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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Abstract. Conserving more soil water is of great importance to the sustainability ~~success~~ of arid and semiarid orchards. Here we integrated fish-scale pits, semicircular mini-catchments for hill slope runoff collecting, with mulches to test their effects on soil water storage in a 12-year-old dryland jujube orchard on the Loess Plateau of China, by using soil water measurements from April 2013 to November 2014. This experiment included four treatments: 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). Soil water was measured using the Trime-IPH TDR tool in 20 cm intervals down to a depth of 180 cm, and measured once every two weeks in the 2013 and 2014 growing seasons. The results showed that fish-scale pits with mulching were better in soil water conservation. Average soil water storage (SWS, for short) of FB at soil layer depths of 0-180 cm increased by 14.23% (2013) and 21.81% (2014), respectively, compared to CK, but only increased by 4.82% (2013) and 5.34% (2014), respectively for the F treatment. The degree of soil water compensation, W_S, was employed here to represent what extent soil water was recharged from precipitation at the end of rainy season relative to that at the beginning of rainy season. A positive (negative) W_S denotes larger (lower) soil water content at the end of rainy season than at the beginning. For the treatment of FB, the values of W_S over the entire soil profile were greater than 0; for the treatment of F, negative values of W_S were observed in the 60-100 cm at both years. However, the bare land treatment showed negative values in the 40-180 cm. This indicated that integrating fish-scale pits with mulching could significantly increase soil water storage by increasing infiltration and decreasing evaporation, and showed greater soil water storage and degree of soil water compensation compared to fish-scale pits alone. Since the branches used for mulching here were trimmed jujube branches, the cost of mulching materials was largely reduced. Therefore, integration of fish-scale pits with branch mulching is recommended in orchards for soil water conservation on the Loess Plateau and potentially for other regions.~~On the hilly areas of the Loess Plateau of China,mini catchments, named fish-scale pits, are widely used in orchards for collecting surface runoff to increase soil water infiltration. However, the flat surface inside fish-scale pits would increase soil evaporation during non-rainfall periods. Therefore, we integratedfish-scale pits with mulching, a popular meaning to reduce soil evaporation, to test whether this integration could improve soil water conservation. The results showed that soil water deficit was observed for all treatments. However, soil water deficit was further intensified in the dry month. An index was used to represent the soil water supply from rainfall infiltration denoted W_S. For the fish-scale pit with branch mulching treatment in the entire soil profile, the compensation degree of soil water storage were greater than 0. However, the bare land treatment showed negative values in the 40-180 cm. In conclusion, integrating fish-scale pits with mulching could conserve significantly more soil water by increasing infiltration and decreasing evaporation compared to fish-scale pits alone. Since the mulching branches were trimmed jujube branches, the integration of fish-scale pit with branch mulching is recommended in jujube orchards in order to both preserve more soil water and reduce the cost of mulching materials.~~

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

1 Introduction

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

Water harvesting systems for runoff water collection and storage represent an attractive solution for resolving water scarcity in various parts of the world (Li et al., 2014b; Mwango et al., 2015; Ola et al., 2015). In many regions of China, semicircular mini-catchments, known as “fish-scale pits”, which are built on slopes in an alternating pattern similar to the arrangement of the scales of a fish, can effectively reduce runoff and soil erosion and improve land productivity (Mekonnen et al., 2015a; 2015b). Fu et al. (2010) found the fish-scale pit could effectively reduce surface runoff and sediment transport during heavy rainstorms and thus increase soil water infiltration. However, Li et al. (2011) showed that the average soil water content inside fish-scale pits were below the levels of external slope during July and August. Because the fish-scale pits increase evaporation because of the enlarged partial soil water and contact area between soil and air (Mekonnen et al., 2015a).

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

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

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

2 Materials and Methods

2.1 Study site

The field study was conducted from October 10 2012 through November 5 2014 at the Mizhi Experimental Station of Northwest A&F University. The station is located at 38°11′ N-109°28′ E in Mizhi County, Yulin City of Shaanxi Province, China. On the basis of data from 1966–2006, this site has a semi-arid continental climate with a mean annual precipitation of 451 mm, that of temperature is 8.5 ℃, solar radiation is 161.46 $W\cdot m^{-2}$ and frost-free periods is 160 days and 2720 h of sunshine on average each year (Bai and Wang, 2011; Zhang et al., 2010). The soil is primarily composed of loess with texture of fine silt and silt loam. Summary information on soil properties in 0–180 cm is shown in Table 1.

