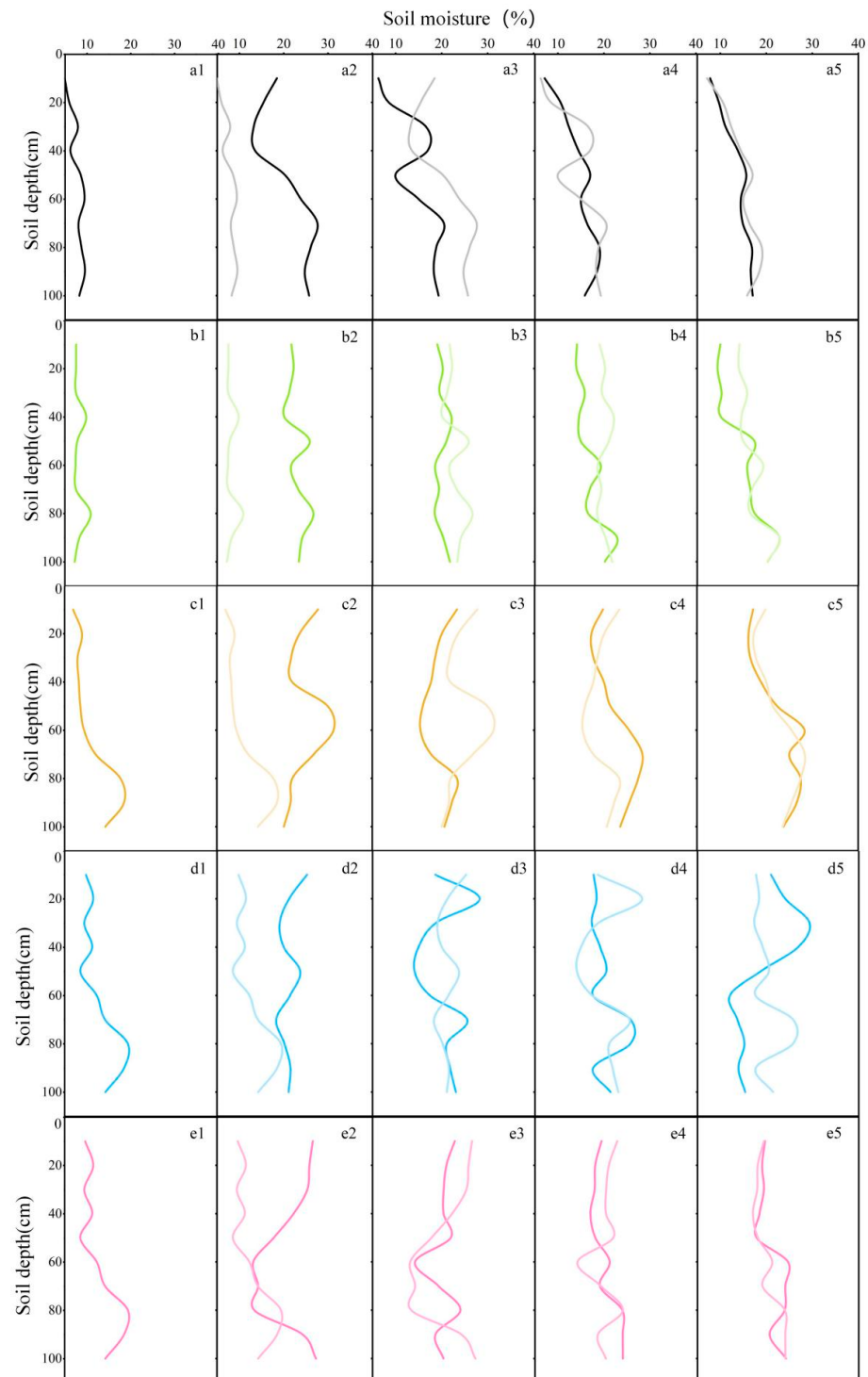


Figure 8. Temporal variations in soil moisture content following irrigation with different mulches. Previous values of soil moisture content are shown in translucent colors. (a1–a5): no mulch; (b1–b5): liquid mulch; (c1–c5): biodegradable mulch; (d1–d5): ordinary black mulch; (e1–e5): ordinary white mulch; (1): before irrigation, (2): first day after irrigation, (3): day 3 after irrigation, (4): day 5 after irrigation, (5): day 7 after irrigation.

