Mulching measures improve soil moisture in rain-fed jujube orchard in the loess hilly region of China

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Abstract

Background: Water shortage is the main bottleneck restricting the healthy and sustainable development of rain-fed jujube orchards in the loess hilly region of China. Given the functions of mulching on soil moisture conservation, evaporation reduction, and water use efficiency improvement, maize straw mulching (SM) and pruned jujube branch mulching (BM) were applied to rain-fed jujube orchards 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 systematically studied.

Results: (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. 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. The soil moisture content of each soil layer under SM and BM was higher than that under CT, and SM showed the most obvious effect of increasing soil moisture. (2) SM and BM showed significant soil water storage effect in all the jujube growth stages in both the normal precipitation year and the dry year, and SM had a better water storage effect than BM. (3) SM and BM reduced the water consumption amount in each jujube growth stage. SM reduced water consumption amount by 94.3, 60.8, and 121.3 mm compared with CT in the whole growth period of jujube in 2014, 2015, and 2016, respectively. The water consumption amount of BM decreased by 34.8 mm and 31.0 mm respectively compared with that of CT in the whole growth period in 2014 and 2015.

(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 the typical rainfall in 2014, 2015, and 2016. With the extension of drought, the soil moisture loss rate under SM increased slowly, while it increased rapidly under CT.

Conclusion: This study suggests that straw mulching is the best mulching measure for rain-fed jujube orchards, and the pruned jujube branches can also be used for in-situ mulching, which can also obtain a certain moisture conservation effect.

Keywords: Soil moisture, Water consumption, Continuous drought, Mulching, Jujube

1. Introduction

The loess hilly region of China is characterized by the dry climate, strong evaporation, scarce precipitation and uneven seasonal distribution, and the mismatch between natural precipitation and crop water demand (Yang et al., 2018; Feng et al., 2020). The topography of the loess hilly region is dominated by sloping land, many of which have great gradient and loose soil structure, resulting in serious soil erosion (Song et al., 2018; Yang and Lu, 2018). In addition, there is little irrigation in the loess hilly region, and most of the crop growth depends on natural precipitation (Qin et al., 2014; Gao et al., 2020). Water shortage severely restricts the development of agriculture and forestry in the loess hilly region (Jin et al., 2018). How to reasonably and efficiently utilize the limited natural precipitation in the loess hilly region has become the focus and main trend.

As the main economic forest and ecological forest for soil and water conservation in the loess hilly region, the jujube cultivation area has expanded rapidly in recent years, and it has exceeded one million hectares (Chen et al., 2014; Ling et al., 2017). The traditional clean tillage is currently widely used in jujube orchards, that is, weeds are manually removed many times and the soil is not loosened during the jujube growth period (Huang et al., 2016). Clean tillage has the advantages of pest control and seedling raising for orchard, with good short-term effects. However, many studies have found that long-term clean tillage will cause serious soil erosion, a decline in soil fertility, deterioration of soil properties, destruction of ecological balance, and ultimately lead to premature ageing of fruit trees, reduction of fruit yield, and deterioration of fruit quality, which is not conducive to the sustainable development of orchards (Pearson, 2002; Hao et al., 2016; Mikha et al., 2017).

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 is beneficial to promote crop growth and water use efficiency (Kader et al., 2017). At present, some 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 (Jafari et al., 2012; Adak et al., 2014; Sofo et al., 2014; Wang et al., 2015; Almagro et al., 2017; Zheng et al., 2017; Li et al., 2018). These researchers 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 background, maize straw and pruned jujube branches were used to cover the soil surface of the 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, efficient utilization of precipitation resources, and 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, which is located in the loess hilly region. The climate of the study site belongs to the warm temperate continental monsoon semi-arid climate, with annual average precipitation of 505 mm, of which the precipitation from June to August accounts for about 80% of the total annual precipitation (Fig. 1). The annual average air temperature at the study site is 9.6℃, with an average air temperature of -6.8℃ in January and 23.8℃ in July (Fig. 1). 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 hours and frost-free period of 160-170 days.

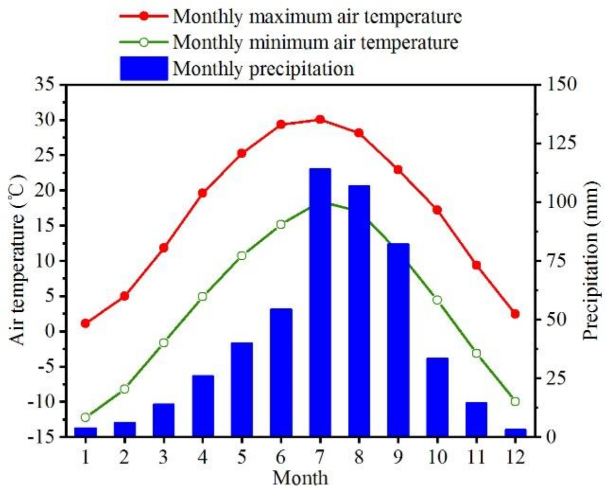

Fig. 1. Climate background of the study site. Air temperature and precipitation data were obtained from the statistical data released by the National Meteorological Center of CMA, and the URL is http://www.nmc.cn/publish/forecast/ASN/qingjian.html.

As shown in Fig. 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. (2003), the year when the precipitation increases or decreases within 10% of the annual average precipitation during the crop growth period is the normal precipitation year, and the year when the precipitation decreases more than 10% than the annual average precipitation during the crop growth period is the 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 strong infiltration capacity. The main physical properties of the 0-100 cm soil layer at the study site are shown in Table 1.

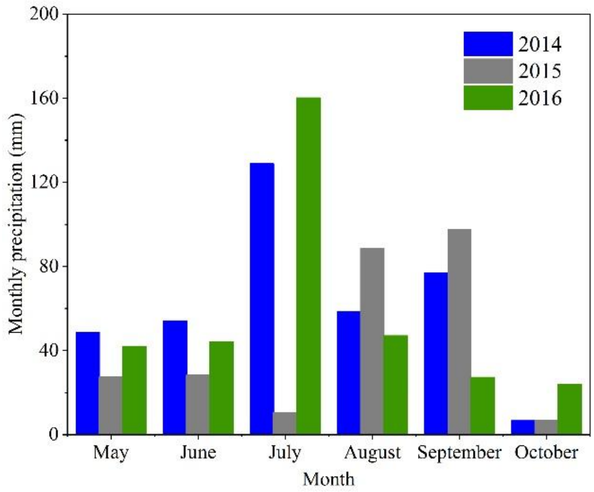

Fig. 2. Monthly precipitation during the jujube growth period in 2014, 2015, and 2016. Since the jujube growth period ended in mid-October, the precipitation from October 1 to October 15 was counted as the precipitation in October.

Table 1 Soil properties of 0-100 cm layer at the study site.

Soil layer	Bulk density	Soil particle composition			K_{sat}	θ_s	θ_{33kPa}	$\theta_{1500kPa}$
cm	$g\cdot cm^{-3}$	Sand/%	Silt/%	Clay/%	$mm\cdot min^{-1}$	$cm^3\cdot cm^{-3}$	$cm^3\cdot cm^{-3}$	$cm^3\cdot cm^{-3}$
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

Soil particle composition: Sand% (2-0.02 mm), Silt% (0.02-0.002 mm), and Clay% (<0.002 mm); K_{sat}: saturated hydraulic conductivity; θ_s: saturated moisture; θ_{33kPa}: soil moisture content at 33 kPa; $\theta_{1500kPa}$: 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. The jujube variety was Lizao, which was planted in 2003 and was in the full bearing period during the experiment. According to jujube growth characteristics, the jujube growth period was divided into four stages, namely, the emerging and leafing stage (early May to mid-June), blossoming and bearing fruits stage (mid-June to mid-July), fruit spreading growth stage (mid-July to mid-September), and fruit maturity stage (mid-September to mid-October). The plant spacing and row spacing of jujube trees were 2 m 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. Jujube trees were pruned to a height of about 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, and a total of six experimental plots were studied. 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. Soil volumetric moisture content was measured by EC-5 soil moisture sensor (Decagon Devices Inc., Pullman, WA) at a frequency of 10 minutes. 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 (Li et al., 2015), the observation depth of soil moisture was 10, 20, 40, 60, 100, 160, 220, and 280 cm (Fig. 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., USA) about 100 m away from the experimental jujube orchard.

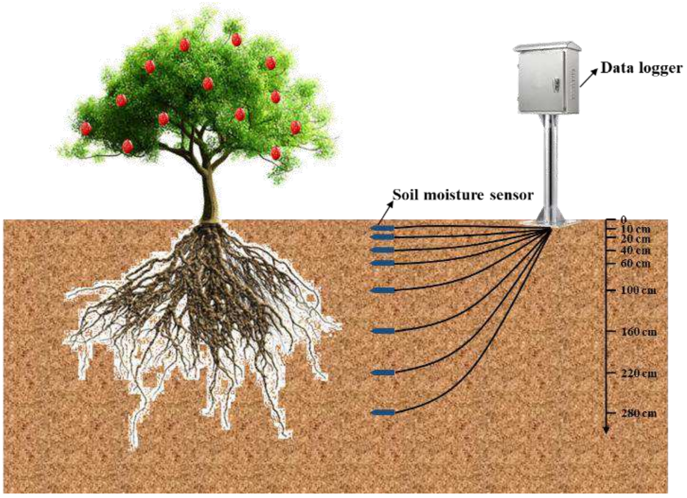

Fig. 3. Schematic diagram of soil moisture sensor layout.

