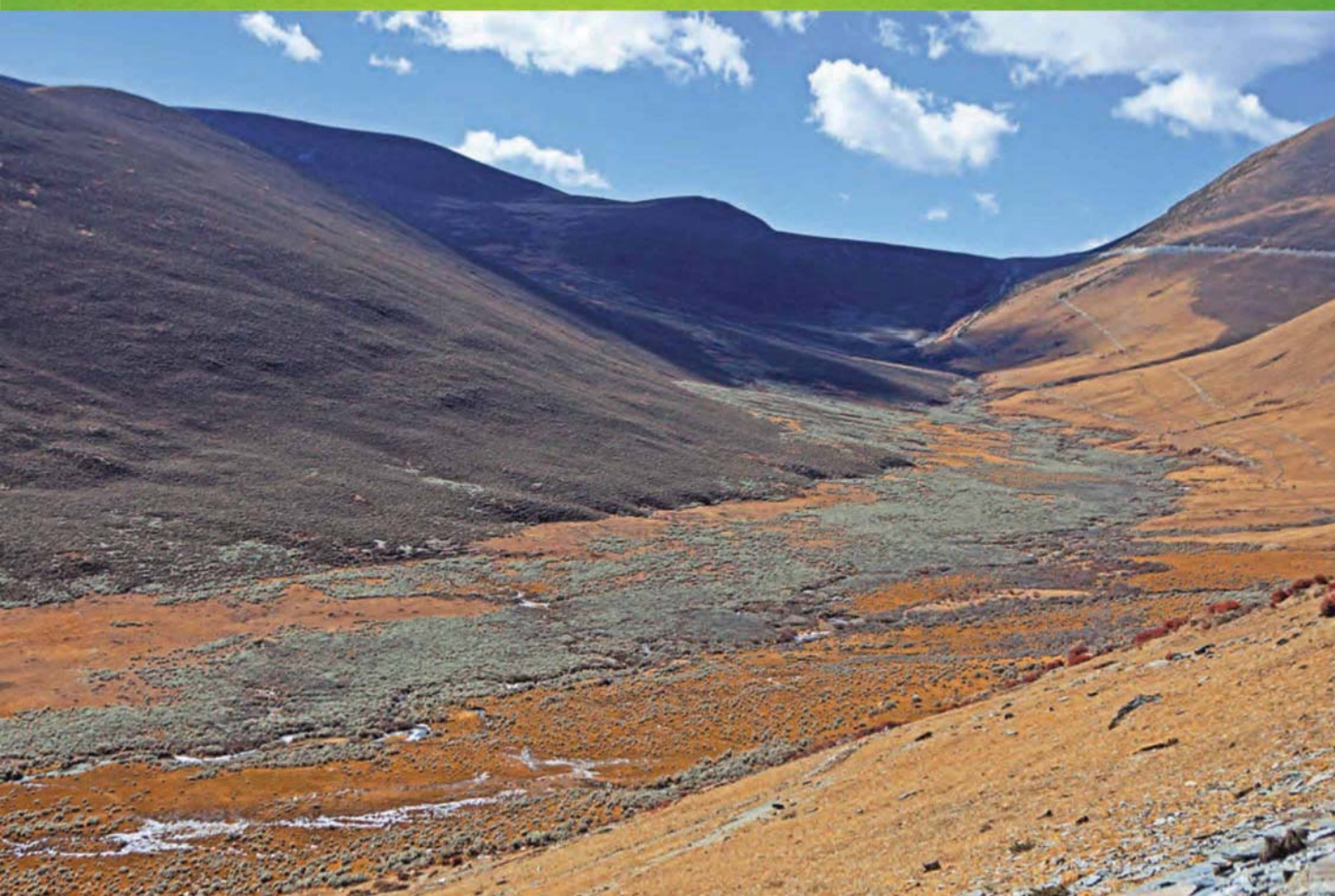


ISSN 1000-0933
CN 11-2031/Q

生态学报

Acta Ecologica Sinica

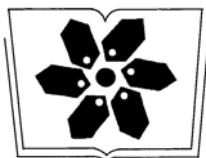
中国生态学会 2013 年学术年会专辑



第 33 卷 第 18 期 Vol.33 No.18 **2013**

中国生态学会
中国科学院生态环境研究中心
科学出版社

主办
出版



中国科学院科学出版基金资助出版

生态学报

(SHENGTAI XUEBAO)

第 33 卷 第 18 期

2013 年 9 月 (半月刊)

目 次

中国生态学会 2013 年学术年会专辑 卷首语

- 美国农业生态学发展综述 黄国勤, Patrick E. McCullough (5449)
- 水足迹研究进展 马 晶, 彭 建 (5458)
- 江西省主要作物(稻、棉、油)生态经济系统综合分析评价 孙卫民, 欧一智, 黄国勤 (5467)
- 植物干旱胁迫下水分代谢、碳饥饿与死亡机理 董 蕾, 李吉跃 (5477)
- 生态化学计量学特征及其应用研究进展 曾冬萍, 蒋利玲, 曾从盛, 等 (5484)
- 三峡库区紫色土植被恢复过程的土壤团粒组成及分形特征 王轶浩, 耿养会, 黄仲华 (5493)
- 城市不同地表覆盖类型对土壤呼吸的影响 付芝红, 呼延佼奇, 李 锋, 等 (5500)
- 华南地区 3 种具有不同入侵性的近缘植物对低温胁迫的敏感性 王宇涛, 李春妹, 李韶山 (5509)
- 沙丘稀有种准噶尔无叶豆花部综合特征与传粉适应性 施 翔, 刘会良, 张道远, 等 (5516)
- 水浮莲对水稻竞争效应、产量与土壤养分的影响 申时才, 徐高峰, 张付斗, 等 (5523)
- 珍稀药用植物白及光合与蒸腾生理生态及抗旱特性 吴明开, 刘 海, 沈志君, 等 (5531)
- 不同温度及二氧化碳浓度下培养的龙须菜光合生理特性对阳光紫外辐射的响应 杨雨玲, 李 伟, 陈伟洲, 等 (5538)
- 土壤氧气可获得性对双季稻田温室气体排放通量的影响 秦晓波, 李玉娥, 万运帆, 等 (5546)
- 免耕稻田氮肥运筹对土壤 NH_3 挥发及氮肥利用率的影响 马玉华, 刘 兵, 张枝盛, 等 (5556)
- 香梨两种树形净光合速率特征及影响因素 孙桂丽, 徐 敏, 李 疆, 等 (5565)
- 沙埋对沙米幼苗生长、存活及光合蒸腾特性的影响 赵哈林, 曲 浩, 周瑞莲, 等 (5574)
- 半干旱区旱地春小麦全膜覆土穴播对土壤水热效应及产量的影响 王红丽, 宋尚有, 张绪成, 等 (5580)
- 基于 Le Bissonnais 法的石漠化区桑树地埂土壤团聚体稳定性研究 汪三树, 黄先智, 史东梅, 等 (5589)
- 不同施肥对雷竹林径流及渗漏水中氮形态流失的影响 陈裴裴, 吴家森, 郑小龙, 等 (5599)
- 黄土丘陵区不同植被土壤氮素转化微生物生理群特征及差异 邢肖毅, 黄懿梅, 安韶山, 等 (5608)
- 黄土丘陵区植被类型对土壤微生物量碳氮磷的影响 赵 彤, 闫 浩, 蒋跃利, 等 (5615)
- 林地覆盖对雷竹林土壤微生物特征及其与土壤养分制约性关系的影响 郭子武, 俞文仙, 陈双林, 等 (5623)
- 降雨对草地土壤呼吸季节变异性的影响 王 旭, 闫玉春, 闫瑞瑞, 等 (5631)
- 基于土芯法的亚热带常绿阔叶林细根空间变异与取样数量估计 黄超超, 黄锦学, 熊德成, 等 (5636)
- 4 种高大树木的叶片性状及 WUE 随树高的变化 何春霞, 李吉跃, 孟 平, 等 (5644)
- 干旱荒漠区银白杨树干液流动态 张 俊, 李晓飞, 李建贵, 等 (5655)
- 模拟增温和不同凋落物基质质量对凋落物分解速率的影响 刘瑞鹏, 毛子军, 李兴欢, 等 (5661)
- 金沙江干热河谷植物叶片元素含量在地表凋落物周转中的作用 闫帮国, 纪中华, 何光熊, 等 (5668)
- 温带 12 个树种新老树枝非结构性碳水化合物浓度比较 张海燕, 王传宽, 王兴昌 (5675)
- 断根结合生长素和钾肥施用对烤烟生长及糖碱比、有机钾指数的影响 吴彦辉, 薛立新, 许自成, 等 (5686)
- 光周期和高脂食物对雌性高山姬鼠能量代谢和产热的影响 高文荣, 朱万龙, 孟丽华, 等 (5696)
- 绿原酸对凡纳滨对虾抗氧化系统及抗低盐度胁迫的影响 王 芸, 李 正, 李 健, 等 (5704)

