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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 success of arid and semiarid orchards. 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 infiltrate more soil water. However, the flat surface inside fish-scale pits would increase soil evaporation during non-rainfall periods. Therefore, we integrated fish-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 SWS were greater than 0. However, the *CK* 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.

1 Introduction

The hilly region of the Loess Plateau in China is a typical semiarid region (Zhao et al., 2014). This region is one of the most suitable places for planting jujube trees (*Zizyphus jujuba*) in China thanks to abundant sunshine, large temperature differences between day and night, and thick, loose loess soil (X. D. Gao et al., 2014; Huang et al., 2014). The soil plays a vital part in the Earth system as control the 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). However, the annual precipitation of the

Loess plateau region ranges from 200 to 750 mm, with 70 % of all rainfall occurring between July and September often in the form of heavy thunderstorms (Zhao et al., 2013). As a result, drought and serious water and soil erosion frequently occur in this region. Vegetation cover on the Loess Plateau was significantly improved after the implementation of “Grain for Green” project, which were helpful for controlling severe soil erosion (Liu et al., 2014; Yu et al., 2014; Zhao et al., 2015). Vegetation could protect the soil surface from drop impact, increasing resistance to concentrated flow erosion (Keesstra et al., 2009; Cerdà, 1998), and decrease runoff discharge during a given rainfall event (Seutloali and Beckedahl, 2015; Q. Y. Li et al., 2014). With the increase of the vegetation coverage, water consumption amount increases quickly, and causes drought conditions worsen (Keesstra, 2007). Therefore, improving water use efficiency of natural rainfall is very important (X. H. Li et al., 2014; Lieskovský and Kenderessy, 2014).

Water harvesting systems for runoff water collection and storage represent an attractive solution for resolving water scarcity in various parts of the world (Mwango et al., 2015; Ola et al., 2015). In many regions of China, semicircular rainwater retention basins, also known as “fish-scale pits”, which are built on the 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, b). Fu (2010) found the fish-scale pit could effectively reduce surface runoff and sediment transport during heavy rainstorms and thus increase soil water infiltration. Li (2011) showed that the average soil water content inside fish-scale pits were below the levels of external slope during July and August. However, the fish-scale pits increase evaporation because of the enlarged partial soil water and contact area between soil and air. A considerable amount of research, under both field and laboratory conditions, has shown that use of a surface organic mulch can result in storing more precipitation water in soil 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 (2010) found that organic mulches provided 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 (2014) investigated the effect of plastic mulch on soil water under apple at Krishi Vigyan Kendra, Himachal Pradesh, India. They found that mulch conserves 2 to 4 % unit higher moisture over unmulched condition especially in surface soil layers. On the tableland orchards in the Loess Plateau of northwestern China, mulching has been widely used for regulating the soil water. Fan (2014) investigated the effect of straw mulching and broken stone mulching on soil water under alfalfa in the northern Loess Plateau. They found that both mulching approaches increased soil water content and water use efficiency with straw mulching performing the best. Liu (2013) found that straw mulching notably increased the soil moisture 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.

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 the soil water profile (0–180 cm) of a non-irrigated sloping jujube orchard in the hilly region of the Loess Plateau.

2 Materials and methods

2.1 Study site

The study site is located in Mengcha Jujube Demonstration Station (38°11′ N, 109°28′ E), Mizhi County, Northern 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 505 mm, that of temperature is 8.5°, solar radiation is 161.46 $\mathrm{W\,m^{-2}}$ and frost-free periods is 160 days and 2720 h of sunshine on average each year (Zhang et al., 2010; Bai and Wang, 2011). 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.

