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Mulching Measures Improve Soil Moisture in Rain-Fed Jujube (*Ziziphus jujuba* Mill.) Orchards in the Loess Hilly Region of China

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Abstract: Water shortage is the main bottleneck restricting the sustainable development of rain-fed jujube (*Ziziphus jujuba* Mill.) orchards in the loess hilly region of China. Given the effect of mulching on soil moisture conservation, straw mulching (SM) and jujube branch mulching (BM) were applied to a rain-fed jujube orchard in this study. Soil moisture dynamics, soil water storage, water consumption, and soil moisture attenuation after typical rainfall under SM, BM, and clean tillage (CT) were studied. The results showed the following: (1) The 0–60 cm soil layer was the seasonal fluctuation layer of soil moisture under SM, BM, and CT in both the normal precipitation year and the dry year studied. The moisture contents of the 0–60, 60–160, and 160–280 cm soil layers under SM and BM were higher than that under CT in the three experimental years studied, and SM showed the most obvious effect of increasing soil moisture. (2) SM and BM showed a significant soil water storage effect in all of the jujube growth stages, and SM had a better water storage effect than BM. (3) SM reduced the amount of water consumption by 94.3, 60.8, and 121.3 mm compared to CT in the whole jujube growth period in 2014, 2015, and 2016, respectively. The amount of water consumption of BM decreased by 34.8 and 31.0 mm compared to that of CT in the whole growth period in 2014 and 2015, respectively. (4) CT had the maximum soil moisture loss rate under continuous drought after rainfall. The soil moisture loss rate of CT was above 37.3% on the eleventh day after typical rainfall in 2014, 2015, and 2016. With the extension of drought, the soil moisture loss rate under SM increased slowly. This study suggests that SM is the best mulching measure for rain-fed jujube orchards, and pruned jujube branches can also be used for in situ mulching to obtain a certain moisture conservation effect.

Keywords: soil moisture; water consumption; continuous drought; mulching; jujube

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1. Introduction

The loess hilly region of China is characterized by a dry climate, strong evaporation, scarce precipitation and uneven seasonal distribution, and a mismatch between natural precipitation and crop water demand [1,2]. The topography of the loess hilly region is dominated by sloping land, much of which has a great gradient and a loose soil structure, resulting in serious soil erosion [3,4]. In addition, there is little irrigation in the loess hilly region, and most of the crop growth depends on natural precipitation [5,6]. Water shortage severely restricts the development of agriculture and forestry in the loess hilly region [7]. How to reasonably and efficiently utilize the limited natural precipitation in the loess hilly region has now become the main focus and trend.

As the main economic and ecological forest for soil and water conservation in the loess hilly region, the jujube (*Ziziphus jujuba* Mill.) cultivation area has expanded rapidly in recent years, and it has exceeded one million hectares [8,9]. Clean tillage, that is, weeding multiple times during the crop growing season, is currently widely used in jujube orchards [10]. Clean tillage has the advantages of pest control and seedling raising for orchards, with good short-term effects. However, many studies have found that long-term clean tillage causes serious soil erosion, a decline in soil fertility, deterioration of soil properties, and the destruction of ecological balance, and ultimately leads to the premature aging of fruit trees, a reduction in fruit yield, and a deterioration of fruit quality, which is not conducive to the sustainable development of orchards [11–13].

As an effective soil management measure in rain-fed areas, mulching has been recognized and widely used in many countries. Mulching has the functions of conserving soil moisture, reducing evaporation, improving soil fertility, adjusting soil temperature, etc., which are beneficial to promoting crop growth and water-use efficiency [14]. At present, several researchers have applied mulching measures (straw, plastic film, organic matter, gravel, pruned branches, gramineous and leguminous grass, rape cultivation, etc.) to rain-fed peach, apricot, olive, apple, jujube, pomegranate, and fig orchards [15–21]. Such researchers have found that appropriate mulching measures can effectively promote rainfall infiltration, weaken soil erosion, increase soil moisture, reduce soil evaporation, improve soil properties, enhance soil fertility, regulate soil temperature, stimulate soil microbial activity, have a positive impact on fruit tree growth, fruit yield and quality, and improve water-use efficiency.

Based on the above-mentioned background, maize straw and pruned jujube branches were used to cover the soil surface of a rain-fed jujube orchard in the loess hilly region, and the impact of these two mulching measures on soil moisture was studied. The findings can provide a scientific basis for the selection and promotion of mulching measures, the efficient utilization of precipitation resources, and the sustainable development of rain-fed jujube orchards in the loess hilly region.

2. Materials and Methods

2.1. Study Site

The experiment was conducted at the Jujube Demonstration Bases (37°15′N,110°21′E) in Dianzegou Town, Qingjian County, Yulin City, Shaanxi Province, China (Figure 1a), which is located in the loess hilly region. The climate of the study site is a warm temperate continental monsoon semi-arid climate, with an annual average precipitation of 505 mm, of which the precipitation from June to August accounts for approximately 80% of the total annual precipitation (Figure 1c). The annual average air temperature at the study site is 9.6 °C, with an average air temperature of –6.8 °C in January and 23.8 °C in July (Figure 1c). Both the air temperature difference between day and night and the air temperature change in seasons is great. The study site has abundant sunshine, with an annual average sunshine duration of 2720 h and a frost-free period of 160–170 days.

