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July 20, 2012

Memorandum

To: Prof. Ge Sun, Editor of "Water, climate, and vegetation: ecohydrology in a changing world" special issue of Hydrology and Earth System Sciences

Subject: **Revision of hessd-2012-149**

Dear Prof. Sun:

Upon your request, we have carefully revised our manuscript hessd-2012-149 entitled "The hydrological responses of different land cover types in a re-vegetation catchment area of the Loess Plateau, China" after considering all the comments made by the editor and reviewers. The comments are constructive and have greatly helped us improve the overall quality of the manuscript.

The following is the point-point response to all the comments. A change-tracked copy of the revised manuscript was also attached.

Response to the comment:

Answers to the comments from reviewer #1

General comments:
The study provides valuable information on soil moisture dynamics and implications for re-vegetation on Loess Plateau in semi-arid area in China, it is valuable for publish. However, the study period is too short (4 months) and only in rain season, it is very difficult to get the general rules on soil moisture in this area.
Response: Thanks for your comments and suggestions. More than 70% precipitation focused in rainy season (June to September) in Loess Plateau. During this season, soil moisture variation is most active. Therefore, most researches related to soil moisture variations were conducted in the rainy season in Loess Plateau. The 5 sites with 60 soil moisture and temperature smart sensors were installed at the end of April 2011, and measurements were begun to record 2 months later until now. As the growing season and the rainy season were coincide in our study area on the Loess Plateau, in order to compare soil moisture dynamics of different vegetation types in the growing season, we selected this rainy season and three typical decreasing periods to compare the differences in their water losses, including periods of both relatively lower and higher water soil moisture contents. We used the continuous soil moisture measurement every 10 minutes could capture the pulses and detect the different.
Details comments:

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1. In the section of "the study area", five typical land cover types were selected, and those five sites with similar slope position, aspect, and slope degree. In fact, the crop land is very different with other land use type, just as said by author, the corn site, situated on check dam land in the bottom of valley. I suggest the author should add some detail information about the five different land cover, for example, forests cover ratio, density, etc.

Response: Yes, in order to avoid the interference of microtopography and other factors on the soil moisture, we selected the four sites on the slope of grass (*Andropogon*), subshrub (*Artemisia scoparia*), shrub (*Spiraea pubescens*) and tree (*Robinia pseudoacacia*) with similar slop position, aspect, and slope degree, but the crop (*Zea mays*) site situated on check dam land in the bottom of valley, it is very different with others. We have made it clear in the revision manuscript and added some detail information about these five sites. Associated with the Grain for Green Project implemented in the Loess Plateau, check dam lands become the main cropland in this area, it is necessary to detect its soil moisture dynamic processes.

2. Please give the detail explaination about infiltration depth (Zf) in the formal (1), and how to monitor it?

Response: When we study the infiltration process it based on the assumption that the water reaches a certain depth when the soil moisture content begins to increase, so we name it infiltration depth. Here we calculate the cumulative loss water, it should be the measured depth, and we have reworded it as "measured depth" in the revision version (SEE page9, line 185). Thank you very much for your comment.

3. Why the daily water loess for corn was the most variable?

Response: It is because the soil evaporation loss of the corn site were large in the measured depth as there is no protection from solar radiation in this period, the soil loss a large amount of water when there are enough moisture after the rainfall, and it reduced gradually with the soil dried. This results in the deviation of water loss for corn bigger than other types (Fig7 and 9). In the period with higher water soil moisture contents and more foliage for shadow, it was more stable.

Answers to the comments from reviewer #2

This manuscript analyzed hydrological impacts of re-vegetation through field experiments in the Loess Plateau, Northwest China. It evaluated the soil moisture and temperature differences among the 5 different land cover types: tree, shrub, subshrub, grass, and crop. The findings contribute to the literature in the soil physics and vegetation change. However, the paper needs to clarify the following points:

Response: Thanks for your constructive suggestions and great efforts in reviewing this paper.

1. Explanation of the temporal differences in soil moisture and temperature;

Response: We have tried to add some explanations. Plant communities influence the temporal and spatial variability of soil moisture content through inputs (infiltration) and outputs (evapotranspiration) processes. The shrub site had the lowest value resulting from the dense shrub layer that intercept much rainfall and consumed much shallow water. The soil moisture content of the tree site was higher than that of the shrub site because of the absence of a dense shrub layer. The highest soil moisture content was recorded on the dam land cultivated with corn (Zea mays) at the bottom of the valley. With a higher nutrient content and water retention capacity, the soil moisture content of the crop site was the highest. The subshrub and grass sites represent the natural vegetative successions after abandonment of cultivation, they have the medium evapotranspiration capacity, leading to the similar soil moisture contents, in the medium range. Temperature is the main factor causing the loss of soil moisture, while also the result. The corn site, which was located on dam land, different from the other cover types because of its terrain and soil properties. Among the other four types, subshrub and grass showed the highest soil temperatures, corresponding to greater moisture losses. The shrub site presented the strongest effect due to high coverage, resulting lower temperatures and less moisture being lost during the wet period. The temperature at the tree site was slightly higher than that of the shrub site, as observed for the moisture losses.

2. Soil water budget and soil water loss. Specifically, explicit explanation soil water loss by ET and other factors such as surface runoff.

Response: we have tried to add some explanation to clarify. We have installed 45 runoff plots to detect the runoff and sediment generation, some results has published by Liu et al (2011) (SEE page16, line 338), we based on it and cited it. Infiltration, surface run-off and evapotranspiration have identified as the key factors determining soil moisture content at fine scales. After the water infiltrated into the soil, the loss of soil moisture mainly took place via evaporation (E) from soil and transpiration (T) from vegetation, which are process that usually cannot be separated. The mutual relation between E and T is not same in different land cover type sites, this eventually led to the different of the ET and soil moisture differences.

3. Presentation of data on dam land advantages in soil and water conservation. Once these clarifications are done, the paper can be published in the journal.

Response: we have cited the paper "Wang, Y. F.; Fu, B. J.; Chen, L. D.; Lü, Y. H.; Gao, Y. Check dam in the Loess Plateau of China: engineering for environmental services and food security. Environ. Sci. Technol. 2011, 45, 10298-10299" to added some data on on dam land advantages in soil and water conservation (SEE page 16, line 342-346). However, there are also some potential negative effects and uncertainties in the construction of check-dams, especially given the risk they pose to downstream water resources, and high clay content and poor water permeability result in salinization and enrichment of pollutant.

Answers to the comments from reviewer #3

General Comments: This manuscript compares soil moisture and temperature observations for five vegetative land cover types on the Loess Plateau in China. This work is important and timely as large-scale revegetation efforts are undertaken in China to mitigate soil erosion, but may have unintended consequences on soil moisture and water availability. The paper is suitable for publication in the Ecohydrology special issue of HESS, provided the following issues are addressed.

Response: We greatly appreciate the time the reviewers put in reading my manuscript, and the comments provided were valuable and constructive.

Specific Comments: 1. The authors present data regarding the height and percent cover of the five land cover types. How representative are these particular plots of the region as a whole? Is 40% cover typical of Robinia pseudoacacia tree stands on the Loess Plateau?