Slopes of 20° represent those commonly 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 orchard with an area of 2 m (plant distance) × 3 m (row distance). The jujube trees were managed 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 straw mulching (FS), fish-scale pit without mulching (F), and bare land treatment (*CK*). Each treatment had three replicates. Each fish-scale pit had a set volume of 100 cm (length) × 80 cm (width) × 30 cm (depth). 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-PICO IPH/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 ($\Phi = 40$ mm). Trime-IPH TDR was used for soil water determination. Previous studies showed this instrument can produce relatively accurate measurements of soil water content after a local calibration (Gao et al., 2011a; Li et al., 2005). Therefore, the system was gravimetrically calibrated for the specific local soils examined in this study, as follows. Soil moisture was measured using the TDR tool in five 20 cm intervals down to a depth of 180 cm. Meanwhile, 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 (X, $\text{cm}^3\,\text{cm}^{-3}$) against the volumetric moisture contents (Y, $\text{cm}^3\,\text{cm}^{-3}$), and fitting a regression equation (Eq. 1).

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

The TDR measurement pipes were deployed in October 2012. The relative positions of the TDR pipe, fish-scale pit and jujube tree are illustrated in Fig. 1. Each measurement pipe was located 30 cm to the west of each corresponding trunk, and offered a measurement depth of 180 cm. The TDR pipes were divided into 9 measurement layers (20 cm for each layer). Soil water content was measured once every two weeks in the 2013 and 2014 growing seasons. Additional measurement was conducted after rains resulting in a total of 24 measurements during the study period. For each measurement, all the sampling points (12 points) were measured within 24 h. In this paper, if no special explanation is given, soil water content refers to soil volumetric water content. According to existing research results (Gao et al., 2011b; 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

In the study site, deep groundwater contributes little to plant water uptake. 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. 3) (Zhang et al., 2009).

$$W_D\ (\%) = D/F_c \times 100\,\%, \tag{2}$$

where D (mm) refers to SWS deficit, ($D = F_c - W_c$); F_c (mm) is field capacity and W_c (mm) is measured SWS.

$$W_S\ (\%) = \Delta W/D_{ac} \times 100\,\% \tag{3}$$

and

$$\Delta W = W_e - W_{cc} \tag{4}$$

$$D_{ac} = F_c - W_{cc}, \tag{5}$$

where ΔW (mm) represents increased SWS at the end of the rainy season, W_e (mm) refers to SWS at the end of the rainy season, W_{cc} (mm) represents SWS at the beginning of the rainy season, and D_{ac} (mm) 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 the degree for which rainfall compensates the soil water deficit. If $W_S \leq 0$, it is indicated that the degree of water storage deficit is significant; if $W_S > 0$, it is suggested that the water storage deficit is compensated; If $W_S = 100\,\%$, it is indicated that the 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 ($\alpha = 0.05$) 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 Fig. 2. The rainfall was mainly concentrated in a period 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 rainfalls. 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 20–100 cm SWS had the same trendlines of change with the surface SWS. Throughout the 2013 growth period, under FB, FS and F treatments, average SWS at soil layer depths of 0–180 cm increased by 14.23, 9.35 and 4.82 %, respectively, compared to *CK*. The values at 2014 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 effects of rainfall events on vertical distribution of soil water. Individual rainfall events in June, July and August produced total typical rainfall values of 41.2, 96.8, and 29.6 mm, respectively. Soil water was measured before rainfall and done again three (June and July) or seven (August) days later of rainfall ceasing.

From Fig. 3, it can be observed that in June, before the typical rainfall, the overall soil water was relatively low. However, soil water increased dramatically in the 0–20 cm for different treatments following 41.2 mm precipitation (19–20 June 2013). However, soil water changed negligible after the rainfall beneath 40 cm, indicating unavailable deep infiltration. The various treatments showed similar soil water contents possibly because the evapotranspiration of jujube was very low during this period and runoff did not occur for the low antecedent moisture conditions of soil and the small rainfall intensity.

The study site had received 217 mm of rain in July of 2013 – the most half of the annual rainfall (503 mm). Before typical rainfalls (96.8 mm, 6–11 July 2013), soil water content was relatively low ($< 13\,\%$) at the entire profiles. Three days after rainfall under FB, FS and F, soil water content had significantly increased at 0–60 cm and under *CK* the depths was 0–40 cm. It was showed that fish-scale pits exhibited far greater storage capacity for continuous rainfalls than that of bare lands.

