Hydrol. Earth Syst. Sci. Discuss., 9, 5809–5835, 2012
www.hydrol-earth-syst-sci-discuss.net/9/5809/2012/
doi:10.5194/hessd-9-5809-2012

Hydrology and Earth System Sciences Discussions

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

S. Wang, B. J. Fu, G. Y. Gao, and J. Zhou

State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, P.O. Box 2871, Beijing 100085, China

Received: 26 March 2012 – Accepted: 10 April 2012 – Published: 4 May 2012

Correspondence to: B. J. Fu (bfu@rcees.ac.cn)

Published by Copernicus Publications on behalf of the European Geosciences Union.

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 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. With the exception of the corn land cover type, the average soil temperature showed the same regime as the average moisture content, but exhibiting a downward trend throughout the observation period. Three typical decreasing periods were chosen to compare the differences in water losses. In periods of both relatively lower and higher water soil moisture contents, subshrubs lost the largest amount of water. The daily water loss associated with corn was most variable. The tree and shrub sites presented an intermediate level, with that of tree being slightly higher compared to shrub; the daily water loss trends of these two land cover types were similar and were more stable than those of the other types. The amount of water loss related to the grass land cover type is determined by the initial moisture content. Soil under subshrubs acquired and retained soil moisture resources more efficiently than the other cover types, representing an adaptive vegetation type in this area.

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 et al., 2008c). 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, 2008a, 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. 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). 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; L. D. Chen et al., 2007a, 2010; H. S. Chen et al., 2008a, b). 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 treeswas 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 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 The study area

We chose five typical land cover types with a similar slope position, aspect, and slope degree, including tree, shrub, subshrub, grass and crop species, in the Yangjuangou catchment (36°42′ N, 109°31′ E), located in Yan'an City of Shaanxi Province 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 1050 m to 1298 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 yr (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 50–200 m depending on topography. The loess in this area usually

HESSD
9, 5809–5835, 2012

exhibits a texture consisting of more than 50 % silt (0.002–0.05 mm) and less than 20 % clay (<0.002 mm), 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).

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 1.36 g 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

HESSD
9, 5809–5835, 2012

100 % with an accuracy of ±1.0 %. 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 recordedat a height of 2 m above the ground every 30 min.

3.2 Field installation

A total of 12 soil moisture and temperature smart sensors were installed at 10, 20, 40, 60, 80 and 100 cm 6 depths below the ground, and data were collected by HOBO weather station logger every 10 min. 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

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.

HESSD
9, 5809–5835, 2012

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 response 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.

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

HESSD
9, 5809–5835, 2012

these five types ($p < 0.01$), and showing a downward trend throughout the observation period (Fig. 3).

4.3 Pattern of soil moisture decreases

Three typical decreasing moisture periods were chosen to compare the differences in the water loss rate between the five land cover types and their vertical distribution. 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:

$$L = (S_\mathrm{i} - S_\mathrm{e}) \times Z_f \qquad (1)$$

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

In the period of relatively lower soil moisture contents, from 6 July to 12 July, the initial average soil moisture content was 15.19 $\mathrm{cm^3\,cm^{-3}}$. 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 2.6 mm. 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 (Figs. 4 and 5).

HESSD
9, 5809–5835, 2012

In the periods of relatively higher water soil moisture content, from 31 July to 15 August (Figs. 6 and 7) and 25 August to 31 August (Figs. 8 and 9), the initial average soil moisture content for all both 22 $cm^3 cm^{-3}$. The data for the tree site were missing for 9 August, and those of the shrub site were missing from 8–15 August. 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.

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. The loss of soil moisture mainly took place via evaporation from soil and transpiration from vegetation, which are process that usually cannot be separated. 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

HESSD
9, 5809–5835, 2012

The hydrological responses of different land cover types

S. Wang et al.

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 is more stable than the evaporation from soil. 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 (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, was covered with dense foliage, protecting the soil from direct solar radiation. Additionally, these croplands 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., 2011). 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

HESSD
9, 5809–5835, 2012

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. 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., 2011). 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 yr, 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

HESSD
9, 5809–5835, 2012

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. Dam lands exhibit a higher moisture content but a low permeability and a potential for salinization as higher clay content and bulk density.

