Journal of Hydrology 525 (2015) 694–705

Contents lists available at ScienceDirect

Journal of Hydrology

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

Field observations of soil water content and nitrogen distribution on two hillslopes of different shape

Yong Li [a,b,*], Manli Huang [b], Jianlan Hua [c], Zhentin Zhang [b], Lixiao Ni [a,b], Ping Li [c], Yong Chen [c], Liang Zhu [a,b]

[a] *Ministry of Education Key Laboratory of Integrated Regulation and Resource Development on Shallow Lakes, Hohai University, Nanjing 210098, China*
[b] *College of Environment, Hohai University, Nanjing 210098, China*
[c] *Nanjing Water Planning and Designing Institute Co. Ltd, Nanjing 210006, China*

ARTICLE INFO

Article history:
Received 29 October 2014
Received in revised form 13 April 2015
Accepted 16 April 2015
Available online 24 April 2015
This manuscript was handled by Corrado Corradini, Editor-in-Chief, with the assistance of Ming Ye, Associate Editor

Keywords:
Soil water content
Nitrogen concentration
Convex hillslope
Concave hillslope
Humid region

SUMMARY

The features of water regimes and nitrogen distribution in hillslope soil could provide information on the design suitability of hillslope shapes near water bodies and knowledge about the interception of nutrients before entering water bodies. Hillslope shape effects on overland flow and subsurface flow have been demonstrated by many previous studies, particularly in arid and semiarid regions. We present results from a 1-year monitoring study of two naturally formed hillslopes (convex and concave) with average gradients of 41% in a humid area (eastern China) to better understand the soil water content (SWC) variations and nitrogen concentration distributions. The SWC at the upper position of the convex hillslope (CVS) varied widely with relatively high coefficients of variance, while those at the lower position of the concave hillslope (CCS) maintained continuous, relatively high values during the study period. Comparatively, the low segment soil profile (top 80 cm) of the CCS maintained the highest soil water storage, followed by the up segment (top 80 cm) of the CCS and the low segment of the CVS, and finally the up segment of the CVS. Lateral subsurface flow discharged out from the 30–80 cm soil layer at the mid positions of the two hillslopes and the lower position of CVS; while the lateral subsurface flow from the upper hillslope recharged into the 30–80 cm soil layer at the upper and lower positions of the CCS and the upper position of CVS. Most of the soil nitrogen infiltrated the hillslope with water. Nitrogen concentrations at 30 cm depth on both the CVS and CCS varied temporally, responding strongly with rainfall events, while nitrogen concentrations at 80 cm depth changed slightly throughout the study period and maintained relatively low values. Nitrogen concentrations remained relatively low at the upper position on the CCS compared with those at the mid and lower positions. Inversely, on the CVS, the upper position had relatively higher or proximate nitrogen concentrations compared to its mid and lower positions. Nitrogen storage in the low segment soil profile of the CCS was higher than its up segment, but they were similar on the CVS. The nitrogen redistributions on the hillslopes were dominantly from water regimes, in particular, from the lateral subsurface flow. Due to the diversity of water regimes in different shaped hillslopes, the interception of lateral subsurface flow and its nitrogen pollution should receive more attention in a humid region.

1. Introduction

Hillslopes, common topographic features in many regions, can be shaped by natural or artificial forces, and various shaped hillslopes comprise integral catchments that cause diverse water regimes and pollution transport processes (Huang et al., 2001; Bracken and Kirkby, 2005; Bagarello and Ferro, 2010). Hillslope hydrology has been studied frequently, particularly in arid and semiarid regions (Liu et al., 1994; Qiu et al., 2001; Bracken and Kirkby, 2005; Sela et al., 2015). However, few studies have been reported on the variability of water and nitrogen infiltration in different shaped hillslopes in humid regions with abundant precipitation (Zhu et al., 2014). In humid environments, different climate conditions, surface soils, vegetation, and groundwater levels result in various flow processes and, consequently, the soil water content (SWC) regimes compared to arid and semiarid regions (Wakindiki and Ben-Hur, 2002; Yair and Kossovsky, 2002; Assouline, 2004;

* Corresponding author at: Ministry of Education Key Laboratory of Integrated Regulation and Resource Development on Shallow Lakes, Hohai University, Nanjing 210098, China.
E-mail address: liyonghh@hhu.edu.cn (Y. Li).

http://dx.doi.org/10.1016/j.jhydrol.2015.04.028
0022-1694/

Lawrence and Hornberger, 2007; Phi et al., 2013; Sela et al., 2015). Understanding and quantifying these variations is critical for designing slope shapes and promoting pollution-removing effects before overland and subsurface flows enter water bodies.

Previous studies have reported that hillslope morphology, including its shape, length, and gradient, significantly affects overland and subsurface flow, and associated solute transport, as well as climate, soil characteristics, and vegetation cover conditions (Qiu et al., 2001; McDonnell, 2003; Şensoy and Kara, 2014). Among these contributory factors, the hillslope shape has a key effect on water regimes and soil erosion. For example, Şensoy and Kara (2014) reported that, in field experiments, surface runoff and soil erosion were greater on uniform hillslope plots than in concave and convex plots. Rieke-Zapp and Nearing (2005) studied five hillslopes based on laboratory conditions and reported that hillslope shape had a significant impact on rill patterns, sediment yield, and runoff production, and that uniform and convex-linear hillslopes yielded more sediment than concave-linear hillslopes.