In August, before the typical rainfalls, soil water content exhibited a trend of gradual increase within soil depths of 0–40 (or 0–60 cm), showed a tendency of gradual decrease within soil depths of 40–100 (or 60–100 cm) and became gradually stable at soil layer depths of > 100 cm. This was primarily caused by rainfall infiltration, soil water evaporation, and plant water consumption. Seven days after typical rainfalls (29.6 mm, 23–26 August 2013), soil water content decreased compared to the values before rainfall. This water content decrease is most likely caused by increased water consumption by jujube trees from higher solar radiation and air temperatures. Seven days after rainfalls under the *CK*, soil water contents in the entire profiles were all around 10 %, The stage of developing fruit period after rainfall is critical for fruit growth and development of jujube trees, and such a low water content limited fruit growth in the *CK* treatment. At soil depths of 0–100 cm (primary depth for jujube tree roots), soil water contents increased significantly under fish-scale pits after typical rainfalls with the FB treatment showing the greatest soil water content.

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 that the 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

From Table 2, it can be clearly seen that SWS deficit existed under all treatments from June to September 2013 and from June to October 2014. Although rainfalls compensated for some of the water consumption, the deficits were still present. In June, before the arrival of the rainy season, SWS deficits became relatively severe under all treatments. 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 after the rainy season with depth are illustrated in Fig. 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 FB treatment in the entire soil profile, the compensation degree of SWS were greater than 0. However, the *CK* treatment showed negative values in the 40–180 cm. This indicates 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. 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 100–160 cm, a compensative effect is observed on the soil water for the F treatment.

4 Discussion

Fish-scale pits and various mulching methods affect SWS by influencing soil water movement and fundamentally alter the connections between the soil surface and atmosphere. Ultimately fish-scale pits and mulching affect the distribution and energy status of soil water and also affect the movement of water vapor. At different stages of jujube tree growth, the combined measures of fish-scale pits and mulching in this study exhibited different effects on moisture preservation and water storage. Before the flowering and fruiting stages of jujube trees, with relatively low rainfall, soil water content remained at relatively low levels and SWS deficit was relatively severe for all treatments. At these growth stages, rainfall did not produce significant runoff, thus fish-scale pits did not help greatly in rainfall accumulation and storage; however, the pits increased areas in the soil for air connection leading to soil evaporation. During the rainy season, which composed of large rainfall volumes and intense events, the fish-scale pits increased the capacity of soil water infiltration. The rainy season (from July to

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

Fish-scale pits affected soil water in two different manners. In terms of rainfall accumulation and storage, fish-scale pits strengthened the roughness of slopes, enhanced rainfall infiltrations, and ensured water supply for plants in the pit (Li et al., 2011). However, at the same time, these pits increased soil aeration, thus improving evaporation (X. H. Li et al., 2014). Under treatments with fish-scale pits and no mulching, no significant differences existed with bare land treatment. In addition, the constructions of fish-scale pits constituted destructions to soil surfaces, enhancing the risks of water and wind erosion. Nevertheless, with the addition of different mulching, fish-scale pits not only reduced erosion risks, but also inhibited soil water evaporation. 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 a relatively strong water holding capacity (Ram et al., 2013). 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. The jujube branches were mainly obtained from the annually dwarfed and trimmed branches. The application of trimmed branches as mulching materials greatly lowered (1) the volume of material, (2) transportation costs, and (3) construction difficulties. 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. The mechanism for the effects of combined measures of fish-scale pits and mulching on soil water conditions in patch scale jujube forests was closely related to factors such as jujube's growth process, characteristics of root system distribution, and features of water consumption at different growth stages. The relationships between soil water evaporation, varying rates of jujube transpiration, different jujube root system distributions, and soil water conditions under different measures need to be further researched to provide scientific 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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References

Bai, Y. R. and Wang, Y. K.: Spatial variability of soil chemical properties in a jujube slope on the loess plateau of china, Soil Sci., 176, 550–558, 2011.

Berendse, F., van Ruijven, J., Jongejans, E., and Keesstra, S.: Loss of plant species diversity reduces soil erosion resistance, Ecosystems, 18, 881–888, 2015.