As shown in Figure 2, the precipitation was 373.6, 258.8, and 344.4 mm during the jujube growth period (early May to mid-October) in 2014, 2015, and 2016. According to Hao et al. [22], a year when the precipitation increases or decreases within 10% of the annual average precipitation during the crop growth period is a normal precipitation year, and a year when the precipitation decreases by more than 10% of the annual average precipitation during the crop growth period is a dry year. Therefore, 2014 and 2016 were classified as normal precipitation years, and 2015 was a dry year. The soil at the study site is loessal soil, belonging to silt loam, with a loose structure and a strong infiltration capacity. The main physical properties of the 0–180 cm soil layer at the study site are shown in Table 1.

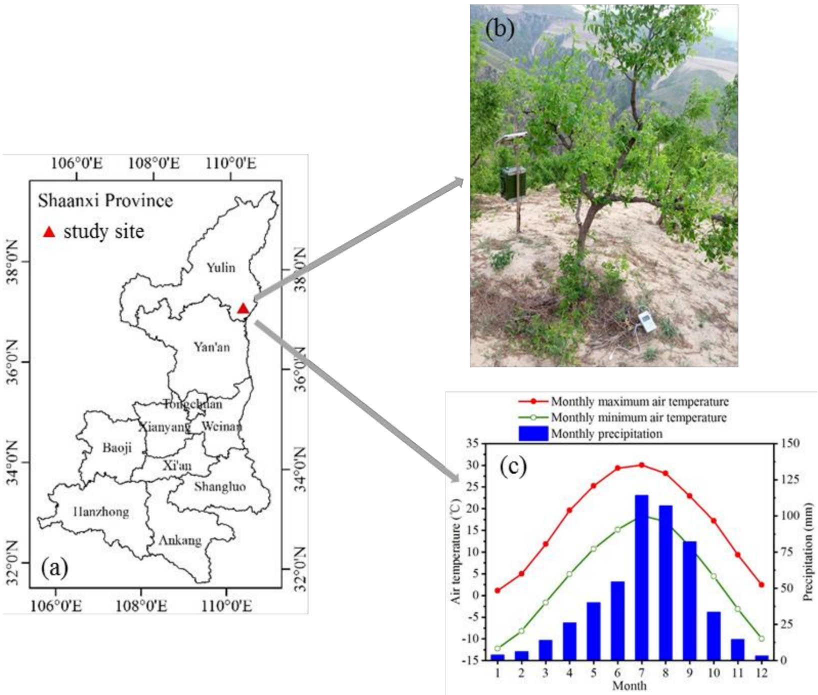

Figure 1. General situation of the study site: (**a**) geographical location, (**b**) experimental jujube orchard, and (**c**) climate background. Air temperature and precipitation data were obtained from the statistical data released by the National Meteorological Center of China Meteorological Administration (http://www.nmc.cn/publish/forecast/ASN/qingjian.html).

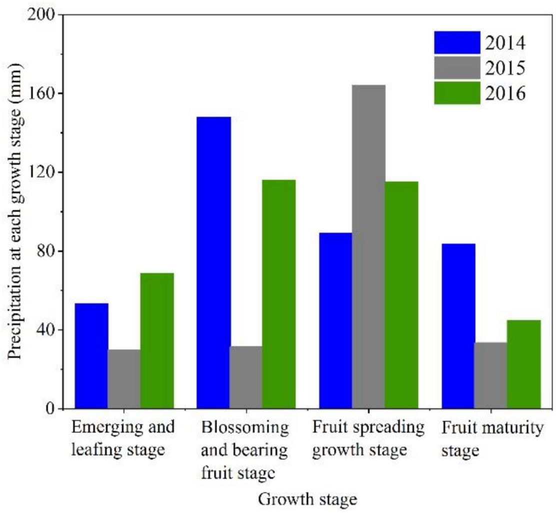

Figure 2. Precipitation at each growth stage of jujube trees in 2014, 2015, and 2016.

Table 1. Soil properties of the 0–180 cm layer at the study site.

Soil Layer (cm)	Bulk Density ($g \cdot cm^{-3}$)	Soil Particle Composition [a] Sand (%)	Silt (%)	Clay (%)	K_{sat} [b] ($mm \cdot min^{-1}$)	θ_s [c] ($cm^3 \cdot cm^{-3}$)	θ_{33kPa} [d] ($cm^3 \cdot cm^{-3}$)	$\theta_{1500kPa}$ [e] ($cm^3 \cdot cm^{-3}$)
0–20	1.27	19.1	64.7	16.2	1.21	50.4	27.5	6.6
20–40	1.31	18.8	64.8	16.4	1.28	50.8	27.1	7.2
40–60	1.31	17.9	63.1	19.0	1.16	53.1	28.4	7.1
60–80	1.45	17.4	64.5	18.1	0.91	52.8	28.1	7.3
80–100	1.37	18.7	62.8	18.5	0.85	52.3	27.8	8.1
100–120	1.40	16.5	62.5	21.0	0.82	57.1	30.4	9.5
120–140	1.37	16.1	63.2	20.7	0.92	55.8	30.2	9.2
140–160	1.41	16.8	62.9	20.3	0.86	56.4	29.0	7.9
160–180	1.46	16.2	64.1	19.7	0.94	55.4	29.2	8.8

[a] Soil particle composition: sand% (2–0.02 mm), silt% (0.02–0.002 mm), and clay% (<0.002 mm); [b] K_{sat}: Saturated hydraulic conductivity; [c] θ_s: Saturated moisture; [d] θ_{33kPa}: Soil moisture content at 33 kPa; [e] $\theta_{1500kPa}$: Soil moisture content at 1500 kPa.

