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Organic Contamination and Remediation in the Agricultural Soils of China: A Critical Review

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Abstract

Soil pollution is a global problem in both developed and developing countries. Countries with rapidly developing economies such as China are faced with significant soil pollution problems due to accelerated industrialization and urbanization over the last decades. This paper provides an overview of published scientific data on soil pollution across China with particular focus on organic contamination in agricultural soils. Based on the related

peer-reviewed papers published since 2000 (n = 203), we evaluated the priority organic contaminants across China, revealed their spatial and temporal distributions at the national scale, identified their possible sources and fates in soil, assessed their potential environmental risks, and presented the challenges in current remediation technologies regarding the combined organic pollution of agricultural soils. The primary pollutants in Northeast China were polycyclic aromatic hydrocarbons (PAHs) due to intensive fossil fuel combustion. The concentrations of organochlorine pesticides (OCPs) and phthalic acid esters (PAEs) were higher in North and Central China owing to concentrated agricultural activities. The levels of polychlorinated biphenyls (PCBs) were higher in East and South China primarily because of past industrial operations and improper electronic waste processing. The co-existence of organic contaminants was severe in the Yangtze River Delta, Pearl River Delta, and Beijing-Tianjin-Hebei Region, which are the most populated and industrialized regions in China. Integrated biological-chemical remediation technologies, such as surfactant-enhanced bioremediation, have potential uses in the remediation of soil contaminated by multiple contaminants. This critical review highlighted several future research directions including combined pollution, interfacial interactions, food safety, bioavailability, ecological effects, and integrated remediation methods for combined organic pollution in soil.

Keywords: Organochlorine pesticides; Polycyclic aromatic hydrocarbons; Polychlorinated biphenyls; Phthalate esters; Agricultural soil; Combined organic contamination

Contents

1. Introduction

The contamination of agricultural soil has been observed around the world due to the long-term application of pesticides, fertilizer, plastic film, wastewater irrigation, sewage application and other activities. Unlike contamination in industrial sites, agricultural soil pollution and its adverse impacts tend to be chronic. The cumulative loading of pollutants in

agricultural soil may pose significant risks to the ecological functions of soils, plant growth, and eventually, human health. For example, nitrobenzene inhibited the growth of soybean seedlings and caused genotoxicity in soybean root tip cells (Guo et al., 2010). Polycyclic aromatic hydrocarbons (PAHs) were found to change the abundance of functional genes in soils (Han et al., 2014). Exposure to PAHs damaged both enzymatic and non-enzymatic antioxidant defenses and harmed human health (Garcon et al., 2001). Agricultural soils were often contaminated in large areas by combined and non-point source pollution, which are difficult to address through normal remediation operations.

The global occurrence and adverse effects of organic pollution have caused increasing public concern. Many organic contaminants (OCs), such as organochlorine pesticides (OCPs), polychlorinated biphenyls (PCBs), phthalate esters (PAEs), and PAHs, are characterized by high toxicity, persistence, and bioaccumulation in the environment (Pies et al., 2007; Sun et al., 2016c). Vast areas of farmland soils are an important reservoir for OCs (Zhang et al., 2013c; Zhong and Zhu, 2013), which can in turn serve as a secondary emission source to air and water (Bidleman and Leone, 2004; Tao et al., 2008; Cabrerizo et al., 2011). Many OCs in agricultural soils are difficult to degrade biologically under normal environmental conditions. The residues of OCs in agricultural soils can enter food chains and eventually present a potential risk to human health through trophic transfers (Fantke and Jolliet, 2015; Liu et al., 2016c).

As one of the major agricultural countries, China has extensive arable land areas (2.03 billion acres) with various soil types (e.g., Anthrosols and Histosols) (IUSS Working Group WRB, 2014) and a wide variety of soil contaminants. Thus, the national-scale summary in

this review can serve as a representative example for addressing the problem of global agricultural soil pollution. Recently, the State Council of China published the Action Plan on Prevention and Control of Soil Pollution (The Central Government of the People's Republic of China, 2016). Understanding the spatial distribution and temporal trend of OCs in agricultural soils across China is necessary for devising pragmatic and enforceable legislation. The fate, source, and interfacial behavior of coexisting organic chemicals in soil should also be studied for efficient pollution control and soil remediation. The revealed spatiotemporal variations based on the published data can help to explain the combined pollution situation in agricultural soils and the effect of pollution regulation in China since 2000. There has been a large volume of literature on organic pollution in the agricultural soils of China. However, these surveys of varying scale (e.g., site-specific, city-wide, or regional-scale) have been scattered, and there is no clear understanding of the status of organic contamination in agriculture throughout China, given that the types of OCs vary across the vast farmland of the country. Most relevant studies have focused on a single class of OCs in a relatively small sampling area during a very short sampling period. A critical review is greatly needed to summarize the concentration levels and characteristics of combined organic pollution in agricultural soils at a national scale.

The primary pollutants in the densely populated regions of China have not been assessed. The priority contaminants that should be controlled would vary across different regions due to the disparity in industrial operations, agricultural practices, and economic development levels. For example, in the Yangtze River Delta, Pearl River Delta, and Beijing-Tianjin-Hebei Region, the combined contamination of pollutants may be more severe due to intensive

industrial and urbanization activities. Some regions accommodate numerous electronic waste recycling sites or coal industry plants, whereas some regions are made up of large and intensive agricultural farmland. Reviewing the up-to-date literature can reveal the geographic distribution of OCs and inform the development of management plans for combined pollution. The source, fate, and risk of coexisting OCs in agricultural soils should be evaluated to reveal their different source-sink mechanisms and devise an effective control strategy. A low-cost and effective approach is essential for the remediation of extensive areas of polluted agricultural soils in addition to industry-impacted soil. The challenges involved in developing proper remediation technologies for soil contaminated with multiple organic contaminants need to be better understood and well addressed.

The present paper provides an extensive and critical review of studies on agricultural soils in China, particularly in addressing the recent literature regarding organic pollution. A total of 203 papers about organic contaminants in Chinese agricultural soils have been published since 2000, of which a total of 155 papers focused on the four classes of OCs (OCPs, PAHs, PCBs, and PAEs), implying that they are of significant concerns within the current research (Fig. S1). The objectives were to (a) reveal the concentration levels, regional characteristics, spatial distribution, and temporal variation of principal organic contaminants in the agricultural soils of China; (b) assess the development and challenges involved in remediation technologies for combined organic pollution in agricultural soils; and (c) identify and suggest possible future directions for research in this field.

2. Characteristics of organic contaminants in agricultural soils

2.1. OCPs

OCPs were extensively used in agriculture for pest control (Li et al., 2001; Liu et al., 2015b). Although their usage was banned for decades, OCPs remain ubiquitous in the environment worldwide even in remote regions (He et al., 2013; Huang et al., 2014c). As a large agricultural country, China has been the largest consumer of pesticides in the world. Abundant OCPs were reportedly produced during the 1950s-1980s, e.g., a total of 4.5 million tons of HCHs and 0.44 million tons of DDTs (Cao et al., 2007).

More than 20 OCPs have been detected in Chinese agricultural soils (Fig. S2). DDT, HCB, heptachlor, Aldrin, and dieldrin were listed in the Stockholm Convention on Persistent Organic Pollutants (POPs) by the United Nations Environment Program (UNEP) (World Wide Found, 2005). HCHs, endosulfan, and methoxychlor have been proposed as potential POP candidates (World Wide Found, 2005). Furthermore, HCH is considered to be a primary pollutant by the USEPA (UNEP, 2003). The total concentrations of OCPs ranged from < LOD (limit of detection) to 3,520 ng/g, with a mean of 58.9 ± 51.5 ng/g (n = 40) (Table 1). The concentrations of OCPs in Central China were higher than other regions (Kruskal-Wallis, $0.289<p<0.796$), possibly due to intensive agricultural activities (Fig. 1 and Fig. 2). The amount of historical pesticide usage (including major OCPs) in farmland was the largest in this region, especially Henan Province (Zhao, 2013). Among the reported OCPs, *p,p'*-DDE exhibited the highest concentration (mean ± standard deviation: 14.6 ± 20.7 ng/g, n = 66), followed by *p,p'*-DDT (mean: 12.7 ± 15.8 ng/g, n =66) and chlordane (mean: 8.36 ± 26.7 ng/g, n =15). Generally, the total concentrations of DDTs and HCHs ranged from < LOD to 3,515 ng/g (mean: 41.6 ± 57.2 ng/g, n = 68), and from < LOD to 760 ng/g (mean: 11.4 ± 18.2 ng/g, n = 64), respectively (Table 1), which was comparable to those reported in Romania and

156 Germany (Covaci et al., 2001; Manz et al., 2001). According to the Chinese Environmental
157 Quality Standard for Soil (GB-15618-1995) (1995), the average concentrations of DDTs and
158 HCHs in all the reports were within in the Class II Limit (Safe). However, the concentrations
159 of DDTs and HCHs in some samples exceeded this safety standard. For example, a relatively
160 high level of DDTs was detected in samples collected from Jiangsu, Tianjin, Hohhot, and
161 Jiangxi (Table 1). To date, the environmental quality standard concerns only DDTs and HCHs.
162 Several studies revealed that some OCPs, such as chlordane and methoxychlor, also exhibited
163 high concentrations in agricultural soils, indicating that the standard should be updated for
164 better soil protection.

