

不同质地土壤中荒漠灌木梭梭“肥岛”的初步探讨*

曹艳峰^{1, 2} 丁俊祥² 于亚军¹ 黄刚^{2†}

(1 山西师范大学地理科学学院, 山西临汾 041000)

(2 中国科学院新疆生态与地理研究所绿洲与荒漠重点实验室, 乌鲁木齐 830011)

摘 要 为检验荒漠灌木“肥岛”是否受土壤质地调节, 本研究选取了中亚干旱区梭梭 (*Haloxylon ammodendron* (C. A. Mey.)) 的两种原生生境: 古尔班通古特沙漠的风沙土和绿洲区的灰漠土。两种土壤的质地有显著差异, 风沙土中砂粒含量是灰漠土的 2.1 倍~2.4 倍, 而灰漠土中粉粒和黏粒含量分别是风沙土的 3.0 倍~3.6 倍、2.9 倍~5.1 倍。通过对比分析两种土壤中梭梭冠下水分和养分的空间变异特征, 获得了如下结果: 两种土壤中均存在灌木“肥岛”效应, 且随深度增加而减弱; 在 0~20 cm 土层, 与灰漠土相比, 风沙土中冠下水分和养分空间异质性更强, 富集程度更高, 风沙土中水分、有机质、有效氮和有效磷的富集率分别是灰漠土的 4.6 倍~12.3 倍、3.4 倍~8.6 倍、3.0 倍~4.9 倍和 2.1 倍~2.6 倍。研究表明, 两种土壤均存在灌木“肥岛”效应, 而土壤质地可能决定了“肥岛”效应的强弱程度。

关键词 荒漠土壤; 梭梭; 肥岛; 土壤质地
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在干旱区和半干旱区生态系统中, 灌木冠下普遍存在土壤水分和养分空间异质性, 即所谓的“肥岛”或“资源岛”^[1-2]。“肥岛”虽是植物个体尺度上土壤水分、养分空间异质性现象, 但对生态系统中植被的分布、生产力, 以及生态系统过程 (如荒漠化) 具有重要影响^[3-5], 因此, “肥岛”深受研究者关注。Klemmenson 和 Barth^[6] 研究表明, “肥岛”从灌木中心向外水分和养分含量呈递减趋势, 且该趋势随深度增加而减弱。李君等^[7] 报道, 在准格尔盆地南缘荒漠—绿洲交错带, 梭梭 (*Haloxylon ammodendron* (C. A. Mey.)) 和怪柳 (*Tamarix* spp.) 的“肥岛”具有不同特征, 验证了“肥岛”效应强度依赖于灌木种类。刘耘华等^[8] 发现古尔班通古特沙漠梭梭“肥岛”效应因灌木发育阶段 (或发育年龄) 的不同而不同。李从娟等^[9] 认为, 梭梭“肥岛”具有根

际、个体、种群、地貌、区域的多尺度特征。然而, 关于不同质地土壤中“肥岛”的研究少有报道, 尤其在荒漠土壤中。

土壤质地比别的土壤性质更为稳定, 它对土壤环境如有机质和水分的保持能力有很大的影响。通常来说, 砂土具有较高的扩散率^[10], 土壤中水分的运动和有机质的周转较快, 而黏土中黏粒稳定有机质的能力较强, 不利于有机质周转^[11]。此外, 砂土中较低的有机质含量限制了阳离子的交换能力, 而黏土中较高的有机质和次生矿物 (如黏粒) 含量增强了阳离子的交换能力^[12]。因此, 土壤质地可能对土壤水分和养分空间异质性具有潜在影响^[13]。

梭梭是中亚干旱区荒漠生态系统主要的优势种之一, 对维持植物群落生产力和生态系统功能具有极其重要的作用^[14-15]。新疆准噶尔盆地是我国

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† 通讯作者 Corresponding author, E-mail: hg@ms.xib.ac.cn

作者简介: 曹艳峰 (1978—), 男, 山西临县人, 硕士, 讲师, 主要从事土壤生态方面的研究。E-mail: sxcyf1006@163.com

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梭梭荒漠植被的主要分布区域。在准噶尔盆地，古尔班通古特沙漠和冲积平原—绿洲区是梭梭的两种典型原生生境，对应分布的地带性土壤为风沙土和灰漠土，其质地有显著差异，为检验土壤质地对“肥岛”的潜在影响提供了理想的研究场所。本文以梭梭冠幅内外的土壤环境为研究对象，对比分析不同质地土壤中冠下水分和养分的空间变异特征。研究个体尺度上植物资源的空间分布格局可为理解种群、群落以及生态系统尺度上资源的分布格局奠定基础，也可作为认识植物与土壤之间的关系提供参考。

1 材料与方法

1.1 研究区概况

本试验开展于中国科学院新疆生态与地理研究所阜康荒漠生态试验站（44° 17' N，87° 56' E，475 m a. s. l）附近的两种原生梭梭的群落，即古尔班通古特沙漠南缘（简称“沙漠区”）和冲积平原—绿洲边缘（简称“绿洲区”）。该区气候属于大陆性干旱气候，冬季严寒，夏季干热，春秋温凉，年平均降水量约为160 mm，年平均气温约为6.6 °C，年平均蒸发潜力约为2 000 mm。

梭梭是本研究区重要的优势种之一，其广泛分布于古尔班通古特沙漠，也偶见于沙漠边缘的绿洲区。沙漠区梭梭的密度约为450 株 hm^{-2} ，冠内主要的草本植物为齿稈草（*Schismus arabicus*）和条叶庭荠（*Alyssum linifolium*），盖度约为15%；绿洲区梭梭的密度约为530株 hm^{-2} ，冠内主要的草本植物为钠猪毛菜（*Salsola nitraria*），盖度约为10%。沙漠区、绿洲区的土壤分别为风沙土和灰漠土。由于两个试验区距离较近，仅约8 km，两种土壤处于同等气候条件下。

1.2 土样采集

2013年5月初，在沙漠区丘间平地 and 绿洲区，分别选取基茎（约10 cm）、冠幅半径（约100 cm）和株高（约200 cm）相近的梭梭8株。采用土钻法采集土样。在水平方向上，随机选择相互间成90° 夹角的4个采样方向，在每一个采样方向上选择代表4种微生境的采样位置：主根附近、冠幅中央、冠幅边缘和株间空地（与主根的距离分别为5、50、100、200 cm）；位于同一采样点处4个方

向上的土样混合组成1个土样。在垂直方向上，采样深度为：0~20、20~60、60~100 cm。

1.3 分析方法

在每一种土壤中，同一土层不同采样点的土样混合组成一个混合样，用于分析土壤机械组成，分析仪器为激光粒度仪（Sympatec GmbH, System-Partikel-Technik, Clausthal-Zellerfeld, 德国）。依据美国农业部粒级划分标准，划分出3个粒级：砂粒0.05~2 mm、粉粒0.05~0.002 mm、黏粒<0.002 mm^[16]。土壤水分含量采用烘干—称重法，在105 °C下持续烘干24 h^[16]；土壤有机质测定采用重铬酸钾外加热法^[16]；土壤有效氮采用碱解扩散法^[16]测定；土壤有效磷采用NaHCO₃浸提—钼锑抗比色法^[16]测定。

1.4 数据分析

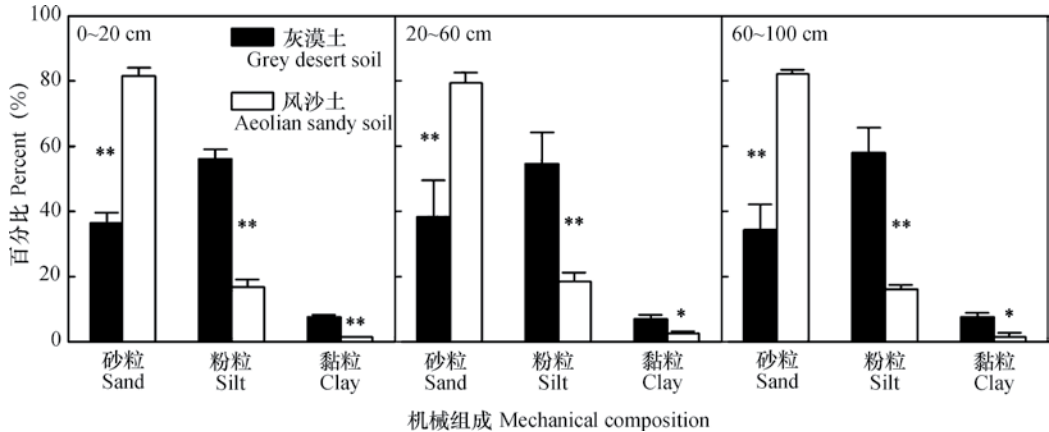
富集率（Enrichment rate, E）是揭示“肥岛”效应的常见指标^[8]，用于表征水分和养分富集程度。在本研究中，主根附近、冠幅中央、冠幅边缘和株间空地的富集率分别采用如下方法换算： $E_A = (A - D) / D$ ， $E_B = (B - D) / D$ ， $E_C = (C - D) / D$ ， $E_D = 0$ ，其中A、B、C、D分别表示主根附近、冠幅中央、冠幅边缘和株间空地的水分、养分含量。此外，本研究也计算了从主根附近到株间空地水分和养分含量的减少率（Reduction rate, R），方法为： $R = (A - D) / A \times 100\%$ 。

采用配对T检验分析同一粒级内两种土壤之间的差异性，分析同一微生境内两种土壤中水分和养分富集率的差异性。采用最小显著差异性（less significant difference, LSD）比较同一深度中水分、养分含量在不同微生境之间的差异性。采用Pearson 相关分析检验土壤各养分变量之间的相关性。上述检验分析由SPSS 16.0软件完成。

2 结 果

2.1 土壤机械组成

从图1可看出，两种土壤的机械组成有显著差异（ $p < 0.05$ ），风沙土的质地较粗，为壤性细砂土（loamy fine sand），砂粒含量为灰漠土的2.1倍~2.4倍；而灰漠土的质地较细，为粉砂质壤土（silt loam），粉粒和黏粒含量分别为风沙土的3.0倍~3.6倍、2.9倍~5.1倍。



注: **、*分别表示差异达显著性水平 $p < 0.01$ 、 $p < 0.05$ Note: ** and * represent significance in difference at $p < 0.01$ and $p < 0.05$, respectively

图1 灰漠土和风沙土的机械组成

Fig. 1 Soil mechanical composition of the grey desert soil and the aeolian sandy soil

2.2 水分和养分的空间变异

从主根向外,水分、有机质、有效氮和有效磷的含量不断减少;从株间空地向内,各土壤性质的富集率不断增加(图2~5),表明两种土壤均存在“肥岛”现象。此外,从主根附近到株间空地,风沙土0~20 cm土层中水分、有机质、有效氮和有效磷含量分别减少了62.0%、79.2%、77.1%和68.2%,高于60~100 cm土层中相应变量的减少率:32.2%、54.9%、47.7%、50.1%;同样,在灰漠土中,从主根附近到株间空地,0~20 cm土层中水分、有机质、有效氮和有效磷含量分别减少了20.7%、50.7%、40.4%和47.8%,也高于60~100 cm土层中对应变量的减少率:13.7%、21.7%、25.9%、40.3%,说明两种土壤中水分和养分的空间变异随土层深度增加而减弱。

两种土壤中冠下水分和养分空间变异的差异主要表现在0~20 cm土层,具体为:

(1)在风沙土中,主根附近、冠幅中央、冠幅边缘的水分、有机质、有效氮和有效磷的含量均显著高于株间空地($p < 0.05$);而在灰漠土中,冠幅中央、冠幅边缘的水分、有机质和有效磷的含量均与株间空地无显著差异($p > 0.05$),冠幅边缘有效氮的含量与株间空地也无显著差异($p > 0.05$)。尽管在主根附近,两种土壤中各变量的含量均显著高于株间空地,但风沙土中水分、有机质、有效氮和有效磷的含量是株间空地的2.6倍、5.0倍、4.4倍和3.3倍,而在灰漠土中仅为1.3

倍、2.2倍、1.7倍和2.1倍。同样,在冠幅中央,两种土壤中有效氮也有类似情况,风沙土中有效氮的含量是株间空地的2.2倍,也高于灰漠土中的1.3倍。由此可见,风沙土较灰漠土水分和养分的空间异质性较强。

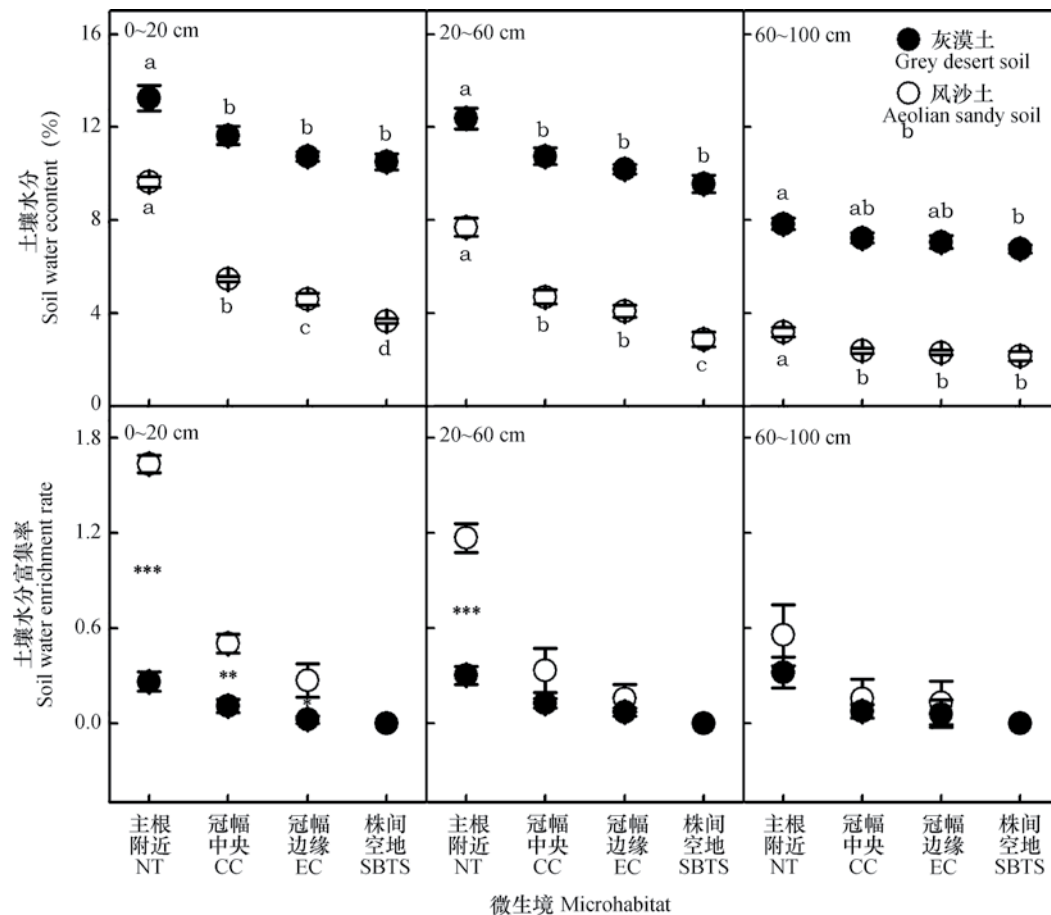
(2)在0~20 cm土层,风沙土中冠内水分和养分的富集率显著高于灰漠土($p < 0.05$)。在风沙土中,主根附近、冠幅中央和冠幅边缘水分的富集率分别是灰漠土的6.3倍、4.6倍和12.3倍,有机质的富集率分别是灰漠土的3.4倍、5.1倍和8.6倍,有效氮的富集率分别是灰漠土的4.9倍、3.9倍和3.0倍,有效磷的富集率分别是灰漠土的2.1倍、2.6倍和2.4倍。

2.3 土壤养分间的相关关系

从表1可看出,土壤有机质与有效氮、有效磷之间呈极显著正相关($p < 0.01$),灰漠土中相关性系数均超过0.70,风沙土中相关性系数均超过0.85,说明两种土壤中梭梭冠下土壤中各养分变量的空间变异密切相关。

3 讨 论

“肥岛”是干旱和半干旱生态系统中普遍存在的现象,本研究也不例外,两种土壤均存在“肥岛”现象。在“肥岛”形成和发育过程中,灌木和冠下草本植物具有重要的作用。灌木和冠下草本植物的凋落物、根系的周转和分泌物是冠内土壤有机



注：同种土壤中不同小写字母表示差异达显著性水平 $p < 0.05$ ，同一微生境中***、**、*分别表示差异达显著性水平 $p < 0.001$ 、 $p < 0.01$ 、 $p < 0.05$ 。NT、CC、EC、SBTS分别表示主根附近、冠幅中央、冠幅边缘、株间空地的英文简写，下同 Note: Different lowercase letters in the same graphic symbol of soil represent significant difference at $p < 0.05$. ***, ** and * in the same microhabitat represent significance in difference at $p < 0.001$, $p < 0.01$, and $p < 0.05$, respectively. NT, CC, EC and SBTS represent nearby the taproot, the center of the canopy, the edge of the canopy and the space between two shrubs, respectively. The same below

图2 从主根向外0~20 cm, 20~60 cm和60~100 cm土层中水分含量和富集率的空间变异

Fig. 2 Spatial variability and enrichment rate of soil water content relative to distance from the taproot in the 0~20, 20~60, and 60~100 cm soil layers

质或有机碳的重要来源，也是冠内土壤养分含量高于冠外的重要原因^[17]。冠内土壤有机质含量的提高有助于改善土壤结构，提高土壤团聚体数量，增强水分的保持能力^[18]。冠幅的遮阴可减少冠下土壤的辐射量，降低土壤温度，防止蒸发损失，从而提高冠下土壤水份。此外，冠幅对降水再分配而引起的树干茎流^[19]和根系参与的水力提升（或水力再分配）^[20]也是冠内水份高于冠外的重要机制。

随土壤深度增加，两种土壤中水分和养分的空间异质性逐渐减弱，与已有的研究结果较为一致。Klemmenson和Barth^[6]曾以总氮为指标构建了“肥岛”的空间结构：总氮含量由灌木中心向外

递减，且该递减趋势随深度增加而减弱，到约40 cm深度后“肥岛”效应趋于消失。在本研究区，李君等^[7]也证实了梭梭“肥岛”效应随深度增加而减弱。梭梭属于浅根系植物，侧根主要分布于浅土层，随深度增加而减少^[15]。此外，也有研究表明，冠下草本植物的根系也随深度增加而减少。因此，与下层土壤相比，表土层中更多的根系分布和凋落物输入量是“肥岛”效应显著的重要原因。

