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Relationship between plants and soil resource patterns on forest land at different scales using a new theoretical model

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ABSTRACT

Recently, plant root or crown size has been used in researching spatial relationships between plants and soil resources in most studies, and different methods have been used to address this relationship. However, few studies have reviewed the quantification of the relationship between plants and soil resources, and few studies have explained the roles of different plant functional groups on the soil resource distribution. In this paper, a method called integration of geostatistics, point pattern analysis and spatial comparison (IGPS) was used to quantify this relationship. The relationships between plants and soil resource patterns were evaluated from four plots with different spatial scales and different slopes within the Ziwuling Mountains of China. Several relationships were identified using IGPS. We have proved that in IGPS, the aggregation scale between plants and soil resources has been substituted for root or crown size to deeply reveal the spatial relationship between plants and soil resources. The results confirm that this method can not only determine which plant functional group can be affected by which resource but can also quantify the spatial relationship between plants and soil resources. These findings are important because this knowledge can be useful in formulating pasture and forest management strategies. IGPS is a powerful method to assist in study of the spatial relationships between plants and soil resources, and we recommend that this method be used worldwide.

1. Introduction

In the last two decades, there has be an increase in studies concerning the formation of heterogeneous soil resources (Ettema and Wardle, 2002). As many studies over the past two decades have reported, in arid and semiarid ecosystems, pedogenic factors can primarily determine soil resource patterns (Okin et al., 2008; Guo et al., 2002), such as climate, topography and vegetation (Oueslati et al., 2013). Soil resources are affected by climate at local or larger scales. The effects of topography on soil resource patterns emerge primarily through the water movement influenced by micro-topography (Oueslati et al., 2013; Liu et al., 2013).

Vegetation exerts important influence on soil resource patterns and availability (Andruschkewitsch et al., 2014; Macdonald et al., 2015). The physical and chemical properties of the soil beneath the plants can be altered through the process of plant growth (Rodríguez et al., 2009a). Many studies completed in arid and semi-arid regions have reported that plants can enhance soil resource variability and affect seedling establishment by generating and containing soil water and nutrients beneath the plants (Yavitt et al., 2009). Simultaneously, the altered soil resource patterns can, in turn, influence the function and performance of the plants (Li et al., 2010; Yizhaq et al., 2014). It is clear, therefore, that there is a bidirectional feedback relationship between soil resources and vegetation (Covelo et al., 2008; Rodríguez et al., 2009b).

More importantly, the effects of vegetation on heterogeneous soil resource patterns in arid and semiarid ecosystems have attracted increasing attention around the world for three main reasons (Yizhaq et al., 2014; Cao et al., 2016). First, it is important to understand the effects of vegetation on soil resources and to identify the ecological function at the community and ecosystem levels (Holdo and Mack 2014), which is beneficial for subject development (Sauer et al., 2006). Second, land managers can benefit from studies of the effects of vegetation on soil resources (Carey 2003) because these studies can provide useful information for land managers to clearly understand the scale of soil nutrient patterns and effectively manage their lands. Third, understanding the feedback

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relationship between vegetation and soil resources and the state of soil resource patterns is important to avoid soil spatial autocorrelation when carrying out field experiments.

Based on the reasons above, related studies have been widely carried out in arid and semi-arid regions of the world. Related studies can be divided into two groups according to both spatial and temporal aspects. In the spatial aspect, some studies have been performed to study the relationship between vegetation and soil resources in different spatial scales (Zarco-Hidalgo et al., 2008; Currie et al., 2016); some studies have compared this relationship in different land cover types (Liu et al., 2015; Fraterrigo et al., 2005), and others compared the effects of vegetation on soil resources under different erosional forces, such as water and wind erosion (Ravi et al., 2007). Most of the temporal research has focused on the formation of fertility islands. For example, many studies have been concerned with the effects of vegetation on soil resources with changes in land cover (Daryanto et al., 2013), while other studies have examined the effects of grazing pressure changes or changes in forest management policy on soil resource patterns (Allington and Valone, 2013) over time. However, both spatial and temporal studies mainly focused on this question: how does vegetation affect soil resource patterns?

