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封面图说: 黄河的宁夏段属于中国的半荒漠地区,这里气候干燥、降水极少(250mm 以下)、植被缺乏、物理风化强烈、风力作用强劲、其蒸发量超过降水量数十倍。人们从黄河中提水引水灌溉土地,就近形成了荒漠中的绿洲。有水就有生命,有水就有绿色。这种独特的条件形成了人与沙较量的生态关系——不是人逼沙退就是沙逼人退。

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

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不同包膜控释尿素对农田土壤氨挥发的影响

卢艳艳¹, 宋付朋^{1,2,*}

(1. 山东农业大学资源与环境学院, 泰安 271018; 2. 山东农业大学作物生物学国家重点实验室, 泰安 271018)

摘要:为了探索包膜控释尿素土壤氨挥发损失规律特征和提高肥料氮素利用率, 采用小麦玉米轮作田间试验, 通过与普通尿素进行对比, 运用土壤氨挥发原位测定方法——通气法系统研究了硫包膜和树脂包膜控释尿素的施用对小麦玉米轮作农田土壤氨挥发的影响。研究表明: 在两种施氮量水平下 (210 kg/hm² 和 300 kg/hm²), 与普通尿素相比, 硫包膜和树脂包膜控释尿素在小麦基肥期、小麦追肥期和玉米施肥期的施用均减少了土壤氨挥发的累积损失量, 分别达 35.1%—54.3%、59.6%—75.2%、65.6%—98.1%; 有效降低了土壤氨挥发通量峰值且延迟其出现时间 3—8 d, 并能延缓土壤氨挥发主要阶段的时间分别为 4—12 d、5—12 d。在小麦玉米轮作周年中, 控释尿素土壤氨挥发累积损失量为 28.39—43.35 kg/hm², 土壤氨挥发损失率为 4.48%—5.63%, 控释尿素时段土壤氨挥发通量比普通尿素降低了 51.0%—70.8%; 且树脂包膜控释尿素的施用降低小麦玉米轮作农田土壤氨挥发的效果优于硫包膜控释尿素。

关键词: 硫包膜; 树脂包膜; 控释尿素; 农田; 土壤氨挥发

Effects of different coated controlled-release urea on soil ammonia volatilization in farmland

LU Yanyan¹, SONG Fupeng^{1,2,*}

1 College of Resources and Environment, Shandong Agricultural University, Taian 271018, China

2 State Key Laboratory of Crop Biology, Shandong Agricultural University, Taian 271018, China

Abstract: Nitrogen fertilization has become one of the important components of agricultural management to guarantee high and stable crop production. China has only 7% of the world's arable land but consumes 35% of the global nitrogen fertilizer. Nitrogen fertilizers are used excessively and the nitrogen use efficiency is only 20%—40%. Apart from some residuals remaining in the soil, most of the excess nitrogen enters the air or water sources, and therefore causes serious environmental pollution. Ammonia volatilization is an important pathway through which nitrogen is lost to the atmosphere. Identifying methods to reduce the ammonia volatilization of nitrogen fertilizer is an important task for agricultural management. Given the increasing prominence of China's food and environmental safety, improvements in agricultural management are important. The application of controlled-release urea fertilizers may be one of the most effective measures to solve the problems of high fertilizer usage and low efficiency rate that leads to pollution.

A field experiment was conducted to evaluate the effects of controlled-release urea coated with sulfur or with polymer on soil ammonia volatilization in a wheat-corn rotation system. The venting method was used for the in situ determination of ammonia volatilization from October 2008 to October 2009 at a Huang-Huai-Hai region test site. The results showed that the flux and the accumulated loss of ammonia with the controlled-release urea fertilizers were significantly lower than those with the common urea fertilizer when the fertilizers were applied at 210 kg/hm² or 300 kg/hm², and at the wheat basal, wheat

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* 通讯作者 Corresponding author. E-mail: fpsong@sdau.edu.cn

top dressing and maize fertilization stages. The time to reach 80% of total loss of nitrogen through ammonia volatilization with the controlled-release urea fertilizer coated with sulfur and with polymer was 4—12 and 5—12 days longer, respectively, than that with the common urea fertilizer at the fertilizer rate of 210 kg/hm².