基于盐分梯度的荒漠植物多样性与群落、种间联接响应	张雪妮,吕光辉,杨晓东,等 (5714)
广西马山岩溶植被年龄序列的群落特征.....	温远光,雷丽群,朱宏光,等 (5723)
戴云山黄山松群落与环境的关联.....	刘金福,朱德煌,兰思仁,等 (5731)
四川盆地亚热带常绿阔叶林不同物候期凋落物分解与土壤动物群落结构的关系.....	王文君,杨万勤,谭 波,等 (5737)
中亚热带常绿阔叶林不同演替阶段土壤活性有机碳含量及季节动态.....	范跃新,杨玉盛,杨智杰,等 (5751)
塔克拉玛干沙漠腹地人工植被及土壤 C N P 的化学计量特征	李从娟,雷加强,徐新文,等 (5760)
鄱阳湖小天鹅越冬种群数量与行为学特征.....	戴年华,邵明勤,蒋丽红,等 (5768)
营养盐加富和鱼类添加对浮游植物群落演替和多样性的影响.....	陈 纯,李思嘉,肖利娟,等 (5777)
西藏达则错盐湖沉积背景与有机沉积结构.....	刘沙沙,贾沁贤,刘喜方,等 (5785)
西藏草地多项供给及调节服务相互作用的时空演变规律.....	潘 影,徐增让,余成群,等 (5794)
太湖水体溶解性氨基酸的空间分布特征.....	姚 昕,朱广伟,高 光,等 (5802)
基于遥感和 GIS 的巢湖流域生态功能分区研究.....	王传辉,吴 立,王心源,等 (5808)
近 20 年来东北三省春玉米物候期变化趋势及其对温度的时空响应	李正国,杨 鹏,唐华俊,等 (5818)
鄱阳湖湿地景观恢复的物种选择及其对环境因子的响应.....	谢冬明,金国花,周杨明,等 (5828)
珠三角河网浮游植物生物量的时空特征.....	王 超,李新辉,赖子尼,等 (5835)
南京市景观时空动态变化及其驱动力	贾宝全,王 成,邱尔发 (5848)
川西亚高山-高山土壤表层有机碳及活性组分沿海拔梯度的变化	秦纪洪 王 琴 孙 辉 (5858)
城市森林碳汇及其抵消能源碳排放效果——以广州为例.....	周 健,肖荣波,庄长伟,等 (5865)
基于机器学习模型的沙漠腹地地下水含盐量变化过程及模拟研究.....	范敬龙,刘海龙,雷加强,等 (5874)
干旱区典型绿洲城市发展与水资源潜力协调度分析	夏富强,唐 宏,杨德刚,等 (5883)
海岸带区域综合承载力评估指标体系的构建与应用——以南通市为例.....	魏 超,叶属峰,过仲阳,等 (5893)
中街山列岛海洋保护区鱼类物种多样性	梁 君,徐汉祥,王伟定 (5905)
丰水期长江感潮河口段网采浮游植物的分布与长期变化.....	江志兵,刘晶晶,李宏亮,等 (5917)
基于生态网络的城市代谢结构模拟研究——以大连市为例.....	刘耕源,杨志峰,陈 彬,等 (5926)
保护区及周边居民对野猪容忍性的影响因素——以黑龙江凤凰山国家级自然保护区为例.....	徐 飞,蔡体久,琚存勇,等 (5935)
三江源牧户参与草地生态保护的意愿.....	李惠梅,张安录,王 珊,等 (5943)
沈阳市降雨径流初期冲刷效应.....	李春林,刘 淼,胡远满,等 (5952)
期刊基本参数:CN 11-2031/Q * 1981 * m * 16 * 514 * zh * P * ¥ 90.00 * 1510 * 59 * 2013-09	



封面图说: 川西高山地带土壤及植被——青藏高原东缘川西的高山地带坡面上为草地,沟谷地带由于低平且水分较充足,生长有很多灌丛。川西地区大约在海拔 4000m 左右为林线,以下则分布有亚高山森林。亚高山森林是以冷、云杉属为建群种或优势种的暗针叶林为主体的森林植被。作为高海拔低温生态系统,高山-亚高山地带土壤碳被认为是我国重要的土壤碳库。有研究表明,易氧化有机碳含量与海拔高度呈显著正相关,显示高海拔有利于土壤碳的固存。因而,这里的表层土壤总有机碳含量随着海拔的升高而增加。

彩图及图说提供: 陈建伟教授 北京林业大学 E-mail: cites.chenjw@163.com

DOI: 10.5846/stxb201304170727

邢肖毅, 黄懿梅, 安韶山, 闫浩. 黄土丘陵区不同植被土壤氮素转化微生物生理群特征及差异. 生态学报, 2013, 33(18): 5608-5614

Xing X Y, Huang Y M, An S S, Yan H. Characteristics of physiological groups of soil nitrogen-transforming microbes in different vegetation types in the Loess Gully region, China. Acta Ecologica Sinica, 2013, 33(18): 5608-5614.

黄土丘陵区不同植被土壤氮素转化 微生物生理群特征及差异

邢肖毅¹, 黄懿梅^{1,*}, 安韶山^{1,2}, 闫浩¹

(1. 西北农林科技大学资源环境学院 农业部西北植物营养与农业环境重点实验室, 杨凌 712100;

2. 西北农林科技大学水土保持研究所 黄土高原土壤侵蚀与旱地农业国家重点实验室, 杨凌 712100)

摘要:采用最大或然计数法(most probable number, MPN)对黄土高原洞子沟流域不同植被恢复阶段土壤氮素微生物生理群(氨化细菌、亚硝化细菌、反硝化细菌)数量分布特征进行了测定,结果表明:1)土壤氨化细菌、亚硝化细菌和反硝化细菌数量随植被恢复而增加,三者最大值分别为最小值的 74、4 和 31 倍,其中氨化细菌和反硝化细菌的数量在铁杆蒿群落最低,辽东栎群落最高,亚硝化细菌数量在丁香群落最低,辽东栎群落最高;2)植被恢复对各氮素生理群影响不同,对氨化细菌影响最大,其次分别为反硝化细菌和亚硝化细菌;3)各氮素生理群数量差异较大,氨化细菌>反硝化细菌>亚硝化细菌。研究区氨化细菌占总数的 75%—80%,反硝化细菌占 20%—25%时,生态系统最为稳定;4)土壤理化性质与各功能菌关系紧密,其中,土壤容重和硝态氮含量与微生物数量相关性最大,全钾、矿化氮和微生物量氮也表现出很大的相关性。

关键词:黄土沟壑区;植物群落;氨化细菌;亚硝化细菌;反硝化细菌

Characteristics of physiological groups of soil nitrogen-transforming microbes in different vegetation types in the Loess Gully region, China

XING Xiaoyi¹, HUANG Yimei^{1,*}, AN Shaoshan^{1,2}, YAN Hao¹

1 Key Laboratory of Plant Nutrition and the Agri-environment in Northwest China, Ministry of Agriculture College of Resource and Environment Science, Northwest A&F University, Yanglin, Shanxi, 712100, China

2 State Key Laboratory of Soil Erosion and Dryland Agriculture of Loess Plateau Institute of Soil and Water Conservation, Northwest A&F University, Yanglin, Shanxi, 712100, China

Abstract: The “Grain for Green” project is one of the important measures used to improve the environment of China’s Loess Plateau. In recent years, soil physicochemical properties in the region have been improved, which in turn promoted ecological succession. Different vegetation types change the soil environment to different extents, influencing the biogeochemical cycling of materials such as nitrogen, an essential nutrient for plants. Recently, a growing amount of attention has been paid to the relationship between vegetation and nitrogen cycling in natural ecological systems. Meanwhile, several physiological groups of nitrogen-transforming microbes in soil are closely associated with soil nitrogen cycling. To determine the effect of vegetation restoration (grass stage, shrub-grass stage and tree-brush-grass stage) on the populations and distribution of physiological groups of nitrogen-transforming microbes (ammonifying bacteria, nitrifying bacteria and denitrobacteria), soil samples were collected from depths of 0—10 cm under seven vegetation types from different stages of restoration in the Dongzigou Basin, Ansai, Shaanxi Province and bacteria populations were measured through the most-probable-number (MPN) method. The results show the populations of ammonifying bacteria, nitrifying bacteria, and denitrobacteria increased as vegetative succession proceeded from grass communities to more complex tree-shrub-grass