6 Conclusions

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. Subshrubs are the natural succession vegetation type following the abandonment of the croplands in the study area for more than 20 yr. The runoff and run-on patches associated with this vegetation type are distributed in intervals, leading to their soils acquiring and retaining soil

HESSD
9, 5809–5835, 2012

moisture resources more efficiently than other cover types. Thus, subshrubs represent an adaptive vegetation type in this area.

Acknowledgements. This work was funded by the National Basic Research Programme of China (2009CB421104), the National Natural Science Foundation of China (Nos. 40930528 and 41101096) and State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau.

References

Chen, H. S., Shao, M. A., and Li, Y. Y.: Soil desiccation in the Loess Plateau of China, Geoderma, 143, 91–100, 2008a.

Chen, H. S., Shao, M. A., and Li, Y. Y.: The characteristics of soil water cycle and water balance on steep grassland under natural and simulated rainfall conditions in the Loess Plateau of China, J. Hydrol., 360, 242–251, 2008b.

Chen, L. D., Huang, Z. L., Gong, J., Fu, B. J., and Huang, Y. L.: The effect of land cover/vegetation on soil water dynamic in the hilly area of the loess plateau, China, Catena, 70, 200–208, 2007a.

Chen, L. D., Wei, W., Fu, B. J., and Lü, Y. H.: Soil and water conservation on the Loess Plateau in China: review and perspective, Prog. Phys. Geog., 31, 389–403, 2007b.

Chen, L. D., Wang, J. P., Wei, W., Fu, B. J., and Wu, D. P.: Effects of landscape restoration on soil water storage and water use in the Loess Plateau Region, China, Forest Ecol. Manag., 259, 1291–1298, 2010.

Cowan, I. R. and Farquhar, G. D.: Stomatal Function in Relation to Leaf Metabolism and Environment, in: Integration of activity in the higher plant, edited by: Jennings, D. H., 471–505, Cambridge University Press, Cambridge, 1977.

Du, S., Wang, Y. L., Kume, T., Zhang, J. G., Otsuki, K., Yamanaka, N., Liu, G. B.: Sapflow characteristics and climatic responses in three forest species in the semiarid Loess Plateau region of China, Agr. Forest Meteorol., 151, 1–10, 2011.

Fan, J., Hao, M. D, and Shao, M. A.: Water consumption of deep soil layers and eco-environmental effects of agricultural ecosystem in the Loess Plateau, Transactions of the CSAE, 20, 61–64, (in Chinese with English abstract) 2004.

Fu, B. J., Wang, J., Chen, L. D., and Qiu, Y.: The effects of land use on soil moisture variation in the Danangou catchment of the Loess Plateau, China, Catena, 54, 197–213, 2003.

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, 2011.

Gong, J., Chen, L. D., Fu, B. J., Huang, Y. L., Huang, Z. L., and Peng, H. J.: Effect of land use on soil nutrients in the loess hilly area of the Loess Plateau, China, Land Degrad. Dev., 17, 453–465, 2006.

Hu, W., Shao, M. A., Wang, Q. J., and Reichardt, K.: Time stability of soil water storage measured by neutron probe and the effects of calibration procedures in a small watershed, Catena, 79, 72–82, 2009.

Legates, D. R., Mahmood, R., Levia, D. F., DeLiberty, T. D., Quiring, S., Houser, C., and Nelson, F. E.: Soil Moisture: A central and unifying theme in physical geography, Prog. Phys. Geog., 35, 65–86, 2011.

Li, X. Y.: Mechanism of coupling, response and adaptation between soil, vegetation and hydrology in arid and semiarid regions, Sci. Sin. Terrae, 41, 1721–1730, 2011 (in Chinese).

Li, Y. S.: The properties of water cycle in soil and their effect on water cycle for land in the Loess Plateau, Acta Ecologica Sinica, 3, 91–101, 1983 (in Chinese with English abstract).

Li, Y. Y. and Shao, M. A.: Climatic change, vegetation evolution and low moisture layer of soil on the Loess Plateau, J. Arid Land Resour. Environ., 15, 72–77, 2001 (in Chinese with English abstract).

Li, Y. Y. and Shao, M. A.: Change of soil physical properties under long-term natural vegetation restoration in the Loess Plateau of China, J. Arid Environ., 64, 77–96, 2006.

Lin, H.: Earth's Critical Zone and hydropedology: concepts, characteristics, and advances, Hydrol. Earth Syst. Sci., 14, 25–45, doi:10.5194/hess-14-25-2010, 2010.

