生活垃圾堆肥淋洗液培植无土草皮的生态特征

多立安[1]，廉　菲[1]，赵树兰[1]，滕　萌[1]，王礼莉[1]，高玉葆[2]

（1. 天津师范大学化学与生命科学学院，天津　300387；2. 南开大学生命科学学院，天津　300071）

摘要：以生活垃圾堆肥淋洗液培植无土草皮，结果表明，垃圾堆肥淋洗液中有机质、全氮、有效磷及其它营养元素含量显著高于对照土壤淋洗液，能够充分满足草坪植物生长需要。高浓度淋洗液使黑麦草和高羊茅种子萌发高峰期推迟出现，但不影响发芽率，到萌发第 11 天，种子发芽率分别达到 94% 和 92% 以上。对黑麦草而言，80% 的淋洗液可显著提高植株高度、地上生物量和叶绿素含量；对高羊茅，60% 的淋洗液则为最佳浓度。当淋洗液培植的无土草皮进行田间铺坪 90 d 时，黑麦草和高羊茅草皮地上生物量分别达到 5.38 g/块和 7.89 g/块，并显著高于对照草皮（$P<0.05$），而地下生物量和根长差异不显著。垃圾堆肥淋洗液改变了黑麦草和高羊茅植株地上/地下生物量的分配格局，使其根冠比降低，其分别为 4.60 和 3.71，并明显低于对照。从坪用性状上看，铺坪后垃圾堆肥淋洗液培养的草皮叶色深绿，质地柔软光滑，明显优于土壤淋洗液培养的对照草皮。

关键词：生活垃圾堆肥；淋洗液；草坪植物；无土草皮

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Ecological characteristics of soilless sods cultivated by leachate from a municipal solid waste compost

DUO Li-An[1], LIAN Fei[1], ZHAO Shu-Lan[1], TENG Meng[1], WANG Li-Li[1], GAO Yu-Bao[2]

1 *College of Chemistry and Life Sciences, Tianjin Normal University, Tianjin 300387, China*

2 *College of Life Sciences, Nankai University, Tianjin 300071, China*

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Abstract: The water leachate from a municipal solid waste (MSW) compost may contain higher contents of organic matters and nutritive elements such as nitrogen, phosphorus and potassium than soil leachate. The MSW compost leachate, if utilized rationally, could be a useful resource for plant growth. In this work, the leachate from a MSW compost was used to cultivate soilless sods of *Lolium perenne* L. and *Festuca arundinacea* L. Initial growth of the two turfgrasses with different percentages of the compost leachate showed that the 100%-leachate caused a slight delay in germination peak but did not reduce the germination rates of *L. perenne* and *F. arundinacea*, which reached above 94% and 92% respectively on the 11^{th} d. For *L. perenne*, the 80%-leachate significantly improved the plant height, aboveground biomass, and chlorophyll content. For *F. arundinacea*, 60% was found to be the optimum leachate concentration. Then with the leachate at the optimum concentrations, the soilless sods of the two turfgrasses were cultivated in a simulated climate box under 16 – 22℃, and relative humidity 36% – 57%. After a 72-d growth, the soilless sods were transplanted to a plot and cultivated for

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作者简介：多立安（1962 ~），男，达斡尔族，黑龙江人，博士，教授，主要从事草业生态、生态工程及环境生态研究. E-mail：duolian_tjnu@163.com

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Biography: DUO Li-An, Ph. D., Professor, mainly engaged in pratacultural ecology, ecological engineering and environmental ecology. E-mail: duolian_tjnu@163.com

another 90 days in order to examine the feasibility of using the leachate for cultivating the sods.

On the 90th d after sodding in the field, the aboveground biomass of *L. perenne* and *F. arundinacea* reached 5.38 g/block and 7.89 g/block, respectively, which were significantly higher than those of control. But there were no significant differences in underground biomass and root length. Compared with control, the compost leachate greatly reduced root/shoot ratios of *L. perenne* and *F. arundinacea*. Besides, the sod greenness as well as the leaf texture, uniformity, density, and quality were considerably improved.

