

白刺灌丛对土壤空间变异特征的影响及其驱动因素*

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摘 要: 荒漠作为陆地生态系统不可或缺的组成部分, 其生境十分脆弱, 受资源环境限制该地区植被多呈斑块状分布, 建群种主要以丛生、旱生植物为主, 其在调节区域气候、保持水土资源、为众多物种提供栖息地等方面作用显著。本研究基于宁夏盐池县与内蒙古、甘肃以荒漠草原区 9 个样点, 以分布较为广泛的白刺(*Nitraria tangutorum*)灌丛为研究对象, 采用大尺度样带调查和室内数学模型模拟的方法, 分析荒漠草原区白刺灌丛土壤的碳(C)、氮(N)、磷(P)土壤空间变异特征, 探究白刺灌丛对土壤 C、N、P 元素的影响机制, 并揭示其主要驱动因素。主要研究结果如下:

(1) 降水和纬度是影响白刺叶片化学计量特征的关键因子。根 P、N/P 与经度呈显著负相关和正相关($p<0.05$), C/N 与纬度显著负相关($p<0.05$), N、N/P 与海拔分别在 0.001 和 0.05 水平上呈负相关。叶片 N 含量、C/N 分别与纬度极显著正相关和负相关($p<0.001$)。海拔、MAP 是影响白刺根系化学计量特征的关键因子。白刺根 P、N/P 与经度在 0.05 水平上呈负相关和正相关, 根 C/N 与纬度在 0.05 水平上呈负相关可能与降水有关, 根 N、N/P 与海拔分别在 0.001 和 0.05 水平上呈负相关。

(2) 年均降水量、纬度、经度是影响草本化学计量特征的主要环境因子。灌丛内草本 C 含量与经度显著负相关($p<0.05$), N 含量、C/N 与纬度呈极显著正相关和负相关($p<0.01$), N/P 与纬度显著正相关($p<0.05$), N 含量、C/N 与海拔呈显著负相关($p<0.05$)和极显著正相关($p<0.01$), P 含量与年均降水量显著负相关($p<0.05$), C/P、N/P 与年均降水量均在 0.05 水平上呈正相关。灌丛外草本 N 含量、C/N 与经度呈极显著正相关和负相关($p<0.01$), N 含量、C/P、N/P 分别与年均降水量在 0.001、0.05、0.01 水平上呈正相关。在降水充足的情况下, P 元素是限制草本生长的主要元素。

(3) 土壤 C、N 总体随土层深度增加而逐渐降低, P 含量在土层深度上没有统一性规律。灌丛内土壤 C、N、P 化学计量指标均高于灌丛外, 灌丛内土壤的 C 源、有机质分解速率和矿化速率相较灌丛外偏低。0-10cm 土层的 C、N 含量最高, 土壤 C 含量表现为南部>北部>中西部, N 含量表现为北部>南部>中西部, P 含量表现为中西部>北部>南部, C/N 表现为南部>中西部>北部, C/P、N/P 均表现为北部>南部>中西部。温度是影响土壤 C 的重要因子, 灌丛内土壤 C、N、P 含量均较为缺乏, 缺乏程度为 N>C>P。

(4) 经度、纬度是影响土壤化学计量特征的主要环境因子, 灌丛内土壤 C/P、N/P 均与海拔极显著负相关($p<0.01$), N/P 与 MAT 显著负相关($p<0.05$)。温度升高不利于土壤 N 的积累, 在温度较高时土壤中 P 元素较 N 元素更容易损失, N 减少有助于提高白刺灌丛内土壤 P 含量, 温度对土壤 C、N、P 元素的影响程度为 P>N>C。灌丛外土壤 C 含量与 MAT 极显著正相关($p<0.01$), 土壤 N 含量与经度、MAP 分别在 0.01 和 0.001 水平上呈正相关, P 含量与经度和海拔分别呈显著负相关($p<0.05$)和极显著正相关($p<0.01$)。在一定温度区间内, 温度增加有利于 C 的积累。

综上所述, 荒漠草原 C、N、P 化学计量特征存在明显空间异质性, N、P 元素是限制灌丛沙堆植被生长的主要元素。因此因地制宜进行区域生态系统植被恢复, 对生态保护具有重要意义。

关键词: 白刺灌丛, 空间变异特征, 植物-土壤互作, 驱动因素, 荒漠草原

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Influence of white thorn scrub on soil spatial variability characteristics and its drivers