2.4. Data analysis

Soil water storage (W, mm) was calculated using the following formula (Song et al. 2012):

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

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).

Crop water consumption, namely evapotranspiration (ET, mm), includes crop transpiration (T, mm) and soil evaporation (E, mm), which can be calculated using the soil water balance equation (Ritchie, 1985):

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

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 end and beginning of the calculation period (mm).

The experimental jujube orchard was rain-fed without irrigation, so I=0. The buried depth of groundwater in the study area exceeds 50 m, so it can be considered that U=0 (Li, 2016). The study area has a deep soil layer and strong water storage capacity, so stored-full runoff rarely occurs. For the runoff yield in excess of infiltration caused by heavy rain, since the 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. (1989) found that the soil water storage capacity of the Loess Plateau is 200-250 mm·m^{-1}, and the soil can still hold about 100 mm·m^{-1} of water after it has accumulated some water. This study focuses on the 0-280 cm soil layer, which can store about 280 mm of precipitation, much higher than the maximum precipitation in the study area, so the deep percolation will not occur after rainfall, that is, D=0. 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 is negligible, that is, IN=0. The calculation equation of ET can be simplified as:

$$ET = P - \Delta W \tag{4}$$

The water consumption percentage (CP) was obtained according to Huang et al. (2013) as follows:

$$CP = WC_i / WC_T \times 100\%$$

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

Soil moisture loss rate ($SMLR$) was estimated from the following equation (Huang et al. 2007):

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

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 a rainfall.

Statistical analysis was performed using Microsoft Excel 2013 (Microsoft, Redmond, Washington, USA) and SPSS 20.0 (IBM Corp., Armonk, NY, USA). Independent samples t-test was conducted to compare the differences of 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 rain-fed jujube orchard under different mulching measures

According to the distribution characteristics of fine roots of jujube trees, the soil profile was divided into fine root dense layer (0-60 cm), fine root diffuse layer (60-160 cm), and 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 (Fig. 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 (Fig. 4a). The soil moisture in this soil layer increased rapidly after effective rainfall and then decreased with the continuous drought. CT obtained the lowest soil moisture content in three growing seasons. Especially in multiple periods of 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 fruits stage, fruit spreading growth stage, and fruit maturity stage in 2016 was 0.21, 0.44, and 1.64℃ higher than that in the same period in 2015, which led to the increase of soil evaporation, making the soil moisture content in the fine root dense layer under CT continuously lower than the wilting moisture from the blossoming and bearing fruits stage to the fruit maturity stage in 2016, which resulted in the formation of 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% respectively in the growing seasons of 2014, 2015, and 2016 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% respectively in the growing seasons of 2014, 2015, and 2016 compared to CT ($p < 0.05$).

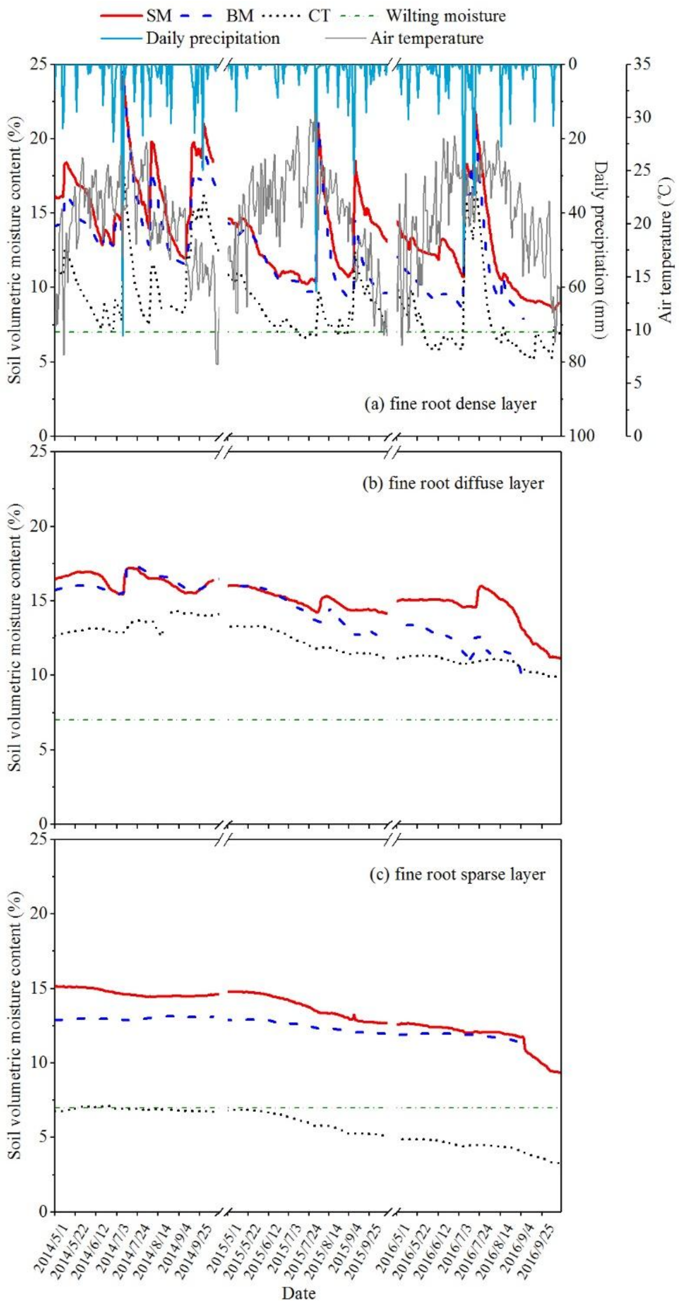

Fig. 4. Daily average soil volumetric moisture content changes in (a) fine root dense layer, (b) fine root diffuse layer, and (c) fine root sparse layer under different mulching treatments during the jujube growth period in 2014, 2015, and 2016.

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 (Fig. 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% respectively compared with CT in the growing seasons of 2014, 2015, and 2016 ($p < 0.05$). The soil moisture in the fine root sparse layer was hardly affected by rainfall (Fig. 4c). The soil moisture content of the fine root sparse layer under CT was lower than the wilting moisture in 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 with CT ($p < 0.05$).

3.2. Soil water storage of rain-fed jujube orchard under different mulching measures

The mulching treatments (SM and BM) showed the obvious effect of increasing soil moisture at each growth stage both in normal precipitation year and dry year (Fig. 5). In the emerging and leafing stage, the water storage of 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 fruits 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, soil water storage of SM and BM was 41.5% and 38.9% higher than that of CT in 2014, 60.4% and 49.0% higher than that of CT in 2015 (Fig. 5a, b). Soil water storage under SM was still 105.4 mm higher than that under CT in 2016 (Fig. 5c). The effect of SM on increasing moisture at each growth stage was better than that of BM in three experimental years.

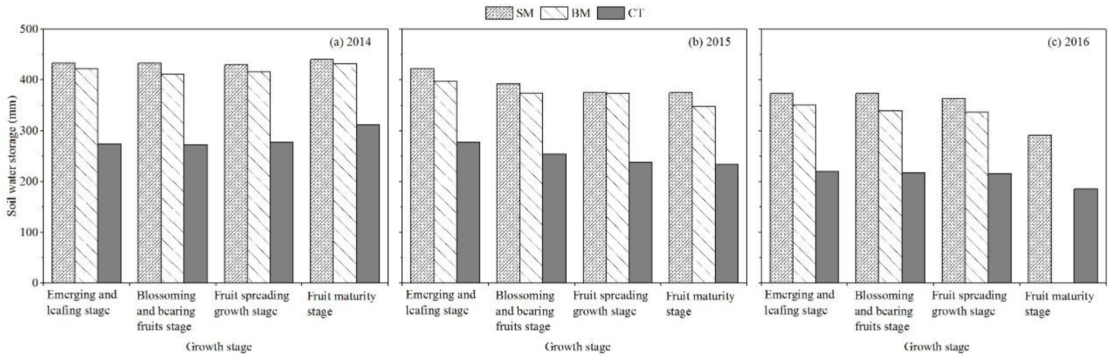

Fig. 5. Soil water storage of 0-280 cm soil layer under different mulching treatments in different jujube growth stages in 2014, 2015, and 2016. Due to the malfunction of the soil moisture monitoring device under BM treatment in the 2016 fruit maturity stage, the collected soil moisture data were incorrect, and the soil water storage under BM treatment could not be calculated in this period.

In the growing season of 2014, the water storage of 0-280 cm soil layer under all experimental treatments gradually decreased from the emerging and leafing stage to the blossoming and bearing fruits stage, and then gradually increased due to the supplement of a large amount of rainfall during fruit spreading growth stage and fruit maturity stage (Fig. 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 (Fig. 5b, c).