Key Words: municipal solid waste compost; leachate; rurfgrass; soilless sod

当今城市生活垃圾(下称垃圾)造成的污染已成为亟待解决的环境问题之一,因此,垃圾资源化利用得到了广泛关注[1,2];而堆肥处理是垃圾资源化利用的重要方法之一[3~5]。垃圾堆肥中含有丰富的有机质,及氮、磷、钾与其它微量元素,这些是植物可利用营养源的基础[6]。尽管垃圾堆肥利用潜力很大,但如果堆肥处理及施用不当,也会引起环境问题[7~12]。

淋洗法是一个从污染土壤、污泥、沉积物中去除有机和无机污染物的过程;它是一个物理和化学过程,能够实现某些污染物的分离减量、隔离及污染物的无害化转变[13]。淋洗法是一项经济的修复污染土壤技术,目前,已有较为详尽的报道[14~19];而利用淋洗法修复生活垃圾堆肥污染研究还尚无文献报道。但需要指出的是,有关利用淋洗液滴灌用于作物栽培的研究已有少量报道[20~23]。同样,生活垃圾堆肥淋洗液中含有丰富的植物生长所需的营养物质,若能将其回收作为无土栽培营养液,进行草皮培植,则无疑是一条利用途径。

另一方面,草坪绿化规模与水平已成为衡量现代化城市环境质量的重要客观标准[24,25]。但是在草皮生产中,每完成一次草皮生产过程,至少要铲去 2 cm 以上的熟土,经连续 3 ~4 次草皮生产过程,肥沃的农田即遭到破坏[26]。再有,近些年来,尽管无土栽培技术在农业栽培各个领域发展很快,但在草皮生产中的应用仍处于研究阶段;此外,现有无土栽培营养液不但制备具有一定难度,而且价格较高。基于上述原因,本研究在淋洗法修复垃圾堆肥基础上,进一步研究将淋洗液用作草皮培植的无土营养液,通过草坪植物的生长响应和成坪效果的评价,为垃圾堆肥修复及淋洗液利用提供基础数据支持。

1 材料与方法

1.1 实验材料

垃圾堆肥来自天津市小淀垃圾堆肥处理厂,经烘干后过 2 mm 筛。草坪植物选用多年生黑麦草(*Lolium perenne* L.)和高羊茅(*Festuca arundinacea* L.)。

1.2 垃圾淋洗液的制备

称取 150 g 的垃圾堆肥,加入 300 ml 的去离子水,充分搅拌后浸泡 24 h。用定性滤纸过滤,所得溶液为堆肥淋洗液。以相同方法制备土壤淋洗液,最后将淋洗液置于棕色瓶内,于 4℃ 冰箱冷藏备用。

1.3 研究方法

1.3.1 垃圾堆肥与对照土壤淋洗液本底背景分析

垃圾堆肥和土壤淋洗液有机质含量采用重铬酸钾容量法测定[27]。有效磷采用 Na_2CO_3浸提-钼锑抗比色法[28]。全氮采用半微量凯氏定氮法。全钾、钠、钙、镁、微量矿质元素及重金属含量采用电感耦合等离子体原子发射光谱法(ICP-AES)[29]。

1.3.2 堆肥淋洗液浸种

垃圾堆肥淋洗液浸种浓度共设 6 个处理:0%(去离子水,CK)、20%、40%、60%、80%及 100%(即原浓度淋洗液),实验为 4 次重复。浸种培养在直径为 5.7 cm 的培养皿中进行,培养皿底部垫两层滤纸为培养基底,选优质饱满的两种草坪草种子各 50 粒放置于其上,再分别加入不同浓度的淋洗液。浸种实验在 18 ~23℃,相对湿度 40% ~70% 的条件下进行。萌发后每天记录发芽数,连续记录 15 d。最后一天从各皿随机取 5 株,

分别测定株高及地上部鲜重、干重。

1.3.3 淋洗液无土草皮培植

依据前期堆肥淋洗液浸种研究获得结果,80%淋洗液对于黑麦草、60%淋洗液对于高羊茅较为适宜。按上述淋洗液制备方法制备足够的堆肥淋洗原液,再分别稀释成80%和60%,用于两种草皮的无土培植。

培植容器为医用托盘,其规格为24 cm×18 cm×3 cm,托盘底部铺入0.5 cm厚淘洗干净的细河沙,再于其上垫一层孔径为0.5 cm尼龙网,而后在尼龙网上面铺一张面巾纸。播种密度为40 g/m^2,1周后,待种子萌发稳定时,每天分别浇1次等体积的淋洗液40 mL,直至实验结束;实验以土壤淋洗液为对照,3次重复。草皮培植在人工气候箱内进行,温度为16~22℃,相对湿度为36%~57%,实验共持续72 d。