Liu, Y., Fu, B. J., Lü, Y. H., Wang, Z., and Gao, G. Y.: Hydrological responses and soil erosion potential of abandoned cropland in the Loess Plateau, China, Geomorphology, 138, 404–414, 2011.

Mu, X. M., Xu, X. X., Wang, W. L., Wen, Z. M., and Du, F.: Impact of artificial forest on soil moisture of the deep soil layer on Loess Plateau, Acta Pedol. Sin., 40, 210–217, 2003 (in Chinese with English abstract).

National Development and Reform Commission: Comprehensive management planning framework for Loess Plateau area (2010–2030), 69 pp., 2010 (in Chinese).

Odindi, J. O. and Kakembo, V.: The hydrological response of Pteroniaincana – invaded areas in the Eastern Cape Province, South Africa, Ecohydrology, 4, 832–840, 2011.
Schwinning, S. and Sala, O. E.: Hierarchy of responses to resource pulses in arid and semi-arid ecosystems, Oecologia, 141, 211–220, 2004.
Schymanski, S. J.: Optimality as a Concept to Understand and Model Vegetation at Different Scales, Geography Compass, 5, 1580–1598, 2008.
Schymanski, S. J., Roderick, M. L., Sivapalan, M., Hutley, L. B., Beringer, J.: A test of the optimality approach to modelling canopy properties and CO_2 uptake by natural vegetation, Plant Cell Environ., 30, 1586–1598, 2007.
Schymanski, S. J., Sivapalan, M., Roderick, M. L., Beringer, J., and Hutley, L. B.: An optimality-based model of the coupled soil moisture and root dynamics, Hydrol. Earth Syst. Sci., 12, 913–932, doi:10.5194/hess-12-913-2008, 2008a.
Schymanski, S. J., Sivapalan, M., Roderick, M. L., Beringer, J., and Hutley, L. B.: An optimality-based model of the dynamic feedbacks between natural vegetation and the water balance, Water Resour. Res., 45, W01412, doi:10.1029/2008WR006841, 2008b.
Schymanski, S. J., Sivapalan, M., Roderick, M. L., Beringer, J., and Hutley, L. B.: A canopy scale test of the optimal water use hypothesis, Plant Cell Environ., 31, 97–111, 2008c.
Shangguan, Z. P. and Zheng, S. X.: Ecological properties of soil water and effects on forest vegetation in the Loess Plateau, Int. J. Sust. Dev. World, 13, 307–314, 2006.
Su, C. H., Fu, B. J., Lü, Y. H., Lü, N., Zeng, Y., He, A. N., and Lamparski, H.: Land use change and anthropogenic driving forces: a case study in Yanhe River Basin, Chinese Geogr. Sci., 21, 587–599, 2011.
Sun, G., Zhou, G. Y., Zhang, A. Q., Wei, X. H., McNulty, S. G., and Vose, J. M.: Potential water yield reduction due to forestation across China, J. Hydrol., 328, 548–558, 2006.
Wang, S., Fu, B. J., He, C. S., Sun, G., and Gao, G. Y.: A comparative analysis of forest cover and catchment water yield relationships in northern China, Forest Ecol. Manag., 262, 1189–1198, 2011.
Wang, Y. F., Fu, B. J., Lü, Y. H., Song, C. J., and Luan, Y.: Local-scale spatial variability of soil organic carbon and its stock in the hilly area of the Loess Plateau, China, Quaternary Res., 73, 70–76, 2010.
Yang, W. X.: The preliminary discussion on soil desiccation of artificial vegetation in the northern regions of China, Scientia Silvae Sinicae, 32, 78–84, 1996 (in Chinese with English abstract).

Yang, W. Z. and Tian, J. L.: Essential exploration of soil aridization in Loess Plateau, Acta Pedol. Sin, 41, 1–6, 2004 (in Chinese with English abstract).
Yang, W. Z., Shao, M. A., Peng, X. D., and Xia, W. S.: On the relationship between environment aridization of the Loess Plateau and soil water in loess, Sci. China Ser. D, 28, 357–365, 1998 (in Chinese with English abstract).

HESSD
9, 5809–5835, 2012

The hydrological responses of different land cover types

S. Wang et al.

Table 1. Main characteristics for different land cover types.

Soil (0–1 m) 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.

