Applied Soil Ecology 95 (2015) 191–203

Contents lists available at ScienceDirect

Applied Soil Ecology

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

Spatial variability of soil microbial biomass and its relationships with edaphic, vegetational and climatic factors in the Three-River Headwaters region on Qinghai-Tibetan Plateau

Ruichang Shen[a,b], Ming Xu[c,*], Renqiang Li[a], Fengxia Zhao[a], Qingkai Sheng[a]

[a] Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences, 11A Datun Road, Beijing 100101, China
[b] University of Chinese Academy of Sciences, Beijing 100049, China
[c] Center for Remote Sensing and Spatial Analysis, Department of Ecology, Evolution and Natural Resources, Rutgers University, 14 College Farm Road, New Brunswick, NJ 08901, USA

ARTICLE INFO

Article history:
Received 9 January 2015
Received in revised form 15 June 2015
Accepted 16 June 2015
Available online 29 July 2015

Keywords:
Carbon
Nitrogen
Alpine ecosystem
Biogeochemical cycle
Stoichiometry
Global warming

ABSTRACT

This study aims to investigate the level of soil microbial biomass (MB) and analyze the relationships between soil MB and edaphic, vegetational and climatic factors at high elevation sites (>3000 m). We collected soil samples from 0 to 10 cm soil depth in 259 plots at 55 sites across 6 biomes in Three-River Headwaters (TRH) region at 3280–5127 m elevation. Soil microbial biomass carbon and nitrogen (MBC and MBN) were measured with the chloroform fumigation–extraction method. Multivariate stepwise regression analyses were used to analyze the combined effects of edaphic, vegetational and climatic factors on soil MB. We found: (1) soil MBC and MBN had an average of 30.95 mmol C/kg dry soil and 5.84 mmol N/kg dry soil in TRH, respectively, and their values were found to be negatively correlated with elevation; (2) soil MB was found to be significantly different among different biomes, and this spatial variation could be explained by the levels of soil organic carbon and belowground plant biomass. Our results indicate that the MB at high elevation region might be very low, and the increasing trend of soil microbial biomass with elevation could reverse at higher elevations.

1. Introduction

Soil microbial biomass (MB), defined as the living microbial component of the soil organic matter, mainly consists of bacteria, archaea, and fungi with a size smaller than 5×10^3 μm in diameter (Jenkinson and Ladd, 1981; Wardle, 1992). Microbial biomass carbon and nitrogen (MBC and MBN) are the primary elemental components of MB. They are closely correlated with each other, and often follow a stoichiometric relationship just like the "Redfield ratio" in marine plankton and other organisms (Cleveland and Liptzin, 2007; Redfield, 1958; Sterner and Elser, 2002; Yang et al., 2014). Although MBC and MBN only contribute to small parts of soil organic matter, MB plays a key role in litter decomposition, nutrient cycling and energy flow in soils (Anderson and Domsch, 1989; Falkowski et al., 2008; Fierer et al., 2009; Xu et al., 2014). Soil MB has become an important ecological indicator due to its close associations with many biotic and abiotic parameters (Chu and Grogan, 2010; Li et al., 2005, 2006) and its rapid response to environmental changes (Hargreaves et al., 2003; Li et al., 2004; Marinari et al., 2006; Powlson et al., 1987).

Many studies on soil MB have been conducted in the past few decades (Dempster et al., 2012; Kaschuk et al., 2010; Xu et al., 2013), and the focus has recently changed from site/ecosystem level (Shen et al., 2014; Wright and Coleman, 2000; Zak et al., 1994) to regional (Dequiedt et al., 2011; Drenovsky et al., 2010) and global scales (Serna-Chavez et al., 2013; Xu et al., 2013). These large-scale studies examined microbial biomass storage and the mechanisms determining its spatial patterns. For example, a recent study (Xu et al., 2013) found that soil MB showed substantial variation across various biomes at global scale and the spatial patterns of MBC and MBN were in line with those of soil C and N with higher densities in northern high latitudes and lower densities in low latitudes and the Southern Hemisphere. Serna-Chavez et al. (2013) suggested that the global pattern of soil MB was driven by moisture and soil nutrient contents, not temperature. Using meta-analysis, Fierer et al.

* Corresponding author at: Center for Remote Sensing and Spatial Analysis, Department of Ecology, Evolution and Natural Resources, Rutgers University, 14 College Farm Road, New Brunswick, NJ 08901, USA. Tel.: 848-932-9211; fax: 732-932-8746.
E-mail address: mingxu@crssa.rutgers.edu (M. Xu).

http://dx.doi.org/10.1016/j.apsoil.2015.06.011

(2009) showed that soil MB was highly correlated with soil organic C and belowground plant NPP across global biomes. Nevertheless, MB studies have rarely been conducted above 3000 m in elevation, therefore, previous studies estimating the global soil MB pattern and its dominant factors lack support from high elevation sites (Serna-Chavez et al., 2013; Wardle, 1992; Xu et al., 2013).

Many studies have investigated the elevation gradients of soil MB at sites below 3000 m (Arunachalam and Pandey, 2003; Djukic et al., 2010; Fierer et al., 2011). These studies conducted on Mt. Da-an in Central Taiwan (Huang et al., 2014), Mt. Kilimanjaro in Tanzania (Pabst et al., 2013) and Cuenca Mountains in Spain (Lucas-Borja et al., 2012), suggested that soil MB at 2000–3000 m elevation is generally higher than those at lower elevations (<1000 m). Yet, it is still unclear whether such positive relationship holds true for higher elevations (>3000 m). Evaluating soil MB at different elevations could also provide indirect evidences for global warming effects based on the "space-for-time" assumption (Huang et al., 2014; Pabst et al., 2013; Smith et al., 2002; Sundqvist et al., 2013).

