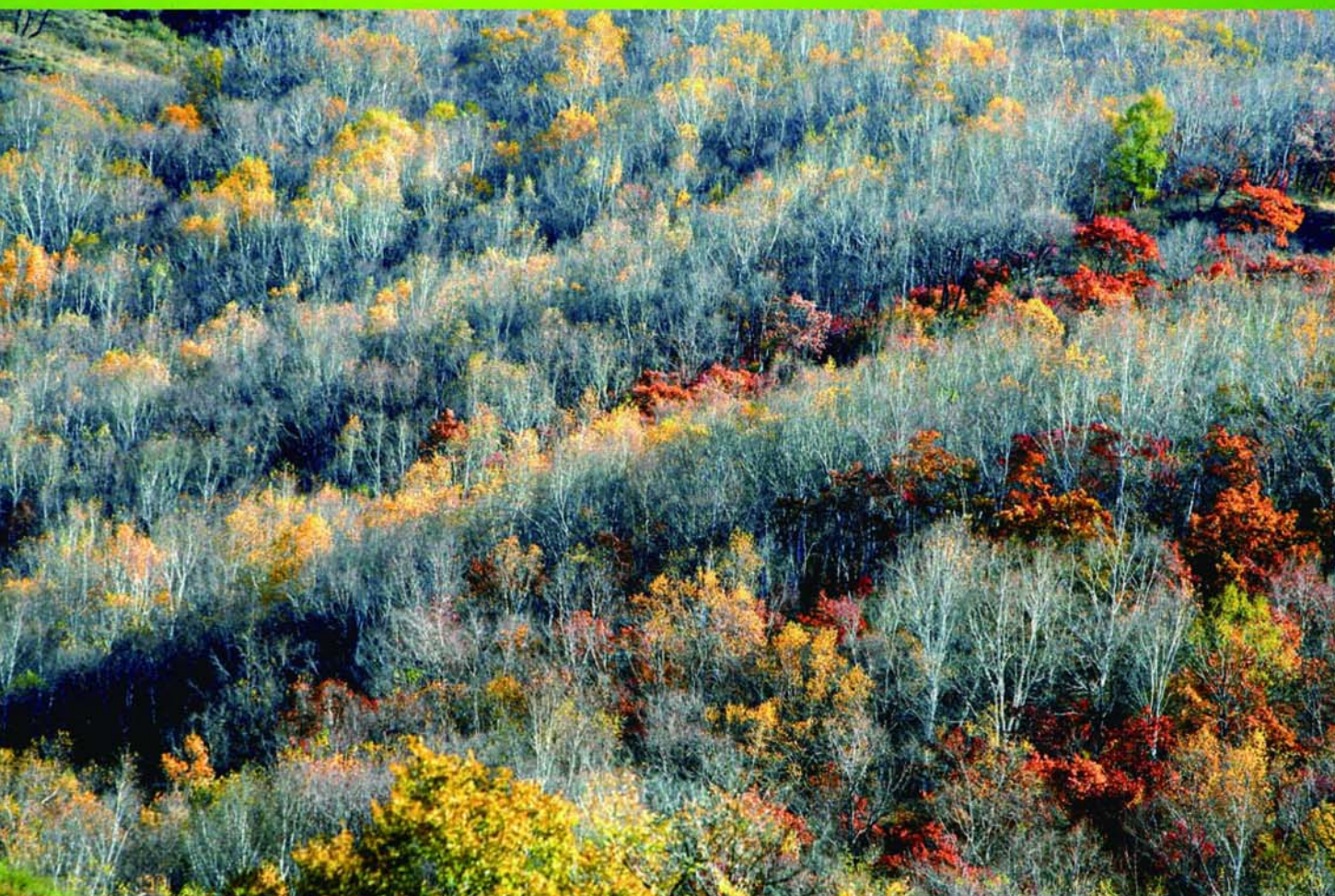


ISSN 1000-0933

CN 11-2031/Q

生态学报

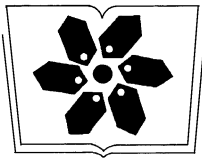
Acta Ecologica Sinica



第31卷 第16期 Vol.31 No.16 **2011**

中国生态学学会
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 31 卷 第 16 期

2011 年 8 月 (半月刊)

目 次

人工和天然湿地芦苇根际土壤细菌群落结构多样性的比较·····	汪仲琼,王为东,祝贵兵,等 (4489)
不同土壤水分下山杏光合作用光响应过程及其模拟·····	郎 莹,张光灿,张征坤,等 (4499)
不同颜色遮阳网遮光对丘陵茶园夏秋茶和春茶产量及主要生化成分的影响·····	秦志敏,付晓青,肖润林,等 (4509)
镉胁迫对烟草叶激素水平、光合特性、荧光特性的影响·····	吴 坤,吴中红,邵付菊,等 (4517)
条浒苔和缘管浒苔对镉胁迫的生理响应比较·····	蒋和平,郑青松,朱 明,等 (4525)
盐胁迫对拟南芥和盐芥莲座叶芥子油苷含量的影响·····	庞秋颖,陈思学,于 涛,等 (4534)
长期双季稻绿肥轮作对水稻产量及稻田土壤有机质的影响·····	高菊生,曹卫东,李冬初,等 (4542)
基于水量平衡下灌区农田系统中氮素迁移及平衡的分析·····	杜 军,杨培岭,李云开,等 (4549)
苏北海滨湿地互花米草种子特征及实生苗生长·····	徐伟伟,王国祥,刘金娥,等 (4560)
基于 AnnAGNPS 模型的三峡库区秭归县非点源污染输出评价·····	田耀武,黄志霖,肖文发 (4568)
镉污染对不同生境拟水狼蛛氧化酶和金属硫蛋白应激的影响·····	张征田,庞振凌,夏 敏,等 (4579)
印度洋南赤道流区水体叶绿素 a 的分布及粒级结构·····	周亚东,王春生,王小谷,等 (4586)
长江口滩涂围垦后水鸟群落结构的变化——以南汇东滩为例·····	张 斌,袁 晓,裴恩乐,等 (4599)
应用鱼类完整性指数 (FAII) 评价长江口沿岸碎波带健康状况·····	毛成贵,钟俊生,蒋日进,等 (4609)
基于渔业调查的南极半岛北部水域南极磷虾种群年龄结构分析·····	朱国平,吴 强,冯春雷,等 (4620)
水稻模型 ORYZA2000 在湖南双季稻区的验证与适应性评价·····	莫志鸿,冯利平,邹海平,等 (4628)
旱地农田不同耕作系统的能量/碳平衡·····	王小彬,王 燕,代 快,等 (4638)
宁夏黄灌区稻田冬春休闲期硝态氮淋失量·····	王永生,杨世琦 (4653)
太湖沉积物有机碳与氮的来源·····	倪兆奎,李跃进,王圣瑞,等 (4661)
日偏食对乌鲁木齐空气可培养细菌群落的影响·····	马 晶,孙 建,张 涛,等 (4671)
灰飞虱与褐飞虱种内和种间密度效应比较·····	吕 进,曹婷婷,王丽萍,等 (4680)
圈养马来熊行为节律和时间分配的季节变化·····	兰存子,刘振生,王爱善,等 (4689)
塔里木荒漠河岸林干扰状况与林隙特征·····	韩 路,王海珍,陈加利,等 (4699)
珍稀植物伯乐树一年生更新幼苗的死亡原因和保育策略·····	乔 琦,秦新生,邢福武,等 (4709)
垃圾堆肥复合菌剂对干旱胁迫下草坪植物生理生态特性的影响·····	多立安,王晶晶,赵树兰 (4717)
CLM3.0-DGVM 中植物叶面积指数与气候因子的时空关系·····	邵 璞,曾晓东 (4725)
基于生态效率的辽宁省循环经济分析·····	韩瑞玲,佟连军,宋亚楠 (4732)
专论与综述	
土壤食物网中的真菌/细菌比率及测定方法·····	曹志平,李德鹏,韩雪梅 (4741)
生态社区评价指标体系研究进展·····	周传斌,戴 欣,王如松,等 (4749)
问题讨论	
不同胁迫条件下化感与非化感水稻 PAL 多基因家族的差异表达·····	方长甸,王清水,余 彦,等 (4760)
研究简报	
钦州湾大型底栖动物生态学研究·····	王 迪,陈丕茂,马 媛 (4768)
人工恢复黄河三角洲湿地土壤碳氮含量变化特征·····	董凯凯,王 惠,杨丽原,等 (4778)
基于地统计学丰林自然保护区森林生物量估测及空间格局分析·····	刘晓梅,布仁仓,邓华卫,等 (4783)
晋西黄土区辽东栎、山杨树干液流比较研究·····	隋旭红,张建军,文万荣 (4791)
小兴安岭典型苔草和灌木沼泽 N ₂ O 排放及影响因子·····	石兰英,牟长城,田新民,等 (4799)
期刊基本参数:CN 11-2031/Q * 1981 * m * 16 * 316 * zh * P * ¥ 70.00 * 1510 * 35 * 2011-08	