在表层0~20 cm土层，与细质地的灰漠土相比，粗质地的风沙土中冠下水分的空间异质性较强，土壤水分含量在各微生境之间具有显著的差异性（ $p < 0.05$ ）。已有研究表明，风沙土中冠下

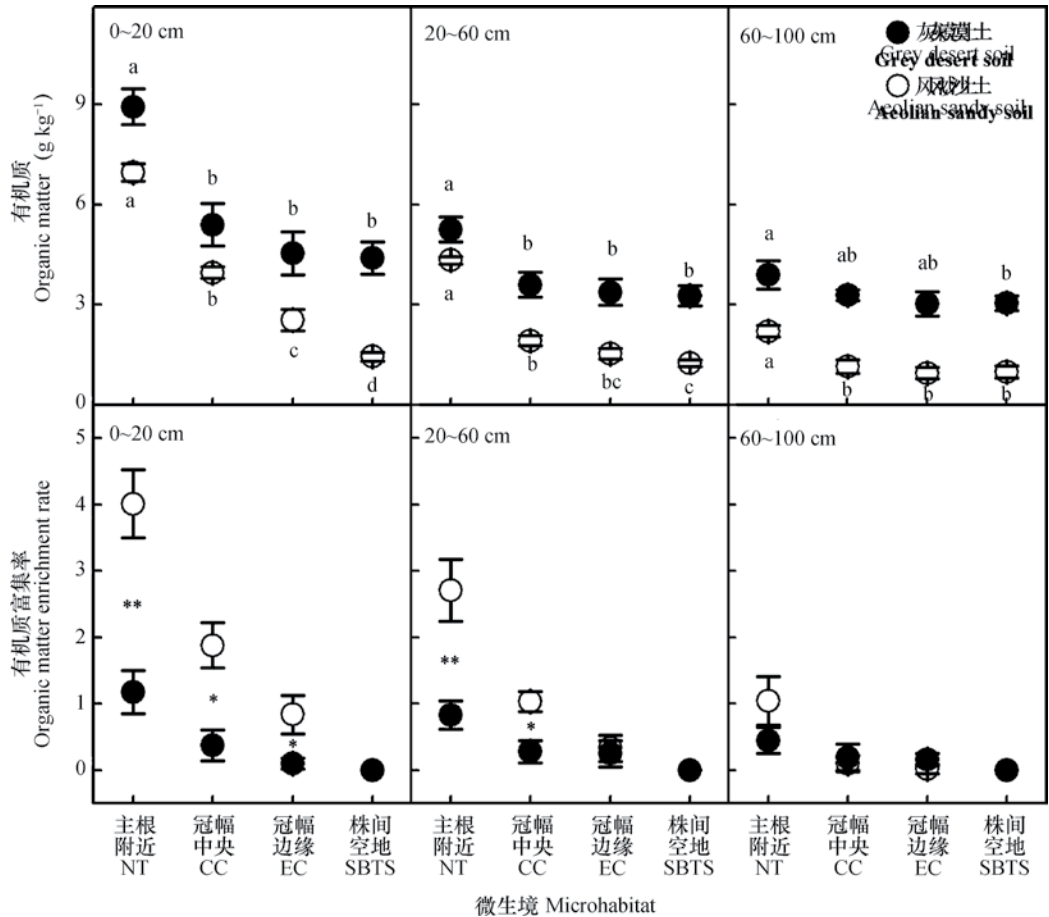


图3 从主根向外0~20 cm, 20~60 cm和60~100 cm土层中有机质含量和富集率的空间变异

Fig. 3 Spatial variability and enrichment rate of soil organic matter content relative to distance from the taproot in the 0~20, 20~60, and 60~100 cm soil layers

水分的空间变异具有季节动态变化特征, 春季4、5月份冠下土壤水分的空间变异较为显著, 而在夏季6、7、8月份, 随干旱程度的增加“肥岛”效应趋于减弱^[21], 支持了本研究中5月份采样时土壤水分的分析结果。在本研究区, 春季梭梭灌木周围土壤水分的格局与积雪融水有关, 积雪从灌木基茎部开始融化, 形成以灌木为中心的“融雪漏斗”效应^[22-23]。与灰漠土相比, 风沙土质地较粗, 水分易于汇入, 融雪水的“漏斗”效应更强, 使得冠内土壤比冠外空地拥有更高的水分含量, 提高了空间异质性水平。加之, 两种土壤中水分本底值明显不同, 风沙土中株间空地的水分含量仅为3.7%, 远低于灰漠土中株间空地的水分含量10.5%, 故风沙土中冠内水分的富集率显著高于灰漠土 ($p < 0.05$)。

在荒漠生态系统中, 来自冠幅的凋落物是冠内表层土壤有机质的重要来源。灰漠土和风沙土中选取的梭梭具有相似大小的基茎、冠幅和株高, 凋落

物的数量和质量在两种土壤之间无差异。然而, 在0~20 cm土层, 与灰漠土相比, 风沙土中冠内养分含量显著高于株间空地, 有更高的富集率, 其中有机质、有效氮和有效磷的富集率分别是灰漠土的3.4倍~8.6倍、3.0倍~4.9倍和2.1倍~2.6倍。一方面, 两种土壤中有机质的周转率有所不同, 在细质地土壤中, 由于黏粒的吸附作用和黏粒团聚体中微孔隙的物理性保护作用较强^[24], 被禁锢于微团聚体内部的有机质不利于分解, 降低了冠幅凋落物提供的新鲜有机质的周转速率^[11, 25], 导致冠内土壤养分含量不利于提高, 减弱了富集水平; 此外, 有效养分与土壤有机质分解和矿化紧密相关, 灰漠土中有机质较慢的周转速率也引起了有效养分较低的富集水平。另一方面, 两种土壤养分含量的本底值具有显著差异, 灰漠土中株间空地有机质、有效氮和有效磷的含量分别是灰漠土的3.0倍、3.8倍和2.1倍; 土壤养分本底值差异与成土过程紧密相关, 灰漠土

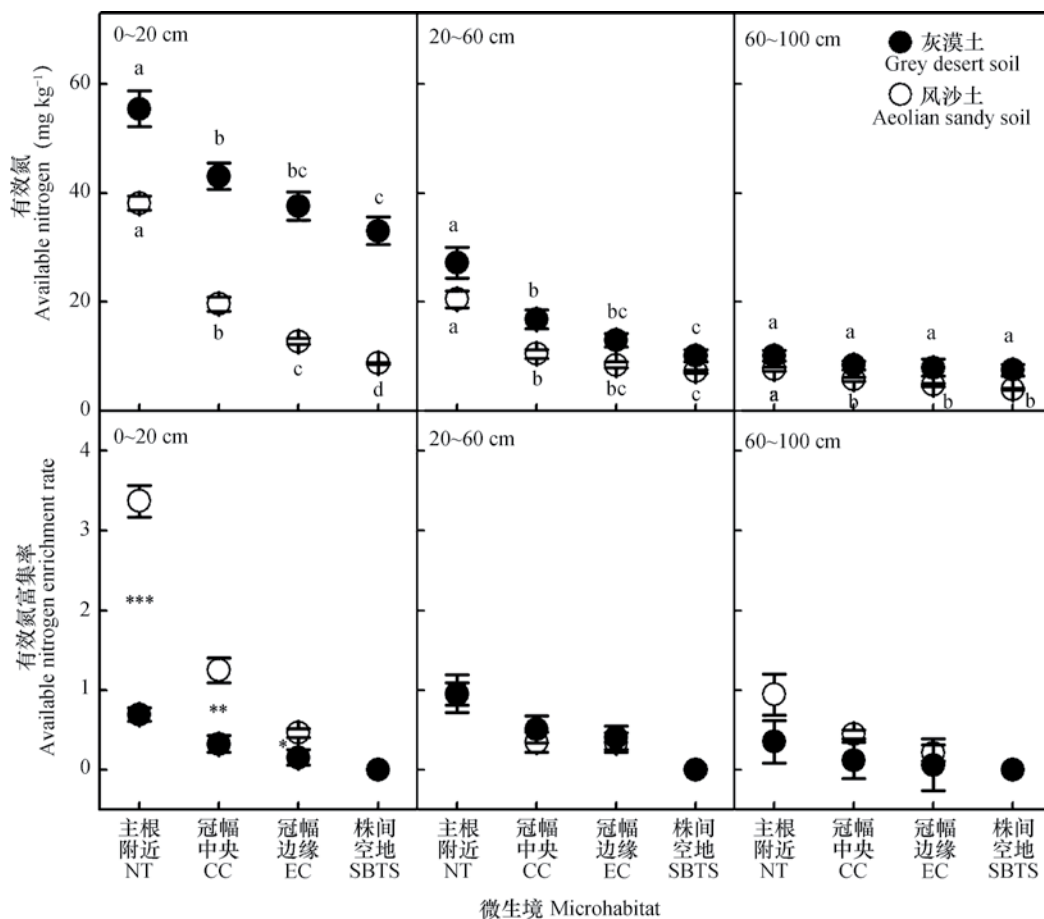


图4 从主根向外0~20 cm, 20~60 cm和60~100 cm土层中有效氮含量和富集率的空间变异

Fig. 4 Spatial variability and enrichment rate of soil available nitrogen content relative to distance from the taproot in the 0~20, 20~60, and 60~100 cm soil layers