In response to an increasing need for studies to answer this question, many methods have been developed to address the relationship between vegetation and characterization of the heterogeneity of soil resource patterns. For example, Gallardo et al. (2006) speculated about the relationship between soil nutrients and vegetation using probability calculations; Alameda et al. (2012) analysed the spatial relationship between soil properties and different plant species using spatial correlation indexes; Simón et al. (2012) developed the Ripley's K-function to explain the relationship between vegetation and soil organic matter; Kardanpour et al. (2014) used principal component analysis and variograms to optimize the process of soil sampling under different vegetation conditions; and Zuo et al. (2008) studied the effects of soil resource patterns on plant distribution by correspondence analysis. The different methods mentioned above have different focuses. In this paper, a method called integration of geostatistics, point pattern analysis and spatial comparison (IGPS) has been used to quantify the relationship between plant functional groups and soil resources, which is important because few studies have explained the effects of different plant functional groups on soil resources. Strictly speaking, IGPS is not a new method, but it is a new workflow, and this workflow can be used to answer some questions that have never been solved. IGPS consists of three parts: geostatistics, point pattern analysis and spatial comparison analysis. The former two parts are classical methods in geoscience and ecology, while spatial comparison analysis is an important characteristic in IGPS. This study can be considered an example of IGPS.

The purpose of this study was to examine the effects of vegetation on soil resources on two spatial scales: one scale related to herbaceous plants and the other scale related to trees. The objectives of this research were to: (i) investigate the pattern of soil resources using the variogram function of different slopes; (ii) use Ripley's K-function to describe the relationship between soil resources and different plant functional groups on different slopes; and (iii) further compare the spatial results to quantify the relationship between soil resources and different plant functional groups.

2. Materials and methods

2.1. Study area

This research was carried out at the Lianjiabian Forest Farm of the Heshui General Forest Farm (36°08′12.0″N, 109°10′–109°07′26.09″E) south of the Loess Plateau in the Ziwuling forest region (Fig. 1), China. The area's long-term mean annual temperature is 10 °C, and the annual precipitation is 587 mm (Deng et al., 2016). According to the FAO classification system, the main soil type of this region is *Cambisols* developed from secondary loess parent materials (Wei et al., 2014), distributed in thicknesses from 50 to 130 m (Zhang and Shangguan 2016). The dominant tree is *Quercus wutaishanica*. The dominant herbaceous is *Carex korshinskii* in sunny slope, and *Patrinia scabiosaefolia* in shady slope.

2.2. Field test

In September 2015, two test slopes (a shady slope and a sunny slope) with similar environmental conditions (except for illumination time) were selected. A nested spatial sampling design with two spatial scales was used to explore the relationship between vegetation and soil resources. One distributed tree plot (10 × 10 m) and 1 herbaceous plot (2 × 2 m) were built into each test slope. In each tree plot, the crown diameter, location and height of each tree was investigated. Systematic samplings of 121 soil samples were collected at regular intervals on a 1 × 1 m grid (Fig. 1). Soil samples were collected to a depth of 0–30 cm below the soil surface for each sampling point with an auger with an inside diameter of 3.3 cm. In each herbaceous plot, the coverage area, location and height of each plant was investigated. Systematic samplings of 121 soil samples were collected at regular intervals on a 20 × 20 cm grid (Fig. 1). The soil sampling methods of the herbaceous plot were the same as used in the tree plot.

2.3. Laboratory test

All soil samples were oven-dried at 80 °C for 48 h. Then, these samples were sieved using a 2 mm mesh size. A laser particle sizer (Mastersizer 2000) was used to measure the particle size composition, and the percent of particle diameter <20 μm (PPD) of each soil sample was calculated after the test. An element analyser (Vario EL III) was used to measure total nitrogen (TN); total phosphorus (TP) was determined using Morgan's extraction solution (10% sodium acetate in a 3% acetic acid buffered at pH 4.8). A total organic carbon analyser (Liqui TOC-Analyzer) was used to measure the dissolved organic carbon (DOC).

These 4 soil parameters were selected for measurement because they are representative parameters of soil resources. TN and TP are common nutrients from different sources. DOC is an available nutrient that might have a different spatial distribution from common nutrients. PPD can be used to describe the general condition of the soil resource, because more nutrients can absorb in silt soil than in coarse particle soil.

2.4. Data analysis

First, the Shapiro–Wilk normality test was used to check the normality of the vegetation and soil data. Then, the data were transformed using Box–Cox transformation when necessary before data analysis.

Herbaceous species were separated into 2 functional groups: forbs and graminales species. These two functional groups were selected based on the hypothesis that the herbaceous species in the different functional groups have different life forms in the study area and that the different life forms can have different impacts on the patterns of soil resources (Liu et al., 2015).

Tree species were grouped into 3 functional groups according to the height of the tree: Tree 1, tree height > 2 m; Tree 2, 2 m > tree height > 1 m; and Tree 3, 1 m > tree height. The functional groups were selected based on the hypothesis that trees of different heights can have different impacts on patterns of soil resources.