Chemosphere 184 (2017) 753–761

Contents lists available at ScienceDirect

Chemosphere

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

Presence, distribution and risk assessment of polycyclic aromatic hydrocarbons in rice-wheat continuous cropping soils close to five industrial parks of Suzhou, China

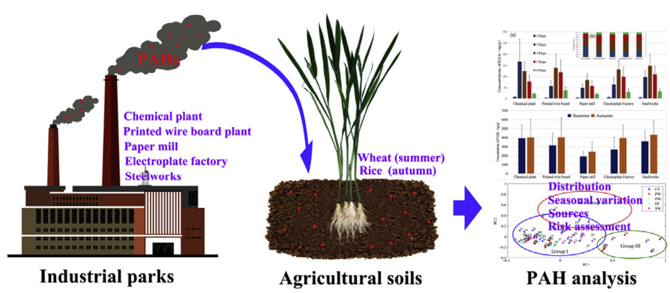
Yong Li [a, b], Ling Long [b], Jing Ge [a, b], Li-xuan Yang [b], Jin-jin Cheng [a, b], Ling-xiang Sun [c], Changying Lu [c, *], Xiang-yang Yu [a, b, **]

[a] Key Lab of Food Quality and Safety of Jiangsu Province-State Key Laboratory Breeding Base, 50 Zhongling Street, Nanjing, 210014, China
[b] Institute of Food Quality and Safety, Jiangsu Academy of Agricultural Sciences, 50 Zhongling Street, Nanjing, 210014, China
[c] Laboratory of Agricultural Resources and Environment, Suzhou Academy of Agricultural Sciences, North of Wangting Town, Suzhou, 215155, China

HIGHLIGHTS

- PAHs in rice-wheat continuous cropping soils around five factories was investigated.
- The highest level of PAHs was detected around Chemical plant and Steelworks.
- PAHs decrease with increasing distance from sampling sites to pollution sources.
- The PAH content in soils during rice harvest is higher than that during wheat harvest.
- Higher carcinogenic risk was found in those sites closer to the industrial park.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 23 March 2017
Received in revised form
28 May 2017
Accepted 14 June 2017
Available online 15 June 2017

Handling Editor: R. Ebinghaus

Keywords:
Polycyclic aromatic hydrocarbons
Agricultural soils
Distribution

ABSTRACT

Polycyclic aromatic hydrocarbons (PAHs) accumulated in agricultural soils are likely to threaten human health and ecosystem though the food chain, therefore, it is worth to pay more attention to soil contamination by PAHs. In this study, the presence, distribution and risk assessment of 16 priority PAHs in rice-wheat continuous cropping soils close to industrial parks of Suzhou were firstly investigated. The concentrations of the total PAHs ranged from 125.99 ng/g to 796.65 ng/g with an average of 352.94 ng/g. Phenanthrene (PHE), fluoranthene (FLT), benzo [a] anthracene (BaA) and pyrene (PYR) were the major PAHs in those soil samples. The highest level of PAHs was detected in the soils around Chemical plant and Steelworks, followed by Printed wire board, Electroplate Factory and Paper mill. The composition of PAHs in the soils around Chemical plant was dominated by 3-ring PAHs, however, the predominant compounds were 4, 5-ring PAHs in the soils around other four factories. Meanwhile, the concentration of the total PAHs in the soils close to the factories showed a higher level of PAHs in November (during rice harvest) than that in June (during wheat harvest). Different with other rings of PAHs, 3-ring PAHs in the

* Corresponding author. Laboratory of Agricultural Resources and Environment, Suzhou Academy of Agricultural Sciences, North of Wangting Town, Suzhou, 215155, China.
** Corresponding author. Key Lab of Food Quality and Safety of Jiangsu Province-State Key Laboratory Breeding Base, 50 Zhongling Street, Nanjing, 210014, China.
E-mail addresses: luchangying@163.com (C. Lu), yu981190@hotmail.com (X.-y. Yu).

http://dx.doi.org/10.1016/j.chemosphere.2017.06.055
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Principal component analysis
Risk assessment

soils around Chemical plant and Steelworks had a higher concentration in June. The results of principal component analysis and isomeric ratio analysis suggested that PAHs in the studied areas mainly originated from biomass, coal and petroleum combustion. The risk assessment indicated that higher carcinogenic risk was found in those sites closer to the industrial park.