HESSD
9, 5809–5835, 2012

The hydrological responses of different land cover types

S. Wang et al.

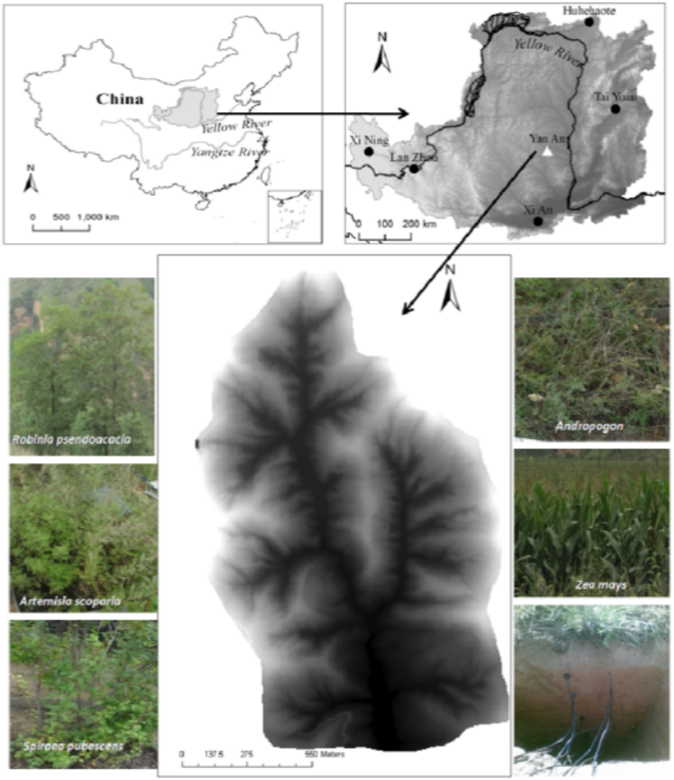

Fig. 1. Location of the study area and the typical land cover types.

HESSD
9, 5809–5835, 2012

The hydrological responses of different land cover types

S. Wang et al.

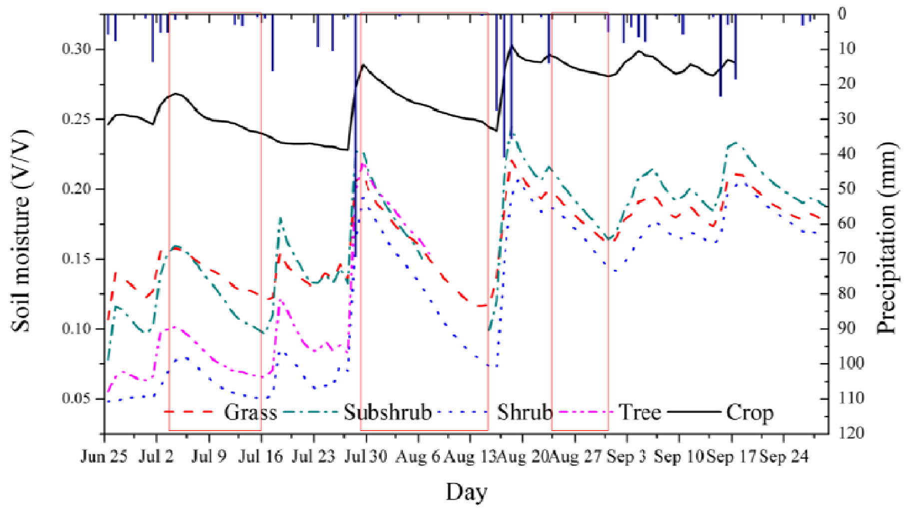

Fig. 2. Dynamics of the mean soil moisture and precipitation profiles and the three selected typical decreasing moisture periods.