在各盘内分别选5株进行标记,每5 d测定1次株高。播种后第30天对地上部进行刈割,留茬高度为3 cm,同时测定地上生物量和叶绿素含量。待二茬草生长30 d后,再对其地上部进行第2次刈割,留茬高度为3 cm,并分别测定地上、地下生物量(鲜重及干重)和叶绿素含量[30]。

1.3.4 无土草皮田间铺坪实验

将淋洗液无土草皮于春末铺坪到实验地,土壤属壤质草甸土。铺坪前充分整地,草皮卷南北横向铺坪,间距为20 cm。实验期间,适量浇水,并随时进行杂草清除。秋季进行起皮,铺坪共计90 d。测定指标包括:观测绿度和质地等性能;地上、地下生物量;根长、入土深度以及分布;评价淋洗液无土草皮铺坪性能。

2 结果与分析

2.1 垃圾堆肥与土壤淋洗液背景分析

淋洗液中有机质、全氮和有效磷含量分别是土壤的3.71、39.85倍和6.48倍;K、Na、Ca和Mg离子含量分别是土壤的8.39、5.98、2.01倍和1.52倍(表1)。可见,垃圾堆肥淋洗液含有丰富的有机质和营养物质,能够充分满足草坪植物生长所需[20]。对淋洗液分析结果表明:堆肥淋洗液中Mn、Ni、Cu、Pb、Cd等重金属含量明显高于土壤淋洗液,因此,利用植物等修复加以处置利用较为适宜(表1)。此外,淋洗液中Na、Ca和Mg含量也较高[31]。

表1 垃圾堆肥与土壤淋洗液的背景分析(mg kg^{-1})

Table 1 Background of leachates from MSW compost and soil (mg kg^{-1})

测定指标 Indexes	堆肥淋洗液 Leachate from compost	土壤淋洗液 Leachate from soil
pH	7.62 ± 0.04	8.30 ± 0.09
有机质% Organic matter	12.12 ± 0.17	3.27 ± 0.08
全氮% Total N	5.18 ± 0.07	0.13 ± 0.005
有效磷 Available P	77.92 ± 11.53	12.03 ± 0.20
K	291.30 ± 7.24	34.73 ± 3.39
Na	1110.33 ± 18.77	185.63 ± 3.35
Ca	829.90 ± 42.73	413.83 ± 8.25
Mg	233.50 ± 9.10	154.00 ± 7.20
Fe	0.29 ± 0.07	—
Mn	0.15 ± 0.001	0.07 ± 0.002
Ni	0.36 ± 0.09	—
Cu	0.19 ± 0.007	—
Zn	1.10 ± 0.27	0.15 ± 0.01
Pb	0.25 ± 0.01	—
Cd	0.03 ± 0.01	—
B	2.46 ± 0.42	—
Co	0.63 ± 0.10	0.34 ± 0.09

2.2 淋洗液浸种对草坪植物种子萌发及幼苗生长的影响

高浓度淋洗液可导致两种草坪植物种子发芽高峰期推迟出现(表2)。20%、40%和60%淋洗液处理的黑麦草与对照相比,萌发情况没有显著差异,发芽高峰期都出现在发芽后的第3天。100%的淋洗液处理,发芽高峰期出现在发芽后的第4天,发芽势为41%,明显低于对照和20%、40%和60%的淋洗液处理。7 d以后,其发芽率才基本稳定,与对照相比无显著差异($P>0.05$)。到11d时,各处理的发芽率都达到94%以上。高羊茅种子经高浓度淋洗液处理,发芽高峰被延迟,这可能与垃圾堆肥中盐分和铵态氮浓度偏高有关[31, 32]。

从表3可以看出,80%淋洗液处理的黑麦草幼苗植株高度、地上生物量均表现最高,且与对照及20%、40%的淋洗液处理相比差异显著($P<0.05$),说明80%淋洗液处理的黑麦草优于其它处理及对照。对于高羊茅,60%淋洗液处理,则地上生物量最高,与对照及20%和100%相比差异显著($P<0.05$);而叶宽和叶长两

方面也明显优于对照。综合分析表明,80%和60%淋洗液分别对黑麦草、高羊茅生长较为适宜。

表 2　淋洗液培养的黑麦草和高羊茅种子发芽率(%)

Table 2　Germination rates of *L. perenne* and *F. arundinacea* cultivated by MSW compost leachate at different concentrations

