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The variability in soil water storage on the loess hillslopes in China and its estimation

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ABSTRACT

Soil water storage (SWS) is a critical water resource for vegetation growth in the Loess Plateau. Changes in SWS during the growing season can reflect soil water depletion or recharge conditions in different hydrological years. This study investigated the soil water in three hillslopes covered with artificial forest, natural forest and natural grass in May and October of 2015–2017. Both path analysis and stepwise multiple linear regression were used to determine the direct and indirect effects of most important variables and develop a model for predicting changes in SWS. The results showed that compared with natural forestland and grassland, artificial forestland had low soil water, but deep SWS maintained a balance of inputs and outputs. In all soil layers, during the growing season, total precipitation (X_4) was the most important variable affecting changes in SWS. The changes in SWS in surface soil layers were affected by more environmental factors than in deeper soil layers. The natural grassland (X_3) and slope position (X_{12}) have different degree of direct and indirect effects by means of antecedent soil water content (X_5), even though their correlations were not significant. In addition, changes in SWS at the 0–100 cm, 100–200 cm and 0–400 cm soil layers were adequately predicted using the multiple regression equation, in which R^2 reached values from 73.4–93.0%. The model simulating the changes in SWS during the growing season can improve understanding on whether rainfall infiltration can replenish soil water depletion.

1. Introduction

Soil water is a vital component of water resources in semi-arid and arid areas (Yang et al., 2014), especially in the Loess Plateau, where groundwater below the thick unsaturated loessial soil (30–100-m thickness) cannot replenish losses from soil evaporation and/or plant transpiration (Mu et al., 2003). Soil water, the main limiting factor for plant growth and ecological development, is affected by the interactions of many environmental factors, such as rainfall characteristics (i.e., rainfall amount and rainfall intensity), soil properties (i.e., bulk density, capillary porosity, soil organic content, clay, silt and sand), vegetation attributes (i.e., vegetation type, coverage and biomass) and topography (i.e., slope position, slope aspect and slope gradient).

In the Loess Plateau, afforestation has been conducted to reduce soil erosion since the 1999 implementation of the "Grain for Green" Project and requires the return of sloping cultivated land (> 25°) to forest and/or grassland (Chen et al., 2007). *Robinia pseudoacacia* is one of the typical plantation species that can enhance soil porosity and hydraulic conductivity (Li and Shao, 2006); thereby, this species can increase water infiltration and decrease runoff and soil erosion. However, artificial forests usually deplete more soil water as a result of plant growth and transpiration. If precipitation cannot supply sufficient water for growth and soil evapotranspiration over long periods, soil desiccation and vegetation/land degradation can occur in an area. Many studies have been conducted on soil water conditions in artificial forestland. Fang et al. (2016) found that black locust and *Caragana korshinskii* induced relatively serious soil desiccation in 80–500 cm soil layers as a result of excessive water depletion compared with farmland and natural grassland in a watershed of the Loess Plateau, China. However, few efforts have been made to evaluate the changes in soil water storage