封面图说:在长白山麓低海拔地区的晚秋季节,成片的白桦林用无数根白色的树干、树枝烘托着林冠上跳动的金黄色叶片,共生的柞木树冠用更浓重的颜色显示了它的存在,整个山梁层林尽染,秋意浓浓。

彩图提供:陈建伟教授 国家林业局 E-mail: cites.chenjw@163.com

高菊生, 曹卫东, 李冬初, 徐明岗, 曾希柏, 聂军, 张文菊. 长期双季稻绿肥轮作对水稻产量及稻田土壤有机质的影响. 生态学报, 2011, 31(16): 4542-4548.

Gao J S, Cao W D, Li D C, Xu M G, Zeng X B, Nie J, Zhang W J. Effects of long-term double-rice and green manure rotation on rice yield and soil organic matter in paddy field. Acta Ecologica Sinica, 2011, 31(16): 4542-4548.

长期双季稻绿肥轮作对水稻产量及 稻田土壤有机质的影响

高菊生^{1,2}, 曹卫东¹, 李冬初^{1,2,*}, 徐明岗^{1,2}, 曾希柏³, 聂 军⁴, 张文菊¹

(1. 中国农业科学院农业资源与农业区划研究所, 农业部作物营养与施肥重点开放实验室, 北京 100081;

2. 中国农业科学院红壤实验站, 祁阳农田生态系统国家野外试验站, 湖南祁阳 426182;

3. 中国农业科学院农业环境与可持续发展研究所, 北京 100081; 4. 湖南省土壤肥料研究所, 湖南长沙 410128)

摘要:以中国农业科学院红壤实验站 1982 年布置的长期定位试验为研究对象, 分析了长期双季稻绿肥轮作体系下水稻产量变化趋势、稻田土壤有机质变化特征及土壤活性有机质组成。结果表明, 绿肥作物与双季稻轮作种植后, 水稻产量显著高于冬闲对照, 绿肥作物紫云英、油菜和黑麦草处理年平均水稻产量 (1982—2008 年) 分别为 $10.8 \text{ t} \cdot \text{hm}^{-2} \cdot \text{a}^{-1}$, $10.2 \text{ t} \cdot \text{hm}^{-2} \cdot \text{a}^{-1}$ 和 $10.0 \text{ t} \cdot \text{hm}^{-2} \cdot \text{a}^{-1}$, 较冬闲对照分别提高 27.2%, 20.5% 和 18.1%。试验前期 (1982—1993 年) 种植绿肥作物各处理之间水稻产量无显著差异, 试验开展 11a 后 (1994—2008 年) 种植紫云英处理水稻产量显著高于油菜和黑麦草处理。长期双季稻绿肥轮作土壤有机质随年份显著增加, 双季稻紫云英轮作土壤有机质积累速度最快, 年增加 0.31 g/kg , 双季稻黑麦草次之, 土壤有机质年增加 0.28 g/kg , 双季稻油菜轮作土壤有机质年增加 0.26 g/kg 。种植绿肥作物紫云英稻田土壤活性有机质显著高于其它处理。种植绿肥作物各处理土壤有机碳、全氮、土壤微生物量碳和土壤微生物量氮含量均显著高于冬闲对照。其中黑麦草和紫云英处理土壤微生物量碳含量及微生物熵显著高于油菜和冬闲对照处理。在湘南红壤丘陵双季稻区, 种植绿肥作物对提高水稻产量、增加土壤有机质、提高土壤有机质活性具有重要意义, 绿肥选择上以紫云英对水稻产量和稻田土壤培肥综合效果最好。

关键词:双季稻绿肥轮作; 水稻产量; 土壤有机质; 土壤活性有机质; 土壤微生物量碳

Effects of long-term double-rice and green manure rotation on rice yield and soil organic matter in paddy field

GAO Jusheng^{1,2}, CAO Weidong¹, LI Dongchu^{1,2,*}, XU Minggang^{1,2}, ZENG Xibai³, NIE Jun⁴, ZHANG Wenju¹

1 Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences/Ministry of Agriculture Key Laboratory of Crop Nutrition and Fertilization, Beijing 100081, China

2 Red Soil Experimental Station, Chinese Academy of Agricultural Sciences/National Observation and Research Station of Farmland Ecosystem in Qiyang, Qiyang Hunan 426182, China

3 Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agricultural Sciences, Beijing 100081, China

4 Hunan Soil and Fertilizer Institute, Changsha 410128, China

Abstract: Rotation cropping systems have important significance to soil fertility, productivity and ecological function in paddy field. We analyzed the long-term data from a field experiment started in 1982 to investigate the effects of rotation cropping of double-rice with various green manure on the dynamics of rice yield and the total and labile soil organic matter