Response: Yes, the five land cover type sites we selected were very representative in this re-vegetation area. The cover typical of *Robinia pseudoacacia* tree in this area was approximately 40%, this can be supported by Jin et al.' paper" Jin, T. T., Fu, B. J., Liu, G. H., and Wang, Z.: Hydrologic feasibility of artificial forestation in the semi-arid Loess Plateau of China, Hydrol. Earth Syst. Sci., 15, 2519-2530, doi:10.5194/hess-15-2519-2011, 2011."

2. The authors attribute differences in soil moisture and temperature to differences in vegetation type, but there are other variables at play, including vegetative cover percentage and soil properties. For example, the authors acknowledge that the crop land cover had "high clay content and poor water permeability, resulting their higher and more stable soil moisture content." The authors need to isolate the vegetative cover effects from the soil property and percent cover effects.

Response: Yes, the soil moisture and temperature differences are results of various factors, including topography, vegetation and soil properties. In order to avoid the interference of microtopography and other factors, we selected the four sites on the slope of grass (*Andropogon*), subshrub (*Artemisia scoparia*), shrub (*Spiraea pubescens*) and tree (*Robinia pseudoacacia*) with similar slop position, aspect, and slope degree, but the crop (*Zea mays*) site situated on check dam land in the bottom of valley, it is very different with others, as it was a important land use type, it can be used as a reference. We also added some soil properties data sets, including soil texture consisting (Clay, Silt, Sand) and bulk density for every land cover types, and compared the differences in the discussion section.

Technical Corrections: 1. Review entire manuscript for typographical errors and sentence structure (e.g. p. 5812 line 25, p. 5816 line 6, and others).

Response: we revised these typographical errors and sentence structure through the manuscript according to your suggensiton.

3. Need to provide some concluding statement to the abstract to relay the significance of the results.

Response: we have added some concluding statement to the abstract based on your suggestion.

3. The meteorological parameters were collected every 30 min, and the HOBO weather station data logger every 10 min?

Response: Yes, our Dynamet weather station collected parameters every 30 min by DNX10 data logger. While our soil moisture and temperature were collected by the HOBO weather station data logger every 10 min.

4. What p value are you considering significant?

Response: here we consider the value of 0.01 is significant.

5. Throughout the manuscript, add clarification as to whether variability described is across time or across vegetation type (e.g. p. 5816 line 4).

Response: we have clarified that it is across vegetation types.

6. In section 4.2, might be good to add a table of mean soil moisture and temperature for each vegetation type, also showing which are significantly different.

Response: we have added table 2 to comparing average soil moisture based on your suggestion.

7. p. 5816 line 18, is the difference between soil moisture of grass and subshrub really different if your p-value is 0.26?

Response: the moisture of grass and subshrub are similar, not significantly different.

8. p. 5816 lines 22-23, how do you know the average soil temperature was clearly affected by the growth of foliage? It would be good to show the air temperature in figure 3 to demonstrate that it is not because of differences in air temperature.

Response: At the end of June early July, the temperature of corn site was higher than the tree site, but then decreased. We know in this period, the corn grown from approximately 20 cm to 2 m. so we supposed the temperature was affected by the grown of foliage. According to your suggestion, we have shown the air temperature in the figure 3.

9. p. 5817 line 1- what was the r for soil moisture and temperature correlation?

Response: Here the r is for the soil moisture and temperature Pearson correlation coefficient.

10. p. 5817 line 14 and p. 5818 line 3, is the initial soil moisture content for all vegetation types the same? Is this an average across all plots? Also, are the units of cm3 cm-3 correct? Should this be 0.15 cm3 cm-3 instead of 15 cm3 cm-3, or 15%?

Response: the initial soil moisture content were not same for the five vegetation types, the average is across all plots, and you are right, the units should be 0.15 cm3 cm-3, we have revised.

11. p. 5818 lines 20-21, How do you know that the loss of soil moisture mainly took place by ET, did you measure runoff or water loss to deep groundwater?

Response: we have installed 45 runoff plots to detect the runoff and sediment generation, some results has published by Liu et al (2011), we based on it and cited it. We now revised as “Infiltration, surface run-off and evapotranspiration have identified as the key factors determining soil moisture content at fine scales. Evapotranspiration (ET) is a large term in the water balance equation in arid and semi-arid area, including evaporation from soil and transpiration from vegetation, which are process that usually cannot be separated."

12. p. 5819 line 2, please clarify what is meant by "higher plants" and "more stable".

Response: we revised as "The loss of soil moisture through the transpiration of higher plants, especially the woody plants with deeper root, is more stable than the evaporation from soil due to their constant water uptake capacity."

If you have any further question about this revision, please contact us.

Sincerely Yours,

Prof. Bojie Fu (bfu@rcees.ac.cn)

Mr. Shuai Wang (shuaiwangnmg@gmail.com)

The hydrological responses of different land cover types in a re-vegetation catchment area of the Loess Plateau, China

A revised manuscript submitted to the "Water, climate, and vegetation: ecohydrology in a changing world" special issue of Hydrology and Earth System Sciences (hess-2012-149)

带格式的: 两端对齐

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Abstract

The impact of re-vegetation on soil moisture dynamics was investigated by comparing five land cover types. Soil moisture and temperature variations under grass (*Andropogon*), subshrub (*Artemisia scoparia*), shrub (*Spiraea pubescens*), tree (*Robinia pseudoacacia*), and crop (*Zea mays*) vegetation were continuously monitored in an experiment performed during the growing season of 2011. There were more than 10 soil moisture pulses during the period of data collection, and the surface soil moisture of all of the land cover types showed an increasing trend. Corn cover was associated with consistently higher soil moisture readings than the other surfaces. Grass and subshrubs showed an intermediate moisture level, with that of grass being slightly higher than that of subshrub most of the time. Shrubs and trees were characterized by lower soil moisture readings, with the shrub levels consistently being slightly higher than those of the trees. Three typical decreasing periods were chosen to compare the differences in water losses. Despite the greater post-rainfall loss of moisture under subshrub and grass vegetation than tree and shrubs, subshrub and grass sites exhibit a higher soil moisture content due to their greater retention capacity in the dry period. The daily water loss trends of the tree and shrub sites were similar and were more stable than those of the other types. Soil under subshrubs acquired and retained soil moisture resources more efficiently than the other cover types, with a competitive advantage in the long term, representing an adaptive vegetation type in this area. The interaction between vegetation and soil moisture dynamics contributes to structure and function in these ecosystems.

1. INTRODUCTION

Soil and water are the core elements of the earth's critical zone (Lin, 2010). Water is the main carrier and driver of mass and energy cycling between the atmosphere, biosphere, hydrosphere and lithosphere (Li, 2011). Especially in arid and semi-arid regions, water represents the main ecological constraint for plant survival, and hydrological processes determine the direction of evolution and ecological functioning of soil-vegetation systems (Li, 2011). Therefore, understanding the relationship and coupling mechanisms that exist among soil, water and vegetation can help to reveal the land surface development processes and nutrient balance in soil ecosystems.