Brevik, E. C., Cerdà, A., Mataix-Solera, J., Pereg, L., Quinton, J. N., Six, J., and Van Oost, K.: The interdisciplinary nature of *SOIL*, SOIL, 1, 117–129, doi:10.5194/soil-1-117-2015, 2015.

Cerdà, A.: The influence of aspect and vegetation on seasonal changes in erosion under rainfall simulation on a clay soil in Spain, Can. J. Soil Sci., 78, 321–330, 1998.

Chakraborty, D., Garg, R. N., Tomar, R. K., Singh, R., Sharma, S. K., Singh, R. K., Trivedi, S. M., Mittal, R. B., Sharma, P. K., and Kamble, K. H.: Synthetic and organic mulching and nitrogen effect on winter wheat (*Triticum aestivum* L.) in a semi-arid environment, Agr. Water Manage., 97, 738–748, 2010.

Dahiya, R., Ingwersen, J., and Streck, T.: The effect of mulching and tillage on the water and temperature regimes of a loess soil, Experimental findings and modeling, Soil Till. Res., 96, 52–63, 2007.

Fan, J., Gao, Y., Wang, Q. J., Malhi, S. S., and Li, Y. Y.: Mulching effects on water storage in soil and its depletion by alfalfa in the Loess Plateau of northwestern China, Agr. Water Manage., 138, 10–16, 2014.

Fu, S., Liu, B., Zhang, G., Lu, B., and Ye, Z.: Fish-scale pits reduce runoff and sediment, T. ASABE, 53, 157–162, 2010.

Gao, M. S., Liao, Y. C., Li, X., and Huang, J. H.: Effects of different mulching patterns on soil water-holding capacity of non-irrigated apple orchard in the weibei plateau, Scientia Agricultura Sinica, 43, 2080–2087, 2010 (in Chinese with English Abstract).

Gao, Q. H., Yu, J. G., Wu, C. S., Wang, Z. S., Wang, Y. K., Zhu, D. L., and Wang, M.: Comparison of drip pipe and surge spring root irrigation for jujube (*Ziziphus jujuba* Mill.) fruit quality in the Loess Plateau of China, Plos One, 9, 1–7, e88912, 2014.

Gao, X. D., Wu, P. T., Zhao, X. N., Shi, Y. G., Wang, J. W., and Zhang, B. Q.: Soil moisture variability along transects over a well-developed gully in the Loess Plateau, China, Catena, 87, 357–367, 2011a.

Gao, X. D., Wu, P. T., Zhao, X. N., Shi, Y. G., and Wang, J. W.: Estimating spatial mean soil water contents of sloping jujube orchards using temporal stability, Agr. Water Manage., 102, 66–73, 2011b.

Gao, X. D., Wu, P. T., Zhao, X. N., Wang, J. W., and Shi, Y. G.: Effects of land use on soil moisture variations in a semi-arid catchment: implications for land and agricultural water management, Land Degrad. Dev., 25, 163–172, 2014.

Huang, J., Wang, J., Zhao, X. N., Li, H. B., Jing, Z. L., Gao, X. D., Chen, X. L., and Wu, P. T.: Simulation study of the impact of permanent groundcover on soil and water changes in orchards on sloping ground, Land Degrad. Dev., doi:10.1002/ldr.2281, 2014.

Keesstra, S. D.: Impact of natural reforestation on floodplain sedimentation in the Dragonja basin, SW Slovenia, Earth Surf. Proc. Land., 32, 49–65, 2007.

Keesstra, S. D., Bruijnzeel, L. A., and van Huissteden, J.: Meso-scale catchment sediment budgets: combining field surveys and modeling in the Dragonja catchment, southwest Slovenia, Earth Surf. Proc. Land., 34, 1547–1561, 2009.

Keesstra, S. D., Geissen, V., van Schaik, L., Mosse., K., and Piiranen, S.: Soil as a filter for groundwater quality, Current Opinions in Environmental Sustainability, 4, 507–516, 2012.

Lieskovský, J. and Kenderessy, P.: Modelling the effect of vegetation cover and different tillage practices on soil erosion in vineyards: a case study in vráble (Slovakia) using WATEM/SEDEM, Land Degrad. Dev., 25, 288–296, 2014.