165 Soil becomes the major sink and reservoir of OCPs (Tao et al., 2008). However, OCPs
166 can also be emitted into the atmosphere and be recycled continuously between the
167 atmosphere and the terrestrial environment. The air-soil exchange analysis of OCPs could
168 help to predict the distribution patterns of OCPs in a certain region (Liu et al., 2016b). It was
169 reported that the re-emission of OCPs from soil is a dynamic process that may be affected by
170 soil properties. Previous studies suggested that DDTs were much easier to be volatilized from
171 soil to air in Zhejiang as compared to southern Ontario, Canada (Kurt-Karakus et al., 2006;
172 Zhang et al., 2012a), indicating that DDTs have higher volatility in soils with higher
173 temperatures and lower organic contents. Comparing evaporation of OCPs from soil to air
174 showed that *p,p'*-DDE, γ-HCH, and δ-HCH have a higher tendency to evaporate from soil to
175 air when compared with *p,p'*-DDD and *p,p'*-DDT (Yu et al., 2013).

176 To assure the quality of agricultural products, particularly in polluted areas, it is
177 necessary to study the bioavailability of OCs that can help evaluating plant uptake and

178 selecting appropriate crops. It is known that the organic pollutants in soils could enter plant
179 via root uptake (Fantke and Jolliet, 2015). Tao et al. (2005) proposed that the accumulation of
180 OCPs was lower in tuberous plants as compared to the plants of fibrous root system. The
181 accumulation of OCPs in plants is closely related to the properties of the chemical concerned
182 and soil medium, for instance, high concentration of SOM in soil could inhibit the
183 accumulation of OCPs in plants (Wu and Zhu 2016). Recently, it was reported that the
184 accumulation of OCPs in plants could be influenced by nanoparticles (De La Torre-Roche et
185 al., 2012).

186 Temporal trends in OCPs in agricultural soils during the last 16 years were analyzed (Fig.
187 3). Except for one study (Wang et al., 2016a), the concentrations of OCPs in recent studies
188 are lower than those that were identified decades ago, indicating that the residues of OCPs
189 decreased significantly after the ban on agricultural uses. Considering that some samples still
190 exhibited high concentrations of OCPs, there may be some new inputs of OCPs, such as
191 dicofol and lindane (Sun et al., 2016c). The spatial analysis results show that the average
192 levels of OCPs in the soils of North and Central China were higher (Fig. 2). The areas, such
193 as Henan and Hebei, in which the agricultural crop sown area is 14,425 and 8,739 hectares,
194 respectively, are also important production bases for foodstuffs, cotton, and edible oil crops
195 (Zhou et al., 2013a; National Bureau of Statistics of China, 2017). Large quantities of OCPs
196 have been used intensively to increase agricultural production for several decades (Wang et
197 al., 1999).

198 The concentrations of OCPs were also closely associated with the land use types. The
199 concentrations of HCHs and DDTs in vegetable soils were reportedly higher than those in

paddy soils collected from the Pearl River Delta (Li et al., 2006), which was probably because the anaerobic-aerobic rotation conditions in paddy fields were more favorable for OCP degradation (Hao et al., 2008). However, according to some other studies, the total concentrations of OCPs in soils decreased in the order paddy field > upland field, because there were greater amounts of OCPs applied during the rice growth periods (An et al., 2005; Gao et al., 2013). Taking the technical HCH as an example, it was estimated that approximately half of this insecticide was used in rice paddies (Li et al., 2001).

2.2. PAHs

PAHs tend to be retained in soils due to their high hydrophobicity (Terashima et al., 2003). PAHs are formed primarily during the incomplete combustion or pyrolysis of organic matter. Sixteen PAHs were identified in a priority control list by the USEPA. Seven PAHs, namely, BaA, Chr, BbF, BkF, BaP, DahA, InP and BghiP, are confirmed to be carcinogenic (Harvey, 1991). Some studies have indicated that China suffers serious PAH contamination from the combustion of fossil fuel and biomass. The total emission of the 16 priority PAHs was 25,300 t in 2003 for China, contributing to over 20% of the global total PAH emissions (Xu et al., 2006; Zhang and Tao, 2009).

PAHs have been detected in a large number of agricultural soil samples. The total PAH concentrations ranged from < LOD to 27,580 ng/g, with a mean of 772 ± 895 ng/g (n = 40) (Table 2). The concentration of carcinogenic PAHs ranged from < LOD to 7,940 ng/g, with an average of 464 ± 889 ng/g (n = 17). In Northeast China, the concentrations of PAHs were higher than other regions (Kruskal-Wallis, $0.180<p<0.938$) due to extensive coal combustion and petroleum industrial operations (Fig. 1 and Fig. 2). Among the carcinogenic PAHs, Chr

and BbF were the most abundant compounds in the soil (Fig. S3). There is currently no recommendation or guideline for regulating the occurrence of PAHs in agricultural soils in China. A classification of soil contamination based on PAHs was proposed as follows, in a previous study: non-contaminated soil (< 200 ng/g); weakly contaminated soil (200-600 ng/g); contaminated soil (600-1000 ng/g) and heavily contaminated soil (> 1000 ng/g) (MaliszewskaKordybach, 1996). According to this classification, the concentrations of PAHs exceeded the limits of heavily contaminated soil in the soils of Nanjing (Ge et al., 2006; Wang et al., 2015a), Shanghai (Sun et al., 2008), Taizhou (Tang et al., 2010), the Pearl River Delta (Cai et al., 2007), Beijing (Ma et al., 2005; Zhou et al., 2013b), Changchun (Chen et al., 2016), and Xi'an (Zhou et al., 2012) (Table 2).

The study of air-soil exchange of PAHs showed that LMW PAHs were more easily to be volatilized from the soil, whereas the HMW PAHs exhibited a net deposition from the atmosphere (Liu et al., 2011). Previous study demonstrated that the soil moisture could accelerate the volatilization of PAHs from soil (Wang et al., 2015c). HMW PAHs were more easily to be adsorbed to soils due to higher hydrophobicity, in other words, the volatilization tendency of HMW PAHs was much lower than that of LMW PAHs (Wang et al., 2015c; Cetin et al., 2017; Dumanoglu et al., 2017).

Accumulation of PAHs in plants was associated with the properties of PAHs and the species of plants. It was proposed that HMW PAHs have greater mobility from soils to plants. The accumulation of PAHs was greater in vegetables than corn, exemplifying the physiological difference between different plants (Chen et al., 2016). It should be noted that the direct contact of plant roots with water might facilitate the uptake of PAHs from soils to

plants (Wang et al., 2015d). The cropping pattern of plants could be a major factor that influences the accumulation of PAHs in plants. Furthermore, a sudden decrease in PAH concentrations was observed in the vegetative organs (roots, stems, and leaves) of rice during the heading stage, which may be due to the organic nutrient-associated transport of PAHs from the vegetative organs to the rice seeds. Factors, such as the properties of PAHs, plant species, tillage method, and growth time, should be considered comprehensively with respect to food safety and phytoremediation concerns.

The temporal trends in PAHs in the farmland topsoil are shown in Fig. 3. During the last 16 years, the concentration of PAHs showed no significant increasing or decreasing trends. However, the total PAH concentrations in Tianjin in 2012 were reportedly higher than those in 2008 (Chen et al., 2015). Further studies should be conducted to measure the temporal trends of PAHs in the city or in certain regions. The PAH levels in Northeast and Northwest China were higher than those in the other regions (Fig. 2). The higher PAH concentrations in the soils of Northeast China are potentially the result of frequent coal combustion for home-heating in the winter, especially in rural areas. Shaanxi and Xinjiang of Northwest China are also important coal and petroleum production areas in China. The production of coal and petroleum could cause significant PAH pollution in the environment. In addition, due to the rapid growth of industrial production, population, and traffic density, cities in East China are also faced with serious PAH pollution.