Soil moisture dynamics are the central component of the hydrological cycle (Legates et al., 2010) and are mainly determined by processes including infiltration, percolation, evaporation and root water uptake. Obtaining accurate estimates of root water uptake and vegetation water use represents the weakest link in producing soil-vegetation-atmosphere transfer (SVAT) models (Schymanski al., 2008 c). Optimality-based models have experienced rapid development in recent years and have shown strong predictive power, leading to the hypothesis that vegetation has developed optimal water use strategies through co-evolution with natural conditions, including reducing water losses passively and increasing water absorption capacities actively (Cowan and Farquhar, 1977, Schymanski, 2008). Schymanski et al. (2007, 2008 a, b, c)successfully reproduced the surface soil moisture dynamics using an optimality-based model and further tested it in catchments with natural vegetation in Europe (Schymanski et al., 2007; 2008a; 2008b; 2008c). These model results show that the natural vegetation has adapted its water use strategies and soil moisture dynamics to local conditions.

The Loess Plateau of China is located in the upper and middle reaches of the Yellow River. It is a transitional zone between the southeastern humid monsoon climate and the northwestern continental dry climate. Almost of the natural vegetation on the Loess Plateau has been destroyed for cultivation as farmland in the last century. In the past three decades, to control soil erosion, a series of large reforestation campaigns was initiated, such as the Grain-for-Green project, which began in 1999. Indeed, approximately 24% of the area of erosion has been controlled, and vegetation coverage increased from 6.5% in the 1970s to 51.13% in 2010 on the Loess Plateau (National development and reform commission, 2010). Most of the farmlands cultivated on slopes were planted with trees and shrubs, and some farmlands were abandoned and developed as grass and subshrub communities (Su et al., 2011). However, a lack of comprehension regarding the ecohydrological effects of these artificial forests and shrubs can induce unwanted environmental problems. Large-scale vegetation restoration has also aggravated water scarcity, gradually leading to soil desiccation in the deep soil layer (Shangguan and Zheng, 2006; Chen et al., 2008a), resulting in low yields and efficiency, and ‘‘small aged tree’’ with heights of 3–5 m have appeared widely (Chen et al., 2008b). Vegetation-soil moisture feedback may lead to pattern Understanding formation (D’Odorico et al., 2007), thus, understanding the interactions between these artificial vegetation types and soil moisture is urgently required as basis for adjusting land use structures and ensuring sustainable provision of ecosystem services in this area.

In recent years, many authors have been dedicated to research on the ecohydrological effects of vegetation restoration in the Loess Plateau area (Gong et al., 2006; Liand Shao, 2006; Sun et al., 2006; Chen et al., 2007a; 2008a; 2008b;2010). Many investigators have paid a great deal of attention to soil desiccation resulting from the excessive depletion of deep soil water by artificial vegetation and long-term insufficient rainwater supplies (Li, 1983; Yang, 1996; Yang et al., 1998; Li and Shao, 2001; Mu et al., 2003; Fan et al., 2004; Yang and Tian, 2004). Chen et al. (2007) measured the soil moisture, runoff and soil erosion in plots of five vegetation types and found that soil water loss during the rainy season and was not fully replenished from rainfall in a shrub land and a semi-natural grassland with moderate-high moisture contents. The xylem sap flow in three species of trees was monitored in the field by Du et al. (2011), who found that the species vary in water use strategies, not only between exotic and native species, but also between the two native species. The number of studies on soil moisture spatial variability and temporal stability in the catchment of the Loess Plateau has continued to increase recently (Hu et al. 2009; Gao et al. 2011). These studies illustrated the water utilized results of different vegetation species. However, the continuous dynamic soil moisture processes occurring under different vegetation cover types are not clear, especially regarding differences in moisture depletion and its vertical distribution, which have been less well studied. The main aim of this study is therefore to monitor the hydrological response in a re-vegetation catchment by comparing soil moisture fluxes under grass (*Andropogon*), subshrubs (*Artemisia scoparia*), shrubs (*Spiraea pubescens*), trees (*Robinia pseudoacacia*), and crops (*Zea mays*) during and after rainfall events.

2. THESTUDY AREA

We chose ~~five~~ four typical land cover types with a similar slope position, aspect, and slope degree, including tree, shrub, subshrub, grass species and a crop~~-~~site on the check dam lands in the bottom of the valley~~species~~, in the Yangjuangou catchment (36°42'N, 109°31'E), located in the central part of the Loess Plateau (Fig. 1). Driven by the implementation of the Grain-for-Green project since 1999, most of the cultivated lands on steep slopes in this catchment were gradually abandoned for natural and artificial re-vegetation. Therefore, a mosaic of patchy land cover is the typical landscape pattern in the area, and the current main vegetation types were formed during different restoration stages associated with varying soil conditions. This region is a typical loess gully and hilly catchment area, with elevations ranging from 1,050 m to 1,298 m and slope gradients between 10° and 30° (Liu et al., 2011). The area has a semi-arid continental climate, in which the mean annual precipitation and air temperature during the past 20 years (1988–2007) were 498 mm and 10.6 ℃, respectively, according to data from the city meteorological station. The rainfall is mainly concentrated between June and September, with large inter annual variations being recorded, and spring and early summer are usually characterized as a dry season. The growing season for the common deciduous species ranges from April to October in this region. The soil in the study area is mainly derived from loess, with a depth of 50–200m depending on topography. The loess in this area usually exhibits a texture consisting of more than 50% silt (0.002–0.05mm) and less than 20% clay (<0.002mm), with a porosity of approximately 50%. The gravimetric field capacity and wilting percentage of the soil water in the region are 20–24% and 3–6%, respectively (Du et al., 2011).

(Fig. 1 and table 1 near here)

The tree site was planted with acacia (*Robinia psendoacacia*) trees with a height of approximately 5.5 m in rows with an interval distance of 2.5 or 3 m; the vegetation cover was approximately 40%, and the soil bulk density was 1.36g cm^{-3}. The shrub site was densely covered with *Spiraea pubescens* with a height of approximately 1.5 m and a sparse layer of planted acacia; the vegetation cover of this site was approximately 90%, and the soil bulk density was 1.22 g cm^{-3}. The subshrub site was covered with *Artemisia scoparia* with a height of approximately 0.45 m imbedded with tussock and bare areas; the vegetation cover was approximately 75%, and the soil bulk density was 1.25 g cm^{-3}. The grass site was covered with *Andropogon* beard grass with a height of approximately 0.40 m with imbedded bare areas; the vegetation cover was approximately 80%, and the soil bulk density was 1.29 g cm^{-3}. The crop site was situated on dam land at the bottom of the valley and was cultivated with corn (*Zea mays*) with a height of approximately 2.20 m; the vegetation cover was approximately 90%, and the soil bulk density was 1.40 g cm^{-3} (Table 1). The grasses and subshrubs grew under conditions of natural succession. The slope gradients of the sites were approximately 22°, with only slight differences, except for the crop site.

3. MATERIALS AND METHODS

3.1 Measurement sensor

H21 Soil moisture & Temp Logger Systems with S-SMC-M005 soil moisture probes and S-TMB-M006 soil temperature probes (Decagon Devices Inc., Pullman, WA) were installed to measure the soil profile moisture and temperature. The S-SMC-M005 soil moisture sensor is capable of measuring volumetric saturations between 0% and 100% with an accuracy of ±1.0%, and data were collected by HOBO weather station logger every 10 minutes. Rainfall was measured using a tipping bucket rain gauge, which was connected to a data logger with a precision of 0.2 mm. Concurrently, other meteorological parameters, such as the air temperature, relative humidity, wind velocity and potential evapotranspiration (ET0), were recorded at a height of 2 m above the ground every 30 minutes.

3.2 Field installation

A total of 12 soil moisture and temperature smart sensors in every site were installed at 10, 20, 40, 60, 80 and 100 cm 6 depths below the ground. To install the probes, a pit was dug in the soil with a sufficient width to allow their insertion. The probes were inserted into the soil through the unaltered side of the pit and were positioned horizontally in the direction of the maximum slope of the terrain. Once the probes had been inserted, the pit was carefully refilled, avoiding perturbations much as possible, and the surface was contoured in a manner similar to the surrounding slope. The site was set up at the end of April 2011, and measurements were not begun until 2 months later, with to the aim of allowing the soil to settle.

3.3 Data analysis

We assumed that the volumetric soil water content was accurately measured with probes matching the different depths in the soil profiles. Based on the soil water balance principle, the cumulative loss water can therefore be described as follows:

$$L = (S_i - S_e) \times Z_f$$

where S_i is the initial volumetric soil water content ($cm^3\ cm^{-3}$); S_e is the volumetric soil water content ($cm^3\ cm^{-3}$) at the end stage; Z_f is the measure depth (cm); and L is the cumulative loss water (mm).

Data on soil moistures of these five types were analysed using SPSS for Windows 16.0. A one-way ANOVA was performed, after verifying the assumptions of normality and homogeneity of variances, to test the effects of land cover types on soil moisture.

4. RESULTS

4.1 Soil moisture pulse

Over the entire duration of the study, from June to September, there was no obvious variability in the sensor readings obtained at the 80 and 100 cm depths, and the average of the other four sensor readings under each land cover type was therefore used. Based on the responses of the moisture probes to rainfall events, there were more than 10 moisture pulses during the period of data collection (Fig. 2). In all of the rainfall episodes, a similar parallel, but different trend in moisture retention and reduction is noticeable between the five investigated land cover types. Typically, the variability in soil moisture readings was correlated with the amount of precipitation received. The highest soil moisture content peak was experienced on 20 August due to three major rainfall events in the three preceding days. Throughout the observation period, the surface soil moisture showed an increasing trend.

(Fig. 2 near here)

4.2 Comparison of soil moisture and temperature in different land cover types

The corn cover was associated with consistently higher soil moisture readings than the other surfaces ($p<0.01$, LSD method). The grass (*Andropogon*) and subshrub (*Artemisia scoparia*) sites showed an intermediate level, with the values for grass being slightly higher than those for subshrub most of the time until 16 September ($p=0.26$), significantly different from others ($p<0.01$). The shrub (*Spiraea pubescens*) and tree (*Robinia pseudoacacia*) sites presented lower soil moisture readings, with the shrub values being slightly higher than those of the tree site consistently ($p=0.01$), and significantly different from others ($p<0.01$). With exception of the corn land cover type, the average soil temperature was clearly affected by the growth of foliage. The average soil temperature exhibits approximately the same regime as the average moisture content among the other four cover types. The temporal trend of the average soil temperature contrasted with the moisture trend, they are significantly negative correlated for all these five types ($p<0.01$), and showing a downward trend throughout the observation period (Fig. 3).

(Fig. 3 near here)

4.3 Pattern of soil moisture decreases

Three typical decreasing moisture periods were chosen to compare the differences

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in the water loss rate between the five land cover types and their vertical distribution.

In the period of relatively lower soil moisture contents, from July 6 to July 12, the initial average soil moisture content was 0.15.19 cm^3 cm^{-3}. The subshrub site lost the greatest amount of water of up to 15 mm over these 7 days, which was mainly contributed by the 0-10 cm and 10-20 cm layers. Additionally, the daily water loss was higher for subshrub than for the other cover types, ranging from 0.7 to 2.6mm. The lowest total water loss value over this 7-days period of only 6 mm was observed for grass cover, which showed a daily water loss trend that was similar to but lower than that of subshrub, ranging from 0.15 to 1.09 mm. The daily water loss for corn was the most variable, ranging from 0.38 to 2.43 mm, and the cumulative water loss for this cover type was 7.8 mm. Tree and shrub showed an intermediate level, with the value for the tree site being slightly higher than that of shrub. These last two sites showed cumulative water losses of 9.5 and 7.2 mm, respectively, and their daily water loss trends were similar and more stable compared to the other cover types. The water losses of these four cover types were mainly contributed by the 0-10 cm layer in this period (Fig. 4 and 5).

(Fig. 4 and 5 near here)

In the periods of relatively higher water soil moisture content, from July 31 to August 15 (Fig. 6 and 7) and August 25 to August 31(Fig. 8 and 9), the initial average soil moisture content for all was 0.22 cm^3 cm^{-3}. The data for the tree site were missing for August 9, and those of the shrub site were missing from August 8 to 15. During these two periods, the average daily water losses for subshrub and grass were 2.3 and

2.2 mm, respectively. Corn showed the lowest average daily water loss of 1 mm. The tree and shrub sites presented an intermediate level, exhibiting average daily water losses of 1.7 and 1.8 mm, respectively. All three layers contributed to the water loss among the five cover types.

(Fig. 6 and 7 near here)

(Fig. 8 and 9 near here)

5. DISCUSSION

5.1 Soil moisture dynamics

Soil moisture was mainly replenished by precipitation events and exhibited various types of pulse events. The precipitation events occurring on the Loess Plateau can be simply divided into two categories: events with small amounts of rainfall occurring at a high frequency and events with large amounts of rainfall with a low frequency. The amount of water received in the form of small events shows little variation, whereas the amount of water in large events varies markedly among years, leading to the large inter-annual variations observed in amount of precipitation in this area (Liu et al., 2011). Small rainfall events affect only the uppermost cm of the soil, and the soil moisture was therefore mainly contributed by the large events. Infiltration, surface run-off and evapotranspiration have identified as the key factors determining soil moisture content at fine scales. Evapotranspiration (ET) is a large term in the water balance equation in arid and semi-arid area, including evaporation from soil and transpiration from vegetation, which are process that usually cannot be separated (Wang et al., 2012). A large fraction of the soil moisture in the soil surface layer is lost through direct evaporation due to high temperatures and low root densities, while the rates of plant water uptake increase, and evaporation and vapor diffusion rates decrease in deeper soil (Susanne and Osvaldo, 2004). Thus, the larger the rainfall event, the deeper the associated pulse depth and the larger the fraction of precipitation leaving the soil via transpiration and contributing to the primary productivity of higher plants. The loss of soil moisture through the transpiration of higher plants, especially the woody plants with deeper root, is more stable than the evaporation from soil due to their constant water uptake capacity. Our observation period fell within the rainy season, when there is higher soil moisture. The subshrub and grass cover types cannot protect the soil surface from solar radiation, leading to greater daily water losses via direct evaporation. The interval of the rainfall events was not sufficiently long for the moisture loss regime to shift from the wet period to the dry period. Higher moisture retention capacity after rainfall events also implies higher moisture loss through direct evapotranspiration before a wet/dry threshold is reached, consistent with the results conducted in the Eastern Cape Province, South Africa (Odindi and Kakembo, 2011). The larger amount of water that infiltrated under the subshrubs led to a higher moisture loss rate, whereas grass cannot maintain this high rate for as long a period due to the smaller amount of water acquired. The initial soil moisture content of the subshrub and grass sites was higher than that of tree and shrub, and the moisture loss rates for subshrub and grass were also higher than those of the tree and shrub sites in this short wet period, leading to the gap between them becoming smaller. The corn site, situated on check dam land in the bottom of the valley, have a high clay content and poor water permeability, resulting their higher and more stable soil moisture content.