Jujube trees were planted in 2001 on a 20-degree southward-facing slope and cultivated under rainfed conditions with row-by-stand spacing of 3 m by 2 m, respectively. Every year, 300 kg N ha^{-1}, 70 kg P_2O_5 ha^{-1} and 150 kg K_2O ha^{-1} of fertilized were applied on the cultivated jujube trees. Pest and weed control measures were also taken every year. The trees were pruned every year not only as a crop water uptake management measure, but also to maintain a 2 m canopy height and a uniform canopy shape of a spherosome. ~~Slopes of 20 degrees represent thosecommonly found in jujube orchards were selected as the sample testing fields. The same slope surfaces were selected with a southward direction, in order to allow soil water contents in the fish-scale pits under different mulching conditions comparable. The sample fields of jujube trees belonged to 12-year dry-land jujube orchardwith an area of 2m (plant distance) ×3m (row distance). The jujube trees weremanaged through the adoption of dwarf cultivation measures with consistent type, frequency and amount of manure used for each jujube tree. Meanwhile, areas of rain collection in fish-scale pits were also ensured to remain consistent.~~

2.2 Treatments

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

2.3 Soil water measurements

A portable Time Domain Reflectometry (TDR) system, TRIME-PICOIPH/T3 (IMKO, Ettlingen, Germany), was used to monitor soil water in this jujube orchard. This TDR system consists of a TRIME-IPH probe, a TRIME-Data Pilot datalogger and fiberglass access tubes (Φ= 40mm). A 180 cm deep pit was excavated 0.5 m from the access tubes to collect undisturbed soil samples from the corresponding depths in order to obtain measurements of the dry soil bulk density and gravimetrical soil moisture content (θ). Values of θ were then transformed to volumetric moisture contents, and a calibration curve was generated by plotting the measured TDR-derived moisture values (θ_{TDR}, cm^3cm^{-3}) against the volumetric moisture contents (θ, cm^3cm^{-3}), and fitting a regression equation (Eq. 1, R^2 = 0.915, RMSE = 3.77%).

$$\theta = 0.926 \times \theta_{TDR} - 3.854 \qquad (1)$$

There were 12 sampling points in total. Soil moisture was sampled at these points at depths of 0-180 cm at 20 cm intervals during two periods: from June 5 to September 20 2013 and from June 10 to September 30 2014. During the two periods, soil moisture was sampled approximately weekly routinely, and 1 h after rainfall events. During the entire sampling periods there were 24 sampling occasions. On each sampling occasion, soil moisture was sampled within 4 min at each sampling point and all the soil moisture measurements were taken within 2 h. During such short times, the temporal variation of soil moisture was expected to be negligible. According to existing research results (Gao et al., 2011; Ma et al., 2012; 2013) concerning root systems of jujube forests, soil layer depths of 0-20 cm were considered the surface layers, 20-100 cm the main root system layers, and 100-180 cm the deep layers.

2.4 Indexes

We hypothesized that precipitation and evapotranspiration are the main factors controlling root-zone soil moisture dynamics at the study site because the groundwater table in the Loess Plateau is usually deeper than 50 m (Gao et al., 2011). Soil water changes are mainly related to precipitation and evapotranspiration. We used the following two indexes to represent the degree of SWS deficit (W_D, Eq. 2) and the degree of water compensated by precipitation (W_S, Eq. 4) (Zhang et al., 2009).

$$W_D = \frac{D}{F_c} \times 100\% \qquad (2)$$

$$D = F_c - W_c \qquad (3)$$

Where, W_D (%) refers the degree of SWS deficit, D (mm) refers to SWS deficit~~, ($D=F_c - W_c$)~~, F_c (mm) is field capacity and W_c (mm) is measured SWS.

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

$$W_S = \frac{\Delta W}{D_{ac}} \times 100\% \qquad (\cancel{3}4)$$

~~and~~

$$\Delta W = W_e - W_{cc} \qquad (\cancel{4}5)$$

$$D_{ac} = F_c - W_{cc} \qquad (\cancel{5}6)$$

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

~~SWS deficit (W_D) is used to represent the degree of SWS deficit before the rainy season, and it can also reflect the degree of recovery of SWS after the rainy season. If W_D =0, it is indicated that soil water storage deficit is completely recovered. If W_D>0, it is suggested that soil water-storage deficit existed with high W_D values indicating severe soil water-storage deficits. Compensation of water-storage deficit (~~W_S~~)~~ is used to reflect what extent SWS is recharged at the end of rainy season relative to SWS at the beginning of the rainy season. ~~the degree for which rainfall compensates the soil water deficit.~~ If $W_S \leq 0$, it means that SWS deficit increases; ~~is indicated that the degree of water storage deficit is significant;~~ if $W_S > 0$, it means SWS deficit is alleviated; ~~it is suggested that the water storage deficit is compensated;~~ If W_S =100%, it is indicated that the SWS~~water storage~~ deficit is completely compensated ~~and recovered~~.

2.5 Statistical methods

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

3 Results and Analysis

3.1 Temporal dynamics of soil water storage (SWS)

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

3.2 Vertical changes of soil water following typical rainfall events

One typical rainfall was chosen in each of June, July and August at 2013 to analyze the effect of single rainfall event on vertical distribution of soil water content. The precipitation in June, July and August was 41.2 mm, 64.2 mm, and 29.6 mm, respectively. Soil water was measured before rainfall and done again three (June and July) or seven (August) days later after rainfall ceasing.

From Figure 3, it can be observed that soil water increased dramatically in the 0-20 cm for different treatments following the 41.2 mm rainfall event (June 19, 2013 - June 20, 2013). However, soil water changed negligible after the rainfall beneath the 40 cm, indicating only shallow soil water was recharged. A heavy rainstorm of 64.2 mm occurred from July 6 to July 11, 2013. ~~The study site had received 217 mm of rain in July of 2013 – the most~~ almost ~~half of the annual rainfall (503 mm).~~ Before the rainfall event soil water content was relatively low (<13%) over the entire profiles. Three days after rainfall the soil water content for the FB, FS and F treatments significantly increased at 0-60 cm but for the CK apparent increase in soil water content was only observed in the 0-40 cm. It showed that fish-scale pits promoted soil water infiltration during heavy rainstorms. Soil water content for the majority of soil layers in the 0-180 cm decreased compared with before the rainfall event. This was probably caused by strong water consumption of jujube trees during this inter-rainstorm period.

~~According to the observations above, it can be seen that the vertical variations of soil water content exhibited seasonal characteristics due to the influence by rainfall, soil water evaporation, and crop transpiration. Note thatthe effects of individual rainfall on soil water content were mainly within the depth~~

~~of 0-100 cm for all treatments.~~

3.3 Soil water deficit and recovery

3.3.1 Soil water deficit

Here we averaged SWS each month to calculate monthly SWS deficit. From Table 2, it can be seen that SWS deficit existed for all treatments from June to September at 2013 and from June to October at 2014. ~~Although rainfall compensated for some of the water consumption, the deficits were still present.~~ In June for both years, ~~before the arrival of the rainy season,~~ SWS deficits ~~became relatively~~ in the 0-180 cm were relatively severe ~~under~~ for all treatments. In the following months, SWS deficits in the 0-20 and 20-100 cm decreased apparently with the increase of rainfall events (Figure 2). This suggests that soil water supply from precipitation could not only meet the large water demand of jujube trees but also provide excess water to recharge soils. Note that in September of 2013 SWS deficit in the top 100 cm increased sharply because of significant decrease in precipitation. However, high SWS deficit in the 100-180 cm persisted over the wet season, indicating little water recharged into this depth. ~~In July, soil water deficits under all treatments within the 0-100 cm layer decreased apparently. Generally, soil water loss in August is greatest because of increased soil water evaporation from higher temperatures as well as greater transpiration from thriving plant growth (Nicolas et al., 2005; Wilson et al., 2001). Despite this greater soil water loss SWS deficits within the 0-100 cm under FB and FS treatments were not serious, but the F and CK treatments were in bad conditions.~~