4.3. Effect of Mulch Type on Soil Moisture after Rainfall

Limited by the availability of irrigation water, the majority of arid areas remain rainfed agricultural areas [47]. In these regions, the suppression of evaporation and an increase in water infiltration are two crucial aspects of soil moisture retention [48]. The analysis

of the effect of mulch on soil moisture after rainfall is critically important for agricultural development in rainfed areas.

Different from other mulches, the soil moisture levels increases significantly after rainfall when covered with LM and BM (3.3% and 2.6%, respectively). Compared to the soil moisture before rainfall, the application of OBM made the soil moisture increase by only 0.26%. The soil moisture after rainfall in OMW farmland (25.3%) was lower than the soil moisture before rainfall (25.8%), having decreased by 0.56%. In terms of maintaining the reduction of soil moisture evaporation, compared to soil moisture on the 1st day and 9th day after rainfall, the soil moisture decreased by 6.3% (NM), 6.4% (LM), 4.8% (BM), 2.7% (OBM), and 3.8% (OWM) (Figure 9). The polyethylene material used in ordinary mulch is not permeable [49], and the amount of water in arid areas is extremely limited during a single rainfall. The barrier of ordinary mulch allows heavy rainfall to remain on the surface of the mulch. When the temperature increases at the end of the rainfall, the vast majority of the water is evaporated and cannot be recharged into the soil moisture. On the other hand, polyethylene mulch plays an obvious role in maintaining a reduced moisture exchange between the atmosphere and the soil, thereby sustaining soil moisture.

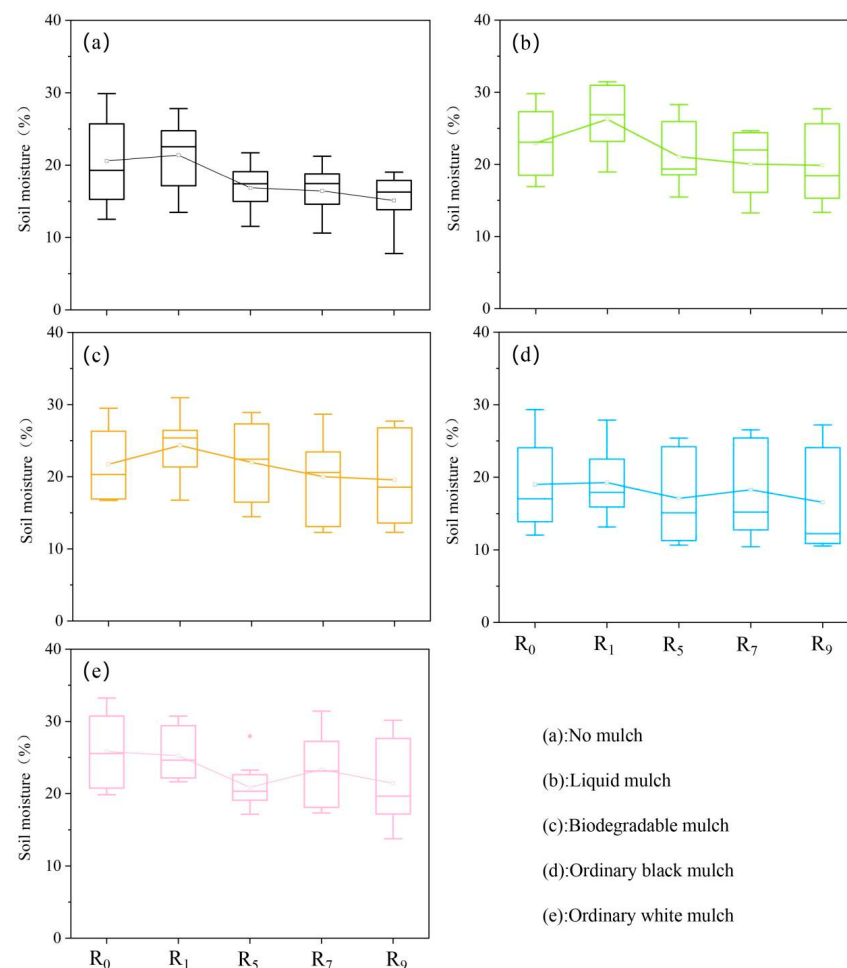


Figure 9. Temporal variations of soil moisture content in different mulch types after rainfall. (The box represents 25–75% percentiles, the required line indicates 95th and 5th percentile, and the point indicates outliers. The line in the box represents median (50th percentile), the square in the box represents average value, and the polyline between the boxes is the connection of the average.) R₀: before rainfall; R₁: 1st day after rainfall; R₅: 5th day after rainfall; R₇: 7th day after rainfall; R₉: 9th day after rainfall.