5.2 Soil temperature and water loss

Temperature is the main factor causing the loss of soil moisture under conditions of high moisture content. In the wet period after a rainfall event, soil moisture loss is controlled by atmospheric demand or energy (Wang et al., 2011a). The corn site, which was located on dam land, different from the other cover types because of its terrain and soil properties. Among the other four types, subshrub and grass showed the highest soil temperatures, corresponding to greater moisture losses. The shrub site presented the strongest effect due to high coverage, resulting lower temperatures and less moisture being lost during the wet period. The temperature at the tree site was slightly higher than that of the shrub site, as observed for the moisture losses. According to Odindi and Kakembo (2011), moisture losses include both wet and dry regimes presenting different loss slopes, with that of the wet regime being steeper than that of the dry regime. There were dense rainfall events during our observation period, which was not sufficiently long to study the entire pattern of moisture decreases, as the study was mostly carried out during the wet stage. This led to the observation of an interesting phenomenon in that for these land cover types, the more soil moisture was lost, the higher the average soil moisture content was. De Lannoy et al. (2006) also observed that a reduction in moisture content leads to a decrease in the rate of evapotranspiration, resulting in wetter patches experiencing more rapid soil moisture loss than other surfaces. It can be assumed that although the tree and shrub vegetation consumed more water in the growing season, as the growing season and the rainy season coincide, it is not possible for a soil moisture content gap to form between the other types during this period. The gap occurred in the dry season when the soil moisture loss was mainly controlled by the capacity of plants to absorb water from the soil (Wang et al., 2011a). Tree and shrub vegetation can maintain stable water absorption and transpiration during the dry season, where as subshrubs and grass cannot, which contributed to the differences in the soil moisture content between them.

5.3 Implications for re-vegetation

The most important lesson regarding water and soil conservation in the Loess Plateau area of China is that "precipitation should be impeded to allow it to infiltrate locally" (Chen et al., 2007b) to reduce surface runoff and enhance infiltration. Following implementation of the Grain-for-Green project for more than 10 years, most of the cultivated lands on the slope were planted with artificial forests and shrubs, though grasses, in some cases succeeding to subshrubs, were also grown on some of the abandoned cultivated lands. The effects of this re-vegetation regarding impeding surface flows are obvious, with runoff being reduced and the goal of soil and water conservation basically being achieved. Unfortunately, because the amount of rainfall interception associated with tree and shrub vegetation is greater, and the bulk density of soil under the trees is larger and the soil become firmer result to a poor infiltration capacity, the amount and depth of infiltration associated with these cover types are lower than for subshrub and grass soils. The stable higher evapotranspiration capacity associated with tree and shrub vegetation results in a lower soil moisture content and even a drier layer, destroying the regional long-term ecological balance (Chen et al., 2010). Patchily distributed subshrubs acquire and retain soil moisture resources more efficiently than tree and shrub vegetation, resulting from the efficient impediment effects and medial root water uptake capacity of subshrub vegetation, also gathered and maintained a high clay content. Hillslope plot experiments suggest that grass cover yields more runoff (Liu et al., 2011), leading to more sand and lower clay content, but it could also retain more moisture due to its shallow root distribution and lower water uptake capacity, and the amount of water loss is determined by the initial moisture content, so grass cover will develop into subshrubs as the subshrubs with a competitive advantage in the long term. More than 100 000 check dams have been built over the last 50 years in the Loess Plateau, which storing 21 billion m3 sediments and 3200 km2 of dam croplands had been created, and the carbon storage in check dams of the Loess Plateau can amount to 0.952 Gt (Wang et al., 2011b). However, ~~Dam~~ dam lands exhibit a higher moisture content but a low permeability and a potential for salinization as higher clay content and bulk density.

6. CONCLUSION

This study identified soil moisture retention and flux variations under tree, shrub, subshrub, grass and corn cover in the re-vegetated catchment area of the Loess Plateau in the rainy season of 2011. Despite the greater post-rainfall loss of moisture under subshrub and grass vegetation than tree and shrubs, subshrub and grass sites exhibit a higher soil moisture content due to their greater retention capacity in the dry period. The soil temperature exhibits the same regime as the moisture loss following rainfall events, with the exception of the corn site; temperature is the main contributor to moisture losses during the wet period. Dam lands present attractive advantages, including promoting soil and water conservation, carbon sequestration and increased food production, but they also show a potential for salinization to occur due to their high clay content and poor water permeability. Changes to soil cover may alter the soil moisture budget, and soil moisture is one of the most important abiotic factors determining vegetation growth, variability and regeneration. The interaction between vegetation and soil moisture dynamics has important implications as it leading to structure and function formation in these ecosystems. Subshrubs are the natural succession vegetation type following the abandonment of the croplands in the study area for more than 20 years. The runoff and run-on patches associated with this vegetation type are distributed in intervals, leading to their soils acquiring and retaining soil moisture resources more efficiently than other cover types. Thus, subshrubs represent an adaptive vegetation type in this area.

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Table 1. Main characteristics for different land cover types.

Soil (0-1m) and vegetation properties	Tree	Shrub	Subshrub	Grass	Crop
Clay (%)	2.92[a]/0.22[b]	3.22/0.43	3.37/0.42	2.57/0.32	3.43/0.28
Silt (%)	59.37/2.60	57.08/3.97	59.00/4.90	55.15/4.18	56.90/3.13
Sand (%)	37.71/2.72	39.70/4.17	37.63/5.28	42.28/4.49	39.66/3.29
bulk density (g cm^{-3})	1.36/0.05	1.22/0.12	1.25/0.11	1.29/0.03	1.4/0.1
Height (m)	5.5	1.5	0.45	0.4	2.2
Cover (%)	40	90	75	80	90

[a] Mean value.

[b] Standard error.

Table. 2. The comparisons of average soil moisture between the five land cover types.

	Average soil moisture(cm^3 cm^{-3})	Grass	Subshrub	Shrub	Tree	Crop
Grass	0.181	0				
Subshrub	0.173	0.008(0.262)	0			
Shrub	0.111	0.070(0.000)**	0.062(0.000)**	0		
Tree	0.096	0.084(0.000)**	0.077(0.000)**	0.015(0.012)	0	
Crop	0.252	-0.071(0.000)**	-0.078(0.000)**	-0.141(0.000)**	-0.155(0.000)**	0

The significance is within the bracket. "**"represents significant correlation at level of 0.01. "*" represents significant correlation at level of 0.05.

