Agriculture, Ecosystems and Environment 247 (2017) 120–129

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Effects of “Grain for Green” program on soil hydrologic functions in karst landscapes, southwestern China

Jiao Yang[a,b,c], Xianli Xu[a,b,*], Meixian Liu[a,b], Chaohao Xu[a,b], Yaohua Zhang[a,b], Wei Luo[a,b], Rongfei Zhang[a,b], Xuezhang Li[a,b], Gerard Kiely[d], Kelin Wang[a,b]

[a] *Key Laboratory for Agro-Ecological Processes in Subtropical Region, Institute of Subtropical Agriculture, Chinese Academy of Sciences, Changsha 410125, Hunan, China*
[b] *Huanjiang Observation and Research Station for Karst Ecosystem, Chinese Academy of Sciences, Huanjiang 547100, Guangxi, China*
[c] *Chinese Research Academy of Environmental Science, China*
[d] *Department of Civil and Enviromental Engineering, and Environmental Research Institute, University College Cork, Cork, Ireland*

ARTICLE INFO

Keywords:
Ecohydrology
Soil hydrology
Earth’s critical zone
Landscape ecology
Climate change

ABSTRACT

Soil hydrologic functions are important for karst landscapes where soil water loss is significant. The largest global ecological restoration engineering project, namely the “Grain for Green” program, is being implemented since 2000 in karst landscapes across southwestern China. However, its effects on soil hydrologic functions are still unknown. Using data acquired in field investigations and a generalized linear model (GLM), this study examines the effects of different vegetation restoration types on soil field saturated-hydraulic conductivity (K_{fs}) in karst landscapes of southwest China. The results indicate that the K_{fs} of artificial grassland (napiergrass) was higher than in other vegetation restoration types (zenia insignis, toona sinensis, orchard, and natural restoration shrubland) and cropland at both the surface and 10 cm depths. The K_{fs} of vegetation restoration lands was lower than that of Mulun nature reserve (primary forest) at both the surface and 30 cm depths. We found significant differences of K_{fs} in different depths of vegetation restoration lands but not significant for primary forest. The GLM model explains 64.75% of the total variation in K_{fs}. Among the input variables, vegetation type explained the largest proportion (11.29%) of the variation, followed by bulk density (BD), soil organic carbon, and BD and vegetation type interactions. The factors above were significantly related to K_{fs}. This study suggests that the implementation of different vegetation restoration types can alter soil hydrologic functions and provides useful knowledge for ecological restoration practices and management in karst landscapes.

1. Introduction

The Chinese government initiated a “Grain for Green” program in the late 1990s/early 2000s, and started in 2003 in the Guangxi Province which is a karst area. This program has since been implemented in 25 provinces located in central and western China, and these areas occupy 82% of the total land area of China (Liu et al., 2008). The primary areas targeted by the “Grain for Green” program were the upper and middle areas of the Yellow River, Yangtze River and Pearl River (karst areas). This program has increased the greenness and associated ecological benefits (e.g. carbon sequestration) across China (Song et al., 2014; Lu et al., 2015). Previous studies in China focused on the impacts of the “Grain for Green” programs on soil organic carbon (SOC) stocks and carbon sequestration (Zhang et al., 2010; Deng et al., 2014). Some studies have examined the effects of different vegetation restoration types on the soil hydrology (Li and Shao, 2006; Hu et al., 2009, 2013; Yang et al., 2006) and on soil erosion (Wang et al., 2015; Zheng, 2006) but mainly in the Loess Plateau. In karst landscapes of southwest China, research on vegetation restoration is mainly focused on the soil fertility quality (properties of SOC, soil microbiology and soil enzymology) (Liu et al., 2016; Long et al., 2005; Yu et al., 2013), and soil ecological effects but not on soil hydrologic functions (Song et al., 2011; Ouyang, 2010). Some studies focused on soil bulk density, water holding capacity (He et al., 2009; Huang et al., 2009) and soil erosion control (Zeng and Wang, 2005; Luo et al., 2003) of vegetation restoration. However, little is known about how vegetation restoration types affect soil hydrologic functions in karst landscapes. Such regions are characterized by complex terrain with a thin soil layer and underground stream structures.