草坪植物 Turfgrass	淋洗液浓度 Concentrations of leachates					
	CK	20%	40%	60%	80%	100%
黑麦草 *L. perenne*	96.0 ± 0.02	95.0 ± 0.01	94.0 ± 0.01	94.0 ± 0.01	96.0 ± 0.01	96.5 ± 0.01
高羊茅 *F. arundinacea*	93.5 ± 0.03	96.5 ± 0.02	94.5 ± 0.02	92.5 ± 0.01	95.5 ± 0.02	92.0 ± 0.01

表 3　淋洗液对黑麦草和高羊茅生长的影响

Table 3　Effects of leachate at different concentrations on growth of *L. perenne* and *F. arundinacea*

草坪植物 Turfgrass	淋洗液浓度 Leachate concentrations(%)	株高(cm) Plant height (cm)	地上生物量(mg/皿) Aboveground biomass (mg/dish)	单株地上生物量(mg/株) Aboveground biomass per plant (mg/plant)
黑麦草 *L. perenne*	CK	9.63 ±0.36c	41.25 ±0.19c	1.40 ±0.17b
	20	10.89 ±0.45bc	50.00 ±0.23b	1.76 ±0.06ab
	40	10.90 ±0.11bc	52.75 ±0.85b	1.70 ±0.17ab
	60	11.79 ±0.25ab	57.75 ±0.85a	1.85 ±0.18ab
	80	12.29 ±0.43a	58.75 ±0.27a	1.86 ±0.16ab
	100	11.59 ±0.56ab	56.75 ±0.14a	1.98 ±0.15a
高羊茅 *F. arundinacea*	CK	8.73 ±0.40c	52.00 ±0.41c	1.35 ±0.04c
	20%	10.90 ±0.36b	66.00 ±1.41b	2.15 ±0.14ab
	40%	10.89 ±0.35b	72.25 ±1.44a	2.04 ±0.31b
	60%	11.00 ±0.25b	76.25 ±1.44a	2.72 ±0.28a
	80%	12.09 ±0.26a	72.75 ±4.15a	2.57 ±0.10ab
	100%	11.58 ±0.40ab	64.75 ±1.25b	2.00 ±0.05b

同一列数据后标注字母相同表示差异不显著,字母不同则差异显著($P<0.05$)　Values within the same column with different letters are significantly different ($P<0.05$)

2.3　淋洗液培植无土草皮植物生长特征

黑麦草一茬草与对照相比,生物量差异极显著($P=0.006$);二茬草与对照相比差异显著($P=0.033$)(表4)。高羊茅一茬草生物量与对照之间存在极显著差异($P=0.002$),二茬草与对照相比差异显著($P=0.05$)(表4)。可见,高羊茅可能更适应淋洗液条件下生长;一茬草地上部对淋洗液的生长响应比二茬草明显。黑麦草和高羊茅淋洗液草皮植株高度前 15 d 内均表现出较一致的生长趋势;15 d 后,两种草坪植物淋洗液草皮的株高增长明显加快。黑麦草和高羊茅 30 d 的植株高度与对照相比差异极显著($P=0.008$;$P=0.022$)。对二茬草,淋洗液培养的黑麦草和高羊茅长势较一茬草平缓,未出现快速增高期;且高羊茅 30 d 的株高与对照相比差异显著($P=0.034$);黑麦草二茬草与对照差异不显著($P=0.229$)。以上分析表明,草坪植物一茬草长势优于二茬草。

表 4　淋洗液对黑麦草和高羊茅草皮生物量的影响(g/托盘)

Table 4　Effects of leachate on sod growth of *L. perenne* and *F. arundinacea* (g/dish)

地上生物量 Aboveground biomass	黑麦草 *L. perenne*		高羊茅 *F. arundinacea*	
	土壤淋洗液 Soil leachate	堆肥淋洗液 Compost leachate	土壤淋洗液 Soil leachate	堆肥淋洗液 Compost leachate
一茬草生物量 The 1st harvest biomass	0.80 ± 0.13**	1.76 ± 0.12	1.01 ± 0.08**	1.71 ± 0.07
二茬草生物量 The 2nd harvest biomass	0.49 ± 0.09*	0.85 ± 0.07	0.56 ± 0.05*	1.07 ± 0.08

