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Influence of bare rocks on surrounding soil moisture in the karst rocky desertification regions under drought conditions

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ABSTRACT

A large number of bare rocks exposed in the field represent one of the most spectacular scenes of the Karst Rocky Desertification (KRD) process. The presence of bare rocks modifies the microenvironment. An understanding of soil moisture variability is necessary to characterize the linkages between a region's hydrology, ecology, and physiography. The objective of the study was to determine the influence of those exposed bare rocks on soil moisture in the surrounding area in a typical KRD region—the Forest Station of Sandoqing, in Fu'yuan County, Yun'nan Province, Southwest China. Dynamic soil moisture was quantified in Feb, 2010 during an extreme drought period. Results showed that during the drought period, soil moisture on the north side of the rocks was significantly higher than those on the east, west and south sides ($p < 0.01$). Soil surface moisture increased with the aboveground height of the rocks. The size of the bare rocks was significantly correlated with soil moisture on the west and north sides of the rocks ($p < 0.01$) and the east side of the rocks ($p < 0.05$). Sharper rocks were associated with declining soil moisture on the east, west and north sides of the rocks. Soil moisture began to increase and then declined on the north, east and west sides, but showed a continued increase on the south side with the distance from the rocks. The soil moisture around the rocks increased gradually with depths of soil layers. During the drought period bare rocks created some shade, resulting in higher soil moisture on the north side of the rocks compared to the other three directions. The location at 15 cm north of the rocks had the highest soil water content, thus becoming the most ideal site for establishing vegetation restoration in the KRD area under stressful environmental conditions. Results from this study can be used to assist in restoration of ecological system damaged by the KRD process.

1. Introduction

Spatial heterogeneity is one of the important properties of soil (Burgess and Webster, 1980), and it occurs on various scales in all types of soil environments (Cain et al., 1999; Farley and Fitter, 1999; Gross et al., 1995; Jackson and Caldwell, 1993; Schlesinger et al., 1996). The moisture of surface soil layer has a significant role in this microenvironment and is a key parameter in soil surface modeling. Soil moisture is also an essential condition for normal plant growth, affecting both quality and survival; therefore, the variability and pattern of soil surface moisture are receiving increased attention from local to continental scales (Koster et al., 2004; Parent et al., 2006; Qi et al., 2004; Qiu et al., 2001). So far, little attention has been paid to surface soil moisture variability, specifically in fragile ecosystems or in the context of vegetation restoration efforts in the karst region of subtropical China (Chen et al., 2010; Zhang et al., 2011).

Karst rocky desertification (KRD) is one major type of desertification caused by human impacts on the vulnerable eco-geo-environment (Huang et al., 2009; Li et al., 2009b; Sweeting, 1993; Wang et al., 2004). KRD is a process in which soil is eroded seriously or even thoroughly, so that bedrock is exposed widespread, carrying capacity of land declines seriously, and at last, landscape appears similar to desert under violent human impacts on the vulnerable eco-geo-environment (Huang and Cai, 2007). The main features are: serious soil erosion; extensive exposure of bedrocks; drastic decrease of soil productivity; and the appearance of a desert-like landscape, caused by human activities degrading the fragile subtropical karst environment. It can have far-reaching effects on the middle-lower reaches of rivers like the Yangtze and Pearl (Wang et al., 2004). In the karst region of southwest China, development and cultivation on steep slopes, and intensive land use in this extremely fragile geological environment often result in serious soil loss by water erosion, which finally lead to a drastic decrease in soil productivity, progressive poverty of the local residents, and extensive exposure of basement rocks in the form of rocky desertification (Wang et al., 2004). The sloping farmlands occur in small patches, distributed irregularly among exposed rocks and in fissures. Compared with other regions, the mosaic of rock and soil increases the complexity of topography and diversity of microhabitats in the karst region of southwest China. This kind of mosaic may play an important role in the spatial

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distribution of nutrients due to differences of soil and water loss at different sites (Crowther, 1982; Descroix et al., 2001). Southwest China is in the fragile karst ecological zone (Sweeting, 1993), with 129,600 km^2 of land undergoing the process of KRD. Exposure of large amounts of rocks above ground level is the most spectacular scene in KRD regions. Karst lands can be very dry where the shallow soil layers and bare rocks are interwoven (Chen et al., 2012; Zhang et al., 2011), forming a highly heterogeneous ecological system with dramatic variation in soil ecological functions (Wang et al., 2004). In general the microenvironment in the KRD regions is changing toward more drought and heat conditions (Li et al., 2009a), which have led to low plant survival rates and reduction in the efficiency of current vegetation restoration practices.

Karst ecosystems with vegetation covers on thin soils overlying limestone are sensitive to global change. They are extremely vulnerable to soil degradation, water loss, and erosion due to intensive land use and other human activities (Tuyet, 2001; Zhang et al., 2011). Although it is known that the surface soil moisture plays an extremely important role in the ecological process of surface soil (Chen et al., 2010), there are very few studies characterizing the relevant factors quantitatively (Zhang et al., 2011); furthermore, no progress has been made toward understanding the effect of exposed rocks on the surface soil water content. Therefore, more attention should be paid to the spatial variability of soil moisture in the karst area of southwest China.

