

Integrating a mini catchment with mulching for soil water management in a sloping jujube orchard on the semiarid Loess Plateau of China

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1 **Abstract.** Conserving more soil water is of great importance to the sustainability success-of arid and
2 semiarid orchards. Here we integrated fish-scale pits, semicircular mini-catchments for hill slope
3 runoff collecting, with mulches to test their effects on soil water storage in a 12-year-old dryland
4 jujube orchard on the Loess Plateau of China, by using soil water measurements from April 2013 to
5 November 2014. This experiment included four treatments: fish-scale pit with branch mulching (FB),
6 fish-scale pit with straw mulching (FS), fish-scale pit without mulching (F), and bare land treatment
7 (CK). Soil water was measured using the Trime-IPH TDR tool in 20 cm intervals down to a depth of
8 180 cm, and measured once every two weeks in the 2013 and 2014 growing seasons. The results
9 showed that fish-scale pits with mulching were better in soil water conservation. Average soil water
10 storage (SWS, for short) of FB at soil layer depths of 0-180 cm increased by 14.23% (2013) and
11 21.81% (2014), respectively, compared to CK, but only increased by 4.82% (2013) and 5.34%
12 (2014), respectively for the F treatment. The degree of soil water compensation, W_s , was employed
13 here to represent what extent soil water was recharged from precipitation at the end of rainy season
14 relative to that at the beginning of rainy season. A positive (negative) W_s denotes larger (lower) soil
15 water content at the end of rainy season than at the beginning. For the treatment of FB, the values of
16 W_s over the entire soil profile were greater than 0; for the treatment of F, negative values of W_s were
17 observed in the 60-100 cm at both years. However, the bare land treatment showed negative values
18 in the 40-180 cm. This indicated that integrating fish-scale pits with mulching could significantly
19 increase soil water storage by increasing infiltration and decreasing evaporation, and showed greater
20 soil water storage and degree of soil water compensation compared to fish-scale pits alone. Since the
21 branches used for mulching here were trimmed jujube branches, the cost of mulching materials was

1 largely reduced. Therefore, integration of fish-scale pits with branch mulching is recommended in
2 orchards for soil water conservation on the Loess Plateau and potentially for other regions.~~On the~~
3 ~~hilly areas of the Loess Plateau of China, mini catchments, named fish-scale pits, are widely used in~~
4 ~~orchards for collecting surface runoff to increase soil water infiltration. However, the flat surface~~
5 ~~inside fish-scale pits would increase soil evaporation during non-rainfall periods. Therefore, we~~
6 ~~integrated fish-scale pits with mulching, a popular meaning to reduce soil evaporation, to test~~
7 ~~whether this integration could improve soil water conservation. The results showed that soil water~~
8 ~~deficit was observed for all treatments. However, soil water deficit was further intensified in the dry~~
9 ~~month. An index was used to represent the soil water supply from rainfall infiltration denoted W_s .~~
10 ~~For the fish-scale pit with branch mulching treatment in the entire soil profile, the compensation~~
11 ~~degree of soil water storage were greater than 0. However, the bare land treatment showed negative~~
12 ~~values in the 40–180 cm. In conclusion, integrating fish-scale pits with mulching could conserve~~
13 ~~significantly more soil water by increasing infiltration and decreasing evaporation compared to~~
14 ~~fish-scale pits alone. Since the mulching branches were trimmed jujube branches, the integration of~~
15 ~~fish-scale pit with branch mulching is recommended in jujube orchards in order to both preserve~~
16 ~~more soil water and reduce the cost of mulching materials.~~

17 **KEY WORDS:** Soil moisture; Jujube; Fish-scale pit; Mulching; Loess Plateau

18 **1 Introduction**

19 The hilly region of the Loess Plateau of China is a typical semiarid region. ~~This region is one of the~~
20 ~~most suitable places for planting jujube trees (*Zizyphus jujuba*) in China thanks to abundant sunshine,~~
21 ~~large temperature differences between day and night, and thick, loose loess soil (Gao et al., 2014b; Huang~~

1 ~~et al., 2014). The soil plays a vital part in the Earth system as control the hydrological, erosional and bio~~
2 ~~geo-chemical cycles and offers services to the societies (Brevik et al., 2015; Berendse et al., 2015;~~
3 ~~Keesstra et al., 2012). However,~~ The annual precipitation of the region ranges from 200 to 750 mm, with
4 70% occurring between July and September often in the form of heavy rainstorms (Zhao et al., 2013). As
5 a result, drought and serious soil erosion frequently occur in this region (Zhao et al., 2014). Soil water
6 content plays a vital part in the land surface system as control hydrological, erosional and bio geo
7 chemical cycles and offers services to the societies (Brevik et al., 2015; Berendse et al., 2015; Keesstra et
8 al., 2012). Vegetation could protect the soil surface from drop impact, increasing resistance to
9 concentrated flow erosion (Cerdà, 1998; Keesstra et al., 2009), and decrease runoff discharge during
10 rainstorms (Seutloali and Beckedahl, 2015; Li et al., 2014a). Vegetation cover on the Loess Plateau was
11 significantly improved after the implementation of "Grain for Green" project, a large-scale ecological
12 project by converting hillslope farmland to forest (including economic plantations such as orchards) or
13 grassland (Liu et al., 2014; Yu et al., 2014; Zhao et al., 2015). However, the regional-scale vegetation
14 restoration in short time should increase soil water consumption quickly and this would further deepen
15 soil water deficit in this region (Gao et al., 2014).