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1. Introduction

Polycyclic aromatic hydrocarbons (PAHs) are a group of chemicals containing two or more fused aromatic rings of carbon and hydrogen atoms (Wilcke, 2000; Maliszewska-Kordybach et al., 2009). This kind of compounds is a class of persistent organic pollutants, which are of persistence, bioaccumulation and toxicity in the environment (Lee and Kim, 2007; Tamamura et al., 2007; Inomata et al., 2012; Zheng et al., 2012; Rojo-Nieto et al., 2013). Up to now, hundreds of PAHs have been discovered, among which 16 PAHs were classified as priority pollutants by the United States Environmental Protection Agency (US EPA), including naphthalene (NAP), acenaphthylene (ACY), acenaphthene (ACP), fluorine (FLR), phenanthrene (PHE), anthracene (ANT), fluoranthene (FLT), pyrene (PYR, benzo[a] anthracene (BaA), chrysene (CHR), benzo[*b*]fluoranthene (BbF), benzo[k]fluoranthene (BkF), benzo[*a*]pyrene (BaP), indeno[1,2,3-*c*,*d*]pyrene (IcdP), dibenzo[a,h]anthracene (DahA) and benzo[g,h,i]perylene (BghiP). Some PAHs pose a severe threat to the environment and human health (Hu et al., 2007; Xia et al., 2010; Wang et al., 2012; Zhang et al., 2012; Soltani et al., 2015; Li and Ma, 2016). Seven of the 16 PAHs are considered to be carcinogens (Cai et al., 2007). There exist two primary sources of PAHs, natural processes and anthropogenic processes (Agarwal et al., 2009; Bi et al., 2016). Natural processes mainly contain forest fires and volcanic activity. Anthropogenic processes mainly include the incomplete combustion of petroleum, fossil fuels, vehicle traffic, coke production and other organic substances. Due to their wide range of sources, PAHs have become ubiquitous in the environment (Ravindra et al., 2008). PAHs can migrate to remote alpine regions though the way of long range atmospheric transport and deposit (Kuang et al., 2011). This process could be affected by geographic locations and atmospheric conditions, such as landform, temperature, humidness, rainfalls and sunlight intensity. PAHs could be adsorbed rapidly onto soil particles, particularly on soil organic matter, and they would remain for months or years due to their persistent property (Yan et al., 2012). In addition, the soil could be one potential PAH source releasing some PAHs into the environment by soil emission and dust production. Some studies have reported that human exposure to PAHs through soil was higher than that through air or water (Maliszewska-Kordybach et al., 2009). Some crops, such as rice and wheat, could accumulate PAHs from the contaminated environment, especially from the soil (Wilcke, 2000; Zhang et al., 2011; Wang et al., 2012). Potential risks to humans or wildlife may be enhanced by consuming contaminated crops (Wilcke, 2000). Thus, it is of great significance to investigate the soil contamination by PAHs. Many studies have reported their investigation about the distribution of PAHs in water (Wang et al., 2015), sediments (Nieuwoudt et al., 2011; Rojo-Nieto et al., 2013), soil (Duan et al., 2015; Wang et al., 2015; Liu et al., 2016), air (Smith et al., 2001; Carratala et al., 2017) and plant (Tao et al., 2004; Zhang et al., 2011). However, few studies focused on the distribution and risk assessment of PAHs in rice-wheat continuous cropping soils close to industrial parks.

Suzhou is a city located in the southern part of Jiangsu Province, China. The city famous as a land of plenty is an important rice-wheat continuous cropping area, where the harvest times of wheat and rice are in June and November, respectively. Meanwhile, Suzhou is a high level of industrialization, containing a large number of factories, such as petrochemical factory, electroplate factory, steelworks, etc. It is worth noting that those industries would cause a certain ecologic influence on the local area, especially on the environment. Few investigations about the concentration, distribution and risk assessment of PAHs in the agricultural soils close to those industrial parks were carried out. In this study, the concentration and spatial distribution of 16 priority PAHs in the agricultural soils close to five kinds of factories were investigated. The levels of PAHs in agricultural soils during harvest times of wheat and rice were compared. Principal component analysis and isomeric ratio analysis were applied to identify the potential sources of PAHs. Finally, the potential carcinogenic risk of PAHs to human health was evaluated by the BaP equivalent concentration. This study would reveal the profile and distribution pattern of PAHs in rice-wheat continuous cropping soils around different factories and the result may be helpful for establishing appropriate regulatory guidelines to protect the environment and human health.

2. Materials and methods

2.1. Sample collection and preparation

In this study, the agricultural topsoil samples from 40 sampling sites around five kinds of factories in Suzhou were collected. The sampling sites were shown in Fig. 1. Among those sampling sites, 5 sites were around Chemical plant I; 6 sites were around Chemical plant II; 9 sites were close to Printed wire board; 5 sites were close to Paper mill; 8 sites were close to Electroplate factory; 7 sites were around Steelworks. For investigation of the level of PAHs in rice-wheat continuous cropping soils, two soil samples for each sampling site were collected in November 2015 (during rice harvest) and June 2016 (during wheat harvest), respectively. In total, 80 agricultural soil samples were collected: S1 ~ S40 were collected in November 2015; S41 ~ S80 were collected in June 2016. Each sample was composed of 5 sub-samples collected within a 5×5 m^2 site. After transported to the laboratory, those soil samples were air dried, ground, passed through a 60-mesh screen, homogenized, and stored at 4 °C until analysis.

2.2. Chemicals and standards

Sixteen PAHs in a mixture were obtained from Aladdin Chemistry Co., Ltd (Shanghai, China), including naphthalene (NAP), acenaphthylene (ACY), acenaphthene (ACP), fluorine (FLR), phenanthrene (PHE), anthracene (ANT), fluoranthene (FLT), pyrene (PYR, benzo[a] anthracene (BaA), chrysene (CHR), benzo[*b*]fluoranthene (BbF), benzo[k]fluoranthene (BkF), benzo[*a*]pyrene (BaP), indeno[1,2,3-*c*,*d*]pyrene (IcdP), dibenzo[a,h]anthracene (DahA) and benzo[g,h,i]perylene (BghiP). All solvents, i.e. n-hexane, acetone, and dichloromethane, used for sample processing and analysis, were of high-performance liquid chromatographic (HPLC) grade. Florisil Columns were obtained from Agilent Technologies, USA.

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