基金项目:国家自然科学基金资助项目(41101254, 41030532);西北农林科技大学基本科研费项目(QN2011020);新世纪优秀人才支持计划(NCET-12-0473)资助

收稿日期:2013-04-17; **修订日期:**2013-07-10

* 通讯作者 Corresponding author. E-mail: ymhuang1971@nwsuaf.edu.cn

communities, and those populations ranged from 2.49 to 185.79×10^6 cfu/gdm, 19.43 to 77.21×10^2 cfu·g⁻¹·dm⁻¹ and 1.23 to 38.24×10^6 cfu·g⁻¹·dm⁻¹, respectively. For ammonifying bacteria and denitrobacteria, the highest N levels were obtained in the *Quercus liaotungensis* Koidz. community and the lowest in the *Artemisia sacrorum* Ledeb. community. The maximum population levels of denitrobacteria and ammonifying bacteria were obtained in the *Q. liaotungensis* Koidz. community and these ranged between 31 to 74 times higher than the lowest levels which were seen in the *Artemisia sacrorum* Ledeb. community, respectively. The highest levels of nitrifying bacteria were obtained in the *Q. liaotungensis* community and these were 4-fold higher than the lowest one in the *Syzygium aromaticum* (L.) Merr. and Perry community. The effect of vegetation restoration on the population of nitrobacteria was the strongest on ammonifying bacteria, followed by denitrobacteria and nitrifying bacteria. Soil nitrogen bacteria groups varied sharply from group to group, forming a decreasing order of ammonifying bacteria > denitrobacteria > nitrify bacteria. In study area, ammonifying bacteria accounted for about 75%—80% of the sum of ammonifying bacteria, nitrifying bacteria and denitrobacteria, while when denitrobacteria accounted for 20%—25% of that sum; this indicates that the ecosystem was relatively stable. Soil physicochemical properties were closely related to soil nitrogen content and the abundance of nitrogen bacteria groups. Soil bulk density had a larger impact on soil nitrogen bacteria groups than other soil physicochemical properties, similar to the relationship of nitrate nitrogen in soil and various forms of nitrogen in soil. Total potassium, mineralizable nitrogen and microbial biomass nitrogen content also had a major impact on soil nitrogen bacteria groups. In general, microbes are more responsive to changes in plant communities than are soil physical and chemical properties. Studying the characteristics of microbial communities, especially functional microbes that modify the availability of key soil nutrients, e.g. nitrogen, provides significant data which are useful in estimating the ecological benefits of restoring vegetative communities. Therefore, more detailed research studies in this field are needed in the future.

Key Words: Loess Gully; vegetation types; ammonifying bacteria; nitrify bacteria; denitrobacteria

黄土高原是我国水土流失最严重地区的典型代表,退耕还林还草是解决该区水土流失问题的必然选择。随着退耕还林还草工作的开展,土壤质量逐渐改善^[1],退耕区及周边的整个生态环境质量得以改善^[2]。目前,很多学者对植被恢复效果进行了评价,其研究主要集中于土壤理化性质及土壤养分方面^[1,3],而从土壤微生物群落角度探讨的研究较少^[4-6],氮素微生物生理群则更为鲜见。土壤微生物是土壤中有生命的成分,对土壤各种变化极为敏感,能充分反映土地利用方式和生态功能的变化^[7],对维持生态系统氮循环极其重要^[8]。土壤氮素转化生理群包括氨化细菌、硝化细菌、自生固氮菌和反硝化细菌,其数量和活性可以反映所处生境氮素物质的水平及转化规律,关系到土壤生态系统的维持和稳定^[9]。目前,对氮素生理群微生物的研究多见于农地和草地,且重在探讨人为干扰^[10-13]对其产生的影响,对自然恢复条件下土壤的研究很少。探究不同植物群落下土壤氮素微生物生理群数量的变化规律,可以揭示黄土高原地区地下生理生态格局,对探明土壤氮素转化的微生物机制及植被恢复对土壤生态环境的改善效果具有重要意义。

1 材料与方法

1.1 野外土壤样品采集

1.1.1 研究区域概况

洞子沟地处安塞县南部楼坪乡, $109^{\circ}7'34''$ — $109^{\circ}10'34''$ E、 $36^{\circ}31'13''$ — $36^{\circ}35'26''$ N,海拔 1166—1490 m,流域总面积 20.61 km²。该区属于中温带大陆性半干旱季风气候,四季长短不等,干湿分明。年平均气温 8.8℃,年平均降水量 505.3 mm,年日照时数为 2395.6 h,日照百分率达 54%,总年无霜期 157 d。土壤类型以黄绵土为主,土地利用以林地为主。

1.1.2 供试土壤样地植被情况

供试土壤取自洞子沟流域不同恢复阶段(草本、灌草、乔灌草)的 7 种典型植被群落。根据各个样地主要建群种名称,样点依次记录为辽东栎(*Quercus liaotungensis*),三角槭(*Acer buergerianum* Miq),侧柏(*Platycladus orientalis*),丁香(*Syzygium aromaticum*),狼牙刺(*Sophora davidii*),茺蒿(*Artemisia giraldii* Pamp),铁杆蒿(*Artemisia sacrorum* Ledeb)。采样点地理信息和植被情况如表 1 所示。

1.1.3 样品采集方法

供试土壤采集于 2011 年 7 月,在选定区域内根据植被类型确定样方大小(乔木 10 m×10 m,灌木 5 m×5 m,草地 2 m×2 m),每个样地在野外设置 3 个重复,即设置 3 个样方,分别相隔约 100 m²。每个样方内以 S 形选取 5 个点,去除土壤上层枯落物,用

土钻采集 0—10 cm 土壤样品,将采集的土样混合,密封后带回实验室内,仔细除去其中可见植物残体及土壤动物,过 2 mm 筛,测定氮素微生物生理群数量。

表 1 采样点地理信息和植被情况
Table 1 Geographic information and vegetation summarize of the sampling sites

植被类型 Vegetation types	样地名称 Sample name	经度/(°) Longitude	纬度/(°) Latitude	海拔/m Altitude	坡向 Slope aspect	坡度/(°) Slope gradient	坡位 Slope position	群落名称 Vegetation community
乔灌木 Arbor-brush-grass	辽东栎	109.174E	36.555N	1259	阴坡	28	下	辽东栎+土庄绣线菊、丁香、多花胡枝子+披针苔草
	三角槭	109.153E	36.575N	1334	阴坡	21	中	三角槭+黄刺玫、黑栒子+披针苔草
	侧柏	109.163E	36.556N	1301	阳坡	30	下	侧柏+六道木、丁香+披针苔草
灌木 Brush-grass	丁香	109.162E	36.570N	1284	阳坡	35	中	丁香、虎榛子、黄刺玫+茺蒿、铁杆蒿
	狼牙刺	109.166E	36.574N	1346	阳坡	27	下	狼牙刺+白羊草、达乌里胡枝子
草本 Grass	茺蒿	109.158E	36.582N	1348	阴坡	25	中	茺蒿、铁杆蒿
	铁杆蒿	109.158E	36.582N	1351	阴坡	30	上	铁杆蒿

辽东栎 *Quercus liaotungensis*;三角槭 *Acer buergerianum* Miq; 侧柏 *Platycladus orientalis*; 丁香 *Syzygium aromaticum*; 狼牙刺 *Sophora davidii*; 茺蒿 *Artemisia giraldii* Pamp; 铁杆蒿 *Artemisia sacrorum* Ledeb

1.2 测定指标及其方法

1.2.1 氮素微生物生理群数量的测定

土壤氨化细菌、亚硝化细菌、反硝化细菌数量采用最大或然计数法(MPN)进行测定。氨化细菌采用蛋白胨琼脂培养基,亚硝化细菌采用改良的斯蒂芬逊培养基,反硝化细菌采用组合培养基,以稀释法测定其数量^[14]。MPN 方法在测定细菌数量时虽不够精确^[15],但所有样品同一步骤测定,结果仍具有一定的可比性。