16 Water harvesting systems for runoff water collection and storage represent an attractive solution for
17 resolving water scarcity in various parts of the world (Li et al., 2014b; Mwangi et al., 2015; Ola et al.,
18 2015). In many regions of China, semicircular mini-catchments, known as "fish-scale pits", which are
19 built on slopes in an alternating pattern similar to the arrangement of the scales of a fish, can effectively
20 reduce runoff and soil erosion and improve land productivity (Mekonnen et al., 2015a; 2015b). Fu et al.
21 (2010) found the fish-scale pit could effectively reduce surface runoff and sediment transport during

1 heavy rainstorms and thus increase soil water infiltration. However, Li et al. (2011) showed that the
2 average soil water content inside fish-scale pits were below the levels of external slope during July and
3 August. Because the fish-scale pits increase evaporation because of the enlarged partial soil water and
4 contact area between soil and air (Mekonnen et al., 2015a).

5 A lot of field and laboratory studies, have shown that organic mulching can increase soil water
6 storage by reducing storm runoff (Moreno-Ramón et al., 2014; Sadeghi et al., 2015), increasing
7 infiltration (Montenegro et al., 2013), and decreasing evaporation (McIntyre et al., 2000; Sas-Paszt et al.,
8 2014). Chakraborty et al. (2010) found that organic mulches had better soil water status and improved
9 plant canopy in terms of biomass, root growth, leaf area index and grain yield, which subsequently
10 resulted in higher water and nitrogen uptake and their use efficiencies. Suman and Raina (2014)
11 investigated the effect of plastic mulch on soil water of apple orchards at Krishi Vigyan Kendra,
12 Himachal Pradesh, India. They found that mulch conserves 2-4% higher soil water content over
13 unmulched condition especially in surface soil layers. On the tableland (relatively flat surface) orchards in
14 the Loess Plateau, mulching has been widely used for conserving soil water content. Fan et al. (2014)
15 found that straw mulching and broken stone mulching increased soil water content and water use
16 efficiency in alfalfa in the northern Loess Plateau. Liu et al. (2013) found that straw mulching notably
17 increased the soil water content by decreasing the soil bulk density and increased the soil porosity of a
18 non-irrigated apple orchard in the Loess Plateau, China. Gao et al. (2010) found that straw mulching
19 enhanced soil porosity and increased the soil water-holding capacity within 60 cm soil layer after three
20 years mulching in apple orchard of the Weibei Plateau.

21 [However, the studies with respect to mulching in the above citations were all implemented at sites](#)

1 with flat surfaces or gentle slope. For sites with apparent slope, mulch materials are not stable and prone
2 to being taken away by gravity or external forces. Since fish-scale pits are built on hill slopes and have
3 low and flat surface inside, here we try to integrate fish-scale pits with mulches aiming to test their effects
4 on soil water storage in sloping jujube orchards in the semiarid region of the Loess Plateau.

5 ~~The reported research mainly focused on the effect of the fish-scale pits on reduction in runoff and~~
6 ~~the effect of mulching on reduction in the invalid evaporation, but there was little research on integrating~~
7 ~~the fish-scale pits with mulching. Thus, further research is needed to better understand: (1) if the~~
8 ~~fish-scale pits can play a role in increasing infiltration from precipitation; and (2) what is the effect of~~
9 ~~integrating the fish-scale pits with mulching on increasing infiltration from precipitation and reducing the~~
10 ~~invalid evaporation? Thus, the main objective of this study was to investigate the effects of the different~~
11 ~~integrating fish-scale pits and mulching on (1) temporal dynamics of the soil water storage, (2) vertical~~
12 ~~changes of soil water following typical rainfall events and (3) soil water deficit and recovery at a~~
13 ~~non-irrigated sloping jujube orchard in the hilly region of the Loess Plateau.~~

14 **2 Materials and Methods**

15 **2.1 Study site**

16 The field study was conducted from October 10 2012 through November 5 2014 at the Mizhi
17 Experimental Station of Northwest A&F University. The station ~~The study site~~ is located in ~~at~~ Mengheha
18 Jujube Demonstration Station (38°11' N, 109°28' E), in Mizhi County, Yulin City of Northern Shaanxi
19 Province, China. On the basis of data from 1966–2006, this site has a semi-arid continental climate with a
20 mean annual precipitation of 451 mm, that of temperature is 8.5 °C, solar radiation is 161.46 W·m⁻² and
21 frost-free periods is 160 days and 2720 h of sunshine on average each year (Bai and Wang, 2011; Zhang

1 et al., 2010). The soil is primarily composed of loess with texture of fine silt and silt loam. Summary
2 information on soil properties in 0–180 cm is shown in Table 1.

3 Jujube trees were planted in 2001 on a 20-degree southward-facing slope and cultivated under
4 rainfed conditions with row-by-stand spacing of 3 m by 2 m, respectively. Every year, 300 kg N ha⁻¹, 70
5 kg P₂O₅ ha⁻¹ and 150 kg K₂O ha⁻¹ of fertilized were applied on the cultivated jujube trees. Pest and weed
6 control measures were also taken every year. The trees were pruned every year not only as a crop water
7 uptake management measure, but also to maintain a 2 m canopy height and a uniform canopy shape of a
8 spherosome. Slopes of 20 degrees represent those commonly found in jujube orchards were selected as the
9 sample testing fields. The same slope surfaces were selected with a southward direction, in order to allow
10 soil water contents in the fish scale pits under different mulching conditions comparable. The sample
11 fields of jujube trees belonged to 12-year dry land jujube orchard with an area of 2m (plant distance) × 3m
12 (row distance). The jujube trees were managed through the adoption of dwarf cultivation measures with
13 consistent type, frequency and amount of manure used for each jujube tree. Meanwhile, areas of rain
14 collection in fish scale pits were also ensured to remain consistent.

15 2.2 Treatments

16 Four different treatments were established in this study including fish-scale pit with branch mulching
17 (FB), fish-scale pit with maize straw mulching (FS), fish-scale pit without mulching (F), and bare land
18 treatment (CK). Each treatment had three replicates. The fish-scale pit had a volume of 100 cm (length) ×
19 80 cm (width) × 30 cm (depth). A photo showing this system is presented in Fig. 1. Trimmed jujube
20 branches and maize straws were utilized for mulching with lengths of 5-10 cm and a mulching thickness
21 of 15 cm.