During the wheat growth season, the soil ammonia volatilization flux with the two controlled-release urea fertilizers increased slowly, and their flux peaks were significantly lower (by 1.6—3.3 kg·hm⁻²·d⁻¹) and later (by 3—8 days) than those with the common urea fertilizer. The time ammonia volatilization flux (193 days) and the accumulated loss amounts of ammonia volatilization over this period with the controlled-release urea fertilizers were significantly lower than those with the common urea fertilizer. The flux and the loss amounts were both lower by 45.4%—61.0%. The ammonia volatilization loss rate of the controlled-release urea fertilizers was lower than that of the common urea fertilizer by 4.7%—5.7%. The soil ammonia volatilization flux peak when using the sulfur-coated controlled-release urea fertilizer was earlier and higher than that when using the polymer-coated controlled-release urea fertilizer. The accumulated ammonia loss amounts when using the sulfur-coated controlled-release urea fertilizer was higher (by 5.8%—10.7%) than that when using the polymer-coated controlled-release urea fertilizer.

During the maize growth season, the soil ammonia volatilization flux peaks with the two controlled-release urea fertilizers were later (by 3—5 days) and the peaks lower (by 1.9—5.2 kg·hm⁻²·d⁻¹) than those with the common urea fertilizer. The ammonia volatilization flux peak when using the sulfur-coated controlled-release urea fertilizer was higher than that when using the polymer-coated controlled-release urea fertilizer; it increased by 76.9% and 12.2% under the high and low levels of nitrogen fertilizer (300 and 210 kg/hm²), respectively. The time ammonia volatilization flux (67 days) and the accumulated loss amounts of ammonia volatilization when using the two controlled-release urea fertilizers were both lower (by 65.6—98.1%) than that when using the common area fertilizer. The ammonia loss rates were also lower by 2.7%—3.3%. The accumulated loss amounts with sulfur-coated fertilizer was higher than those with polymer-coated fertilizer by 19.7% at the fertilizer rate of 300 kg/hm²; however there was no significant difference at the rate of 210 kg/hm².

During the wheat-corn rotation growth period, the controlled-release urea fertilizers coated with polymer or with sulfur was able to significantly reduce the time ammonia volatilization flux and loss rate. The time flux was 0.11—0.17 kg/(hm²·d) over the whole period (260 days). The total loss amount of the soil ammonia when using the controlled-release urea fertilizers (coated with sulfur or with polymer) was 28.39—43.35 kg/hm², which was lower than that of the common urea fertilizer by 51.0—70.8%. The loss rate of soil ammonia of the controlled-release urea fertilizers was 4.48%—5.63%, which was lower (by 3.7%—4.5%) than that of the common urea fertilizer.

Based on our findings, controlled-release urea fertilizers can significantly reduce soil ammonia volatilization, and therefore may cause less pollution than common urea fertilizers. The controlled-release urea fertilizer coated with polymer was found to have more desirable properties than the controlled-release urea fertilizer coated with sulfur.

Key Words: sulfur-coated; polymer-coated; controlled-release urea; farmland; soil ammonia volatilization

目前,氮肥的施用成为保障我国农业高产的重要手段。我国仅占世界7%的耕地却消耗了全球35%的氮肥,氮肥施用过量现象严重,而氮肥利用率仅有20%—40%^[1-3],除了残留在土壤中以外,大部分氮素以各种形式进入到大气或水环境。这不仅加大氮肥投入,导致氮肥资源的大量浪费,产生巨大的经济损失,而且引起土壤酸化和水体富营养化等环境问题,对农业生态系统造成严重危害。其中氨挥发是氮素损失的主要途径之一,专家估算我国农田氮肥的氨挥发损失率在11%左右,其对肥料氮损失的贡献率可达5%—47%^[2]。因此,降低农田土壤氨挥发能够提高氮肥资源的利用效率,并有利于保护农业生态环境。

降低土壤氨挥发损失的途径有很多种,例如改进施肥技术,添加化学物质(如沸石,硅酸钠,羧甲基纤维素钠),混施尿素——氯化钾等来降低土壤微域的pH值,从而减少土壤氨挥发。近年来,人们试图通过改变

肥料本身的特性来抑制土壤氮挥发,提高氮肥利用率,例如脲甲醛、尿酶抑制剂等缓/控释肥料的开发已成为国内外的研究热点^[4-6]。土壤氮挥发的研究方法有间歇通气法、风洞法、微气象学法、质量平衡法、模型法、密闭气室法等。这些方法各有优缺点,其中通气法是在密闭法基础上改进的,与其它方法相比,这种方法装置简单,组合方便,条件易控,成本低廉,测定结果的准确度和精确度高,回收率高达 99.51%,变异系数仅为 0.77%^[7]。

