International Biodeterioration & Biodegradation 95 (2014) 200–207

Contents lists available at ScienceDirect

International Biodeterioration & Biodegradation

journal homepage: www.elsevier.com/locate/ibiod

Dissipation of polycyclic aromatic hydrocarbons in soil amended with sewage sludge compost

Lijuan Feng, Liqiu Zhang, Li Feng*

College of Environmental Science and Engineering, Beijing Forestry University, Qinghua East Road 35, Haidian District, Beijing 100083, China

ARTICLE INFO

Article history:
Received 22 December 2013
Received in revised form
21 April 2014
Accepted 21 April 2014
Available online 10 May 2014

Keywords:
PAHs
Sludge compost
Dehydrogenase activity
Tall fescue
First-order kinetics

ABSTRACT

Greenhouse experiments were conducted with amendment ratios of fresh sludge compost to soil of 0, 10, 25 and 50% (w/w) to investigate the dissipation of polycyclic aromatic hydrocarbons (PAHs) in soils planted with tall fescue (*Festuca arundinacea*). The initial PAH concentrations in four amended soils increased with the more addition of compost. During the experiment, PAH concentrations decreased in all treatments, and the PAH dissipation followed the first-order kinetics. The residual concentrations in planted soils were lower than those in non-planted soils at every sampling time. After 126 days, the lowest PAH concentration was observed in the soil amended with compost at 10%. These results suggest that appropriate compost addition and planting vegetation could improve the dissipation of PAHs in soil, and the increase of soil dehydrogenase activities due to the increased density and activity of microorganism was an important indicator to obtain the high PAH removal efficiencies in soil. Moreover, some PAHs in soil were absorbed by the roots of tall fescue, then transferred to the shoots and accumulated. During this process, 2–3-ring PAHs were more likely to be absorbed, transferred, and removed in plant, but 4–6-ring PAHs were prone to be accumulated in plant tissues.

1. Introduction

Polycyclic aromatic hydrocarbons (PAHs) ubiquitously occur in the atmosphere, hydrosphere and pedosphere (Ma et al., 2005; Li et al., 2006a,b). PAHs are a group of non-polar organic compounds comprising two or more fused benzene rings. The number of benzene rings is one of the factors determining PAH physical-chemical properties such as water solubility and vapor pressure. Low-molecular-weight (LMW) PAHs, containing less than four fused benzene rings, are more volatile, water soluble and less lipophilic; high-molecular-weight (HMW) PAHs, containing more than three rings, are more stable and toxic compared with the LMW PAHs (Wenzl et al., 2006; Ferrarese et al., 2008). Because of the potentially carcinogenic and mutagenic properties of these compounds, sixteen PAHs with high toxicity to aquatic and terrestrial life are included in the United States Environmental Protection Agency (US EPA) priority pollutant list.

Sewage sludge is a byproduct of the wastewater treatment process. It is rich in organic matter and mineral nutrients, such as nitrogen, phosphorus and potassium. Sewage sludge containing plant-available nutrients can be recycled as organic fertilizer to improve soil fertility. However, toxic pollutants are also enriched in sludge during the wastewater treatment process. Previous studies have shown that PAHs were the most abundant pollutants of 44 semi-volatile organic components with total concentrations of 1.4–79 mg kg^{-1} in sewage sludge from 11 wastewater treatment plants in 9 Chinese cities (Cai et al., 2007). The presence of toxic pollutants in sludge poses some risk to the environment and human health (Smith et al., 2001; Gale, 2005). Therefore, it is necessary to minimize or remove these contaminants before land application of sewage sludge.