Due to the special geological nature of karst landscapes, rapid soil

---

[*] Corresponding author at: Key Laboratory for Agro-Ecological Processes in Subtropical Region, Institute of Subtropical Agriculture, Chinese Academy of Sciences, Changsha 410125, Hunan, China.

E-mail addresses: yangjiao@craes.org.cn (J. Yang), xianlixu@isa.ac.cn (X. Xu), liumeixian@isa.ac.cn (M. Liu), xuchaohao0072@gmail.com (C. Xu), 442967467@qq.com (Y. Zhang), 2009301610278@whu.edu.cn (W. Luo), rongfei330@126.com (R. Zhang), lixuezhang839@isa.ac.cn (X. Li), g.kiely@ucc.ie (G. Kiely), kelin@isa.ac.cn (K. Wang).

http://dx.doi.org/10.1016/j.agee.2017.06.025
Received 28 February 2017; Received in revised form 16 June 2017; Accepted 19 June 2017

and water loss and desertification are widespread and serious problems (Cai, 1996; Deng et al., 2009; Fan et al., 2011). Due to the unique nature of karst, the precipitation infiltrating karst rock percolates to the aquifer below, leaving little moisture at the topsoil, resulting in the natural hazards of floods and droughts to occur frequently. (Liu et al., 2014, 2015). Knowledge of the soil hydrologic function and its influencing factors are therefore crucial to successfully implement the "Grain for Green" program in karst landscapes. Therefore, improving the soil hydrologic function is key to successful ecological restoration. Soil hydrologic function is often influenced by the changes of soil structure due to biological influences (Suwardji and Eberbach, 1998) or compaction (Alakukku, 1996), each of which can be influenced by different vegetation restoration types. Structural and hydrological changes in combination with runoff concentration of sediment in arable cultivation lines, can contribute to erosion of arable soil (Fullen, 1985). Therefore, soil field saturated-hydraulic conductivity (K_{fs}) which quantifies the soil water infiltration capacity is a most important hydraulic properties. K_{fs} also controls the hydrologic and soil erosion processes, such as rainfall infiltration, runoff production, aquifer recharge, loss of nutrients to streamflow, pesticides and contaminants through the soil profile (Bagarello et al., 2005; Pirastru et al., 2013).

By measuring soil field saturated-hydraulic conductivity (K_{fs}), this study aims to examine the effects of different "Grain for Green" measures on soil hydraulic functions.

2. Materials and methods

2.1. Field study

2.1.1. Site descriptions

The experiment (i.e. soil sampling, in-situ infiltration tests, soil analyses, etc.) was carried out at three research areas: Mulian (24°44′N, 107°51′E), Guzhou (24°54′N, 107°57′E), and at the Mulun national nature reserve (107°54′ to 108°05′E, 25°07′ to 25°12′N). All three sites are associated with the Huanjiang Observation and Research Station for Karst Ecosystems of the Chinese Academy of Sciences (CAS), located in the northwest Guangxi Province, southwest China (Fig. 1).

The climate in this area is dominated by subtropical monsoon with a mean annual temperature of 18.5 °C and a mean annual precipitation of 1389 mm (concentrated from April to August). The altitudinal ranges from 400 to 1000 m, with altitudes generally decreasing from northwest to southeast. The three catchments are typical peak-cluster depressions in karst landscapes of southwestern China. The soil of Mulian is calcareous formed from a dolostone base; Guzhou is calcareous formed from a limestone base; and the soil of Mulun reserve is formed predominantly of soluble and porous limestone (Nie et al., 2010; Drew, 1983).

The Mulun nature reserve was established in 1991 to protect the subtropical karst mixed evergreen and deciduous broadleaf forest ecosystem. It was approved as a Chinese National Nature Reserve in 1998. Before its establishment, there were some human influences on the edges of the reserve such as farming, logging, grazing and fire. The zonal vegetation of the region is subtropical mixed evergreen-deciduous broadleaf forest with a high biodiversity quality (Zheng, 1999). 915 species of vascular plants in 173 families have been identified in this area, among them 64 fern species in 26 families, 11 gymnosperm species in 6 families, and 840 flowering plant species in 141 families. The plant communities are composed mainly of families belonging to tropical and subtropical zones, with subtropical species being dominant (Zheng, 1999). This area is currently a primeval forest, and therefore is a good reference for this study.