1 **2.3 Soil water measurements**

2 A portable Time Domain Reflectometry (TDR) system, TRIME-PICOIPH/T3 (IMKO, Ettlingen,
3 Germany), was used to monitor soil water in this jujube orchard. This TDR system consists of a
4 TRIME-IPH probe, a TRIME-Data Pilot datalogger and fiberglass access tubes ($\Phi = 40\text{mm}$). ~~Trime-IPH
5 TDR was used for soil water determination. Previous studies showed this instrument can produce
6 relatively accurate measurements of soil water content after a local calibration (Gao et al., 2011a; Li et al.,
7 2005). Therefore, the system was gravimetrically calibrated for the specific local soils examined in this
8 study, as follows. Soil moisture was measured using the TDR tool in five 20 cm intervals down to a depth
9 of 180 cm. Meanwhile, a 180 cm deep pit was excavated 0.5 m from the access tubes to collect
10 undisturbed soil samples from the corresponding depths in order to obtain measurements of the dry soil
11 bulk density and gravimetric soil moisture content (θ). Values of θ were then transformed to volumetric
12 moisture contents, and a calibration curve was generated by plotting the measured TDR-derived moisture
13 values (θ_{TDR} , $\text{cm}^3\text{cm}^{-3}$) against the volumetric moisture contents (θ , $\text{cm}^3\text{cm}^{-3}$), and fitting a regression
14 equation (Eq. 1, $R^2 = 0.915$, $\text{RMSE} = 3.77\%$).~~

15
$$\theta = 0.926 \times \theta_{TDR} - 3.854 \tag{1}$$

16 ~~$$Y = 0.926X - 3.854; R^2 = 0.915; \text{RMSE} = 3.77\% \tag{1}$$~~

17 ~~The TDR measurement pipes were deployed in October 2012. The relative positions of the TDR pipe,
18 fish-scale pit and jujube tree are illustrated in Figure.1. Each measurement pipe was located 30 cm to the
19 west of each corresponding trunk, and offered a measurement depth of 180 cm. The TDR pipes were
20 divided into 9 measurement layers (20 cm for each layer). Soil water content was measured once every
21 two weeks in the 2013 and 2014 growing seasons. Additional measurement was conducted after rains~~

1 ~~resulting in a total of 24 measurements during the study period. For each measurement, all the sampling~~
2 ~~points (12 points) were measured within 24h. In this paper, if no special explanation is given, soil water~~
3 ~~content refers to soil volumetric water content.~~ There were 12 sampling points in total. Soil moisture was
4 sampled at these points at depths of 0-180 cm at 20 cm intervals during two periods: from June 5 to
5 September 20 2013 and from June 10 to September 30 2014. During the two periods, soil moisture was
6 sampled approximately weekly routinely, and 1 h after rainfall events. During the entire sampling periods
7 there were 24 sampling occasions. On each sampling occasion, soil moisture was sampled within 4 min at
8 each sampling point and all the soil moisture measurements were taken within 2 h. During such short
9 times, the temporal variation of soil moisture was expected to be negligible. According to existing
10 research results (Gao et al., 2011b; Ma et al., 2012; 2013) concerning root systems of jujube forests, soil
11 layer depths of 0-20 cm were considered the surface layers, 20-100 cm the main root system layers, and
12 100-180 cm the deep layers.

13 2.4 Indexes

14 ~~In the study site, deep groundwater contributes little to plant water uptake. We hypothesized that~~
15 ~~precipitation and evapotranspiration are the main factors controlling root-zone soil moisture dynamics at~~
16 ~~the study site because the groundwater table in the Loess Plateau is usually deeper than 50 m (Gao et al.,~~
17 ~~2011).~~ Soil water changes are mainly related to precipitation and evapotranspiration. We used the
18 following two indexes to represent the degree of SWS deficit (W_D , Eq. 2) and the degree of water
19 compensated by precipitation (W_S , Eq. 3) (Zhang et al., 2009).

$$20 \quad W_D = \frac{D}{F_c} \times 100\% \quad \text{_____} \quad (2)$$

$$21 \quad D = F_c - W_c \quad (3)$$

1 Where, W_D (%) refers the degree of SWS deficit, D (mm) refers to SWS deficit, F_c (mm) is field
2 capacity and W_c (mm) is measured SWS.

3 W_D is used to represent the degree of SWS deficit relative to field capacity-. If $W_D=0$, it means that
4 soil water storage deficit is completely recovered. If $W_D>0$, it means that soil water-storage deficit existed
5 with higher values indicating severer SWS deficits.

$$6 \quad W_S = \frac{\Delta W}{D_{ac}} \times 100\% \quad (4)$$

$$7 \quad \Delta W = W_e - W_{cc} \quad (5)$$

$$8 \quad D_{ac} = F_c - W_{cc} \quad (6)$$

9 Where, ΔW (mm) represents increased SWS at the end of the rainy season, W_e (mm) represents
10 SWS at the end of the rainy season (25 September 2013 and 25 October 2014), W_{cc} (mm) represents SWS
11 at the beginning of the rainy season (5 June 2013 and 2014), and D_{ac} (mm) represents SWS deficit at the
12 beginning of the rainy season.

13 W_S is used to reflect what extent SWS is recharged at the end of rainy season relative to SWS at the
14 beginning of the rainy season. If $W_S \leq 0$, it means that SWS deficit increases; if $W_S > 0$, it means SWS
15 deficit is alleviated; If $W_S = 100\%$, it is indicated that the SWS deficit is completely compensated.

16 **2.5 Statistical methods**

17 Statistical analysis was conducted using Microsoft Excel 2010 (Microsoft, Redmond, USA) and
18 SPSS16.0 (SPSS, Chicago, USA) software. Differences ($\alpha=0.05$) among the various treatments were
19 analyzed using two methods: one-way ANOVA and multiple comparison analysis least significant
20 difference (LSD).

21 **3 Results and Analysis**

1 3.1 Temporal dynamics of soil water storage (SWS)

2 The characteristics of rainfall, temperature and SWS of 2013 and 2014 at different soil layers with
3 time are shown in Figure 2. The rainfall ~~mainly occurred was mainly concentrated in a period~~ from July
4 to September, which accounted for 66.7% (345.6 mm) and 65.9% (289 mm) of annual rainfall at 2013
5 and 2014, respectively. Water in the soil surface layers was greatly influenced by rainfall events and
6 evapotranspiration, which increased clearly following apparent rainfall events. The larger values of
7 surface SWS always occurred after heavy rainfall events, and the lowest SWS usually occurred at the end
8 of the dry season, and there was also remarkable increase just after the rainy season compared with the
9 dry season. The 20-100 cm SWS in the 20-100 cm had the same trendlines of change behaved similarly in
10 time with the surface SWS. The FB and FS treatment showed consistently higher SWS than the F and CK
11 in the 0-20 cm and 20-100 cm, particularly following rainstorms. The SWS in the deep soil layers was
12 weakly affected by precipitation. Overall, for the whole study period in 2013~~throughout 2013 growth~~
13 ~~period, under FB, FS and F treatments, the~~ average SWS at soil layer depths of in 0-180 cm for the FB, FS
14 and F treatment increased by 14.23%, 9.35% and 4.82%, respectively, compared ~~to with CK;~~ and in
15 2014, ~~t~~The values ~~at 2014~~ were 21.81%, 17.18% and 5.34%, respectively.

16 3.2 Vertical changes of soil water following typical rainfall events

17 One typical rainfall was chosen in each of June, July and August at 2013 to analyze the effects of
18 single rainfall events on vertical distribution of soil water content. ~~Individual rainfall events~~ The
19 precipitation in June, July and August ~~produced total typical rainfall values of was~~ 41.2 mm, ~~96.8~~64.2 mm,
20 and 29.6 mm, respectively. Soil water was measured before rainfall and done again three (June and July)
21 or seven (August) days later ~~of~~ after rainfall ceasing.

1 From Figure 3, it can be observed that ~~in June, before the typical rainfall, the overall soil water was~~
2 ~~relatively low. However,~~ soil water increased dramatically in the 0-20 cm for different treatments
3 following ~~the~~ 41.2 mm ~~precipitation-rainfall event~~ (June 19, 2013 - June 20, 2013). However, soil water
4 changed negligible after the rainfall beneath ~~the~~ 40 cm, indicating ~~only shallow soil water was recharged.~~
5 ~~A heavy rainstorm of 64.2 mm occurred from July 6 to July 11, 2013. unavailable deep infiltration. The~~
6 ~~various treatments showed similar soil water contents possibly because the evapotranspiration of jujube~~
7 ~~was very low during this period and runoff did not occur for the low antecedent moisture conditions of~~
8 ~~soil and the small rainfall intensity.~~

9 The study site had received 217 mm of rain in July of 2013 ~~the most almost~~ half of the annual
10 rainfall (503 mm). Before ~~the rainfall event typical rainfall~~rainfall (96.8 mm, July 6, 2013 ~~July 11,~~
11 ~~2013~~), soil water content was relatively low (<13%) ~~at over~~ the entire profiles. Three days after rainfall
12 ~~under FB, FS and F,~~ ~~the~~ soil water content ~~for the FB, FS and F treatments had~~ significantly increased at
13 0-60 cm ~~and under but for the CK~~ ~~apparent increase in soil water content was only observed in the the~~
14 ~~depths was~~ 0-40 cm. It ~~was~~ showed that fish-scale pits ~~promoted soil water infiltration during heavy~~
15 ~~rainstorms. exhibited far greater storage capacity for continuous rainfall than that of bare lands.~~

16 In August, before the typical rainfall, soil water content exhibited a trend of gradual increase within
17 soil depths of 0-40 cm (or 0-60 cm), showed a tendency of gradual decrease within soil depths of 40-100
18 cm (or 60-100 cm) and became gradually stable at soil layer depths of >100 cm. This was primarily
19 caused by rainfall infiltration, soil water evaporation, and plant water consumption. Seven days after
20 typical rainfall (29.6 mm, August 23, 2013 ~~August 26, 2013~~), soil ~~Soil~~ water content ~~for the majority of~~
21 ~~soil layers in the 0-180 cm~~ decreased compared ~~to the values with~~ before ~~the~~ rainfall ~~event~~. This was

1 probably caused by strong water consumption of jujube trees during this inter-rainstorm period. This
2 water content decrease is most likely caused by increased water consumption by jujube trees from higher
3 solar radiation and air temperatures. Seven days after rainfallrainfall under the CK, soil water contents in
4 the entire profiles were all around 10%. The stage of developing fruit period after rainfall is critical for
5 fruit growth and development of jujube trees, and such a low water content limited fruit growth in the CK
6 treatment. At soil depths of 0-100cm (primary depth for jujube tree roots), soil water contents increased
7 significantly under fish-scale pits after typical rainfallrainfall with the FB treatment showing the greatest
8 soil water content.

9 According to the observations above, it can be seen that the vertical variations of soil water content
10 exhibited seasonal characteristics due to the influence by rainfall, soil water evaporation, and crop
11 transpiration. Note thatthe effects of individual rainfall on soil water content were mainly within the depth
12 of 0-100 cm for all treatments.