The water regime and SWC variation in the hillslope and their controlling factors have been investigated in a wide range of studies (McDonnell, 2003; Sela et al., 2012; Penna et al., 2013). Zhao et al. (2013) reported that vertical flow was the predominant water flow pattern on the hillslope. Mueller et al. (2014) reported that vertical percolation plays an important role, even with hillslope gradients up to 46%, and lateral subsurface flow and/or mixing of soil water at lower hillslope gradients might occur in deeper soil layers and at sites near small streams. During medium-large rainfall events, lateral flow can occur in the unsaturated zone along the hillslope; both the shape and gradient of the hillslope strongly influenced the amount of lateral subsurface flow (Ticehurst et al., 2003). McCord and Stephens (1987) found that subsurface lateral flow in the unsaturated zone can occur even in a sandy hillslope without low-permeability sublayers. Hammermeister et al. (1982) found that, with an antecedent water potential between -10 and -20 cm, as little as 20 mm of rainfall in a day was sufficient to generate saturated conditions above an impermeable layer on a convex hillslope in Oregon. Qiu et al. (2001) reported that the temporal variability of SWC shows a strong and positive correlation with hillslope shape but a weak correlation with hillslope position and no relation with hillslope gradient.

Hillslope shape strongly affects the redistribution of nutrients and organic matter on the hillslope surface and in the soil profile (Li et al., 2006; Zhang et al., 2007). Nitrogen and organic matter generally accumulate at lower and toe hillslope positions through overland flow and subsurface flow (Rieke-Zapp and Nearing, 2005). Meanwhile, the soil moisture conditions at lower and toe hillslopes form a more optimal microenvironment for storing organic matter and removing nitrate nitrogen, compared with upper and top hillslopes (Whittinghill et al., 2014). Zhu et al. (2015) reported that on an agricultural hillslope, the spatial variability of maize yield and its response to nitrogen rate was affected by profile curvature and the degree of soil water content temporal variation. Jackson-Blake et al. (2012) assessed the spatial variability in soil solution nitrogen and the factors and processes driving this variability based on a 5-year monitoring period. They found that the highest soil solution inorganic nitrogen concentrations were found in the alpine soils at the top of the hillslope. Wang et al. (2004) reported that the content of soil organic matter and nitrogen had an ascending trend with the increase of elevation on an eastern hillslope of Gonnga Mountain (China), and that the ratio of soil carbon to nitrogen increased with the increase of the elevation.

Observation of temporal variations in soil water content is important when examining hydrological processes on a hillslope (Kim, 2014). In this study, field observations on two naturally formed hillslopes (concave and convex shapes) in a humid region were conducted throughout 2009 to investigate the temporal variations of soil water content and nitrogen concentration. The aims were (1) to compare the water regime and nitrogen transport between the two shaped hillslopes; (2) to compare and discuss the potential nitrogen transformations and lateral subsurface flow at different hillslope positions and their discrepancies between the two shaped hillslopes; and (3) to compare the soil water regimes of the two hillslopes with those reported in semiarid or arid regions.

2. Material and methods

2.1. Description of study site

The study site is located in the Danyang Region (N32°04′, E119°40′), a mountainous and hilly area at the upstream of Taihu Lake Basin in eastern China. This region has a subtropical monsoon climate characterized by warm summers. The annual mean temperature in this area is 14.9 °C, and the average monthly temperatures range from 2.3 °C (January) to 27.8 °C (July). The mean annual precipitation is 1056.5 mm, most of which falls from May through October. The annual pan evaporation from the water surface is approximately 822 mm.

Two naturally formed experimental plots, one concave slope and one convex slope, about 90 m apart, were located on a south-facing hillslope. The concave hillslope plot (CCS) and convex hillslope plot (CVS) were approximately 1.5 and 2.2 m in width, respectively, about 18.4 m in length, and had an average gradient of 41.2% (Fig. 1). The two study plots have similar gradients, shape, and surface elevation with respective adjacent lands (within 10 m). The hillslope surface was mainly covered by a native vegetation species *Setaria viridis* (a type of weed with no harvest or management), and a few small short shrubs (removed before observation). In this region, the annual *S. viridis* generally germinates in late April or early May, flowers and fruits from June to September, and withers and falls in late October or early November. The soil of the study site, developed on the alluvial plain of the Yangtze River Delta, is fine-textured.

Prior to observation, each plot was bordered by strips of PVC sheets buried at a depth of 20 cm and buttressed by PVC bars on either side of the whole plot to restrict the runoff collection area. Three soil pits (150 cm deep by ~40 cm wide) for each plot were opened at upper, mid, and lower positions in adjacent lands (Fig. 1). At each hillslope position, undisturbed soil cores (6 cm in diameter, 4 cm in height) of each 10 cm soil layer (3 replicates) were sampled by hand. Disturbed soil of each layer (10 cm) was separately collected and transported to a laboratory for further analysis. The remaining soil was backfilled into these opened pits and tamped after all monitoring devices were installed. Additionally, three supplemental soil samples in 10 cm increments for each hillslope were taken using a drill (3 replicates) in the adjacent lands (close to the opposite side boundary to the opened pits) to further examine the major horizons.

2.2. Measurements and data analysis

Daily climate data during 2009, including precipitation, temperature, wind speed, humidity, and daylight hours, were obtained from an adjacent agro-meteorological station (about 6 km southeast) in the Danyang region. Daily meteorological data were used to calculate the potential evapotranspiration (Fig. 2a) with Penman–Monteith methods (Allen et al., 1998).

To characterize wet nitrogen deposition inputs, three empty buckets (30 cm diameter and 20 cm height) were placed vertically on the hillslope. Wet depositions were measured every day during raining days. The NH_4^+–N and NO_3^-–N depositions were calculated