This study began with a data collection survey in a typical KRD region of Fuyuan County in Yunnan Province, China. The influence of bare rocks on surface soil moisture was then analyzed. Results from this study can be used to guide vegetation restoration under stressful environmental conditions, and to direct ecological management of areas affected by KRD.

2. Methods

2.1. Site description

The study was carried out in San-do-qing Forestry Station (25°02′30″–25°58′22″N, E103°58′37″–104°49′48″), which is in Fuyuan County, Yunnan Province (Fig. 1). Fuyuan County has a total area of 3251 km^2. It is on the eastern Yunnan karst plateau. The topography is mainly mid-mountain at the early developmental stage of karst landform. The whole county has 2049.311 km^2 of karst. The KRD area is up to 601.018 km^2, which is 18.49% of the total arable land, or 29.33% of the karst region.

The area has a northern subtropical monsoon climate. The annual average temperature is 13.8 °C. July is the hottest month with an average temperature of 19.8 °C; January is coldest with an average air temperature of 5.7 °C. The annual hottest temperature is 39.4 °C, and the lowest is −10.7 °C. The annual sunshine duration is 1819.9 h. The frost free season is 240 days, and annual average precipitation is 1332 mm. The rainy season is from May to October (Fig. 2). The main soil type is Haplic Alfisols (Chinese for ‘red limestone soil’), according to FAO soil classification systems (FAO, 1998). Rivers within the county are in the Pearl River basin. County population is 716,400, with a population density of 220 per km^2. From Sept., 2009 to April, 2010, this region experienced an extreme drought period. The precipitation during this period was 107.8 mm, and was 57.2% compared with that of the dry reason of normal years (188.6 mm).

2.2. Data collection

In Feb., 2010, on the south slope of the experimental site, a plot with typical mid-level KRD features, 50% vegetation cover, 60% outcrops cover, soil depth between 10 cm and 30 cm and minor human disturbance was selected (Fig. 3). 102 rock outcrops were chosen along a 1000 meter sampling line. These rocks were selected with length from 0.20 m to 3.70 m, width from 0.19 m to 3.50 m and height from 0.13 m to 2.5 m. The cover area and height of the rocks were measured. Soil moisture in the upper 5 cm of the soil at 5 cm north, west, south and east of the rocks was measured as volumetric soil water content in $m^3\ m^{-3}$, with a soil moisture sensor (5TE, Decagon Devices, Pullman, Washington, USA) coupled to a readout device (ProCheck, Decagon Devices, Pullman, Washington, USA) (Moody and Ebel, 2012; Sperdouli and Moustakas, 2012). Each rock's location was recorded using a GPS device (Fig. 1).

Rocks were selected that were well-separated from each other and had regular external shapes. There was any soil but no large shrubs around the rocks (Fig. 4b).

On the south slope of the experimental site in Feb., 2010, an agricultural field, a mixed (needle leaf and broad leaf) scrub, a *Pinus armandii* scrub, and a KRD field were selected for study. At a depth of 5 cm soil moisture was measured using a 5TE probe coupled to a ProCheck readout device.

Two pieces of rock (A and B in Fig. 1) with uniform size and shape were selected from the 102 rocks. Locations at 5, 15, and 25 cm to the east, west, north, and south of these two rocks were chosen to detect soil moisture, respectively. Soil moisture was measured at depths of 5, 10, and 15 cm for each location as described above (Fig. 4a). Mean value of soil bulk density around the rock is 1.17 $g\cdot cm^{-3}$. Three measurements were taken for each spot, and the mean was

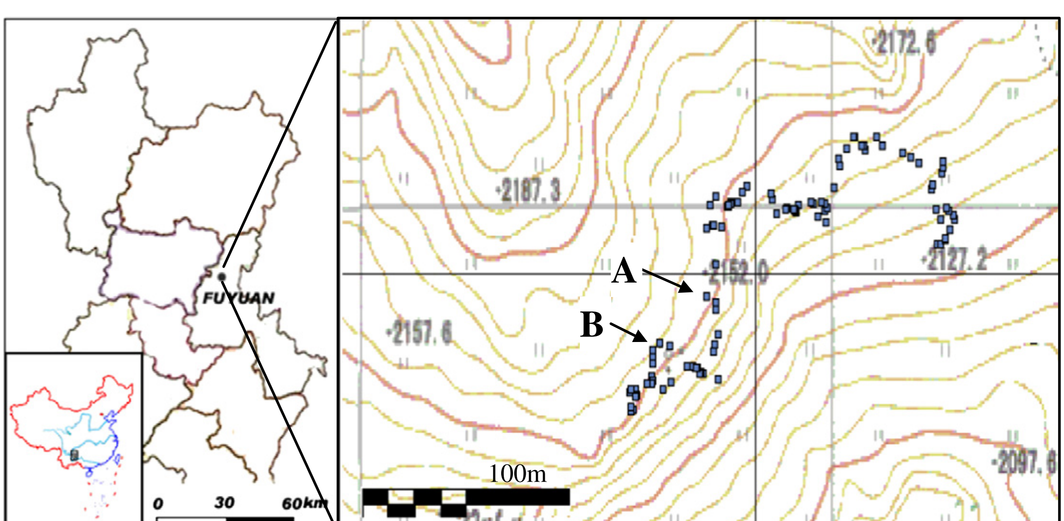

Fig. 1. Research area and the GPS map of investigation sites of bare rocks for surface soil moisture determination.