3.3. Water consumption amount and water consumption percentage of jujube trees under different mulching measures

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

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

Year	Mulching treatment	Emerging and leafing stage		Blossoming and bearing fruits stage		Fruit spreading growth stage		Fruit maturity stage		Whole growth period
		ET(mm)	CP(%)	ET(mm)	CP(%)	ET(mm)	CP(%)	ET(mm)	CP(%)	ET(mm)
2014	SM	60.1	19.8	97.7	32.3	92.8	30.6	52.3	17.3	302.9
	BM	61.9	17.1	105.9	29.2	135.1	37.3	59.5	16.4	362.4
	CT	62.8	15.8	109.7	27.6	144.7	36.4	80.1	20.2	397.2
2015	SM	51.6	22.5	45.4	19.8	80.4	35.0	52.2	22.7	229.7
	BM	53.7	20.7	48.9	18.8	101.7	39.2	55.2	21.3	259.4
	CT	55.3	19.0	54.4	18.7	124.2	42.8	56.5	19.5	290.5
2016	SM	76.5	22.6	76.1	22.5	137.2	40.5	48.8	14.4	338.6
	BM	88.5	-	95.0	-	178.1	-	-	-	-
	CT	88.7	19.3	98.8	21.5	202.7	44.1	69.6	15.1	459.9

The water consumption amount and water consumption percentage of the experimental rain-fed jujube orchard were significantly different in different growth stages (Table 2). In the emerging and leafing stage, the water consumption amount of 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% respectively compared with that of CT during the growth period in 2014, 2015, and 2016. The water consumption percentage under BM increased by 1.3% and 1.6% respectively in 2014 and 2015 compared with CT. Similar to the previous growth stage, during the blossoming and bearing fruits stage, the mulching treatments had the effects of reducing water consumption amount and increasing the water consumption percentage in the three experimental years, of which SM had the most obvious effect. 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 different precipitation years. In the fruit spreading growth stage in 2014, 2015, and 2016, SM reduced water consumption amount by 35.9%, 35.3%, and 32.3%, respectively, and reduced water consumption percentage by 5.8%, 7.8%, and 3.6%, respectively, compared to CT. Compared with CT, the water consumption amount of BM was reduced by 6.6%, 18.1%, and 12.2% respectively during the fruit spreading growth stage in 2014, 2015, and 2016. With the advancement of the growth stage, during the fruit maturity stage, the water consumption amount under SM was reduced by 7.6%-34.7% compared with 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. SM and BM both had the effect of reducing the water consumption percentage 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 three experimental years for study, i.e. one typical rainfall occurred from July 8 to 9, 2014 with a total rainfall of 86.6 mm, another typical rainfall occurred from September 9 to 10, 2015 with a total rainfall of 51.6 mm, and the other typical rainfall occurred from July 18 to 19, 2016 with a total rainfall of 59.2 mm. There was no effective rainfall (> 5 mm) in 2 days before and 11 days after the above three typical rainfalls.

Affected by rainfall and evapotranspiration, the vertical distribution of soil moisture in the experimental rain-fed jujube orchard under different mulching measures was different (Fig. 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 soil moisture increase (Fig. 6A), indicating this typical rainfall mainly supplemented the soil moisture of 0-60 cm soil layer for these three experimental treatments. The typical rainfall in 2015 supplemented soil moisture of 0-60 cm, 0-40 cm, and 0-20 cm soil layers for SM, BM, and CT, respectively (Fig. 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 soil moisture increase (Fig. 6C).

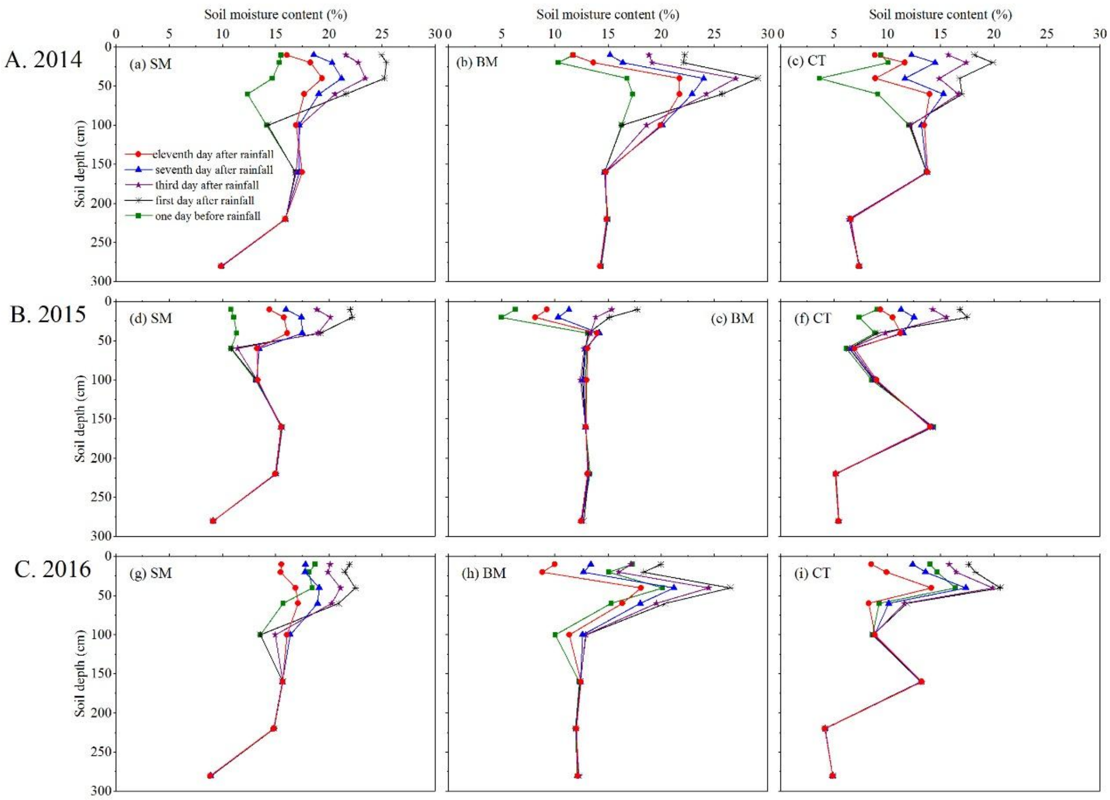

Fig. 6. Soil moisture loss over time from the 0 to 280 cm profile under different mulching treatments after typical rainfall in (A) 2014, (B) 2015, and (C) 2016.

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

4. Discussion

4.1. Soil moisture dynamic changes and its attenuation characteristics after typical rainfall in 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 the profile. The soil moisture in the 0-60 cm soil layer of the jujube orchard fluctuated violently (Fig. 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 (Fig. 4a). Jujube trees are very sensitive to moisture in the fruit spreading growth stage (Ma et al., 2020). The 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 (Fig. 4b). The soil moisture in 160-280 cm soil layer was hardly affected by rainfall (Fig. 4c). The 160-280 cm soil layer under CT formed a perennial low humidity zone in three experimental years (Fig. 4c), indicating that the rain-fed jujube orchard did not form a soil reservoir that can regulate the jujube growth under natural rainfall. Once in a dry year, the jujube growth is bound to be adversely affected.

As the drought continued after typical rainfall, the rain-fed jujube orchard covered with straw and jujube branches had a lower soil moisture loss rate than the clean tillage treatment (CT) (Fig. 6). The reason may be that the covering materials can effectively block solar radiation, weaken the gas exchange between the soil and the air, reduce the heat supply to the soil moisture evaporation, greatly reduce the surface soil temperature, hinder the soil moisture evaporation, to play a role of soil moisture conservation, which is conducive to soil water storage (Hou and Li, 2019; Zheng et al., 2019).

4.2. Suggestions on soil moisture management in rain-fed jujube orchard

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 decline of artificial forests (Jia et al., 2017; Liang et al., 2018). The results showed that both straw mulching and jujube branch mulching could well enhance soil water storage capacity (Fig. 5), reduce water consumption amount during the whole growth period (Table 2), and improve the soil moisture environment in the rain-fed jujube orchard, which was consistent with previous research results (Pan et al., 2018; Wang et al., 2018). In this study, straw mulching was better than jujube branch mulching in improving the soil moisture environment in 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, which is difficult to meet the demand for 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 with jujube branch, straw has a larger specific surface area, which makes it have strong adsorption for rainfall and water vapour (Blanco-Canqui and Lal, 2007), and straw has a smaller 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 the soil evaporation, thus improving the soil moisture content, showing a good performance in soil moisture conservation (Chen et al., 2019). The improvement of 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 with the bare soil without mulching, the 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. So if the jujube branches and straw are combined to cover the soil surface of the rain-fed jujube orchard, whether it can achieve a good moisture preservation effect is a topic worthy of study.

5. Conclusions

In this study, soil moisture dynamics, soil water storage, water consumption, and soil moisture attenuation after typical rainfall in rain-fed jujube orchards in the loess hilly region under straw mulching (SM), jujube branch mulching (BM), and clean tillage (CT) were studied, and the following results were obtained:

(1) The 0-60 cm soil layer of rain-fed jujube orchard was the seasonal fluctuation

layer of soil moisture under SM, BM, and CT in both the normal precipitation year 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 effect in all the jujube growth stages in both the normal precipitation year and the dry year, and SM had better water storage effect than BM.