是发育于黄土状洪积—冲积物母质上的土壤^[26], 腐殖质化程度较强, 基本上具备了完善的土壤层次, 属于新疆绿洲灌耕农业开发的主要土壤类型; 而风沙土是发育于砂性母质上的幼年土壤, 成土过程微弱, 土壤发育对自然植被出现、繁衍的依赖性较强^[27]。当相似大小的灌木生长于成土过程微弱、养分本底值较低的土壤中时, 冠幅提供的凋落物对冠内养分含量应有更大程度的影响, 养分的富集水平易于提高。

4 结 论

通过对比分析两种不同质地土壤中梭梭冠下水分和养分空间变异特征, 本研究获得了如下认识: 两种荒漠土壤中均存在“肥岛”现象; 然而, 在0~20 cm土层, 与细质地的灰漠土相比, 在粗质地的风沙土中, 梭梭冠内水分和养分有更强的空间

异质性、更高的富集水平, 表明土壤质地可能决定了“肥岛”效应的强弱。未来需要对不同的生态系统加以研究, 进一步印证本研究的基本结果。

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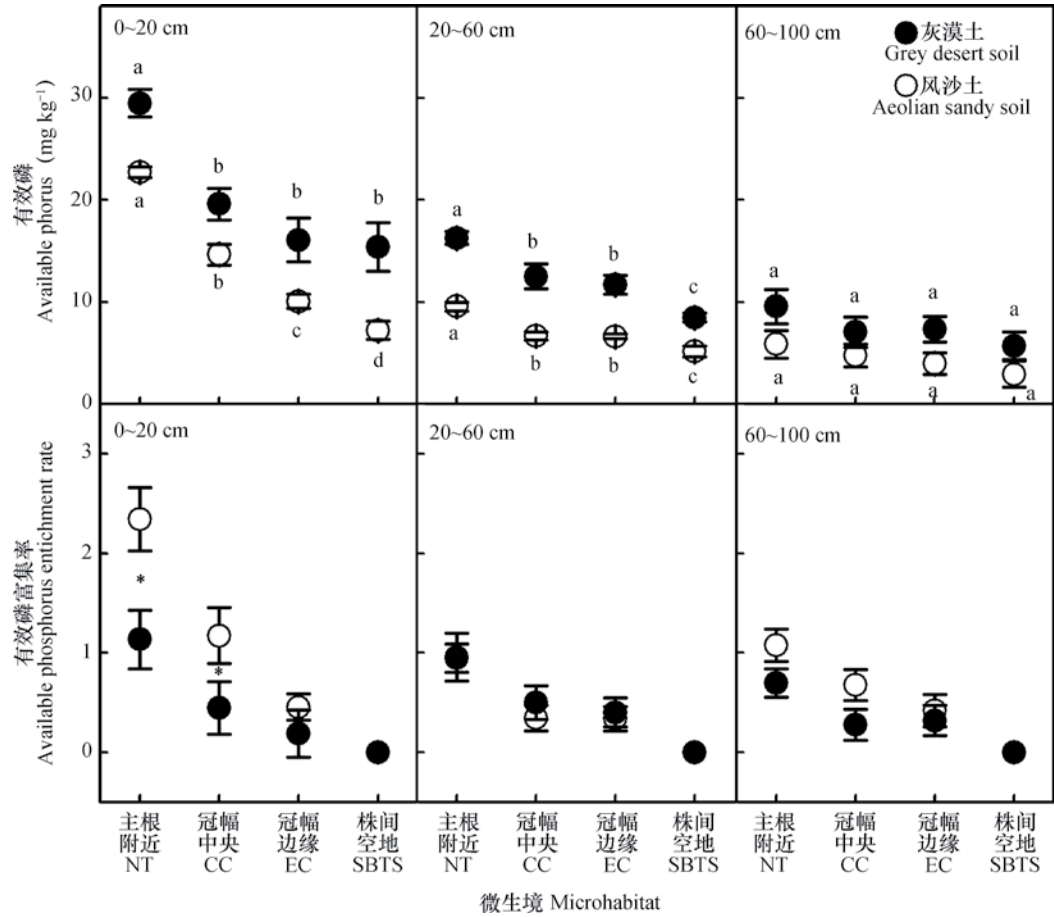


图5 从主根向外0 ~ 20 cm, 20 ~ 60 cm和60 ~ 100 cm土层中有效磷含量和富集率的空间变异

Fig. 5 Spatial variability and enrichment rate of soil available phosphorus content relative to distance from the taproot in the 0 ~ 20, 20 ~ 60, and 60 ~ 100 cm soil layers

表1 土壤养分各变量之间的相关系数矩阵

Table 1 Correlation matrix between soil nutrient variables

	灰漠土 Grey desert soil				风沙土 Aeolian sandy soil		
	有机质①	有效氮②	有效磷③		有机质①	有效氮②	有效磷③
有机质①	1			有机质①	1		
有效氮②	0.75**	1		有效氮②	0.94**	1	
有效磷③	0.82**	0.86**	1	有效磷③	0.89**	0.92**	1