Several studies have compared the concentrations of PAHs in different types of fields. The total concentrations of PAHs in vegetable fields were higher than they were in paddy fields (Yang et al., 2007a; Cao et al., 2013). Multi-cropping practices, such as cover cropping,

266 double cropping, and integrated crop-livestock systems, have been employed in the vegetable
267 fields to meet the growing demand for agricultural commodities. Thus, more agricultural
268 materials, such as organic fertilizer and pesticide, were applied to the vegetable fields, and
269 they led to PAH pollution (Yang et al., 2007a). However, the deep plowing activity in paddy
270 fields may also dilute the LMW PAHs in surface soil, but facilitate their transfer to the
271 subsoil (Wang et al., 2012b).

272 *2.3. PCBs*

273 PCBs are halogenated aromatic compounds, and they were recognized as POPs by the
274 Stockholm Convention in 2001 (Zhang et al., 2008). Some PCB congeners, such as PCB-77,
275 81, 105, 114, 118, 12, 126, 156, 157, 167, 169, and 189, were considered as dioxin-like PCBs
276 due to their higher toxicities (Sun et al., 2016b). Despite being banned in many countries,
277 PCBs still represent an important class of pollutants that present high risks to humans and
278 ecosystems (Su et al., 2012; Sun et al., 2016b).

279 Soils are among the most important environmental sinks for PCBs. However, in
280 comparison with the studies on OCPs and PAHs, the surveys on PCBs in agricultural soils
281 were fewer (Fig. S1). The total concentrations of PCBs in agricultural soil were between <
282 LOD and 202 ng/g, with an average of 9.31 ± 15.4 ng/g (n = 21) (Table 3 and Fig. S4). The
283 total concentrations of dioxin-like PCBs ranged from < LOD to 78.9 ng/g, with a mean of
284 4.64 ± 4.41 ng/g (n = 6). Higher PCB levels were found in South (Kruskal-Wallis,
285 $0.180<p<0.655$) and East China (Kruskal-Wallis, $0.088<p<0.827$), as compared to other
286 regions (Fig. 1 and Fig. 2). The average non-cancer risk of PCBs was relatively high (Hazard
287 Index = 44.0 for children, and 24.7 for adults) in agricultural soils from the Yangtze River

288 Delta (Sun et al. 2016b). High cancer risks from PCBs in children and adults were also found
289 in that region. The high risks were primarily from the dioxin-like PCBs, such as PCB-126,
290 PCB-81, and PCB-169, which should be considered for new legislation and policy relating to
291 soil pollution protection in the future.

292 Li et al. (2010) demonstrated that soil was more supersaturated when compared to air
293 since the PCB concentrations in the air declined relatively faster, whereas the concentrations
294 in the soils needed longer to respond. Generally, the soil composition and environment
295 parameters, including the organic carbon, particle size composition, soil porosity, relative
296 humidity, and temperature, could affect the air-soil exchange of PCBs. A comparison of the
297 coupled soil and air concentration in China has been conducted by Zhang et al (2008), in
298 which the low-chlorinated PCBs were more easily volatilized to air, while the
299 high-chlorinated PCBs were more strongly bound to soil particles. Soil could be an important
300 contributor of the low-chlorinated PCBs (very volatile 2-Cl and in some cases 3-Cl PCBs)
301 that were observed in the air. For high-chlorinated PCBs, the soil was likely to be the sink for
302 a long time (Li et al., 2010).

303 Accumulation of low-chlorinated PCBs was higher in plant tissue as compared to the
304 high-chlorinated PCBs (Li et al., 2015b). The accumulation of PCBs in plant was also plant
305 species dependent: higher accumulation of PCBs was found in wild plants, followed by the
306 vegetable (*Raphanus sativus* L., *Brassica rapa* L., etc.) and rice stalk (Wang et al. 2011b).
307 The accumulation of PCBs in plant was positively correlated with the growing time (Li et al.,
308 2015b).

309 Higher concentrations of PCBs were observed in the electronic waste-dismantling areas

310 in China (especially for Guiyu and Taizhou). It has been estimated that globally,
311 approximately 40 million tons of e-waste are generated every year, with an increasing rate of
312 4% per year (Wong et al., 2007). Most of the world's e-waste is exported from developed
313 countries to developing countries such as China (Fu et al., 2012a). Discarded PCB-containing
314 equipment has become an important source of PCBs in the environment (Ogunseitan et al.,
315 2009; Sepulveda et al., 2010; Wang et al., 2013a), and it may explain the elevated PCB
316 concentrations in the soils of Guangdong and Zhejiang (Cai et al., 2008).

317 The concentrations of PCBs varied with the land-use types, in the order paddy fields >
318 upland fields > uncultivated fields (Zhang et al., 2007; Wang et al., 2010b; Zhang et al.,
319 2013d; Sun et al., 2016b). This difference is probably related to the soil conditions and
320 planting patterns. The water in the paddy fields reduces the volatilization of PCBs to the air,
321 and it prevents the aerobic degradation of PCBs. However, the concentrations of PCB in the
322 upland field soils of Guangdong province were nearly four times higher than those in the
323 paddy field soils (Wang et al., 2011b). The probable reason is that the deep plowing activity
324 of paddy fields and the irrigation water diluted the PCBs in the topsoil and transferred them
325 to the deep soil layer.

326 *2.4. PAEs*

327 PAEs are a class of chemicals that are widely used as plasticizers in polyvinyl acetates,
328 polyvinyl chloride, and polyurethanes (Wang et al., 2010a). Due to their potentially
329 hazardous impacts on human health and the environment, both the USEPA and the China
330 State Environmental Protection Administration have classified six PAEs as priority pollutants.

331 During the last decade, PAEs were frequently identified in farmland from different

regions of China (Cai et al., 2005; Yang et al., 2007b; Zhang et al., 2015; Sun et al., 2016c). PAEs exhibited the highest levels among the studied POPs with an average concentration of 3,738 ± 5,840 ng/g (n = 21) in Chinese soils, covered from < LOD to 157,620 ng/g (Table 4). The highest concentration was observed in the farmlands of Hubei (Wu et al., 2015) (Fig. 1). The high concentration of PAEs might be due to the widespread application of plastic materials, such as agricultural plastic film. The extensive use of fertilizer and pesticides could also cause elevated PAE levels. In the polluted area, DEHP presented the highest concentrations (mean: 3,011 ± 5,964 ng/g, n = 14), followed by DBP (mean: 1,131 ± 2,039 ng/g, n = 7) (Fig. S5).

The studies on the air-soil exchange of PAEs indicated that the polluted soils could be a secondary source of atmospheric contamination of PAEs. Previous studies suggested that one of the dominant losses of PAEs from the soils was attributable to soil-air volatilization (Cheng et al., 2015). DMP was more readily volatilized to air as compared with other five EPA-PAEs, and the volatilization from soil to air decreased with the increase of logK_{ow} of PAEs.

The studies of the uptake, translocation, and accumulation of PAHs in plant showed that the accumulation of MnBP in plants was higher as compared with DnBP, DEHP, and MEHP (Sun et al., 2015). The concentrations of PAEs differed in various plants (Ji et al., 2014; Sun et al., 2015). More studies on the accumulation and tissue distribution of PAEs in plants should be conducted in future.

No significant temporal trend in PAEs was observed in China during the last 16 years (Fig. 3). However, the concentrations of PAEs in South China showed an increasing trend

354 from 2005 to the time of this study. The production and utilization of agricultural plastic films
355 have reportedly increased in recent years, which could be causing the increasing pollution in
356 South China. In general, the concentration of PAEs in South China was much higher than
357 those in other regions (Fig. 2 and Table 4). Some cities in South China, such as Guangzhou,
358 were large metropolitan areas and intensive agricultural areas for a long-time period. Along
359 with the fast urbanization and industrialization of the last few decades, the environmental
360 quality of these urban areas in South China has severely deteriorated.