2.2. Experimental Design

A jujube orchard with a slope gradient of 20° and a south slope direction was selected as the experimental plot (Figure 1b). The jujube variety was Lizao, which was planted in 2003 and was in the full bearing period during the experiment. According to jujube's growth characteristics, the jujube growth period was divided into four stages, namely, the emerging and leafing stage (early May to mid-June), the blossoming and bearing fruit stage (mid-June to mid-July), the fruit spreading growth stage (mid-July to mid-September), and the fruit maturity stage (mid-September to mid-October). The plant and row spacing of jujube trees were 2 and 3 m, respectively. A small amount of farmyard manure and 0.3 kg per plant of urea were applied to the experimental jujube orchard at the beginning of each year. The jujube trees were pruned to a height of approximately 2 m in April every year, and the jujube orchard was regularly weeded manually. The jujube orchard was managed under rain-fed conditions without irrigation during the experiment.

Three treatments were designed, namely, straw mulching (SM), jujube branch mulching (BM), and clean tillage (CT). Each treatment was repeated twice, with a total of six experimental plots, which were completed in March 2013. The mulching material of SM was maize straw, the mulching thickness was 15 cm, and maize straw was supplemented at the end of the jujube growth period every year to ensure the designed mulching thickness. The pruned jujube branches were broken to 10 cm in length under BM, and the mulching thickness was also 10 cm. The soil surface under CT was exposed without any mulching measures.

2.3. Soil Moisture and Precipitation Measurement

An automatic soil moisture measuring device was installed in each experimental plot in late April 2014. The soil volumetric moisture content was measured using an EC-5 soil moisture sensor (Decagon Devices Inc., Pullman, WA, USA) at a frequency of 10 min. The monitor point was 30 cm away from the jujube trunk. Given that 90% of the fine roots of jujube trees are concentrated in the 0–300 cm soil layer [23], the observation depth of the soil moisture was 10, 20, 40, 60, 100, 160, 220, and 280 cm (Figure 3). For two plots with the same experimental treatment, their soil moisture content at the same depth was averaged. The precipitation data in the study area were collected by an AR-5 automatic weather station (Avolon Scientific, Inc., Jersey City, USA) approximately 100 m away from the experimental jujube orchard.

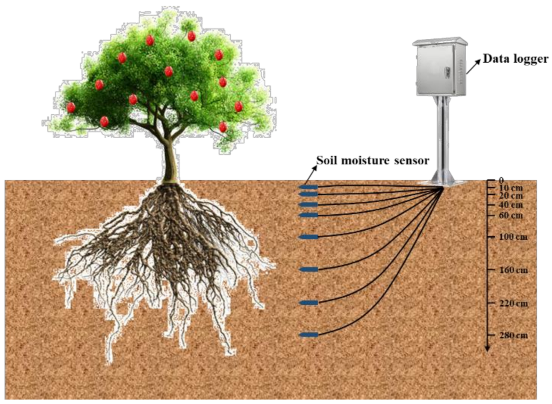

Figure 3. Schematic diagram of soil moisture sensor layout.

2.4. Data Analysis

Soil water storage (W, mm) was calculated using the following formula [24]:

$$W = \sum_{i=1}^{n} (\theta_i \times h_i) \tag{1}$$

where n represents the number of soil layers, θ_i is the volumetric moisture content of the i-th soil layer ($cm^3 \cdot cm^{-3}$), and h_i is the thickness of the i-th soil layer (mm).

For rain-fed fields, the crop water consumption is the crop water requirement, that is, the evapotranspiration (ET, mm), including crop transpiration (T, mm) and soil evaporation (E, mm), which can be calculated using the soil water balance equation [25]:

$$ET = P + I + U - R - D - IN - \Delta W \tag{2}$$

where P represents the precipitation (mm), I is the irrigation (mm), U is the groundwater recharge (mm), R is the surface runoff (mm), D is the deep percolation (mm), IN is the interception of precipitation by plant canopy, and ΔW is the change of soil water storage, defined as the difference between the soil water storage measured at the beginning and the end of the calculation period (mm).

The experimental jujube orchard was rain-fed without irrigation, so $I = 0$. The buried depth of the groundwater in the study area exceeds 50 m, so it can be considered that $U = 0$ [23]. The study area has a deep soil layer and strong water storage capacity, so stored-full runoff rarely occurs. For a runoff yield in excess of the infiltration caused by heavy rain, wide horizontal steps were built in the experimental jujube orchard, which can reduce the runoff outflow from the jujube orchard, so it can be considered that $R = 0$. Han et al. [26] found that the soil water storage capacity of the Loess Plateau is 200–250 $mm \cdot m^{-1}$, and the soil can still hold approximately 100 $mm \cdot m^{-1}$ of water after it has accumulated some water. This study focused on the 0–280 cm soil layer, which can store approximately 280 mm of precipitation, which is much higher than the maximum precipitation in the study area, so deep percolation will not occur after rainfall, that is, $D = 0$. The jujube trees were pruned every April, and the invalid rainfall with daily rainfall less than 5 mm was ignored when the effective rainfall was counted, so the canopy interception can be considered negligible, that is, $IN = 0$. The calculation equation of ET can be simplified as:

$$ET = P - \Delta W \tag{3}$$

The water consumption percentage (CP) was obtained according to Huang et al. [27] as follows:

$$CP = WC_i / WC_T \times 100\% \tag{4}$$

where WC_i represents the water consumption of the jujube trees in the i-th growth stage (mm), and WC_T is the total water consumption in all growth stages (mm).

The soil moisture loss rate ($SMLR$) was estimated from the following equation [28]:

$$SMLR = \frac{SMC_1 - SMC_{n+1}}{SMC_1} \times 100\% \quad (5)$$

where SMC_1 represents the soil volumetric moisture content on the first day after rainfall, and SMC_{n+1} represents the soil volumetric moisture content on the (n+1)-th day after rainfall.

Statistical analysis was performed using Microsoft Excel 2013 (Microsoft, Redmond, WA, USA) and SPSS 20.0 (IBM Corp., Armonk, NY, USA). An independent samples t-test was conducted to compare the differences in soil moisture in the same soil layer under different experimental treatments. Differences were considered statistically significant when $p < 0.05$. The software OriginPro 2017 (OriginLab, Northampton, MA, USA) was used for making figures.

3. Results

3.1. Soil Moisture Dynamics in the Rain-Fed Jujube Orchard under Different Mulching Measures

According to the distribution characteristics of the fine roots of the jujube trees, the soil profile was divided into a fine root dense layer (0–60 cm), a fine root diffuse layer (60–160 cm), and a fine root sparse layer (160–280 cm). The soil moisture changes in the three soil layers of the jujube orchard under different mulching measures were almost consistent in three experimental years (Figure 4). Due to the influence of rainfall and evaporation, the soil moisture in the fine root dense layer fluctuated violently, which belonged to the seasonal fluctuation layer (Figure 4a). The soil moisture in this soil layer increased rapidly after effective rainfall, and then decreased with continuous drought. CT obtained the lowest soil moisture content in the three growing seasons. Particularly in multiple periods of the fruit spreading growth stage in the dry year (2015), the soil moisture content was even lower than the wilting moisture (7%). Although the rainfall at each growth stage in 2016 was significantly higher than that in the same period in 2015, the air temperature in the blossoming and bearing fruit stage, the fruit spreading growth stage, and the fruit maturity stage in 2016 was 0.21, 0.44, and 1.64 °C higher than that in the same period in 2015, respectively, which led to an increase in soil evaporation, resulting in the soil moisture content in the fine root dense layer under CT being continuously lower than the wilting moisture from the blossoming and bearing fruit stage to the fruit maturity stage in 2016, which resulted in the formation of a seasonal low-humidity zone. The soil moisture content in the fine root dense layer under SM increased by 5.68%, 4.60%, and 4.41% in the growing seasons of 2014, 2015, and 2016, respectively, compared to CT ($p < 0.05$). The soil moisture content in the fine root dense layer under BM increased by 4.41%, 3.24%, and 3.27% in the growing seasons of 2014, 2015, and 2016, respectively, compared to CT ($p < 0.05$).

The soil moisture content of the fine root diffuse layer was mainly affected by the distribution density of fine roots and was weakly affected by rainfall (Figure 4b). SM had the highest soil moisture content with 16.38%, 15.04%, and 14.25% in the growing seasons of 2014, 2015, and 2016, respectively. The soil moisture content under BM increased by 2.77%, 2.09%, and 1.43% compared to CT in the growing seasons of 2014, 2015, and 2016, respectively ($p < 0.05$). The soil moisture in the fine root sparse layer was hardly affected by rainfall (Figure 4c). The soil moisture content of the fine root sparse layer under CT was lower than the wilting moisture in the three growing seasons, forming a perennial low-humidity zone. The soil moisture content of the fine root sparse layer under the mulching treatments (SM and BM) increased by 6.11–7.80% compared to CT ($p < 0.05$).