基金项目:公益性行业 (农业) 科研专项经费 (200803029, 201103005-01); 中央级公益性科研院所基本科研业务费专项资金项目 (2010-7); 国家科技支撑计划重点项目 (2009BAD6B05); 国家高技术研究发展计划“863”专题 (2006AA10Z419)

收稿日期:2010-08-18; **修订日期:**2010-12-02

* 通讯作者 Corresponding author. E-mail: dchuli@163.com

in Red Soil Experimental Station CAAS. Four rotation cropping systems were selected by three replicates, which were rotation of double rice with Chinese milk vetch (*Astragalus sinicus* L.), rape (*Astragalus sinicus* L.), ryegrass (*Lolium multiflorum*) and winter fallow. Results showed that, during the duration from 1982 to 2008, the averaged annual rice yield were $10.8 \text{ t} \cdot \text{hm}^{-2} \cdot \text{a}^{-1}$, $10.2 \text{ t} \cdot \text{hm}^{-2} \cdot \text{a}^{-1}$ and $10.0 \text{ t} \cdot \text{hm}^{-2} \cdot \text{a}^{-1}$ for the rotation cropping systems with Chinese milk vetch (*Astragalus sinicus* L.), rape (*Astragalus sinicus* L.) and ryegrass (*Lolium multiflorum*) respectively. Compared with double-rice and winter-fallow cropping, rice yield was increased significantly by 27.2%, 20.5%, and 18.1% under the rotation cropping with Chinese milk vetch (*Astragalus sinicus* L.), rape (*Astragalus sinicus* L.) and ryegrass (*Lolium multiflorum*) respectively. There was no significant difference among these rotation cropping systems with three kinds of green manure during the early period from 1982 to 1993, while the rice yield under the rotation with cultivating Chinese milk vetch was significantly higher than that under the other two kinds green manure rotations at the latter period from 1994 to 2008. Sustainability index of grain yield (SYI) was a reliable parameter on evaluate the productivity of sustainable cropping systems. Cultivating Chinese milk vetch could fix atmospheric nitrogen and improve soil fertility. The Sustainability index of grain yield (SYI) and potential of yield increased with cultivating Chinese milk vetch was the highest.

Soil organic matter showed an increasing trend under the rotation cropping of double rice and green manure. The rotation of double rice with Chinese milk vetch had the highest annually increasing rate (0.31 g/kg) of soil organic matter, while the rate was 0.28 g/kg and 0.26 g/kg for the rotation cropping with ryegrass and rape, respectively. The labile soil organic matter under the rotation with Chinese milk vetch was the highest of all the treatments. Total organic carbon, total nitrogen, soil microbial biomass carbon and nitrogen under the rotation with three kinds of green manure were significantly higher than that under the winter-fallow cropping systems. Compared with rape, ryegrass has strong fibrous root system which content high organic matter and crude protein. More carbon and nitrogen were cumulated in the soil under the rotation of double rice with Chinese milk vetch and ryegrass than that under the other two cropping systems. Additionally, the two rotation cropping systems of double-rice with ryegrass and Chinese milk vetch increased the microbial biomass carbon content and the ratio of microbial biomass carbon to total organic carbon ($C_{\text{mic}}\text{-to-}C_{\text{org}}$) significantly compared with the cropping of double-rice and rape or fallow.

In conclusion, rotation cropping of double rice with green manure had significant effects on enhancing rice yield and promoting soil organic matter quantity and quality. Rice cropping with Chinese milk rotation vetch was recommendable for rice productivity and soil fertility.

Key Words: rotation cropping of double rice and green manure; rice yield; soil organic matter; labile soil organic matter; soil microbial biomass

稻田轮作系统生态效应明显,具有改善土壤理化性状,调节土壤肥力,提高系统生产力等优点^[1-3]。双季稻是湘南红壤丘陵区农业结构的主体,双季稻长期连作由于浸水时间长,造成土壤耕层板结,理化性状变劣,甚至出现次生潜育化,已成为水稻生产的限制因子^[4]。双季稻绿肥轮作种植方式具有增产效果,其土壤肥力也有上升和进化趋势^[5],因此研究双季稻绿肥轮作对于提高农业生产力、改善土壤环境和促进农民增收等具有重要意义。

农作物种植制度是影响土壤质量演化及其可持续利用最为深刻的农业措施之一^[6],合理的轮作方式是提高土壤生物学活性的有效手段。黄国勤等研究认为^[1],稻田轮作改善了土壤的理化性状,容重下降,孔隙度增加,有效阻止土壤次生潜育化和土壤酸化。张帆等研究结果表明,冬作物双季稻轮作显著增加了稻田土壤微生物量碳、氮和微生物熵^[7]。双季稻区冬种覆盖物能显著提高土壤有机质含量,促进土壤微生物活动,从而有利于保持土壤肥力^[8-10]。章秀福等研究发现冬作物有提高土壤酶活性和抗叶片衰老作用^[11]。邢光熹

等研究认为冬季种植豆科作物可显著降低稻田 N_2O 的排放量^[12]。为探讨湘南红壤稻田多熟制增产潜力,不断提高经济效益和土壤肥力,促进农业可持续发展,从 1982 年开始,对湘南红壤稻田轮作制度进行了长期定位试验^[13-14]。通过比较不同绿肥-双季稻轮作制度下稻田土壤生产力和土壤有机质变化特征,土壤微生物量碳氮差异,研究双季稻绿肥轮作体系对水稻产量和稻田土壤肥力影响,为合理调整和配置双季稻绿肥轮作提供理论支持。

1 材料与方法

1.1 试验区概况

试验在中国农业科学院红壤实验站内进行,地理位置为东经 $111^\circ 52'$,北纬 $26^\circ 45'$,海拔 150 m,年平均温度 18.3°C , $>10^\circ\text{C}$ 的积温 5600°C ,多年平均降雨量 1250 mm,无霜期约 300d,年日照 1610—1620 h。试验地位于红壤丘岗中部,供试土壤为第四纪红色粘土发育的水稻土,土壤质地为壤质粘土,试验前土壤 pH 为 6.5,有机质含量为 20.1 g/kg ,全氮、全磷、有效钾含量分别为 0.94 g/kg 、 0.66 g/kg 和 176 mg/kg 。

1.2 试验设计

长期定位试验于 1982 年开始,采用“双季稻-绿肥”轮作种植^[15-16]。设 4 个处理:(1)稻稻(冬闲);(2)稻稻(麦);(3)稻稻(油);(4)稻稻(肥),绿肥作物分别为黑麦草(*Lolium multiflorum*)、油菜(*Brassica napus* L.)和紫云英(*Astragalus sinicus* L.)。采用随机区组排列,重复 3 次,小区面积 37.5 m^2 ($2.5\text{ m}\times 15.0\text{ m}$),小区之间用深 60 cm 水泥埂隔开。绿肥作物(紫云英、油菜、黑麦草)不施肥,于晚稻收割前 10—15d 将种子撒播于田间,次年早稻移栽前 15 d 全部翻压还田,紫云英播种量为 37.5 kg/hm^2 ,油菜播种量为 7.5 kg/hm^2 ,黑麦草播种量为 15.0 kg/hm^2 。所有处理水稻施肥量相同,早晚稻施肥量分别为 $\text{N } 153\text{ kg/hm}^2$, $\text{P}_2\text{O}_5\text{ } 84\text{ kg/hm}^2$, $\text{K}_2\text{O } 129\text{ kg/hm}^2$,分基肥和追肥 2 次撒施,基肥施用复合肥 600 kg/hm^2 (养分含量: $\text{N } 14\%$, $\text{P}_2\text{O}_5\text{ } 14\%$, $\text{K}_2\text{O } 14\%$),追肥施纯 $\text{N } 69\text{ kg/hm}^2$, $\text{K}_2\text{O } 45\text{ kg/hm}^2$,肥料类型为尿素和氯化钾。基肥在水稻移栽前施入,追肥在移栽后 6—10 d 作为返青分蘖肥一次施入。水稻插植规格早稻为 $20\text{ cm}\times 20\text{ cm}$,晚稻为 $20\text{ cm}\times 25\text{ cm}$ 。早稻及晚稻收获后,所有处理稻草均带走,不还田。各处理田间管理措施相同。

1.3 取样分析与数据统计方法

水稻生长季定期进行田间调查,每年早、晚稻成熟期进行考种及测定稻谷产量。每年晚稻收割后取土样(0—20cm)分析养分含量。土壤有机质、全氮测定方法参见《土壤农化分析》^[17]。土壤活性有机质采用 KMnO_4 氧化-重铬酸钾容量法测定^[18]。土壤微生物量碳采用氯仿熏蒸浸提-重铬酸钾容量法测定^[19],土壤微生物量氮采用氯仿熏蒸浸提-凯氏法定氮^[20]。

数据计算统计及相关分析采用 Microsoft Excel 2003 软件进行,处理之间方差分析和多重比较采用 SPSS13.0 软件进行,多重比较采用 Duncan 新复极差法。

2 结果与分析

2.1 水稻产量变化

绿肥的种植,显著提高了水稻产量(图 1)。1982—2008 年各处理水稻年平均产量分别为稻稻(肥) $10.8\text{ t}\cdot\text{hm}^{-2}\cdot\text{a}^{-1}$,稻稻(油) $10.2\text{ t}\cdot\text{hm}^{-2}\cdot\text{a}^{-1}$,稻稻(麦) $10.0\text{ t}\cdot\text{hm}^{-2}\cdot\text{a}^{-1}$,稻稻(冬闲) $8.5\text{ t}\cdot\text{hm}^{-2}\cdot\text{a}^{-1}$ 。种植绿肥的各处理水稻平均产量显著高于冬闲处理($P<0.01$),由于气候、品种等原因,水稻产量年际变化大,1982—2008 年种植绿肥作物各处理水稻平均产量未达到显著差异水平。

由产量年变化曲线可知(图 1),试验前期各处理水稻产量波动大,处理之间差异不明显;随着试验年限增

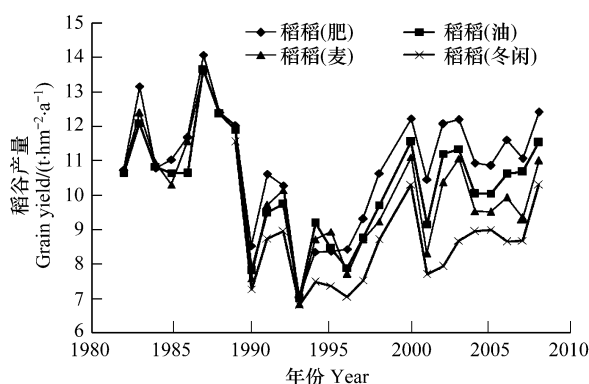


图 1 稻谷产量年际变化

Fig. 1 Annual change of grain yield

加,各处理之间水稻产量呈现明显的高低排列次序,分别为稻稻(肥)高于稻稻(油),高于稻稻(麦),高于稻稻(冬闲)。统计分析表明(表1),试验前11a(1982—1993年)水稻平均产量为种植绿肥作物显著高于冬闲($P<0.05$),前三者之间无显著差异。试验开展11a后(1994—2008年),各处理水稻产量存在显著差异,冬季种植紫云英绿肥水稻年产量显著高于种植油菜和黑麦草($P<0.05$),绿肥作物油菜处理水稻年平均产量高于黑麦草处理,但未达到显著差异水平。

产量可持续性指数(SYI)是测定系统是否持续生产的一个可靠参数,SYI越大系统的可持续性越好^[8]。该试验结果表明,种植紫云英,水稻产量的可持续性指数最高,其次分别为油菜和冬闲,种植黑麦草处理,产量可持续性指数最低。

表1 长期双季稻绿肥轮作不同时期稻谷产量及产量可持续性指数

Table 1 Grain yield and SYI under long term rotation of double rice and green manure

处理 Treatments	稻谷产量 Grain yield/(t·hm ⁻² ·a ⁻¹)		产量可持续性指数 SYI Sustainability index of grain yield
	1982—1993	1994—2008	
稻稻(冬闲) Rice-Rice (fallow)	8.65±1.86b	8.44±1.01c	0.63
稻稻(麦) Rice-Rice (ryegrass)	10.68±1.98a	9.53±1.06b	0.62
稻稻(油) Rice-Rice (rape)	10.56±1.89a	10.00±1.20b	0.63
稻稻(肥) Rice-Rice (Chinese milk vetch)	11.02±1.91a	10.63±1.48a	0.65

同列字母表示差异达5%显著水平

2.2 土壤有机质

长期双季稻绿肥轮作土壤有机质均随年份表现上升趋势(图2)。对1982—2007年土壤有机质含量的年变化趋势进行统计分析表明,长期双季稻紫云英轮作土壤有机质增长速度最快,年增加量为0.31 g/kg,长期双季稻黑麦草轮作次之,土壤有机质年增加量为0.28 g/kg,长期双季稻油菜轮作土壤有机质年增加量为0.26 g/kg。双季稻冬闲处理土壤有机质含量随年份也表现上升趋势,回归分析表明,其土壤有机质上升趋势未达到统计学上显著水平。经过26a的轮作种植,各处理2007年土壤有机质含量分别为稻稻(肥)28.38 g/kg,稻稻(油)29.25 g/kg,稻稻(麦)28.90 g/kg,稻稻(冬闲)27.08 g/kg,种植绿肥作物各处理土壤有机质含量显著高于冬闲处理($P<0.05$)。

2.3 土壤活性有机质

长期双季稻绿肥轮作增加土壤有机质含量,也改变了土壤活性有机质组分及其含量。由表2可知,稻稻(肥)处理土壤高活性有机质高于稻稻(冬闲)处理,显著高于稻稻(麦)和稻稻(油)处理,后两者之间无显著差异。土壤中活性有机质则表现为稻稻(肥)处理高于稻稻(油)处理,高于稻稻(冬闲)处理,显著高于稻稻(麦)处理。土壤低活性有机质高低次序分别为稻稻(肥)处理显著高于稻稻(麦)处理,高于稻稻(油)处理,高于稻稻(冬闲)处理。由三部分求和计算得出的土壤总的活性有机质含量分别为稻稻(肥)10.99 g/kg,稻稻(油)8.72 g/kg,稻稻(麦)8.57 g/kg,稻稻(冬闲)8.25 g/kg,与种植绿肥作物油菜、黑麦草和冬闲相比,种植紫云英稻田土壤总的活性有机质有显著提高。长期双季稻绿肥轮作26a后各处理土壤总的活性有机质占总

表2 长期双季稻绿肥轮作26a后土壤活性有机质状况(2007年)

Table 2 Content of the active soil organic matter under long term rotation of double rice and green manure after 26 years (2007)

处理 Treatments	土壤有机质/(g/kg) Soil organic matter	高活性有机质/(g/kg) Highlabile soil organic matter	中活性有机质/(g/kg) Middle labile soil organic matter	活性有机质/(g/kg) Labile soil organic matter
稻稻(冬闲) Rice-Rice (fallow)	27.08±0.31c	1.45±0.03a	3.36±0.32b	3.44±0.47c
稻稻(麦) Rice-Rice (ryegrass)	28.90±0.19a	1.23±0.06b	2.78±0.06c	4.56±0.68b
稻稻(油) Rice-Rice (rape)	29.25±0.20a	1.20±0.16b	3.78±0.10ab	3.74±0.01bc
稻稻(肥) Rice-Rice (Chinese milk vetch)	28.38±0.18b	1.58±0.03a	3.91±0.29a	5.50±0.32a

同列字母表示差异达5%显著水平

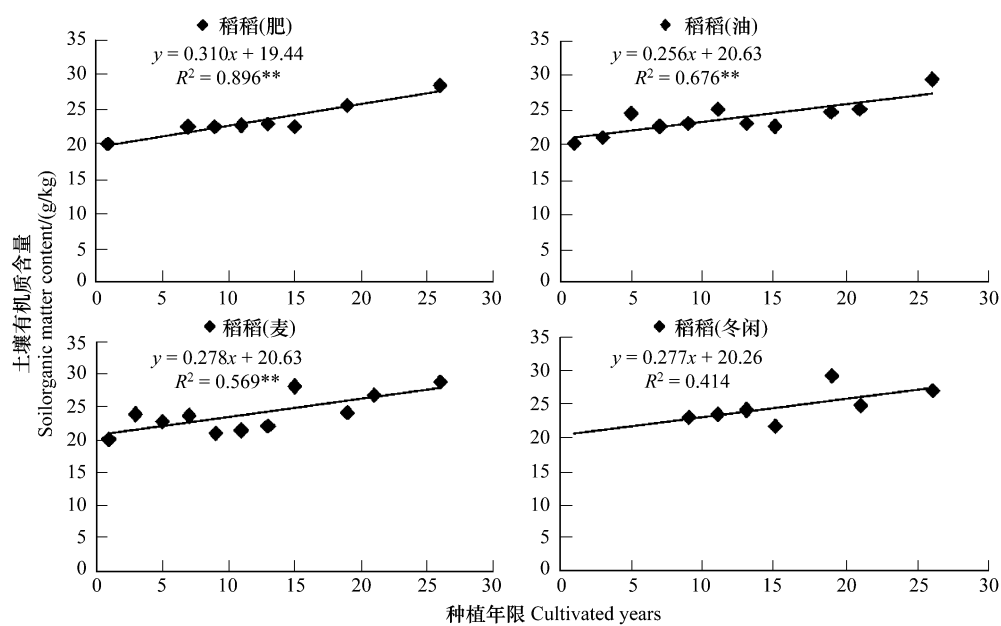


图2 土壤有机质年变化趋势

Fig.2 Annual change of the soil organic matter

的有机质比例分别为稻稻(肥)38.7%,稻稻(油)29.8%,稻稻(麦)29.6%,稻稻(冬闲)30.5%。

2.4 土壤有机碳、全氮及微生物量碳氮

从2007年土壤养分分析测定结果可知(表3),种植绿肥作物各处理土壤有机碳、全氮、土壤微生物量碳和土壤微生物量氮含量均显著高于冬闲。稻稻(肥)、稻稻(油)和稻稻(麦)处理土壤有机碳含量分别较对照稻稻(冬闲)处理提高了4.77%,8.02%和6.75%;土壤全氮含量分别较对照稻稻(冬闲)处理提高了8.94%,4.82%和4.12%;土壤微生物量碳含量分别较对照稻稻(冬闲)处理提高了29.81%,15.98%和31.72%;土壤微生物量氮含量则分别较对照稻稻(冬闲)处理提高了1.82%,2.69%和6.89%。

种植绿肥作物油菜和黑麦草土壤总的有机碳含量要显著高于紫云英;土壤全氮含量则表现为种植紫云英显著高于种植油菜和黑麦草,由土壤微生物量碳(C_{mic})和土壤有机碳(C_{org})比值计算得到的土壤微生物熵结果表明(表3),种植绿肥作物紫云英和黑麦草处理稻田土壤微生物熵显著高于种植油菜处理,显著高于冬闲对照。紫云英和黑麦草能提高土壤微生物活性,从而增加了微生物碳在土壤有机碳中的比重,这从另一方面也说明种植绿肥能显著提高土壤活性有机碳,其中紫云英和黑麦草效果要好于油菜处理。

表3 长期双季稻绿肥轮作26a后土壤有机碳、全氮及土壤微生物碳、氮状况(2007年)

Table 3 Content of SOM, TN, SMBC and SMBN under long term rotation of double rice and green manure after 26 years (2007)

处理 Treatments	土壤有机碳/(g/kg) Soil organic carbon	全氮/(g/kg) Total nitrogen	土壤微生物量碳 /(mg/kg) Soil microbial biomass carbon	土壤微生物量氮 /(mg/kg) Soil microbial biomass nitrogen	微生物熵/% C _{mic} /C _{org}
稻稻(冬闲) Rice-Rice (fallow)	15.71±0.18c	1.79±0.02c	576.9±21.34c	36.9±1.81b	3.67±0.17c
稻稻(麦) Rice-Rice (ryegrass)	16.77±0.11a	1.86±0.01b	759.9±5.50a	39.4±1.56a	4.53±0.03a
稻稻(油) Rice-Rice (rape)	16.97±0.12a	1.88±0.01b	669.1±9.50b	37.9±0.50ab	3.94±0.06b
稻稻(肥) Rice-Rice (Chinese milk vetch)	16.46±0.10b	1.95±0.01a	748.9±10.48a	37.6±0.61ab	4.55±0.08a

同列字母表示差异达5%显著水平 C_{mic}/C_{org}

3 讨论

3.1 不同双季稻绿肥轮作体系土壤生产力评价

湘南地区属亚热带气候,水热资源丰富,有利于发展多熟制农业。冬季种植绿肥是南方稻田实行多熟制,

提高土壤生产力的重要手段之一。发展绿肥可作为培肥土壤,提高双季稻产量的重要途径^[3,5]。绿肥作物紫云英为豆科植物,能够利用根瘤菌共生固氮,紫云英还田既增加土壤养分循环中氮,也增加了土壤有效磷钾和有机质,提高了土壤肥力^[21]。油菜能活化土壤中磷、钾等养分,黑麦草属禾本科,其碳水化合物含量比较多,有利于有机质累积。本试验开展的3种绿肥作物,种植紫云英,提高水稻产量潜力最高,产量稳定性最好。

绿肥作物还田还受土壤水肥条件、气候等因素影响。试验前期,由于土壤肥力相对偏低,绿肥腐解又需要消耗土壤氮素,可能出现与水稻争肥现象。同时微生物活动受水热条件制约,因此试验前期气候和土壤水热条件是导致水稻产量变异大的主要原因。气候条件与水稻产量关系值得进一步分析^[22-23]。

3.2 双季稻绿肥轮作对土壤有机质影响分析

土壤有机质是土壤的重要组成物质,与作物产量和土壤肥力密切相关。生物活性有机质组分是指土壤中被微生物快速利用和转化的有机质组分^[24]。土壤活性有机质、土壤微生物量碳、土壤微生物量氮等都是生物活性有机质组分。土壤中生物活性有机质组分的含量和动态变化可以反映土壤有效养分库的大小及其在土壤中的周转。土壤活性有机质变化情况为土壤系统有机质动态的更精确的指示物。豆科作物紫云英能固定大气中氮素,其有机质转化快,长期双季稻紫云英轮作显著提高了稻田土壤有机质含量,尤其是土壤活性有机质和土壤微生物碳、氮比例。黑麦草和油菜相比,黑麦草须根系发达,粗蛋白含量高,其土壤微生物碳、氮累积量高^[7]。该试验结果也表明,种植黑麦草和紫云英处理土壤微生物量碳含量显著高于种植油菜和冬闲对照处理。

选择合适的绿肥作物应充分根据作物生长所需的土壤气候条件,因地制宜。在绿肥作物利用方式上要发挥其最大经济和生态效益。如紫云英和黑麦草可采用直接还田、青贮和饲养过腹还田相结合,油菜采收后秸秆还田以发挥其最大经济效益。

4 结论

(1)与双季稻冬闲对照相比,双季稻绿肥轮作种植显著提高了稻谷产量,绿肥作物选择上又以紫云英对水稻增产潜力和产量可持续性指数最高。

(2)双季稻绿肥轮作种植稻田土壤有机质逐年累积,不同作物累积速度分别为紫云英高于黑麦草,高于油菜。

(3)双季稻绿肥轮作种植土壤活性有机质组分显著高于双季稻冬闲,紫云英和黑麦草能提高土壤微生物活性,增加微生物碳在土壤有机碳中的比重,效果要好于油菜处理。

(4)综上,在湖南双季稻区,种植绿肥对提高水稻产量、增加土壤有机质和有机质活性具有重要意义,绿肥作物选择上以紫云英对水稻产量和稻田土壤培肥综合效果最好。

References:

- [1] Huang G Q, Xiong Y M, Qian H Y, Wang S B, Liu L W, Zhao Q G. Ecological analysis on crop rotation systems of paddy field. *Acta Ecologica Sinica*, 2006, 26(4): 1159-1164.
- [2] Prasad R, Gangalah B, Aipe K C. Effect of crop residue management in rice-wheat cropping system on growth and yield of crops and on soil fertility. *Experimental Agriculture*, 1999, 35(4): 427-435.
- [3] Yang D F, Li X Y. A study of the influence of double-rice multiple cropping rotation and continuous cropping on the properties of soil organic matter. *Scientia Agricultura Sinica*, 1990, 23(2): 51-56.
- [4] Wang H, Du N M. Research and prospect of Rice cropping system. *Crop Research*, 2006, (5): 498-503.
- [5] Zeng X B, Guan G F. The change of organic, nitrogen, phosphorus and potassium nutrient in the different cropping system. *Acta Ecologica Sinica*, 1999, 19(1): 90-95.
- [6] Zhang L L, Wu Z J, Chen L J, Chen Z H, Zhang Y L. Soil oxidoreductase activity and its kinetic characteristics under different cropping system. *Ecology and Environment*, 2009, 18(1): 343-347.
- [7] Zhang F, Huang F Q, Xiao X P, Wu J M. Short-term influences of winter crops on microbial biomass carbon, microbial biomass nitrogen and C_{mic} -to- C_{org} in a paddy soil. *Acta Ecologica Sinica*, 2009, 29(2): 734-739.
- [8] Liu X B, Song C Y, Herbert S J, Xing B S. Ecological effects of cover crops. *Chinese Journal of Applied Ecology*, 2002, 13(3): 365-368.
- [9] Bauer P J, Busscher W J. Winter cover and tillage influences on coastal plain cotton production. *Journal of Production Agriculture*, 1996, 9(1):

50-54.