361 The cultivation methods of farmland might affect the residual levels and fates of PAEs in
362 the soils. The concentrations of PAEs were lower in non-cultivated fields when compared
363 with the cultivated fields (Xu et al., 2008). This finding was because the cultivation methods
364 and farm management could introduce PAEs into the fields. Regarding the cultivated fields,
365 the concentrations of PAEs were higher in paddy fields than those in the upland field (Wang
366 et al., 2013b). Plastic agricultural films, municipal biosolids, agricultural chemicals, and
367 wastewater irrigation have been identified as the main sources for PAEs contamination in
368 soils (He et al., 2015). Surface coverage by irrigation water could partially result in different
369 PAE levels between paddy and upland fields. In paddy fields, the surface soils were
370 frequently covered with water, which may considerably reduce the volatilization of PAEs
371 (Wang et al., 2013b). Moreover, the water coverage may greatly reduce the contact that PAEs
372 have with sunlight irradiation and air exposure, thus lowering the abiotic degradation of the
373 PAEs (Wang et al., 2013b). By contrast, PAEs were more easily degraded by microbes under
374 aerobic conditions, and thus a higher biodegradation of PAEs was found in upland soils (Liu
375 et al., 2010). However, it is also reported that orchard and vegetable fields showed higher

PAEs concentration than paddy field since orchard and vegetable fields require more intensive application of fertilizers and pesticides, and more plastic packing (Liu et al. 2010).

3. Remediation of soil organic contamination

Various organic pollutants remain ubiquitous in the agricultural soils of China. These pollutants will not only pose adverse effect to soil properties, but they can also enter food chains and eventually pose risks to human health. It is thus important to reduce and eliminate organic pollutants and lower the contamination that is already present in the environment. Many remedial attempts, including physical, chemical, and biological treatments, have been made to reach an environmentally sound and cost-effective remediation of contaminated lands. A summary table of all the remediation technologies for soil organic pollution according to different categories is provided in Table S1 (Supporting Information).

Previous studies have demonstrated that physical remediation (such as thermal treatment and vapor extraction technology) and chemical remediation (such as oxidation and reduction technology, and soil washing technology) could be effectively used to remedy organic pollutant-contaminated soils (Gan et al., 2009; Falciglia et al., 2016; Jia et al., 2016). However, the use of physical or chemical remediation technologies may severely compromise the biological and chemical quality of soils (Lim et al., 2016). Problems such as high equipment and treatment costs and damage to soil quality have not been resolved, which limits the large-scale application of physical or chemical methods in the remediation of extensive areas of agricultural soil that is contaminated by persistent organic pollutants. To date, physical and chemical remediation methods are mainly used for industry-impacted soil.

3.1. Bioremediation and phytoremediation

The area of pollution in farmland is usually much larger than that of contaminated industrial fields. The contamination degree of agricultural soil is comparably lower than that of the soil in industrial zones. The remediation of agricultural soil requires the protection of soil fertility and ecological function. Compared with physical and chemical remediation, bioremediation and phytoremediation have greater potential applications for the remediation of agricultural soil because they have the advantages of low cost, easy *in situ* operation, and no secondary pollution. Bioremediation/phytoremediation in agricultural soils have been applied both in China and abroad (Gerhardt et al., 2009; Teng et al., 2010; Ma et al., 2012).

Bioremediation, primarily microbial degradation, is a natural way of eliminating pollutants by breaking down polluted substrates for nutrients. Soil microorganisms, either in the presence of oxygen (aerobic biodegradation) or without oxygen (anaerobic biodegradation), have been found to degrade and mineralize OCs. Bioremediation of OCs has been successfully conducted in agricultural fields under natural conditions (Labana et al., 2005; Odukkathil and Vasudevan 2016； Ayotamuno et al., 2006). Small-scale field studies showed that *p*-Nitrophenol could be completely depleted in the presence of *Arthrobacter protophormiae* AKJ100 (Labana et al., 2005). Efficiency of bioremediation could be optimized by agitation, aeration, and addition of nutrients. For instance, heterotrophic bacteria have been used in remediation of crude-oil polluted agricultural soil. Results showed that between 75 and 200 g of fertilizer per 0.16 m^2 lead to the best biodegradation (degradation efficiency covered from 93% to 95%) (Ayotamuno et al., 2006). Highly chlorinated PCBs could be the substrate for aerobic bacteria (Gomes et al., 2013), and they can be dechlorinated to form less chlorinated congeners under anaerobic conditions

(Furukawa and Fujihara, 2008). The significant anaerobic biodegradation of LMW PAHs such as fluorine, phenanthrene, and pyrene has been observed in paddy soil with nitrate being used as an electron acceptor (Ambrosoli et al., 2005). The microbial degradation of PAEs in soils is more effective under aerobic than anaerobic conditions (Yuan et al., 2002). The biodegradation efficiency of fluxapyroxad in soils was investigated, and the results showed that higher oxygen levels caused a higher potential for fluxapyroxad degradation (Li et al., 2015c). Currently, researchers are proposing that coupling anaerobic and aerobic conditions could increase the efficiency of remediation strategies (Master et al., 2002; Meade and D'Angelo, 2005). Sequential anaerobic then aerobic composting was suggested for the biodegradation of PCBs (Long et al., 2015).

Plants have been reported to mineralize a wide range of complex organic pollutants into non-toxic constituents such as chlorine, carbon dioxide, and nitrate (Vidali, 2001). Phytoremediation is an environmentally friendly, low cost, and sustainable method for remediation. The accumulation of OCPs in plant tissue has been studied (Gonzalez et al., 2005). The concentration of OCPs in plant tissues might be 4- to 45-fold higher than those in soils. The grasses of the *Poaceae* and the legumes of the *Fabaceae* were considered as excellent candidates for removing PAHs from soils. Moderately hydrophobic chemicals are most likely to be bioavailable to rooted and vascular plants. Some hydrophilic OCs could also be taken up by plants through hydrogen bonding with transpiration water or the partition effect (Chiou et al., 2001; Dietz and Schnoor, 2001). The OCs in the plants might then be translocated to the stem and leaf tissues, which were subsequently degraded (Liu and Schnoor, 2008; Zhai et al., 2013). Phytoextraction and phytovolatilization are the two approaches used

442 to remove and detoxify OCs in agricultural soils. Phytoextraction removes pollutants from
443 soil by concentrating them in the harvestable plant part. Previous studies have demonstrated
444 that zucchini (*Cucurbita pepo*) is a good accumulator of OCs from agricultural soil (Wang et
445 al., 2004; White et al., 2006). For phytovolatilization, some OCs could be converted into
446 volatile forms within the plants and subsequently volatilized. It has been reported that
447 compounds with low octanol-air partitioning coefficients (log K_{oa} < 5) are more prone to
448 being phytovolatilized (Limmer and Burken, 2016). Field experiments showed that the plant
449 could facilitate the mobilization and/or degradation of OCs in soils and the *Fimbristylis*
450 *littoralis* could be useful for the bioremediation of crude oil polluted agricultural soils (up to
451 92% of total PAHs were removed after 90 days) (White, 2001; Nwaichi et al., 2015).

452 *3.2. Integrated remediation technologies*

453 Each remediation technology discussed in the preceding section has its own problems.
454 Therefore, some integrated remediation technologies were developed.
455 Plant-microbe-associated bioremediation has been used for agricultural soil remediation.
456 Synergistic interactions between plants and microbial communities in the rhizosphere are
457 effective for the degradation of recalcitrant OCs (Vergani et al., 2017). Root exudates (amino
458 acids, flavonones, sugars, enzymes, phenolic compounds and other organic materials) could
459 enhance the bioavailability of OCs and microbial activities in the immediate vicinity of the
460 roots (Javorska et al., 2009). To eliminate PAHs with increasing ring numbers, root
461 exudate-enhanced degradation becomes more important (Sun et al., 2010). Rhizosphere
462 microbes can occur naturally, or they can be activated by introducing specific microbes into
463 the rhizosphere (Gerhardt et al., 2009). Chaudhry et al. (2005) suggested that microbial

464 strains capable of breaking down OCs were widely present in rhizosphere soils.

465 Bioremediation alone was usually unable to remove persistent and highly toxic pollutants
466 quickly from agricultural soil (Huang et al., 2017). The use of a biological treatment as a
467 secondary step after chemical remediation has been performed (Kulik et al., 2006). It was
468 ascertained that a combined Fenton-like treatment and biological remediation was more
469 efficient at PAH removal than either one alone. Surfactant-enhanced bioremediation (SEBR)
470 is a promising technology for improving the bioavailability and removal efficiency of OCs in
471 agricultural soil (Wang et al., 2016d). Several studies have shown that surfactant can not only
472 increase the partition of OCs to microbial cells, but it can also facilitate the transmembrane
473 transportation of OCs into the cells and hence accelerate intracellular biodegradation (Zhang
474 and Zhu, 2012; Li and Zhu, 2014; Li et al., 2014). Different types of surfactants imposed
475 various impacts on the biodegradation of PAHs via distinct mechanisms such as disrupting
476 bacterial membranes and the modification of cell surface hydrophobicity (Zhang et al.,
477 2013a). Recently, the ring-hydroxylating dioxygenase (RHDase) and the
478 1-hydroxyl-2-naphthoate dioxygenase genes (1H2Nase), which play a key role in the
479 decomposition of hydrophobic aromatic compounds, were found to be induced in the
480 presence of surfactants (Li et al., 2015a).