1.2.2 土壤基本理化性质及各形态氮素含量的测定

土壤理化性质及各形态氮素含量均采用常规方法,见《土壤农化分析》^[16]。

1.3 数据处理方法

试验数据处理采用 Microsoft Excel 2003 和 SPSS18.0 软件。多重比较采用 LSD 方法,相关分析采用 Pearson 相关分析法。

2 结果与分析

2.1 土壤基本理化性质及氮素含量

研究区土壤呈弱碱性,从草本群落到乔灌木群落,土壤 pH 值和容重均逐渐降低,最大值分别比最小值高出了 7.7% 和 42.3%。土壤有机质、全氮、全磷、硝态氮、铵态氮、可矿化氮(好气培养 14d)、微生物量氮含量随着植被的恢复逐渐增加,最大值分别是最小值的 11.1、9.20、1.31、27.9、2.35、8.70 和 6.46 倍,硝态氮在含量不同植被群落下变异最大,即对植被变化最为敏感。土壤 C/N 介于 8.56—15.9 之间,变化呈现波动性。全钾含量较稳定,最大值和最小值相差仅 2.64 g/kg。

表 2 不同植被群落下土壤基本理化性质及氮素含量
Table 2 Soil physicochemical properties and nitrogen contents under different vegetation types

植被类型 Vegetation types	土壤 pH Soil pH	容重 BD /(g/cm ³)	有机质 SOM /(g/kg)	全氮 Total N /(g/kg)	土壤 C/N Soil C/N	全磷 Total P /(g/kg)	全钾 Total K /(g/kg)	硝态氮 Nitrate N /(mg/kg)	铵态氮 Ammonium N /(mg/kg)	可矿化氮 Available N /(mg/kg)	微生物量氮 MBN /(mg/kg)
辽东栎	8.18f	0.78b	71.5a	3.22a	12.9b	0.75a	21.1a	53.2a	2.89b	101a	129a
侧柏	8.34e	0.83b	59.5b	2.81b	12.3b	0.72a	19.5ab	49.3a	3.17a	70.1b	1046a
三角槭	8.48d	1.01a	54.5b	2.69b	11.8b	0.76a	19.8ab	21.0b	2.66b	65.9b	64.81b
丁香	8.64c	1.05a	31.19c	1.22c	14.8a	0.71a	18.6b	10.6c	2.42b	36.2c	42.2c
狼牙刺	8.81a	1.14a	11.1de	0.66d	9.72c	0.62b	18.9b	8.05d	2.56b	19.6e	41.8c
茺蒿	8.70b	1.07a	18.4d	0.85d	12.6b	0.61b	19.4ab	11.0c	1.93c	27.4d	37.4c
铁杆蒿	8.76b	1.11a	6.46e	0.35e	14.5a	0.58b	18.5b	1.91e	1.35d	11.6e	20.0d

BD: 容重 Bulk density; SOM: 有机质 Soil organic matter; MBN: 微生物生物量氮 Microbial biomass nitrogen; 不同字母表示同一土层总氮在不同植被群落下差异显著($P < 0.05$)

2.2 土壤氮素转化微生物生理群

从草本群落到乔灌木群落,3 种氮素微生物生理群数量均增加。氨化细菌和反硝化细菌数量均表现为辽东栎群落最大,铁

杆蒿群落最小。氨化细菌最大值是最小值的 74.6 倍,反硝化细菌为 31.1 倍。亚硝化细菌最大值和最小值分别为辽东栎群落和丁香群落,相差 2.97 倍。可见,氨化细菌对植被变化最为敏感,反硝化细菌次之,亚硝化细菌最不敏感。3 种微生物数量差异很大,氨化细菌最多,平均占总数的 83%,其次是反硝化细菌,占 17%,亚硝化细菌最少。同一植被类型内各类微生物占总数的比例不同。两种草本群落相比,3 种微生物所占比例变化较大,以氨化细菌为例,茭蒿群落为 90.9%,而铁杆蒿群落仅为 66.8%,亚硝化细菌和反硝化细菌变化更大。灌草群落氨化细菌比例明显增加,反硝化细菌明显减小,两个样地间差别不大。乔灌草群落 3 个样地相比,各微生物占总数的比例差异最小,其中,氨化细菌所占比例较灌草群落有所下降,而反硝化细菌有所增加。

表 3 不同植被类型下土壤微生物氮素生理群数量

Table 3 Soil nitrogen bacteria group communities under different vegetation types

植被类型 Vegetation types	氨化细菌($\times 10^6$) Ammonifying bacteria /(cfu·g ⁻¹ ·dm ⁻¹)	占总数百分比 Percentage of total/%	亚硝化细菌($\times 10^2$) Nitrify bacteria /(cfu·g ⁻¹ ·dm ⁻¹)	占总数百分比 Percentage of total/%	反硝化细菌($\times 10^6$) Denitrobacteria /(cfu·g ⁻¹ ·dm ⁻¹)	占总数百分比 Percentage of total/%
辽东栎	186a	82.9	77.2a	0.0034	38.2a	17.1
三角槭	137b	80.7	57.3b	0.0034	32.8a	19.3
侧柏	74.0c	73.8	50.2c	0.0050	26.3b	26.3
丁香	55.3bc	97.1	19.4d	0.0034	1.66d	2.92
狼牙刺	48.8bc	95.2	24.5d	0.0048	2.44c	4.76
茭蒿	27.0c	90.9	24.4d	0.0082	2.69c	9.08
铁杆蒿	2.49d	66.8	25.1d	0.0671	1.23d	33.0

2.3 氮素微生物生理群数量与理化因子及氮素含量的相关分析

土壤理化性质、土壤氮素及氮素微生物生理群之间密切相关。氨化细菌、亚硝化细菌和反硝化细菌与土壤 pH 值及土壤容重显著或极显著负相关,与土壤有机质、全氮、全磷、全钾、硝态氮、可矿化氮及微生物量氮含量显著或极显著正相关,与 C/N 不相关。对于铵态氮,仅氨化细菌与其显著正相关,亚硝化细菌和反硝化细菌与之不相关(表 4)。

表 4 氮素微生物数量与理化因子及氮素含量简单相关分析

Table 4 Correlation coefficients of nitrogen bacteria groups and physicochemical properties and N contents

相关系数 Correlation coefficients	氨化细菌 Ammonifying bacteria	亚硝化细菌 Nitrify bacteria	反硝化细菌 Denitrobacteria
土壤 pH Soil pH	-0.82 *	-0.92 **	-0.77 *
容重 BD	-0.90 **	-0.92 **	-0.83 *
有机质 SOM	0.77 *	0.88 **	0.76 *
全氮 Total N	0.80 *	0.90 **	0.81 *
土壤 C/N Soil C/N	-0.26	-0.09	-0.26
全磷 Total P	0.74 *	0.72 *	0.74 *
全钾 Total K	0.83 *	0.91 **	0.80 *
硝态氮 Nitrate N	0.89 **	0.92 **	0.82 *
铵态氮 Ammonium N	0.79 *	0.67	0.69
可矿化氮 Available N	0.84 **	0.93 **	0.80 *
微生物量氮 MBN (SMN)	0.87 **	0.92 **	0.77 *

* * $P<0.01$, * $P<0.05$; BD: 容重 Bulk density; SOM: 有机质 Soil organic matter; MBN: 微生物生物量氮 Microbial biomass nitrogen

3 讨论

3.1 植被恢复对土壤理化性质及氮素含量的影响

黄土丘陵区自 20 世纪 90 年代施行退耕还林还草以来,随着植被恢复的进行,植被覆盖度逐渐增加,土壤质量逐渐改善^[17],氮素含量增加^[18]。主要原因有以下几点:一是植物生长过程中通过凋落物和分泌物向土壤中返还大量无机营养元素^[1,3];二是植物通过凋落物覆盖和根系的生长减少土壤侵蚀和水分蒸发;三是植物根系的生长穿插改善了土壤的通气状况,四是植物残体腐解过程中产生的酸类物质促进土壤中难溶物质向有效态转化^[19]。研究者们普遍发现,不同形态氮素对植被恢复的敏感性不同,一般认为,速效氮较全氮敏感^[1,3]。采样季节研究区域降雨较多,虽氨化作用强烈^[19],但铵态氮一方面易于转化为硝态氮,另一方面,易于被微生物摄取^[20],最终导致硝态氮含量升高较多,而铵态氮升高较少。