Li, P., Zhu, Q. K., Zhao, L. L., Chang, C., and Zhou, Y.: Soil moisture of fish-scale pit during rainy season in Loess hilly and gully region, Transactions of the Chinese Society of Agricultural Engineering, 27, 76–81, 2011 (in Chinese with English Abstract).

Li, Q. Y., Fang, H. Y., Sun, L. Y., and Cai, Q. G.: Using the ^{137}Cs technique to study the effect of soil redistribution on soil organic carbon and total nitrogen stocks in an agricultural catchment of Northeast China, Land Degrad. Dev., 25, 350–359, 2014.

Li, R., Hou, X. Q., Jia, Z. K., Han, Q. F., Ren, X. L., and Yang, B. P.: Effects on soil temperature, moisture, and maize yield of cultivation with ridge and furrow mulching in the rainfed area of the Loess Plateau, China, Agr. Water Manage., 116, 101–109, 2013.

Li, X. H., Yang, J., Zhao, C. Y., and Wang, B.: Runoff and sediment from orchard terraces in southeastern China, Land Degrad. Dev., 25, 184–192, 2014.

Li, X. Y., Bi, H. X., Diao, R. M., Liu, L. F., Li, X. G., and Li, J.: The measurement principles of TRIME-TDR system and its application in Caijiachuan watershedof Loess Plateau, China, Science of Soil and Water Conservation, 3, 112–115, 2005 (in Chinese with English Abstract).

Liu, Y., Gao, M. S., Wu, W., Tanveer, S. K., Wen, X. X., and Liao, Y. C.: The effects of conservation tillage practices on the soil water-holding capacity of a non-irrigated apple orchard in the Loess Plateau, China, Soil Till. Res., 130, 7–12, 2013.

Liu, Z., Yao, Z., Huang, H., Wu, S., and Liu, G.: Land use and climate changes and their impacts on runoff in the Yarlung Zangbo river basin, China, Land Degrad. Dev., 25, 203–215, 2014.

Ma, L. H., Wu, P. T., and Wang, Y. K.: Spatial distribution of roots in a dense jujube plantation in the semiarid hilly region of the Chinese Loess Plateau, Plant Soil, 354, 57–68, 2012.

Ma, L. H., Liu, X. L., Wang, Y. K., and Wu, P. T.: Effects of drip irrigation on deep root distribution, rooting depth, and soil water profile of jujube in a semiarid region, Plant Soil, 373, 995–1006, 2013.

McIntyre, B. D., Speijer, P. R., Riha, S. J., and Kizito, F.: Effects of mulching on biomass, nutrients, and soil water in banana inoculated with nematodes, Agron. J., 92, 1081–1085, 2000.

Mekonnen, M., Keesstra, S. D., Baartman, J. E., Ritsema, C. J., and Melesse, A. M.: Evaluating sediment storage dams: structural off-site sediment trapping measures in northwest Ethiopia, Cuad. Desarro. Rural, 41, 7–22, 2015a.

Mekonnen, M., Keesstra, S. D., Stroosnijder, L., Baartman, J. E. M., and Maroulis, J.: Soil conservation through sediment trapping: a review, Land Degrad. Dev., 26, 544–556, 2015b.

Moreno-Ramón, H., Quizembe, S. J., and Ibáñez-Asensio, S.: Coffee husk mulch on soil erosion and runoff: experiences under rainfall simulation experiment, Solid Earth, 5, 851–862, doi:10.5194/se-5-851-2014, 2014.

Montenegro, A. A. A., Abrantes, J. R. C. B., De Lima, J. L. M. P., Singh, V. P., and Santos, T. E. M.: Impact of mulching on soil and water dynamics under intermittent simulated rainfall, Catena, 109, 139–149, 2013.

Mwango, S. B., Msanya, B. M., Mtakwa, P. W., Kimaro, D. N., Deckers, J., and Poesen, J.: Effectiveness of mulching under miraba in controlling soil erosion, fertility restoration and crop yield in the usambara mountains, tanzania, Land Degrad. Dev., doi:10.1002/ldr.2332, 2015.