国内外关于土壤氮素淋溶损失的影响研究已有大量报道^[8-11],而对施用控释肥料土壤氮素挥发损失的影响研究相对较少,且多以盆栽和室内模拟为主^[12-13],小麦玉米轮作体系农田土壤氮挥发的田间原位测定试验更少,尤为缺少硫包膜和树脂包膜控释尿素对小麦玉米轮作体系农田土壤氮挥发的影响研究。因此本试验采用通气法研究了硫包膜和树脂包膜控释尿素对粮食主产区黄淮海平原小麦玉米轮作农田土壤氮挥发的影响,以期验证控释尿素能减少土壤氮挥发,提高氮肥利用率,为从环境友好的角度选择合理肥料及其大面积的推广应用提供科学依据。

1 材料和方法

1.1 供试材料

供试肥料:氮肥品种分别为山东省泰安市肥城阿斯德化工厂生产的普通颗粒尿素(N:46%);山东金正大生态工程股份有限公司生产的“沃夫特”硫包膜和树脂包膜控释尿素(《GB/T 23348—2009 缓释肥料》),硫包膜控释尿素养分(N)35%,树脂包膜控释尿素养分(N)43%,养分释放期均为 3 个月。磷肥为湖北祥云产粉末状过磷酸钙(P_2O_5 14%)。钾肥为俄罗斯产红色大颗粒氯化钾(K_2O 60%)。

供试作物:小麦品种选用山农 15;玉米品种选用郑单 958。

1.2 试验设计

田间试验布置在山东农业大学南校区黄淮海区域(山东)玉米技术创新中心,供试土壤类型为潮褐土(土壤系统分类为斑纹筒育干润淋溶土),作物种植方式为小麦/玉米轮作。该地区地属半湿润暖温带大陆性季风气候,全年的降水量集中在 6—9 月,年均降水量约为 700 mm,年均温 11—15℃。耕层土壤部分理化性质为:pH 值 7.89,电导率 149.13 $\mu S/cm$,有机质 8.33 g/kg,速效钾 50.09 mg/kg,有效磷 22.68 mg/kg,全氮 0.30 g/kg,硝态氮 11.14 mg/kg,铵态氮 2.24 mg/kg。

本试验于 2008 年 10 月—2009 年 10 月进行,共设 0,210,300 kg/hm^2 3 个施氮水平 7 个处理:1) 无氮肥对照 CK;2) 高量普通尿素 HCU;3) 低量普通尿素 LCU;4) 高量硫包膜控释尿素 HSU;5) 低量硫包膜控释尿素 LSU;6) 高量树脂包膜控释尿素 HPU;7) 低量树脂包膜控释尿素 LPU。其中,高量和低量处理的施氮量分别为 300,210 kg/hm^2 ;施磷量和施钾量分别为 105,210 kg/hm^2 。每个处理设四次重复,小区面积 22.5 m^2 ,不同小区随机排列。小麦季氮肥施用量各小区按照处理 2/3 基施、1/3 追施分两次施入土壤;玉米季各处理肥料在播种之日作基肥一次性施入。小麦基施和追施为撒施,玉米基施的施肥方式是用耩隔行条施。小麦基肥,追肥,玉米施肥分别于 2008 年 10 月 24 日,2009 年 3 月 11 日,2009 年 6 月 22 日进行。

1.3 测定方法

土壤氮挥发的捕获方法采用通气法^[7,14],测定采用凯氏定氮法。在施肥当天开始进行土壤氮挥发气体的收集,施肥后第 2 天 8:00 取样,试验开始第 1 周,每天取样 1 次;第 2—3 周,每 2 d 取样 1 次,以后延长到 7 d 取样 1 次,直至监测不到氮挥发时为止。

1.4 数据分析

试验数据均采用 SAS(SAS Institute, 1999) 软件进行统计分析。田间土壤的氮挥发通量和氮挥发损失率的计算公式分别为:

土壤氮挥发通量($kg \cdot hm^{-2} \cdot d^{-1}$) = 单个装置每次所测氮量 / (捕获装置横截面积 \times 每次连续捕获时间)

土壤氮挥发损失率(%) = (施肥区土壤氮挥发累积损失量 - 对照区土壤氮挥发累积损失量) / 土壤施氮量 $\times 100$

2 结果与分析

2.1 硫包膜和树脂包膜控释尿素对小麦玉米不同施肥期土壤氨挥发的影响

2.1.1 硫包膜和树脂包膜控释尿素对小麦基肥期土壤氨挥发通量及其累积损失量的影响

小麦基肥期(小麦播种—返青拔节期)控释尿素土壤氨挥发通量及其累积损失量如图1,图2所示。硫包膜和树脂包膜控释尿素,普通尿素土壤氨挥发通量峰值分别出现在施肥后第6,7,3天,其大小顺序为:普通尿素>硫包膜控释尿素>树脂包膜控释尿素。在两种施氮量水平下(210、300 kg/hm²),与普通尿素相比,硫包膜和树脂包膜控释尿素土壤氨挥发通量峰值分别降低1.8—3.2 kg·hm⁻²·d⁻¹和2.8—3.3 kg·hm⁻²·d⁻¹,峰值出现时间分别推迟了3,4 d。硫包膜控释尿素比树脂包膜控释尿素土壤氨挥发通量峰值高出了0.2—0.9 kg·hm⁻²·d⁻¹。