After rainfall, the distribution of soil moisture coverage with different mulch types differed at different soil layers. Soil moisture in the soil layer of 0–20 cm increased greatly

with NM, LM and BM, especially in the surface soil layer of 0–10 cm. Compared with other mulch types, soil moisture increased slightly in the surface layer covered with OBM and OMW (Figure 10). Due to the limitation in rainfall, the effect of rainfall recharge on soil moisture is concentrated in the surface soil layer (0–20 cm). The barrier of impermeable mulching materials to precipitation causes precipitation to remain on the surface of the mulch or to flow directly to the inter-monopoly furrow, and the wetting degree of the soil surface is low, which reduces the effect of rainfall recharge [50].

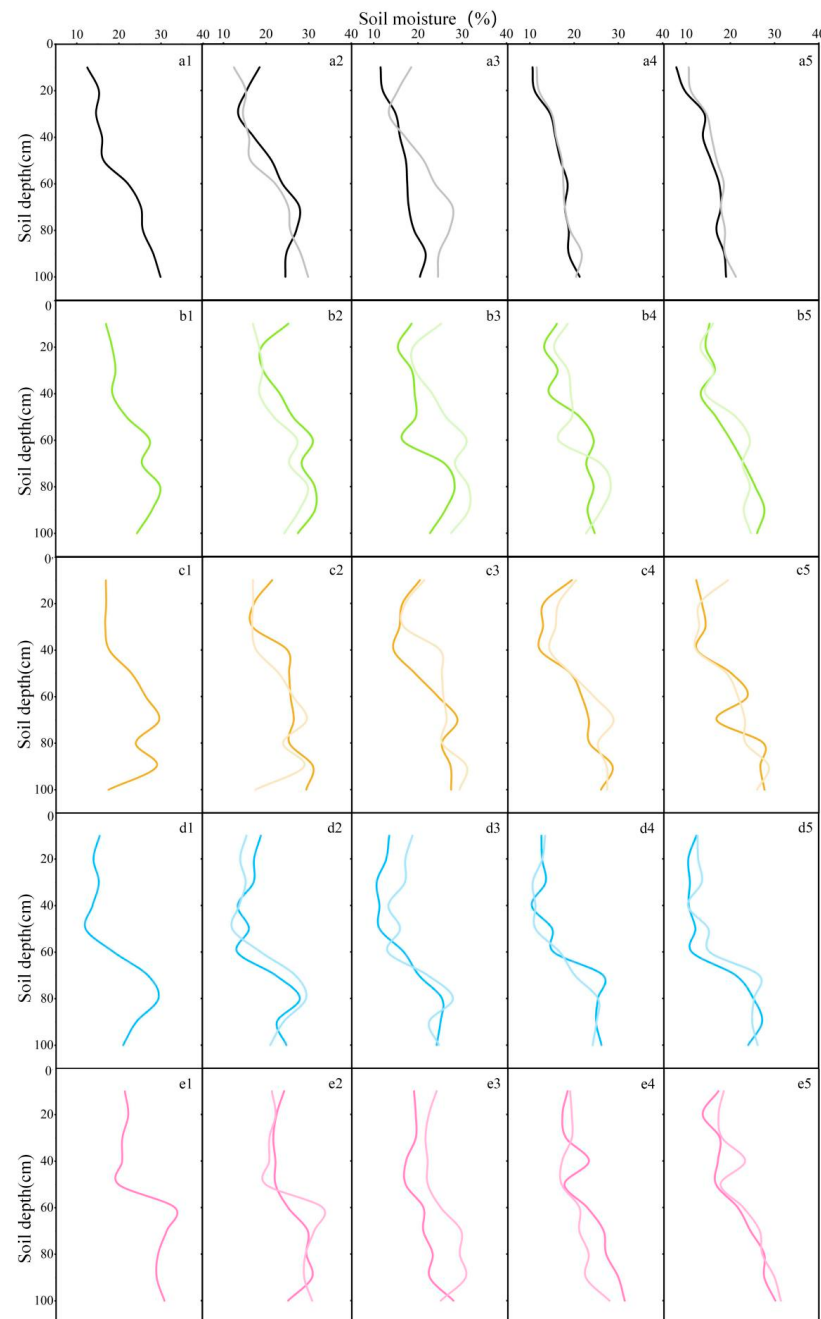


Figure 10. Temporal variations of soil moisture content after rainfall for different mulch types. Previous values of soil moisture content are shown in translucent colors. **(a1–a5):** no mulch; **(b1–b5):** liquid mulch; **(c1–c5):** biodegradable mulch; **(d1–d5):** ordinary black mulch; **(e1–e5):** ordinary white mulch; **(1):** before rainfall, **(2):** day 1 after rainfall, **(3):** day 5 after rainfall, **(4):** day 7 after rainfall, **(5):** day 9 after rainfall.

After a period of biodegradation, BM cracks or gaps appear on the surface, and rainfall enters the soil along the gaps or cracks to replenish soil water. Soil moisture showed a marked decline in all experimental plots on the 5th day after rainfall due to the increase in temperature. NM and LM showed a more consistent pattern of change, with the most significant decrease in soil moisture at 0–10 cm and 60–80 cm depth. BM showed no significant decrease in soil moisture at 0–20 cm depth and a significant decrease at 40–50 cm depth. OBM and OWM showed a more consistent pattern, with a decrease in soil moisture throughout the 0–100 cm profile (Figure 10(a3,b3,c3,d3,e3)).

Polyethylene mulch has a significant role in retaining soil moisture and stabilizing soil properties. In humid climatic zones with adequate rainfall, mulch does not seem to provide benefits in terms of water conservation [18]. However, for rain-fed agricultural areas in arid regions, the choice of mulch material is extremely important in retaining water, blocking precipitation, and even preventing soil erosion. The use of liquid or biodegradable mulches in rain-fed areas can make better use of precipitation.

4.4. Impact of Mulch Use and Recommendations

The growing environment and crop yield can clearly be enhanced by the mulch; additionally, it has a significant influence on improving water use efficiency [51]. However, the environmental pollution caused by mulch cannot be ignored. From 1982 to 2011, the use of mulch, mainly low-density polyethylene (PE), in China increased from 6×10^3 t to 1.2×10^6 t, and the area of mulched land increased from 117.0×10^3 ha to 197.9×10^6 ha. However, as the use of PE films has increased, their negative impacts have become increasingly evident [52]. Plastic residues in the soil have reached 324.5 kg/ha in some Chinese provinces, and the average plastic residue in the soil of agricultural fields after crop harvest is as high as 83.6 kg/ha [53]. In light of these environmental concerns, this study aims to compare the hydrological effects of several different types of mulch in arid zones. Although OWM mulch has the highest soil moisture, it is not easy to decompose. In contrast, BM also has a better ability to maintain soil moisture and is less polluting to the environment due to the ease of decomposition of its material, so it is recommended to use BM more in irrigated areas in arid zones.

Irrigation guarantees the main source of water for crop growth in arid areas, and proper mulching efficiently reduces soil water evaporation after irrigation and increases the efficiency of irrigation water use. The irrigation interval in the study area was 7 days, but the soil moisture in the fields with mulch did not decrease significantly (Figure 7). The higher water content of the mulch offset some of the irrigation effects [18]. Therefore, the interval between irrigation times can be extended to reduce unnecessary over-irrigation and conserve water resources. The amount of rainfall from a single precipitation event is limited in arid areas, and the barrier of OWM and OBM allows most of the precipitation to be left at the surface to evaporate, resulting in little direct recharge of precipitation to soil water. LM and BM allow more precipitation to enter the soil. At the same time, LM is rich in woody and herbaceous cellulose, which is easily degraded by soil microorganisms [54]. Therefore, LM is recommended in rainfed agricultural areas and for some water-saving or rarely irrigated crops, which can allow for more water recharge.

5. Conclusions

In this study, the hydrological effects of different mulch types on farmland were investigated through observation experiments at the Jingtai River Electricity Irrigation Management Experiment Station in Jingtai County, Gansu Province, China. Our analysis revealed that mulching significantly increased soil moisture, highlighting variations in the capacity of different types of mulch to retain and hold soil moisture. The farmland covered with OWM had the highest soil moisture levels throughout the observation period. BM demonstrated commendable performance in facilitating irrigation water penetration and reducing soil water evaporation. LM, NM, and BM enhanced the absorption of precipitation into soil water. Notably, BM provides advantages similar advantages to

polyethylene mulch in maintaining soil moisture in agricultural fields, while being less harmful to the soil and environment by not requiring labor-intensive removal after tillage. Considering the environmental impact and precipitation utilization efficiency, BM and LM emerge as promising choices for widespread application in arid areas.

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