HESSD
9, 5809–5835, 2012

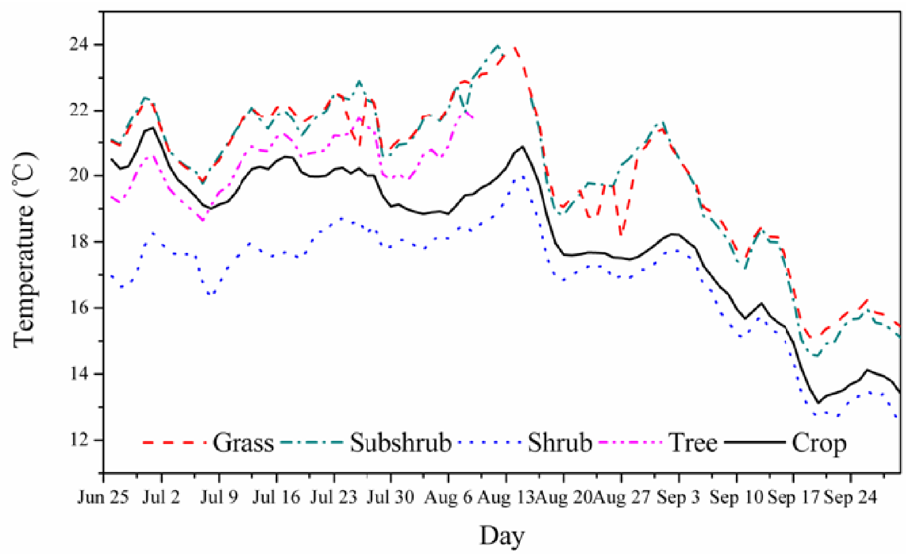

Fig. 3. Dynamics of the mean soil temperature during the study period.

HESSD
9, 5809–5835, 2012

Title Page
Abstract | Introduction
Conclusions | References
Tables | Figures
◂ | ▸
Back | Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

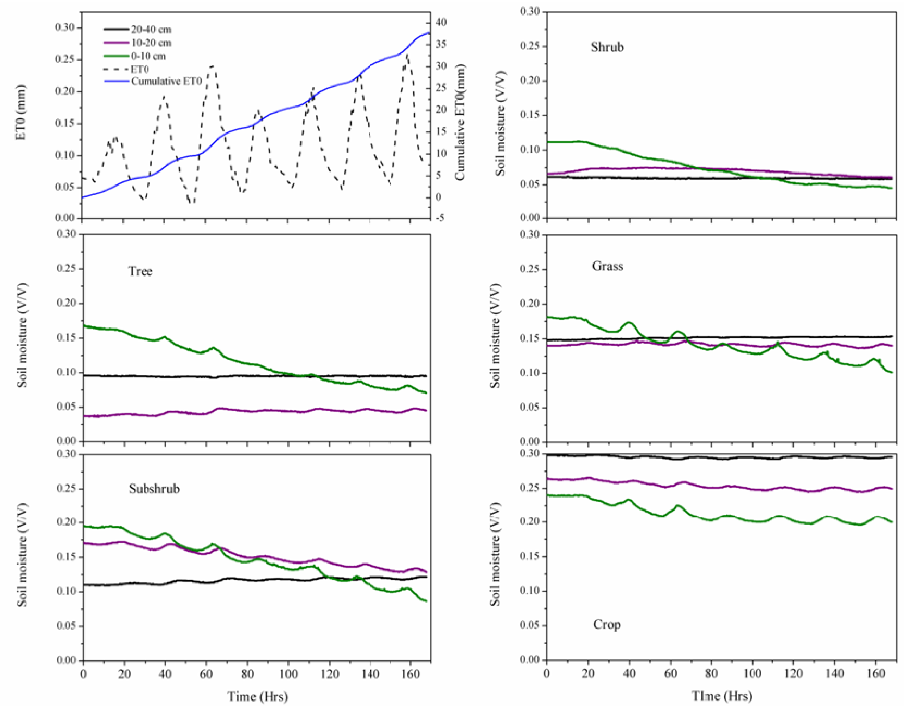

Fig. 4. Soil moisture decrease process under the five land cover types from 6 July to 12 July.

HESSD
9, 5809–5835, 2012

The hydrological responses of different land cover types

S. Wang et al.

Title Page
Abstract
Introduction
Conclusions
References
Tables
Figures
◀◀
▶▶
◀
▶
Back
Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