13 **3.3 Soil water deficit and recovery**

14 **3.3.1 Soil water deficit**

15 Here we averaged SWS each month to calculate monthly SWS deficit. From Table 2, it can be
16 clearly seen that SWS deficit existed under for all treatments from June to September at; 2013 and from
17 June to October, at 2014. Although rainfall compensated for some of the water consumption, the
18 deficits were still present. In June for both years, before the arrival of the rainy season, SWS deficits
19 became relatively in the 0-180 cm were relatively severe under for all treatments. In the following months,
20 SWS deficits in the 0-20 and 20-100 cm decreased apparently with the increase of rainfall events (Figure
21 2). This suggests that soil water supply from precipitation could not only meet the large water demand of

1 jujube trees but also provide excess water to recharge soils. Note that in September of 2013 SWS deficit
2 in the top 100 cm increased sharply because of significant decrease in precipitation. However, high SWS
3 deficit in the 100-180 cm persisted over the wet season, indicating little water recharged into this depth.
4 ~~In July, soil water deficits under all treatments within the 0-100 cm layer decreased apparently. Generally,~~
5 ~~soil water loss in August is greatest because of increased soil water evaporation from higher temperatures~~
6 ~~as well as greater transpiration from thriving plant growth (Nicolas et al., 2005; Wilson et al., 2001).~~
7 ~~Despite this greater soil water loss SWS deficits within the 0-100 cm under FB and FS treatments were~~
8 ~~not serious, but the F and CK treatments were in bad conditions.~~

9 3.3.2 Soil water recovery

10 The changes of the degree of SWS compensation (W_s) after the rainy season with depth are
11 illustrated in Figure 4. From the figure, it can be observed that there were apparent differences of the
12 degrees of SWS compensation for different treatments after the rainy season. For the treatment of FB, the
13 values of WS over the entire soil profile were greater than 0; for the treatment of F, negative values of
14 WS were observed in the 60-100 cm at both years. For the FB treatment in the entire soil profile, the
15 ~~compensation degree of SWS were greater than 0.~~ However, the CK treatment showed negative values in
16 the 40-180 cm. This ~~indicates~~ indicated that the FB treatment exerted positive compensative effects on
17 soil water within the 0-180 cm depth. For the FB, FS, and F treatments, positive compensative effects
18 existed in the 100-160 cm, demonstrating that fish-scale pits played active roles in water compensation in
19 deep soil layers. The pits artificially improved the roughness of the slopes leading to enhanced rainfall
20 infiltration. In both years, the WS of 20-100 cm soil layer with the FB treatment was significantly higher
21 than for the F and CK. Within the 20-100 cm, the compensation degree of SWS was greatest for the

1 ~~treatments FB and FS, followed by F treatment, and finally treatment the CK, which had the lowest~~
2 ~~compensation degree.~~ For the F treatment in the 0-100 cm, the compensation degree fluctuated around 0,
3 demonstrating that the fish-scale pits without mulching exerted basically no compensative effects on the
4 depths of 0-100 cm. However, in the 100-160cm, a compensative effect is observed on the soil water for
5 the F treatment.

6 **4 Discussions**

7 The annual precipitation of the hilly region of the Loess Plateau is only 250-550 mm, while annual
8 field evapotranspiration is 750–950 mm, and the groundwater table is usually deeper than 50 m (Gao et
9 al., 2011). Therefore perennial jujubes are often under the stress of drought. The fish-scale pits can
10 strengthen the roughness of slopes, enhance rainfall infiltrations, and ensure water supply for plants in the
11 pits during the rainy season (Fu et al., 2010). Our results indicated that the fish-scale pits improved the
12 soil water by 5.08% compared with control. The value was much lower compared with Wang et al. (2015)
13 who found soil water content increased by 14.06% inside fish-scale pits for 1-year-old Robinia
14 Pseudoacacia in Loess Plateau of China. A possible explanation was that the 12-year-old jujube trees in
15 our study used more soil water.

16 The results of our study indicated that integrating fish-scale pits with mulching increased SWS
17 (Figure 2) and decreased SWS (Table 2) deficit during both rainstorms and drying periods compared to
18 the treatment of fish-scale pits alone. On the one hand, over inter-rainstorms fish-scale pits would
19 increase soil evaporation because of the larger contact area of soil and air; during the rainstorms the
20 physical crust which is caused by runoff also reduced the infiltration (Previati et al., 2010). On the other
21 hand, mulching could effectively reduce the formation of soil physical crust by filtering soil particles

1 during rainstorms, improved soil water-stable aggregates, and increased soil water-holding capacity (Lin
2 and Chen, 2015). Previous studies have also suggested that organic mulching promotes the activity of soil
3 microorganisms and the formation of a soil aggregate structure, thereby improving the soil structure and
4 increasing the soil water content (Siczek and Lipiec, 2011). Meanwhile, we found that integrating
5 fish-scale pits and mulching increased soil water consumption (Figure 2). In general, organic mulching
6 provides better soil water status and improve plant canopy in terms of biomass, root growth, leaf area
7 index and grain yield (Ram et al., 2013). These together subsequently would result in higher water and
8 nutrient uptake. However, mulching can largely reduce soil evaporation (Liu et al., 2013, Sadeghi et al.,
9 2015). Since soil water consumption is generally equal to the sum of soil evaporation and plant canopy
10 transpiration (Chakraborty et al., 2010), it means that the mulching would increase the ratio of
11 transpiration in the total of soil water use.

12 In this study, jujube branches and maize straw, two kinds of easily accessible local materials, were
13 selected as mulching materials for the fish-scale pits. The results showed that jujube branches exerted
14 better mulching effects than maize straw, possibly because the straw had relatively strong water holding
15 capacity. During the rainfall stages, the straw intercepted and preserved the rainfall water, and after the
16 rainfall stage, the intercepted and preserved water dissipated rapidly as vapor when the exposed areas of
17 the straw to air were relatively high. Similar results had been reported by several studies in the past (Lin
18 and Chen, 2015, Ramet al., 2013). In addition, maize straw is more and more difficult to obtain following
19 the decrease of cultivated land. The jujube branches were mainly obtained from the annually trimmed
20 branches. The application of trimmed branches as mulching materials decreased the cost of the processing
21 and transportation of material. The use of trimmed branches also helped with the double objectives of

1 rainfall interception and storage, and soil water preservation, providing both an economic and ecological
2 benefit in jujube orchards of loess hilly regions. However, the mechanism of the effects of integration of
3 fish-scale pits and mulching on soil water storage in sloping jujube orchards is still not fully understood.
4 Furthermore, how the integration of fish-scale pits and mulching affect evapotranspiration and its
5 partitioning of jujube orchards as well as jujube yield is still under investigation. Future studies should
6 pay more attentions on these questions to provide better guidance for the sustainable development of
7 jujube orchard on the Loess Plateau.