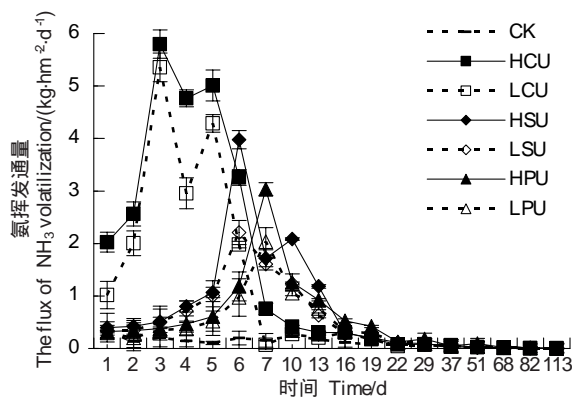


图1 小麦基肥期不同处理的土壤氨挥发通量

Fig.1 Flux of soil ammonia volatilization of different treatments at wheat basal stage

CK 无氮肥对照; HCU 高量普通尿素; LCU 低量普通尿素; HSU 高量硫包膜控释尿素; LSU 低量硫包膜控释尿素; HPU 高量树脂包膜控释尿素; LPU 低量树脂包膜控释尿素

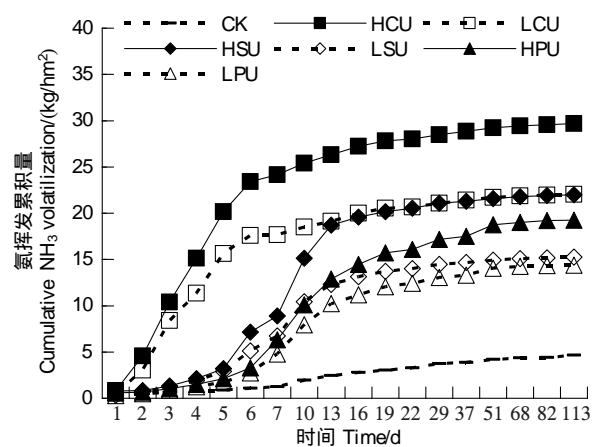


图2 小麦基肥期不同处理的土壤氨挥发累积损失量

Fig.2 Accumulation loss amounts of soil ammonia volatilization of different treatments at wheat basal stage

在小麦基肥期,硫包膜和树脂包膜控释尿素土壤氨挥发累积损失量显著低于普通尿素,降低百分数分别为35.1%—44.6%和53.0%—54.3%;其中硫包膜控释尿素土壤氨挥发累积损失量高于树脂包膜控释尿素,高出百分数达5.8%—14.3%。

可见,相同氮肥品种处理不同施氮量水平下,土壤氨挥发通量和氨挥发累积损失量随着施氮量的减少而降低;不同氮肥品种处理则表现为控释尿素土壤氨挥发通量、氨挥发累积损失量均低于普通尿素,且树脂包膜控释尿素低于硫包膜控释尿素。

2.1.2 硫包膜和树脂包膜控释尿素对小麦追肥期土壤氨挥发通量和累积损失量的影响

小麦追肥期(返青拔节期至成熟期),硫包膜、树脂包膜控释尿素处理与普通尿素处理的土壤氨挥发通量和氨挥发累积损失量变化趋势与小麦基肥期相似,但数值均低于小麦基肥期(图3,图4)。

小麦追肥后,各处理的土壤氨挥发通量和氨挥发累积损失量随着施氮量的增加而增加。在高、低两种施氮量水平下(210 kg/hm²和300 kg/hm²),与普通尿素相比,硫包膜和树脂包膜控释尿素土壤氨挥发通量峰值出现时间分别延迟了5,8 d,且二者的土壤氨挥发通量峰值降低范围分别为1.6—2.2 kg·hm⁻²·d⁻¹和1.9—2.3 kg·hm⁻²·d⁻¹;其中树脂包膜比硫包膜控释尿素降低0.1—0.3 kg·hm⁻²·d⁻¹。各处理土壤氨挥发累积损失量大小顺序为:普通尿素>硫包膜控释尿素>树脂包膜控释尿素;在高、低两种施氮量水平下,两种控释尿素土壤氨挥发累积损失量比普通尿素降低59.6%—75.2%;硫包膜比树脂包膜控释尿素高了3.1%—5.7%。