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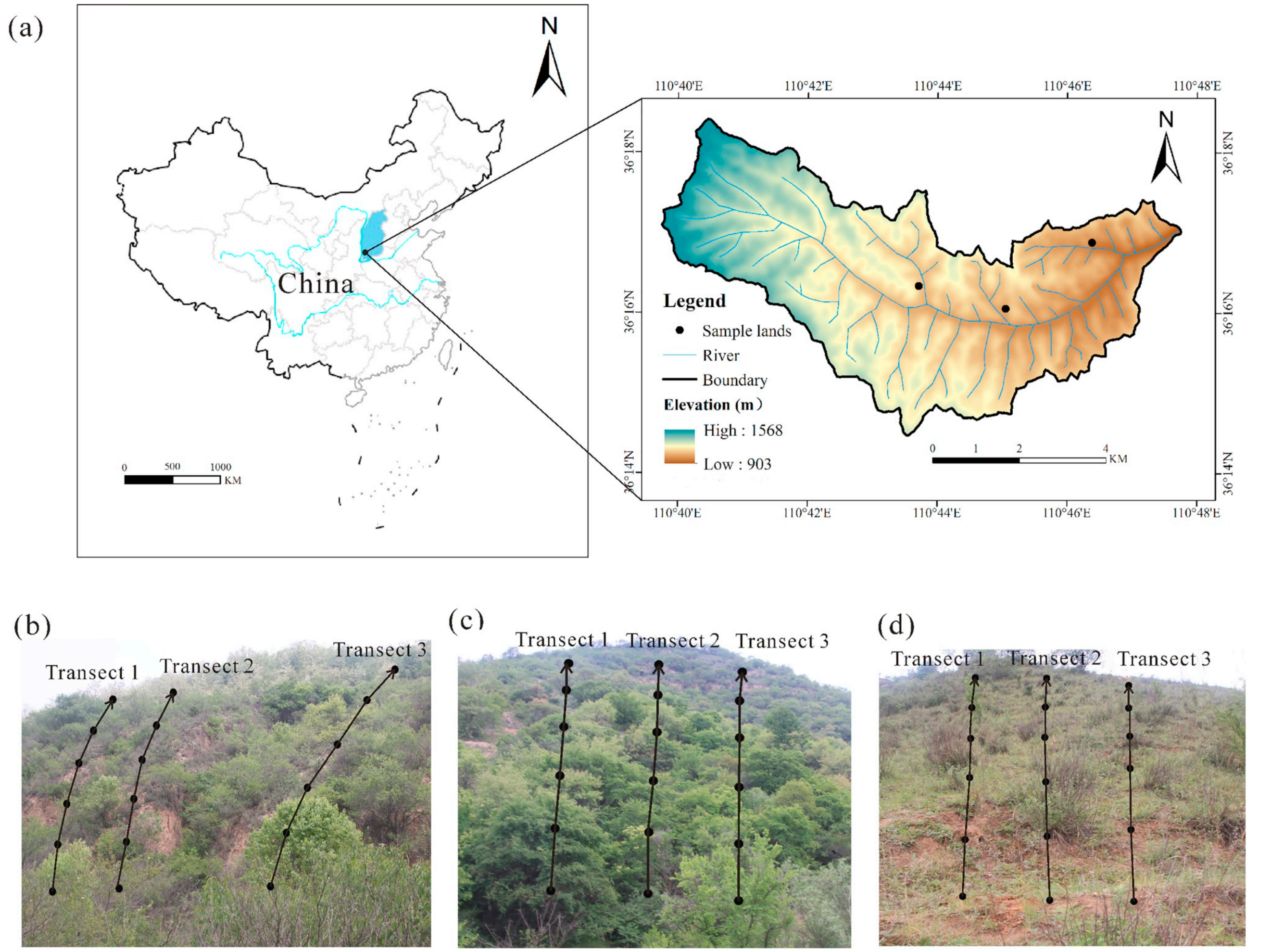

Fig. 1. Location of the study area and sampling sites: (a) location of the Caijiachuan Catchment, (b) artificial forestland, (c) natural forestland, and (d) natural grassland.

(SWS) caused by *Robinia pseudoacacia* in different hydrological years, and these changes should be compared with those of natural forestland and natural grassland, rather than cropland which has relative high soil water content in all areas due to cultivation, to determine whether afforestation is suitable on the loess hillslope.

The effects of rainfall, vegetation type, soil conditions and topography on soil water have also been studied in recent years. Precipitation directly affects variation in soil water (Famiglietti et al., 1998). Wang et al. (2008b) found that in the Tengger Desert of northwestern China, the infiltration rate was linearly correlated with rainfall intensity. Yu et al. (2017) reported that rainfall was a vital factor affecting soil water by altering the amount of rainfall and the soil texture in deeper layers (60–80 cm) during input processes, and rainfall mainly contributed to direct leakage and evaporation during output processes. The degree of response of soil water dynamics to precipitation differed depending on land use and soil depth (Sun et al., 2015). In woodlands, precipitation interception by tree canopy and surface organic matter could decrease the degree of soil water change during rainfall events (Zhu et al., 2014). Vegetation type, topography and soil conditions affected soil water by influencing rainfall or soil water redistribution. For example, the toes of slopes and gentle slopes contain larger amounts of runoff than do the upper parts of slopes and steep slopes, leading to higher soil water content in the toes of slopes and gentle slopes (Ali et al., 2010; Qiu et al., 2001; Western et al., 2004). However, the processes of rainfall infiltration and replenishment identified by soil water and their relationship with rainfall characteristics, soil conditions and vegetation types are unknown. These factors interact to affect changes in SWS, and this interaction makes it difficult to determine how each component contributes to changes in SWS. Thus, simple correlation analysis alone may not be sufficient for establishing causal relationships between changes in SWS and many environmental variables. Path analysis, which could partition correlations into direct and indirect effects and distinguish between correlation and causation (Ding et al., 2014), can be applied to investigate these relationships.

The factors affecting changes in SWS are complex and variable. In addition, obtaining data on changes in SWS would require too much time and labor. Therefore, the key to improving hydrological processes is to develop predictive models that consider the substantial influence of multiple environmental factors on the changes in SWS. Previous studies have focused on estimating soil water content based on the water balance model (Jian et al., 2015; Liu et al., 2015; Fu et al., 2012). The water balance model includes many parameters over a long investigation period; these parameters can include precipitation, runoff, canopy interception, soil evaporation and plant transpiration. Thus, a prediction model based on fewer key parameters is necessary for predicting changes in SWS and estimating rainfall replenishment or water depletion conditions during the growing season.

This study investigated the spatial distribution of soil water at a soil depth of 0–400 cm on three hillslopes covered with artificial forestland, natural forestland and natural grassland during the growing seasons of moderately wet, severe drought, and near normal hydrological years.