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Figure Legends:

Fig. 1. Location of the study area and the typical land cover types.

Fig. 2. Dynamics of the mean soil moisture and precipitation profiles and the three selected typical decreasing moisture periods.

Fig. 3. Dynamics of the mean soil temperature during the study period.

Fig. 4. Soil moisture decrease process under the five land cover types from Jul 6 to Jul 12.

Fig. 5. Daily soil water loss and cumulative water loss under the five land cover types from Jul 6 to Jul 12.

Fig. 6. Soil moisture decrease process under the five land cover types from Jul 31 to Aug 15.

Fig. 7. Daily soil water loss from Jul 31to Aug 15 and cumulative water loss under the five land cover types from Jul 31 to Aug 7.

Fig. 8. Soil moisture decrease process under the five land cover types from Aug 25 to Aug 31.

Fig. 9. Daily soil water loss and cumulative water loss under the five land cover types from Aug 25 to Aug 31.

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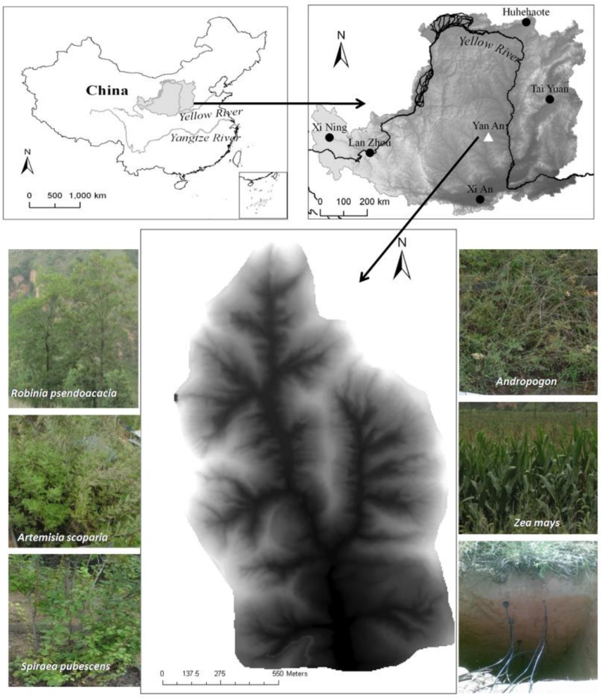

Fig. 1. Location of the study area and the typical land cover types.

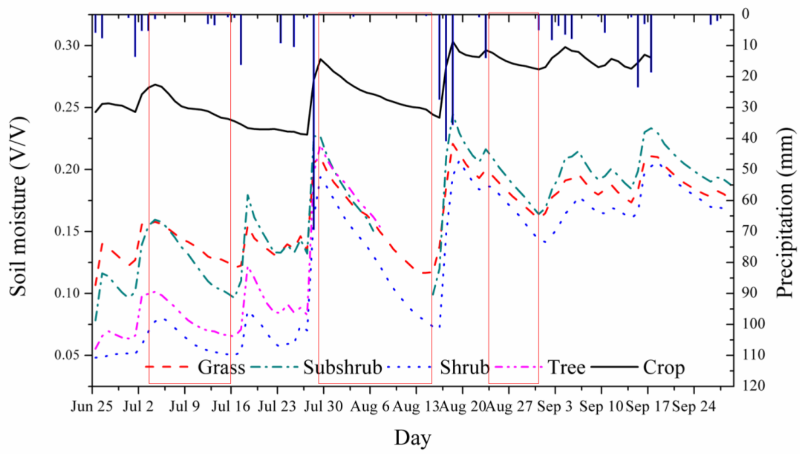

Fig. 2. Dynamics of the mean soil moisture and precipitation profiles and the three selected typical decreasing moisture periods.

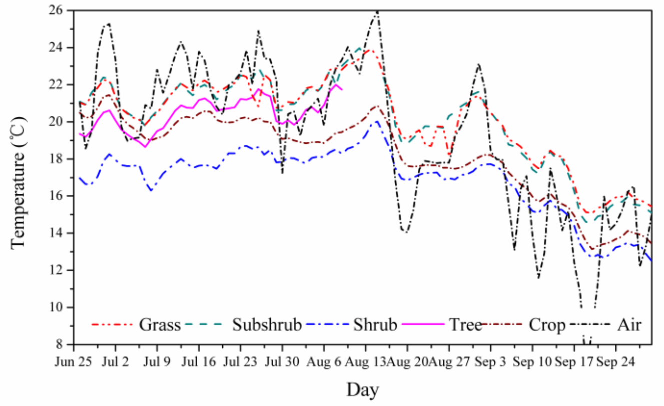

Fig. 3. Dynamics of the mean soil temperature during the study period.

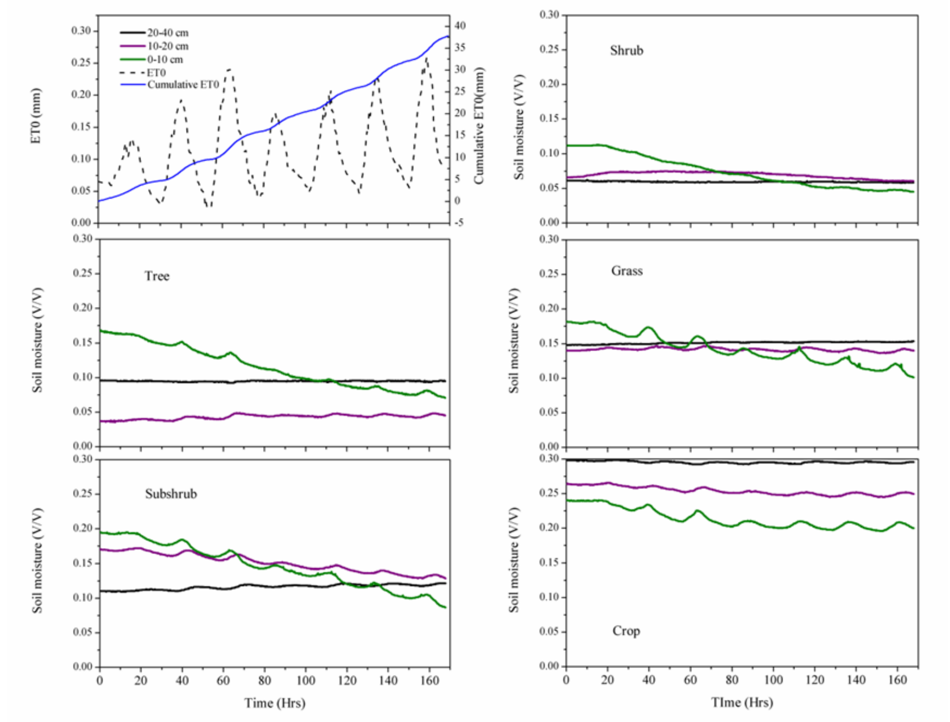

Fig. 4. Soil moisture decrease process under the five land cover types during Jul 6 to Jul 12.