3.2 植被恢复对土壤氮素转化微生物生理群数量的影响

如上所述,黄土丘陵区植被恢复促进了土壤质量的提高,一方面,植物返还的营养物质为微生物提供了能源物质^[1,3],另一方面,土壤质地和通气状况的改善为微生物创造了较为有利的生长繁殖环境^[21],因此,氨化细菌和硝化细菌数量增加^[22],而硝化作用为反硝化作用提供了反应物硝态氮,有利于反硝化作用的进行,反硝化细菌数量增加^[23]。因此,3种微生物数量随着植被恢复逐渐增加,与前人的研究相符^[24]。黄土高原森林区植被的演替序列为草本群落-灌草群落-乔灌草群落^[25],随着演替的进行,生态系统稳定性提高^[2]。草本阶段微生物种群易于变化。灌草阶段,由于土壤中有机物质增多,土壤理化性质改善,氨化细菌数量增加,反硝化细菌数量较少。顶级乔灌草群落,林内郁闭度较高,光照不充足,土壤含水量升高,氨化细菌比例降低,占总数的75%—80%,反硝化细菌比例增加,占20%—25%。此时,生态系统最为稳定。

植被恢复对不同微生物的影响不同,对氨化细菌的影响最大,其次是反硝化细菌,亚硝化细菌最小。姚拓等发现扰动对草地硝化细菌的影响最大,反硝化细菌和氨化细菌次之^[26]。这说明土壤的退化和恢复的微生物机制不同,可以推测,退化首先表现为硝化细菌的减少,而恢复则是首先是氨化细菌的增加。然而,由于土壤微生物各生理群的分布数量等受多种因素的影响,例如土壤环境、植被状况、气候特点等^[27-28],因此上述推测还需进一步论证。研究区域3种氮素微生物生理群的数量差异较大,表现为氨化细菌和反硝化细菌较多,而亚硝化细菌数量较少,与前人的研究结果一致^[10,12]。这是因为植物将大量有机物返还给土壤,为氨化作用提供了丰富的基质,促进了氨化细菌的生长繁殖,而土壤中大量的易溶性有机物(根系分泌物、凋落物)消耗了氧气^[29],同时研究区域土壤呈碱性,为反硝化细菌提供了良好的环境条件^[30]。亚硝化细菌含量不高,一方面可能是因为植物根系分泌物中的酚类物质和有机酸会抑制硝化作用^[31]。另一方面,研究区域土壤属弱碱性,此时,硝化反应的第一步,即氨转化为亚硝酸的速度很快,而亚硝酸转化为硝酸的速度很慢^[32]。

研究区域土壤中铵态氮的累积量并不多,硝态氮的累积量却较大。这是因为铵态氮既参与后期的硝化作用,又易于被微生物吸收利用^[20],而硝态氮含量高可能有以下几方面的原因,一是土壤中硝态氮并不都是通过铵态氮的进一步硝化而产生的,土壤中存在将有机氮直接转化为亚硝态氮的异养型微生物^[33-34]。二是土壤中硝态氮的累积量并不一定与硝化细菌的活动强度相一致^[35],刁治民发现高寒草地硝酸盐在夏季会出现积累现象^[36]。

3.3 植被恢复过程中影响氮素转化微生物生理群的关键因素

氮素微生物生理群与土壤基本理化性质和土壤氮素的相关分析表明,除C/N和铵态氮外,其他理化因子和氮素均与3种氮素微生物显著或极显著相关。这是由于植被恢复改善了土壤理化性质,增加了氮素含量,刺激了微生物的生长,因此微生物数量与理化指标、氮素表现出了很好的相关性,理化性质中以容重,氮素中以硝态氮对微生物数量影响最大,全钾、矿化氮和微生物量氮也有较大影响。3种微生物数量和容重均极显著负相关。研究区域土壤C/N较低,土壤氮素供给相对充足^[37],同时,温度、水分、土壤本身差异不大,因此,氧气含量就成了影响微生物数量的关键因素。氨化细菌和硝化细菌只有在好氧条件下才能发挥作用^[38],因此容重越小,土壤通气性相对越好,微生物数量相应增加。反硝化作用是在嫌气条件下进行的微生物过程,O₂留存不利于其生长。而反硝化细菌数量同样与容重负相关,说明较高的硝酸盐和易溶性有机物(根系分泌物、凋落物)对反硝化细菌的有利作用^[23]大于O₂的不利影响。王小纯等发现土壤中硝态氮的增加可以显著提高氨化细菌的活性^[39]。齐文娟也发现氮素是微生物的重要影响因子,与微生物数量正相关^[40]。而硝态氮是土壤中对植被恢复最为敏感的氮素,矿化氮、微生物量氮均属活性较大的有机氮组分,因此其均与3种氮素微生物正相关。有研究认为,土壤钾含量与微生物数量正相关^[40],其影响机制有待于深入研究。

4 结论

从草本群落到辽东栎群落,土壤质量得以改善,氮素含量逐渐增加,氨化细菌、亚硝化细菌和反硝化细菌数量增加,表现为乔灌草群落>灌草群落>草本群落。植被恢复对3种微生物的影响程度各不相同,对氨化细菌影响最大,反硝化细菌次之,亚硝化细菌最小。3种氮素微生物生理群的数量差异较大,氨化细菌>反硝化细菌>亚硝化细菌。当植被恢复至乔灌草相结合的较为稳定的阶段时,氨化细菌占总数的75%—80%,反硝化细菌占20%—25%左右。

容重、硝态氮和氮素微生物生理群数量关系最为密切,土壤通气性是影响微生物生长的重要因素,氮素微生物生理群的生长首先促进了植物有效氮含量的升高。另外,全钾、pH值、总氮、矿化氮和微生物量氮同样与氮功能微生物关系紧密。

References:

- [1] Peng W Y, Zhang K L, Chen Y, Yang Q K. Research on soil quality change after returning farmland to forest on the Loess sloping croplands. *Journal of Natural Resources*, 2005, 20(2): 272-278.
- [2] Jia X J, Chang Q R, Xue A L, Wei L, Wang D C. Ecological effects of returning farmland to forest land in the Loess Gully and Hilly region. *Bulletin of Soil and Water Conservation*, 2008, 28(3): 182-185.
- [3] Wen Z M, Jiao F, Hao X H, Jiao J Y. Spontaneous succession and its impact on soil nutrient on abandoned farmland in the northern edge of the forest zone on the Loess Plateau. *Acta Prataculturae Sinica*, 2007, 16(1): 16-23.

