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Large heterogeneity of water and nutrient supply derived from runoff of nearby rock outcrops in karst ecosystems in SW China

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ABSTRACT

Rock outcrops are frequently visible in terrestrial landscapes, typically in karst. However, there has been insufficient research conducted on their effects on the formation of soil water and nutrients heterogeneity in nearby soil patches. In: 1) a rock desertification ecosystem, 2) an anthropogenic forest ecosystem, and 3) a secondary forest ecosystem in Shilin, Southwest China, rock occupancy ratio was measured, water received by and subsequently funneled off by rock outcrops was quantified, and their concentrations of the total organic carbon, nitrogen, phosphorus, and potassium were determined. Receiving rate R_r of those elements of the remaining soil patches in various 2 m × 2 m soil + rock outcrop samples were calculated, and r_{200} at which R_r of the remaining soil patch was twice that without rock emergence was calculated to evaluate the heterogeneity difference among different elements in different ecosystems. There were 1.43–5.44 folds differences between R_r under the highest rock ratio (79.4%) sample and the rate of non-rock emergence sample for water, organic carbon, nitrogen, phosphorus, and potassium in the three ecosystems respectively, indicating a large supply heterogeneity for those elements within an ecosystem and between ecosystems. The r_{200} were between 47% (water, at rock desertification ecosystem) to 90% (potassium at rock desertification ecosystem, depending on the receiving rate and funneling rate of the rock for different element in different ecosystem. In conclusion, large supply heterogeneity has derived from high variation of rock runoff determined by rock emergency ratio, the rate of receiving and the rate of funneling off by the rock. Our study provided new evidence to trace soil and water heterogeneity of microhabitats in rocky ecosystems. Additionally, rock outcrop is also an important factor in evaluating hydrological and related nutrient characteristics in rocky ecosystems.

1. Introduction

Heterogeneity is essential in explaining the biodiversity and productivity of ecosystems. From landscape to small scale, the spatial heterogeneity of soil water and nutrients has been highly recognized (Moldovan et al., 2012). This heterogeneity may derive from parent material of soil, topography of slope and ephemeral channels, plant-soil feedbacks, fertilization, irrigation, past land use patterns (Camara et al., 2017; Zhang et al., 2017), etc. Rock outcrops (ROCs), either connected to bedrock or independent, are frequently visible in terrestrial landscapes. However, there has been insufficient research conducted on the effects of ROCs on the formation of soil water and nutrients heterogeneity in nearby soil patches.

When an area occupied by ROCs is large enough, the ecosystem's matrix will be recognized as "rocky" (Fig.1). Karst landscapes, which are reported to account for 12%–20% of the terrestrial land surface of the earth (Ford and Williams, 2007), are among the most possible places to be rocky. The acreage of rock desertification land ((the rock occupancy rate ≥ 30%, vegetation cover ≦ 50% (tree) or ≦70% (grass)) in China was 129,600 km^2 in 2006 and 120,020 km^2 in 2011 (State Forestry of China, 2012), corresponding to 28.7% (2006) and 26.5% (2011) of the total karst area in southern China. These were the first data on rocky ecosystem. Other rocky ecosystems were reported in European karst areas (Kranjc, 2009).

Horizontally, a ROC accompanies soil patches in the plant growing matrix (Ford and Williams, 2007) and is thus assumed to cause negative effects on the flora community on underlying soil patches (Jiang et al., 2014). On the other hand, it is clear that rock outcrops can act as a

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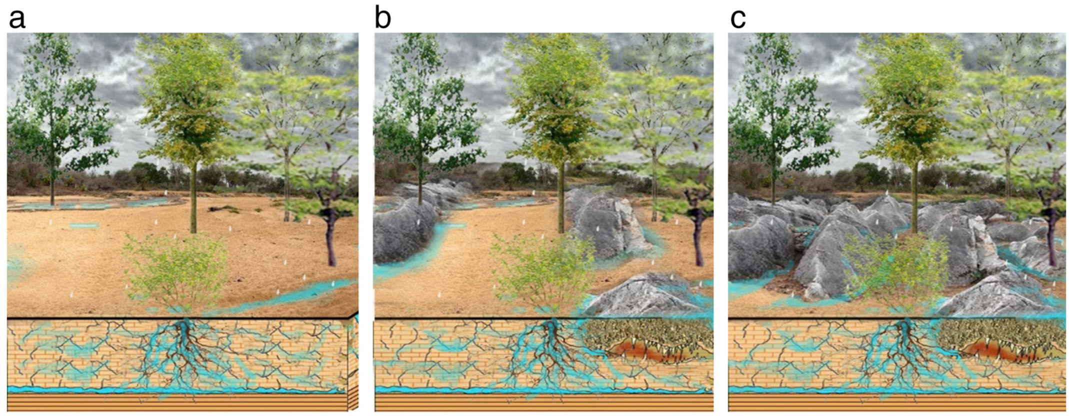

Fig. 1. Illustration showing land surface with: a: all soil; b: lower proportion of rock outcrops; and c: higher proportion of outcrops. With the increase of the proportion of rock outcrops, the land looks like gradually "rocky".