- [10] Zhu B, Hu Y G, Zeng Z H, Xiao X P, Yang G L, Huang F Q. Cover crop effects on the soil microbial biomass in double-rice cropping system. *Ecology and Environment*, 2008, 17(5): 2074-2077.
- [11] Fu G F, Wang D Y, Xu C M, Peng J, Han B, Tao L X, Zhang X F. Relationships between soil enzyme activities and rice grain yield, leaf senescence during grain filling under winter conservation tillage in paddy field. *Chinese Journal of Rice Science*, 2009, 23(1): 43-50.
- [12] Xiong Z Q, Xing G X, Tsuruta H, Shi S L, Shen G Y. Nitrous oxide emissions from agricultural soils as affected by winter cropping system. *Journal of Nanjing Agricultural University*, 2002, 25(4): 49-52.
- [13] Liu G L. Discussion on scientific cropping system//Investigation on Agricultural Development in the Upland Region of Red Soil. Beijing: Chinese Agricultural Science and Technology Press, 1995: 201-205.
- [14] Liu G L, Chen Y Z, Chen F X. Fertilization systems under Rice-rice-green Manure Rotation Cropping System// Investigation on the Agricultural Development in the Upland Region of Red Soil. Beijing: Chinese Agricultural Science and Technology Press, 1995: 141-145.
- [15] Gao J S, Liu G L, Qin D Z, Zou C M, Huang P N. Effect of different rotation mode on growth of rice in red soil paddy field. *Culture with Planting*, 2002, (2): 1-2.
- [16] Gao J S, Xu M G, Qin D Z. Effects of long-term rotation of rice, rice and milk vetch on growth and yield in rice. *Hunan Agricultural Science*, 2008, (6): 25-27.
- [17] Bao S D. Soil and Agricultural Chemistry Analysis. Beijing: China Agricultural Science and Technology Press, 2000: 25-69.
- [18] Lefroy R D B, Blair G J, Strong W M. Changes in soil organic matter with cropping as measured by organic carbon fractions and ^{13}C natural isotope abundance. *Plant and Soil*, 1993, 155-156: 399-402.
- [19] Vance E D, Brookes P C, Jenkinson D S. An extraction method for measuring soil microbial biomass C. *Soil Biology and Biochemistry*, 1987, 19(6): 703-707.
- [20] Brookes P C, Landman A, Pruden G, Jenkinson D S. Chloroform fumigation and the release of soil nitrogen, a rapid direct extraction method to measure microbial nitrogen in soil. *Soil Biology and Biochemistry*, 1985, 17(6): 827-842.
- [21] Gao J S. Influence of long term fertilization on crops output of cruciferae in three typical parent material soil in south Hunan. *Chinese Agricultural Science Bulletin*, 2009, 25(15): 235-239.
- [22] Zhu D W, Jin Z Q. Impacts of changes in both climate and its variability on food production in Northeast China. *Acta Agronomica Sinica*, 2008, 34(9): 1588-1597.
- [23] Zhou S D, Zhou W K. Influence and countermeasure of climate changes on agricultural production in Yangtze Delta. *Acta Agriculturae Zhejiangensis*, 2009, 21(4): 307-310.
- [24] Wander M M, Traina S J, Stinner B R, Peters S E. Organic and conventional management effects on biologically active soil organic matter pools. *Soil Science Society of America Journal*, 1994, 58(4): 1130-1139.

参考文献:

- [1] 黄国勤,熊云明,钱海燕,王淑彬,刘隆旺,赵其国. 稻田轮作系统的生态学分析. *生态学报*, 2006, 26(4): 1159-1164.
- [3] 杨东方,李学垣. 双季稻复种轮作与连作对土壤有机质形状影响的研究. *中国农业科学*, 1990, 23(2): 51-56.
- [4] 王辉,屠乃美. 稻田种植制度研究现状与展望. *作物研究*, 2006, (5): 498-503.
- [5] 曾希柏,关光复. 稻田不同耕作制下有机质和氮磷钾的变化研究. *生态学报*, 1999, 19(1): 90-95.
- [6] 张丽莉,武志杰,陈利军,陈振华,张玉兰. 不同种植制度土壤氧化还原酶活性和动力学特征. *生态环境学报*, 2009, 18(1): 343-347.
- [7] 张帆,黄凤球,肖小平,吴家梅. 冬季作物对稻田土壤微生物量碳、氮和微生物熵的短期影响. *生态学报*, 2009, 29(2): 734-739.
- [8] 刘晓冰,宋春雨,Herbet S J,邢宝山. 覆盖作物的生态效应. *应用生态学报*, 2002, 13(3): 365-368.
- [10] 朱波,胡跃高,曾昭海,肖小平,杨光立,黄凤球. 双季稻区冬种覆盖作物对土壤微生物量的影响. *生态环境*, 2008, 17(5): 2074-2077.
- [11] 符冠富,王丹英,徐春梅,彭建,韩博,陶龙兴,章秀福. 稻田冬季保护性耕作条件下的土壤酶活性与水稻成熟期叶片衰老和籽粒产量之间的关系. *中国水稻科学*, 2009, 23(1): 43-50.
- [12] 熊正琴,邢光熹,鹤田治雄,施书莲,沈光裕. 冬季耕作制度对农田氧化亚氮排放的贡献. *南京农业大学学报*, 2002, 25(4): 49-52.
- [13] 刘更另. 论科学的耕作制度//红壤丘陵区农业发展研究. 北京:中国农业科技出版社, 1995: 201-205.
- [14] 刘更另,陈永安,陈福兴. 双季稻绿肥轮作制度下的施肥体系//红壤丘陵区农业发展研究. 北京:中国农业科技出版社, 1995: 141-145.
- [15] 高菊生,刘更另,秦道珠,邹长明,黄平娜. 红壤稻田不同轮作方式对水稻生长发育的影响. *耕作与栽培*, 2002, (2): 1-2.
- [16] 高菊生,徐明岗,秦道珠. 长期稻-稻-紫云英轮作对水稻生长发育及产量的影响. *湖南农业科学*, 2008, (6): 25-27.
- [17] 鲍士旦. 土壤农化分析. 北京:中国农业科技出版社, 2000: 25-69.
- [21] 高菊生. 湘南三种典型红壤生土长期施肥对十字花科作物产量影响. *中国农学通报*, 2009, 25(15): 235-239.
- [22] 朱大威,金之庆. 气候及其变率变化对东北地区粮食生产的影响. *作物学报*, 2008, 34(9): 1588-1597.
- [23] 周曙东,周文魁. 气候变化对长三角地区农业生产的影响及对策. *浙江农业学报*, 2009, 21(4): 307-310.

ACTA ECOLOGICA SINICA Vol.31 ,No. 16 August ,2011 (Semimonthly)