3.3.2 Soil water recovery

The changes of the degree of SWS compensation (W_S) after the rainy season with depth are illustrated in Figure 4. From the figure, it can be observed that there were apparent differences of the degrees of SWS compensation for different treatments after the rainy season. For the treatment of FB, the values of WS over the entire soil profile were greater than 0; for the treatment of F, negative values of WS were observed in the 60-100 cm at both years. ~~For the FB treatment in the entire soil profile, the compensation degree of SWS were greater than 0.~~ However, the ~~CK~~ bare land treatment showed negative values in the 40-180 cm. This indicated that the FB treatment exerted positive compensative effects on soil water within the 0-180 cm depth. For the FB, FS, and F treatments, positive compensative effects existed in the 100-160 cm, demonstrating that fish-scale pits played active roles in water compensation in deep soil layers. The pits artificially improved the roughness of the slopes leading to enhanced rainfall infiltration. In both years, the W_S of 20-100 cm soil layer with the FB treatment was significantly higher than for the F and CK. ~~Within the 20-100 cm, the compensation degree of SWS was greatest for the treatments FB and FS, followed by F treatment, and finally treatment the CK, which had the lowest compensation degree.~~ For the F treatment in the 0-100 cm, the compensation degree fluctuated around 0, demonstrating that the fish-scale pits without mulching exerted basically no compensative effects on the depths of 0-100 cm. However, in the 100-160cm, a compensative effect is observed on the soil water for the F treatment.

4 Discussions

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

The results of our study indicated that integrating fish-scale pits with mulching increased SWS (Figure 2) and decreased SWS (Table 2) deficit during both rainstorms and drying periods compared to the treatment of fish-scale pits alone. On the one hand, over inter-rainstorms fish-scale pits would increase soil evaporation because of the larger contact area of soil and air; during the rainstorms the physical crust which is caused by runoff also reduced the infiltration (Previati et al., 2010). On the other hand, mulching could effectively reduce the formation of soil physical crust by filtering soil particles during rainstorms, improved soil water-stable aggregates, and increased soil water-holding capacity (Lin and Chen, 2015). Previous studies have also suggested that organic mulching promotes the activity of soil microorganisms and the formation of a soil aggregate structure, thereby improving the soil structure and increasing the soil water content (Siczek and Lipiec, 2011). Meanwhile, we found that integrating fish-scale pits and mulching increased soil water consumption (Figure 2). In general, organic mulching provides better soil water status and improve plant canopy in terms of biomass, root growth, leaf area index and grain yield (Ram et al., 2013). These together subsequently would result in higher water and nutrient uptake. However, mulching can largely reduce soil evaporation (Liu et al., 2013, Sadeghi et al., 2015). Since soil water consumption is generally equal to the sum of soil evaporation and plant canopy transpiration (Chakraborty et al., 2010), it means that the mulching would increase the ratio of transpiration in the total of soil water use.

In this study, jujube branches and maize straw, two kinds of easily accessible local materials, were selected as mulching materials for the fish-scale pits. The results showed that jujube branches exerted better mulching effects than maize straw, possibly because the straw had relatively strong water holding capacity. During the rainfall stages, the straw intercepted and preserved the rainfall water, and after the rainfall stage, the intercepted and preserved water dissipated rapidly as vapor when the exposed areas of the straw to air were relatively high. Similar results had been reported by several studies in the past (Lin and Chen, 2015, Ramet al., 2013). In addition, maize straw is more and more difficult to obtain following the decrease of cultivated land. The jujube branches were mainly obtained from the annually trimmed branches. The application of trimmed branches as mulching materials decreased the cost of the processing and transportation of material. The use of trimmed branches also helped with the double objectives of rainfall interception and storage, and soil water preservation, providing both an economic and ecological benefit in jujube orchards of loess hilly regions. However, the mechanism of the effects of integration of fish-scale pits and mulching on soil water storage in sloping jujube orchards is still not fully understood. Furthermore, how the integration of fish-scale pits and mulching affect evapotranspiration and its partitioning of jujube orchards as well as jujube yield is still under investigation. Future studies should pay more attentions on these questions to provide better guidance for the sustainable development of jujube orchard on the Loess Plateau.

5 Conclusions

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

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Table 1

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

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

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; θ_s: saturated water content; $\theta_{33\ kPa}$: soil moisture content at 33 kPa; $\theta_{1500\ kPa}$: soil moisture content at 1500 kPa.

Table 2

Deficit degree of soil water storage under 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).

`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

Figure 1. A photo of fish-scale pit.