8 ~~Fish-scale pits and various mulching methods affect SWS by influencing soil water movement and~~
9 ~~fundamentally alter the connections between the soil surface and atmosphere. Ultimately fish-scale pits~~
10 ~~and mulching affect the distribution and energy status of soil water and also affect the movement of water~~
11 ~~vapor. At different stages of jujube tree growth, the combined measures of fish-scale pits and mulching in~~
12 ~~this study exhibited different effects on moisture preservation and water storage. Before the flowering and~~
13 ~~fruiting stages of jujube trees, with relatively low rainfall, soil water content remained at relatively low~~
14 ~~levels and SWS deficit was relatively severe for all treatments. At these growth stages, rainfall did not~~
15 ~~produce significant runoff, thus fish-scale pits did not help greatly in rainfall accumulation and storage;~~
16 ~~however, the pits increased areas in the soil for air connection leading to soil evaporation. During the rainy~~
17 ~~season, which composed of large rainfall volumes and intense events, the fish-scale pits increased the~~
18 ~~capacity of soil water infiltration. The rainy season (from July to September) represented a crucial period~~
19 ~~for fruit development and jujube tree growth, with the leaves of the trees becoming increasingly~~
20 ~~flourished. The rainfall collection effects of the fish-scale pits constituted a supplementation for soil water,~~
21 ~~thus playing a vital role in the development and growth of jujube trees. In addition, the decreased~~

1 evaporation caused by the mulching measures helped the jujube trees take advantage of the water input
2 during the rainy season. The combined measures of fish scale pits and mulching during the rainy season
3 played crucial roles in the early accumulation of SWS, the inhibition of surface soil water evaporation and
4 the supplementation of SWS at the fruit maturation stage. In addition, straw mulching and jujube branch
5 mulching also aided with soil temperature regulation, which provide suitable temperatures for root
6 systems(Li et al.,2013; Dahiya et al., 2007). Under preferable soil water conditions, jujube trees grew well
7 with relatively flourishing branches and leaves, although soil water consumption enhanced
8 correspondingly. Soil water was essentially uncompensated under the measures of fish scale pits without
9 mulching in the soil layer depths of 0-100 cm, whereas within the 100-160 cm, soil water was fairly
10 compensated. This trend is consistent with the field observations of Previati (2010), who found that the
11 SWS increase with depth in fish scale pits. At the beginning of the growth period in the soil layer depths
12 of 20-180 cm, all treatments except for the CK treatment displayed a decrease in the SWS deficit. For the
13 CK treatment in the 100-180 cm, the SWS deficit tended to increase from the beginning to the end of the
14 growth period. This indicates that during the growth period, jujube trees consumed soil water at deep
15 layers, which could lead to the formation of dry soil layer if this phenomenon persists for a long term.
16 However, Gao (2014a) found that soil water in the 100-160 cm of 3-year old and 8-year old jujube
17 orchards without mulching also increased apparently following a continuous precipitation of 93 mm on
18 the Loess Plateau. This suggests that deep soil water could probably be compensated if heavy rainstorms
19 occur in this region.

20 Fish scale pits affected soil water in two different manners. In terms of rainfall accumulation and
21 storage, fish scale pits strengthened the roughness of slopes, enhanced rainfall infiltrations, and ensured

1 water supply for plants in the pit (Li et al., 2011). However, at the same time, these pits increased soil
2 aeration, thus improving evaporation (Liet al., 2014b). Under treatments with fish scale pits and no
3 mulching, no significant differences existed with bare land treatment. In addition, the constructions of
4 fish scale pits constituted destructions to soil surfaces, enhancing the risks of water and wind erosion.
5 Nevertheless, with the addition of different mulching, fish scale pits not only reduced erosion risks, but
6 also inhibited soil water evaporation. In this study, jujube branches and maize straw, two kinds of easily
7 accessible local materials, were selected as mulching materials for the fish scale pits. The results showed
8 that jujube branches exerted better mulching effects than maize straw, possibly because the straw had a
9 relatively strong water holding capacity (Ramet al., 2013). During the rainfall stages, the straw
10 intercepted and preserved the rainfall water, and after the rainfall stage, the intercepted and preserved
11 water dissipated rapidly as vapor when the exposed areas of the straw to air were relatively high. The
12 jujube branches were mainly obtained from the annually dwarfed and trimmed branches. The application
13 of trimmed branches as mulching materials greatly lowered (1) the volume of material, (2) transportation
14 costs and (3) construction difficulties. The use of trimmed branches also helped with the double
15 objectives of rainfall interception and storage, and soil water preservation, providing both an economic
16 and ecological benefit in jujube orchards of loess hilly regions. The mechanism for the effects of
17 combined measures of fish scale pits and mulching on soil water conditions in patch scale jujube forests
18 was closely related to factors such as jujube's growth process, characteristics of root system distribution,
19 and features of water consumption at different growth stages. The relationships between soil water
20 evaporation, varying rates of jujube transpiration, different jujube root system distributions, and soil water
21 conditions under different measures need to be further researched to provide scientific guidance for the

2 **5 Conclusions**

3 During the growth periods of jujube, all the combinations of fish-scale pits with mulching measures
4 significantly improved SWS in surface layers (depths of 0-20 cm) and main root system layers (depths of
5 20-100 cm). Among these combinations, the fish-scale pits with branch mulching treatment (FB)
6 exhibited the most significant effects, followed by treatment of fish-scale pits with straw mulching(FS).
7 For dryland jujube orchards in loess hilly regions, the application of trimmed branches as mulching
8 materials not only reduced the volume of materials, transportation costs, and difficulties in construction,
9 but also achieved the goals of increasing rainfall interception and storage, as well as improving soil
10 moisture preservation and water storage.