注: **表示差异达显著性水平 $p < 0.01$ Note: ** represent significant difference at $p < 0.01$; ① Organic matter, ② Available nitrogen, ③ Available phosphorus

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Preliminary Studies on *Haloxylon Ammodendron* ‘Fertile Islands’ in Desert Soils Different in Texture

CAO Yanfeng^{1, 2} DING Junxiang² YU Yajun¹ HUANG Gang^{2†}

(1 College of Geographical Science, Shanxi Normal University, Linfen, Shanxi 041000, China)

(2 State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, China)

Abstract In arid and semi-arid ecosystems, shrubs often create patches of soil underneath spatially heterogenous in distribution of soil water and nutrients, which are called “fertile islands” or “resource islands”. Although the so-called “fertile island” is a phenomenon of spatial heterogeneity in distribution of soil water and nutrients at a plant scale, it may have some great impacts on vegetation distribution, productivity and evolution processes (like desertification) of the ecosystem. Therefore, the phenomenon of “fertile islands” has attracted more and more attention from more and more researchers. So far, researches have demonstrated that distribution pattern of the soil resources underneath shrub canopies was related to soil depth, plant species, plant development stage and spatial scales (e.g., rhizosphere, individual, population, geomorphology, and region). However, little has been reported on spatial pattern of soil resources relative to soil textured soil, especially in desert soils. This calls for further attention.

In this study, two different types of native habitats of *Haloxylon ammodendron* in the Junggar Basin were selected: the Gurbantonggut Desert and nearby oasis. *Haloxylon ammodendron* is a dominant species in arid regions of Central Asian, playing a key role in maintaining structure and functions of these desert ecosystems. Aeolian sandy soil and grey desert soil are the zonal soils of the two habitats and have developed under the same climatic conditions and experienced the same weather process, but are markedly different in mechanical composition even though they are only 8 km apart. Specifically, the aeolian sandy soil is of loamy fine sand soil, and the grey desert soil is silt loam soil. The former is 2.1 ~ 2.4 times as high as the latter in sand content, while the latter is 3.0 ~ 3.6 and 2.9 ~ 5.1 times as high as the former in silt and clay content, respectively. This provides an ideal environment for determining whether the effect of individual plants on spatial variability of soil properties under their canopies might be mediated by soil texture.

In each of the two native habitats, eight *Haloxylon ammodendron* plants similar in size (about 200 cm in plant height, about 10 cm in basal diameter and about 100 cm crown radius) were selected. For soil sampling, the soil under each plant was divided vertically into three soil layers, 0 ~ 20, 20 ~ 60, and 60 ~ 100 cm. Then in each soil layer, four sampling sites were set representing four micro-habitats, that is, near the taproot, in the center of the shrub canopy, at the edge of the canopy, and in the space between two shrubs, or at 5, 50, 100, and 200 cm away from the taproot, respectively. At each sampling site, soil samples were collected at four directions of the site, with an angle of 90° apart and then mixed into

one for analysis of soil properties, soil texture, water, organic carbon, available nitrogen, and available phosphorus with a laser particle analyzer, the oven-drying and weighing method, the $K_2Cr_2O_7-H_2SO_4$ oxidation method, the alkalysis diffusion method, and $NaHCO_3$ extraction-Mo-Sb colorimetric method.

Through comparative analysis of the soils under the canopies of *Haloxylon ammodendron* in the two habitats in spatial distribution of soil water and nutrients, attempts were made to characterize “fertile islands” in the two soils sharply different in texture. Results showed that (1) spatial heterogeneity of soil water and nutrients existed in both soils under the canopies of the shrubs, and weakened with soil depth; and (2) at the soil depth of 0 ~ 20 cm, the aeolian sandy soil was more obvious in spatial heterogeneity of the distribution of soil water and nutrients than the grey desert soil under the canopy of *Haloxylon ammodendron*, and higher in enrichment level of soil water and nutrients, too. The former was 4.6 ~ 12.3, 3.4 ~ 8.6, 3.0 ~ 4.9 and 2.1 ~ 2.6 times as high as the latter in enrichment rate of soil water, organic matter, available nitrogen and available phosphorus, respectively. All these findings indicated that the phenomenon of “fertile islands” caused by shrubs exists in both soils, and soil texture may determine intensity of the “fertile island” effect. Knowledge of the spatial variability pattern of plant resources at individual scale may help better understand spatial distribution pattern of the resources at the population, community, and ecosystem scales, as well as relationships between soils and plants. Further studies need to be done on such a phenomenon in different ecosystems.

Key words Desert soils; *Haloxylon ammodendron*; Fertile islands; Soil texture

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