2.1.3 硫包膜和树脂包膜控释尿素对玉米施肥期土壤氨挥发通量和累积损失量的影响

在玉米施肥期的土壤氨挥发监测期间,所有氮肥处理的土壤氨挥发通量可分为快速和慢速两个阶段

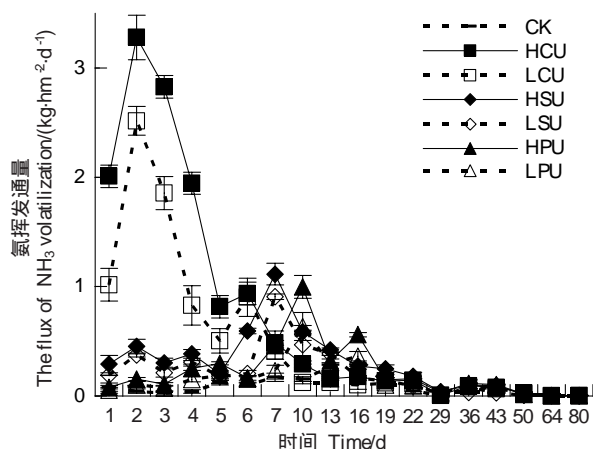


图3 小麦追肥期不同处理的土壤氨挥发通量

Fig.3 Flux of soil ammonia volatilization of different treatments at wheat top dressing stage

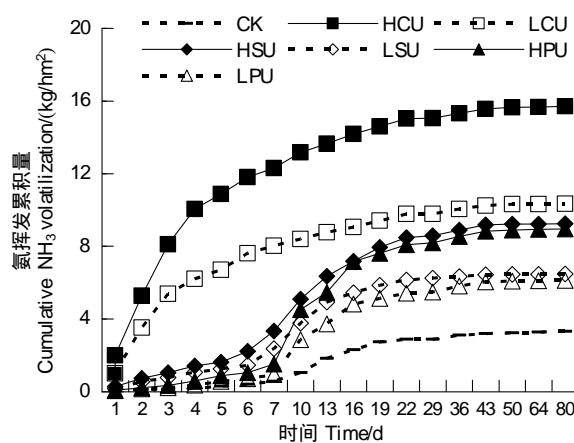


图4 小麦追肥期不同处理的土壤氨挥发累积损失量

Fig.4 Accumulation loss amounts of soil ammonia volatilization of different treatments at wheat top dressing stage

(图5,图6)。相同氮肥品种处理的土壤氨挥发通量随着施氮量的减少而降低,且不同施氮量水平下其峰值出现的时间相同。两种控释尿素与普通尿素在相同施氮量水平下,土壤氨挥发通量峰值差异显著。与普通尿素相比,两种控释尿素土壤氨挥发通量峰值出现的时间延后3—5 d,峰值降低1.9—5.2 kg·hm⁻²·d⁻¹;与树脂包膜控释尿素相比,硫包膜控释尿素峰值出现时间早且其峰值大,在高、低两种施氮量水平下,硫包膜比树脂包膜控释尿素土壤氨挥发通量峰值分别提高了76.9%和12.2%。

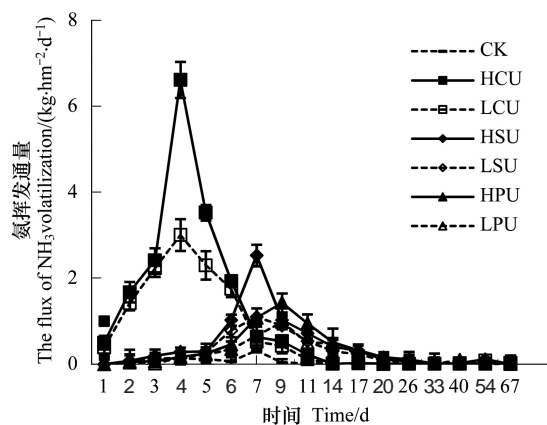


图5 玉米施肥期不同处理的土壤氨挥发通量

Fig.5 Flux of soil ammonia volatilization of different treatments at maize fertilization stage

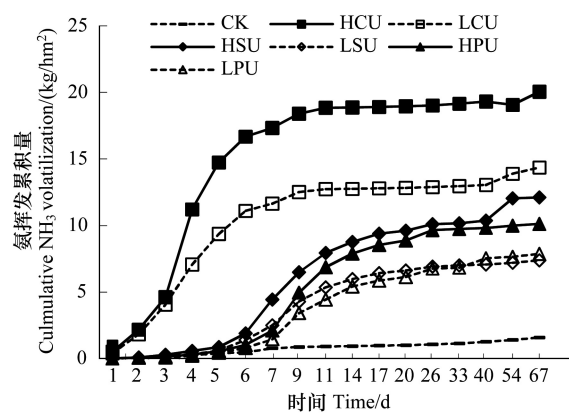


图6 玉米施肥期不同处理的土壤氨挥发累积损失量

Fig.6 Accumulation loss amounts of soil ammonia volatilization of different treatments at maize fertilization stage

在玉米施肥期,硫包膜和树脂包膜控释尿素土壤氨挥发累积损失量显著低于普通尿素,降低范围在65.6%—98.1%。控释尿素的土壤氨挥发累积损失量是先慢后快的变化趋势,高施氮量水平下(300 kg/hm²),树脂包膜比硫包膜控释尿素降低了19.7%,低施氮量水平下(210 kg/hm²),则差异不明显。

2.2 硫包膜和树脂包膜控释尿素对小麦玉米轮作农田土壤氨挥发持续时长的影响

将小麦基肥期、追肥期与玉米施肥期土壤氨挥发累积量百分比(各施肥期每次监测土壤氨挥发累积量占其累积损失总量的百分数)与监测时间进行作图并拟合,得出相应拟合曲线和方程(图7)。在300 kg/hm²与210 kg/hm²施氮量水平下,土壤氨挥发累积量百分比曲线大体相似,因而仅对低施氮量水平(210kg/hm²)土壤氨挥发累积量百分比与时间进行拟合。运用伯恩斯坦定理与C语言编程解析拟合方程,得到各处理土壤氨

挥发累积量百分比为 80% 对应持续挥发的天数,并根据小麦和玉米轮作时期不同的土壤条件、气候条件等影响因素进行选择确定。

根据拟合方程,在 210 kg/hm²施氮量水平下,硫包膜、树脂包膜控释尿素和普通尿素处理土壤氨挥发累积量百分比为 80% 对应持续挥发的天数在小麦玉米轮作体系不同施肥时期各不相同,小麦基肥期分别为 19、19、7 d;小麦追肥期为 19、19、7 d;玉米生长期为 11、12、7 d。控释尿素比普通尿素延缓的天数,小麦基肥期为 12 d、小麦追肥期为 12 d、玉米生长期为 4—5 d;在玉米生长期,树脂包膜控释尿素比硫包膜最长能够延续 1 d 左右,而在小麦生长期差异不明显。

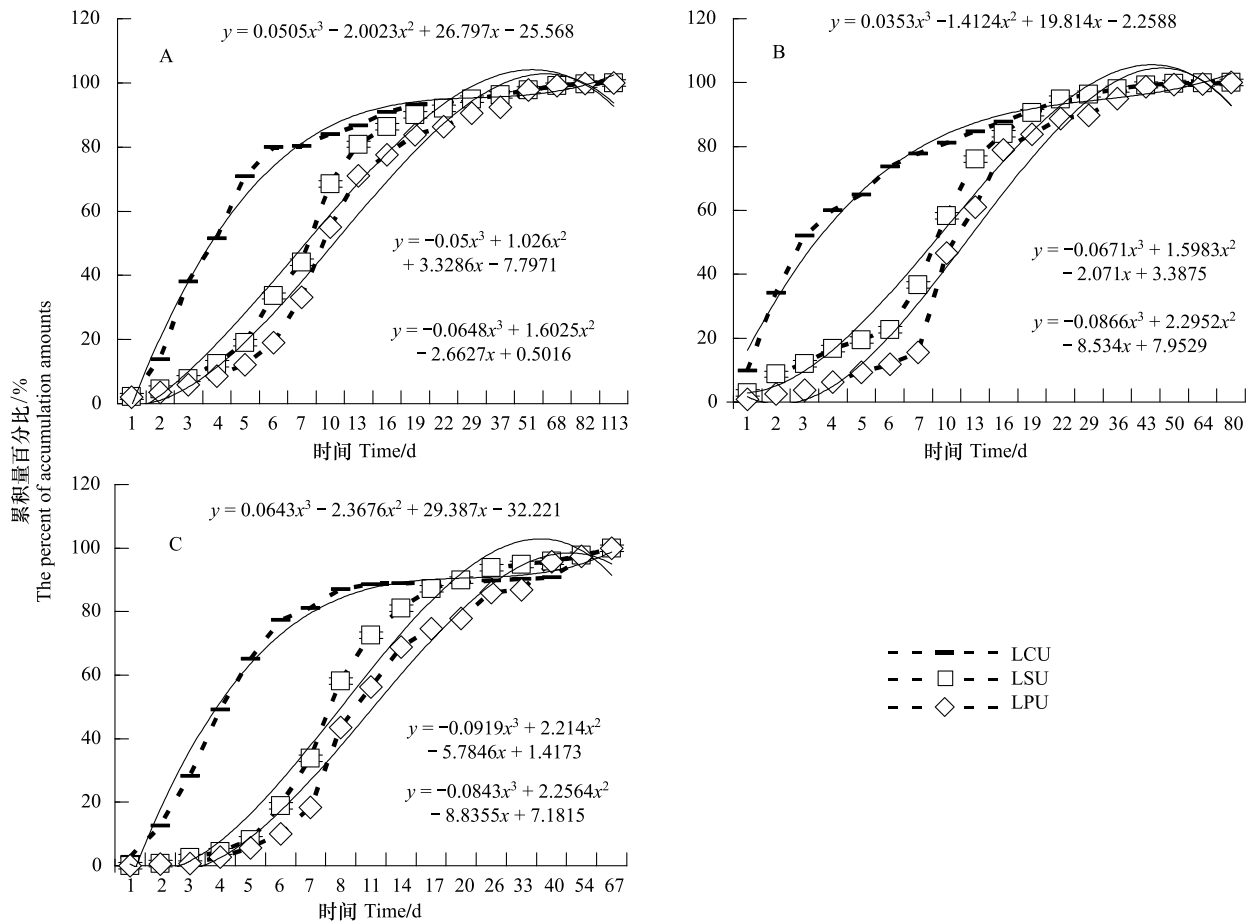


图7 小麦基肥期(A)、小麦追肥期(B)、玉米施肥期(C) 210 kg/hm²施氮量水平下土壤氨挥发累积量百分比与时间拟合方程

Fig. 7 Fitted equations of the percent of soil ammonia volatilization accumulation amounts and time at wheat basal stage, top dressing stage and maize fertilization stage under 210 kg/hm² (N)

LCU 低量普通尿素; LSU 低量硫包膜控释尿素; LPU 低量树脂包膜控释尿素

由于普通尿素施入土壤后水解成铵态氮而挥发迅速,因此普通尿素处理土壤氨挥发主要集中于施肥后一周内;而包膜控释尿素对养分的控释是通过膜上的微孔和裂隙来实现的,包膜材料阻隔了尿素与部分土壤尿酶的直接接触,减少了参与土壤氨挥发的底物氮素^[15],从而有效延缓了土壤氨挥发的主要阶段,最长能够比普通尿素推迟 12 d。硫膜与树脂膜相比,硫膜易溶解和破碎,所以树脂包膜控释尿素降低土壤氨挥发效果优于硫包膜控释尿素。

2.3 硫包膜和树脂包膜控释尿素小麦玉米轮作周期时段土壤氨挥发通量和累积损失量的影响

小麦玉米轮作体系中,在低量(210 kg/hm²)和高量(300 kg/hm²)两种施氮水平下,硫包膜、树脂包膜控释尿素处理时段土壤氨挥发通量和累积损失量与普通尿素处理相比差异显著(表 1)。

小麦季,控释尿素时段土壤氨挥发通量、累积损失量和损失率分别为 0.11—0.16 $\text{kg}\cdot\text{hm}^{-2}\cdot\text{d}^{-1}$ 、20.53—31.24 kg/hm^2 和 5.98%—7.75%;玉米季,控释尿素时段土壤氨挥发通量、累积损失量和损失率分别为 0.11—0.18 $\text{kg}\cdot\text{hm}^{-2}\cdot\text{d}^{-1}$ 、7.37—12.11 kg/hm^2 和 2.76%—3.51%。与普通尿素相比,小麦季时段土壤氨挥发通量和累积损失量均降低 45.4%—61.0%,损失率降低了 4.7%—5.7%;玉米季时段土壤氨挥发通量和累积损失量均降低 65.6%—98.1%,损失率降低了 2.7%—3.3%。

表 1 不同监测期的土壤氨挥发累积损失量、损失率和通量

Table 1 Accumulative loss amounts, loss rate and flux of soil ammonia volatilization in different monitoring periods