The Three-River Headwaters (TRH) region, the source water for Yangtze, Yellow and Mekong rivers, is located on the Qinghai-Tibet Plateau at 2578–6824 m in altitude. A field survey was conducted here to (1) investigate the level of soil MB; (2) explore the role of elevation on the spatial variation of MB and (3) analysis the relationships between soil MB and edaphic, vegetational and climatic factors. According to the patterns found in previous studies, we hypothesized that soil MB in TRH region would be the highest among all previous records.

2. Materials and methods

2.1. Study site

The Three-River Headwaters region, the headwaters of three major rivers in China, the Yellow River, the Yangtze River and the Lancang River (upper reach of Mekong River), is known as "the water tower of China" (Fig. 1). The TRH region is located in southern Qinghai Province (30°39′–36°12′ N, 89°45′–102°23′ E) and covers a total area of about 363,000 km^2, slightly larger than the area of Germany. The altitude stretches from ~2578 m in the east to ~6824 m in the west with an average of ~4500 m. The study area features a typical plateau continental monsoon climate. The annual average temperature and precipitation in this area are 3.96 °C and 500 mm, respectively. Grassland is the primary biome in TRH which accounts for 65.37% of the total area, of which, 76.18% is classified as alpine meadow and 23.36% is classified as alpine steppe. Other biomes in this region include bare land (12.70%), desert (8.57%), wetland (8.40%), forest and shrubland (4.71%) and cropland (0.25%) (Xu et al., 2008).

2.2. Experimental design and field investigation

This study was conducted at 55 sites in 6 biomes in TRH region: 7 sites in forest (F), 8 in shrubland (S), 16 in alpine meadows (M), 8 in alpine steppe (P), 7 in desert (D), and 9 in wetland (W) (Fig. 1). These sites were selected based on the area and distribution of each biome, and they varied from 3280 m to 5127 m in elevation. The snow line in this region is at 5200–5600 m in elevation (Zhang et al., 2010). Specifically, forests and shrublands are located in the southeast of the region at lower elevations (3280–4390 m). Alpine meadows are located at 3360–4513 m. Alpine steppes are mainly found in the west part of the region at 3454–5127 m. Considering the high homogeneity and poor accessibility, we selected a smaller number of sites from deserts relative to the total desert area. All the deserts in TRH region are classified as cold deserts and the altitudes of the selected desert ecosystems are all higher than 4000 m (4248–4586 m). The wetlands in our study contained various types, including rivers, lakes, and swamps, scattering across the TRH region (3605–4580 m) (Tong et al., 2014).

Field investigation was done during the plant growing season in August, 2013. In the field, we sampled vegetation and soils with a square plot of 800 m^2 for each forest and shrubland site. In each plot, we measured understory shrubs in three sub-plots (5 m × 5 m) and sampled understory herbs and soils in 9 sub-plots (1 m × 1 m) located at the four corners, mid-points and the center of each 800 m^2 plot. For the other biomes (alpine meadow, alpine steppe, desert, and wetland), we established transects of 100–200 m in length, depending on the variation of topography and vegetation conditions at each site. Along each transect, we set up 3–5 plots (1 m × 1 m) at 50 m intervals, to measure vegetation biomass and soil properties. Three cores of soil samples along the diagonal were

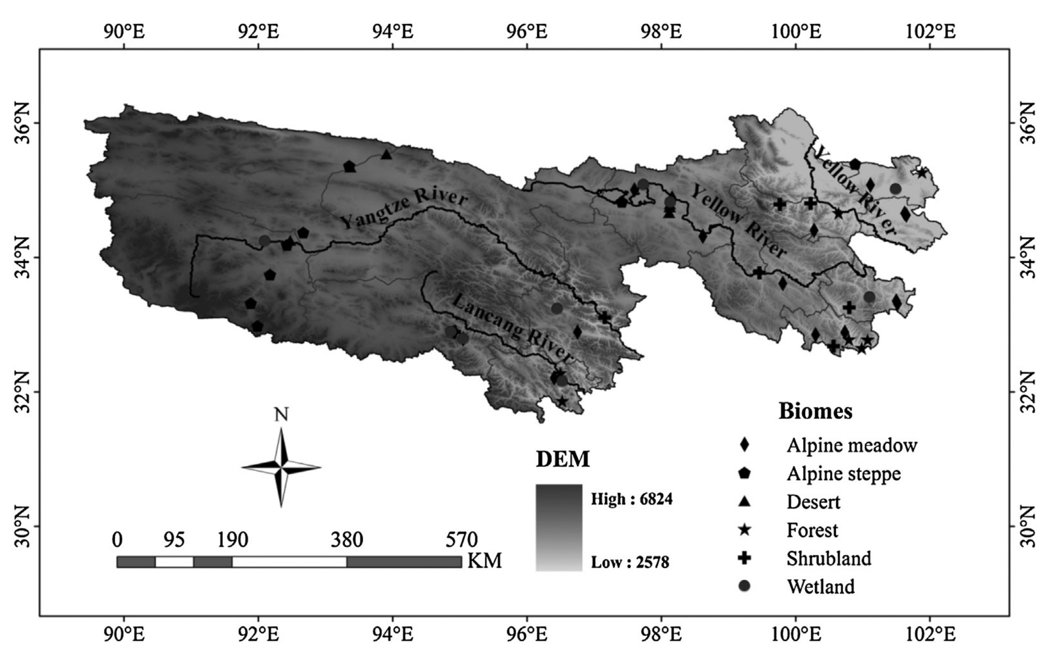

Fig. 1. Locations of the sampling sites in the Three-River Headwaters region.