481 Surfactants could be applied to increase the solubility and bioavailability of OCs and thus
482 assist in the mobilization of OCs into the soil solution (Chirakkara et al., 2016). A recent
483 study revealed that surfactants could enhance the bioavailability of PAHs and the efficiency
484 of plant-microbe-associated bioremediation (Ni et al., 2014). Another study found that
485 surfactant can enhance the degradation of DDTs by microorganisms in agricultural soil

(Wang et al., 2016e). Overall, surfactant-enhanced bioremediation could be a promising technology for addressing combined organic pollution in agricultural soil, and it should be developed in future studies.

4. Future research needs

4.1. Combined pollution and interfacial interactions

Because of the rapid growth of industrial processes, traffic density, agricultural activities, and the population, a wide range of chemicals such as POPs, heavy metals, antibiotics, and nanomaterials may coexist in the soil environment at elevated concentrations. From the reviewed literature, it is clearly illustrated that the research highlights have gradually transferred from single pollution to combined pollution in recent years. Emerging pollutants enter the soil ecosystem and possibly interact with conventional pollutants that remain from the historical contamination (Zhu et al., 2005; Li et al., 2013a). These potential interactions between the coexisting chemicals and soil constituents can influence their behavior and fates in soils (Liang et al., 2015). There were recent studies on combined pollution in a simulated aqueous environment (Lei et al., 2016) and an atmospheric environment (Pandey et al., 2013; Ercan and Dinçer, 2015; Hassanvand et al., 2015). Future studies are needed to reveal the adsorption, transportation, and transformation of multi-class pollutants in soil environment and at the air-water-soil interfaces. It is important to clarify the interactions associated with physical and chemical processes for the pollution control and remediation of contaminated agricultural soils to accomplish environmental sustainability under a rapidly changing climate. Climate changes (temperature and precipitation, etc.) and more often occurrence of extreme weather may affect the soil quality and the air-soil exchange of OCs (Dumanoglu et al., 2017),

508 which should be considered in the future.

509 A number of factors may influence the interfacial interactions. The characteristics of
510 contaminants (i.e., their hydrophobicity, polarity, and electron density), and the composition
511 of natural and amended soil media (i.e., minerals, humus, biochar, and nanoparticles) could
512 be the key contributing factors. It is important to reveal the molecular-level mechanisms of
513 the pollutant fate and interactions in future studies. For example, electrospray ionization
514 coupled with Fourier-transform ion cyclotron resonance mass spectrometry (ESI-FT-ICR-MS)
515 have been proved helpful in the characterization of interfacial behavior (Lv et al., 2016). To
516 characterize the interactions in soil interfaces, new analytical methods should be developed.

517 *4.2. Ecological effects on soil microbial communities*

518 Soil microbes are crucial to biogeochemical cycles on Earth and play a key role in soil
519 ecosystems. Numerous studies have found that environmental pollution may affect the
520 metabolic activities of soil microbes and consequently change the soil microbial community
521 composition and diversity (Liu et al., 2015a; Sun et al., 2016b). Pollutants in soils could
522 decrease the diversity of microorganisms but enrich the tolerant species via the environmental
523 filtering process, which may in turn affect the overall ecosystem functions and natural
524 balance of soil microorganisms. The consequence of soil microbial responses to
525 environmental changes is still the key question that is in urgent need of an answer.

526 For example, antibiotics along with antibiotic resistance genes (ARGs) have been
527 extensively investigated through a metagenomic study recently (Martinez, 2009; Xu et al.,
528 2016). The large amounts of antibiotics applied to agricultural production systems can exert
529 selection pressure on environmental microorganisms, contributing to proliferating antibiotic

530 resistance in microorganisms. The ARGs were further disseminated among bacteria through
531 horizontal gene transfer mechanisms via various mobile genetic elements (Fang et al., 2015).
532 However, methods for analyzing the genetic diversity in soil microbes were rarely employed
533 in the study of soil pollutants, such as PAHs, OCPs, PCBs, and PAEs. There were very few
534 field studies focused on the effects of combined pollution on the indigenous microbiota. The
535 responses of soil microbiota community to the combined pollution and its ecological
536 consequences should be explored in the future.

537 However, soil microorganisms also play an important role in the remediation of polluted
538 soil through active involvement in the degradation and transformation of different organic
539 compounds. Understanding the effects of OC pollution on soil ecosystems is helpful for
540 developing the selection and application of microbes for remediation purposes.
541 High-throughput sequencing has enabled the in-depth exploration of microbial biodiversity in
542 the polluted soil environment. The rapidly developing metagenomic analysis provides
543 advanced technology for exploring the ecological consequences caused by combined organic
544 pollution of soil. The predictions for indigenous bacteria in terms of their ability to degrade
545 various pollutants on the dynamics of agricultural production are necessary for systematic
546 ecological evaluations.

547 *4.3. Bioavailability, food safety, and risk assessments*

548 The uptake and accumulation of OCs in crops is closely related to their bioavailability
549 (White, 2002). Although a great number of studies on the occurrences of OCs in Chinese
550 agricultural soils have been published, few data are available on the bioavailability of OCs in
551 soil. Thus, one of the major issues is to investigate the *in vivo* bioavailability of OCs in a

552 wide range of edible crops and poultry animals, to provide important information on risk
553 evaluations of OCs in soil and agricultural products. To predict bioavailability accurately, the
554 distribution of OCs and the influencing factors should be studied. The available concentration
555 in the soil integrated with the plant metabolism coefficient and the foliar uptake factor should
556 be considered (Sun et al., 2016a). The regulation principle regarding the bioavailability of
557 OCs based on the behaviors at multimedia soil-water-air-plant-cell interfaces have not been
558 revealed yet.

559 Food safety is closely related to the bioavailability and accumulation of OCs in
560 agricultural produce, which is a priority for future research. The availability of arable land is
561 limited in many countries such as China. In response to rapid population growth and
562 increasing food demand, inappropriate strategies including excessive application of pesticides
563 and fertilizers have been adopted to achieve high production. These agricultural practices can
564 lead to the accumulation of pollutants in vegetable and crops. Root-accumulated DDTs in
565 vegetables were reported from 7.1 to 152 ng/g (cabbage, spinach, etc.) in a study (Tao et al.,
566 2005). Total concentrations of PAHs in the corn along main roadside ranged from 220 to 627
567 ng/g (Chen et al., 2016). Organic pollutants at theses concentrations may present serious
568 health risk for human consumption. PAEs were found to show broad inhibition on the activity
569 of enzymes UDP-glucuronosyltransferases (UGTs) (Cao et al., 2017). Hydroxylated-PCBs
570 are considered to disrupt the thyroid hormone metabolism (Meerts et al., 2002).Therefore, to
571 protect the diet safety of local residents, it is essential to understand the accumulation status
572 and potential food safety risk in soil-vegetable system.

573 The potential risks of OCs to human health and the ecological system are less understood.

574 Due to the widespread distribution of OCs, individuals are unavoidably exposed to OCs via
575 dietary and non-dietary (e.g., ingestion, dermal contact, and inhalation) routes. Soil is the
576 major sink and reservoir of pollutants in the environment. Soil-air partitioning makes soil a
577 secondary source of pollutants to the atmosphere (Sweetman et al., 2005; Cabrerizo et al.,
578 2011). The leaching of pollutants from soil is one of the most important threats to the
579 groundwater quality (Hantush et al., 2000; Calderon-Preciado et al., 2011). In addition, global
580 climate change can affect the pollution situation of the environment (Nadal et al., 2015;
581 Tambo et al., 2016). It is necessary to thoroughly evaluate the risk from soil pollutants and
582 establish a systematic strategy for the control of the whole process. Valid and realistic risk
583 assessments of OCs to both human health and ecological receptors should be considered in
584 future studies to provide key information for risk management and remediation decisions.