- [4] Cheng Y, An S S, Li G H, Li D H. Soil nutrient and microbial biomass in the Loess hilly area of Ningxia under different plant rehabilitation patterns. *Chinese Journal of Eco-Agriculture*, 2010, 18(2): 261-266.
- [5] Lv C H, Zheng F L. Evaluation of soil quality during vegetation restoration in the Ziwuling Area of Loess Plateau. *Science of Soil and Water Conservation*, 2009, 7(3): 12-18.
- [6] Cong H J, Cheng Y, An S S, Li D H. Changes of soil nutrient and soil microbial biomass C, N and P in different plant rehabilitation on the Loess Hilly area of Ningxia. *Journal of Soil and Water Conservation*, 2010, 24(4): 217-221.
- [7] Lundquist E J, Jackson L K, Scow K M, Hsu C. Changes in microbial biomass and community composition, and soil carbon and nitrogen pools after incorporation of rye into three California agricultural soils. *Soil Biology and Biochemistry*, 1999, 31(2): 221-236.
- [8] Yergeau E, Kang S, He Z L, Zhou J Z, Kowalchuk G A. Functional microarray analysis of nitrogen and carbon cycling genes across an Antarctic latitudinal transect. *The ISME Journal*, 2007, 1(2): 163-179.
- [9] Prasad P, Basu S, Behera N. A comparative account of the microbiological characteristics of soils under natural forest, grassland and cropfield from Eastern India. *Plant and Soil*, 1995, 175(1): 85-91.
- [10] Zhao Y Y, Cai L Q, Wang J, Zhang R Z. Effects of different conservation tillage on amount and distribution of soil ammonifying bacteria, nitrobacteria and nitrogen-fixing bacteria. *Acta Prataculturae Sinica*, 2009, 18(4): 125-130.
- [11] Ndayegamiye A, Côté D. Effect of long-term pig slurry and solid cattle manure application on soil chemical and biological properties. *Canadian Journal of Soil Science*, 1989, 69(1): 39-47.
- [12] Gao X F, Han G D. Study on effect of grazing on steeper soil nitrogen cycle. *Soil*, 2011, 43(2): 161-166.
- [13] Patra A K, Abbadie L, Clays-Josserand A, Degrange V, Grayston S J, Guillaumaud N, Loiseau P, Louault F, Mahmood S, Nazaret S, Philippot L, Poly F, Prosser J I, Le Roux X. Effects of management regime and plant species on the enzyme activity and genetic structure of N-fixing, denitrifying and nitrifying bacterial communities in grassland soils. *Environmental Microbiology*, 2006, 8(6): 1005-1016.
- [14] Xu G H, Zheng H Y. *Manual on Analysis Method of Soil Microbiology*. Beijing: Agriculture Press, 1986.
- [15] Davidson E A, Strand M K, Galloway L F. Evaluation of the most probable number method for enumerating denitrifying bacteria. *Soil Science Society of America Journal*, 1985, 49(3): 642-645.
- [16] Bao S D. *Agricultural Soil Analysis*. 3rd ed. Beijing: China Agriculture Press, 2007.
- [17] Ma Y H, Guo S L, Yang Y L, Wang X L, Yang G. Influence of vegetation types on soil organic C at Yangou Catchment in the Loess Hilly-gully region. *Journal of Natural Resources*, 2007, 22(1): 97-106.
- [18] Zhang X P, Yang G H, Ren G X, Feng Y Z. Effects of vegetation restoration on soil physical-chemical properties and activities of soil enzyme in the gully region of the Loess Plateau. *Agricultural Research in the Arid Areas*, 2010, 28(6): 64-68.
- [19] Maithani K, Arunachalam A, Tripathi R S, Pandey H N. Nitrogen mineralization as influenced by climate, soil and vegetation in a subtropical humid forest in northeast India. *Forest Ecology and Management*, 1998, 109(1/3): 91-101.
- [20] Jackson L E, Schimel J P, Firestone M K. Short-term partitioning of ammonium and nitrate between plants and microbes in an annual grassland. *Soil Biology and Biochemistry*, 1989, 21(3): 409-415.
- [21] Guo Y J, Han J G. Effects on soil enzyme activities of returning cultivated land to artificial grassland in an agro-pastoral transitional zone of north China. *Acta Prataculturae Sinica*, 2008, 17(5): 23-29.
- [22] Rutigliano F A, Castaldi S, D'Ascoli R, Papa S, Carfora A, Marzaioli R, Fioretto A. Soil activities related to nitrogen cycle under three plant cover types in Mediterranean environment. *Applied Soil Ecology*, 2009, 43(1): 40-46.
- [23] Liu Y, Chen J S, Liu Q, Wu Y. Nitrification and denitrification in subalpine coniferous forests of different restoration stages in western Sichuan, China. *Journal of Plant Ecology*, 2006, 30(1): 90-96.
- [24] Wei Y, Zhang J C, Yu Y C, Yu L F. Amount changes of soil microbial physiological group in different restoration stage of degraded Karst vegetation in Huajiang of Guizhou Province. *Research of Agricultural Modernization*, 2010, 31(3): 356-359.
- [25] Zhu Z C. Recovering succession of vegetation in forest region of north Shaanxi Loess Plateau. *Journal of Northwest Forestry College*, 1993, 8(1): 87-94.
- [26] Yao T, Long R J, Shi S L, Zhang D G. Populations of soil nitrogen bacteria groups in alpine steppe of different disturbed habitats in Tianzhu. *Acta Pedologica Sinica*, 2007, 44(1): 122-129.
- [27] Zhang Q C, Wang G H, Fang B. Influence of fertilization treatment on nutrients uptake by rice and soil ecological characteristics of soil microorganism in paddy field. *Acta Pedologica Sinica*, 2005, 42(1): 16-121.
- [28] Zhang W J, Rui W Y, Tu C, Diab H G, Louws F J, Mueller J P, Creamer N, Bell M, Waggener M G, Hu S. Responses of soil microbial community structure and diversity to agricultural deintensification. *Pedosphere*, 2005, 15(4): 440-447.
- [29] Zhang S L, Cai G X, Wang X Z, Xu Y H, Zhu Z L, Freney J R. Losses of Urea-Nitrogen applied to maize grown on a calcareous Fluvo-Aquic soil in north China Plain. *Pedosphere*, 1992, 2(2): 171-178.
- [30] Rosswall T. Microbiological regulation of the biogeochemical nitrogen cycle. *Plant and Soil*, 1982, 67(1/3): 15-34.
- [31] Bremner J M, McCarty G W. Inhibition of nitrification in soil by alleochemicals derived plants and plant residues. *Soil Science Society of America*

- Journal, 1991, 8: 181-218.
- [32] Morrill L G, Dawson J E. Patterns observed for the oxidation of ammonium to nitrate by soil organisms. *Soil Science Society of America Journal*, 1967, 31(6): 757-760.
- [33] Adams J A. Nitrification and ammonification in acid forest litter and humus as affected by peptone and ammonium-N amendment. *Soil Biology and Biochemistry*, 1986, 18(1): 45-51.
- [34] Schimel J P, Firestone M K, Killham K S. Identification of heterotrophic nitrification in a Sierran forest soil. *Applied and Environmental Microbiology*, 1984, 48(4): 802-806.
- [35] Ding L L, Qi B, Shang Z H, Long R J, Chen X R, Xu C L, Zhou Q X. Dynamics of different soil microbial physiological groups and their relationship to soil conditions under sub-alpine grasslands vegetation in the eastern-Qilian mountain. *Acta Prataculturae Sinica*, 2007, 16(2): 9-18.
- [36] Diao Z M. Studies on soil nitrogen bacteria groups in alpine meadow. *Soils*, 1996, (1): 49-53.
- [37] Lin B, Liu Q, Wu Y, He H, Qiao Y K. Dynamics of litters in artificial restoration process of subalpine coniferous forest. *Chinese Journal of Applied Ecology*, 2004, 15(9): 1491-1496.
- [38] Deenik J. Nitrogen mineralization potential in important agricultural soils of Hawai'i. *Soil and Crop Management*, 2006, 15: 1-5.
- [39] Wang X C, Li G F, An S, Xiong S P, Ma X M. Effects of nitrogen forms on rhizosphere microorganisms and soil enzyme activity for nitrogen transform of wheat cultivar during elongation and grain filling stage. *Journal of Soil and Water Conservation*, 2010, 24(6): 204-207, 245.
- [40] Qi W J. Studies on Quantity Dynamics of Soil Microorganism and the Relation with Soil Nutrients of Alpine Meadow in the Headwater Area of Yellow River [D]. Lanzhou: Gansu Agricultural University, 2007.

参考文献:

- [1] 彭文英, 张科利, 陈瑶, 杨勤科. 黄土坡耕地退耕还林后土壤性质变化研究. *自然资源学报*, 2005, 20(2): 272-278.
- [2] 贾晓娟, 常庆瑞, 薛阿亮, 蔚霖, 王德彩. 黄土高原丘陵沟壑区退耕还林生态效应评价. *水土保持通报*, 2008, 28(3): 182-185.
- [3] 温仲明, 焦峰, 赫晓慧, 焦菊英. 黄土高原森林边缘区退耕地植被自然恢复及其对土壤养分变化的影响. *草业学报*, 2007, 16(1): 16-23.
- [4] 成毅, 安韶山, 李国辉, 李第红. 宁夏黄土丘陵区植被恢复对土壤养分和微生物生物量的影响. *中国生态农业学报*, 2010, 18(2): 261-266.
- [5] 吕春花, 郑粉莉. 黄土高原子午岭地区植被恢复过程中的土壤质量评价. *中国水土保持科学*, 2009, 7(3): 12-18.
- [6] 从怀军, 成毅, 安韶山, 李第红. 黄土丘陵区不同植被恢复措施对土壤养分和微生物量 C、N、P 的影响. *水土保持学报*, 2010, 24(4): 217-221.
- [10] 赵有翼, 蔡立群, 王静, 张仁陟. 不同保护性耕作措施对三种土壤微生物氮素类群数量及其分布的影响. *草业学报*, 2009, 18(4): 125-130.
- [12] 高雪峰, 韩国栋. 放牧对羊草草原土壤氮素循环的影响. *土壤*, 2011, 43(2): 161-166.
- [14] 许光辉, 郑洪元. 土壤微生物分析方法手册. 北京: 农业出版社, 1986.
- [16] 鲍士旦. 土壤农化分析 (第三版). 北京: 中国农业出版社, 2007.
- [17] 马玉红, 郭胜利, 杨雨林, 王小利, 杨光. 植被类型对黄土丘陵区流域土壤有机碳氮的影响. *自然资源学报*, 2007, 22(1): 97-106.
- [18] 张笑培, 杨改河, 任广鑫, 冯永忠. 黄土高原南部植被恢复对土壤理化性状与土壤酶活性的影响. *干旱地区农业研究*, 2010, 28(6): 64-68.
- [21] 郭彦军, 韩建国. 农牧交错带退耕还草对土壤酶活性的影响. *草业学报*, 2008, 17(5): 23-29.
- [23] 刘义, 陈劲松, 刘庆, 吴彦. 川西亚高山针叶林不同恢复阶段土壤的硝化和反硝化作用. *植物生态学报*, 2006, 30(1): 90-96.
- [24] 魏媛, 张金池, 俞元春, 喻理飞. 贵州花江退化喀斯特植被不同恢复阶段土壤微生物生理类群数量变化. *农业现代化研究*, 2010, 31(3): 356-359.
- [25] 朱志诚. 陕北黄土高原森林区植被恢复演替. *西北林学院学报*, 1993, 8(1): 87-94.
- [26] 姚拓, 龙瑞军, 师尚礼, 张德罡. 高寒草地不同扰动生境土壤微生物氮素生理群数量特征研究. *土壤学报*, 2007, 44(1): 122-129.
- [27] 张奇春, 王光火, 方斌. 不同施肥处理对水稻养分吸收和稻田土壤微生物生态特性的影响. *土壤学报*, 2005, 42(1): 116-121.
- [35] 丁玲玲, 祁彪, 尚占环, 龙瑞军, 陈秀荣, 徐长林, 周启星. 东祁连山亚高山草地土壤微生物功能群数量动态及其与土壤环境关系. *草业学报*, 2007, 16(2): 9-18.
- [36] 刁治民. 高寒草地的微生物氮素生理群区系研究. *土壤*, 1996, (1): 49-53.
- [37] 林波, 刘庆, 吴彦, 何海, 乔永康. 亚高山针叶林人工恢复过程中凋落物动态分析. *应用生态学报*, 2004, 15(9): 1491-1496.
- [39] 王小纯, 李高飞, 安帅, 熊淑萍, 马新明. 氮素形态对中后期小麦根际土壤氮转化微生物及酶活性的影响. *水土保持学报*, 2010, 24(6): 204-207, 245.
- [40] 齐文娟. 黄河源区高寒草地土壤微生物数量动态及其与土壤养分关系研究 [D]. 兰州: 甘肃农业大学, 2007.

ACTA ECOLOGICA SINICA Vol.33 ,No.18 Sep. ,2013(Semimonthly)

CONTENTS

Development of agroecology in USA	HUANG Guoqin, McCullough Patrick E. (5449)
Research progress on water footprint	MA Jing, PENG Jian (5458)
Analysis and evaluation of the eco-economic systems of the main crops (rice, cotton and rapeseed) in Jiangxi Province, China	SUN Weimin, OU Yizhi, HUANG Guoqin (5467)
Relationship among drought, hydraulic metabolic, carbon starvation and vegetation mortality	DONG Lei, LI Jiyue (5477)
Reviews on the ecological stoichiometry characteristics and its applications	ZENG Dongping, JIANG Liling, ZENG Congsheng, et al (5484)
Composition and fractal features of purple soil aggregates during the vegetation restoration processes in the Three Gorges Reservoir Region	WANG Yihao, GENG Yanghui, HUANG Zhonghua (5493)
Impacts of different surface covers on soil respiration in urban areas	FU Zhihong, HUYAN Jiaoqi, LI Feng, et al (5500)
Chilling sensitivities of three closely related plants with different invasiveness in South China	WANG Yutao, LI Chunmei, LI Shaoshan (5509)
The flower syndrome and pollination adaptation of desert rare species <i>Eremosparton songoricum</i> (litv.) Vass.(Fabaceae)	SHI Xiang, LIU Huiliang, ZHANG Daoyuan, et al (5516)
Competitive effect of <i>Pistia stratiotes</i> to rice and its impacts on rice yield and soil nutrients	SHEN Shicai, XU Gaofeng, ZHANG Fudou, et al (5523)
Photosynthetic physiological ecology characteristics of rare medicinal plants <i>Bletilla striata</i>	WU Mingkai, LIU Hai, SHEN Zhijun, et al (5531)
Photosynthetic responses to Solar UV radiation of <i>Gracilaria lemaneiformis</i> cultured under different temperatures and CO ₂ concentrations	YANG Yuling, LI Wei, CHEN Weizhou, et al (5538)
The effect of soil oxygen availability on greenhouse gases emission in a double rice field	QIN Xiaobo, LI Yu'e, WAN Yunfan, et al (5546)
Effects of nitrogen management on NH ₃ volatilization and nitrogen use efficiency under no-tillage paddy fields	MA Yuhua, LIU Bing, ZHANG Zhisheng, et al (5556)
Study on characteristics of net photosynthetic rate of two kinds of tree shape and Impact Factors in Korla fragrant pear	SUN Guili, XU Min, LI Jiang, et al (5565)
Effects of sand burial on growth, survival, photosynthetic and transpiration properties of <i>Agriophyllum squarrosum</i> seedlings	ZHAO Halin, QU Hao, ZHOU Ruilian, et al (5574)
Effects of using plastic film as mulch combined with bunch planting on soil temperature, moisture and yield of spring wheat in a semi-arid area in drylands of Gansu, China	WANG Hongli, SONG Shangyou, ZHANG Xucheng, et al (5580)
Study on soil aggregates stability of mulberry ridge in Rocky Desertification based on Le Bissonnais method	WANG Sanshu, HUANG Xianzhi, SHI Dongmei, et al (5589)
Effects of fertilization on nitrogen loss with different forms via runoff and seepage under <i>Phyllostachy praecox</i> stands	CHEN Peipei, WU Jiasen, ZHENG Xiaolong, et al (5599)
Characteristics of physiological groups of soil nitrogen-transforming microbes in different vegetation types in the Loess Gully region, China	XING Xiaoyi, HUANG Yimei, AN Shaoshan, et al (5608)
Effects of vegetation types on soil microbial biomass C, N, P on the Loess Hilly Area	ZHAO Tong, YAN Hao, JIANG Yueli, et al (5615)
Influence of mulching management on soil microbe and its relationship with soil nutrient in <i>Phyllostachys praecox</i> stand	GUO Ziwu, YU Wenxian, CHEN Shuanglin, et al (5623)
Effect of rainfall on the seasonal variation of soil respiration in Hulunber Meadow Steppe	WANG Xu, YAN Yuchun, YAN Ruirui, et al (5631)
Spatial heterogeneity of fine roots in a subtropical evergreen broad-leaved forest and their sampling strategy based on soil coring method	HUANG Chaochao, HUANG Jinxue, XIONG Decheng, et al (5636)
Changes of leaf traits and WUE with crown height of four tall tree species	HE Chunxia, LI Jiyue, MENG Ping, et al (5644)
Sap flow dynamics of <i>Populus alba</i> L.× <i>P.talassica</i> plantation in arid desert area	ZHANG Jun, LI Xiaofei, LI Jiangui, et al (5655)
Effects of simulated temperature increase and vary little quality on litter decomposition	LIU Ruipeng, MAO Zijun, LI Xinghuan, et al (5661)
The effects of leaf stoichiometric characters on litter turnover in an arid-hot valley of Jinsha River, China	YAN Bangguo, JI Zhonghua, HE Guangxiong, et al (5668)
Comparison of concentrations of non-structural carbohydrates between new twigs and old branches for 12 temperate species	ZHANG Haiyan, WANG Chuankuan, WANG Xingchang (5675)
Combined effects of root cutting, auxin application, and potassium fertilizer on growth, sugar:nicotine ratio, and organic potassium index of flue-cured tobacco	WU Yanhui, XUE Lixin, XU Zicheng, et al (5686)
Effects of photoperiod and high fat diet on energy intake and thermogenesis in female <i>Apodemus chevrieri</i>	GAO Wenrong, ZHU Wanlong, MENG Lihua, et al (5696)
Effects of dietary chlorogenic acid supplementation on antioxidant system and anti-low salinity of <i>Litopenaeus vannamei</i>	WANG Yun, LI Zheng, LI Jian, et al (5704)