* $P<0.05$, ** $P<0.01$

叶绿素含量是反映草坪观赏性能和生长状态的重要指标[33]。在一茬草中,黑麦草和高羊茅叶绿素含量

与对照相比差异极显著($P=0.001$,$P=0.002$);二茬草,黑麦草与对照相比无显著差异($P=0.08$),而高羊茅与对照相比差异显著($P=0.013$,表5)。表明淋洗液在提高草坪植物叶绿素含量方面效果显著,这与 Baker 的研究结果相一致[34]。

表5 黑麦草和高羊茅两茬草叶绿素含量 (g·kg⁻¹鲜重)

Table 5 Chlorophyll contents of *L. perenne* and *F. arundinacea* cultivated by leachate ($g \cdot kg^{-1}$ FW)

处理 Treatments	一茬草 The 1st harvest		二茬草 The 2nd harvest	
	黑麦草 *L. perenne*	高羊茅 *F. arundinacea*	黑麦草 *L. perenne*	高羊茅 *F. arundinacea*
土壤淋洗液 Soil leacheate	1.51 ±0.095 **	1.84 ±0.074 **	1.06 ±0.217	1.55 ±0.068 *
堆肥淋洗液 Compost leacheate	2.55 ±0.08	2.78 ±0.097	1.83 ±0.249	2.52 ±0.216

* $P<0.05$, ** $P<0.01$

2.4 淋洗液培植草皮铺坪应用生态特征

淋洗液草皮田间铺坪经过90 d后,黑麦草和高羊茅草皮的地上生物量与对照相比差异显著($P=0.048$, $P=0.017$),地下生物量和根长差异不显著($P>0.05$),说明淋洗液对草坪植物根系生长具有一定的抑制作用(表6)。黑麦草和高羊茅的根冠比明显低于对照($P>0.05$)。可见,淋洗液改变了草坪植物地上和地下生物量的分配格局,有增加地上部生长的趋势,且根系主要集中在0到30 cm土层内。

表6 黑麦草和高羊茅草皮铺坪生长特征

Table 6 The growing characteristics of *L. perenne* and *F. arundinacea* after sodding

草坪植物 Turfgrass	淋洗液 Leachate	地上生物量(g/块) Aboveground biomass (g / block)	地下生物量(g/块) Underground biomass (g / block)	根冠比 Root/shoot ratio	根长 (cm) Root Length (cm)
黑麦草 *L. perenne*	土壤 Soil leachate	4.1 ± 0.22 *	23.71 ± 4.58	5.78 ± 1.08	23.27 ± 2.88
	堆肥 Compost leachate	5.38 ± 0.75	24.64 ± 1.95	4.60 ± 0.35	19.78 ± 0.86
高羊茅 *F. arundinacea*	土壤 Soil leachate	6.69 ± 0.43 *	29.72 ± 4.81	4.40 ± 0.56	24.1 ± 0.97
	堆肥 Compost leachate	7.89 ± 0.30	29.2 ± 1.03	3.71 ± 0.02	27.26 ± 4.04

* $P<0.05$

草坪绿度与质地除与所选草种相关外,也与草坪建植方法及管理水平密切相关[35]。淋洗液草皮颜色深绿,而对照草皮叶片颜色黄绿且有部分植株叶尖黄化。淋洗液草皮叶片柔软光滑,而对照草皮叶片粗硬;两种草坪植物叶宽分别在2~3 mm和2~5 mm范围内。

3 讨论与结论

与对照相比,80%的淋洗液对于黑麦草和60%淋洗液对于高羊茅,均能明显提高地上生物量,可见,不同的草坪植物对淋洗液浓度有不同的要求;因此,在淋洗液大规模应用前,需做淋洗液的小试优化实验,以确定适宜的淋洗液浓度。在生长前期,淋洗液可明显促进地上生物量、草坪密度和盖度的增加,并加快成坪速度。淋洗液培植草皮的生长势为一茬草优于二茬草,因此,一茬草刈割后立即铺坪应用可以大大加快草皮的繁殖速度。淋洗液可显著提高叶片中叶绿素含量,这有利于草皮保持较好的绿度。另外,不同草坪植物对淋洗液生长响应存在明显差异,因此,选择适宜的草坪植物进行淋洗液无土草皮培植也很重要。