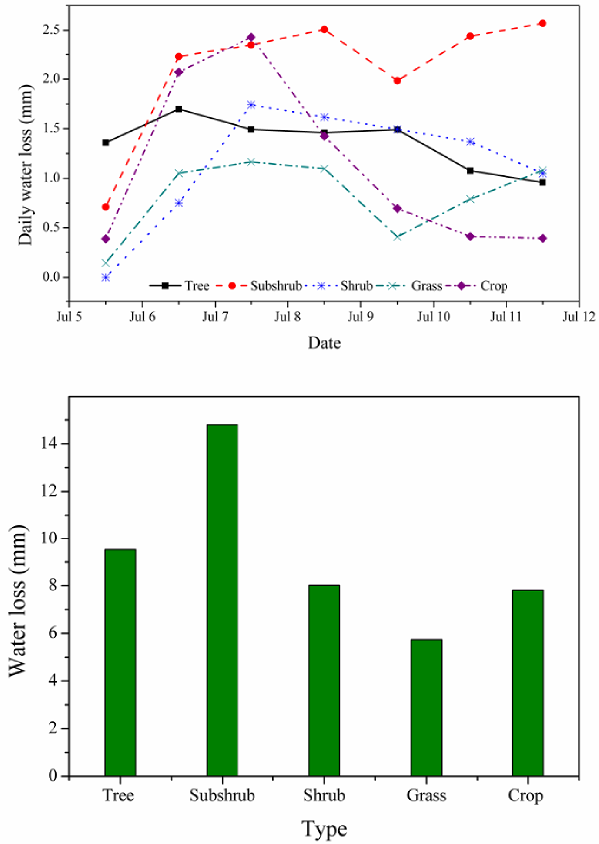

Fig. 5. Daily soil water loss and cumulative water loss under the five land cover types from 6 July to 12 July.

HESSD
9, 5809–5835, 2012

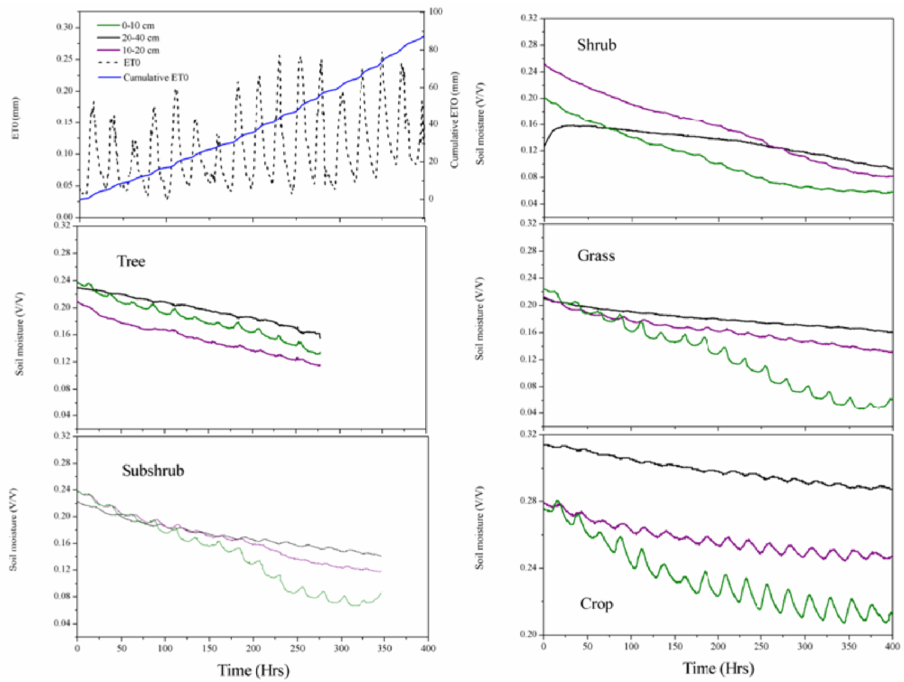

Fig. 6. Soil moisture decrease process under the five land cover types from 31 July to 15 August.