2.1.2. Sampling design

Soil samples were randomly taken from different vegetation restoration types: 5 sample sites at Mulian (9–12 duplicates for each) (restoration from cropland since 2003); 4 sites at Guzhou (6–9 duplicates for each) (restoration from cropland since 2007); and 1 site at Mulun reserve (buffer area) (10 duplicates). The vegetation types include zenia insignis (*Zenia insignis Chun*), Toona sinensis (*Toona sinensis* (*A. Juss.*) *Roem.*), loquat (*Eriobotrya japonica*), cirtus (*Citrus sinensis*), pear (*Pirus spp. pear*), peach (*Amygdaluspersica* L.), napiergrass (*Pennisetumhydridum*) and natural restoration shrubland in Mulian and Guzhou (Fig. 2). The area of each vegetation type was: zenia insignis 1107 m^2, toona sinensis 421 m^2, peach 203 m^2, citrus 166 m^2, pear 211 m^2, loquat 115 m^2, natural restoration shrubland in Guzhou 330 m^2, natural restoration shrubland in Mulian 879 m^2, napiergrass 240 m^2, cropland in Guzhou 266 m^2, cropland in Mulian 347 m^2, and natural reserve (buffer area) was about 1647 m^2 (Fig. 2). Those croplands are planted with corn, soybean and sweet potato (crop-rotation). Because of the different vegetation types and different research areas, the sampling sites were classified into seven groups as shown in Table 1: croplands; a nature reserve (Mulun reserve, primary forest as a reference); and another five vegetation restoration types- (1) Zenia insignis, (2) Toona sinensis, (3) Orchard (citrus, loquat, pear, and peach), (4) Napiergrass and (5) Natural restoration shrubland.

2.1.3. Infiltration measurements

2.1.3.1. Theory of BEST method. Several studies have used Beerkan method to determine soil hydraulic properties by field infiltration data. (Braud et al., 2005; Lassabatère et al., 2006, 2009; Yilmaz et al., 2010). The original method is known as the BEST-slope and the modified version is called the BEST-intercept following Yilmaz et al. (2010). The BEST method is based on the van Genuchten relationship (Van Genuchten, 1980) for the water retention curve:

$$\frac{\theta - \theta_r}{\theta_s - \theta_r} = [1 + (\alpha h)^n]^{-m} \tag{1a}$$

with the Burdine condition (Burdine, 1953),

$$m = 1 - \frac{2}{n} \tag{1b}$$

and the Brooks and Corey relationship (Brooks and Corey, 1964) for hydraulic conductivity:

$$\frac{K(\theta)}{K_{fs}} = \left(\frac{\theta - \theta_r}{\theta_s - \theta_r}\right)^{\eta} \tag{2a}$$

$$\eta = \frac{2}{\lambda} + 2 + pand\lambda = mn \tag{2b}$$

where θ is soil water content and K_{fs} is soil field saturated-hydraulic conductivity (scale parameter); n, m and η are shape parameters; α, h, θ_s, θ_r are scale parameters; p is a tortuosity parameter that depends on the capillary model.

For an infiltration experiment with zero pressure on an internal-radius r of a circular cylindrical surface above a uniform soil with a uniform initial soil water content, the three-dimensional cumulative infiltration and steady infiltration rate can be determined using the explicit transient two-term equation:

$$I_{+\infty}(\mathrm{t}) = (ES^2 + K_S) + G\frac{S^2}{K_{fs}} \tag{3a}$$

$$q_s = ES^2 + K_{fs} \tag{3b}$$

and steady-state expansion:

$$I_{+\infty}(\mathrm{t}) = (ES^2 + K_S) + G\frac{S^2}{K_{fs}} \tag{3c}$$

$$q_s = ES^2 + K_{fs} \tag{3d}$$

where t is time, $I(t)$ is cumulative infiltration at a transient state, $q(t)$ is the infiltration rate, q_s is the steady infiltration rate, $I_{+\infty}$ is the cumulative infiltration at steady state, and S is the sorptivity; The constants E–G are defined by Haverkamp et al. (1994) as: