

(HUANJING KEXUE)

ENVIRONMENTAL SCIENCE

第35卷 第2期

Vol.35 No.2

2014

中国科学院生态环境研究中心 主办

斜学出版社出版



林 龙 科 享 (HUANJING KEXUE)

ENVIRONMENTAL SCIENCE

第35卷 第2期 2014年2月15日

目 次

我国环境空气中颗粒物达标统计要求研究 $ = $)1)
北京城区 PM _{2.5} 中致癌重金属季节变化特征及其来源分析 ····································	
	11)
Ψ 宣軸反复差 DM 到 DM 污浊水平时穴公东及甘与与免久性的关系	10 \
北京市 PM-。可吸入颗粒物反演及其时空分布分析 · · · · · · · · · · · · · · · · · · ·	28)
北京市 PM _{5.0} 可吸入颗粒物反演及其时空分布分析	36)
表古相同古言十二年 (成出版) 在 1	12)
首中朔門用环甲八 () (イ田) (1) (1) (1) (1) (1) (1) (1) (1) (1) (1	t4)
用录印入飞刺型初中有机峽和儿系峽型全分中特性。)I)
	38)
广州某工业区大气中 PCDD/Fs 含量水平及其季节性变化特征 青宪,苏原,苏青,张素坤,任明忠(46	
燃煤电厂锅炉 PM _{2.5} 排放危害度评价模型建立及案例分析 … 史妍婷,杜谦,高建民,边昕,王知溥,董鹤鸣,韩强,曹阳(47	70)
中国南海大气降水化学特征	75)
临安本底站酸雨长期观测特征分析 李正泉, 马浩, 毛裕定, 冯涛(48	31)
北京城区大气氛湿沉降特征研究) (`0€
烟雾箱与数值模拟研究某和乙苯的息氨生成港热 曹龙 徐永福(49	95)
和为市了及民族的几年中心不可见不可见不可见的。	ν3 <i>)</i> γ4)
$\mathcal{P}_{\mathbf{L}}$ 中产用 $\mathcal{L}_{\mathbf{L}}$ \mathcal{L}_{L	12)
生活垃圾填埋场作业面恶臭散发率研究	13)
生物滴滤哈处理本酚气体研究	20)
国 V 柴油机燃用丁醇-柴油混合燃料颗粒粒径分布特性试验研究 楼秋明,徐宁,范文佳,张涛(52	26)
翻堆频率对猪粪条垛堆肥过程温室气体和氨气排放的影响 赵晨阳,李洪枚,魏源送,钟佳,郑嘉熹,韩圣慧,万合锋(53	33)
CuBr ₂ 分解缓释-膜催化对零价汞的氧化性能研究 胡林刚,瞿赞,晏乃强,郭永福,谢江坤,贾金平(54	1 1)
浙闽沿岸海域总溶解态无机锑的分布及影响因素研究 张许州,任景玲,刘宗广,樊孝鹏,刘诚刚,吴莹(54	1 7)
浙闽沿岸海域总溶解态无机锑的分布及影响因素研究 张许州,任景岭,刘宗广,樊孝鹏,刘诚刚,吴莹(54基于双向算法的湖库允许纳污负荷量计算及案例 贾海峰,郭羽(55北京平原区第四系地下水污染风险评价 郭高轩,李宇,许亮,李志萍,杨庆,许苗娟(56不同季节辽河口营养盐的河口混合行为 张晋华,于立霞,姚庆祯,田琳(56太滆南运河人湖河口沉积为东特征 马久远,王国祥,李振国,张佳,周传,魏宏农,欧媛(57	55)
北京平原区第四系地下水污染风险评价	52)
不同季节辽河口营姜卦的河口混合行为 ************************************	59)
大源南泛河人湖河口河和物夏麦分布蛙征	77)
A. Mith是自己人的自己 0.000	!
业然市地区借加入工业地小个生物加坡一种化借力计划	33)
省流人上遊地基與结构与水刀特性相关性研究) 2)
亚热带地区潜流人工湿地木本植物筛选与净化潜力评价) 7)
不同換氧化剂对长江原水氯(胺)化 DBPs 生成潛能的影响 田富箱,徐斌,荣蓉,陈荚荚,张天阳,朱贺振(60)5)
风眼莲刈铜绿减饕澡生长及澡母系与宫疗盐释放的影响	11)
四环素光催化降解特性与选择性研究 宋晨怡,尹大强(61	19)
微生物电解系统生物阴极的硫酸盐还原特性研究 符诗雨,刘广立,骆海萍,张仁铎,章莹颖(62	26)
市政污水 A/DAT-IAT 系统中溶解性有机物表征与生态安全 ····································	33)
膜-牛物反应器处理高盐废水膜面污染物特性研究 李彬 王志伟 安莹 吴志超(64	43)
臭氧-曝气生物滤池组合工艺处理石化二级出水的试验研究	51)
医每件物法的细目胶底水的研究 ————————————————————————————————————	,ı , 57)
从书工初公处还不放及小时则况	(2)
型型型型型型型型型型型型型型型型型型型型型型型型型型型型型型型型型型型型	(0.)
于婚困棟对废水中铜岗丁的生物吸附性能)9)
基于流态化作用的吸附反应动刀字和穿透特位 土若,土培,黄星,哀益龙,陈墙库,周肌,周升升(6/	/8)
- J 州城市污泥甲重金属形态特征及县生态风险评价 ············· 郭鹏然,雷永乾,察大川,张涛,吴锐,潘佳钏(68	84)
中国农田土壤重金属富集状况及其空间分布研究 张小敏,张秀英,钟太洋,江洪(69) 2)
中国农田土壤重金属富集状况及其空间分布研究 ····································	
	04)
深圳市表层土壤多环芳烃污染及空间分异研究 章迪,曹善平,孙建林,曾辉(71 洋河流域万全段重金属污染风险及控制对策 "谭冰,王铁宇,朱朝云,李奇锋,徐笠,吕永龙(71	11)
洋河流域万全段重金属污染风险及控制对策 潭冰、王铁宇、朱朝云、李奇锋、徐笠、吕永龙(71	19)
施用组配周化剂对分裁+增重全属交换态令量及在水稻中累积分布的影响	27)
施用组配固化剂对盆栽土壤重金属交换态含量及在水稻中累积分布的影响 曾卉,周航,邱琼瑶,廖柏寒(72 螯合剂复配对实际重金属污染土壤洗脱效率影响及形态变化特征 尹雪,陈家军,吕策(73	22)
P Seudomonas sp. QJX-1 的锰氧化特性研究 ·················· 周娜娜, 柏耀辉, 梁金松, 罗金明, 刘锐平, 胡承志, 袁林江(74	10)
Pseudomonas sp. UlA-1 的抽氧化付性研究	1 0)
$n(NO_3^N)/n(NO_2^N)$ 对混培养菌与纯培养菌同步脱氮除硫的影响 ····································	
施子爱,陈会娟,魏本平,刘刚金,邓良伟,吴力斌(74 杭州市空气微生物群落碳代谢特征研究 ————————————————————————————————————	1 6)
杌州巾空气微生物群洛碳代谢特征研究	53)
鼠李糖脂逆胶束体系中纤维素酶的后萃研究 赵艳鸧,袁兴中,黄华军,崔凯龙,彭馨,彭子原,曾光明(75	59)
黄海党队角类体内无含量的种内和种间差显研究	54)
3 种 PAEs 对蚯蚓的毒性作用和组织酶活性影响的研究	70)
新型保水剂应用于土壤-小白菜系统的环境安全评价 李希. 贺纪正. 郑袁明. 郑明兰(78	30 Ĵ
黄河三角洲翅碱篷湿地硫化氢和羰基硫排放动态研究 李新华 郭泄海 杨丽蓝 朱振林 孙略青(78	36
农田土壤 NO 产生的关键微生物 计程及减排措施	32 \
黄河三角洲翅碱蓬湿地硫化氢和羰基硫排放动态研究 · · · · 李新华,郭洪海,杨丽萍,朱振林,孙晓青(78 农田土壤 N_O 产生的关键微生物过程及减排措施 · · · · · · · · 朱永官,王晓辉,杨小茹,徐会娟,贾炎(79 《环境科学》征订启事(691) 《环境科学》征稿简则(800) 信息(489,519,591,791))
** **	

农田土壤 N,O 产生的关键微生物过程及减排措施

朱永官^{1,3}, 王晓辉^{1,2}, 杨小茹³, 徐会娟^{2,3}, 贾炎^{1,2}

(1. 中国科学院生态环境研究中心城市与区域生态国家重点实验室,北京 100085; 2. 中国科学院大学,北京 100049; 3. 中国科学院城市环境研究所,厦门 361021)

摘要:氧化亚氮(N_2O)作为一种重要的温室气体,其全球排放总量仍然在持续上升.它不仅可以产生温室效应,还可以间接破坏臭氧层,使其在全球气候变化和生态环境变化研究中备受关注.土壤生态系统是大气中 N_2O 的最重要排放源.本文详细论述了农田土壤中反硝化作用、硝化作用、硝化微生物的反硝化作用以及硝酸盐异化还原成铵作用等过程产生 N_2O 的微生物学机制,并从土壤理化性质(土壤 pH、氮素、有机质、土壤温度和湿度)和土壤生物等方面对农田土壤 N_2O 排放的影响进行综述,在此基础上对农田土壤 N_2O 的减排措施进行总结,并就今后农田土壤 N_2O 排放的研究重点和方向进行了展望,为调控农田土壤温室气体排放、氮转化过程和提高氮素利用效率提供科学依据.

关键词:农田土壤;氧化亚氮;硝化作用;反硝化作用;减排措施

中图分类号: X144: X172 文献标识码: A 文章编号: 0250-3301(2014)02-0792-09

Key Microbial Processes in Nitrous Oxide Emissions of Agricultural Soil and Mitigation Strategies

ZHU Yong-guan^{1, 3}, WANG Xiao-hui^{1, 2}, YANG Xiao-ru³, XU Hui-juan^{2, 3}, JIA Yan^{1, 2}

(1. State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China; 2. University of Chinese Academy of Sciences, Beijing 100049, China; 3. Institute of Urban Environment, Chinese Academy of Sciences, Xiamen 361021, China)

Abstract: Nitrous oxide (N_2O) is a powerful atmospheric greenhouse gas, which does not only have a strong influence on the global climate change but also depletes the ozone layer and induces the enhancement of ultraviolet radiation to ground surface, so numerous researches have been focused on global climate change and ecological environmental change. Soil is the foremost source of N_2O emissions to the atmosphere, and approximately two-thirds of these emissions are generally attributed to microbiological processes including bacterial and fungal denitrification and nitrification processes, largely as a result of the application of nitrogenous fertilizers. Here the available knowledge concerning the research progress in N_2O production in agricultural soils was reviewed, including denitrification, nitrification, nitrification and dissimilatory nitrate reduction to ammonium, and the abiotic (including soil pH, organic and inorganic nitrogen, organic matter, soil humidity and temperature) and biotic factors that have direct and indirect effects on N_2O fluxes from agricultural soils were also summarized. In addition, the strategies for mitigating N_2O emissions and the future research direction were proposed. Therefore, these studies are expected to provide valuable and scientific evidence for the study on mitigation strategies for the emission of greenhouse gases, adjustment of nitrogen transformation processes and enhancement of nitrogen use efficiency.

Key words: agricultural soil; nitrous oxide; nitrification; denitrification; mitigation strategies

氧化亚氮(N_2O)作为一种重要的温室气体,它不仅可以产生温室效应,还对位于平流层的臭氧层具有破坏作用,因此其浓度变化及其对全球气候变化的影响备受关注.据估计,大气中 70%的 N_2O 来自土壤,特别是农田土壤是全球最主要的 N_2O 排放源[1].我国是世界上氮肥施用量最多的国家之一,2011年氮肥施用量已达到 $2.38\times10^7~t^{[2]}$.化学氮肥施用量的增加是农田土壤 N_2O 排放增加的重要原因[$3\sim5$].由于作物生长周期短,产量高,施肥和灌溉频繁量大,因此农田土壤生态系统的 N_2O 排放问题不容忽视.

农田土壤是大气中 N,O 的最重要排放源,反硝

化作用(denitrification)、硝化作用(nitrification)、硝化微生物的反硝化作用(nitrifier denitrification)以及硝酸盐异化还原成铵作用(dissimilatory nitrate reduction to ammonium, DNRA)等微生物过程均能生成 N_2O ,其中反硝化作用和硝化作用被认为是农田土壤释放 N_2O 的最重要途径 [6,7]. 但是,长期以来,对农田土壤 N_2O 排放的其他途径的研究相对较少. 本文综述了目前已知的 N_2O 产生的关键微生物

收稿日期: 2013-04-24; 修订日期: 2013-08-02

基金项目: 国家自然科学基金项目(31000254); 福建省自然科学基金项目(2012J05070)

作者简介: 朱永官(1967~),男,博士,研究员,主要研究方向为环境 生物学与生物技术,E-mail;ygzhu@ rees. ac. cn 过程及其机制,总结了土壤理化性质和土壤生物对 N₂O 排放的影响,在此基础上提出了农田土壤 N₂O 的减排措施,并就今后农田土壤 N₂O 排放的研究重点和方向进行展望,旨在为调控农田土壤温室气体排放、氮转化过程和提高氮素利用效率提供科学依据.

1 农田土壤 N,O 排放的微生物学机制

1.1 反硝化作用

反硝化作用是指微生物将 NO₃ 或 NO₂ 还原成 NO₃ NO₃ NO₄ NO₅ NO₅

气或低氧土壤系统中^[8]. 在多种微生物的参与下,硝酸盐通过四步还原反应,在硝酸盐还原酶(nitrate reductase, Nar)、亚硝酸盐还原酶(nitrite reductase, Nir)、一氧化氮还原酶(nitric oxide reductase, Nor)和氧化亚氮还原酶(nitrous oxide reductase, Nos)作用下,最终被还原为 N_2 ,并在中间过程释放强效应的温室气体 $N_2O^{[8]}$ (图 1).

通常认为反硝化只发生于严格厌氧的环境中, 但现在已发现许多微生物具有周质型硝酸盐还原酶 (Nap),Nap 位于细胞周质内,对氧分子不敏感,使 得反硝化作用也能在好氧条件下发生^[9].因此,影

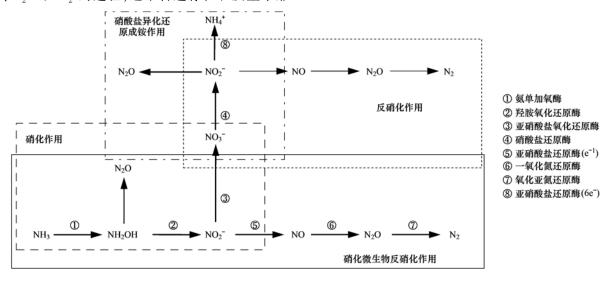


图 1 土壤 N_2O 排放的微生物学过程^[6]

Fig. 1 Microbial processes of soil N2O emissions

响反硝化作用的主要因子不是氧,而是有机质和硝酸盐含量.通过为反硝化作用提供底物,硝化-反硝化作用通常耦合发生,二者作用构成土壤 N₂O 释放的最主要途径.同时,参与反硝化作用的微生物种类繁多,已发现有80多个属的细菌和部分古菌、真菌和放线菌都可能参与反硝化作用[10~12].但是,对于反硝化真菌和古菌的研究多限于纯培养体系和森林等自然生态系统,对农田土壤生态系统中真菌和古菌反硝化的研究相对较少[13].因此,在未来的研究中需要对反硝化真菌和古菌的生态学特征及其反硝化对农田土壤 N₂O 排放的贡献做更深入的研究.

1.2 硝化作用

硝化作用是指微生物将氨(NH₃)氧化成亚硝酸盐(NO₂⁻)或者硝酸盐(NO₃⁻)的过程. 硝化过程分为两个阶段^[14]:第一阶段是氨氧化细菌(ammonia-oxidizing bacteria, AOB)或氨氧化古菌(ammonia-oxidizing archaea, AOA)在氨单加氧酶(ammonia

monooxygenase, AMO) 和 羟 胺 氧 化 还 原 酶 (hydroxylamine oxidoreductase, HAO)的催化下,将 NH₃ 氧化成 NO₂-,羟氨(NH₂OH)是其中间产物;第二阶段是亚硝酸盐氧化菌(nitrite-oxidizing bacteria, NOB) 在 亚 硝 酸 盐 氧 化 还 原 酶 (nitrite oxidoreductase, NOR)催化下,将 NO₂-进一步氧化成 NO₃-(图 1). 在氨氧化过程中,其中间产物会发生化学分解而释放出 N₂O^[15, 16].

硝化作用包括自养硝化作用和异养硝化作用. 自养硝化作用是指化能自养微生物利用 CO_2 作为碳源,将 NH_3 氧化成 NO_2^- 和 NO_3^- 的微生物过程;而异养硝化作用是指异养微生物以有机碳作为碳源和能源,将还原态氮(无机氮或有机氮)转化为氧化态氮的微生物过程^[17]. 与自养硝化微生物不同的是,某些异养硝化微生物还可以提供 NO_3^- 进行好氧反硝化作用产生 $N_2O^{[18,19]}$. 在好氧环境中,单体异养硝化微生物产生 N_2O 的能力远高于自养硝化微

生物. 尽管在通常情况下,异养硝化过程产生的 N_2O 仅占土壤 N_2O 总排放量的很小部分,但是在特定的环境下(如低 pH、高 O_2 和较高含量有机碳等),异养硝化微生物却可以产生大量的 $N_2O^{[7,18]}$. Anderson 等 O_2 的研究发现,在氧分压为 O_2 ~ 4 kPa 的环境下,异养硝化微生物 (Alcaligenes faecalis) 生成 O_2 的能力为自养硝化微生物 (Nitrosomonas europaea) 的 10 倍. Cai 等 O_2 对长期施用氮肥的耕作黑土(其 O_2 时由 7. 22 降至 6. 11,土壤有机碳含量为 1. 55%)中 O_2 中 O_2 排放的研究发现,异养硝化作用对土壤 O_2 以排放的贡献量为自养硝化作用的 O_2 倍. 然而,关于异养硝化作用耦合好氧反硝化作用的反应机制及其在氮循环中的作用和生态位仍不甚明确.

1.3 硝化微生物的反硝化作用

硝化微生物的反硝化作用是指仅在硝化微生物 驱动下 NO; 被还原为 N,O 或 N, 的过程,通常在低 氧环境中发生. 该过程分为两个阶段:第一阶段是 将NH、氧化成NO,,,第二阶段是将NO,还原成 N_2O 或 N_2 (图 1). 硝化微生物的反硝化作用产生 N₂O 可能是 N₂O 产生的最主要机制之一,已在氨氧 化细菌中得到证实^[21]. Santoro 等^[22]利用¹⁸O-¹⁵N 同 位素双标记技术解析15N 异构体在 N,O 分子内的分 配情况,发现 AOA 是海洋环境 N,O 排放的主要贡 献者,但对于农田土壤中硝化微生物的反硝化作用 对 N₂O 排放的贡献以及特征如何还不清楚. 此前研 究多把硝化微生物的反硝化作用对 N₂O 排放的贡 献看作是硝化作用或反硝化作用,使得硝化作用或 反硝化作用对 N₂O 排放的贡献被高估或低估,也使 得人们对农田土壤 N,O 排放机制的理解不够全面. 迄今为止关于陆地生态系统土壤硝化微生物的反硝 化作用的研究还相对较少,因而在未来的研究中需 要对硝化微生物的反硝化作用加以重视,深入研究 其发生机制及其对农田土壤 N₂O 排放的贡献.

1.4 硝酸盐异化还原成铵作用

硝酸盐异化还原成铵作用是指 NO_3^- 在厌氧条件下被微生物异化还原成 NH_4^+ 的过程 [6,23]. DNRA过程主要分为两个阶段:第一阶段在硝酸盐还原酶 (Nar)的催化下,将 NO_3^- 还原成 NO_2^- ;第二阶段在亚硝酸还原酶 (Nir)的作用下将 NO_2^- 转化为 NH_4^+ (图 1). 参与 DNRA 过程的 Nir 可以进行 $6e^{-1}$ 传递作用,这与反硝化过程的 Nir 不同. DNRA 过程除生成 NH_4^+ 外,还常伴有 NO_2^- 的短暂积累和 N_2 O 的排

放. 许多微生物包括专性厌氧细菌、兼性厌氧细菌、好氧细菌和真菌等都能进行 DNRA^[24]. 通常情况下,反硝化作用是土壤中 NO₃ 异化还原的主要过程. 然而在特定环境(高 C/NO₃ 比)中,DNRA 也可能在土壤氮素转化过程中起着重要的作用^[25, 26]. DNRA 多在有机碳含量丰富的草地、森林等自然土壤中发现^[25~27],而其在农田土壤中的研究比较少^[25].

与硝化作用和反硝化作用导致土壤氮损失不同,DNRA 将土壤中的 NO_3^- 还原为可供植物利用的 NH_4^+ ,有利于土壤中氮元素的蓄持. 由于 DNRA 和 反硝化作用对底物 NO_3^- 的利用存在着竞争,因而 DNRA 作用增强,不仅有利于降低土壤氮素损失,还可以减少土壤反硝化过程产生的 N_2O . 因此,DNRA 在氮循环中的作用不可忽视.

2 N,O 排放的主要影响因素

2.1 氮肥

氮肥有效性是影响农田土壤 N₂O 排放的最重 要因素之一. 施用化学氮肥能够显著增加土壤中 NH₄+N与NO₃-N的含量,继而增强硝化作用和反 硝化作用的强度,从而促进土壤 N2O 的产生与排 放^[28~31]. He 等^[29]的研究证明施用氮肥显著提高 了设施栽培土壤 N,O 的排放通量和排放总量. 贾俊 香等[32] 通过集约化大棚蔬菜地 N2O 排放的研究也 表明氮肥的大量施用显著促进了蔬菜地 N,O 的排 放. Gregorich 等[31]在总结同行研究的基础上,指出 农田土壤N₂O的排放通量随着化学氮肥施用量的 增加呈线性增加. 此外,土壤 NO, -N 含量过高会抑 制 Nos 酶的还原活性,改变反硝化过程气体产物的 组成,提高 N₂O/N₂,尤其是在较高 pH 的土壤环境 中. 但也有研究[33] 表明,土壤 NO, -N 含量只影响 反硝化作用强度,并不改变反硝化过程气体产物的 N,O/N,. 氮肥类型也会影响农田土壤 N,O 的排放 速率[34]. 铵态氮肥或者尿素通过水解可以为微生 物硝化过程提供底物 NH₄+,而硝化作用的产物 NO₃-反过来又可以直接参与反硝化过程,硝化反硝化作 用相互促进,增加土壤 N₂O 的排放^[35]. 有机肥除了 提供矿质氮外,还提供有机碳. 有机碳的大量摄入 增强土壤异养微生物的呼吸作用和活性,加快了土 壤中 0, 的消耗,加速土壤厌氧环境的形成,间接增 强了土壤微生物的反硝化作用活性[36]. 有研究表 明与施用无机氮肥的草原土壤相比,施用有机肥能 够增加 N_2O 的排放^[37]. 然而,也有研究揭示在暴雨之后,撒施有机肥却可以降低土壤 N_2O 的排放. 主要原因是有机质的矿化消耗了土壤中的 O_2 ,进而抑制了土壤微生物的硝化作用,同时土壤反硝化过程进行完全,将 N_2O 还原成为 N_2 ,从而减少土壤 N_2O 的排放^[38]. 因此,需要探索合适的氮肥使用途径来降低农田土壤 N_2O 的排放.

2.2 生物因素

影响农田土壤 N₂O 排放的生物因素主要为土壤微生物、土壤动物和作物.

2.2.1 土壤微生物

农田土壤中 N,O 的产生主要是在微生物驱动 下通过硝化和反硝化作用来完成的. 因此,土壤中 相关微生物的种群丰度、结构与活性对 N,O 的排放 具有重要影响. 氮肥和土壤理化性质通过改变硝化 微生物和反硝化微生物的菌群丰度和结构来影响土 壤硝化作用和反硝化作用的活性[39,40],从而影响土 壤 N₂O 的产生与排放. 比如在高氮投入的中性和碱 性土壤中, AOB 是硝化过程 N,O 产生的主要驱动 者[41], 而在低氮投入的酸性土壤中, AOA 是硝化过 程 N₂O 产生的主要驱动者^[42]. Nishio 等^[43]的研究 表明在一定范围内硝化作用强度随硫铵使用量增加 而增高,但施肥过量反而使硝化速率迅速降低,这是 由于高浓度的氨所产生的毒害作用以及过量的硫铵 使土壤 pH 值下降所致. 土壤中的 NO, -N 和 NH, -N 是反硝化微生物进行硝酸盐呼吸的电子受体和产 物,可直接影响土壤的反硝化作用. 施用化学氮肥 能够显著增加土壤中 NH₄ -N 与 NO₃ -N 的含量,继 而增强反硝化作用强度,从而促进土壤 N,O 的产生 与排放^[29,30]. 另外,土壤 NO, -N 含量过高也会抑 制 Nos 酶的还原活性,改变反硝化过程气体产物的 组成,提高 N₂O/N₂.

2.2.2 土壤动物

土壤动物也会对 N_2O 的排放产生重要影响. Borken 等[44]在酸性森林土壤中发现蚯蚓能够显著促进反硝化微生物的活性,从而增加土壤 N_2O 的排放总量. Giannopoulos 等[45]的研究也发现蚯蚓的活动可以显著增强土壤微生物的硝化和反硝化作用,继而促进土壤 N_2O 的排放. 但是,也有研究发现蚯蚓的活动会降低土壤中反硝化细菌的数量和改变其种群结构,从而降低土壤 N_2O 的排放^[46]. Zhang 等[47]利用稳定同位素和微生物磷脂脂肪酸技术研究蚯蚓入侵机制,进一步发现蚯蚓通过取食土壤微

生物来降低土壤硝化和反硝化微生物的数量,从而降低土壤 N_2O 的产生与排放.因此,需要深入研究土壤动物对 N_2O 排放的影响作用.

2.2.3 作物

作物主要是通过影响土壤无机氮源、有机质和 02 的含量与分布来影响土壤氮相关功能微生物的 反应过程与活性[48],从而影响土壤 N2O 的产生和排 放. 此外,作物种类也会影响土壤微生物硝化与反 硝化过程与活性,继而影响土壤 N,O 的产生和排 放[48~50]. 某些作物(如豆科作物)生长可以增加土 壤 N,O 的排放^[48],其途径有多种:作物吸收溶解在 土壤水中的 N,O,通过浓度差可将 N,O 排放到体外; 作物根系的呼吸作用和根系分泌的可利用有机质分 解造成根区厌氧环境,同时其凋落物矿化能够提供 无机氮源,增强土壤反硝化微生物活性[49,50];根际 泌氧促进硝化微生物的活性而增加土壤 NO;-N^[51],从而增加 N₂O 的产生和排放. 然而,研究发现 一些植物(如糖蜜草)对 N2O 排放有抑制作用,这些 作物植株通过吸收土壤中的 NH,+-N 和根系分泌硝 化抑制物质,降低土壤硝化微生物菌群活动所需的 底物和活性[49],从而降低土壤 N₂O 的排放. 此外, Subbarao 等[52]的研究也发现湿生臂形草(Brachiaria humidicola) 可以通过根系分泌生物硝化抑制物 质——亚油酸和亚麻酸来抑制土壤硝化微生物的活 性,从而降低土壤 N₂O 的排放.

2.3 土壤性质

2.3.1 pH

土壤 pH 值可通过影响氮相关功能微生物的活 性及改变相应的氮素转化过程而影响 N₂O 的排放. 首先,氮相关功能微生物比较适宜生存在中性或弱 碱性环境中,但异养微生物可在较大 pH 范围内活 动[53]; 其次,强酸性土壤可以直接抑制硝化和反硝 化微生物的代谢过程与活性[39,40,54,55],从而降低土 壤 N₂O 的排放; 第三, 土壤 pH 影响反硝化酶 Nos 的 活性: 当 pH > 7 时其活性增强, 然而当 pH < 7 时 其活性逐渐减小,而其他反硝化酶的活性增强,从而 导致反硝化过程产生更多的 N₂O^[56];第四,土壤有 机质的降解速率随着 pH 的降低而降低[57],减少了 N,O生成所需的无机氮源,从而降低土壤N,O的生 成与排放;第五,铁氨氧化作用(feammox)的速率随 着土壤 pH 的升高而增强[58],减少了 N2O 产生的无 机氮源 (NH_4^+) ,从而降低土壤 N_2O 的生成与排放; 最后,pH 是调控土壤化学反硝化过程的一个重要因 素. NO_2^- 可以在碱性土壤中进行短暂积累,而 NO_2^- 在严重酸化土壤中可以直接通过化学反硝化作用生成 $N_2O^{[59]}$,可见反硝化过程也是酸性土壤氮损失的重要途径.

2.3.2 有机质

绝大多数异养微生物以土壤有机质作为碳源和 电子供体,因此土壤有机质是调控 N₂O 排放的重要 因子[25]. 土壤碳源对微生物活性具有重要的影响, 硝化或反硝化微生物在同化 NH,或 NO; 的过程中 需要有机质提供碳源. 土壤中高含量的有机质能够 促进微生物的异养硝化和反硝化过程,产生大量的 $N_2O^{[7]}$. Enwall 等 $^{[60]}$ 通过长期施肥对土壤反硝化微 生物作用强度及群落结构(narG、nosZ)影响的研 究,发现长期施用有机肥的土壤,其有机质含量明显 增加,随之反硝化活性显著增强. 同时,施用酸性肥 料(NH₄)₂SO₄ 后,显著改变土壤中 narG 和 nosZ 基 因型反硝化微生物的群落结构,从而促进土壤 N,O 的排放. 另外,土壤有机质 C/N 比也会影响氮素的 转化过程,从而影响 N,O 的排放. 一般土壤微生物 适宜的 C/N 为 25~30,当 C/N > 30 时有机质分解 慢,微生物活性弱,抑制土壤 N₂O 的排放; 当 C/N <25 时有机质分解迅速,微生物活性强,促进土壤 N₂O 的排放^[51].

2.3.3 水分和温度

影响 N_2O 释放的物理因素主要包括土壤水分状况和温度等,并且这些因素之间相互关联. 土壤水分状况主要通过影响土壤通气状况、土壤的氧化还原状况以及土壤中微生物的活性来影响土壤 N_2O 的排放. 已有研究表明 [61] ,在 $35\% \sim 60\%$ 孔隙含水率 (water filled pore space, WFPS) 时硝化作用是土壤 N_2O 排放的主要来源,而在土壤 WFPS 为 70% 时所有的 N_2O 排放量均来自于反硝化作用,但是当土壤完全淹水时,由于反硝化作用进行完全降低了土壤 N_2O 的排放量. 此外,干湿交替过程可引起土壤硝化作用和反硝化作用交替产生 N_2O ,并且抑制 N_2O 继续还原为 N_2 ,从而促进 N_2O 的产生与排放.

土壤温度也是影响 N_2O 释放的重要因素,主要通过控制土壤有机质的分解和微生物代谢过程中相关酶的活性来调节土壤 N_2O 的释放. 研究表明 [62] N_2O 的排放通量与温度呈正相关性,通常高于 5 % 时就适于硝化和反硝化微生物发挥生物活性而开始产生 N_2O ,且在 $25 \sim 35$ % 范围内达到 N_2O 的最大排放通量.

3 N,O 减排措施

农田土壤是 N₂O 的重要排放源,因此,深入研究农田土壤 N₂O 的排放机制及影响因素并提出切实可行的减排措施,对控制全球气候变暖具有重要意义.目前,采用的减排措施主要包括改善施肥措施、施用生物抑制剂以及施用生物炭等.

3.1 施肥管理

我国是世界上氮肥施用量最多的国家,2011 年已达到 $2.38 \times 10^7 \, t^{[2]}$. 要削減土壤 N_2O 的排放,首先要提高氮肥利用率,减少氮肥的施用量 $^{[63]}$. 依据作物不同生长阶段需肥特征,分次撒施,提高作物吸收,减少氮素在土壤中的累积;其次,调整 N_*P_*K 的施肥比例,选用长效氮肥和缓释化肥. 研究表明,与碳酸氢铵相比,施用长效碳酸氢铵后土壤 N_2O 的排放量降低了 59.2%,而施用缓释尿素可以减排73.3%的 $N_2O^{[64]}$. 最后,优化施肥时间与方式 $^{[63]}$. 采用混施、深施或叶面喷施,可以提高氮肥的利用率,减少 N_*O 的排放 $^{[41]}$.

3.2 施用硝化抑制剂

硝化抑制剂又称为氮肥增效剂,可以抑制土壤中 NH_4^+ -N 向 NO_3^- -N 的转化,从而抑制土壤微生物硝化和反硝化过程产生的 $N_2O^{[65]}$. 目前常用的硝化抑制剂包括双氰铵 (dicyandiamide, DCD)、3,4-二甲基吡唑(3,4-dimethylpyrazol phosphate, DMPP)和乙炔等. 研究发现使用硝化抑制剂可以显著降低农田土壤 N_2O 的产生和排放 $^{[66,67]}$. 虽然硝化抑制剂对降低农田土壤 N_2O 的排放具有巨大的潜能,但是硝化抑制剂在特定田间条件下的作用效果及其有效量仍然缺乏足够的认识,需要进一步深入研究.

3.3 施用生物炭

生物炭(Biochar)一般指生物质(作物秸秆、枯枝落叶、养殖业废弃物和污泥等)在缺氧和相对"较低"(<700℃)温度条件下热解而形成的固体产物^[68].生物炭一般显碱性,具有高度羧酸酯化和芳香化结构,难降解,拥有较大的孔隙度和比表面积,这些基本性质使其具有减缓土壤酸化、减少土壤中无机态氮的淋溶和抑制温室气体排放的潜能^[69~71].

生物炭通过影响土壤 pH、 O_2 分压和关键的电子受体(NO_3^-)及电子供体(NH_4^+ ,可溶有机物)的生物有效性和分布来影响土壤 N_2O 的产生和还原^[71]. 生物炭中含有多种碱性灰分(比如 $CaCO_3$ 、KCl等),施用生物炭能显著提高土壤 $pH^{[72,73]}$,继而增

强反硝化还原酶 Nos 的活性,促进 N₂O 还原为 N₂, 从而降低农田土壤 N,O 的排放. 生物炭具有多孔 性,施用后可改变土壤的通气状况,增加0,含量,明 显减少反硝化作用产生的 N₂O^[28]. 但由于反硝化还 原酶 Nos 比其他酶对 O, 更敏感[37,74], 因此如果土 壤 O, 的增加仅影响到 Nos 的活性,那么 O, 分压升 高也有可能造成反硝化过程进行到 N₂O 时停止,从 而引发土壤 N₂O 排放增加. 氮素流转过程需要大量 氧化剂和还原剂的参与. 硝化过程中硝化微生物需 要氧化 NH; 获取能量和电子,利用有机碳或 CO, 作为碳源,用 O。作电子接受体;而反硝化细菌要利 用 NO: 作为电子受体,用含碳有机物作为碳源和能 源. 施用生物炭后, NH₄ 、NO₅ 和可溶性有机物的 有效性都会显著降低[75],从而降低农田土壤 N₂O 的 产生和排放. 然而,生物炭对农田土壤 N,O 排放影 响的反应机制尚不十分清楚,需要深入研究和综合 考虑生物炭对农田土壤氮循环的整体影响,合理进 行氮素和生物炭的施用.

4 展望

综上所述,农田土壤 N₂O 的产生和排放有多种途径,并且这些途径之间相互关联,同时受多种环境因素的共同制约. 尽管有关农田土壤 N₂O 的产生与排放研究已取得了重要的进展,但是目前仍然还有许多问题亟须解决.

- (1)强化 N₂O 排放与氮转化关键微生物过程与机理的研究,并与反应速率(矿化速率、硝化速率、反硝化速率等)研究结合,为调控农田土壤 N₂O 的排放提供依据. 硝化作用产生 N₂O 的机制和路径尚有争议,并且硝化作用与反硝化作用通常可以耦合发生,尤其是异养硝化过程耦合好氧反硝化过程的共同发生,其反应机制及其对 N₂O 排放的贡献仍不甚明确.
- (2)目前对农田土壤 N₂O 排放的研究多只针对某一过程独立开展,同一体系内硝化、反硝化、硝化微生物的反硝化和硝酸盐异化还原成铵等过程如何交替或共同发生以及如何影响参与这些过程转化的微生物的多样性和代谢活性,尚不清楚.
- (3)目前关于硝化抑制剂和生物炭对农田土壤 N_2O 的排放影响多停留在研究阶段,大田验证试验 亟需开展,从而为调控农田土壤温室气体排放、氮 转化过程和提高氮素利用效率提供理论依据和切实 可行的措施.

参考文献:

- [1] IPCC. Climate Change 2007; Mitigation. Contribution of working group III to the fourth assessment report of the intergovernmental panel on climate change[M]. Cambridge: Cambridge University Press, 2007.
- [2] 中华人民共和国国家统计局. 中国统计年鉴[M]. 北京: 中国统计出版社, 2012.
- [3] Chen Q, Zhang X S, Zhang H Y, et al. Evaluation of current fertilizer practice and soil fertility in vegetable production in the Beijing region [J]. Nutrient Cycling in Agroecosystems, 2004, 69(1): 51-58.
- [4] Ju X T, Kou C L, Zhang F S, et al. Nitrogen balance and groundwater nitrate contamination: Comparison among three intensive cropping systems on the North China Plain [J]. Environmental Pollution, 2006, 143(1): 117-125.
- [5] Zhu Z L, Chen D L. Nitrogen fertilizer use in China-Contributions to food production, impacts on the environment and best management strategies [J]. Nutrient Cycling in Agroecosystems, 2002, 63(2-3): 117-127.
- [6] Baggs E M. A review of stable isotope techniques for N₂O source partitioning in soils: recent progress, remaining challenges and future considerations [J]. Rapid Communications in Mass Spectrometry, 2008, 22(11): 1664-1672.
- [7] Wrage N, Velthof G L, Van Beusichem M L, et al. Role of nitrifier denitrification in the production of nitrous oxide[J]. Soil Biology & Biochemistry, 2001, 33(12-13): 1723-1732.
- [8] Morley N, Baggs E M, Dörsch P, et al. Production of NO, N_2O and N_2 by extracted soil bacteria, regulation by NO_2^- and O_2 concentrations[J]. FEMS Microbiology Ecology, 2008, $\mathbf{65}(1)$: 102-112.
- [9] Zhou Z M, Takaya N, Sakairi M A C, et al. Oxygen requirement for denitrification by the fungus Fusarium oxysporum [J]. Archives of Microbiology, 2001, 175(1): 19-25.
- [10] Cabello P, Roldán M D, Moreno-Vivián C. Nitrate reduction and the nitrogen cycle in archaea [J]. Microbiology, 2004, 150 (11); 3527-3546.
- [11] Pina-Ochoa E, Hogslund S, Geslin E, et al. Widespread occurrence of nitrate storage and denitrification among Foraminifera and Gromiida [J]. Proceedings of the National Academy of Sciences of the United States of America, 2010, 107 (3): 1148-1153.
- [12] Risgaard-Petersen N, Langezaal A M, Ingvardsen S, et al. Evidence for complete denitrification in a benthic foraminifer [J]. Nature, 2006, 443 (7107): 93-96.
- [13] Thamdrup B. New pathways and processes in the global nitrogen cycle [J]. Annual Review of Ecology, Evolution, and Systematics, 2012, 43(1): 407-428.
- [14] Prosser J I. Autotrophic nitrification in bacteria [J]. Advances in Microbial Physiology, 1989, 30: 125-181.
- [15] Frame C H, Casciotti K L. Biogeochemical controls and isotopic signatures of nitrous oxide production by a marine ammonia-oxidizing bacterium [J]. Biogeosciences, 2010, 7(9): 2695-

- 2709
- [16] Wrage N, Van Groenigen J W, Oenema O, et al. A novel dualisotope labelling method for distinguishing between soil sources of N₂O[J]. Rapid Communications in Mass Spectrometry, 2005, 19(22): 3298-3306.
- [17] Papen H, Von Berg R. A Most Probable Number method (MPN) for the estimation of cell numbers of heterotrophic nitrifying bacteria in soil[J]. Plant and Soil, 1998, 199(1): 123-130.
- [18] Anderson I C, Poth M, Homstead J, et al. A comparison of NO and N₂O production by the autotrophic nitrifier Nitrosomonas europaea and the heterotrophic nitrifier Alcaligenes faecalis [J]. Applied and Environmental Microbiology, 1993, 59(11): 3525-3533.
- [19] Richardson D J, Wehrfritz J M, Keech A, et al. The diversity of redox proteins involved in bacterial heterotrophic nitrification and aerobic denitrification [J]. Biochemical Society Transactions, 1998, 26(3): 401-408.
- [20] Cai Y J, Ding W X, Zhang X L, et al. Contribution of heterotrophic nitrification to nitrous oxide production in a longterm N-fertilized arable black soil [J]. Communications in Soil Science and Plant Analysis, 2010, 41(19): 2264-2278.
- [21] Shaw L J, Nicol G W, Smith Z, et al. Nitrosospira spp. can produce nitrous oxide via a nitrifier denitrification pathway [J]. Environmental Microbiology, 2006, 8(2): 214-222.
- [22] Santoro A E, Buchwald C, McIlvin M R, et al. Isotopic signature of N₂O produced by marine ammonia-oxidizing archaea [J]. Science, 2011, 333(6047): 1282-1285.
- [23] Zhou Z M, Takaya N, Nakamura A, et al. Ammonia fermentation, a novel anoxic metabolism of nitrate by fungi [J]. Journal of Biological Chemistry, 2002, 277(3): 1892-1896.
- [24] Yin S X, Chen D, Chen L M, et al. Dissimilatory nitrate reduction to ammonium and responsible microorganisms in two Chinese and Australian paddy soils [J]. Soil Biology & Biochemistry, 2002, 34(8): 1131-1137.
- [25] Morley N, Baggs E M. Carbon and oxygen controls on N₂O and N₂ production during nitrate reduction [J]. Soil Biology & Biochemistry, 2010, 42(10); 1864-1871.
- [26] Schmidt C S, Richardson D J, Baggs E M. Constraining the conditions conducive to dissimilatory nitrate reduction to ammonium in temperate arable soils [J]. Soil Biology & Biochemistry, 2011, 43(7): 1607-1611.
- [27] Rütting T, Boeckx P, Müller C, et al. Assessment of the importance of dissimilatory nitrate reduction to ammonium for the terrestrial nitrogen cycle [J]. Biogeosciences, 2011, 8 (7): 1779-1791.
- [28] Dong Y, Scharffe D, Qi Y C, et al. Nitrous oxide emissions from cultivated soils in the North China Plain[J]. Tellus B, 2001, 53 (1): 1-9.
- [29] He F F, Jiang R F, Chen Q, et al. Nitrous oxide emissions from an intensively managed greenhouse vegetable cropping system in Northern China [J]. Environmental Pollution, 2009, 157 (5);

- 1666-1672.
- [30] Sánchez-Martín L, Vallejo A, Dick J, et al. The influence of soluble carbon and fertilizer nitrogen on nitric oxide and nitrous oxide emissions from two contrasting agricultural soils [J]. Soil Biology & Biochemistry, 2008, 40(1): 142-151.
- [31] Gregorich E, Rochette P, Vandenbygaart A, et al. Greenhouse gas contributions of agricultural soils and potential mitigation practices in Eastern Canada [J]. Soil and Tillage Research, 2005, 83(1): 53-72.
- [32] 贾俊香, 张曼, 熊正琴, 等. 南京市郊区集约化大棚蔬菜地 N₂O 的排放[J]. 应用生态学报, 2012, **23**(3): 739-744.
- [33] Munch J C. Organism specific denitrification in samples of an Udifluvent with different nitrate concentrations [J]. Zeitschrift für Pflanzenernährung und Bodenkunde, 1989, 152(4): 395-400.
- [34] Vallejo A, Skiba U M, García-Torres L, et al. Nitrogen oxides emission from soils bearing a potato crop as influenced by fertilization with treated pig slurries and composts [J]. Soil Biology & Biochemistry, 2006, 38(9): 2782-2793.
- [35] Skiba U, Smith K A. The control of nitrous oxide emissions from agricultural and natural soils [J]. Chemosphere-Global Change Science, 2000, 2(3): 379-386.
- [36] Cannavo P, Richaume A, Lafolie F. Fate of nitrogen and carbon in the vadose zone: in situ and laboratory measurements of seasonal variations in aerobic respiratory and denitrifying activities [J]. Soil Biology & Biochemistry, 2004, 36(3): 463-478.
- [37] Ding W X, Meng L, Cai Z C, et al. Effects of long-term amendment of organic manure and nitrogen fertilizer on nitrous oxide emission in a sandy loam soil[J]. Journal of Environmental Sciences, 2007, 19(2): 185-193.
- [38] Ball B C, McTaggart I P, Scott A. Mitigation of greenhouse gas emissions from soil under silage production by use of organic manures or slow-release fertilizer[J]. Soil Use and Management, 2004, 20(3): 287-295.
- [39] Saleh-Lakha S, Shannon K E, Henderson S L, et al. Effect of pH and temperature on denitrification gene expression and activity in *Pseudomonas mandelii* [J]. Applied and Environmental Microbiology, 2009, 75(12); 3903-3911.
- [40] Liu B B, Morkved P T, Frostegard A, et al. Denitrification gene pools, transcription and kinetics of NO, N₂O and N₂ production as affected by soil pH[J]. FEMS Microbiology Ecology, 2010, 72(3): 407-417.
- [41] Di H J, Cameron K C, Shen J P, et al. Nitrification driven by bacteria and not archaea in nitrogen-rich grassland soils [J]. Nature Geoscience, 2009, 2(9): 621-624.
- [42] Zhang L M, Hu H W, Shen J P, et al. Ammonia-oxidizing archaea have more important role than ammonia-oxidizing bacteria in ammonia oxidation of strongly acidic soils [J]. The ISME Journal, 2012, 6(5): 1032-1045.
- [43] Nishio T, Fujimoto T. Kinetics of nitrification of various amounts of ammonium added to soils [J]. Soil Biology & Biochemistry, 1990, 22(1): 51-55.
- [44] Borken W, Gründel S, Beese F. Potential contribution of

- Lumbricus terrestris L. to carbon dioxide, methane and nitrous oxide fluxes from a forest soil[J]. Biology and Fertility of Soils, 2000, 32(2): 142-148.
- [45] Giannopoulos G, Pulleman M M, Van Groenigen J W. Interactions between residue placement and earthworm ecological strategy affect aggregate turnover and N₂O dynamics in agricultural soil [J]. Soil Biology & Biochemistry, 2010, 42 (4): 618-625.
- [46] Patra A K, Abbadie L, Clays-Josserand A, et al. Effects of grazing on microbial functional groups involved in soil N dynamics [J]. Ecological Monographs, 2005, 75(1): 65-80.
- [47] Zhang W X, Hendrix P F, Snyder B A, et al. Dietary flexibility aids Asian earthworm invasion in North American forests [J]. Ecology, 2010, 91(7): 2070-2079.
- [48] Knops J M H, Bradley K L, Wedin D A. Mechanisms of plant species impacts on ecosystem nitrogen cycling [J]. Ecology Letters, 2002, 5(3): 454-466.
- [49] Patra A K, Abbadie L, Clays-Josserand A, et al. 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[J]. Environmental Microbiology, 2006, 8(6): 1005-1016.
- [50] Guo G X, Deng H, Qiao M, et al. Effect of long-term wastewater irrigation on potential denitrification and denitrifying communities in soils at the watershed scale [J]. Environmental Science & Technology, 2013, 47(7): 3105-3113.
- [51] Chen X P, Zhu Y G, Xia Y, et al. Ammonia-oxidizing archaea: important players in paddy rhizosphere soil? [J]. Environmental Microbiology, 2008, 10(8): 1978-1987.
- [52] Subbarao G V, Nakahara K, Ishikawa T, et al. Free fatty acids from the pasture grass Brachiaria humidicola and one of their methyl esters as inhibitors of nitrification [J]. Plant and Soil, 2008, 313(1-2): 89-99.
- [53] Stevens R J, Laughlin R J, Malone J P. Soil pH affects the processes reducing nitrate to nitrous oxide and di-nitrogen [J]. Soil Biology & Biochemistry, 1998, 30(8-9); 1119-1126.
- [54] Sitaula B K, Bakken L R, Abrahamsen G. N-fertilization and soil acidification effects on N₂O and CO₂ emission from temperate pine forest soil [J]. Soil Biology & Biochemistry, 1995, 27 (11): 1401-1408.
- [55] Nicol G W, Leininger S, Schleper C, et al. The influence of soil pH on the diversity, abundance and transcriptional activity of ammonia oxidizing archaea and bacteria [J]. Environmental Microbiology, 2008, 10(11): 2966-2978.
- [56] Richardson D, Felgate H, Watmough N, et al. Mitigating release of the potent greenhouse gas N₂O from the nitrogen cycle-could enzymic regulation hold the key? [J]. Trends in Biotechnology, 2009, 27(7): 388-397.
- [57] Persson T, Lundkvist H, Wiren A, et al. Effects of acidification and liming on carbon and nitrogen mineralization and soil organisms in mor humus [J]. Water, Air, and Soil Pollution, 1989, 45(1-2): 77-96.

- [58] Yang W H, Weber K A, Silver W L. Nitrogen loss from soil through anaerobic ammonium oxidation coupled to iron reduction [J]. Nature Geoscience, 2012, 5(8): 538-541.
- [59] Van Cleemput O, Baert L. Nitrite: a key compound in N loss processes under acid conditions? [J]. Plant and Soil, 1984, 76 (1-3): 233-241.
- [60] Enwall K, Philippot L, Hallin S. Activity and composition of the denitrifying bacterial community respond differently to long-term fertilization [J]. Applied and Environmental Microbiology, 2005, 71(12): 8335-8343.
- [61] Case S D C, McNamara N P, Reay D S, et al. The effect of biochar addition on N₂O and CO₂ emissions from a sandy loam soil-The role of soil aeration [J]. Soil Biology & Biochemistry, 2012, 51; 125-134.
- [62] Agehara S, Warncke D D. Soil moisture and temperature effects on nitrogen release from organic nitrogen sources [J]. Soil Science Society of America Journal, 2005, 69(6): 1844-1855.
- [63] Canfield D E, Glazer A N, Falkowski P G. The evolution and future of earth's nitrogen cycle[J]. Science, 2010, 330(6001): 192-196.
- [64] 梁巍, 张颖, 岳进, 等. 长效氮肥施用对黑土水旱田 CH_4 和 N_2O 排放的影响[J]. 生态学杂志, 2004, **23**(3): 44-48.
- [65] Di H J, Cameron K C, Sherlock R R, et al. Nitrous oxide emissions from grazed grassland as affected by a nitrification inhibitor, dicyandiamide, and relationships with ammoniaoxidizing bacteria and archaea [J]. Journal of Soils and Sediments, 2010, 10(5): 943-954.
- [66] Menéndez S, Barrena I, Setien I, et al. Efficiency of nitrification inhibitor DMPP to reduce nitrous oxide emissions under different temperature and moisture conditions [J]. Soil Biology & Biochemistry, 2012, 53: 82-89.
- [67] Akiyama H, Morimoto S, Hayatsu M, et al. Nitrification, ammonia-oxidizing communities, and N₂O and CH₄ fluxes in an imperfectly drained agricultural field fertilized with coated urea with and without dicyandiamide [J]. Biology and Fertility of Soils, 2013, 49(2): 213-223.
- [68] Lehmann J. Bio-energy in the black [J]. Frontiers in Ecology and the Environment, 2007, 5(7): 381-387.
- [69] Cornelissen G, Kukulska Z, Kalaitzidis S, et al. Relations between environmental black carbon sorption and geochemical sorbent characteristics [J]. Environmental Science & Technology, 2004, 38(13); 3632-3640.
- [70] Kramer R W, Kujawinski E B, Hatcher P G. Identification of black carbon derived structures in a volcanic ash soil humic acid by Fourier transform ion cyclotron resonance mass spectrometry [J]. Environmental Science & Technology, 2004, 38 (12): 3387-3395.
- [71] Singh B P, Hatton B J, Singh B, et al. Influence of biochars on nitrous oxide emission and nitrogen leaching from two contrasting soils [J]. Journal of Environmental Quality, 2010, 39 (4): 1224-1235.
- [72] Yanai Y, Toyota K, Okazaki M. Effects of charcoal addition on

- N_2O emissions from soil resulting from rewetting air-dried soil in short-term laboratory experiments [J]. Soil Science and Plant Nutrition, 2007, ${\bf 53}(2)$: 181-188.
- [73] 王晓辉,郭光霞,郑瑞伦,等. 生物炭对设施退化土壤氮相 关功能微生物群落丰度的影响[J]. 土壤学报, 2013, **50** (3): 624-631.
- [74] Thomson A J, Giannopoulos G, Pretty J, et al. Biological
- sources and sinks of nitrous oxide and strategies to mitigate emissions[J]. Philosophical Transactions of the Royal Society of London Series B: Biological Sciences, 2012, **367**(1593): 1157-1168.
- [75] Lehmann J, Gaunt J, Rondon M. Bio-char sequestration in terrestrial ecosystems-a review [J]. Mitigation and Adaptation Strategies for Global Change, 2006, 11(2): 395-419.

《环境科学》征稿简则

- 1. 来稿报道成果要有创新性,论点明确,文字精炼,数据可靠.全文不超过8000字(含图、表、中英文摘要及参考文献).国家自然科学基金项目、国家科技攻关项目、国际合作项目或其它项目请在来稿中注明(在首页以脚注表示).作者投稿时请先登陆我刊网站(www. hjkx. ac. cn)进行注册,注册完毕后以作者身份登录,按照页面给出的提示信息投稿即可.
- 2. 稿件请按 GB 7713-87《科学技术报告、学位论文和学术论文的编写格式》中学术论文的规范撰写. 论文各部分的排列顺序为:题目;作者姓名;作者工作单位、地址、邮政编码;中文摘要;关键词;中图分类号;英文题目;作者姓名及单位的英译名;英文摘要;关键词;正文;致谢;参考文献.
 - 3. 论文题目应简练并准确反映论文内容,一般不超过20字,少用副标题.
- 4. 中文摘要不少于300字,以第三人称写. 摘要内容包括研究工作的目的、方法、结果(包括主要数据)和结论,重点是结果和结论. 英文摘要与中文对应,注意人称、时态和语言习惯,以便准确表达内容.
 - 5. 前言包括国内外前人相关工作(引文即可)和本工作的目的、特点和意义等. 科普知识不必赘述.
- 6. 文中图表应力求精简,同一内容不得用图表重复表达,要有中英文对照题目.图应大小一致,曲线粗于图框,图中所有字母、文字字号大小要统一.表用三线表.图表中术语、符号、单位等应与正文一致.
- 7. 计量单位使用《中华人民共和国法定计量单位》(SI). 论文中物理计量单位用字母符号表示,如 mg(毫克),m(米),h(小时)等. 科技名词术语用国内通用写法,作者译的新名词术语,文中第一次出现时需注明原文.
 - 8. 文中各级标题采用 1,1.1,1.1 的形式,左起顶格书写,3 级以下标题可用(1),(2) ……表示,后缩 2 格书写.
- 9. 文中外文字母、符号应标明其大小写,正斜体.生物的拉丁学名为斜体.缩略语首次出现时应给出中文全称,括号内给出英文全称和缩略语.
 - 10. 未公开发表资料不列入参考文献,可在出现页以脚注表示. 文献按文中出现的先后次序编排. 常见文献书写格式为:期刊:作者(外文也要姓列名前). 论文名[J]. 期刊名,年,卷(期):起页-止页.
 - 图书:作者. 书名[M]. 出版地:出版社,年. 起页-止页.
 - 会议文集:作者. 论文名[A]. 见(In):编者. 文集名[C]. 出版地:出版社(单位),年. 起页-止页.
 - 学位论文:作者.论文名[D].保存地:保存单位,年份.
 - 报告:作者.论文名[R].出版地:出版单位,出版年.
 - 专利:专利所有者.专利题名[P].专利国别:专利号,出版日期.
- 11. 来稿文责自负,切勿一稿多投. 编辑对来稿可作文字上和编辑技术上的修改和删节. 在 3 个月内未收到本刊选用通知,可来电询问.
- 12. 投稿请附作者单位详细地址,邮编,电话号码,电子邮箱等. 编辑部邮政地址:北京市 2871 信箱;邮编:100085;电话: 010-62941102,010-62849343;传真:010-62849343;E-mail:hjkx@rcees. ac. cn; 网址:www. hjkx. ac. cn

HUANJING KEXUE

Environmental Science (monthly)

Vol. 35 No. 2 Feb. 15, 2014

CONTENTS

Temporal of Spatial Hieróristons of Phys., and Palla, millation stans. and the Corelation of Deviation Maters and Maters and Maters and Spatial-Temporal Discisions. Intelligence on Phys., a plantable Pateclade in Beijing. Materia of Materia Parish Charles Pallace (Materia) and Spatial-Temporal Discisions. In Materia Pallace (Materia) and Materia Pallace (Materia) and Materia Pallace (Materia). In Materia Pallace (Materia) and Materia Pallace (Materia) and Materia Pallace (Materia). In Materia Pallace (Materia) and Materia Pallace (Ma	Form of the Particulate Matter Ambient Air Standards in China Seasonal Variation of Carcinogenic Heavy Metals in PM _{2, 5} and Source Analysis in Beijing	····· TAO Jun, ZHANG Ren-jian, DUAN Jing-chun, et al. (411)
Investion and Spatial Prosport Brothston Analysis on PM, published Pariculate in Spiring Markedings MCA and Marked Pariculate String Period in Naujing WANG Houge-lie, 2011 Ris, SLEN Lijsins, et al. (44) Size Definitions of Connel During the Syring Period in Naujing WANG Houge-lie, 2011 Ris, SLEN Lijsins, et al. (44) Chraceteration of Organic and Elemental Canton in PM jon Naubou Gry. SIR Medician, PENG Lis, LIU Xinsiper, et al. (48) Chraceteration of Organic and Elemental Canton in PM jon Naubou Gry. SIR Medician, PENG Lis, LIU Xinsiper, et al. (48) Sanoad Variation of Conventrions and Elemental Canton in PM jon Naubou Gry. SIR Medician, PENG Lis, LIU Xinsiper, et al. (48) Sanoad Variation of Conventrions and Elementation Characteristics of Principal Residence of String Medicine Pendels and Cance Analysis SIR Variant, PM (10), and, On Insent, et al. (410) Chemical Characteristics of Elementary Teacher of Lord Berlin and Cance Analysis Manylasis of Adol Bina Characteristics of Elementary Teacher of Lord Berlin String Medicine Delin Medicine String Medicine	Temporal and Spatial Distribution of PM _{2,5} and PM ₁₀ Pollution Status and the Correlation of Particulate Matters and Meteorological	Factors During Winter and Spring in Beijing
Characterization of Uniform Particle Ser. Bendination of the Union Annesphere of Hangabon in Spring WAND Hangele, GRI Bios., 1981. And a control bring in Spring and all Section in Surjing. Across Particles. WAND Hangele, GRI Bios., 1981. And a control of the Spring and Section of Hangeles, et al. (482) Size Distributions of Organic Calcino and Homestal Union to Surjing. Across Dec. 109. Size Distributions of Committee and Hangeles, et al. (482) Same of Warning and Elevanted Union in Phys., in Nation of Calcino and Section of the Market Calcino and Section and Hangeles, et al. (483) Same of Warning and Particle Market Entirely by Carl-Fred Bioles and Case Analysis Characterization of Manageria of Tains Biopical Background Station Union and Case Analysis Characterization of Manageria of Tains Biopical Background Station Union Longian Characterization of Manageria (1906 Acissa), the Union Calcinotrical of Attendance of Tains Biopical Background Station Union Longian Characterization of Manageria (1906 Acissa), the Union Case Acissa of Case Acissa (1908 Acissa), the Union Case Acissa (1908 Acissa), the Union Case Acissa (1908 Acissa), the Union Calcinotrical of Manageria (1908 Acissa), the Union Case Acissa (1908 Acissa) (1908 Acissa), the Union Case Acissa (1908 Acissa) (1908 Acissa), the Union Case Acissa (1908 Acissa) (1908 Acissa), and (1908 Acissa) (1908 A	Inversion and Spatial-Temporal Distribution Analysis on PM _{5.0} Inhalable Particulate in Beijing	
See Beninkstos of Uganic Lebema of Demonstral Carbon in Nanjing Aerond Particles Will Senge-long, COL Zhan-Sing, HD Fengling, et al. (\$45) Sensonal Viration of Concentrations and Destribution Characteristics of PCDD's in Atmosphere of an Industrial Area, Camaghou QING Xian, SU Yuan, SU Qing, et al. (\$46) Brazant Condition Modeling of Particulate Matters Famind by Coal-Freed Bollers and Cine Analysis Olemania Characteristics of Amount of Propinghate in Stand China San Alla Diseagewel, 1900A. Senior, et al. (\$40) Analysis of Ariel Main Characteristics of Manufolds and Mills San II D'American, MA Ham, MO Yu-ding, et al. (\$41) Analysis of Ariel Main Characteristics of Manufolds Sandania and Ham Area Ham Characteristics of Manupolecis Ningawa We Broophous in Design Under London Sandania and Ham Area Ham Characteristics of Manupolecis Ningawa We Broophous in Design Under London Sandania and Ham Area Ham Characteristics of Mark Path Patholoch Popolism in the Senguels of Longone Characteristics of The Ab Patholoch Popolism in the Senguels of Longone Characteristics of The Ab Patholoch Popolism in the Senguels of Longone Characteristics of The Ab Patholoch Popolism in the Senguels of Longone Characteristics of The Ab Patholoch Popolism in the Senguels of Longone Characteristics of The Ab Patholoch Popolism in the Senguels of Longone Characteristics of the Manuford Shid Waste four Landfli Waring, Iwas Patholoches Waste Manuford Shid Waste four Landfline Characteristics of Chinese Plante V Devel Engine Rusel on Batton-Based Bleeck Hall Control Waring, Hall Waring, Iwas Manuford Shid Waste Characteristics of Chinese Plante V Devel Engine Rusel on Batton-Based Bleeck Hall Control Waring, Hall Waring, Iwas Manuford M	Characterization of Ultrafine Particle Size Distribution in the Urban Atmosphere of Hangzhou in Spring	XIE Xiao-fang, SUN Zai, YANG Wen-jun (436)
See Beninkstos of Uganic Lebema of Demonstral Carbon in Nanjing Aerond Particles Will Senge-long, COL Zhan-Sing, HD Fengling, et al. (\$45) Sensonal Viration of Concentrations and Destribution Characteristics of PCDD's in Atmosphere of an Industrial Area, Camaghou QING Xian, SU Yuan, SU Qing, et al. (\$46) Brazant Condition Modeling of Particulate Matters Famind by Coal-Freed Bollers and Cine Analysis Olemania Characteristics of Amount of Propinghate in Stand China San Alla Diseagewel, 1900A. Senior, et al. (\$40) Analysis of Ariel Main Characteristics of Manufolds and Mills San II D'American, MA Ham, MO Yu-ding, et al. (\$41) Analysis of Ariel Main Characteristics of Manufolds Sandania and Ham Area Ham Characteristics of Manupolecis Ningawa We Broophous in Design Under London Sandania and Ham Area Ham Characteristics of Manupolecis Ningawa We Broophous in Design Under London Sandania and Ham Area Ham Characteristics of Mark Path Patholoch Popolism in the Senguels of Longone Characteristics of The Ab Patholoch Popolism in the Senguels of Longone Characteristics of The Ab Patholoch Popolism in the Senguels of Longone Characteristics of The Ab Patholoch Popolism in the Senguels of Longone Characteristics of The Ab Patholoch Popolism in the Senguels of Longone Characteristics of The Ab Patholoch Popolism in the Senguels of Longone Characteristics of the Manuford Shid Waste four Landfli Waring, Iwas Patholoches Waste Manuford Shid Waste four Landfline Characteristics of Chinese Plante V Devel Engine Rusel on Batton-Based Bleeck Hall Control Waring, Hall Waring, Iwas Manuford Shid Waste Characteristics of Chinese Plante V Devel Engine Rusel on Batton-Based Bleeck Hall Control Waring, Hall Waring, Iwas Manuford M		
Sammi Warinfor of Concentations and Destinion Characteristics of PUGD's in Anneyhere of an Industrial Acea, Gaugebau (1987). See Marsing, 10 (Jun, 1987). Control Characteristics of Precipitation in South China Su. Mahajasis (1987). See Marsing, 10 (Jun, 1987). Analysis of Acid Rain Characteristics of Armsporie Nanoya, Well Publishers of Ling and Acid Rain Characteristics of Armsporie Nanoya, Well Publishers of Ling and Acid Rain Characteristics of Armsporie Nanoya, Well Publishers of Ling and Sunday Characteristics of Armsporie Nanoya, Well Publishers of Ling and Sunday Characteristics of Armsporie Nanoya, Well Publishers of Ling and Sunday Characteristics of Armsporie Nanoya, Well Publishers of Ling and Sunday Characteristics of Lings of Sunday Characteristics of Sunday Characteristics of Lings of Sunday Characteristics of Lings of Sunday Characteristics of Lings of Sunday Characteristics of Sunday Characteristics of Lings of Sunday Characteristics of Sunday Characteristics of Sun		
Hannel Fealmien Mochling of Phrienlands Matters Emintel by Gold-Free Roberts and Case Analysis of Acid Rain Characteristics of Designation and Case Same Same Same Same Same Same Same Sam	Characterization of Organic and Elemental Carbon in PM ₁₀ in Xinzhou City	SHI Mei-xian, PENG Lin, LIU Xiao-feng, et al. (458)
Chemical Characteristics of Pacipitation in North Cham. Son. Analysis of Acid Rain Characteristics of Linius Regional Redgemund Station Using Long-term Observation Bata. 11 Zeneg-un, N. H. Ind., M. N. Veding, et al. (481) Characteristics of Almospheric Ninegae Wei Deposition in Beijing Cham. Area. 11 E. Cheng-wa, R. W. N. Was, W. N. Nachek, et al. (480) Studies of Obnee Foundaire Meteristics for Beneare and Displacences Using a Strug Chamber and Model Standarium. 13 L. Long, N. V. Yong-lin, (495) Obor Emission Rate of Municipal Studies was from Landfill Worling, Area (240) Obor Emission Rate of Municipal Studies from Landfill Worling, Area (240) Obor Emission Rate of Municipal Studies from Landfill Worling, Area (240) Obor Emission Rate of Municipal Studies from Landfill Worling, Area (240) Obor Emission Rate of Municipal Studies from Landfill Worling, Area (240) Obor Emission Rate of Municipal Studies of Dissesses of Corecultures Sea and Ammonia Daving Swine Manner Windows Composing (240) Particulate Distribution Chameteristics of Chimses Planes V Biosel Engine Based on Batanch-Bosed Blends 100 U. Be-min, X. Wing, FAN Weis-jin, et al. (528) Distributions and Influencing Institute of Visid Dissesses of Composing Confidence on Henry by Cally Sp. Composition Understance Occurred to Planes of Visid Dissesses of Composition and Confidence of Memory by Cally Sp. Composition Understance Occurred to Confidence of Benefic on Benefic Confidence on Henry by Cally Sp. Composition of Confidence of Memory of Understance Consumentation in Enging Plain 13 Confidence of Number in Different Seasons at Linche Delany Basin North Confidence of Suntwer in Different Seasons at Linche Delany Basin North Confidence of Confidence in Confidence of Suntwer in Different Seasons at Linche Delany Basin North Confidence of Confidence in Confidence of Confidence of Confidence in Confidence of Confidence of Confidence of Confidence in Confidence of Confidence of Confidence in Confidence of Confidence of Confidence of Confidence of	Seasonal Variation of Concentrations and Distribution Characteristics of PCDD/Fs in Atmosphere of an Industrial Area, Guangzhou	QING Xian, SU Yuan, SU Qing, et al. (464)
Jacksis of Acid Rain Characteristics of Linius Regional Relaymont Station Using Long-term Observation Data HE Characteristics of Phraphesic Nitrogen, We Deposition in Buijing Ushan Area HE Characteristics of Phr. Sch. Parkies Proposition in the Supposition of During Vision of Other Community Observation (Parkies) and Phraphesis of Phr. Sch. Parkies Deposition in the Supposition of Landagous Glacier No. 12 in Western (Dian Mountains, China DONG Pressor, ON Drobe, (B) Nange, et al. (501) Observation of Mountains, China DONG Pressor, (B) Nange, et al. (501) Observation of Community of the Community of Phraphesis of Chinases Pressor V Dosed Engine Based on Basand-Based Blends Dosed Destriction Characteristics of Chinases Pressor V Dosed Engine Based on Basand-Based Blends Dosed National Property on Emission of Generalized Chinases Chinases Chinases (Chinases) Pressor V Dosed Engine Based on Basand-Based Blends Dosed National Property on Emission of Generalized Schelesse Membrane Charles's Condition HIL Linguage, QU Zin, YAN Na-gia, et al. (532) Oscidation of Morning by Cally, Benezopositin Larder Cantalde-Relation Chinases (Chinases) (Parkies) (P		
Characteristics of Amospheris Winger Wet Deposition in Beijing Urkan Area Saladies of Ours Centurin Potentials for Beaters and Ehyllomene Ling a Stong Charles and Model Standardson [March 1975] And Particles Deposition in the Stampack of Ladragou Glacire NJ. 2 in Western Qilam Mountains, China [March 2076] And Particles Deposition in the Stampack of Ladragou Glacire NJ. 2 in Western Qilam Mountains, China [March 2076] And Particles Deposition in the Stampack of Ladragou Glacire NJ. 2 in Western Qilam Mountains, China [March 2076] And Particles Deposition in the Stampack of Ladragou Glacire NJ. 2 in Western Qilam Mountains, China [March 2076] And Particles Deposition in the Stampack of Ladragou Glacire NJ. 2 in Western Qilam Mountains, China [March 2076] And Particles Deposition in the Stampack of Ladragou Glacire NJ. 2 in Western Qilam Mountains, China [March 2076] And Particles Deposition in China Common Particles of China In March Windows Composition [March 2076] Deposition of Mercury by Calley, Decomposition Under Controlled Release Membrane Catalysis Condition [Mercury by Calley, Decomposition Under Controlled Release Membrane Catalysis Condition [Mercury by Calley, Decomposition Under Controlled Release Membrane Catalysis Condition [Mercury by Calley, Decomposition Under Controlled Release Membrane Catalysis Condition [Mercury by Calley, Decomposition Under Controlled Release Membrane Catalysis Condition [Mercury by Calley, Decomposition Under Controlled Release Membrane Catalysis Condition [Mercury by Calley, Decomposition Under Controlled Release Membrane Catalysis Condition [Mercury by Calley, Decomposition Under Controlled Release Membrane Catalysis Condition [Mercury by Calley, Decomposition Under Controlled Release Membrane Catalysis Condition [Mercury by Calley, Decomposition Under Controlled Release Membrane Catalysis Condition [Mercury by Calley, Decomposition Under Controlled Release Membrane Catalysis Catalysis Condition of National Pathological Pathological Catalysis Catalysis Catalysis Catalys		
Studies of Once Formation Peterialis for Bermene and Belighermene Using a None Countrie and Model Simulation (Characteristics of Fly Ash Particles Deposition in the Storopack of Landangue Glacier No. 12 in Western Qlian Munitarian, China (Science, 1984). Policy Research (Science, 1984). Policy Re		
Characteristics of Fly Ard Particles Deposition in the Nomquek of Lordupoz Calorier No. 12 in Western Qlian Mountains, China		
Oder Emissien Rater of Municipal Solid Waste from Landfill Working Area. (Eacescas Heand Remord in a Bio-Trickling Filter HE Jac-cung, HUANC (Sun-ou, CHEN Zhaw-yang, et al. (520) Particulate Distribution Characteristics of Chinese Planae V Decel Engine Rased on Batanal-Deced Blends LOU Bening, UN Ning, FAN Wen-jin, et al. (526) Effects of Unning Frequency or Emission of Georelanous Cas and Ammonia Diving Swine Manure Window Geoposing HE Lineary, UN Ning, FAN Wen-jin, et al. (526) Effects of Unning Frequency or Emission of Georelanous Cas and Ammonia Diving Swine Manure Window Geoposing HI Lineary, UN Ning, FAN Wen-jin, et al. (512) Distributions and Induscring Excitors of Total Disordered Disorpair Antimory in the Coastal Area of Zhejiang and Fijian Effects of Different Season at Linear Intelligence on Biodirection Algorithm and Its Case Study History Belavior of Nationals of Nationaris in Different Season at Linear Engineering Control of Silva Season and Control of Silva Season and Control of Silva Season and Linear Engineering in the Secienter of Taigs South River Estuary Estudion of Silvateria Silvateria in Different Season at Linear Engineering in the Secienter of Taigs South River Estuary Estudion of Silvateria Silvateria in Different Season at Linear Engineering in the Secienter of Taigs South River Estuary Estudion of Silvateria Silvateria in Different Season at Linear Estuary Estudion of Silvateria Silvateria in Different Season at Linear Estuary Estudion of Silvateria Silvateria in Different Season at Linear Estuary Estudion of Silvateria Silvateria in Estudion of Woody Plant in Ventical Flow Constructed Wetlands in the Saltonpical Area CHEN Yang-han, WU Xiao-fa, HAO Jim, et al. (587) Selection and Particulate Silvateria Caracteristics in subhardance Flow Constructed Wetlands English Silvateria Caracteristics of Silvateria Silvateri		