Nicolas, E., Torrecillas, A., Ortuno, M. F., Domingo, R., and Alarcon, J. J.: Evaluation of transpiration in adult apricot trees from sap flow measurements, Agr. Water Manage., 72, 131–145, 2005.

Ola, A., Dodd, I. C., and Quinton, J. N.: Can we manipulate root system architecture to control soil erosion, Soil, 1, 603–612, 2015.

Previati, M., Bevilacqua, I., Canone, D., Ferraris, S., and Haverkamp, R.: Evaluation of soil water storage efficiency for rainfall harvesting on hillslope micro-basins built using time domain reflectometry measurements, Agr. Water Manage., 97, 449–456, 2010.

Ram, H., Dadhwal, V., Vashist, K. K., and Kaur, H.: Grain yield and water use efficiency of wheat (*Triticum aestivum* L.) in relation to irrigation levels and rice straw mulching in North West India, Agr. Water Manage., 128, 92–101, 2013.

Sadeghi, S. H. R., Gholami, L., Sharifi, E., Khaledi Darvishan, A., and Homaee, M.: Scale effect on runoff and soil loss control using rice straw mulch under laboratory conditions, Solid Earth, 6, 1–8, doi:10.5194/se-6-1-2015, 2015.

Sas-Paszt, L., Pruski, K., Zurawicz, E., Sumorok, B., Derkowska, E., and Gluszek, A.: The effect of organic mulches and mycorrhizal substrate on growth, yield and quality of Gold Milenium apples on M.9 rootstock, Can. J. Plant Sci., 94, 281–291, 2014.

Seutloali, K. E. and Beckedahl, H. R.: Understanding the factors influencing rill erosion on roadcuts in the south eastern region of South Africa, Solid Earth, 6, 633–641, doi:10.5194/se-6-633-2015, 2015.

Suman, S. and Raina, J. N.: Efficient use of water and nutrients through drip and mulch in apple, J. Plant Nutr., 37, 2036–2049, 2014.

Wilson, K. B., Hanson, P. J., Mulholland, P. J., Baldocchi, D. D., and Wullschleger, S. D.: A comparison of methods for determining forest evapotranspiration and its components: sap-flow, soil water budget, eddy covariance and catchment water balance, Agr. Forest Meteorol., 106, 153–168, 2001.

Yu, B., Stott, P., Di, X. Y., and Yu, H. X.: Assessment of land cover changes and their effect on soil organic carbon and soil total nitrogen in daqing prefecture, China, Land Degrad. Dev., 25, 520–531, 2014.

Zhang, B. Y., Xu, X. X., and Liu, W. Z.: Soil water condition under different measures of soil and water conservation in loess hilly and gully region, Transactions of the Chinese Society of Agricultural Engineering, 25, 54–58, 2009 (in Chinese with English Abstract).

Zhang, P., Wang, Y. K., Zhan, J. W., Wang, X., and Wu, P. T.: Scheduling irrigation for jujube (*Ziziphus jujuba* Mill.), Afr. J. Biotechnol., 9, 5694–5703, 2010.

Zhao, G., Mu, X., Wen, Z., Wang, F., and Gao, P.: Soil erosion, conservation, and eco-environment changes in the Loess Plateau of China, Land Degrad. Dev., 24, 499–510, 2013.

Zhao, X. N., Wu, P. T., Gao, X. D., Tian, L., and Li, H. C.: Changes of soil hydraulic properties under early-stage natural vegetation recovering on the Loess Plateau of China, Catena, 113, 386–391, 2014.

Zhao, X. N., Wu, P. T., Gao, X. D., and Persaud, N.: Soil Quality Indicators in Relation to Land Use and Topography in a Small Catchment on the Loess Plateau of China, Land Degrad. Dev., 26, 54–61, 2015.

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

Depth cm	BD $g\,cm^{-3}$	Soil texture Sand%	 Silt%	 Clay%	K_{sat} $mm\,min^{-1}$	θ_s $cm^3\,cm^{-3}$	$\theta_{33\,kPa}$ $cm^3\,cm^{-3}$	$\theta_{1500\,kPa}$ $cm^3\,cm^{-3}$
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.