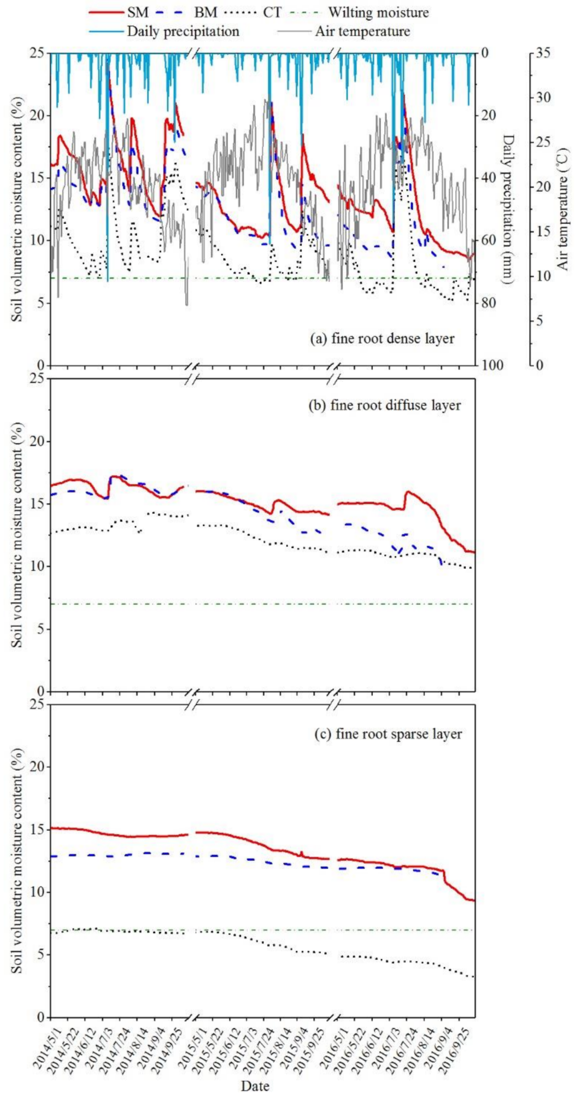

Figure 4. Daily average soil volumetric moisture content changes in (**a**) the fine root dense layer, (**b**) the fine root diffuse layer, and (**c**) the fine root sparse layer under different mulching treatments during the jujube growth period in 2014, 2015, and 2016. SM, straw mulching; BM, jujube branch mulching; CT, clean tillage.

3.2. Soil Water Storage of the Rain-Fed Jujube Orchard under Different Mulching Measures

The mulching treatments (SM and BM) showed the obvious effect of increasing the soil moisture at each growth stage, both in the normal precipitation years and the dry year (Figure 5). In the emerging and leafing stages, the water storage of the 0–280 cm soil layer under SM and BM was 158.8 and 148.5 mm higher in 2014, 144.3 and 119.4 mm higher in 2015, and 153.5 and 130.7 mm higher in 2016 than that under CT, respectively. In the blossoming and bearing fruit stage, the soil water storage of SM and BM was 160.7 and 139.7 mm in 2014, 138.7 and 119.5 mm in 2015, and 155.9 and 121.5 mm in 2016, respectively, higher than that of CT. In the fruit spreading growth stage, the soil water storage under SM and BM was 54.6% and 49.5% in 2014, 58.0% and 56.9% in 2015, and 68.5% and 55.9% in 2016, respectively, higher than that under CT. In the fruit maturity stage, the soil water storage of SM and BM was 41.5% and 38.9% higher than that of CT in 2014, and 60.4% and 49.0% higher than that of CT in 2015 (Figure 5a,b). Soil water storage under SM was still 105.4 mm higher than that under CT in 2016 (Figure 5c). The effect of SM on increasing moisture at each growth stage was better than that of BM in three experimental years.

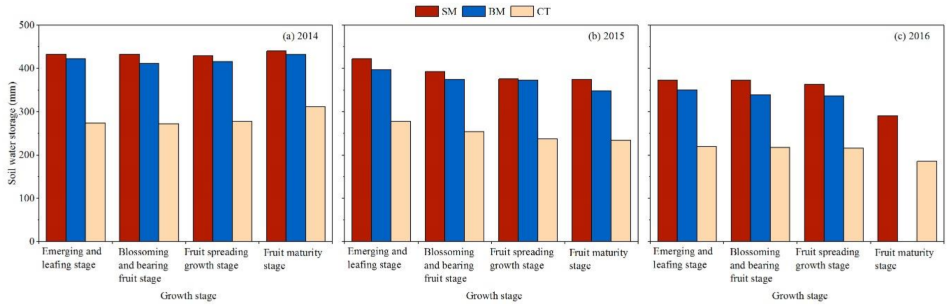

Figure 5. Soil water storage of the 0–280 cm soil layer under different mulching treatments in the different jujube growth stages in (**a**) 2014, (**b**) 2015, and (**c**) 2016. Due to the malfunction of the soil moisture measuring device under the BM treatment in the 2016 fruit maturity stage, the collected soil moisture data were incorrect, and the soil water storage under the BM treatment could not be calculated in this period.

In the growing season of 2014, the water storage of the 0–280 cm soil layer under all experimental treatments gradually decreased from the emerging and leafing stage to the blossoming and bearing fruit stage, and then gradually increased due to the supplement of a large amount of rainfall during the fruit spreading growth and fruit maturity stages (Figure 5a). In the growing seasons of 2015 and 2016, the soil water storage of each experimental treatment showed a decreasing trend as the growth stage progressed (Figure 5b,c).