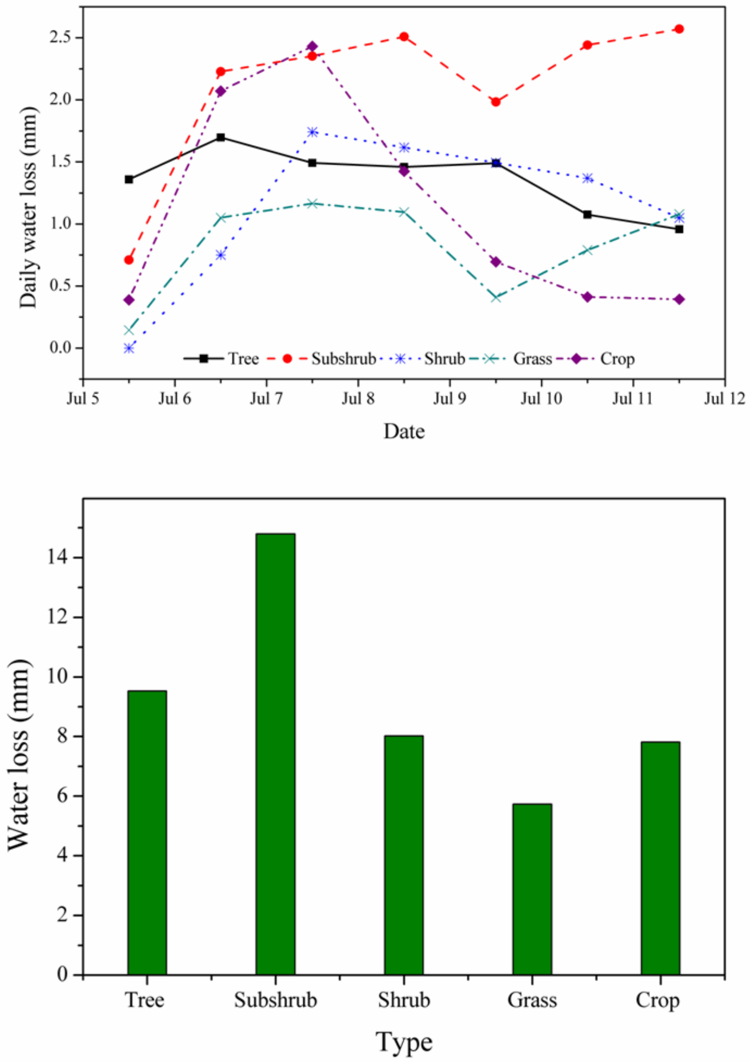

Fig. 5. Daily soil water loss and cumulative water loss under the five land cover types from Jul 6 to Jul 12.

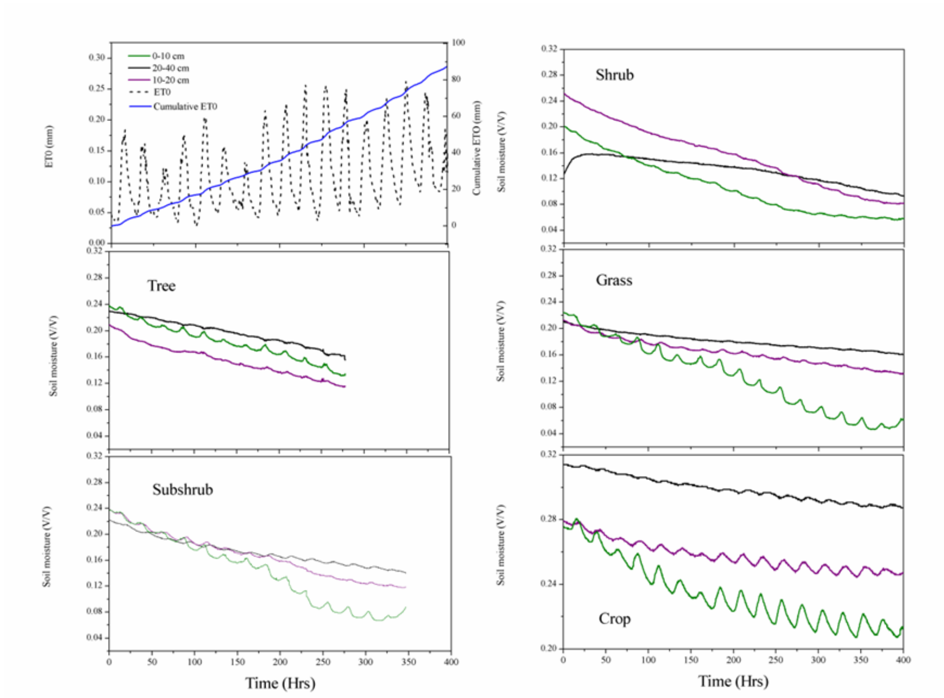

Fig. 6. Soil moisture decrease process under the five land cover types from Jul 31 to Aug 15.