草皮铺坪研究结果表明,淋洗液可改变草坪植物地上和地下生物量的分配格局,而如此分配格局对草坪植物而言,可能是有益的,地上生物量配额增加更有利于其成坪和观赏价值的提高,而有效光合面积的增加也可制造出更多的光合产物,最终促进植株更快速的生长;另一方面,根系的减少可有效防止板结现象,使根系呼吸作用顺畅,这有可能延长草坪的使用寿命。此外,如果通过垃圾堆肥淋洗液离子形态、淋洗液的平衡、植

物吸收方式等机制问题的深入研究,也会为垃圾堆肥淋洗液用于无土草皮培植的大规模开发和制备提供更可靠的数据支持。总之,用淋洗法修复垃圾堆肥并进行无土草皮培植,既可以提高垃圾堆肥使用安全性,又可实现降低草皮培植成本,节约耕地土壤的目的。

References:

[1] Jiang Y, Kang M Y, Liu Z, *et al.* Urban garbage disposal and management in China. Journal of Environmetal Science, 2003, 15(4): 531－540.

[2] Lemieux P M, Lutes C C, Abbott J A, *et al.* Emission of polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans from the open burning of household waste in barrels. Environ. Sci. Technol., 2000, 34(3): 377－384.

[3] Wei Y S, Fan Y B, Wang M J, *et al.* Composting and compost application in China. Resources Conservation and Recycling, 2000, 30(4): 277－300.

[4] Duo L A, Zhao S L. Raising medium function of environmental engineering by using life rubbish to produce carpet turf. J. Environ. Sci., 2000, 12(4): 498－505.

[5] Wolkowski R P. Nitrogen management considerations for landspreading municipal solid waste compost. J. Environ. Qual., 2003, 32(5): 1844－1850.

[6] Soumareé M, Tack F M G, Verloo M G. Ryegrass response to mineral fertilization and organic amendment with municipal solid waste compost in two tropical agricultural soils of Mali. Journal of Plant Nutrition, 2003, 26(6): 1169－1188.

[7] Paré T, Dinel H, Schnitzer M. Extractability of trace metals during co-composting of biosolids and municipal solid wastes. Biol. Fertil. Soils, 1999, 29(1): 31－37.

[8] Giusquiani P L, Pagliai M, Gigliotti G, *et al.* Urban waste compost: effects on physical, chemical, and biochemical soil properties. J. Environ. Qual., 1995, 24(1): 175－182.

[9] Jaber F H, Shukla S, Hanlon E A, *et al.* Groundwater phosphorus and trace element concentrations from organically amended sandy and calcareous soils in Florida. Compost Science and Utilization, 2006, 14(1): 6－15.

[10] Pinamonti F. Compost mulch effects on soil fertility, nutritional status and performance of grapevine. Nutrient Cycling in Agroecosystems, 1998, 51(3): 239－248.

[11] Duo L A, Gao Y B, Zhao S L. Heavy metal accumulation of urban domestic rubbish compost in turfgrass by EDTA chelating. Journal of Environmental Sciences, 2005, 17(5): 813－816.

[12] Bhattacharyya P, Chakraborty A, Chakrabarti K, *et al.* Chromium uptake by rice and accumulation in soil amended with municipal solid waste compost. Chemosphere, 2005, 60(10): 1481－1486.

[13] Semer R, Reddy K R. Evaluation of soil washing process to remove mixed contaminants from a sandy loam. J. Hazard. Mater., 1996, 45(1): 45－47.

[14] Van Benschoten J E, Matsumoto M R, Young W H. Evaluation and analysis of soil washing for seven lead contaminated soils. J. Environ. Eng., 1997, 123(3): 217－224.

[15] Wasay S A, Barrington S, Tokunaga S. Organic acids for the in-situ remediation of soils polluted by heavy metals: soil flushing in columns. Water, Air, and Soil Pollution, 2001, 127(1-4): 301－314.

[16] Richardson W S, Phillips C R, Luttrell J, *et al.* Application of remedy studies to the development of a soil washing pilot plant that uses mineral processing technology: a practical experience. Joural of Hazardous Materials, 1999, 66(1-2): 47－65.

[17] Petruzzelli G, Barbafieri M, Bonomo L, *et al.* Bench scale evaluation of soil washing for heavy metal contaminated soil at a former manufactured gas plant site. Environ. Contam. Toxicol., 2004, 73(1): 38－44.

[18] Juhasz A L, Smith E, Smith J, *et al.* Remediation of persistent organic pollutants using a novel two-phase washing biosorption process. Water, Air, and Soil Pollution, 2003, Focus 3(3): 233－242.