3.3. Amount and Percentage of the Water Consumption of Jujube Trees under Different Mulching Measures

As shown in Table 2, the different mulching measures had a significant impact on the amount of water consumption of the jujube trees during the whole growth period. SM reduced the amount of water consumption of the jujube trees by 94.3, 60.8, and 121.3 mm compared to CT in the growth periods of 2014, 2015, and 2016. The amounts of water consumption of the jujube trees under BM were 34.8 and 31.0 mm lower than those under CT in the growth periods of 2014 and 2015, respectively.

Table 2. Amount (ET) and percentage (CP) of water consumption of the jujube trees under different mulching treatments at each growth stage in 2014, 2015, and 2016.

Year	Mulching Treatment	Emerging and Leafing Stage		Fruit Spreading Growth Stage		Fruit Maturity Stage		Whole Growth Period
		ET(mm)	CP(%)	ET(mm)	CP(%)	ET(mm)	CP(%)	ET(mm)
2014	SM	60.1	19.8	92.8	30.6	52.3	17.3	302.9
	BM	61.9	17.1	135.1	37.3	59.5	16.4	362.4
	CT	62.8	15.8	144.7	36.4	80.1	20.2	397.2
2015	SM	51.6	22.5	80.4	35.0	52.2	22.7	229.7
	BM	53.7	20.7	101.7	39.2	55.2	21.3	259.4
	CT	55.3	19.0	124.2	42.8	56.5	19.5	290.5
2016	SM	76.5	22.6	137.2	40.5	48.8	14.4	338.6
	BM	88.5	- [a]	178.1	-	-	-	-
	CT	88.7	19.3	202.7	44.1	69.6	15.1	459.9

[a] **The symbol "-" indicates a lack of data.** Due to the malfunction of the soil moisture measuring device under the BM treatment during the fruit maturity stage in 2016, the collected soil moisture data were abnormal. As a result, the ET of the jujube trees during this period and the whole growth period could not be calculated, and therefore, the CP at each growth stage could not be calculated.

The amount and percentage of water consumption of the experimental rain-fed jujube orchard were significantly different in the different growth stages (Table 2). In the emerging and leafing stage, the amount of water consumption of the jujube trees under SM and BM was less than that under CT, which decreased by 4.3–13.7% and 0.3–3.0%, respectively, in the three experimental years. The water consumption percentage of SM increased by 4.0%, 3.4%, and 3.3% compared to that of CT during the growth periods in 2014, 2015, and 2016, respectively. The percentage of water consumption under BM increased by 1.3% and 1.6% in 2014 and 2015, respectively, compared to CT. Similarly to the previous growth stage, during the blossoming and bearing fruit stage, the mulching treatments had the effects of reducing the amount of water consumption and increasing the percentage of water consumption in the three experimental years, of which SM had the most obvious effect. The jujube trees consumed a lot of water during the fruit spreading growth stage, accounting for 30.6–44.1% of the total water consumption amount during the whole growth period, and the same experimental treatment showed differences in the different precipitation years. In the fruit spreading growth stage in 2014, 2015, and 2016, SM reduced the amount of water consumption by 35.9%, 35.3%, and 32.3%, respectively, and reduced the percentage of water consumption by 5.8%, 7.8%, and 3.6%, respectively, compared to CT. Compared to CT, the amount of water consumption of BM was reduced by 6.6%, 18.1%, and 12.2% during the fruit spreading growth stage in 2014, 2015, and 2016, respectively. With the advancement of the growth stage, during the fruit maturity stage, the amount of water consumption under SM was reduced by 7.6–34.7% compared to that under CT in the three experimental years. The water consumption amount of BM was 25.7% and 2.4% lower than that of CT in the fruit maturity stage of 2014 and 2015, respectively. SM and BM both had the effect of reducing the percentage of water consumption during the fruit maturity stage in 2014 and 2016. The water consumption percentage under SM and BM increased by 3.3% and 1.8%, respectively, during the fruit maturity stage in 2015 compared to CT.

3.4. Soil Moisture Attenuation Characteristics after Typical Rainfall

Three typical rainfalls were selected in the three experimental years for the study, i.e., one typical rainfall occurred from 8 to 9 July 2014 with a total rainfall of 86.6 mm, another typical rainfall occurred from 9 to 10 September 2015 with a total rainfall of 51.6 mm, and the other typical rainfall occurred from 18 to 19 July 2016 with a total rainfall of 59.2 mm. There was no effective rainfall (>5 mm) in the two days before and the 11 days after the above three typical rainfalls.

Affected by rainfall and evapotranspiration, the vertical distribution of the soil moisture in the experimental rain-fed jujube orchard under different mulching measures was different (Figure 6). On the first day after the typical rainfall in 2014, the increase in soil moisture in the 0–60 cm soil layer of the rain-fed jujube orchard under SM, BM, and CT accounted for more than 99.3% of the total increase in soil moisture (Figure 6A), indicating that this typical rainfall mainly supplemented the soil moisture of the 0–60 cm soil layer for these three experimental treatments. The typical rainfall in 2015 supplemented the soil moisture of the 0–60, 0–40, and 0–20 cm soil layers for SM, BM, and CT, respectively (Figure 6B). After the typical rainfall in 2016, the increase in soil moisture in the 0–60 cm soil layer under SM and CT and the 0–100 cm soil layer under BM accounted for more than 99.2% of the total increase in soil moisture (Figure 6C).