Gaseous Pherod Removal in a Bio-Trickling Filter (152) Particulate Distribution Chameteristics of Chiesee Phrase V Diesel Engine Based on Batami-Diesed Blends (152) Particulate Distribution Chameteristics of Chiesee Phrase V Diesel Engine Based on Batami-Diesed Blends (152) Particulate Distribution and Human Pictorial Particulate Distributions and Human Pictorial Particulate (152) Particulation of Murrary by Calle, Decomposition Under Controlled-Release Membrane Catalysis Condition (152) Particulation and Human Pictorial Particulation of Murrary by Calle, Decomposition Under Controlled-Release Membrane Catalysis Condition (152) Particulation of Allowable Pullution Loads for Lake and Reservoir Based on Bi-direction Algorithm and Its Case Study (152) Particulation of Allowable Pullution Loads for Lake and Reservoir Based on Bi-direction Algorithm and Its Case Study (152) Particulation of Vinterion in Different Seasons at Linds Festuary (152) Particulation of Numery in the Science of Chiefman Seasons at Linds Festuary (152) Particulation of Numery in the Science of Chiefman Seasons at Linds Festuary (152) Particulation of Numery in the Science of Chiefman of Woody Plant in Vertical Flow Constructed Wetlands in the Subtropical Area (152) Numery (152) Particulation of Substrate Structure and Hydraulic Chameteristics in Substrate Structure and Hydraulic Chameteristics in Substrate Structure and Hydraulic Chameteristics in Microsoft Numery (152) Particulation of Substrate Structure and Hydraulic Chameteristics in Microsoft Numery (152) Particulation of Substrate Structure and Hydraulic Chameteristics in Substrate Structure and Hydraulic Chameteristics in Numery (152) Particulation of Different Pre-oxidants on DBPs Formation Potential by Chlorination and Chloramination of Yangze River Raw Water Has Tay Substrate Numery (152) Particulation of Numery (152) Particulation of Different Pre-oxidants on DBPs Formation Potential by Chlorination and Chloramination of Yangze River Raw Water Has Tay In Jun Jun Jun Jun Jun Jun J		
Effects of Tuning Frequency on Emission of Greenbasse Gas and Ammonia During Saire Manuew Windows Composting — ZHAO Chen-yang, 11 Hangmen's Life Yuan-sang, et al. (533) Oralization of Mercup) College (Decoposition Lorder Cartella) Destributions and Influencing Factors of Youl Dissorbed Incognic Actinomy in the Coastal Area of Abrajang and Fujian — ZHANC Xu-zhou, REN Jing-ling, IUI Zong-gaung, et al. (537) Oralization of Mercup by Cultip Proceedings of Allowable Pollution Loads for Lake and Reservoir Researe on Bedienter of Allowable Pollution Loads for Lake and Reservoir Researe on Bedienter of Allowable Pollution Loads for Lake and Reservoir Researe on Bedienter of Allowable Pollution Loads for Lake and Reservoir Researe on Bedienter of Allowable Pollution Loads for Lake and Reservoir Researe on Research of Allowable Pollution Loads for Lake and Reservoir Researe on Research of Allowable Pollution Loads for Lake and Reservoir Researe of Research of Allowable Pollution Loads for Lake and Reservoir Researe of Research of Allowable Pollution Loads for Lake and Reservoir Researe of Research of Allowable Pollution Loads for Lake and Reservoir Research (Lake Research R		
Ellets of Taming Frequency and Emission of Generolause Gas and Ammonia During Svine Manure Windrow Composing 2H4O Chen-yang, I. Hong-meir, R.P. Yum-ong, et al. (541) Distributions and fullmenting Factors of Total Dissolved Integrate Healess Membeane Catalysis Condition 3 Allowable Pullution Loads for Idade and Reservoir Based on Bedieveton Algorithm and Its Case Study 2HANO Xus-bana, R.P. Ning-ling, I.U. Zong-gaung, et al. (541) Calculation of Allowable Pullution Loads for Idade and Reservoir Based on Bedieveton Algorithm and Its Case Study 2HANO Xus-bana, R.P. Ning-ling, I.U. Zong-gaung, et al. (542) Mixing Behavior of Nutrients in Different Seasons at Liade Estuary 2HANO Industrian Control Construction of Nutrients in Different Seasons at Liade Estuary 2HANO Industrian Control Constructed Wellands in the Subtropical Area and Cataly Seasons at Liade Estuary 2HANO Industrian Control Control Control Control Wellands in the Subtropical Area and Cite Study on Mixing Industrian Control Control Control Wellands in the Subtropical Area and Cite Study and Walk Study (March, 140) And and (S85) Correlation of Substants Structure and Hydradis Characteristics in Subandare Flore Constructed Wellands in the Subtropical Area and Richards Albaryama, SONG Zinia, DING Yan-li, et al. (592) Imputed of Eichhornia crossipes (Mart.) Solas Stress on the Goroth Characteristics, Microcystim and Natrients Release of Microcystia oranginosom 2HONG yan, ANN Slas-hau, et al. (685) Adaption of Phenautherone from Appears Subtines on Certifyripidinium Bounide (CPB) Adolffied Zeolite 11 Jin, 11N Jian-wein, X.N. King, RONG Rong, et al. (685) Characteristics of Different Pre-oxidations on Different in ADAT-ATA Steacher for Muricipal Walkerster Production of Phenautherone from Appears Subtines on Certifyripidinium Bounide (CPB) Adolffied Zeolite 11 Jin, 11N Jian-wein, X.N. King, et al. (685) Characteristics of Subsed Organic Mixing and Control Mixing State of Microcystia and Selectivity of Photocatalytic-Degradation of Terracycline Hydrotherionic		
Distribution of Mercury by Gulfz, Decomposition Under Controlled-Release Membrane Catalysis Condition MI Uni-gang, Qu'An, YAN Nai-qiang, et al. (541) Distributions and Influencing Factors of Total Dissolved Inorganic Antimony in the Costal Area of Zhejiang and Fujian ZHANG Xu-zhou, REN Jing-ling, LIU Zong-gang, et al. (547) (555) Risk Assessment of Quaternany Geometrater Contamination in Beijing Plain (100 Costal) and Influence Seasons at Linde Estuary Influence Costal Area of Seasons at Linde Estuary ZHANG Din-Bua, YU Lixia, YAO Qing-ghen, et al. (569) Distribution of Nitorgen in the Sediment of Taige South River Estuary MA Jin-yuan, WANG Guo-xiang, II Zhon-guo, et al. (577) Selection and Purification Potential Evaluation of Woody Plant in Vertical Plow Constructed Wellands in the Subropical Area (100 Cortection of Subardare Southern and Plantification Potential Evaluation of Woody Plant in Vertical Plow Constructed Wellands in the Subropical Area (100 Cortection of Subardare Southern and Plantification Potential Potential Evaluation of Woody Plant in Vertical Plow Constructed Wellands in the Subropical Area (100 Cortection of Subardare Southern and National Southern a		
Destribations and Influencing Factors of Total Dissolved Inarganic Antimony in the Coastal Area of Zhejiung and Fujian ZHANG Xu-abou, REN Jing-ling, LIU Zang-gaung, et al. (547) Calculation of Allowshie Pollubino Loads for Lake and Reservoir Isseed on Bri-direction Algoriulm and Its Case Study		
Calculation of Allocadels Pollution Look for Take and Reservoir Rased on Bi-direction Algorithm and Its Case Study Iki Assessment of Quaternucy Groundwater Contamination in Beijing Plain CUO Gao-xuam, I. I'u, X. U Liang, at al. (592) Bistilhoiton of Nitrogen in the Sediment of Taige South River Estuary ZHANG Jin-lum, Y. U Li-zia, YAO (Ring-then, et al. (592) Bistilhoiton of Nitrogen in the Sediment of Taige South River Estuary Ma Jio-yuam, WANG Gao-xiang, I. I Zhen-guo, et al. (572) Bistilhoiton of Nitrogen in the Sediment of Taige South River Estuary Ma Jio-yuam, WANG Gao-xiang, I. I Zhen-guo, et al. (572) Bistilhoiton of Nitrogen in the Sediment of Taige South River Estuary Ma Jio-yuam, WANG Gao-xiang, I. I Zhen-guo, et al. (585) Correlation of Substrate Structure and Hydraulic Clasureteristics in Substrated Wellands in the Subtropical Area CHEN Yong-han, WU Xiao-fu, HAO Jim, et al. (582) Impacts of Eichhornia cruzipies (Mart.) Solms Stress on the Crowth Characteristics, Microcystins and Natrients Release of Microcystic aeruginosa ZHOU Qing, HAN Shi-qua, YAN Shao-hua, et al. (592) Effects of Different Pre-oxidants on DBPs Fornation Potential by Chlorination and Chlocamination of Yangize River Raw Water Tal Na Fu-xiang, XU Bin, RONG Rong, et al. (605) Adsosption of Phenauthener from Aqueous Solution on Cetylpyridinium Bomide (CPB)-Modified Zoolite U. Jia, I. Ni Jian-revi, ZHAN Yan-Hui, et al. (611) Characterization of Biocadalysed Sublate Reduction in a Cathode of Microbial Electrohysis System Tal Substrate of Potenthenical Secondary Ellicard by Connor-biological Mentel Protection of Biocadalysed Sublate Reduction in a Cathode of Microbial Electrohysis System Talment of Petrochemical Secondary Effluent by Ozono-biological Aerated Filter III Wing-guo, WU Changyong, ZHOU Yue-si, et al. (681) Treatment of Petrochemical Secondary Effluent by Ozono-biological Aerated Filter III Wing-guo, WU Changyong, ZHOU Yue-si, et al. (681) Treatment of Petrochemical Secondary Effluent by Ozono-biological Aerated F	• • • • • • • • • • • • • • • • • • • •	
Bisk Assessment of Quaternaur, Li Yu, XU Liang, et al. (582) Mixing Behavior of Nutriens in Different Scontamination in Beijing Plain CHO Gas-man, Li Yu, XU Liang, et al. (589) Distribution of Nitrogen in the Sediment of Taige Stath Kiver Fatary MA Jin-yuan, WANG Guo-siang, Li Zhen-guo, et al. (597) Selection and Purification Potential Evaluation of Woody Plant in Vertical Flow Constructed Wetlands in the Subtropical Area CHEN Yong-han, WU Xiao-fu, HAO Jum, et al. (585) Correlation of Substate Structure and Hydraulic Characteristics in Substatice Plow Constructed Wetlands in the Subtropical Area CHEN Yong-han, WU Xiao-fu, HAO Jum, et al. (585) Correlation of Substate Structure and Hydraulic Characteristics in Substatice Plow Constructed Wetlands BAI Shao-yuan, 5006 Zhi-xin, DING Yan-li, et al. (592) Effects of Different Pre-oxidants on DBPs Formation Potential by Chlorinatoria and Chloramination of Yangzae River Raw Water TAN Fu-xiang, XU Bin, RONG Rong, et al. (607) Characteristics and Selectivity of Potocatalytic-Degradation of Tetracycline Hydrochloride Characteristics and Selectivity of Potocatalytic-Degradation of Tetracycline Hydrochloride Characteristics of Sioos-deel Organic Matter in ADAT-ATT System for Municipal Mastereater Treatment Based on Ecological Safety YANG Sai, Zillo Qi-xing, HIAI Tano (633) Membrane Surface Fooling Properties in MBRs for High-Salinity Wastewater Treatment Based on Ecological Safety YANG Sai, Zillo Qi-xing, HIAI Tano (633) Membrane Surface Fooling Properties in MBRs for High-Salinity Wastewater Treatment Based on Ecological Safety YANG Sai, Zillo Qi-xing, HIAI Tano (633) Membrane Surface Fooling Properties in MBRs for High-Salinity Wastewater Treatment Based on Ecological Safety YANG Sai, Zillo Qi-xing, HIAI Tano (633) Membrane Surface Fooling Properties in MBRs for High-Salinity Wastewater Treatment Based on Ecological Safety YANG Sai, Zillo Qi-xing, HIAI Tano (633) Membrane Surface Fooling Properties in MBRs for High-Salinity Wastewater Treatment Based on Ecol		
Ming Behavior of Nutrients in Different Seasons at Liaobe Estuary		
Distribution of Nitrogon in the Sediment of Taige Soath River Estuary Selection and Purification Potential Evaluation of Woody Plant in Vertical Flow Constructed Wetlands in the Subtropical Area		
Selection and Purification Potential Evaluation of Woody Plant in Vertical Flow Constructed Wetlands in the Subtrapical Area		
Correlation of Substrate Structure and Hydraulic Characteristics in Subsurface Flow Constructed Wetlands Impacts of Eichhornia crassips (Mart.) Solms Stress on the Growth Characteristics, Microcystins and Natrients Release of Microcystins aeraigmona History of Product of Eichhornia crassips (Mart.) Solms Stress on the Growth Characteristics, Microcystins and Natrients Release of Microcystins aeraigmona History of Product of Product of Street (1987) Effects of Different Pre-exidants on DBPs Formation Potential by Chlorination and Chloramination of Yangtze River Raw Water HAN Fu-xiang, XU Bin, RONG Rong, et al. (615) Adsorption of Phenanthrene from Aqueous Solution on Cetylpyridinium Bonnide (CPB) -Modified Zeolite LJ Jia, LM Jian-wei, ZHAN Yan-hui, et al. (611) Characteristics and Selectrivity of Photocatalytic-Degradation of Tetracycline Hydrochloride Local Characteristics of Dissolved Organic Matter in A/DAT-IAT System for Municipal Wastewater Treatment Based on Ecological Safety YANG Sai, ZHOU Qi-xing, HUA Tao (633) Membrane Surface Fouling Properties in MBRs for High-Salinity Wastewater Treatment Based on Ecological Safety YANG Sai, ZHOU Qi-xing, HUA Tao (633) Membrane Surface Fouling Properties in MBRs for High-Salinity Wastewater Treatment Hung goo, WU Chang-yong, ZHOU Yu-xi, et al. (651) Treatment of Petric Meastewater by Anaerobic Biological Process CHEN Bing-hing, XANG Chum-ping, LI Xiang, Det al. (657) Sorption Mechanism of Ofloxacin by Carbon Nanotubes HUA Sun-ping, ZANG Ting-ting, GU Hai-Jong, et al. (657) Sorption Dynamics and Breakthrough Characteristics Based on the Fluidization Condition WANG Jun, WANG Yao, HUANG Xing, et al. (678) Adsorption Dynamics and Breakthrough Characteristics Based on the Fluidization Condition WANG Jun, WANG Yao, HUANG Xing, et al. (678) Characteristics of Speciation and Evaluation of Evological Risk of Heavy Metals in Sewage Sludge of Guangibou CHO Peng-ran, LEI Yong-qian, CAll Du-chuan, et al. (684) Spatial Distribution and Accumulation of Heavy Me		
Impacts of Eichhornia crassipes (Mart.) Solms Stress on the Growth Characteristics, Microcystins and Nutrients Release of Microcystis aeruginosa ZHOU Qing, HAN Shi-qun, YAN Shao-hua, et al. (597) Effects of Different Pre-socidants on DBPs Formation Potential by Chlorination and Chloramination of Yangtee River Raw Water TIAN Fu-xiang, XU Bin, RONG Rong, et al. (605) Adsorption of Phenanthrene from Aqueous Solution on Cetylpyridinium Bromide (CPB)-Medified Zeolite LI Jia, LIN Jian-wei, ZHAY Yan-hui, et al. (611) Characteristics and Selectivity of Photocatalytic-Degradation of Tetracycline Hydrochloride SONG Chen-yi, YIN Da-ping, et al. (626) Characteristics of Dissolved Organic Mater in ArDA-HAT System for Municipal Wastewater Treatment Based on Ecological Safety YANG Sai, ZHOU Q-sing, HUA Tao (633) Membrane Surface Fouling Properties in MBRs for High-Salinity Wastewater Treatment Based on Ecological Safety YANG Sai, ZHOU Q-sing, HUA Tao (633) Membrane Surface Fouling Properties in MBRs for High-Salinity Wastewater Treatment Based on Ecological Safety YANG Sai, ZHOU Q-sing, HUA Tao (633) Membrane Surface Fouling Properties in MBRs for High-Salinity Wastewater Treatment and Preatment of Petrochemical Secondary Effluent by Ozone-biological Aerated Filter LIU Minegoso, WU Chang-yong, ZHOU Yue-si, et al. (651) Treatment of Pectric Wastewater by Anaerobic Biological Process CHEN Bing-bing, YANG Chun-ping, LI Xiang, Det al. (657) Sorption Mechanism of Ofloxacin by Carbon Nanotubes ZHAO Xing-xing, YU Shui-il, WANG Zho, (669) Adsorption Dynamics and Breakthrough Characteristics Based on the Fluidization Condition Wand Ang Jun, WANG Jun, WANG Yao, HUANG Xing, et al. (679) Adsorption Dynamics and Breakthrough Characteristics Sussessment for Polycyclic Aromatic Hydrocarbons in Surface Solidge of Guangrhou CHO Peng-ran, ET Peng-grain, CAI Decompting, et al. (684) Spatial Distribution and Accumulation of Ecological Risk of Heavy Metals in Sewage Sludge of Guangrhou CHO Peng-ran, ET Peng-grain, CAI Dec		
Effects of Different Pre-oxidants on DBPs Formation Potential by Chlorination and Chloramination of Yangzæ River Raw Water		
Effects of Different Pre-oxidants on DBPs Formation Potential by Chlorination and Chloramination of Yangtæ River Raw Water TIAN Fu-xiang, XU Bin, RONG Rong, et al. (605) Adsorption of Phenauthrene from Aqueous Solution on Cetylpyridinium Bromide (CPB)-Modified Zeolite LI Jia, LIN Jian-wei, ZHAN Yan-hui, et al. (611) Characteristics and Selectivity of Photocatalytic-Degradation of Tetracycline Hydrochloride SONG Chen-yi, XIN Da-qiang (619) Characteristics of Dissolved Organic Matter in A/DAT-IAT System for Municipal Wastewater Treatment Based on Ecological Safety YANG Sai, ZHOU Qi-xing, HUA Tao (633) Membrane Surface Fouling Properties in MBRs for High-Salinity Wastewater Treatment Based on Ecological Safety YANG Sai, ZHOU Qi-xing, HUA Tao (633) Membrane Surface Fouling Properties in MBRs for High-Salinity Wastewater Treatment Huang Properties in MBRs for High-Salinity Wastewater Treatment Huang Properties in MBRs for High-Salinity Wastewater Treatment Huang Properties in MBRs for High-Salinity Wastewater Treatment of Petrochemical Secondary Effluent by Ozone-biological Acrated Filter LIU Ming-guo, Wu Chang-yong, ZHOU Yue-xi, et al. (651) Treatment of Petric Wastewater by Anaerobic Biological Process CHEN Bing-bing, YANG Chun-ping, LI Xiang, Det al. (657) Sorption Mechanism of Ofloxacin by Carbon Nanotubes ZHAO Xing-xing, YU Shui-li, WANG Zho (663) Biosorption Characteristics of Ca ²⁺ by Spent Substrate of Pleurotus Oyster Hu Xiao-jing, ZANG Ting-ting, GU Hai-dong, et al. (669) Adsorption Dynamics and Breakthrough Characteristics Based on the Fluidization Condition WANG Jun, WANG Yao, HUANG Xing, et al. (678) Characteristics of Speciation and Evaluation of Ecological Risk of Heavy Metals for Congruence and Special Distribution and Accumulation of Heavy Metals for Huang and Canacteristics of Counged and Canacteristics of Counged and Canacteristics of Morphologic Change in Soil from Leavy Metals Contaminated Sites — YIN Xing, ZHONG Tiai-yang, et al. (704) Occurrence and Spatial Differentiation of Polycy	Impacts of Eichhornia crassipes (Mart.) Solms Stress on the Growth Characteristics, Microcystins and Nutrients Release of Microcystins	stis aeruginosa
Adsorption of Phenanthrene from Aqueous Solution on Cetylpyridinium Bromide (CPB)-Modified Zeolite		
Characteristics and Selectivity of Photocatalytic-Degradation of Tetracycline Hydrochloride Characterization of Biocatalysed Sulfate Reduction in a Cathode of Microbial Electrolysis System FU Shi-yu, IIU Guang-li, ItO Hai-ping, et al. (626) Characteristics of Dissolved Organic Matter in A/DAT-IAT System for Municipal Wastewater Treatment Based on Ecological Safety YANG Sai, ZHOU Qi-xing, HUA Tao (633) Membrane Surface Fouling Properties in MBRs for High-Salinity Wastewater Treatment III Ming-guo, WU Chang-yong, ZHOU Yue-xi, et al. (643) Treatment of Petrochemical Secondary Effluent by Ozone-biological Areated Filter III Ming-guo, WU Chang-yong, ZHOU Yue-xi, et al. (651) Treatment of Petrolin Wastewater by Anaerobic Biological Process CHEN Bing-bing, YANG Chun-ping, II Xiang, Det al. (657) Sorption Mechanism of Olfoxacin by Carbon Nanotubes ZHAO Xing-xing, YU Shui-li, WANG Zhe (663) Biosorption Characteristics of Cu ² by Spent Substrate of Pleurolus Oyster HU Xiao-jing, ZANG Ting-ting, GU Hai-dong, et al. (669) Biosorption Dynamics and Breakthrough Characteristics Based on the Fluidization Condition WANG Jun, WANG Yao, HUANG Xing, et al. (678) Characteristics of Speciation and Evaluation of Ecological Risk of Heavy Metals in Sewage Sludge of Guangzhou GUO Peng-ran, LEI Yong-qian, CAI Da-chuan, et al. (684) Spatial Distribution and Accumulation of Heavy Metal in Arable Land Soil of China ZHANG Xiao-min, ZHANG Xiu-ying, ZHONG Tai-yang, et al. (692) Pollution Patterns and Health Risk Assessment for Polychlorinated Biphenyls in Soils from a Capacitor Storage Site ZHOU Ling-li, WU Guang-long, XUE Nan-dong, et al. (704) Occurrence and Spatial Differentiation of Polycyclic Aromatic Hydrocarbons in Surface Soils from Shenzhen, China ZHANG Xiao-min, ZHANG Xiu-ying, ZHONG Tai-yang, et al. (719) Effects of Group Matching Curing Agent on Exchangeable Pb, Cd, Zn Contents in the Potted Soils and their Accumulation in Rice Plants ZENG Hui, ZHOU Hang, QIU Qiong-yao, et al. (727) Impact of Compounded Chelants on Removal of Hea		
Characterization of Biocatalysed Sulfate Reduction in a Cathode of Microbial Electrolysis System		
Characteristics of Dissolved Organic Matter in A/DAT-IAT System for Municipal Wastewater Treatment Based on Ecological Safety YANG Sai, ZHOU Qi-xing, HUA Tao (633) Membrane Surface Fouling Properties in MBRs for High-Salinity Wastewater Treatment LI Bin, WANG Zhi-wei, AN Ying, et al. (643) Treatment of Petrochemical Secondary Effluent by Ozone-biological Aerated Filter LIU Ming-guo, WU Chang-yong, ZHOU Yue-xi, et al. (651) Treatment of Petrochemical Secondary Effluent by Ozone-biological Aerated Filter LIU Ming-guo, WU Chang-yong, ZHOU Yue-xi, et al. (657) Treatment of Petrochemical Secondary Effluent by Ozone-biological Process CHEN Bing-bing, YANG Chun-ping, Li Xiang, Det al. (657) Sorption Mechanism of Ofloxacin by Carbon Nanotubes JHAO Xing-xing, YU Shui-li, WANG Zho (663) Biosorption Characteristics of Cu ²⁺ by Spent Substrate of Pleurotus Oyster HU Xiao-jing, ZANG Ting-ting, CU Hai-dong, et al. (669) Adsorption Dynamics and Breakthrough Characteristics Based on the Fluidization Condition WANG Jun, WANG Yao, HUANG Xing, et al. (684) Spatial Distribution and Accumulation of Heavy Metal in Arable Land Soil of China ZHANG Xiao-min, SUN Jian-lin, et al. (704) Occurrence and Spatial Differentiation of Polycyclic Aromatic Hydrocarbons in Surface Soils from Shenzhen, China ZHANG Di, CAO Shan-ping, SUN Jian-lin, et al. (711) Risk Assessment and Countermeasures of Heavy Metals Pollution in Wanquan Segment of Yanghe River TAN Bing, WANG Tie-yu, ZHU Zhao-yun, et al. (712) Effects of Group Matching Curing Agent on Exchangeable Pb, Cd, Zn Contents in the Potted Soils and their Accumulation in Rice Plants ———————————————————————————————————		
Membrane Surface Fouling Properties in MBRs for High-Salinity Wastewater Treatment II Bin, WANG Zhi-wei, AN Ying, et al. (643) Treatment of Petrochemical Secondary Effluent by Ozone-biological Aerated Filter IIU Ming-guo, WU Chang-yong, ZHOU Yue-xi, et al. (651) Treatment of Petrochemical Secondary Effluent by Ozone-biological Aerated Filter IIU Ming-guo, WU Chang-yong, ZHOU Yue-xi, et al. (651) Sorption Mechanism of Ofloxacin by Carbon Nanotubes CHEN Bing-bing, YANG Chun-ping, LI Xiang, Det al. (663) Sorption Mechanism of Ofloxacin by Carbon Nanotubes THO Xiang-ping, ZHOU Shui-li, WANG Zhe (663) Biosorption Characteristics of Ca ²⁺ by Spent Substrate of Pleurotus Oyster HU Xiang-jing, ZANG Ting-ting, GU Haid-dong, et al. (669) Adsorption Dynamics and Breakthrough Characteristics Based on the Fluidization Condition WANG Jun, WANG Yao, HUANG Xing, et al. (669) Adsorption Dynamics and Breakthrough Characteristics Based on the Fluidization Condition WANG Jun, WANG Yao, HUANG Xing, et al. (684) Spatial Distribution and Accumulation of Ecological Risk of Heavy Metals in Sewage Sludge of Guangzhou CUO Peng-ran, LEI Yong-qian, CAI Da-chuan, et al. (684) Spatial Distribution and Accumulation of Heavy Metal in Arable Land Soil of China ZHANG Xiao-min, ZHANG Xiao-min, ZHANG Xiu-ying, ZHONG Tai-yang, et al. (692) Pollution Patterns and Health Risk Assessment for Polychlorinated Biphenyls in Soils from a Capacitor Storage Site ZHOU Ling-li, WU Guang-long, XUE Nan-dong, et al. (704) Occurrence and Spatial Differentiation of Polycyclic Aromatic Hydrocarbons in Surface Soils from Shenzhen, China ZHANG Di, CAO Shan-ping, SUN Jian-lin, et al. (711) Risk Assessment and Countermeasures of Heavy Metals Pollution in Wanquan Segment of Yanghe River TAN Bing, WANG Tie-yu, ZHU Zhao-yun, et al. (719) Effects of Group Matching Curing Agent on Exchangeable Pb, Cd, Zn Contents in the Potted Soils and their Accumulation in Rice Plants ZENG Hui, ZHOU Hang, QIU Qiong-yao, et al. (727) Impact of Compounded Chelant		
Treatment of Petrochemical Secondary Effluent by Ozone-biological Aerated Filter LIU Ming-guo, WU Chang-yong, ZHOU Yue-xi, et al. (651) Treatment of Pectin Wastewater by Anaerobic Biological Process CHEN Bing-bing, YANG Chun-ping, LI Xiang, Det al. (657) Soption Mechanism of Ofloxacin by Carbon Nanotubes ZHAO Xing-xing, TU Shui-li, WANG Zhe (663) Biosoption Characteristics of Cu ²⁺ by Spent Substrate of Pleurotus Oyster HU Xiao-jing, ZANG Ting-ting, GU Hai-dong, et al. (669) Adsorption Dynamics and Breakthrough Characteristics Based on the Fluidization Condition WANG Jun, WANG Yao, HUANG Xing, et al. (678) Characteristics of Speciation and Evaluation of Ecological Risk of Heavy Metals in Sewage Sludge of Guangzhou CUO Peng-ran, LEI Yong-qian, CAI Da-chuan, et al. (684) Spatial Distribution and Accumulation of Heavy Metal in Arable Land Soil of China ZHANG Xiao-min, ZHANG Xiu-ying, ZHONG Tai-yang, et al. (692) Pollution Patterns and Health Risk Assessment for Polychlorinated Biphenyls in Soils from a Capacitor Storage Site ZHOU Ling-li, WU Guang-long, XUE Nan-dong, et al. (704) Occurrence and Spatial Differentiation of Polycyclic Aromatic Hydrocarbons in Surface Soils from Shenzhen, China ZHANG Di, CAO Shan-ping, SUN Jian-lin, et al. (711) Risk Assessment and Countermeasures of Heavy Metals Pollution in Wanquan Segment of Yanghe River TAN Bing, WANG Tie-yu, ZHU Zhao-yun, et al. (719) Effects of Group Matching Curing Agent on Exchangeable Pb, Cd, Zn Contents in the Potted Soils and their Accumulation in Rice Plants ZENG Hui, ZHOU Hang, QlU Qiong-yao, et al. (727) Impact of Compounded Chelants on Removal of Heavy Metals and Characteristics of Morphologic Change in Soil from Heavy Metals Contaminated Sites ZHOU Na-na, BAI Yao-hui, LIANG Jin-song, et al. (740) Effects of the Ratio of NO ₃ ⁻ -N to NO ₂ ⁻ -N on the Removal of Sulfide and Nitrogen by Mixed Culture and Pure Culture CHEN Zi-ai, CHEN Hui-juan, WEI Ben-ping, et al. (746) Effects of the Ratio of NO ₃ ⁻ -N to NO ₂ ⁻ -N on the R		
Treatment of Pectin Wastewater by Anaerobic Biological Process CHEN Bing-bing, YANG Chun-ping, Ll Xiang, Det al. (657) Sorption Mechanism of Ofloxacin by Carbon Nanotubes ZHAO Xing-xing, YU Shui-li, WANG Zhe (663) Biosorption Characteristics of Cu ²⁺ by Spent Substrate of Pleurotus Oyster HU Xiao-jing, ZANG Ting-ting, GU Hai-dong, et al. (669) Adsorption Dynamics and Breakthrough Characteristics Based on the Fluidization Condition WANG Jun, WANG Yao, HUANG Xing, et al. (678) Characteristics of Speciation and Evaluation of Ecological Risk of Heavy Metals in Sewage Sludge of Guangzhou GUO Peng-ran, LEI Yong-qian, CAI Da-chuan, et al. (684) Spatial Distribution and Accumulation of Heavy Metal in Arable Land Soil of China Spatial Distribution Patterns and Health Risk Assessment for Polychlorinated Biphenyls in Soils from a Capacitor Storage Site ZHANG Xiao-min, ZHANG Xiu-ying, ZHONG Tai-yang, et al. (692) Pollution Patterns and Health Risk Assessment of Polycyclic Aromatic Hydrocarbons in Surface Soils from Shenzhen, China ZHANG Di, CAO Shan-ping, SUN Jian-lin, et al. (711) Risk Assessment and Countermeasures of Heavy Metals Pollution in Wanquan Segment of Yanghe River TAN Bing, WANG Tie-yu, ZHU Zhao-yun, et al. (719) Effects of Group Matching Curing Agent on Exchangeable Pb, Cd, Zn Contents in the Potted Soils and their Accumulation in Rice Plants ZENG Hui, ZHOU Hang, QIU Qiong-yao, et al. (727) Impact of Compounded Chelants on Removal of Heavy Metals and Characteristics of Morphologic Change in Soil from Heavy Metals Contaminated Sites YIN Xue, CHEN Jia-jun, LÜ Ce (733) Characterization of Manganese Oxidation by Pseudomonas sp. QIX-1 ZHOU Na-na, Bal Yao-hui, LIANG Jin-song, et al. (746) Effects of the Ratio of NO ₃ -N to NO ₂ -N on the Removal of Sulfide and Nitrogen by Mixed Culture and Pure Culture CHEN Zi-ai, CHEN Hui-juan, WEI Ben-ping, et al. (746) Carbon Metabolic Characteristics of Airborne Microbes in Hangzhou Study on the Backward Extraction of Cellulase in Rhamnolipid Reverse Micel		
Sorption Mechanism of Ofloxacin by Carbon Nanotubes		
Biosorption Characteristics of Cu ²⁺ by Spent Substrate of Pleurotus Oyster		
Adsorption Dynamics and Breakthrough Characteristics Based on the Fluidization Condition		
Characteristics of Speciation and Evaluation of Ecological Risk of Heavy Metals in Sewage Sludge of Guangzhou		
Spatial Distribution and Accumulation of Heavy Metal in Arable Land Soil of China		
Pollution Patterns and Health Risk Assessment for Polychlorinated Biphenyls in Soils from a Capacitor Storage Site ZHOU Ling-li, WU Guang-long, XUE Nan-dong, et al. (704) Occurrence and Spatial Differentiation of Polycyclic Aromatic Hydrocarbons in Surface Soils from Shenzhen, China ZHANG Di, CAO Shan-ping, SUN Jian-lin, et al. (711) Risk Assessment and Countermeasures of Heavy Metals Pollution in Wanquan Segment of Yanghe River TAN Bing, WANG Tie-yu, ZHU Zhao-yun, et al. (719) Effects of Group Matching Curing Agent on Exchangeable Pb, Cd, Zn Contents in the Potted Soils and their Accumulation in Rice Plants ZENG Hui, ZHOU Hang, QIU Qiong-yao, et al. (727) Impact of Compounded Chelants on Removal of Heavy Metals and Characteristics of Morphologic Change in Soil from Heavy Metals Contaminated Sites YIN Xue, CHEN Jia-jun, LÜ Ce (733) Characterization of Manganese Oxidation by Pseudomonas sp. QIX-1 Effects of the Ratio of NO ₃ ⁻ -N to NO ₂ ⁻ -N on the Removal of Sulfide and Nitrogen by Mixed Culture and Pure Culture CHEN Zi-ai, CHEN Hui-juan, WEI Ben-ping, et al. (746) Carbon Metabolic Characteristics of Airborne Microbes in Hangzhou GONG Chan-juan, XU Jing, FANG Zhi-guo, et al. (753) Study on the Backward Extraction of Cellulase in Rhamnolipid Reverse Micelles ZHAO Yan-ge, YUAN Xing-zhong, HUANG Hua-jun, et al. (759) Inner- and Inter-Species Differences of Mercury Concentration in Common Fishes from the Yellow Sea ZHO Xin-juan, WI Zhan-zhou, LIU Gui-ze, et al. (764) Study on the Effect of Enzymatic Activity and Acute Toxicity of Three PAEs on Eisenia foetida WANG Yan, MA Ze-min, WU Shi-jin (770) Environmental Safety Assessment on the New Super Absorbent Polymers Applied into a Soil-Chinese Cabbage System LI Xi, HE Ji-zheng, ZHENG Yuan-ming, et al. (786)		
Occurrence and Spatial Differentiation of Polycyclic Aromatic Hydrocarbons in Surface Soils from Shenzhen, China ZHANG Di, CAO Shan-ping, SUN Jian-lin, et al. (711) Risk Assessment and Countermeasures of Heavy Metals Pollution in Wanquan Segment of Yanghe River TAN Bing, WANG Tie-yu, ZHU Zhao-yun, et al. (719) Effects of Group Matching Curing Agent on Exchangeable Pb, Cd, Zn Contents in the Potted Soils and their Accumulation in Rice Plants ZENG Hui, ZHOU Hang, QIU Qiong-yao, et al. (727) Impact of Compounded Chelants on Removal of Heavy Metals and Characteristics of Morphologic Change in Soil from Heavy Metals Contaminated Sites YIN Xue, CHEN Jia-jun, LÜ Ce (733) Characterization of Manganese Oxidation by Pseudomonas sp. QJX-1 Effects of the Ratio of NO ₃ ⁻ -N to NO ₂ ⁻ -N on the Removal of Sulfide and Nitrogen by Mixed Culture and Pure Culture CHEN Zi-ai, CHEN Hui-juan, WEI Ben-ping, et al. (746) Carbon Metabolic Characteristics of Airborne Microbes in Hangzhou GONG Chan-juan, XU Jing, FANG Zhi-guo, et al. (753) Study on the Backward Extraction of Cellulase in Rhamnolipid Reverse Micelles ZHAO Yan-ge, YUAN Xing-zhong, HUANG Hua-jun, et al. (759) Inner- and Inter-Species Differences of Mercury Concentration in Common Fishes from the Yellow Sea ZHU Ai-jia, XU Zhan-zhou, LIU Gui-ze, et al. (764) Study on the Effect of Enzymatic Activity and Acute Toxicity of Three PAEs on Eisenia foetida WANG Yan, MA Ze-min, WU Shi-jin (770) Environmental Safety Assessment on the New Super Absorbent Polymers Applied into a Soil-Chinese Cabbage System LI Xi, HE Ji-zheng, ZHENG Yuan-ming, et al. (780) Study on Dynamics of Hydrogen Sulfide and Carbonyl Sulfide Emission Fluxes from Suaeda salsa Marsh in the Yellow River Estuary LI Xin-hua, GUO Hong-hai, YANG Li-ping, et al. (786)	· ·	
Risk Assessment and Countermeasures of Heavy Metals Pollution in Wanquan Segment of Yanghe River		
Effects of Group Matching Curing Agent on Exchangeable Pb, Cd, Zn Contents in the Potted Soils and their Accumulation in Rice Plants ZENG Hui, ZHOU Hang, QIU Qiong-yao, et al. (727) Impact of Compounded Chelants on Removal of Heavy Metals and Characteristics of Morphologic Change in Soil from Heavy Metals Contaminated Sites		
Impact of Compounded Chelants on Removal of Heavy Metals and Characteristics of Morphologic Change in Soil from Heavy Metals Contaminated Sites YIN Xue, CHEN Jia-jun, LÜ Ce (733) Characterization of Manganese Oxidation by Pseudomonas sp. QJX-1	Effects of Group Matching Curing Agent on Exchangeable Pb., Cd., Zn Contents in the Potted Soils and their Accumulation in Rice	Plants
Impact of Compounded Chelants on Removal of Heavy Metals and Characteristics of Morphologic Change in Soil from Heavy Metals Contaminated Sites YIN Xue, CHEN Jia-jun, LÜ Ce (733) Characterization of Manganese Oxidation by Pseudomonas sp. QJX-1		ZENG Hui, ZHOU Hang, QIU Qiong-yao, et al. (727)
Effects of the Ratio of NO $_3^-$ -N to NO $_2^-$ -N on the Removal of Sulfide and Nitrogen by Mixed Culture and Pure Culture		
Carbon Metabolic Characteristics of Airborne Microbes in Hangzhou	Characterization of Manganese Oxidation by Pseudomonas sp. QJX-1	······ ZHOU Na-na, BAI Yao-hui, LIANG Jin-song, et al. (740)
Study on the Backward Extraction of Cellulase in Rhamnolipid Reverse Micelles	Effects of the Ratio of NO ₃ ⁻ -N to NO ₂ ⁻ -N on the Removal of Sulfide and Nitrogen by Mixed Culture and Pure Culture	······· CHEN Zi-ai, CHEN Hui-juan, WEI Ben-ping, et al. (746)
Inner- and Inter-Species Differences of Mercury Concentration in Common Fishes from the Yellow Sea	Carbon Metabolic Characteristics of Airborne Microbes in Hangzhou	······ GONG Chan-juan, XU Jing, FANG Zhi-guo, et al. (753)
Study on the Effect of Enzymatic Activity and Acute Toxicity of Three PAEs on Eisenia foetida		
Environmental Safety Assessment on the New Super Absorbent Polymers Applied into a Soil-Chinese Cabbage System		
Study on Dynamics of Hydrogen Sulfide and Carbonyl Sulfide Emission Fluxes from Suaeda salsa Marsh in the Yellow River Estuary LI Xin-hua, GUO Hong-hai, YANG Li-ping, et al. (786)		
	Environmental Safety Assessment on the New Super Absorbent Polymers Applied into a Soil-Chinese Cabbage System	LI Xi, HE Ji-zheng, ZHENG Yuan-ming, et al. (780)
Key Microbial Processes in Nitrous Oxide Emissions of Agricultural Soil and Mitigation Strategies	· · · · · · · · · · · · · · · · · · ·	
	Key Microbial Processes in Nitrous Oxide Emissions of Agricultural Soil and Mitigation Strategies	ZHU Yong-guan, WANG Xiao-hui, YANG Xiao-ru, et al. (792)

《环境科学》第6届编辑委员会

主 编:欧阳自远

副主编:赵景柱 郝吉明 田 刚

编 委: (按姓氏笔画排序)

万国江 王华聪 王凯军 王绪绪 田 刚 田 静 史培军

朱永官 刘志培 汤鸿霄 陈吉宁 孟 伟 周宗灿 林金明

欧阳自远 赵景柱 姜 林 郝郑平 郝吉明 聂永丰 黄 霞

黄耀 鲍强潘纲潘涛魏复盛

环维种草

(HUANJING KEXUE)

(月刊 1976年8月创刊)

2014年2月15日 35卷 第2期

ENVIRONMENTAL SCIENCE

(Monthly Started in 1976)
Vol. 35 No. 2 Feb. 15, 2014

2	014 年 2 月 13 日 53 仓 第 2 朔		,
主	中国科学院	Superintended by	Chinese Academy of Sciences
主	中国科学院生态环境研究中心	Sponsored by	Research Center for Eco-Environmental Sciences, Chinese
协 が	N (以参加先后为序)		Academy of Sciences
	北京市环境保护科学研究院	Co-Sponsored by	Beijing Municipal Research Institute of Environmental
	清华 大学环境学院		Protection
主 纲			School of Environment, Tsinghua University
编辑		Editor-in -Chief	OUYANG Zi-yuan
>m +	北京市 2871 信箱(海淀区双清路	Edited by	The Editorial Board of Environmental Science (HUANJING
	18 号,邮政编码:100085)		KEXUE)
	电话:010-62941102,010-62849343		P. O. Box 2871, Beijing 100085, China
	传真:010-62849343		Tel:010-62941102,010-62849343; Fax:010-62849343
	E-mail; hjkx@ rees. ac. cn		E-mail:hjkx@ reees. ac. cn
	http://www.hjkx.ac.en		http://www.hjkx.ac.cn
出 覑	1	Published by	Science Press
_ ~ ~	北京东黄城根北街 16 号		16 Donghuangchenggen North Street,
	邮政编码:100717		Beijing 100717, China
印刷装订		Printed by	Beijing Bei Lin Printing House
发 往	5 斜华出版社	Distributed by	Science Press
	电话:010-64017032		Tel:010-64017032
	E-mail:journal@mail.sciencep.com		E-mail:journal@mail.sciencep.com
订购负	全国各地邮电局	Domestic	All Local Post Offices in China
国外总发行	· 中国国际图书贸易总公司	Foreign	China International Book Trading Corporation (Guoji
	(北京 399 信箱)		Shudian), P. O. Box 399, Beijing 100044, China

中国标准刊号: ISSN 0250-3301 CN 11-1895/X

国内邮发代号: 2-821

国内定价:90.00元

国外发行代号: M 205

国内外公开发行