collection plate for receiving rainfall, throughfall in the forest, and dry and wet deposition, which may occur in large quantities across the earth (Clark et al., 1998). The exposed rock surface weathers naturally under local climatic conditions. However, the water, materials and chemicals received and produced are not easily been held on the surface of a ROC. They will be funneled to underlying soil patches by natural gravity and water runoff (Goransson et al., 2014), or may be channeled underground in a karst (Ford and Williams, 2007). Wang et al. (2016a, 2016b) found that ROCs in semi-humid southern China redistributed nearly 50% of the water they received to nearby soil patches when they were in ecosystems covered with various types of vegetation and huge amount of organic carbon, N, P, K were contained inside. The extent of funneling will increase the supply of external water and nutrient input (Goransson et al., 2014). In an ecosystem with ROCs, ROCs intersected into soil matrices in various combinations; thus, different soil patches may be served by multiple supplies from ROCs runoff. However, there is no research evaluating this type of supply heterogeneity.

Lithobiontic communities, including epiliths (which live only on rock surfaces) and endoliths (which colonize the inside of a rock matrix) may inhabit various types of rock (Antony et al., 2012). Their functions (i.e., weathering, soil formation, fueling food webs by photosynthesis and nitrogen fixation), have long been recognized and studied (Chen et al., 2000). The most popular cyanobacterial component, lichen, usually occupies rocks as a substrate (Chen et al., 2000) and affects substrate rocks both in their natural state and when used as building stones. The extent to which lichen affects rock weathering and soil development has varied greatly. Other factors, such as forest canopy also influence rock weathering via environment changes (De Schrijver et al., 2007). Different rock outcrops dwell within varying biological communities, and rocks have emerged with different physical and chemical features after exposure to various climatic conditions. The extent to which the water received and the materials received and produced on ROCs affect the proportion contributed to the soil patches by each ROC remains unknown.

Huge research efforts have been conducted on karst ecosystems, i.e., hydrogeology and geomorphology (Ford and Williams, 2007), water uptake (Elkington et al., 2014; Liu et al., 2014) and biodiversity (Clements et al., 2006). At a small karst area in Yucatán, Mexico (1350 m^2), six indigenous soil classes were identified (Bautista et al., 2005). Direct measurements showed that water and nutrients were funneled to nearby soil patches (Wang et al., 2016a, 2016b), and the soil moisture in areas immediately adjacent to the karst outcrops was greater than that of areas away from outcrops (Li et al., 2014). Li et al. (2014) found that the height and direction of rocks also contributed to soil moisture variations. However, the effects of rock outcrops on heterogeneity of soil patches had seldom been studied and evaluated (Schwinning, 2010; Moldovan et al., 2012). South China is the largest continuous distribution area of carbonate rock in the world. In this study, we quantified rock outcrop emergence ratios in three karst ecosystems with ROCs covered by various types of vegetation. We installed equipment to collect water from rock surfaces and atmospheric deposition, and determined the organic carbon, N, P, and K content of each water sample. The purpose was to: 1) determine the supplies of water, organic carbon, N, P, and K received by soil patches in various combinations of rock outcrop + soil patches, and 2) calculate and evaluate the supply heterogeneity and the related impact on karst ecosystems.

2. Method

2.1. The study site

The study site was located at the Shilin Stone Forest Geographical Park (SGP) (24°38′–24°58′N, 103°11′–103°29′E), Yunnan, China, a typical karst formation and geo-park famous for its karst landforms. This karst developed on Early Permian carbonate rocks, mainly limestone, with a thickness reaching 365 m, and a dip angle of approximately 5°. The climate is subtropical and semi-humid. The mean annual temperature is 16.2 °C. The mean maximum temperature of the warmest month (July) of the year is 20.7 °C. The mean minimum temperature of the coldest month (January) of the year is 8.2 °C. The average annual precipitation is 967.9 mm, 80% of which falls between May and October.

Vegetation at the site consists of semi-evergreen broad-leaved forests dominated by *Cyclobalanopsis glaucoides, Olea yunnanensis,* and *Neolitsea homilantha*. Historical agricultural practices outside SGP were rudimentary, based on subsistence cultivation on gentle slopes and flat areas. However, intensive forest clearing for fuel, wood harvesting, and animal grazing occurred mainly due to rapid population growth at the hill slopes. Thus, karst landscapes with large proportions of rock exposures (karst rock desertification, KRD) emerged, mostly in the middle of the last century. Three ecosystems covered with various vegetation (Fig.2a, b, c) were selected: 1) KRD site dominated by grass, 2) covered with natural forest (NF), and 3) covered with anthropogenic forest (AF).

2.1.1. Rock outcrop/soil patch ratio, soil sample collection

Three 20 m × 20 m sites were established and then divided into 5 m × 5 m quadrats at each ecosystem. Then, three 2 m × 2 m samples were established at the cross of 5 m × 5 m quadrats on each site with a frame. All plants inside the selected 2 m × 2 m frame were removed and soils were excavated, collected to a depth of 20 cm, and then weighed. Soil samples were taken to measure the water content, and cores (53 mm height, 70 mm inner diameter) were taken to measure the bulk density. The position of core was visually selected on the four side