585 *4.4. Novel control and remediation method*

586 Control and remediation methods for soil pollution should be developed according to the
587 land use types and pollution levels. Compared to industrial sites in China, farmlands are
588 characterized by large areas of low-level but combined pollution. The integrated techniques
589 of chemical treatment and bioremediation methods have many advantages. For agricultural
590 soils with low pollution, mitigation methods may be developed to enhance the sorption of
591 pollutants to soil components, for reducing their bioavailable concentrations as well as
592 decreasing the uptake and accumulation in plants. The addition of biochar or surfactant has
593 been demonstrated to be useful for fixing pollutants in soil (Zhou and Zhu, 2008; Kusmierz et
594 al., 2016). However, the biochemistry processes and mechanisms in the crop rhizosphere
595 have not been clearly evaluated. New mitigation methods should aim to produce safe food in

596 relatively lightly polluted soil.

597 The selection of suitable crops is also important for the sustainable utilization of
598 agricultural soil. Collaborations between plants and soil microorganisms can accelerate the
599 degradation of OCs, although the mechanism still must be elucidated (Jin et al., 2013; Ni et
600 al., 2014). For agricultural soils with heavy pollution, remediation methods should be
601 developed to remove OCs from the soil and assure the environmental safety of farmlands.
602 The addition of certain chemicals such as biosurfactants can promote the elution of OCs from
603 soil particles (Song et al., 2008). The development of nanotechnology has attracted
604 significant attention. Nanomaterials have great application potentials for the remediation of
605 polluted soil due to their superior reactivity (Zhan and Jiang, 2015; Zhu et al., 2015). The use
606 of nanomaterials for enhancing plant-microbe-associated bioremediation technology has a
607 bright future. The recently developed electrokinetic-biological remediation of
608 pesticide-contaminated soil has an advantage in that it enables *in situ* pollutant elimination
609 (Barba et al. 2017). Monitored natural attenuation has attracted increasing attention from the
610 perspective of economic management strategies. The prudent and controlled use of naturally
611 occurring pollutant degradation and retardation processes is applicable for a large area of
612 complex contaminated agricultural soils (Rugner et al., 2008). In addition, to ensure
613 productivity, the control and remediation technology for agricultural soil in China should
614 consider a field-scale application in vast areas of farmland as well as different regions of
615 China.

616 ## 5. Conclusions

617 As widely detected environmental pollutants, OCPs, PAHs, PCBs, and PAEs are the

618 primary organic contaminants in the agricultural soils of China. The average concentrations
619 of PAEs, PAHs, OCPs, and PCBs in agricultural soils of China were 3,724 ± 5,844 ng/g, 772
620 ± 895 ng/g, 58.9 ± 51.5 ng/g, and 9.31 ± 15.4 ng/g, respectively. These organic contaminants
621 present distinct spatial patterns across the nation. Therefore, management guidelines for
622 organic pollution should be adapted to local conditions. It is necessary to conduct regular
623 surveys to monitor the evolutionary trends. Integrated remediation technologies, such as
624 surfactant-enhanced bioremediation, should be further refined for the cost-effective
625 remediation of large areas of contaminated farmlands. The combined pollution, interfacial
626 interactions, ecological effects, bioavailability, food safety, risk assessment, and integrated
627 pollution control and remediation methods for agricultural soil pollution are major research
628 topics in the future. More effective and imperative activities are needed for the management
629 and control of organic contaminants in the agricultural soils in developing countries.
630

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638 ## References

639 Ambrosoli, R., Petruzzelli, L., Luis Minati, J., Ajmone Marsan, F., 2005. Anaerobic PAH degradation

640 in soil by a mixed bacterial consortium under denitrifying conditions. Chemosphere 60, 1231-1236.
641 An, Q., Dong, Y.H., Wang, J., Ge, C.J., 2005. Residues and distribution character of organochlorine
642 pesticides in soils in Nanjing area. Acta. Scien. Circum. 25, 470-474 (in Chinese).
643 Ayotamuno, M.J., Kogbara, R.B., Ogaji, S.O.T., Probert, S.D., 2006. Bioremediation of a crude-oil
644 polluted agricultural-soil at Port Harcourt, Nigeria. Appl. Energ. 83, 1249-1257..
645 Barba, S., Villasenor, J., Rodrigo, M.A., Canizares, P., 2017. Effect of the polarity reversal frequency
646 in the electrokinetic-biological remediation of oxyfluorfen polluted soil. Chemosphere 177, 120-127.
647 Bidleman, T.F., Leone, A.D., 2004. Soil–air exchange of organochlorine pesticides in the Southern
648 United States. Environ. Pollut. 128, 49-57.
649 Cabrerizo, A., Dachs, J., Moeckel, C., Ojeda, M.J., Caballero, G., Barcelo, D., Jones, K.C., 2011.
650 Factors influencing the soil-air partitioning and the strength of soils as a secondary source of
651 polychlorinated biphenyls to the atmosphere. Environ. Sci. Technol. 45, 4785-4792.
652 Cai, Q.Y., Mo, C.H., Li, Y.H., Zeng, Q.Y., Katsoyiannis, A., Wu, Q.T., Ferard, J.F., 2007. Occurrence
653 and assessment of polycyclic aromatic hydrocarbons in soils from vegetable fields of the Pearl River
654 Delta, South China. Chemosphere 68, 159-168.
655 Cai, Q.Y., Mo, C.H., Li, Y.H., Zeng, Q.Y., Wang, B.G., Xiao, K.E., Li, H.Q., Xu, G.S., 2005. The study
656 of PAEs in soils from typical vegetable fields in areas of Guangzhou and Shenzhen, South China. Acta
657 Ecol. Sin. 25, 283-288 (in Chinese).
658 Cai, Q.Y., Mo, C.H., Wu, Q.T., Katsoyiannis, A., Zeng, Q.Y., 2008. The status of soil contamination
659 by semivolatile organic chemicals (SVOCs) in China: a review. Sci. Total Environ. 389, 209-224.
660 Calderon-Preciado, D., Jimenez-Cartagena, C., Matamoros, V., Bayona, J.M., 2011. Screening of 47
661 organic microcontaminants in agricultural irrigation waters and their soil loading. Water Res. 45,

221-231.

Cao, H.Y., Liang, T., Tao, S., Zhang, C.S., 2007. Simulating the temporal changes of OCP pollution in Hangzhou, China. Chemosphere 67, 1335-1345.

Cao, X.F., Liu, M., Song, Y.F., Ackland, M.L., 2013. Composition, sources, and potential toxicology of polycyclic aromatic hydrocarbons (PAHs) in agricultural soils in Liaoning, People's Republic of China. Environ. Monit. Assess. 185, 2231-2241.

Cao, Y.F., Du, Z., Zhu, Z.T., Sun, H.Z., Fu, Z.W., Yang, K., Li, Y.Z., Hu, C.M., Dong, P.P., Gonzalez, F.J., Fang, Z.Z., 2017. Inhibitory effects of fifteen phthalate esters in human Cdna-expressed UDP-glucuronosyltrase supersomes. 185, 983-990.

Cetin, B., Yurdakul, S., Keles, M., Celik, I., Ozturk, F., Dogan, C., 2017. Atmospheric concentrations, distributions and air-soil exchange tedencies of PAHs and PCBs in a heavily industrialized area in Kocaeli, Turkey. Chemosphere 183, 69-79.

Chaudhry, Q., Blom-Zandstra, M., Gupta, S., Joner, E.J., 2005. Utilising the synergy between plants and rhizosphere microorganisms to enhance breakdown of organic pollutants in the environment. Environ. Sci. Pollut. R. 12, 34-48.

Chen, M., Huang, P., Chen, L., 2013. Polycyclic aromatic hydrocarbons in soils from Urumqi, China: distribution, source contributions, and potential health risks. Environ. Monit. Assess. 185, 5639-5651.

Chen, P., Chen, L., Huang, P., 2014. Residues and possible sources of organochlorine pesticides in surface soil of Urumqi. China Environ. Sci. 34, 1838-1846 (in Chinese).

Chen, R., Lv, J.G., Zhang, W., Liu, S., Feng, J.M., 2015. Polycyclic aromatic hydrocarbon (PAH) pollution in agricultural soil in Tianjin, China: a spatio-temporal comparison study. Environ. Earth Sci. 74, 2743-2748.