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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				
		Jun	Jul	Aug	Sep	Jun	Jul	Aug	Sep	Oct
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

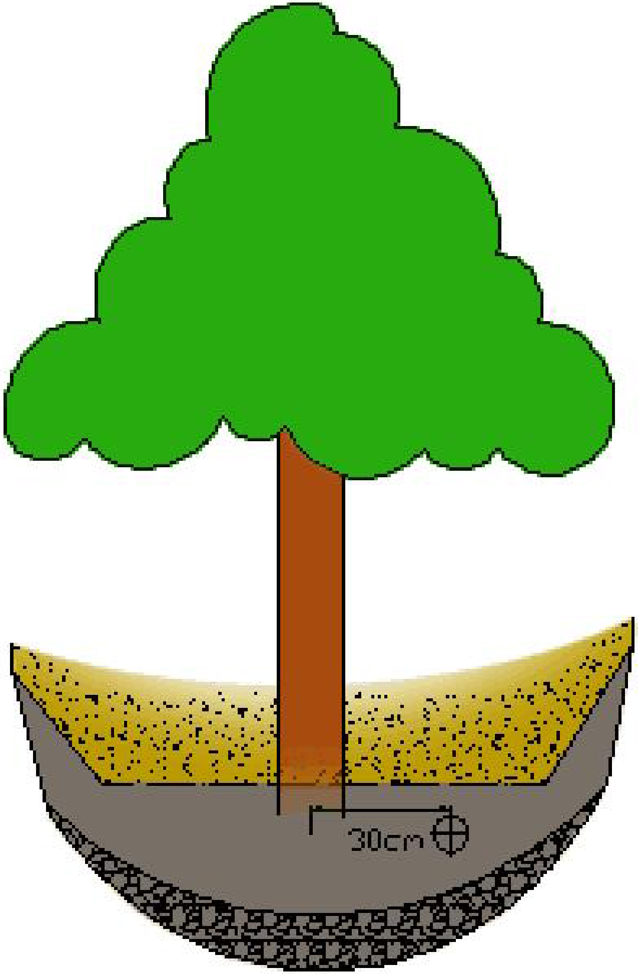

Figure 1. Relative positions of the fish-scale pit, the jujube tree and TDR pipe.

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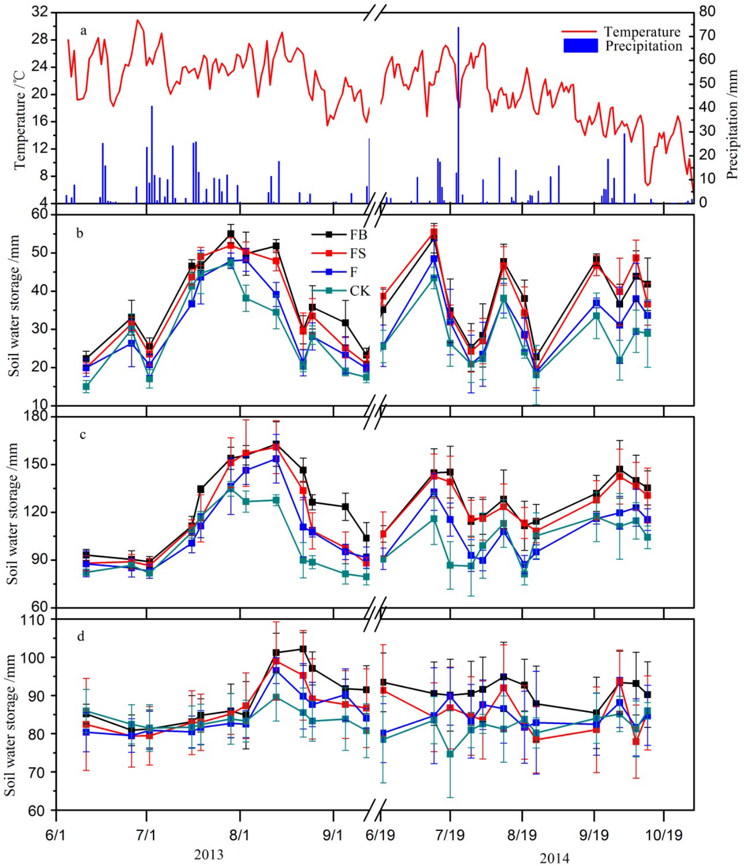