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Abstract: As an indispensable part of terrestrial ecosystems, deserts have very fragile habitats, and the vegetation in this area is mostly patchy in distribution due to the limitation of the resource environment, and the established species are mainly dominated by tufted and arid plants, which play a significant role in regulating the regional climate, maintaining soil and water resources, and providing habitats for a large number of species. In this study, we analyzed the spatial variability of carbon (C), nitrogen (N), and phosphorus (P) in the soil of white thorn scrub in the desert grassland area based on nine sample sites in Yanchi County, Ningxia, Inner Mongolia, and Gansu, with widely distributed white thorn (*Nitraria tangutorum*) scrub as the object of the study, and analyzed the characteristics of carbon, nitrogen, and phosphorus (P) in the soil of white thorn scrub in the desert grassland area using the method of large-scale sample survey and indoor mathematical model simulation. The study analyzed the spatial variability of carbon (C), nitrogen (N) and phosphorus (P) in white thorn scrub soils in the desert grassland area, explored the mechanism of white thorn scrub's influence on soil C, N and P elements, and revealed its main driving factors. The main results of the study are as follows:

(1) Precipitation and latitude were the key factors influencing the leaf stoichiometric characteristics of white thorn. Root P and N/P were significantly negatively and positively correlated with longitude ($p < 0.05$), C/N was significantly negatively correlated with latitude ($p < 0.05$), and N and N/P were negatively correlated with altitude at the 0.001 and 0.05 levels, respectively. Leaf N content and C/N were highly significant positively and negatively correlated with latitude ($p < 0.001$), respectively. Altitude and MAP were the key factors affecting the stoichiometric characteristics of white spurge roots. White spurge root P and N/P were negatively and positively correlated with longitude at the 0.05 level, root C/N was negatively correlated with latitude at the 0.05 level possibly related to precipitation, and root N and N/P were negatively correlated with elevation at the 0.001 and 0.05 levels, respectively.

(2) Mean annual precipitation, latitude and longitude were the main environmental factors affecting herb stoichiometric characteristics. Herb C content within the thicket was significantly negatively correlated with longitude ($p < 0.05$), N content and C/N were highly significant positively and negatively correlated with latitude ($p < 0.01$), N/P was significantly positively correlated with latitude ($p < 0.05$), N content and C/N were significantly negatively correlated ($p < 0.05$) and highly significant positively correlated ($p < 0.01$) with altitude, P content was significantly negatively correlated with mean annual precipitation ($p < 0.05$), and C/P and N/P were positively correlated with mean annual precipitation at the 0.05 level. The N content and C/N of the herb outside the scrub were significantly positively and negatively correlated with longitude ($p < 0.01$), and N content, C/P, and N/P were positively correlated with mean annual precipitation at the 0.001, 0.05, and 0.01 levels, respectively. In the case of sufficient precipitation, element P was the main element limiting herbaceous growth.

(3) Soil C and N in general decreased gradually with the increase of soil depth, and P content did not have a uniform pattern in soil depth. The soil C, N and P stoichiometries in the thicket were higher than those outside the thicket, and the C source, organic matter decomposition rate and mineralization rate of the soil in the thicket were

low compared with those outside the thicket. Midwest>North, and C/P and N/P were North>South>Midwest. Temperature is an important factor affecting soil C. Soil C, N, and P contents in the thicket were all more deficient, and the degree of deficiency was N>C>P.

(4) Longitude and latitude are the main environmental factors affecting soil stoichiometric characteristics. Soil C/P and N/P within the scrub were all highly significantly negatively correlated with altitude ($p<0.01$), and N/P was significantly negatively correlated with MAT ($p<0.05$). Elevated temperature was unfavorable to soil N accumulation, and at higher temperatures soil P elements were more easily lost than N elements, and N reduction helped to increase the soil P content within the white thorn scrub, and the degree of influence of temperature on soil C, N, and P elements was P>N>C. Soil C content outside the scrub was highly significantly positively correlated with MAT ($p<0.01$), and soil N content was positively correlated with longitude and MAP at the 0.01 and 0.001 levels, and P content was significantly negatively correlated ($p<0.05$) and highly significantly positively correlated ($p<0.01$) with longitude and elevation, respectively. Within a certain temperature interval, the increase in temperature favored C accumulation.

In summary, there was obvious spatial heterogeneity in the C, N and P stoichiometric characteristics of desert grassland, and N and P elements were the main elements limiting the growth of scrub sand pile vegetation. Therefore, it is important for ecological protection to carry out regional ecosystem vegetation restoration according to local conditions.

Key words: White thorn scrub, spatial variability characteristics, plant-soil interactions, drivers, desert grassland