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Spatial heterogeneity of soil and vegetation characteristics and soil-vegetation relationships along an ecotone in Southern Mu Us Sandy Land, China

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Introduction

Spatial pattern analysis is an essential component of spatial heterogeneity studies on soil properties and vegetation characteristics. It was conducted in several studies for both soil and vegetation characteristics (Strand *et al*., 2007; Dick and Gilliam, 2007; Zuo *et al*., 2010). This study aims to examine the changes in the spatial heterogeneity of soil properties at different soil layers, the spatial heterogeneity of soil and vegetation characteristics along an ecotone, and soil-vegetation relationships along the ecotone in a critical area of desertification.

Materials and Methods

The field survey and sampling were conducted in the end of July, 2009, in Yanchi County, China. We set a study site, from the inner part of a Lespedeza potaninii (dominant) community (LPC) to an Artemisia ordosica (dominant) community (AOC), with the ecotone in the middle of these two communities. In this study, "along the ecotone" means from LPC, via the ecotone, and then to AOC. Three parallel transects (300-m long) were arranged at 50-m intervals along the site. Along each transect, at 10-m spacings, 1 m×1-m quadrates were marked for the vegetation survey and soil sampling. Soil samples were analyzed in the laboratory after natural air-drying (ISSCAS 1978). Data analyses were conducted with a combination of classical and geo-statistical methods (Cressie, 1993; Wang *et al*., 2007).

Results and Discussion

Plant community composition changed along the ecotone, from the LPC to the AOC. Almost all plant species (31) encountered in this study site could be found in the LPC. However, good quality forage grasses such as *A. mongolicum* and *S. bungeana* disappeared in the AOC. Changes of IVs along the ecotone were also caused (mainly) by the development of *A. ordosica*. The data set of species richness, diversity, and evenness all exhibited a high central tendency with close mean and median values. The coefficient of variance (CV) for vegetation variables showed that all of them shared a moderate data variation along the ecotone There was a significant difference ($P < 0.05$) in the values of soil organic C (SOC), total N (TN), available K (AK), and electrical conductivity (EC) between the LPC and the AOC at both soil layers. Significant differences between the ecotone and the LPC were seen in the following averaged values: SOC (0-5-cm); AK (0-5 and 5-10-cm). Between the ecotone and the AOC, significant differences were seen in the averaged SOC and EC values both at 5-10-cm. However, there were no significant differences between the ecotone and the AOC observed in the values of AP and pH at both layers. All values of SOC, TN, AP, and EC at both layers decreased along the ecotone, while the value of AK at 0-5-cm decreased significantly ($P < 0.05$) from the LPC to the ecotone, and then increased slightly from the ecotone to the AOC. All these results showed that soil nutrient content diminished along the ecotone from the LPC to the AOC in general. Soil and vegetation properties had moderate spatial heterogeneity. Soil properties had a stronger spatial heterogeneity at subsurface layers compared to surface layers. TN1, EC1, and AK2 were the predominant factors for the plant community structure along the ecotone in the critical area of desertification. The spherical model is the best for both SOC and pH at 5-10-cm, EC at 0-5-cm, and species diversity. The exponential model is the best for SOC at 0-5-cm and EC at 5-10-cm. The linear model is the best for pH at 0-5-cm and species evenness. However, the values of C/ (Co+C) for SOC, EC at both layers, pH at 5-10-cm, and species diversity, were relatively large, all being over 0.500, and showed relatively strong spatial autocorrelations within the ranges (A), changing from 20.40 m (pH at 5-10-cm) to 510.9 m (EC at 5-10-cm). All analyzed soil variables had larger spatial structural variances at 5-10-cm than those at 0-5-cm. Results of cross-validation showed that the regression coefficients of soil chemical properties were close to 1.0 in general. For soil properties, significant correlations were found mainly among SOC, TN, and EC. There were positively significant correlations between all of the following variables: TN (0-5-cm), TN (5-10-cm), SOC (0-5-cm), SOC (5-10-cm), EC (0-5-cm), and EC (5-10-cm) ($P<0.05$). In addition, positively significant correlations were also found between AP (0-5-cm), AP (5-10-cm), AK (0-5-cm), and AK (5-10-cm) ($P<0.05$). For vegetation characteristics, species richness was positively correlated with TN (0-5-cm), TN (5-10-cm), SOC (0-5-cm), SOC (5-10-cm), EC (0-5-cm), and EC (5-10-cm) ($P<0.05$). At the same time, species diversity was positively correlated with TN (0-5-cm) and SOC (0-5-cm) ($P<0.05$), and negatively correlated with pH (0-5-cm) ($P<0.05$). All these results indicate that SOC, TN, EC, and pH could be important soil factors associated with vegetation distribution along the community ecotone in the sandy grassland.

The spatial heterogeneity of soil properties has been recognized as a common characteristic of terrestrial ecosystems and is often associated with different effects on vegetation patterns (Fransen *et al.*, 2001; Buxbaum and Vanderbilt, 2007; Franz *et al.*, 2011). However, in previous studies, soil spatial heterogeneity was commonly assumed to be horizontal heterogeneity, i.e., soil heterogeneity across a given area at a certain layer, *e.g.*, 0-10-cm. This kind of heterogeneity does not include spatial heterogeneity at any other soil layers. However, the spatial heterogeneity of another soil layer may have an important effect on plant competition and vegetation attributes due to the differences of the depth of root distribution for different plants. Therefore, there is a need to study the horizontal spatial heterogeneity of soil properties at different layers. The spatial process of retrogressive succession of plant community along the ecotone has been characterized by two different factors: the population and size changes of *A. ordosica* and the changes in vegetation composition in the study site. The latter, in turn, were indicated by species important values. This spatial process may be caused by the changes of soil properties and plant species competition, and even the combined ecological effects of soil and vegetation. Soil and vegetation are thought to interact normally with each other under all kinds of environmental conditions (Martinez-Fernandez *et al.*, 1995; El-Ghani and Amer, 2003).

Conclusion

Soil properties at surface and subsurface layers have different SV models, indicating a change of horizontal heterogeneity at different depths. SOC and EC shared larger spatial heterogeneity at subsurface layers than that at surface layers, which is due to wind erosion in this area. Smaller scale sampling intervals on the horizontal level would be useful for determining the spatial heterogeneity of some properties such as pH at depth of 5-10-cm and species evenness. Spatial heterogeneity in soil layers at 5-10-cm can explain plant species diversity best. Soil nutrients decreased at both depths along the ecotone. Vegetation characteristics could be closely correlated to SOC, TN, and EC, whereas only TN1, EC1, and AK2 are the main factors affecting the vegetation succession in this critical area of desertification.

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