On the third day after all of the typical rainfalls, the soil moisture of the infiltration layer under all experimental treatments showed attenuation (Figure 6). CT had the maximum soil moisture loss rate, with 9.0% and 13.2% in 2014 and 2015, respectively (Figure 6c,f), and SM had the minimum value, with 8.0% and 4.3% in 2014 and 2015, respectively (Figure 6a,d). The soil moisture loss rate of the three experimental treatments was 5.5–6.0% without a significant difference in 2016 (Figure 6C). On the seventh day after typical rainfall, the maximum soil moisture loss rate was obtained by CT, with 23.8%, 30.7%, and 19.7% in 2014, 2015, and 2016, respectively (Figure 6c,f,i). The soil moisture loss rate under BM came second, and that under SM was the lowest, with only 17.1%, 8.7%, and 14.3% in 2014, 2015, and 2016, respectively (Figure 6a,d,g). Compared to the soil moisture loss rate on the third day after a typical rainfall, the soil moisture loss rate on the seventh day under CT increased significantly, with the increments all being above 14.2% in the three experimental years (Figure 6c,f,i). The soil moisture loss rate under SM increased slowly, especially in 2015, when the increment was only 4.4% (Figure 6d). With the prolongation of drought after typical rainfall, the soil moisture loss rate of the three experimental treatments continued to increase. On the eleventh day after the typical rainfall, CT still maintained the maximum soil moisture loss rates—all above 37.3% from 2014 to 2016 (Figure 6c,f,i). SM still maintained the minimum soil moisture loss rate, which was approximately 24.0% in 2014 and 2016, and only 14.7% in 2015 (Figure 6a,d,g). Compared to the soil moisture loss rate on the seventh day after a typical rainfall, the rate of increase of the soil moisture loss rate on the eleventh day after a typical rainfall under CT was significantly higher than that under the mulching treatments, which was above 11.4% in the three experimental years (Figure 6c,f,i), while the rate of increase of the soil moisture loss rate under SM was slow, not exceeding 9.7% (Figure 6a,d,g).

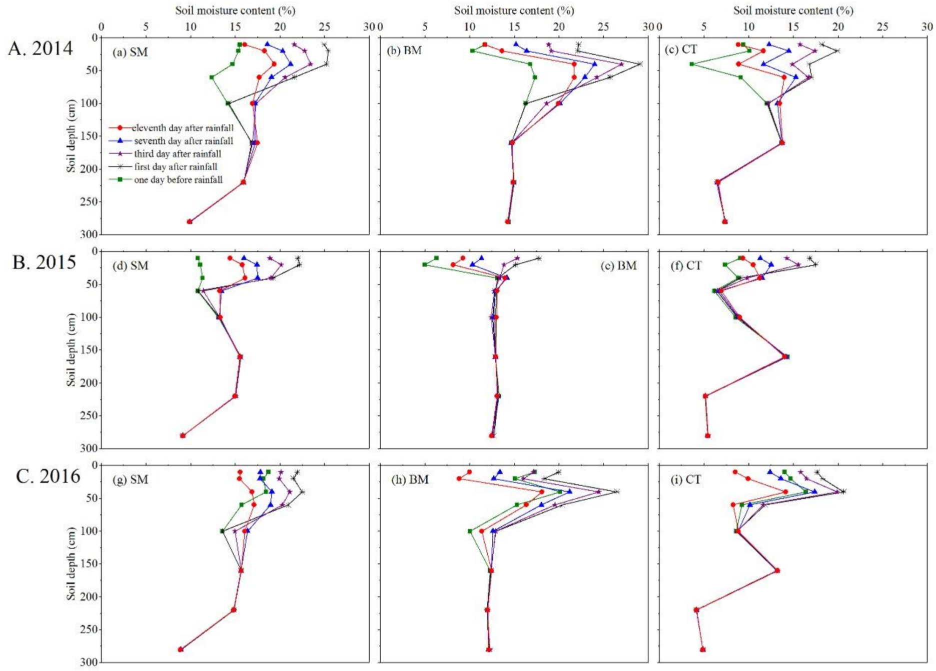

Figure 6. Soil moisture loss over time from the 0–280 cm profile under different mulching treatments, namely, (a,d,g) SM, (b,e,h) BM, and (c,f,i) CT, after typical rainfall in (**A**) 2014, (**B**) 2015, and (**C**) 2016.