(3) SM and BM reduced water consumption amount in each jujube growth stage. SM and BM increased the water consumption percentage in the emerging and leafing stage and blossoming and bearing fruits stage in the three experimental years. SM reduced the water consumption percentage in the fruit spreading growth stage. During the fruit maturity stage in the normal precipitation year, SM and BM both reduced the water consumption percentage; while in the dry year, they increased the water consumption percentage. The effect of SM on water consumption amount and water consumption percentage 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 to ensure efficient utilization of precipitation and sustainable development of jujube orchards. Straw mulching is the best mulching measure, and the pruned jujube branches can also cover the rain-fed jujube orchard in situ, which can achieve a certain moisture conservation effect.

Declarations

Ethics approval and consent to participate

No applicable.

Consent for publication

No applicable.

Availability of data and material

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Min Tang: Conceptualization, Methodology, Formal analysis, Investigation, Data Curation, Writing - Original Draft, Visualization. **Hongchen Li:** Investigation, Data Curation. **Chao Zhang:** Writing - Review & Editing, Funding acquisition. **Xining Zhao:** Conceptualization, Resources, Supervision, Funding acquisition. **Xiaodong Gao:** Writing

- Review & Editing, Project administration. **Pute Wu:** Conceptualization, Resources, Supervision, Funding acquisition.

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Figures

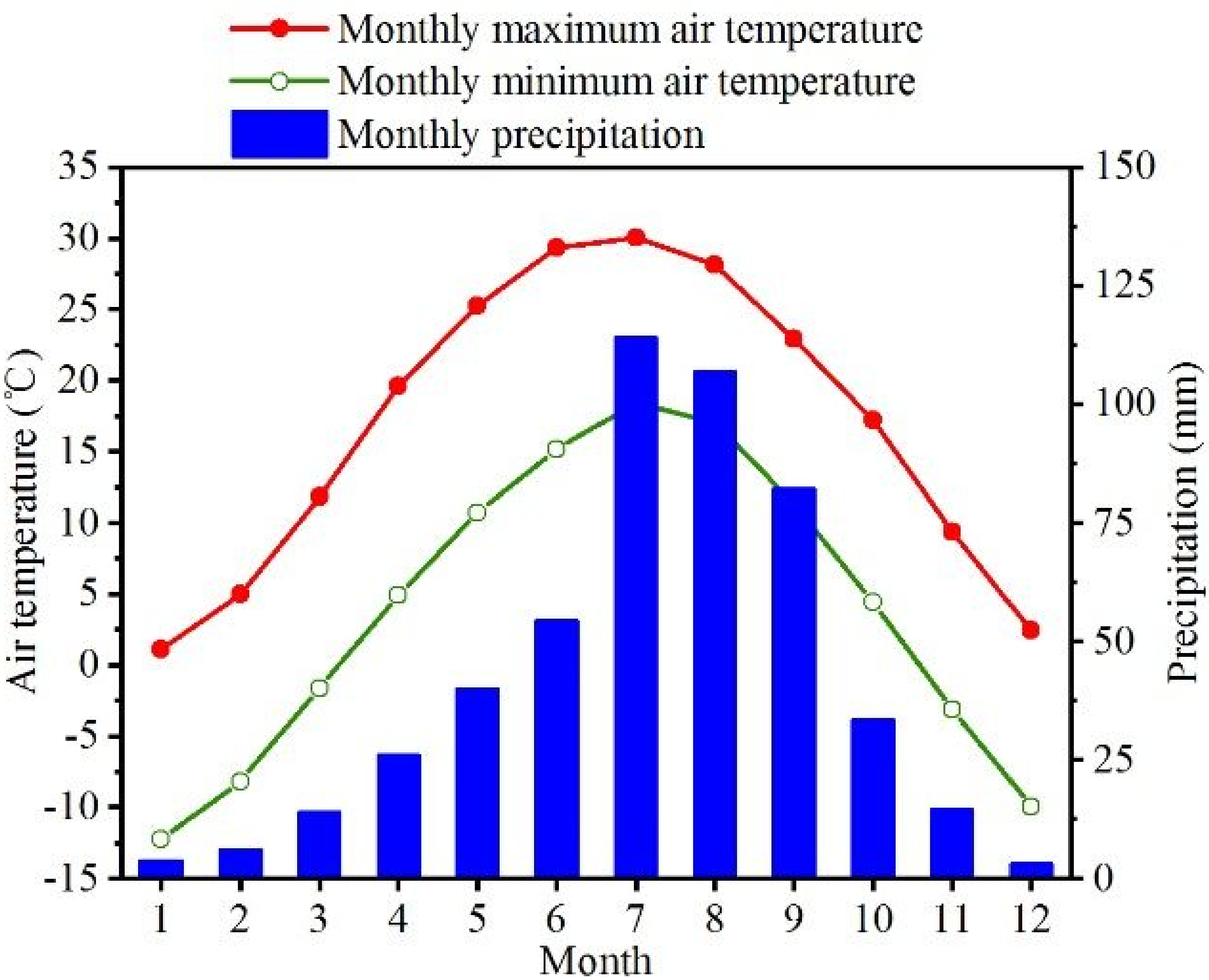
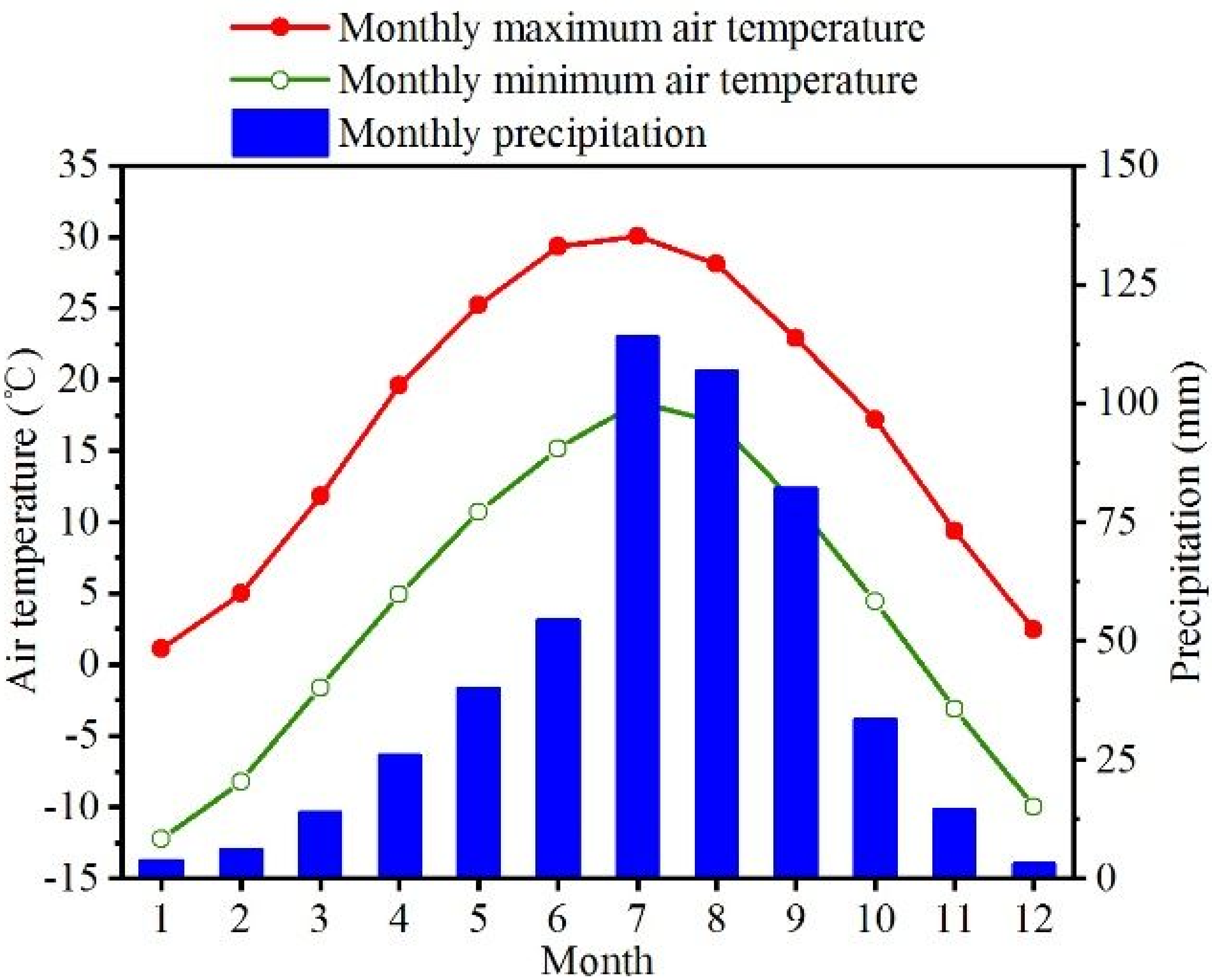


Figure 1

Climate background of the study site. Air temperature and precipitation data were obtained from the statistical data released by the National Meteorological Center of CMA, and the URL is http://www.nmc.cn/publish/forecast/ASN/qingjian.html.



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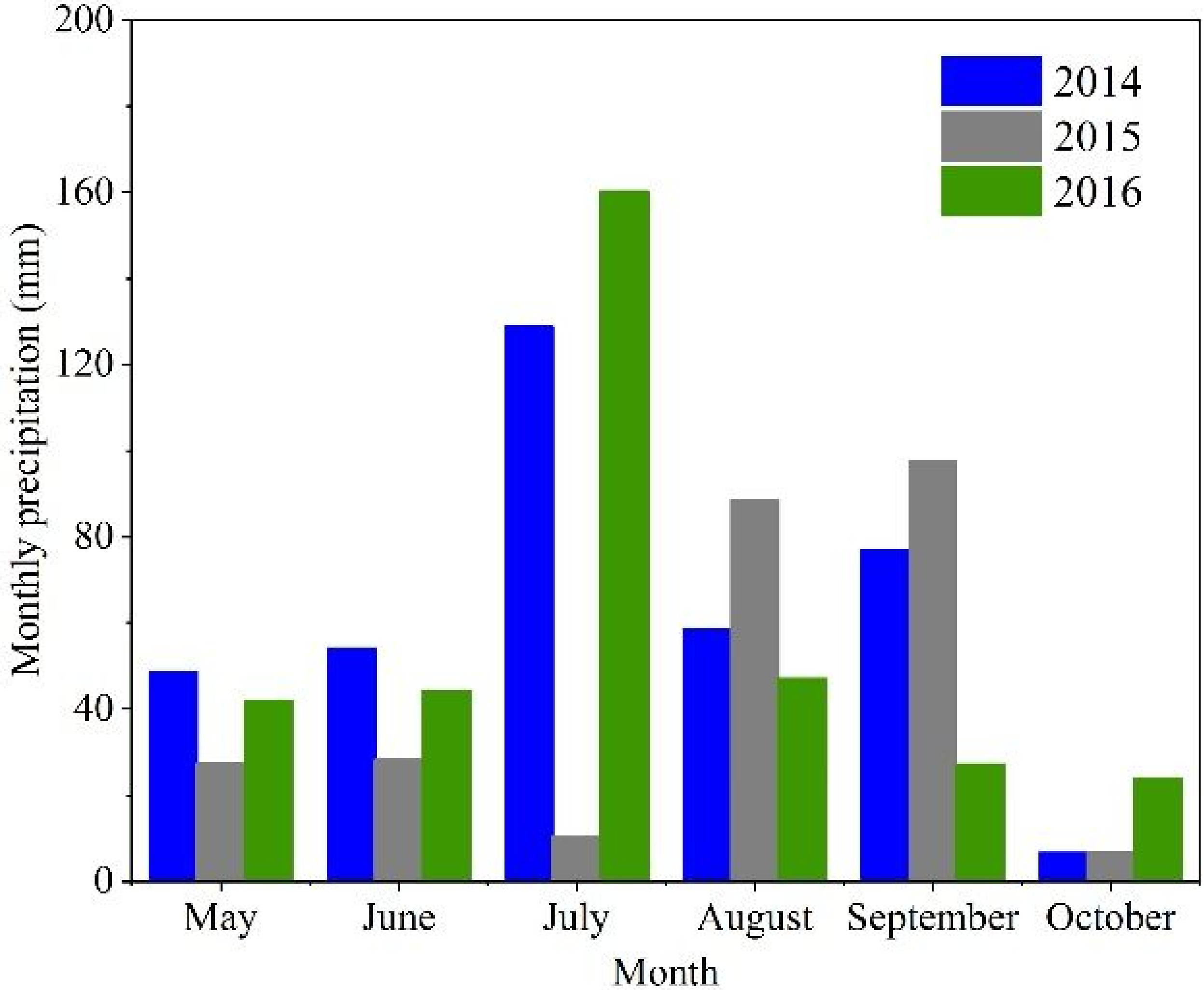
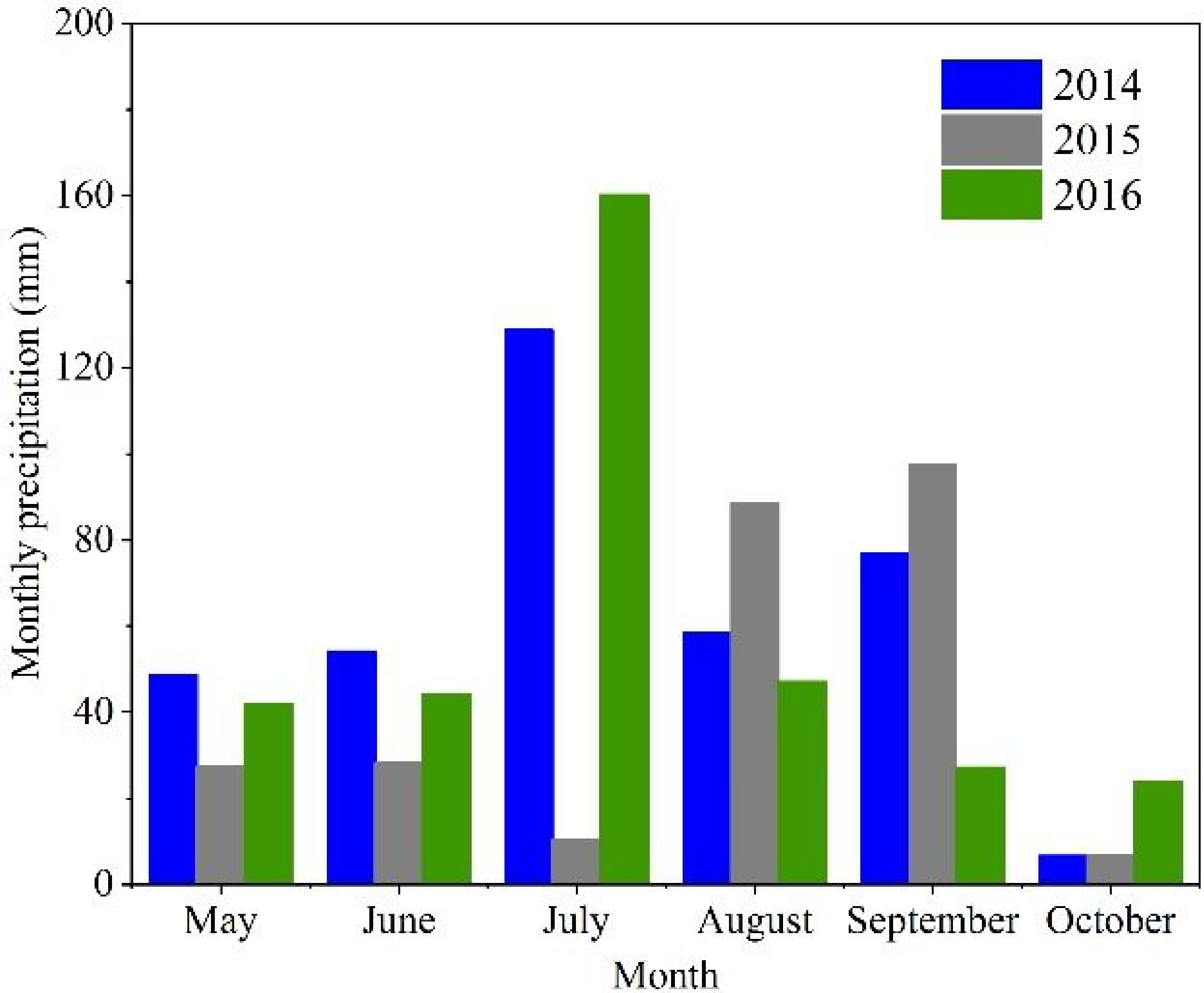


Figure 2

Monthly precipitation during the jujube growth period in 2014, 2015, and 2016. Since the jujube growth period ended in mid-October, the precipitation from October 1 to October 15 was counted as the precipitation in October.



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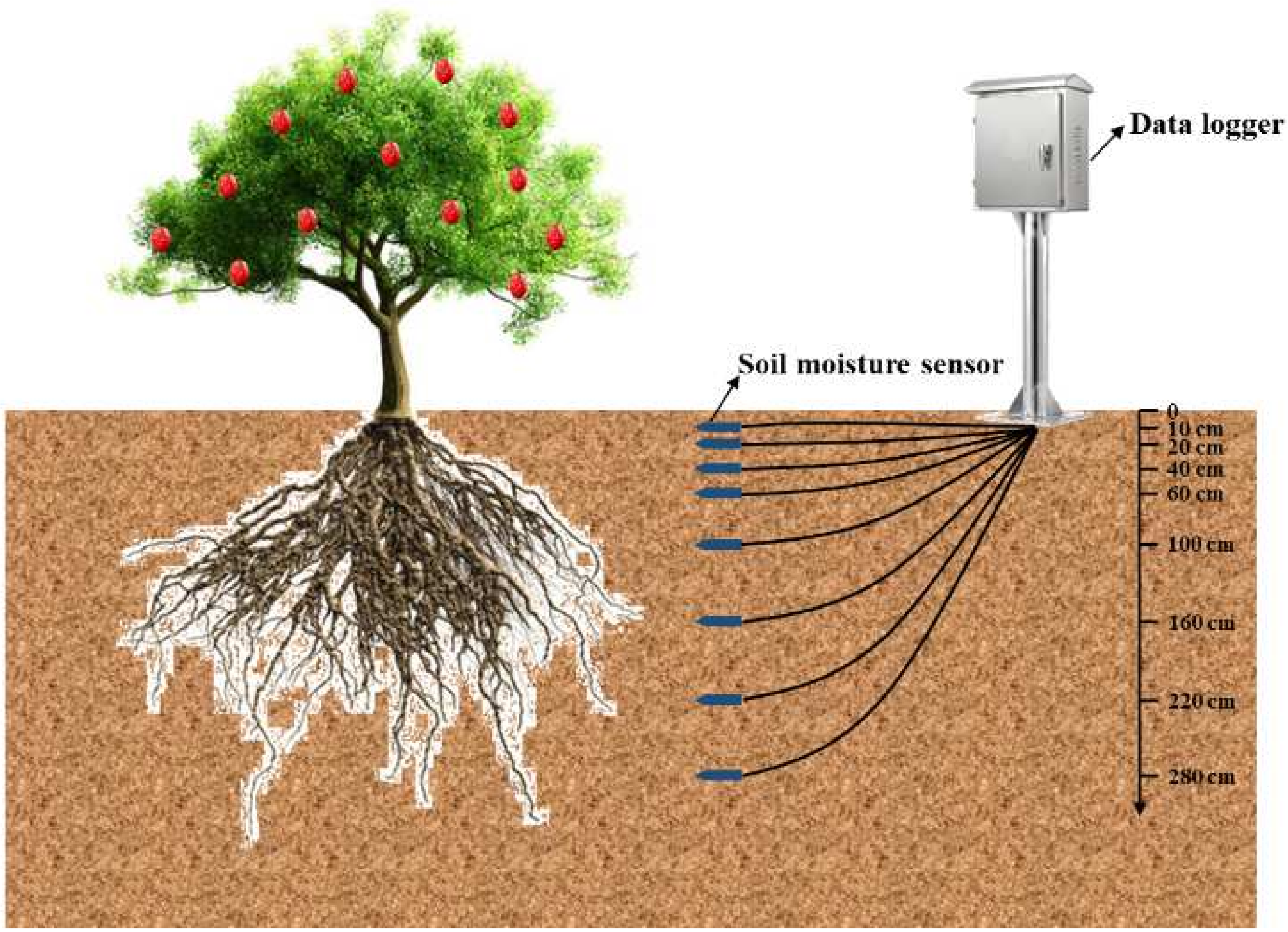
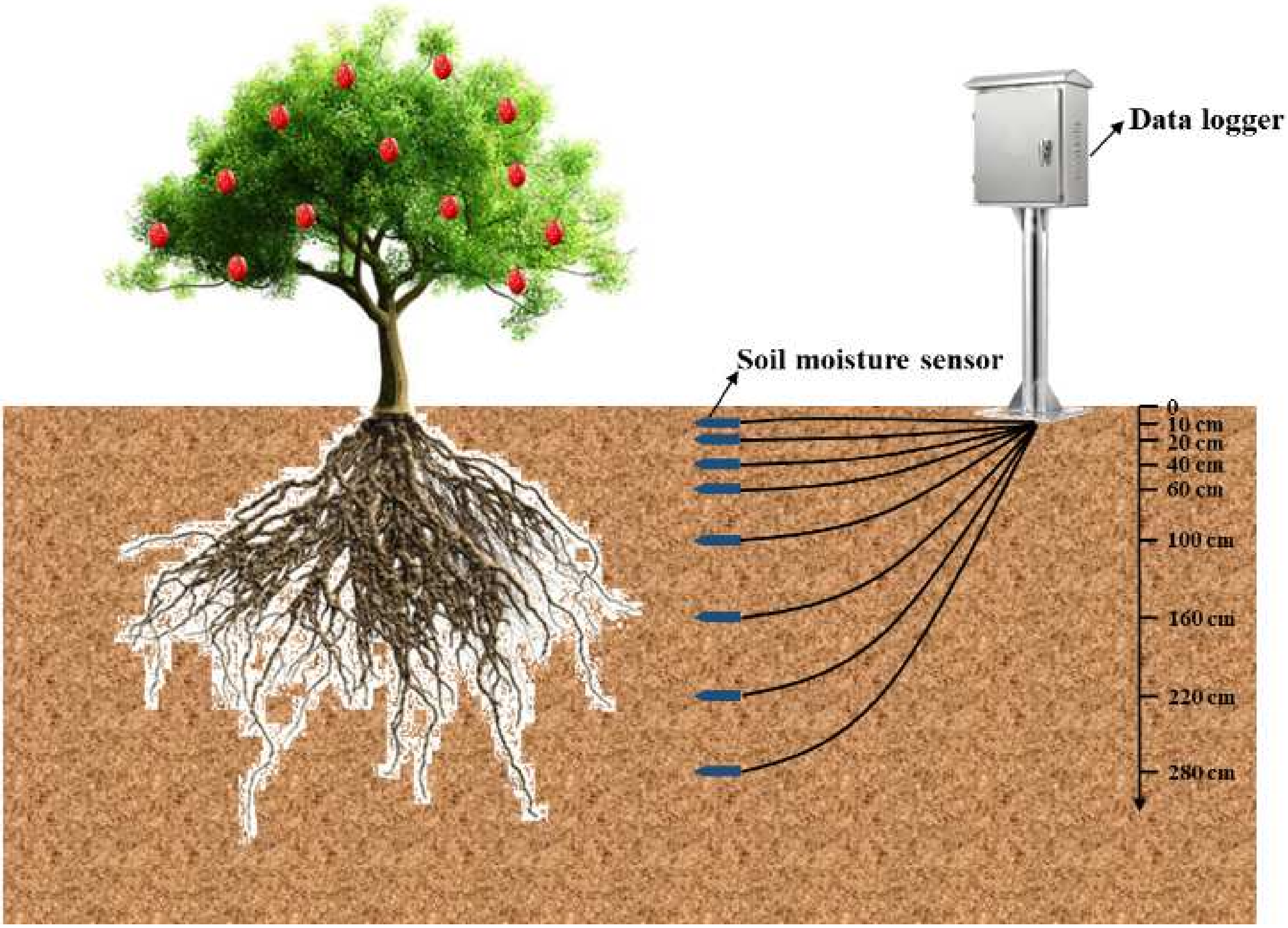


Figure 3

Schematic diagram of soil moisture sensor layout.



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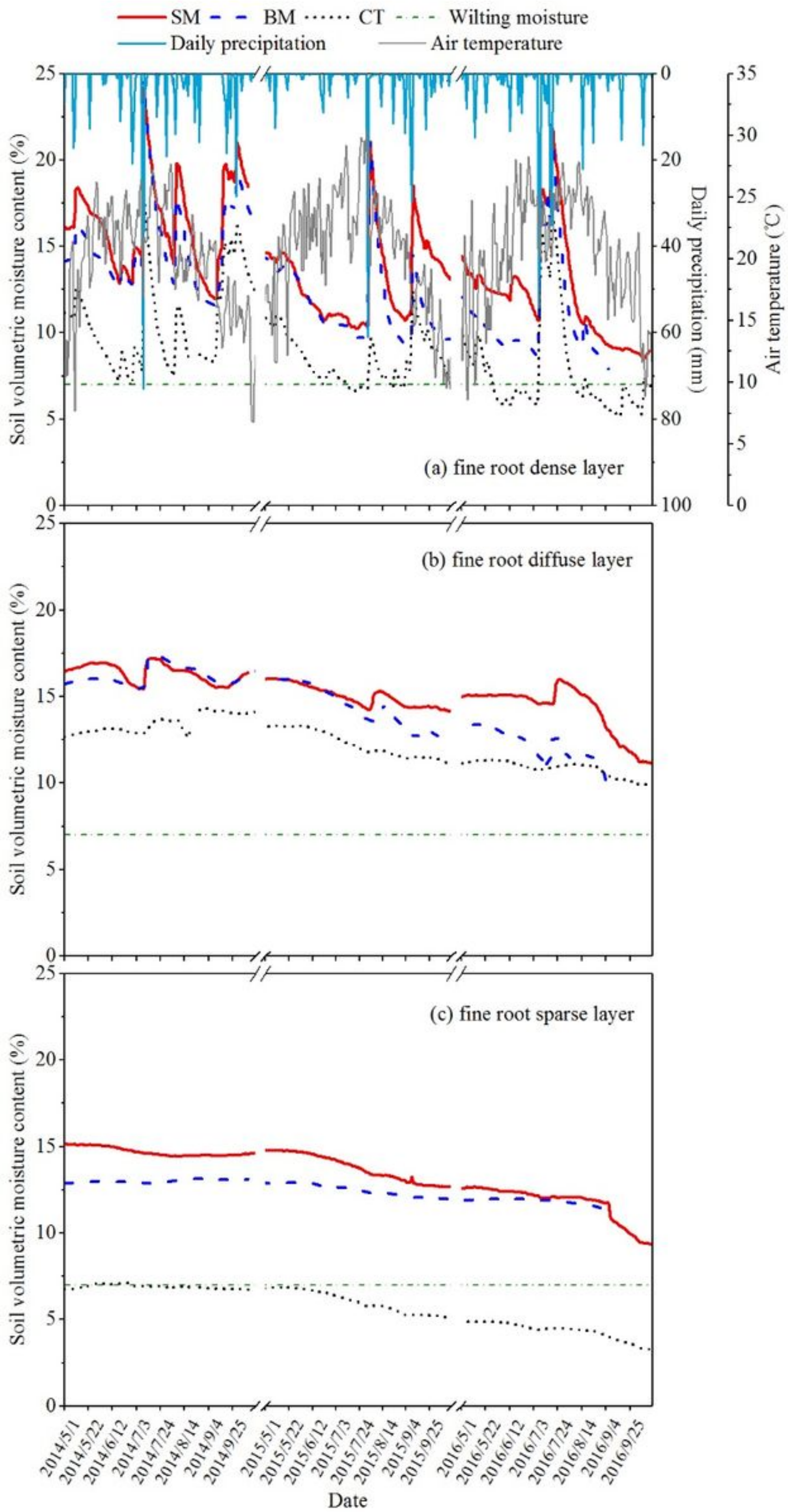
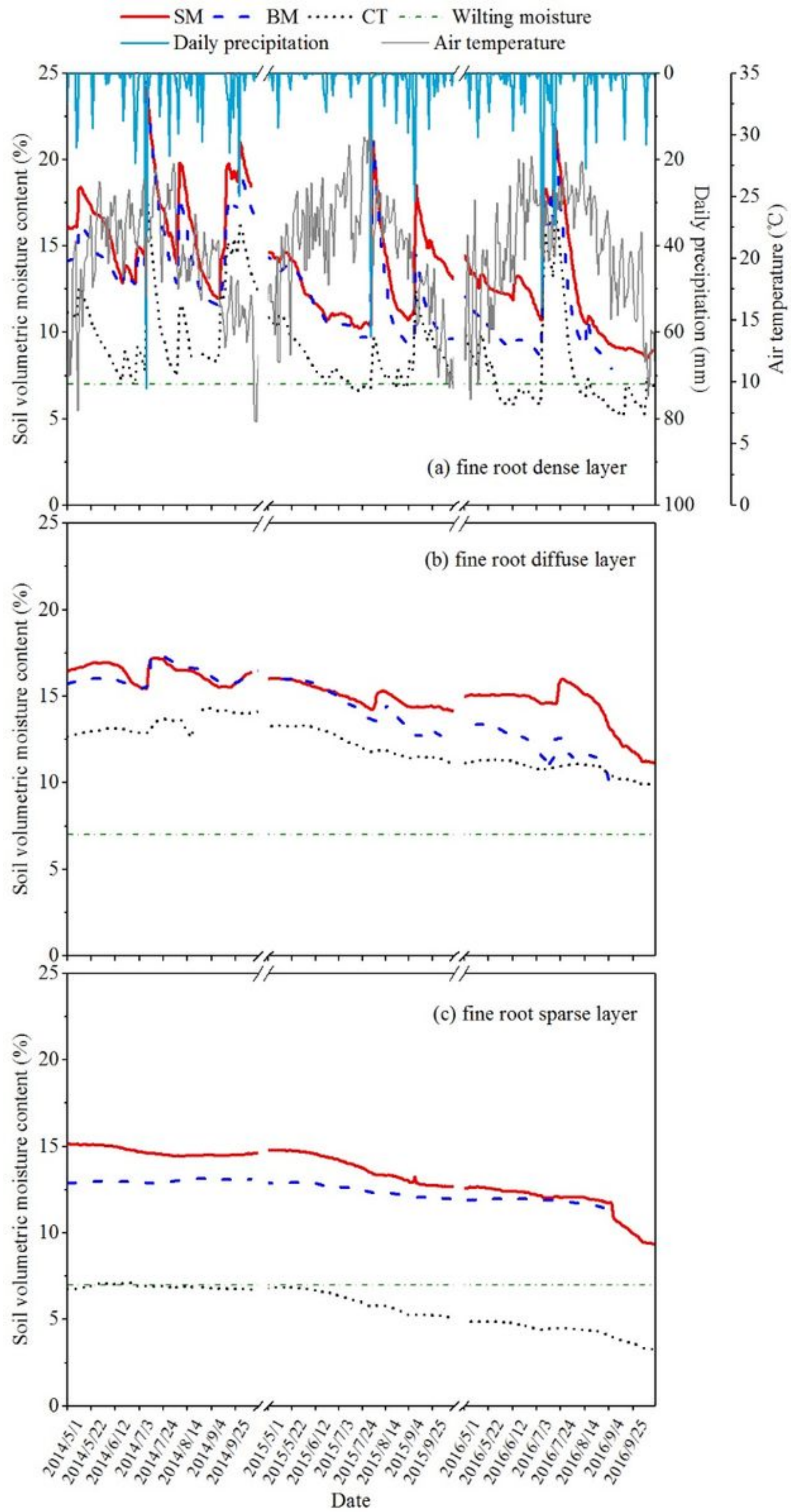


Figure 4

Daily average soil volumetric moisture content changes in (a) fine root dense layer, (b) fine root diffuse layer, and (c) fine root sparse layer under different mulching treatments during the jujube growth period in 2014, 2015, and 2016.



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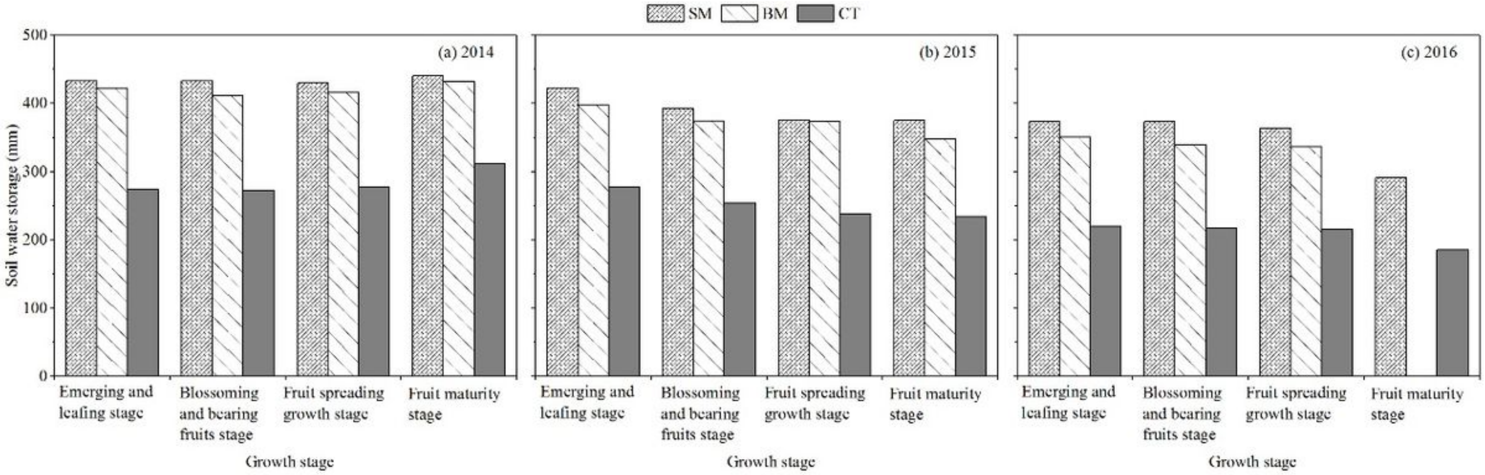

Figure 5

Soil water storage of 0-280 cm soil layer under different mulching treatments in different jujube growth stages in 2014, 2015, and 2016. Due to the malfunction of the soil moisture monitoring device under BM treatment in the 2016 fruit maturity stage, the collected soil moisture data were incorrect, and the soil water storage under BM treatment could not be calculated in this period.

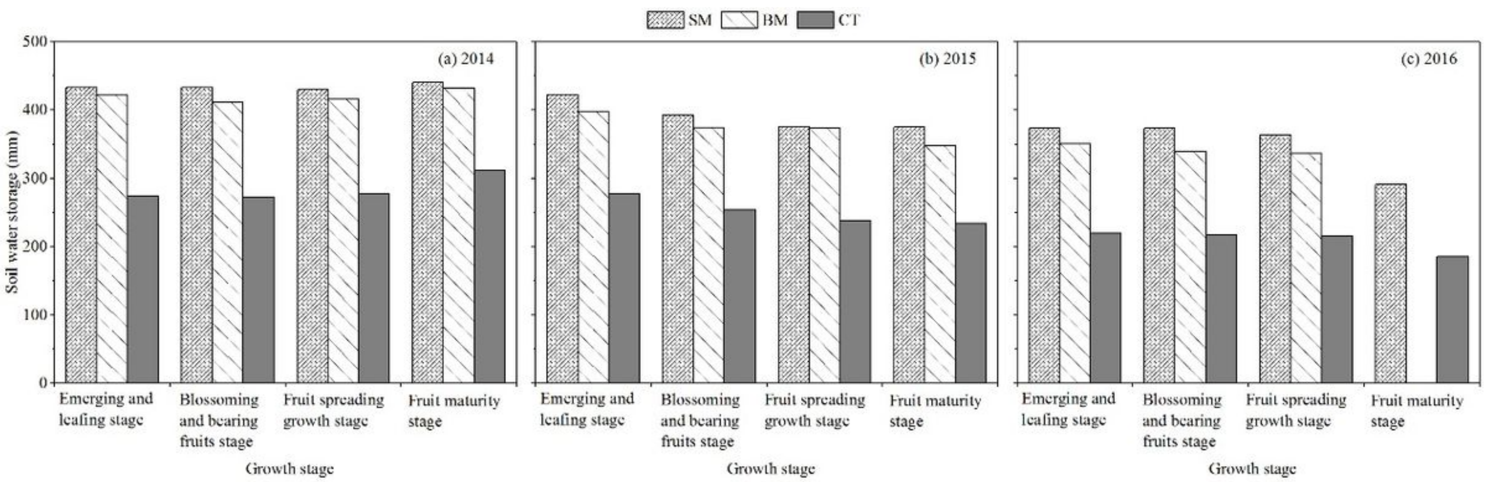
SM
BM
CT
(a) 2014
(b) 2015
(c) 2016
Soil water storage (mm)
0
100
200
300
400
500
Emerging and leafing stage
Blossoming and bearing fruits stage
Fruit spreading growth stage
Fruit maturity stage
Growth stage