Figure 2. Temporal changes of **(a)** temperature and precipitation, **(b)** 0–20 cm soil water storage, **(c)** 20–100 cm soil water storage and **(d)** 100–180 cm soil water storage for fish-scale pit with branch mulching (FB), fish-scale pit with straw mulching (FS), fish-scale pit without mulching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

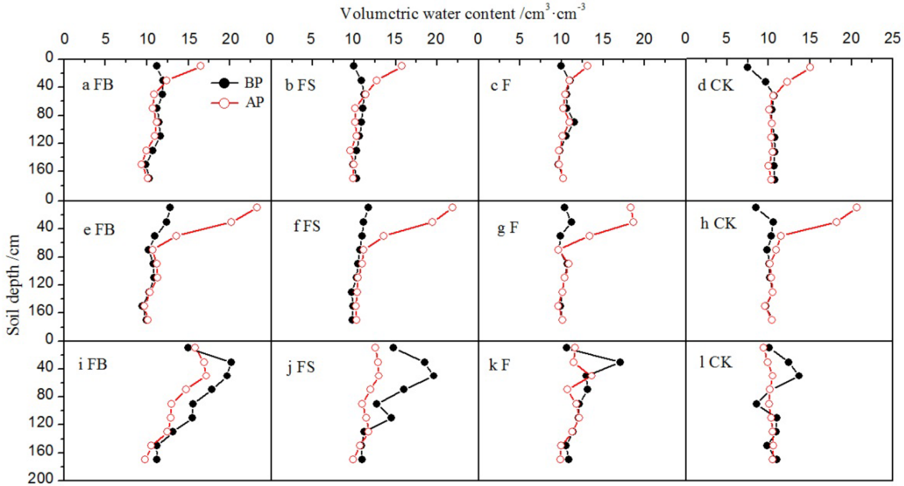

Figure 3. Vertical changes of soil moisture before (BF) and after (AP) typical precipitation in June **(a–d)**, July **(e–h)** and August **(i–l)** under fish-scale pit with branch mulching (FB), fish-scale pit with straw mulching (FS), fish-scale pit without mulching (F), and bare land treatment (*CK*).

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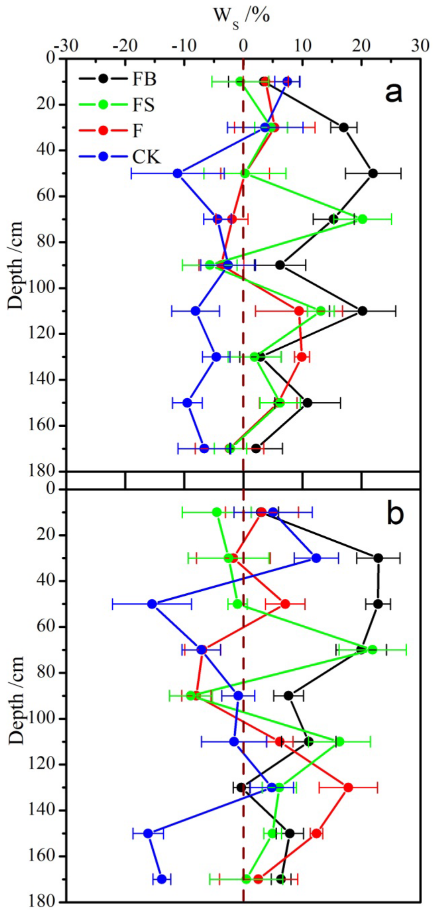

Figure 4. Relationship between compensation degree of soil water storage deficit (W_S) and soil depth at 2013 **(a)** and 2014 **(b)** under fish-scale pit with branch mulching (FB), fish-scale pit with straw mulching (FS), fish-scale pit without mulching (F), and bare land treatment (*CK*).