处理 Treatments	小麦季节(监测期 193d) Wheat growth season			玉米季节(监测期 67d) Maize growth season			小麦玉米轮作周期(共 260d) Wheat-corn rotation growth period		
	累积损失量 /(kg/hm^2)	损失率/%	时段氨挥发通量 /($\text{kg}\cdot\text{hm}^{-2}\cdot\text{d}^{-1}$)	累积损失量 /(kg/hm^2)	损失率/%	时段氨挥发通量 /($\text{kg}\cdot\text{hm}^{-2}\cdot\text{d}^{-1}$)	累积损失量 /(kg/hm^2)	损失率/%	时段氨挥发通量 /($\text{kg}\cdot\text{hm}^{-2}\cdot\text{d}^{-1}$)
	Accumulative loss amounts	Loss rate	Time flux	Accumulative loss amounts	Loss rate	Time flux	Accumulative loss amounts	Loss rate	Time flux
CK	7.98d	—	0.04	1.58e	—	0.02	9.56e	—	0.04
HCU	45.41a	12.48	0.24	20.05a	6.16	0.30	65.46a	9.32	0.25
LCU	32.37b	11.61	0.17	14.37a	6.09	0.21	46.74b	8.85	0.18
HSU	31.24b	7.75	0.16	12.11b	3.51	0.18	43.35b	5.63	0.17
LSU	21.72c	6.54	0.11	7.37d	2.76	0.11	29.09d	4.65	0.11
HPU	28.21b	6.74	0.15	10.12c	2.85	0.15	38.33c	4.80	0.15
LPU	20.53c	5.98	0.11	7.86d	2.99	0.12	28.39d	4.48	0.11

同一列内同一品种不同字母表示差异达 5% 显著水平 ($n=3$)

在整个小麦玉米轮作周期,各试验处理的时段土壤氨挥发通量均有一定差异。硫包膜、树脂包膜控释尿素时段土壤氨挥发通量比普通尿素分别降低 51.0%—60.7% 和 64.6%—70.8%,而树脂包膜比硫包膜控释尿素处理降低了 2.5%—13.1%。

土壤氨挥发累积损失量大小顺序均为:普通尿素>硫包膜控释尿素>树脂包膜控释尿素;其中,两种包膜控释尿素周年土壤氨挥发累积损失量和损失率在 28.39—43.35 kg/hm^2 和 4.48%—5.63%,比普通尿素分别降低 51.0%—70.8% 和 3.7%—4.5%。两种控释尿素土壤氨挥发损失差异不显著,硫包膜比树脂包膜控释尿素土壤氨挥发累积损失量、损失率分别要高 2.5%—13.1% 和 0.2%—0.8%。与杜建军^[15] 模拟试验得出的控释氮肥比普通尿素减少氨挥发损失达 30% 以上的结果相近,只是降低幅度更大,且与赵斌^[16] 等在玉米田间试验的研究结果一致。

3 结论

(1) 在小麦基肥期、小麦追肥期和玉米施肥期,与普通尿素相比,硫包膜和树脂包膜控释尿素均能推迟土壤氨挥发通量峰值的出现 3—8 d,降低了土壤氨挥发通量峰值,最大降幅达 1.9—5.2 $\text{kg}\cdot\text{hm}^{-2}\cdot\text{d}^{-1}$;3 个时期显著减少土壤氨挥发累积损失量分别达 35.1%—54.3%、59.6%—75.2%、65.6%—98.1%;树脂包膜控释尿素在两种施氮量水平下土壤氨挥发降低效果优于硫包膜控释尿素。

(2) 硫包膜和树脂包膜控释尿素均能有效延缓土壤氨挥发的主要阶段,普通尿素施用后 7 d 内土壤氨挥发累积量达到 80%,硫包膜和树脂包膜控释尿素比普通尿素分别延迟了 4—12 d、5—12 d。

(3) 硫包膜和树脂包膜控释尿素能够明显降低小麦季、玉米季和轮作周年时段土壤氨挥发通量和损失率,控释尿素的不同时段土壤氨挥发通量均在 0.11—0.18 $\text{kg}\cdot\text{hm}^{-2}\cdot\text{d}^{-1}$ 范围内;损失率最高仅为 7.75%。在整个轮作周期,控释尿素土壤氨挥发累积损失量为 28.39—43.35 kg/hm^2 ;土壤氨挥发损失率为 4.48%—5.63%,比普通尿素分别降低了 51.0%—70.8% 和 3.7%—4.5%;硫包膜和树脂包膜控释尿素具有较高的生态环境效应和推广价值。

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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
主 管 中国科学技术协会
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
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