11 **Acknowledgements**

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2 Table 1

3 Soil properties of 0-180 cm at the study site.

Depth	BD	Soil texture			K_{sat}	θ_s	$\theta_{33\text{ kPa}}$	$\theta_{1500\text{ kPa}}$
		Sand (%)	Silt (%)	Clay (%)				
cm	(g/cm ³)				(mm/min)	(cm ³ /cm ³)	(cm ³ /cm ³)	(cm ³ /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

4 BD: bulk density; Soil texture: Sand% (2-0.02 mm), Silt% (0.02-0.002 mm), and Clay% (<0.002 mm); K_{sat} : saturated hydraulic conductivity;5 θ_s : saturated water content; $\theta_{33\text{ kPa}}$: soil moisture content at 33 kPa; $\theta_{1500\text{ kPa}}$: soil moisture content at 1500 kPa.

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9 **Table 2**10 Deficit degree of soil water storage under fish-scale pit with branch mulching (FB), fish-scale pit
11 with straw mulching (FS), fish-scale pit without mulching (F), and bare land treatment (CK).

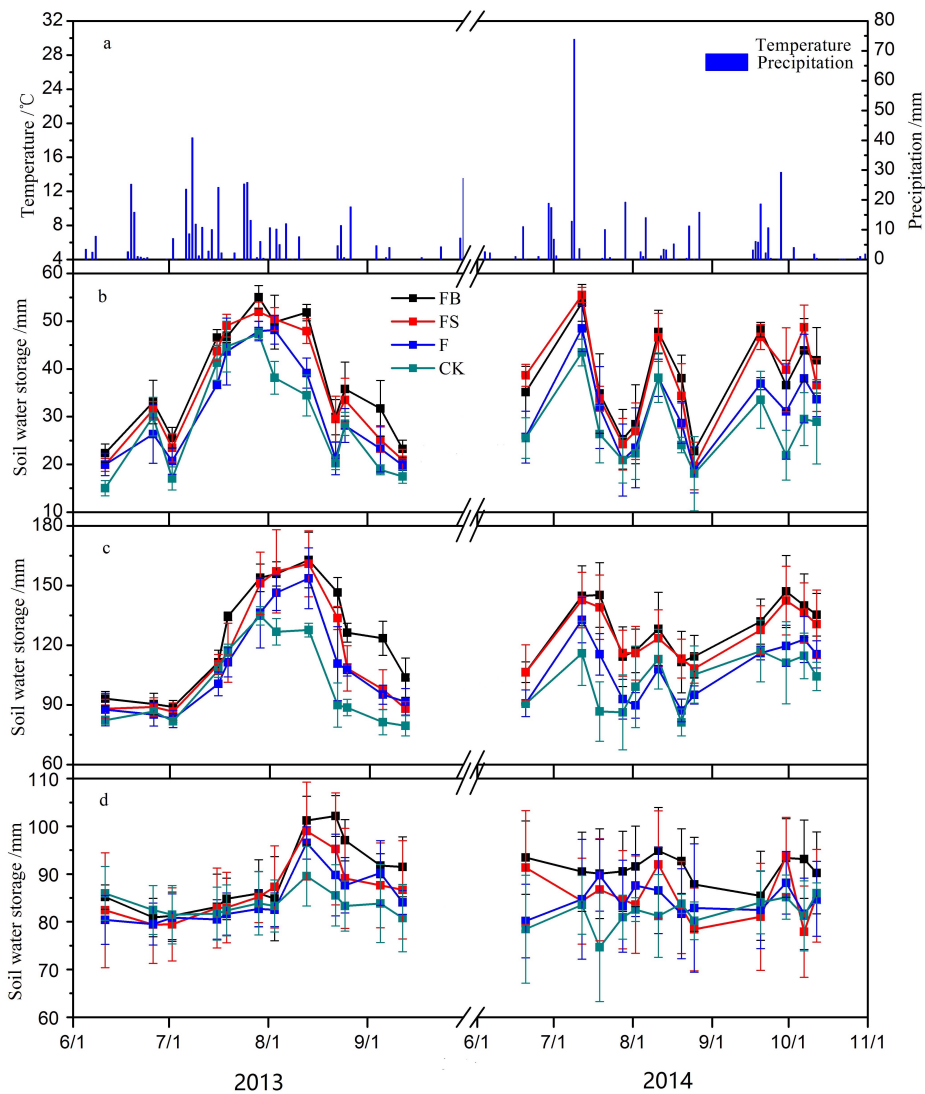
Treatments	Depth (cm)	Degree of soil water storage deficit (%)								
		2013				2014				
		June	July	August	September	June	July	August	September	October
FB	0-20	41.77	8.72	12.13	42.25	39.66	20.20	28.04	10.90	9.98
	20-100	43.86	25.27	9.56	30.52	40.21	17.56	27.95	14.70	15.83
	100-180	47.31	46.84	38.88	41.86	34.37	42.66	41.78	43.27	41.83
FS	0-20	46.06	11.65	15.23	51.55	42.18	20.52	32.96	9.10	10.38
	20-100	45.85	29.00	14.35	43.18	44.98	18.90	29.50	17.40	18.37
	100-180	48.66	47.57	41.20	44.70	42.99	45.92	46.55	44.54	48.17
F	0-20	51.34	21.72	28.19	54.73	48.78	29.06	42.68	28.57	24.75
	20-100	47.15	34.06	20.75	42.91	40.01	30.48	41.92	27.91	27.13
	100-180	49.27	48.34	43.45	44.71	36.45	45.48	46.27	45.86	47.18
CK	0-20	52.67	21.03	36.26	61.83	46.13	36.51	46.11	41.72	38.61
	20-100	48.32	32.51	33.81	50.83	43.19	41.10	39.07	30.19	33.05
	100-180	46.58	47.74	45.80	47.79	42.94	49.42	48.01	46.31	46.94

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Figure 1. A photo of fish-scale pit.