HESSD

9, 5809–5835, 2012

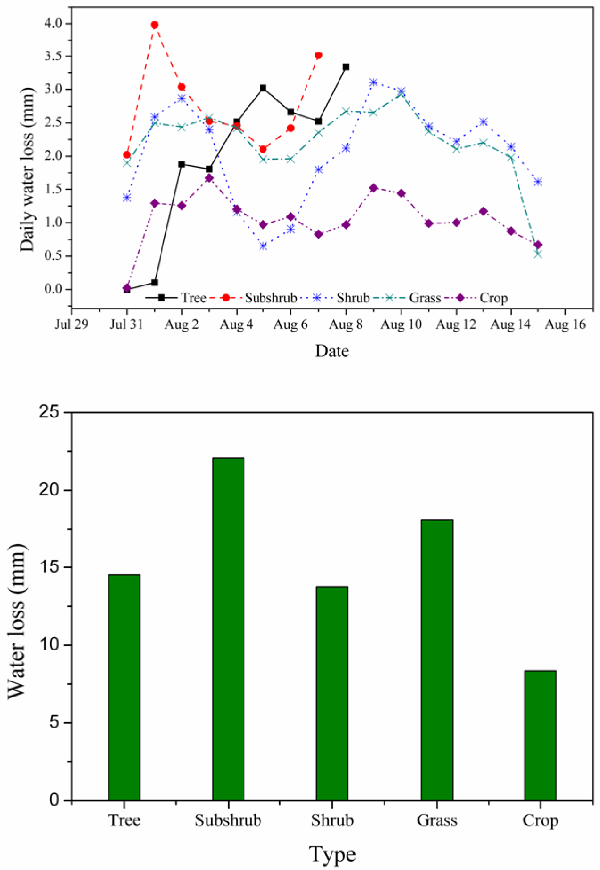

Fig. 7. Daily soil water loss from 31 July to 15 August and cumulative water loss under the five land cover types from 31 July to 7 August.

HESSD
9, 5809–5835, 2012

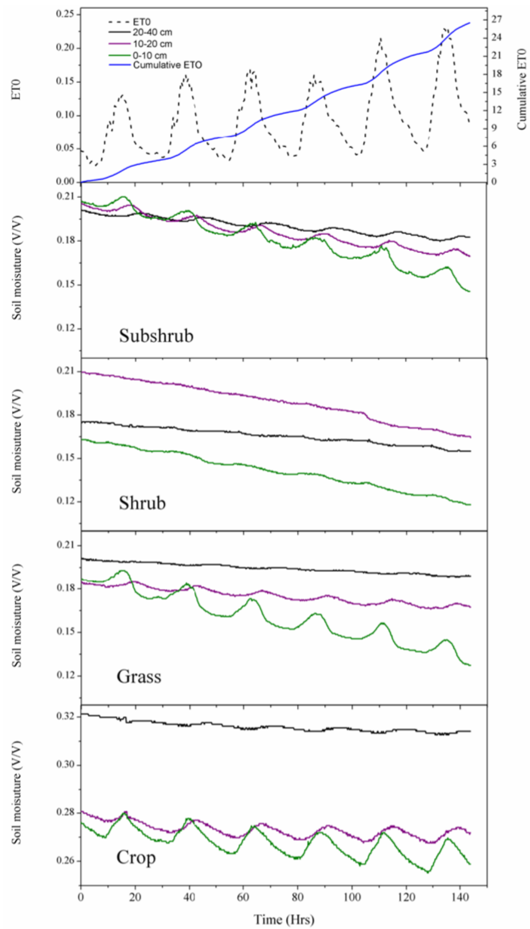

Fig. 8. Soil moisture decrease process under the five land cover types from 25 August to 31 August.

HESSD
9, 5809–5835, 2012

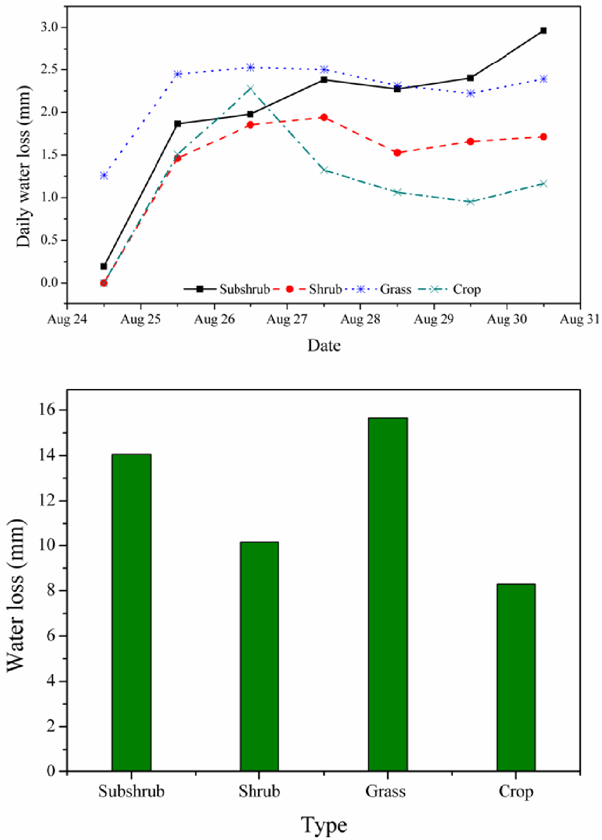

Fig. 9. Daily soil water loss and cumulative water loss under the five land cover types from 25 August to 31 August.

HESSD
9, 5809–5835, 2012

The hydrological responses of different land cover types

S. Wang et al.