[19] Kos B, Leštan D. Soil washing of Pb, Zn and Cd using biodegradable chelator and permeable barriers and induced phytoextraction by *Cannabis sativa*. Plant and Soil, 2004, 263(1): 43－51.

[20] Mcquilken M P, Whipps J M, Lynch J M. Effects of water extracts of a composted manure-straw mixture on the plant pathogen *Botrytis Cinerea*. World Journal of Microbiology and Biotechnology, 1994, 10(1): 20－26.

[21] Zhang W, Dick W A, Hoitikin H A J. Compost induced systemic acquired resistance in cucumber to *Pythium*, root rot and anthracnose. Phytopathology, 1996, 86(10): 1066－1070.

[22] Pascual J A, Garcia C, Hernandez T, *et al.* Effectiveness of municipal waste compost and its humic fraction in suppressing *Pythium ultimum*. Microbial Ecology, 2002, 44(1): 59－68.

[23] Ayuso M, Pascual J A, García C, *et al*. Evaluation of urban wastes for agricultural use. Soil Sci. Plant Nutrition. 1996, 42(1): 105 −111.

[24] Hu S L. The contents and development of modern turf science. Grassland and Turf, 1991, (1): 1 −5.

[25] Sun J X, Han L B, Zhou H, *et al*. Turf Science (second edition). Beijing: Agricultural Press, 2004. 7.

[26] Epstein E, Taylor J M, Chaney R I. Effect of sewage sludge compost applied to soil on some physical and chemical properties. J. Environ. Qual., 1976, 5(4): 422 −426.

[27] Institute of Soil Science, CAS, Nanjing. Analysis for soil physical and chemical properties. Shanghai: Science and Technology Press, 1983. 132 −136.

[28] Lu R K. The Analytical Methods for Soil and Agricultural Chemistry. Beijing: Agricultural Technology Publication of China, 2000. 146 −195.

[29] Duo L A, Gao Y B, Zhao S L. Heavy metal accumulation and ecological responses of turfgrass to rubbish compost with EDTA addition. Journal of Integrave Plant Biology, 2005, 47(9): 1047 −1054.

[30] Ma C C, Gao Y B, Wang J L, *et al*. The comparison studies of photosynthetic characteristics and protective enzymes of *Caragana microphylla* and *Caragana stenophylla*. Acta Ecologica Sinica, 2004, 24(8): 1594 −1601.

[31] O'Brien T A, Barker A V. Evaluation of ammonium and soluble salts on grass sod production in compost. Ⅱ. Delaying seeding after compost application. Communications in Soil Science and Plant Analysis, 1996, 27(1-2): 77 −85.

[32] Linde D T, Hepner L D. Turfgrass seed and sod establishment on soil amended with biosolid compost. HortTechnology, 2005, 15(3): 577 −583.

[33] Li Y X, Zhao L, Chen T B. The municipal sewage sludge compost used as lawn medium. Acta Ecologica Sinica, 2002, 22(6): 797 −801.

[34] Baker A V. Evaluation of composts for growth of grass sods. Communications in Soil Science and Plant Analysis, 2001, 32(11-12): 1841 −1860.

[35] Duo L A, Zhao S L. Ecological engineering of using cellulose bonding carrier of wasted materials for belt seeding establishment. Acta Ecologica Sinica, 2001, 21(1): 143 −150.

参考文献:

[24] 胡叔良.现代草坪科学的研究内容和发展方向.草原与牧草, 1991,(1):1 ~5.

[25] 孙吉雄,韩烈保,周禾,等. 草坪学(第二版). 北京: 中国农业出版社, 2004. 7.

[27] 中国科学院南京土壤研究所.土壤理化分析.上海:上海科技出版社,1983.132 ~136.

[28] 鲁如坤.土壤和农业化学分析.北京:中国农业技术出版社,2000.146 ~195.

[30] 马成仓,高玉葆,王金龙,等.小叶锦鸡儿和狭叶锦鸡儿的光合特性及保护酶系统比较.生态学报, 2004,24(8):1594 ~1601.

[33] 李艳霞,赵莉,陈同斌.城市污泥堆肥用作草皮基质对草坪植物生长的影响.生态学报,2002,22(6): 797 ~801.

[35] 多立安,赵树兰.纤维素粘合废弃物载体植生建坪环境生态工程应用研究.生态学报,2001,21(1):143 ~150.