684 Chen, Y.N., Zhang, J.Q., Ma, Q.Y., Sun, C.Y., Ha, S., Zhang, F., 2016. Human health risk assessment
685 and source diagnosis of polycyclic aromatic hydrocarbons (PAHs) in the corn and agricultural soils
686 along main roadside in Changchun, China. Hum. Ecol. Risk Assess. 22, 706-720.
687 Cheng, X.M., Ma, L.L., Xu, D.D., Cheng, H.X., Yang, G.S., Luo, M., 2015. Mapping of phthalate
688 esters in suburban surface and deep soils around a metropolis-Beijing, China. J. Geoche. Explor. 155,
689 56-61.
690 China National Environmental Protection Agency, 1995. Environemntal Quality Standard for Soils.
691 GB15618-1995.
692 Chiou, C.T., Sheng, G.Y., Manes, M., 2001. A partition-limited model for the plant uptake of organic
693 contaminants from soil and water. Environ. Sci. Technol. 35, 1437-1444.
694 Chirakkara, R.A., Cameselle, C., Reddy, K.R., 2016. Assessing the applicability of phytoremediation
695 of soils with mixed organic and heavy metal contaminants. Rev. Environ. Sci. Bio. 15, 299-326.
696 Covaci, A., Hura, C., Schepens, P., 2001. Selected persistent organochlorine pollutants in Romania.
697 Sci. Total Environ. 280, 143-152.
698 De La Torre-Roche, R., Hawthoren, J., Deng, Y.Q., Xing, B.S., Cai, W.J., Newman, L.A., Wang, C.,
699 Ma, X.B.M White, J.C., 2012. Fullerene-enhanced accumylation of p,p'-DDE in agricultyral crop
700 species. Environ. Sci. Technol. 45, 9315-9323.
701 Dietz, A.C. and Schnoor, J.L., 2001. Advances in phytoremediation. Environ. Health Persp. 109,
702 163-168.
703 Ding, A.F., Pan, G.X., Li, L.Q., 2007. Contents and sources of PAH s in top soils of farmlands in parts
704 of Jiangsu, China. J. Ecol. Rural Environ. 23, 71-75 (in Chinese).
705 Dumanoglu, Y., Gaga, E.O., Gungormus, E., Sofuoglu, S.C., Odabasi, M., 2017. Spatial and seasonal

706 variations, sources, air-soil exchange, and carcinogenic risk assessment for PAHs and PCBs in air and
707 soil of Kutahya, Turkey, the province of thermal power plants. Sci. Total Environ. 580, 920-935.
708 Ercan, Ö. and Dinçer, F., 2015. Atmospheric concentrations of PCDD/Fs, PAHs, and metals in the
709 vicinity of a cement plant in Istanbul. Air Qual. Atmos. Hlth. 9, 159-172.
710 Falciglia, P.P., De Guidi, G., Catalfo, A., Vagliasindi, F.G.A., 2016. Remediation of soils contaminated
711 with PAHs and nitro-PAHs using microwave irradiation. Chem. Eng. J. 296, 162-172.
712 Fang, H., Wang, H., Cai, L., Yu, Y., 2015. Prevalence of antibiotic resistance genes and bacterial
713 pathogens in long-term manured greenhouse soils as revealed by metagenomic survey. Environ. Sci.
714 Technol. 49, 1095-1104.
715 Fantke, P. and Jolliet, O., 2015. Life cycle human health impacts of 875 pesticides. Int. J. Life Cycle
716 Ass. 21, 722-733.
717 Feng, A.H., Zhu, Z.C., Chen, S.J., Wang, J., Luo, X.J., Mai, B.X., 2013. Spatial distribution and risk
718 assessment of polycyclic aromatic hydrocarbons in soils of Shouguang City, North China. China
719 Environ. Sci. 33, 1607-1614 (in Chinese).
720 Feng, H.Y., Fu, X.Q., Zhang, Q., Fan, Y.G., 2012. Health riskassessment of persistent toxic substances
721 in agricultural soils of Ningbo. Mod. Sci. Instrum. 4, 128-133 (in Chinese).
722 Fu, J.J., Wang, T., Wang, P., Qu, G.B., Wang, Y.W., Zhang, Q.H., Zhang, A.Q., Jiang, G.B., 2012a.
723 Temporal trends (2005-2009) of PCDD/Fs, PCBs, PBDEs in rice hulls from an e-waste dismantling
724 area after stricter environmental regulations. Chemosphere 88, 330-335.
725 Fu, Y., Sun, Y.C., Mao, H.H., Shen, L.C., Jia, Y.N., 2012b. Distribution tendency and source
726 identification of organochlorine pesticides in soils of an underground river catchment. China Environ.
727 Sci. 32, 517-522 (in Chinese).

728 Furukawa, K. and Fujihara, H., 2008. Microbial degradation of polychlorinated biphenyls:
729 Biochemical and molecular features. J. Biosci. Bioeng. 105, 433-449.
730 Gai, N., Pan, J., Tang, H., Chen, S., Chen, D.Z., Zhu, X.H., Lu, G.H., Yang, Y.L., 2014.
731 Organochlorine pesticides and polychlorinated biphenyls in surface soils from Ruoergai high altitude
732 prairie, east edge of Qinghai-Tibet Plateau. Sci. Total Environ. 478, 90-97.
733 Gan, S., Lau, E.V., Ng, H.K., 2009. Remediation of soils contaminated with polycyclic aromatic
734 hydrocarbons (PAHs). J. Hazard. Mater. 172, 532-549.
735 Gao, H.J., Wei, J.L., Ma, J.J., Zhen, B., 2012. Characteristics of PAHs contamination in soil and
736 vegetable in typical city outskirt of Anhui Province, China. J. Agro-Environ. Sci. 31, 1913-1919 (in
737 Chinese).
738 Gao, J., Zhou, H., Pan, G., Wang, J., Chen, B., 2013. Factors influencing the persistence of
739 organochlorine pesticides in surface soil from the region around the Hongze Lake, China. Sci Total
740 Environ. 443, 7-13.
741 Garcon, G., Zerimech, F., Hannothiaux, M.H., Gosset, P., Martin, A., Marez, T., Shirali, P., 2001.
742 Antioxidant defense disruption by polycyclic aromatic hydrocarbons-coated onto Fe_2O_3 particles in
743 human lung cells (A549). Toxicology 166, 129-137.
744 Ge, C.J., An, Q., Dong, Y.H., Yu, H.M., 2006. Distribution of organic pollutants in agricultural soil in
745 Nanjing City. Resour. Environ. Yangtze Basin 3, 361-365 (in Chinese).
746 Geng, C.Z., Li, M.L., Yang, Y.L., Zhang, L.F., Nie, L.M., 2006. Study and analysis of pollution levels
747 of OCPs and PCBs in soils in Qingdao area. J. Qingdao Univ. 21, 42-48 (in Chinese).
748 Gerhardt, K.E., Huang, X.-D., Glick, B.R., Greenberg, B.M., 2009. Phytoremediation and
749 rhizoremediation of organic soil contaminants: Potential and challenges. Plant Sci. 176, 20-30.

750 Gomes, H.I., Dias-Ferreira, C., Ribeiro, A.B., 2013. Overview of in situ and ex situ remediation
751 technologies for PCB-contaminated soils and sediments and obstacles for full-scale application. Sci.
752 Total Environ. 445-446, 237-260.
753 Gong, Z.M., Tao, S., Xu, F.L., Dawson, R., Liu, W.X., Cui, Y.H., Cao, J., Wang, X.J., Shen, W.R.,
754 Zhang, W.J., Qing, B.P., Sun, R., 2004. Level and distribution of DDT in surface soils from Tianjin,
755 China. Chemosphere 54, 1247-1253.
756 Gonzalez, M., Miglioranza, K.S.B., de Moreno, J.E.A., Moreno, V.J., 2005. Evaluation of
757 conventionally and organically produced vegetables for high lipophilic organochlorine pesticide (OCP)
758 residues. Food Chem. Toxicol. 43, 261-269.
759 Guo, D.L., Ma, J., Li, R., Guo, C.H., 2010. Genotoxicity effect of nitrobenzene on soybean (Glycine
760 max) root tip cells. J. Hazard. Mater. 178, 1030-1034.
761 Han, X.M., Liu, Y.R., Zheng, Y.M., Zhang, X.X., He, J.Z., 2014. Response of bacterial pdo1, nah, and
762 C12O genes to aged soil PAH pollution in a coke factory area. Environ. Sci. Pollut. R. 21, 9754-9763.
763 Han, Y.M., Bandowe, B.A.M., Wei, C., Cao, J.J., Wilcke, W., Wang, G.H., Ni, H.Y., Jin, Z.D., An, Z.S.,
764 Yan, B.Z., 2015. Stronger association of polycyclic aromatic hydrocarbons with soot than with char in
765 soils and sediments. Chemosphere 119, 1335-1345.
766 Hantush, M.M., Marino, M.A., Islam, M.R., 2000. Models for leaching of pesticides in soils and
767 groundwater. J. Hydrol. 227, 66-83.
768 Hao, H.T., Sun, B., Zhao, Z.H., 2008. Effect of land use change from paddy to vegetable field on the
769 residues of organochlorine pesticides in soils. Enviro. Pollut. 156, 1046-1052.
770 Hao, R., Song, Y.T., Wan, H.F., Peng, S.L., 2007a. Polycyclic aromatic hydrocarbons and
771 organochlorine pesticides in agricultural soils from typical area of south subtropics, China. Acta Ecol.