4. Discussion

4.1. Soil Moisture Dynamic Changes and Their Attenuation Characteristics after Typical Rainfall in the Rain-Fed Jujube Orchard

Affected by rainfall and evapotranspiration, the soil moisture of the rain-fed jujube orchard in the loess hilly region presented dynamic and hierarchical characteristics in its profile. The soil moisture in the 0–60 cm soil layer of the jujube orchard fluctuated violently (Figure 4a), which was a seasonal fluctuation layer, mainly because the soil moisture was greatly affected by rainfall and evaporation. The 0–60 cm soil layer of the rain-fed jujube orchard without mulch had a soil moisture content lower than the wilting moisture and became a low-humidity zone during the fruit spreading growth stage in 2015 and 2016 (Figure 4a). Jujube trees are very sensitive to moisture in the fruit spreading growth stage [29], and a lack of soil moisture during this period will significantly affect fruit expansion, resulting in lower yield and fruit deformity. The soil moisture in the 60–160 cm soil layer was less affected by rainfall (Figure 4b), and the soil moisture in the 160–280 cm soil layer was hardly affected by rainfall (Figure 4c). The 160–280 cm soil layer under CT formed a perennial low humidity zone in the three experimental years (Figure 4c), indicating that the rain-fed jujube orchard did not form a soil reservoir that can regulate jujube growth under natural rainfall. Once entering a dry year, the jujube growth is bound to be adversely affected.

As the drought continued after a typical rainfall, the rain-fed jujube orchard covered with straw and jujube branches had a lower soil moisture loss rate than under the CT treatment (Figure 6). The reason may be that the covering materials used can effectively block solar radiation, weaken the gas exchange between the soil and the air, reduce the heat supply to the soil moisture evaporation process, greatly reduce the surface soil temperature, and hinder the soil moisture evaporation, thereby playing a role in soil moisture conservation, which is conducive to soil water storage [30,31].

4.2. Suggestions for Soil Moisture Management in Rain-Fed Jujube Orchards

Soil moisture is a key factor that determines the success or failure of artificial afforestation in the loess hilly region. Unreasonable afforestation is likely to cause soil drought, restrict the growth of artificial forests, and lead to a decline in artificial forests [32,33]. The results showed that both straw mulching and jujube branch mulching could well enhance soil water storage capacity (Figure 5), reduce the amount of water consumption during the whole growth period (Table 2), and improve the soil moisture environment in the rain-fed jujube orchard, which is consistent with previous research results [34,35]. In this study, straw mulching was better than jujube branch mulching in improving the soil moisture environment in the rain-fed jujube orchard. Although jujube branch mulching can also intercept rainwater, store water, and reduce soil moisture evaporation, the number of branches pruned from jujube trees is extremely limited, making it difficult to meet the demand for the large-scale coverage of jujube orchards. The reason why straw mulching has a better moisture retention effect may be that the supply of straw is sufficient, which can minimize ineffective soil evaporation. In addition, compared to jujube branches, straw has a larger specific surface area, which affords it a strong adsorption capacity for rainfall and water vapor [36], and straw has a lower porosity, which blocks the direct water connection between the soil surface and the atmosphere, weakens the convection exchange between the air in the soil and the atmosphere, and inhibits soil evaporation, thus improving the soil moisture content, showing a good performance in soil moisture conservation [37]. The improvement of a soil moisture environment plays an important role in the growth of rain-fed jujube trees. Therefore, it is recommended to use straw mulching in rain-fed jujube orchards in the loess hilly region to ensure the efficient use of natural precipitation and the healthy and sustainable development of jujube orchards. Compared to bare soil without mulching, jujube branch mulching also has a good moisture retention effect. If the pruned jujube branches are discarded and burned, this not only pollutes the environment but also increases transportation costs. Thus, if jujube branches and straw are combined to cover the soil surface of a rain-fed jujube orchard, whether it can achieve a good moisture preservation effect is a topic worthy of study.

5. Conclusions

(1) The 0–60 cm soil layer of the rain-fed jujube orchard was the seasonal fluctuation layer of the soil moisture under straw mulching (SM), jujube branch mulching (BM), and clean tillage (CT) in both the normal precipitation years and the dry year. The 0–60, 60–160, and 160–280 cm soil layers under CT all obtained the lowest soil moisture content in the three experimental years, and the 160–280 cm soil layer formed a perennial low-humidity zone. The soil moisture content of each soil layer under SM and BM was higher than that under CT, and SM had the most obvious effect of improving soil moisture.

(2) SM and BM showed significant soil water storage effects in all of the jujube growth stages in both the normal precipitation years and the dry year, and SM had a better water storage effect than BM.

(3) SM and BM reduced the amount of water consumption in each jujube growth stage. SM and BM increased the water consumption percentage in the emerging, leafing,

blossoming and bearing fruit stages in the three experimental years. SM reduced the percentage of water consumption in the fruit spreading growth stage. During the fruit maturity stages in the normal precipitation years, SM and BM both reduced the water consumption percentage, while in the dry year, they increased the percentage of water consumption. The effect of SM on the amount and percentage of water consumption was more obvious than that of BM.

(4) The soil moisture loss rate of CT was significantly higher than that of SM and BM under continuous drought after rainfall. With the extension of drought, the soil moisture loss rate under SM increased slowly, while it increased rapidly under CT.

In conclusion, it is recommended to adopt mulching measures in rain-fed jujube orchards in the loess hilly region to ensure the efficient utilization of precipitation and the sustainable development of said jujube orchards. Straw mulching is the best mulching measure, while pruned jujube branches can also cover a rain-fed jujube orchard in situ, which can achieve a certain moisture conservation effect.

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