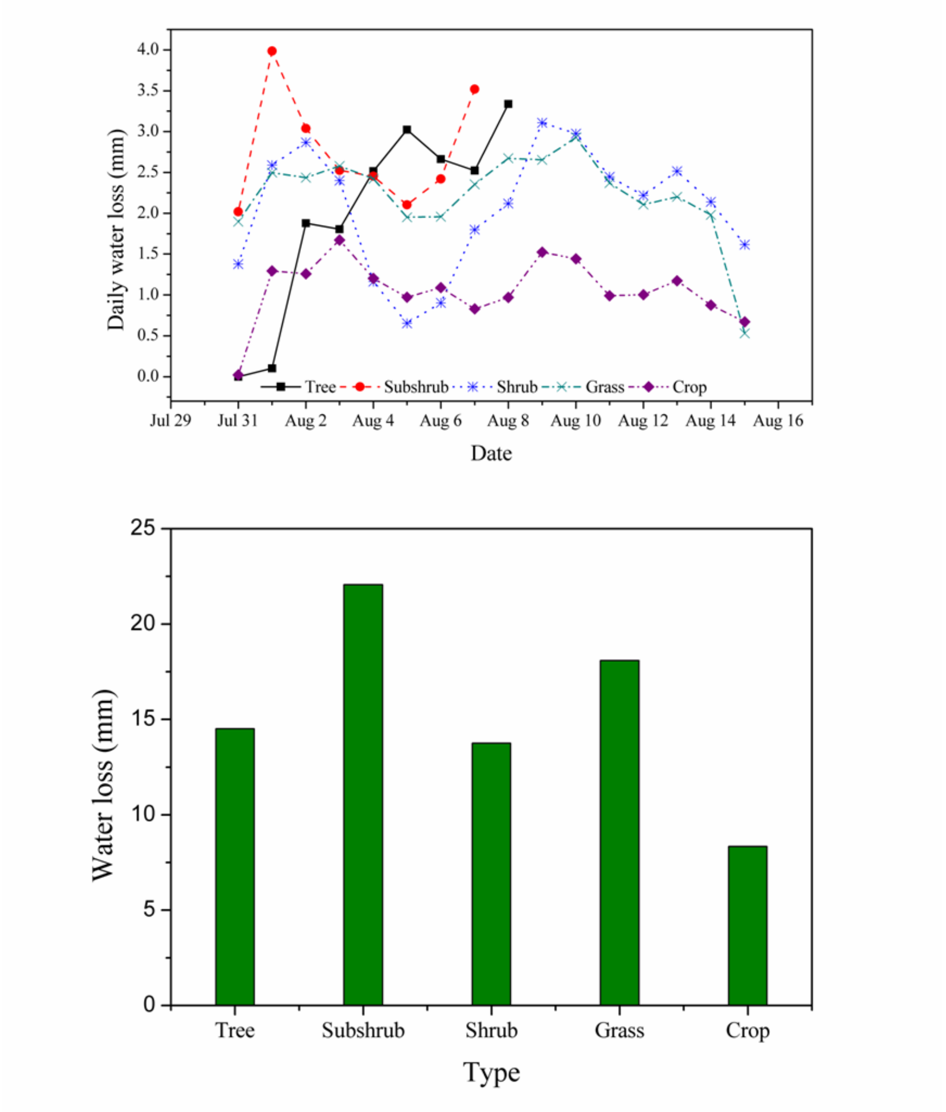

Fig. 7. Daily soil water loss from Jul 31to Aug 15 and cumulative water loss under the five land cover types from Jul 31to Aug 7.

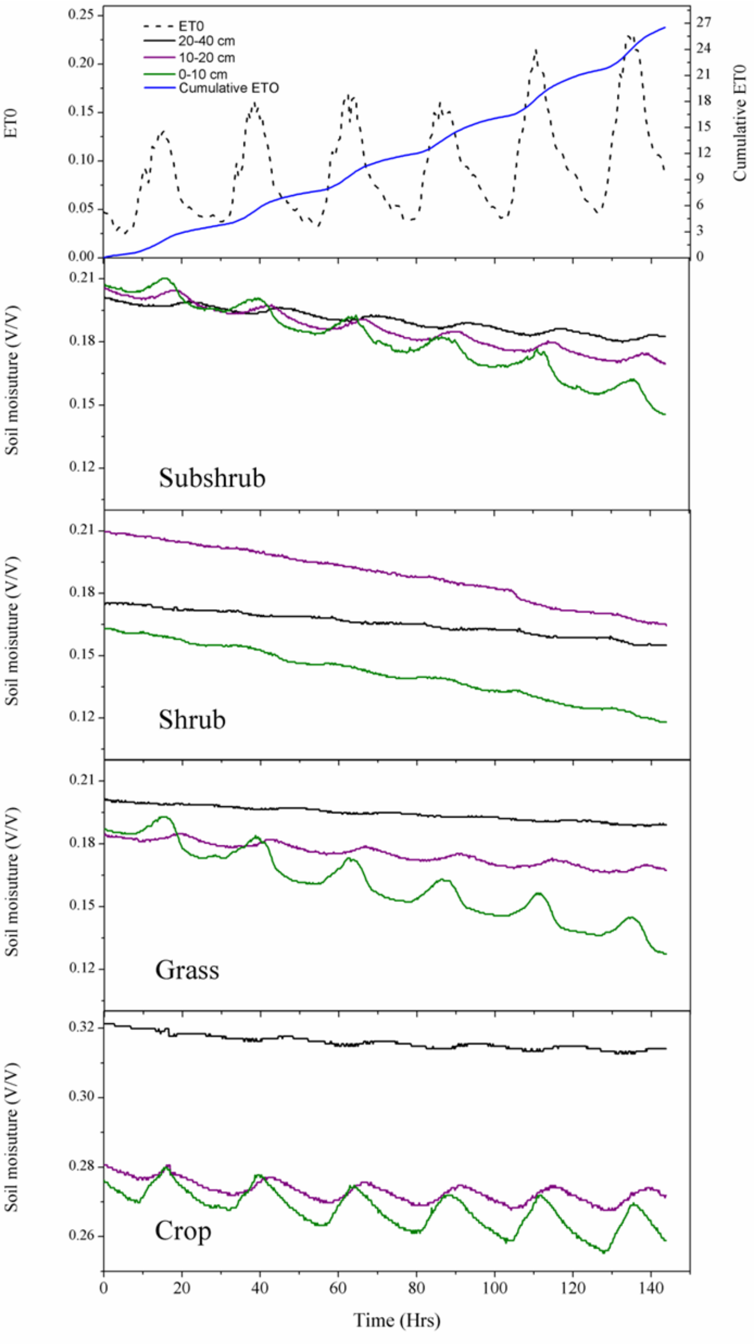

Fig. 8. Soil moisture decrease process under the five land cover types from Aug 25 to Aug 31.

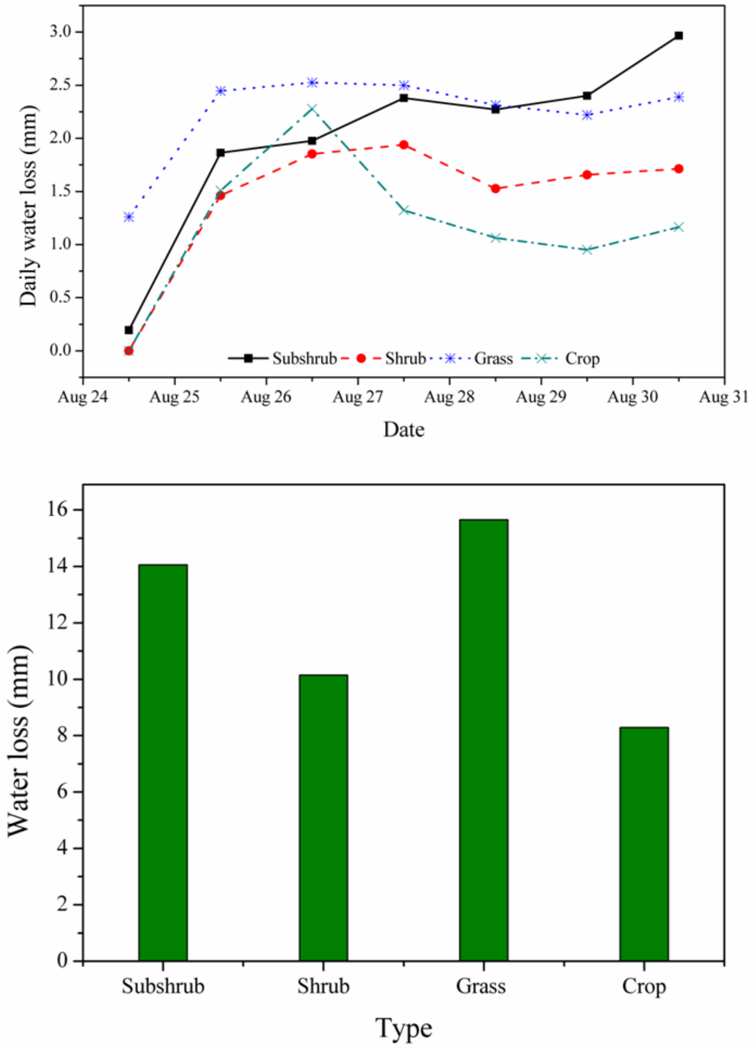

Fig. 9. Daily soil water loss and cumulative water loss under the five land cover types from Aug 25 to Aug 31.