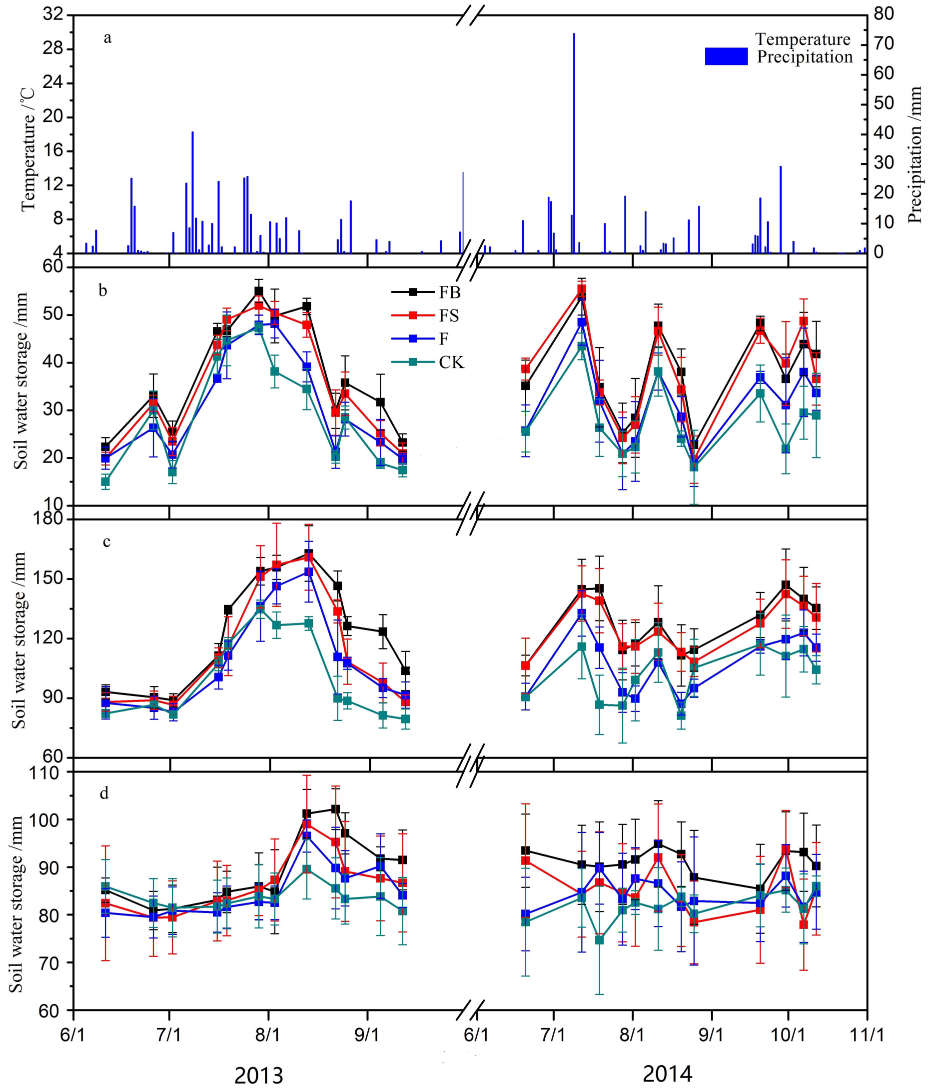

Figure 2. Temporal changes of (a) temperature and precipitation, (b) 0-20 cm soil water storage, (c) 20-100 cm soil water storage and (d) 100-180 cm soil water storage for fish-scale pit with branch mulching (FB), fish-scale pit with straw mulching (FS), fish-scale pit without mulching (F), and bare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