- Responses of desert plant diversity, community and interspecific association to soil salinity gradient ZHANG Xueni, LÜ Guanghui, YANG Xiaodong, et al (5714)
- Community characteristics in a chronosequence of karst vegetation in Mashan county, Guangxi WEN Yuanguang, LEI Liquan, ZHU Hongguang, et al (5723)
- Association between environment and community of *Pinus taiwanensis* in Daiyun Mountain LIU Jinfu, ZHU Dehuang, LAN Siren, et al (5731)
- The dynamics of soil fauna community during litter decomposition at different phenological stages in the subtropical evergreen broad-leaved forests in Sichuan basin WANG Wenjun, YANG Wanqin, TAN Bo, et al (5737)
- Seasonal dynamics and content of soil labile organic carbon of mid-subtropical evergreen broadleaved forest during natural succession FAN Yuexin, YANG Yusheng, YANG Zhijie, et al (5751)
- The stoichiometric characteristics of C, N, P for artificial plants and soil in the hinterland of Taklimakan Desert LI Congjuan, LEI Jiaqiang, XU Xinwen, et al (5760)
- A preliminary investigation on the population and behavior of the Tundra Swan (*Cygnus columbianus*) in Poyang Lake DAI Nianhua, SHAO Mingqin, JIANG Lihong, et al (5768)
- Effects of nutrient enrichment and fish stocking on succession and diversity of phytoplankton community CHEN Chun, LI Sijia, XIAO Lijuan, HAN Boping (5777)
- The depositional environment and organic sediment component of Dagze Co, a saline lake in Tibet, China LIU Shasha, JIA Qinxian, LIU Xifang, et al (5785)
- Spatiotemporal variation of interacting relationships among multiple provisioning and regulating services of Tibet grassland ecosystem PAN Ying, XU Zengrang, YU Chengqun, et al (5794)
- Spatial distribution of dissolved amino acids in Lake Taihu, China YAO Xin, ZHU Guangwei, GAO Guang, et al (5802)
- RS- and GIS-based study on ecological function regionalization in the Chaohu Lake Basin, Anhui Province, China WANG Chuanhui, WU Li, WANG Xinyuan, et al (5808)
- Trends of spring maize phenophases and spatio-temporal responses to temperature in three provinces of Northeast China during the past 20 years LI Zhengguo, YANG Peng, TANG Huajun, et al (5818)
- Species selection for landscape rehabilitation and their response to environmental factors in Poyang Lake wetlands XIE Dongming, JIN Guohua, ZHOU Yangming, et al (5828)
- Temporal and spatial pattern of the phytoplankton biomass in the Pearl River Delta WANG Chao, LI Xinhui, LAI Zini, et al (5835)
- Spatio-temporal dynamics of land use/land cover and its driving forces in Nanjing from 1995 to 2008 JIA Baoquan, WANG Cheng, QIU Erfa (5848)
- Changes of organic carbon and its labile fractions in topsoil with altitude in subalpine-alpine area of southwestern China QIN Jihong, WANG Qin, SUN Hui (5858)
- The carbon sink of urban forests and efficacy on offsetting energy carbon emissions from city in Guangzhou ZHOU Jian, XIAO Rongbo, ZHUANG Changwei, et al (5865)
- Groundwater salt content change and its simulation based on machine learning model in hinterlands of Taklimakan Desert FAN Jinglong, LIU Hailong, LEI Jiaqiang, et al (5874)
- Analysis of coordination degree between urban development and water resources potentials in arid oasis city XIA Fuqiang, TANG Hong, YANG Degang, et al (5883)
- Constructing an assessment indices system to analyze integrated regional carrying capacity in the coastal zones: a case in Nantong WEI Chao, YE Shufeng, GUO Zhongyang, et al (5893)
- Fish species diversity in Zhongjieshan Islands Marine Protected Area (MPA) LIANG Jun, XU Hanxiang, WANG Weiding (5905)
- Distribution and long-term changes of net-phytoplankton in the tidal freshwater estuary of Changjiang during wet season JIANG Zhibing, LIU Jingjing, LI Hongliang, et al (5917)
- Study of urban metabolic structure based on ecological network: a case study of Dalian LIU Gengyuan, YANG Zhifeng, CHEN Bin, et al (5926)
- Factors influencing of residents' tolerance towards wild boar in and near nature reserve: Taking the Heilongjiang Fenghuangshan Nature Reserve as the example XU Fei, CAI Tiji, JU Cunyong, et al (5935)
- Herdsmen's willingness to participate in ecological protection in Sanjiangyuan Region, China LI Huimei, ZHANG Anlu, WANG Shan, et al (5943)
- Analysis of first flush in rainfall runoff in Shenyang urban city LI Chunlin, LIU Miao, HU Yuanman, et al (5952)

《生态学报》2013 年征订启事

《生态学报》是由中国科学技术协会主管,中国生态学学会、中国科学院生态环境研究中心主办的生态学高级专业学术期刊,创刊于 1981 年,报道生态学领域前沿理论和原始创新性研究成果。坚持“百花齐放,百家争鸣”的方针,依靠和团结广大生态学科工作者,探索生态学奥秘,为生态学基础理论研究搭建交流平台,促进生态学研究深入发展,为我国培养和造就生态学科人才和知识创新服务、为国民经济建设和发展服务。

《生态学报》主要报道生态学及各分支学科的重要基础理论和应用研究的原始创新性科研成果。特别欢迎能反映现代生态学发展方向的优秀综述性文章;研究简报;生态学新理论、新方法、新技术介绍;新书评价和学术、科研动态及开放实验室介绍等。

《生态学报》为半月刊,大 16 开本,300 页,国内定价 90 元/册,全年定价 2160 元。

国内邮发代号:82-7,国外邮发代号:M670

标准刊号:ISSN 1000-0933 CN 11-2031/Q

全国各地邮局均可订阅,也可直接与编辑部联系购买。欢迎广大科技工作者、科研单位、高等院校、图书馆等订阅。

通讯地址:100085 北京海淀区双清路 18 号 电 话:(010)62941099; 62843362

E-mail: shengtaixuebao@rcees.ac.cn 网 址: www.ecologica.cn

本期责任副主编 陈利顶

编辑部主任 孔红梅

执行编辑 刘天星 段 靖

生 态 学 报

(SHENGTAI XUEBAO)

(半月刊 1981 年 3 月创刊)

第 33 卷 第 18 期 (2013 年 9 月)

ACTA ECOLOGICA SINICA

(Semimonthly, Started in 1981)

Vol. 33 No. 18 (September, 2013)

编 辑	《生态学报》编辑部 地址:北京海淀区双清路 18 号 邮政编码:100085 电话:(010)62941099 www.ecologica.cn shengtaixuebao@rcees.ac.cn	Edited by	Editorial board of ACTA ECOLOGICA SINICA Add: 18, Shuangqing Street, Haidian, Beijing 100085, China Tel: (010)62941099 www.ecologica.cn shengtaixuebao@rcees.ac.cn
主 编	王如松	Editor-in-chief	WANG Rusong
主 管	中国科学技术协会	Supervised by	China Association for Science and Technology
主 办	中国生态学学会 中国科学院生态环境研究中心 地址:北京海淀区双清路 18 号 邮政编码:100085	Sponsored by	Ecological Society of China Research Center for Eco-environmental Sciences, CAS Add: 18, Shuangqing Street, Haidian, Beijing 100085, China
出 版	科 学 出 版 社 地址:北京东黄城根北街 16 号 邮政编码:100717	Published by	Science Press Add: 16 Donghuangchenggen North Street, Beijing 100717, China
印 刷	北京北林印刷厂	Printed by	Beijing Bei Lin Printing House, Beijing 100083, China
发 行	科 学 出 版 社 地址:东黄城根北街 16 号 邮政编码:100717 电话:(010)64034563 E-mail: journal@cspg.net	Distributed by	Science Press Add: 16 Donghuangchenggen North Street, Beijing 100717, China Tel: (010)64034563 E-mail: journal@cspg.net
订 购	全国各地邮局	Domestic	All Local Post Offices in China
国外发行	中国国际图书贸易总公司 地址:北京 399 信箱 邮政编码:100044	Foreign	China International Book Trading Corporation Add: P.O.Box 399 Beijing 100044, China
广告经营 许 可 证	京海工商广字第 8013 号		



ISSN 1000-0933
CN 11-2031/Q

国内外公开发刊

国内邮发代号 82-7

国外发行代号 M670

定价 90.00 元