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Research article

Glomalin changes in urban-rural gradients and their possible associations with forest characteristics and soil properties in Harbin City, Northeastern China

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ABSTRACT

Glomalin-related soil protein (GRSP) is a glycoprotein from the hyphae and spores of arbuscular mycorrhizal fungi. Despite urbanization being the leading cause of present-day land-use changes, there is limited information available on the effects of urbanization on GRSP. We sampled soil from 257 plots in Harbin City, China, and surveyed forest characteristics, soil properties, and urbanization gradients related to ring road development, urban history, and land use. Two glomalin components (easily extracted glomalin, EEG; and total glomalin, TG) and their relative contributions to soil organic carbon (SOC: EEG/SOC, TG/SOC) were measured in the laboratory. We found exponential increases in EEG/SOC and TG/SOC from the most urbanized to the most rural regions, indicating that urbanization sharply reduced glomalin-related SOC sequestration. In general, 1.3–1.4-fold higher glomalin levels were found in the newly urbanized, previously rural areas, while glomalin contribution to SOC sequestration was lower by 38–59% for EEG and 74–85% for TG in the most urbanized regions compared to rural regions. Accompanying these recorded changes in glomalin, linear decreases in soil pH and electrical conductance were observed in all three urban-rural gradients from the urban center to the rural area, and steep decreases in conifer ratio and shrub richness were seen in two of the gradients. The complex associations among glomalin and forest characteristics, soil properties, and urbanization gradients were decoupled and cross-checked using redundancy analysis variation partitioning and structural equation model analysis. Urbanization indirectly changed glomalin features by altering soil properties, with soil properties accounting for over 60% of the glomalin variation. Forest characteristics and urbanization gradients contributed to 10–15% of the glomalin variation. With rapid urbanization occurring in China and on a global scale, glomalin variation should be considered when evaluating soil carbon sequestration and in developing effective forest management strategies, with the aim of ameliorating soil degradation in urbanized regions by rehabilitating glomalin accumulation.

1. Introduction

Glomalin-related soil protein (GRSP) is part of a group of thermo-resistant proteins in soil, released from the hyphae and spores of arbuscular mycorrhizal fungi (AMF) (Driver et al., 2005). The majority of land plants are colonized by AMF (Balota et al., 2016), which are ubiquitous symbionts in terrestrial ecosystems and are mainly responsible for the accumulation of GRSP (Wright et al., 1996; Wright and Upadhyaya, 1996; Wu et al., 2014). GRSP is an important component of soil carbon stocks with a long turnover time (Singh et al., 2017), playing a major role in soil structure and quality (López-Merino et al., 2015). It forms a lattice-like coating on aggregate surfaces that stabilizes the soil against wind and water erosion, stores carbon, and improves overall soil quality (Chen et al., 2012; He et al., 2009; Zhu and Michael, 2003). Numerous studies have shown that a variety of factors, such as soil properties, plant diversity, and changes in climate can affect GRSP production and its stability in soils (Fokom et al., 2012; López-Merino et al., 2015; Wang et al., 2014a, 2015). Two climatic-related parameters, temperature and precipitation, are the most frequently used measures for assessing the effects of climate on GRSP production

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and stability. Additionally, decreases in GRSP production and soil aggregate stability have been observed under higher temperatures (Rillig and Steinberg, 2002), while drought-induced reductions in AMF root colonization and extraradical hyphae growth in wet soils may increase the decomposition of GRSP (Clark et al., 2009). With regards to soil properties, GRSP production has shown close association with pH, bulk density (BD), and electrical conductance (EC) (Wang and Wang, 2015; Wang et al., 2014a; Zhang et al., 2017b). Plant species diversity can directly or indirectly impact hyphal growth and activity of associated AMF, which may further affect GRSP production (Caravaca et al., 2003; Hausmann and Hawkes, 2009). Tree density may also indirectly affect AMF and GRSP via alterations in soil organic matter content (Bernatchez et al., 2008). Understanding of the GRSP changes and their associations with soil and plant characteristics may favor GRSP-mediated regulation of degraded soil management (Rillig and Steinberg, 2002).

Urbanization is a major social and environmental change occurring worldwide, and an important driver of present-day land-use changes (Chen, 2007; Kalantari et al., 2017; Lorenz and Lal, 2015). GRSP is an important component of soil organic matter and acts as an important soil conditioner in the natural environment (Fokom et al., 2012). Urbanization has a close association with soil organic carbon (SOC) sequestration in forests (Lv et al., 2016; Zhai et al., 2017). Urbanization may alter GRSP production and stability as a result of rapid land-use changes, and therefore GRSP may possibly be used as a reference when developing urban soil management strategies. Urban-rural gradients are typically used to evaluate the impact of urbanization on urban ecosystems (Lv et al., 2016; Xiao et al., 2016; Zhai et al., 2017; Zhang et al., 2017a). To the best of our knowledge, no studies to date have quantified the effects of urbanization on GRSP and SOC concurrently, particularly the contribution of GRSP to the SOC pool (GRSP/SOC ratio). Statistical analyses, such as stepwise regression, Pearson correlation, and redundancy analyses, may help clarify these complex associations (Legendre and Legendre, 1998; Wang et al., 2017a).

In this study, we hypothesized that urbanization can alter both GRSP content and GRSP/SOC ratio, and that the changes in forest characteristics and soil properties might contribute to these GRSP patterns. Specifically, we aimed to answer the following questions: 1) How does urbanization affect GRSP and what is its contribution to SOC sequestration? Are these changes similar across gradients related to urban history, ring road, and land use? 2) How do forest characteristics and soil properties influence these urban-rural GRSP patterns? 3) What are the implications for future research and management to improve degraded urban soils? Considering the rapid urbanization in China within recent years, addressing these questions is of great importance in the management of forests and soils with respect to glomalin-related soil rehabilitation.

2. Materials and methods

2.1. Study area description and urbanization level identifications

The study area was located in Harbin (125°42′-130°10′E, 44°04′-46°40′N), the capital of Heilongjiang Province in Northeastern China (Fig. 1), and the most densely populated city in the northernmost province of China. The municipal district covers an area of 10,198 km^2. The developed area within the fourth ring road covers an area of 345.31 km^2. The annual mean temperature and precipitation are 4°C and 569 mm, respectively (Lv et al., 2016; Xiao et al., 2016). Sampling plots are presented in Fig. 1.

Gradients related to urban history, ring road development, and land use were used to represent the urbanization levels in this study. For the urban history-related gradient, seven categories were established based on the years in which the urban region was built up: 1906, 1933, 1945, 1962, 2005, 2014, and non-urban region, indicating the urban history of 100 y, 80 y, 70 y, 50 y, 10 y, 0 y, and non-urbanized region,

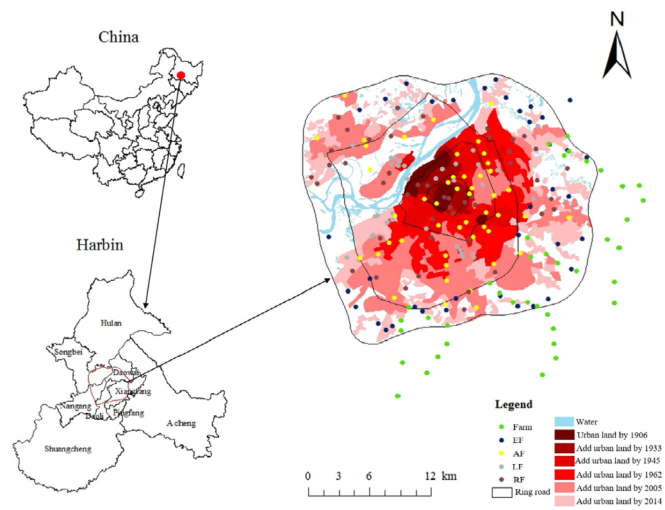

Fig. 1. Location of the study site and the three urban-rural gradients used in this study (land uses, ring road, and urban history). Ring road-related urban rural gradients are indicated by the black lines in the figure, adapted from Lv et al. (2016). Different colors indicate the urban history of urban-rural gradients, and colored dots indicate the different land uses of RF (roadside forest), AF (affiliated forest), LF (landscape and recreation forest), EF (ecological public welfare forest), and Farm (farmland).

respectively (Lv et al., 2016). Ring road numbers were generally used as proxies for the degree of urbanization (Zhang et al., 2016) or urban-rural gradients (Zhai et al., 2017). The urban area was divided into the 1st, 2nd, 3rd, 4th, and outermost ring road (outside the 4th ring) regions (Fig. 1), with the ring road urban-rural gradient ranked as 1, 2, 3, 4, and 5 (i.e., the higher the number, the lower the urbanization degree) during data analysis. For the land use-related gradient, relative proportions of the various forest types were used as identifying criteria. A higher percentage of a certain forest type within the downtown region indicated a degree of higher urbanization. From downtown to the rural area, the gradient was designated as 1: roadside forests (RF, distributed on either road side or along railway), 2: affiliated forests (AF, which are located on the premises of various universities, public institutes, and large community districts), 3: landscape and recreational forests (LF, including urban botanical garden forest and various public parks covered by forests), 4: ecological public welfare forests (EF, which are shelterbelts for farmland and nursery forests providing greening infrastructure development), and 5: farmland (Farm, which was the original land use in the vicinity of Harbin after rangeland and forest reclamation). A recent study in NE China reported concurrent changes in ring road development, urban history, and land-use proportion of the above-mentioned vegetation types (Zhai et al., 2017).

The urban-rural gradient transect method is generally used to evaluate time-space substitutions and assess urbanization effects (Chen et al., 2014). Nevertheless, transect selection is subjective and may bias the urbanization level identified. The present study surveyed the whole urban region and used the application of urban-rural gradients related to ring road development, vegetation land uses, and urban history time contributing to the objective urbanization level determinations and reflecting the genuine urbanization process (Zhai et al., 2017).

2.2. Soil sample and field data collection

Field surveys were conducted in August and September 2014. A total of 257 plots were sampled using stratified random sampling (Fig. 1). At each plot, four replicate soil samples were taken under the trees at a depth of 20 cm. Samples were collected using a 100 cm^3 cutting ring driven into the soil with a plastic hammer. Samples of intact soil (400 cm^3) were stored in cloth pouches and transported to a