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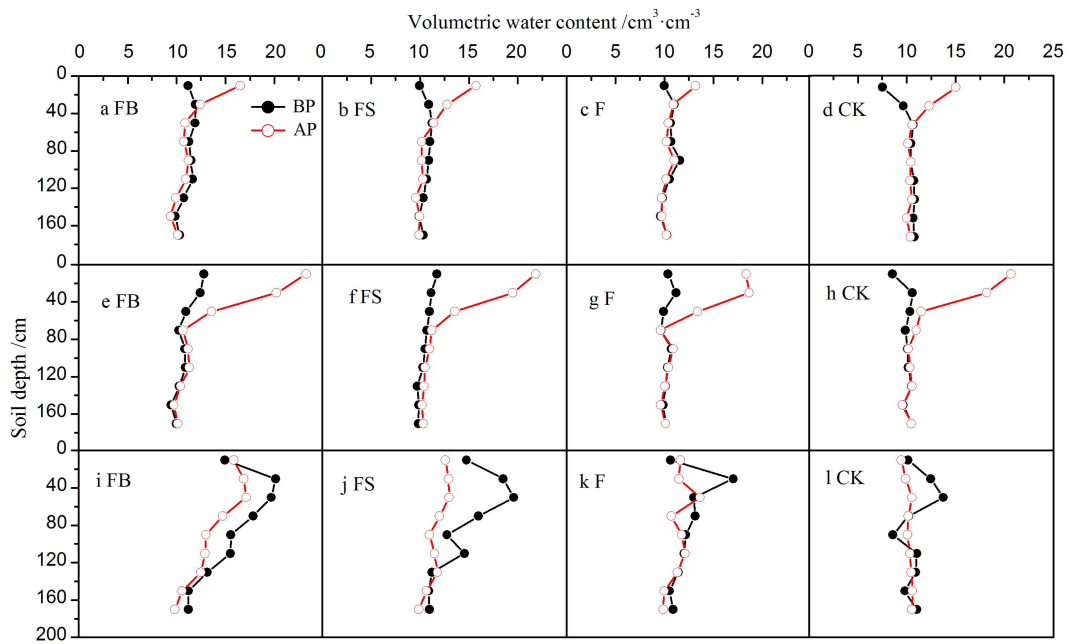
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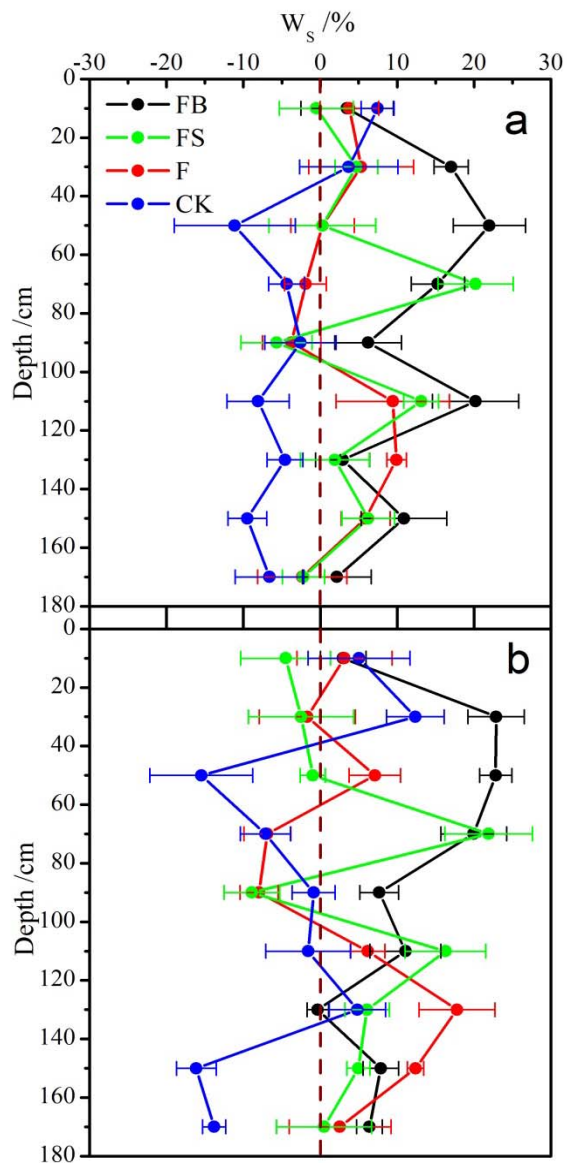
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Figure 2. Temporal changes of (a) temperature and precipitation, (b) 0-20 cm soil water storage, (c) 20-100 cm soil water storage and (d) 100-180 cm soil water storage for fish-scale pit with branch mulching (FB), fish-scale pit with straw mulching (FS), fish-scale pit without mulching (F), and bare land treatment (CK). Error bars represent \pm one standard deviation.



1
 2 Figure 3. Vertical changes of soil moisture before (BF) and after (AP) typical precipitation in June (a,
 3 b, c, d), July (e, f, g, h) and August (i, j, k, l) under fish-scale pit with branch mulching (FB),
 4 fish-scale pit with straw mulching (FS), fish-scale pit without mulching (F), and bare land treatment
 5 (CK).
 6



1

2 Figure 4. Relationship between compensation degree of soil water storage deficit (W_s) and soil
 3 depth at 2013 (a) and 2014 (b) under fish-scale pit with branch mulching (FB), fish-scale pit with
 4 straw mulching (FS), fish-scale pit without mulching (F), and bare land treatment (CK).