Composting, a cost-effective method for sewage sludge disposal, is able to suppress pathogenic organisms, reduce the bioavailability of heavy metals, and stabilize organic matters (Antizar-Ladislao et al., 2006). Composting has been proven effective for the degradation of PAHs with high removal rates (>90% in some cases) (Guerin, 2000). Hua et al. (2008) showed that more than 79% of 16 PAHs at high concentrations (average concentration of 95.05 mg kg^{-1} in sludge collected in different seasons) were removed after 50 days of composting. Degradation by microbial populations is considered to be the main removal mechanism of PAHs during the composting process. Fungi and Gram-negative bacteria are the main populations involved in PAH degradation (Zhang et al., 2011). Volatilization at high temperature can also

* Corresponding author. Tel.: +86 10 62336528; fax: +86 10 62336900.
E-mail address: fengli_hit@163.com (L. Feng).

http://dx.doi.org/10.1016/j.ibiod.2014.04.012
0964-8305/

contribute to PAH dissipation (Oleszczuk, 2006). Although most PAHs are removed by degradation and volatilization, residual PAHs can accumulate in soil when sludge compost is used as a fertilizer or soil conditioner in a long-term application. There remains a need for further information about the dissipation of PAHs in soil-plant systems after land application of sludge compost.

The PAH dissipation in soil-plant system mainly contains two processes, biodegradation by microorganisms and phytoaccumulation by vegetation. PAHs in soil could be degraded by indigenous microbes. PAH dissipation in soil could be improved by stimulating indigenous microbes through adding manure to soil, which would increase PAH degraders by one to two orders of magnitude (Liu et al., 2010). Inoculation of microbial consortia (both bacteria and fungi) isolated from PAH-contaminated soil could also degrade PAHs efficiently (Jacques et al., 2008; Li et al., 2008a; Silva et al., 2009). Planting vegetation could enhance PAH degradation in soil. The presence of plants increases the number of microorganism in rhizosphere, ameliorates the physicochemical properties of soil, and impacts positively on microbial growth and soil enzyme activities (Hamdi et al., 2012). More microorganism and higher enzyme activities could accelerate PAH dissipation in soil. Besides, phytoaccumulation also contributes to PAH dissipation. PAHs could be absorbed by plant and accumulated in plant tissues (Cai et al., 2008). The bioaccumulation capacity and bioconcentration factor are related to plant species and PAH concentration in soil (Gao and Zhu, 2004; Xu et al., 2009).

The microbial density and community are rich in mature compost. Comparing with dry compost or sludge, moist compost could keep the activity and the composition of microbial community involved in organic pollutants removal. Different amounts of moist compost were used to evaluate the optimal amendment ratio of sludge compost to soil. Soil dehydrogenase activity (DHA) was used to reflect the effect of microbes on PAH dissipation. Tall fescue (*Festuca arundinacea*) was designed to estimate the ability of vegetation contribution to PAH removal. The aim of this study was to investigate the PAH dissipation in compost-amended soils planted with tall fescue and the PAH accumulation in plant tissues, which will help to the better understanding of PAH removal mechanisms in soils and plants.

2. Materials and methods

2.1. Materials

2.1.1. Soil and sludge compost

The soil used in this study was collected from the upper 20 cm layer of Jiufeng Park (Beijing, latitude 39°54′N and longitude 116°28′E), and then sieved through a 5 mm mesh to remove stones and roots. The moisture content and pH of the soil were 16.6% and 7.5 (1:5, dry soil: distilled water, w/w). The content of total nitrogen, total phosphorus and organic matter in the soil were 1.4 mg g^{-1}, 0.7 mg g^{-1} and 14.1 mg g^{-1}, respectively. The sludge compost was produced from a sewage sludge treatment plant in Beijing by aerobic composting. The moisture content and pH of the sludge compost were 51.1% and 7.8 (1:5, dry compost: distilled water, w/w). The nutrient levels in the compost were 28.9 mg g^{-1} total nitrogen, 7.0 mg g^{-1} total phosphorus and 365.8 mg g^{-1} organic matter. The total concentration of 16 PAHs in the compost was 945 μg kg^{-1} dry matter (d.m.), and the 2-ring (naphthalene), 3-ring (acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene), 4- ring (fluoranthene, pyrene, benzo(a)anthracene, chrysene), 5-ring (benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, dibenzo(a,h)anthracene), and 6-ring (indeno(1,2,3-cd)pyrene, benzo(g,h,i)perylene) PAHs accounted for 4.8%, 16.7%, 46.8%, 23.8%, and 7.9% of the total, respectively.