Figure 5

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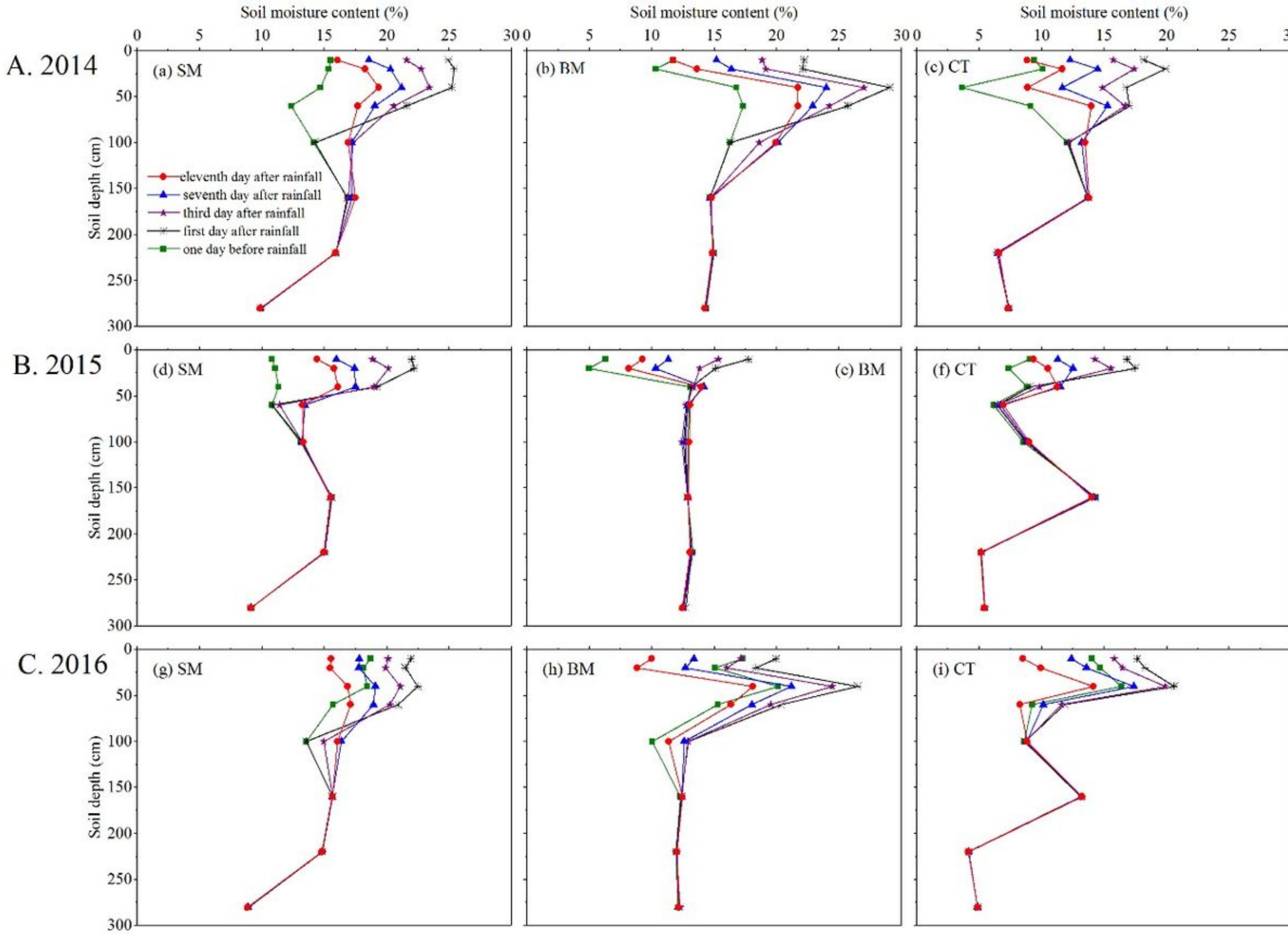
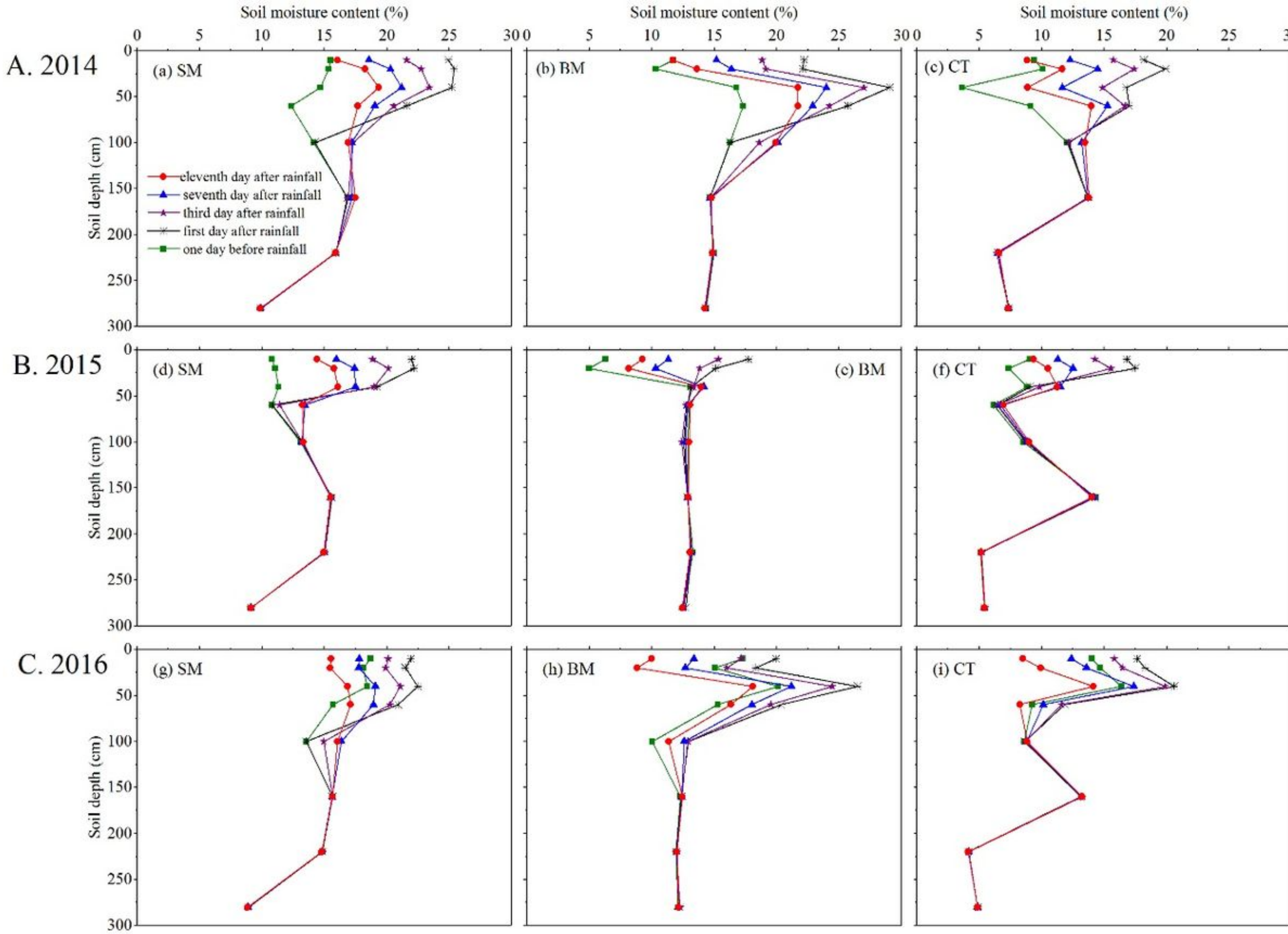


Figure 6

Soil moisture loss over time from the 0 to 280 cm profile under different mulching treatments after typical rainfall in (A) 2014, (B) 2015, and (C) 2016.



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