CONTENTS

A comparative study on the diversity of rhizospheric bacteria community structure in constructed wetland and natural wetland with reed domination	WANG Zhongqiong, WANG Weidong, ZHU Guibing, et al (4489)
Light response of photosynthesis and its simulation in leaves of <i>Prunus sibirica</i> L. under different soil water conditions	LANG Ying, ZHANG Guangcan, ZHANG Zhengkun, et al (4499)
Effects of colour shading on the yield and main biochemical components of summer-autumn tea and spring tea in a hilly tea field	QIN Zhimin, FU Xiaoqing, XIAO Runlin, et al (4509)
Effects of cadmium on the contents of phytohormones, photosynthetic performance and fluorescent characteristics in tobacco leaves	WU Kun, WU Zhonghong, TAI Fujun, et al (4517)
Comparative physiological responses of cadmium stress on <i>Enteromorpha clathrata</i> and <i>Enteromorpha linza</i>	JIANG Heping, ZHENG Qingsong, ZHU Ming, et al (4525)
Effects of salt stress on glucosinolate contents in <i>Arabidopsis thaliana</i> and <i>Thellungiella halophila</i> rosette leaves	PANG Qiuying, CHEN Sixue, YU Tao, et al (4534)
Effects of long-term double-rice and green manure rotation on rice yield and soil organic matter in paddy field	GAO Jusheng, CAO Weidong, LI Dongchu, et al (4542)
Nitrogen balance in the farmland system based on water balance in Hetao irrigation district, Inner Mongolia	DU Jun, YANG Peiling, LI Yunkai, et al (4549)
Seed characteristics and seedling growth of <i>Spartina alterniflora</i> on coastal wetland of North Jiangsu	XU Weiwei, WANG Guoxiang, LIU Jin'e, et al (4560)
Assessment of non-point source pollution export from Zigui county in the Three Gorges Reservoir area using the AnnAGNPS model	TIAN Yaowu, HUANG Zhilin, XIAO Wenfa (4568)
Effects of Cadmium pollution on oxidative stress and metallothionein content in <i>Pirata subpiraticus</i> (Araneae: Lycosidae) in different habitats	ZHANG Zhengtian, PANG Zhenling, XIA Min, et al (4579)
The distribution of size-fractionated chlorophyll a in the Indian Ocean South Equatorial Current	ZHOU Yadong, WANG Chunsheng, WANG Xiaogu, et al (4586)
Change of waterbird community structure after the intertidal mudflat reclamation in the Yangtze River Mouth: a case study of NanHui Dongtan area	ZHANG Bin, YUAN Xiao, PEI Enle, et al (4599)
Application of fish assemblage integrity index (FAII) in the environment quality assessment of surf zone of Yangtze River estuary	MAO Chengze, ZHONG Junsheng, JIANG Rijin, et al (4609)
Population age structure of Antarctic krill <i>Euphausia superba</i> off the northern Antarctic Peninsula based on fishery survey	ZHU Guoping, WU Qiang, FENG Chunlei, et al (4620)
Validation and adaptability evaluation of rice growth model ORYZA2000 in double cropping rice area of Hunan Province	MO Zhihong, FENG Liping, ZOU Haiping, et al (4628)
Coupled energy and carbon balance analysis under dryland tillage systems	WANG Xiaobin, WANG Yan, DAI Kuai, et al (4638)
The nitrate-nitrogen leaching amount in paddy winter-spring fallow period	WANG Yongsheng, YANG Shiqi (4653)
The sources of organic carbon and nitrogen in sediment of Taihu Lake	NI Zhaoxui, LI Yuejin, WANG Shengrui, et al (4661)
Effect of partial solar eclipse on airborne culturable bacterial community in Urumqi	MA Jing, SUN Jian, ZHANG Tao, et al (4671)
Comparative study on density related intra- and inter-specific effects in <i>Laodelphax striatellus</i> (Fallen) and <i>Nilaparvata lugens</i> (Stål)	LÜ Jin, CAO Tingting, WANG Liping, et al (4680)
Behavior rhythm and seasonal variation of time budget of sun bear (<i>Helarctos malayanus</i>) in captivity	LAN Cunzi, LIU Zhensheng, WANG Aishan, et al (4689)
Disturbance regimes and gaps characteristics of the desert riparian forest at the middle reaches of Tarim River	HAN Lu, WANG Haizhen, CHEN Jiali, et al (4699)
Death causes and conservation strategies of the annual regenerated seedlings of rare plant, <i>Bretschneidera sinensis</i>	QIAO Qi, QIN Xinsong, XING Fuwu, et al (4709)
Effects of municipal compost extracted complex microbial communities on physio-ecological characteristics of turfgrass under drought stress	DUO Lian, WANG Jingjing, ZHAO Shulan (4717)
Spatiotemporal relationship of leaf area index simulated by CLM3.0-DGVM and climatic factors	SHAO Pu, ZENG Xiaodong (4725)
Analysis of circular economy of Liaoning Province based on eco-efficiency	HAN Ruiling, TONG Lianjun, SONG Yanan (4732)
Review and Monograph	
The fungal to bacterial ratio in soil food webs, and its measurement	CAO Zhiping, LI Depeng, HAN Xuemei (4741)
Indicators for evaluating sustainable communities: a review	ZHOU Chuanbin, DAI Xin, WANG Rusong, et al (4749)
Discussion	
Differential expression of <i>PAL</i> multigene family in allelopathic rice and its counterpart exposed to stressful conditions	FANG Changxun, WANG Qingshui, YU Yan, et al (4760)
Scientific Note	
Ecology study on the benthic animals of QinZhou Bay	WANG Di, CHEN Pimao, MA Yuan (4768)
Change characteristics of soil carbon and nitrogen contents in the Yellow River Delta soil after artificial restoration	DONG Kaikai, WANG Hui, YANG Liyuan, et al (4778)
Estimation and spatial pattern analysis of forest biomass in Fenglin Nature Reserve based on Geostatistics	LIU Xiaomei, BU Rencang, DENG Huawei, et al (4783)
Study on sap flow in forest of <i>Quercus liaotungensis</i> and <i>Populus davidiana</i> by using the TDP method	SUI Xuhong, ZHANG Jianjun, WEN Wanrong (4791)
N ₂ O Emission and its driving factors from typical marsh and shrub swamp in Xiaoxing'an Mountains, Northeast China	SHI Lanying, MU Changcheng, TIAN Xinmin, et al (4799)

2009 年度生物学科总被引频次和影响因子前 10 名期刊★

(源于 2010 年版 CSTPCD 数据库)

排序 Order	期刊 Journal	总被引频次 Total citation	排序 Order	期刊 Journal	影响因子 Impact factor
1	生态学报	11764	1	生态学报	1.812
2	应用生态学报	9430	2	植物生态学报	1.771
3	植物生态学报	4384	3	应用生态学报	1.733
4	西北植物学报	4177	4	生物多样性	1.553
5	生态学杂志	4048	5	生态学杂志	1.396
6	植物生理学通讯	3362	6	西北植物学报	0.986
7	JOURNAL OF INTEGRATIVE PLANT BIOLOGY	3327	7	兽类学报	0.894
8	MOLECULAR PLANT	1788	8	CELL RESEARCH	0.873
9	水生生物学报	1773	9	植物学报	0.841
10	遗传学报	1667	10	植物研究	0.809

★《生态学报》2009 年在核心版的 1964 种科技期刊排序中总被引频次 11764 次,全国排名第 1;影响因子 1.812,全国排名第 14;第 1—9 届连续 9 年入围中国百种杰出学术期刊;中国精品科技期刊

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 31 卷 第 16 期 (2011 年 8 月)

ACTA ECOLOGICA SINICA
(Semimonthly, Started in 1981)
Vol. 31 No. 16 2011

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	冯宗炜	Editor-in-chief	FENG Zong-Wei
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

国内外公开发行

国内邮发代号 82-7

国外发行代号 M670

定价 70.00 元