2.1.2. Chemicals and seeds

The standard solutions of 16 EPA PAHs, 5 deuterated PAHs (naphthalene-d_8, acenaphthene-d_{10}, phenanthrene-d_{10}, chrysene-d_{12} and perylene-d_{12}) and a surrogate standard (2-fluorobiphenyl) with a concentration of 2000 μg ml^{-1} were purchased from Sigma–Aldrich Co. Ltd. (USA). The solvents used for PAH analysis were pesticide residue grade and obtained from Duksan Co. Ltd. (KR). The other chemicals and solvents used in the study were of guaranteed or analytical purity.

Tall fescue was chosen as the test plant in this experiment because of its previously reported ability to enhance the dissipation of PAHs from soils. Seeds of tall fescue were purchased from Beijing Forestry University Forest Science Co. Ltd. (China).

2.2. Pot experiment

2.2.1. Experimental design

Soil was mixed with different amounts of sludge compost. On the basis of fresh weight, the amendment ratios of sludge compost to soil were 0 (T1), 10% (T2), 25% (T3) and 50% (T4). All the amended soils of four treatments were sieved through 8 mm mesh to achieve homogeneity, and then dispensed into plastic pots. Each 2 kg of amended soil was placed in a 15 cm diameter plastic pot with a drainage hole at the bottom. A dish was placed under each pot to catch any leachate, and the leachate was irrigated back onto the top of the soil. The soil (planted and non-planted) was maintained at about 70% of water holding capacity by irrigating with distilled water during the experiment.

There were two groups in each treatment, a non-planted group and a planted group. In the planted group, tall fescue was planted in all treatments. Seeds were surface-disinfected by soaking in 3% (v/v) H_2O_2 for 15 min at room temperature (20 ± 2 °C) and washed five times with sterile distilled water. Tall fescue was sowed at the next day after soil amended and dispensed. Two gram seeds of tall fescue were planted in each pot. After sowing, planted and non-planted soils were watered until the soil saturated. During the experiment, the seedlings continued to grow, but began to wilt after 105 days.

All the pots (84 planted pots and 84 non-planted pots) were randomly placed in a greenhouse at 25 °C with a 14-h photoperiod and 70% relative humidity. The planted and non-planted pots were watered with about 300 ml distilled water once a week. Tall fescue was seeded on March 6, 2012. The seeding day was considered to be day 0. And the experiments ran for 126 days.

2.2.2. Sampling and sample preparation

Plants, planted and non-planted soils were destructively sampled every three weeks. In every sampling time (0 d, 21 d, 42 d, 63 d, 84 d, 105 d and 126 d), three replicates of each group in four treatments were obtained in a completely randomized manner. The soils in planted and non-planted pots were carefully collected, homogenized and divided into two sets, one for PAH analysis and the other for dehydrogenase activity (DHA) analysis. Soils for PAH analyses were freeze-dried, ground, sieved through 1 mm mesh, bagged, and stored at −20 °C before analysis. Soils for DHA analyses were fresh, ground, sieved through 2 mm mesh, bagged, and stored at −4 °C before analysis. The analysis of PAHs and DHA should be completed within two weeks and one week.

For the pots with tall fescue, plants were carefully separated from the soil, rinsed with tap water and distilled water to remove any attached soil particles, and cut into above- and below-ground fractions with scissors. The plant materials were freeze-dried, cut into pieces, ground with agate mortar, sieved through 1 mm mesh, bagged, and stored at −20 °C before analysis. And the PAH analysis of plant tissues should be completed in two weeks.