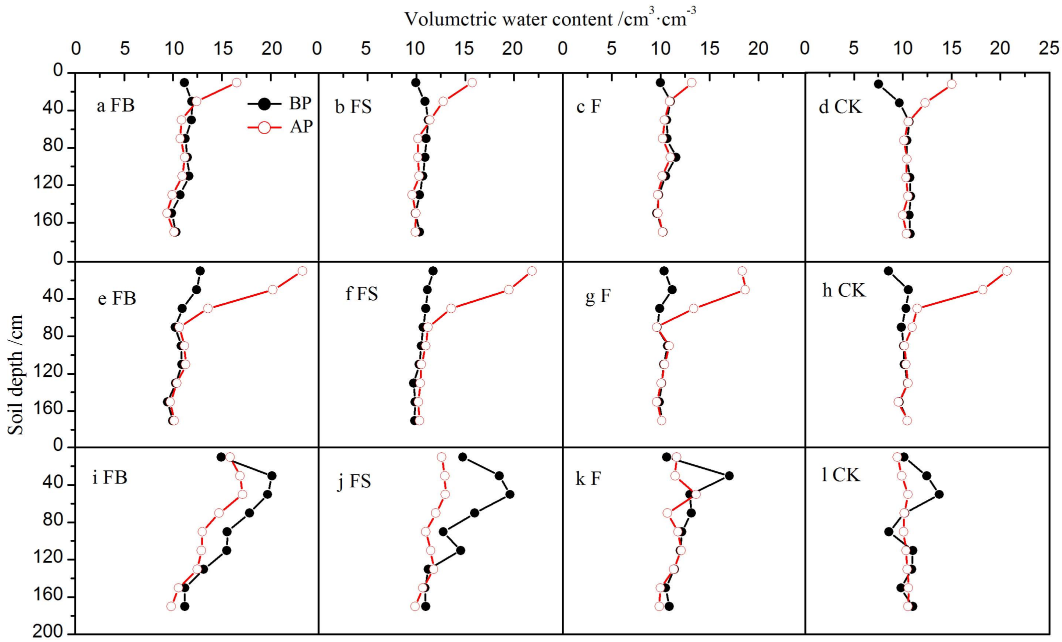

Figure 3. Vertical changes of soil moisture before (BF) and after (AP) typical precipitation in June (a, b, c, d), July (e, f, g, h) and August (i, j, k, l) under fish-scale pit with branch mulching (FB), fish-scale pit with straw mulching (FS), fish-scale pit without mulching (F), and bare land treatment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

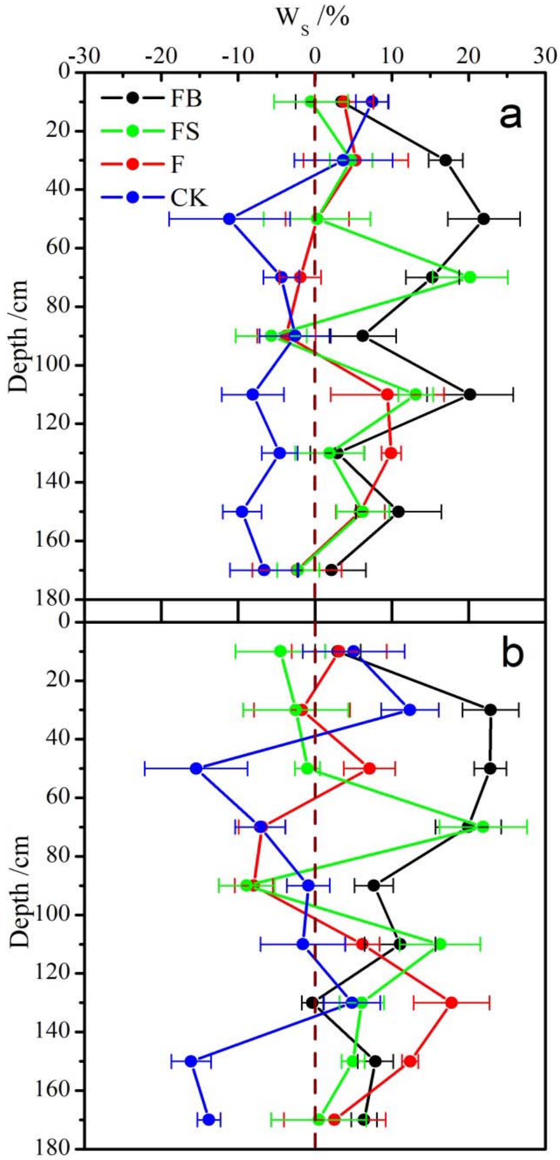

Figure 4. Relationship between compensation degree of soil water storage deficit (W_S) and soil depth at 2013 (a)and 2014 (b) under fish-scale pit with branch mulching (FB), fish-scale pit with straw mulching (FS), fish-scale pit without mulching (F), and bare land treatment (CK).