772 Sin. 27, 2021-2029 (in Chinese).

773 Hao, R., Wan, H.F., Song, Y.T., Jiang, H., Peng, S.L., 2007b. Polycyclic aromatic hydrocarbons in
774 agricultural soils of the southern subtropics, China. Pedosphere 17, 673-680.

775 Harvey, R.C., 1991. Polycyclic aromatic hydrocarbons: Chemistry and carcinogenicity. in: Cambridge
776 Univ. Press, N.Y. (Ed.).

777 Hassanvand, M.S., Naddafi, K., Faridi, S., Nabizadeh, R., Sowlat, M.H., Momeniha, F., Gholampour,
778 A., Arhami, M., Kashani, H., Zare, A., Niazi, S., Rastkari, N., Nazmara, S., Ghani, M., Yunesian, M.,
779 2015. Characterization of PAHs and metals in indoor/outdoor PM10/PM2.5/PM1 in a retirement home
780 and a school dormitory. Sci. Total Environ. 527-528, 100-110.

781 He, C.Q., Liu, J.M., Li, J., Liang, X., Chen, X.P., Lei, Y.R., Zhu, D., 2013. Spatial distribution, source
782 analysis, and ecological risk assessment of DDTs in typical wetland surface soils of Poyang Lake.
783 Environ. Earth Sci. 68, 1135-1141.

784 He, J., Zhen, Y.X., Ding, H.W., Xu, X.M., Li, Z.J., 2010. Soil environment and pollutants ecological
785 risk assessment for the vegetable cultivation farmland in Dianchi Lakeshore Region. Envir. Sci. Surv.
786 29, 75-78 (in Chinese).

787 He, L.Z., Gielen, G., Bolan, N.S., Zhang, X.K., Qin, H., Huang, H.G., Wang, H.L., 2015.
788 Contamination and remediation of phthalic acid esters in agricultural soils in China: a review. Agron.
789 Sustain. Dev. 35, 519-534.

790 Hu, G.J., Chen, S.L., Shi, W., Zhang, B.B., Zhang, Y., Huang, J., Chen, J., Giesy, J.P., Yu, H.X., 2015.
791 Identification of polycyclic aromatic hydrocarbons in soils in Taizhou, East China. Environ. Geochem.
792 Health 37, 429-439.

793 Hu, G.J., Sun, C., Zhao, Y.G., Li, J., Wang, H., Ding, X.N., Zhang, Y., Liao, Q.L., 2009. Investigation

794 of persistent toxic substances in agricultural soil of Wuzhong district, Suzhou. Environ. Sci. Technol.
795 32, 113-124 (in Chinese).
796 Hu, W.Y., Huang, B., Zhao, Y.C., Sun, W.X., Gu, Z.Q., 2011. Organochlorine pesticides in soils from
797 a typical alluvial plain of the Yangtze River Delta Region, China. B. Environ. Contam. Tox. 87,
798 561-566.
799 Hu, W.Y., Huang, B., Zhao, Y.C., Sun, W.X., Gu, Z.Q., 2014. Distribution, sources and potential risk
800 of HCH and DDT in soils from a typical alluvial plain of the Yangtze River Delta region, China.
801 Environ. Geochem. Hlth. 36, 345-358.
802 Hu, W.Y., Lu, Y.L., Wang, T.Y., Luo, W., Zhang, X., Geng, J., Wang, G., Shi, Y.J., Jiao, W.T., Chen,
803 C.L., 2010. Factors affecting HCH and DDT in soils around watersheds of Beijing reservoirs, China.
804 Environ. Geochem. Hlth. 32, 85-94.
805 Hu, X.Y., Wen, B., Shan, X.Q., 2003. Survey of phthalate pollution in arable soils in China. J. Environ.
806 Monitor. 5, 649-653.
807 Huang, D., Hu, C., Zeng, G., Cheng, M., Xu, P., Gong, X., Wang, R., Xue, W., 2017. Combination of
808 Fenton processes and biotreatment for wastewater treatment and soil remediation. Sci. Total Environ.
809 574, 1599-1610.
810 Huang, D.Y., Liu, C.P., Li, F.B., Liu, T.X., Liu, C.S., Tao, L., Wang, Y., 2014a. Profiles, sources, and
811 transport of polycyclic aromatic hydrocarbons in soils affected by electronic waste recycling in
812 Longtang, south China. Environ. Monit. Assess. 186, 3351-3364.
813 Huang, H.F., Qi, S.H., Qu, C.K., Li, H., Chen, W.W., Zhang, L., Hu, T., Shi, L., 2014b. Distribution
814 characteristics and risk assessment of organochlorine pesticides in soil from Jiufeng Mountain Range
815 in Fujian, China. Environ. Sci. 35, 2691-2697 (in Chinese).

816 Huang, T., Guo, Q., Tian, H., Mao, X.X., Ding, Z.Y., Zhang, G., Li, J., Ma, J.M., Gao, H., 2014c.
817 Assessing spatial distribution, sources, and human health risk of organochlorine pesticide residues in
818 the soils of arid and semiarid areas of northwest China. Environ. Sci. Pollut. R. 21, 6124-6135.
819 IUSS Working Group WRB (2014). World Reference Base for Soil Resources 2014. International Soil
820 Classification System for Naming Soils and Creating Legends for Soil Maps.
821 Javorska, H., Tlustos, P., Kaliszova, R., 2009. Degradation of polychlorinated biphenyls in the
822 rhizosphere of rape, Brassica napus L. B. Environ. Contam. Tox. 82, 727-731.
823 Jia, J.L., Wang, B.B., Wu, Y., Niu, Z., Ma, X.Y., Yu, Y., Hou, P., 2016. Environmental risk
824 controllability and management of VOCs during remediation of contaminated sites. Soil Sediment
825 Contam. 25, 13-25.
826 Jiang, P., Zhao, P., Wan, H.F., Guo, Z.X., Zhang, T.B., Yang, G.Y., Hou, M.F., 2011a. Concentrations
827 of PCBs in agricultural soils of typical regions in Pearl River Delta. Soils 43, 948-953 (in Chinese).
828 Jiang, Y.F., Wang, X.T., Jia, Y., Wang, F., Wu, M.H., Sheng, G.Y., Fu, J.M., 2009. Occurrence,
829 distribution and possible sources of organochlorine pesticides in agricultural soil of Shanghai, China.
830 J. Hazard. Mater. 170, 989-997.
831 Jiang, Y.F., Wang, X.T., Wu, M.H., Sheng, G.Y., Fu, J.M., 2011b. Contamination, source identification,
832 and risk assessment of polycyclic aromatic hydrocarbons in agricultural soil of Shanghai, China.
833 Environ. Monit. Assess. 183, 139-150.
834 Jin, H., Zhou, W., Zhu, L., 2013. Utilizing surfactants to control the sorption, desorption, and
835 biodegradation of phenanthrene in soil-water system. J. Environ. Sci. 25, 1355-1361.
836 Ji, Y.Q., Wang, F.M., Zhang, L.B., Shan, C.Y., Bai, Z.P., Sun, Z.R., Liu, L.L., Shen, B.X., 2014. A
837 comprehensive assessment of human exposure to phthalates from environmental media and food in

838 Tianjin, China. J. Hazard. Mater. 279, 133-140.
839 Kong, S.F., Ji, Y.Q., Liu, L.L., Chen, L., Zhao, X.Y., Wang, J.J., Bai, Z.P., Sun, Z.R., 2012. Diversities
840 of phthalate esters in suburban agricultural soils and wasteland soil appeared with urbanization in
841 China. Environ. Pollut. 170, 161-168.
842 Kulik, N., Goi, A., Trapido, M., Tuhkanen, T., 2006. Degradation of polycyclic aromatic hydrocarbons
843 by combined chemical pre-oxidation and bioremediation in creosote contaminated soil. J. Environ.
844 Manage. 78, 382-391.
845 Kurt-Karakus, P.B., Bidleman, T.F., Staebler, R.M., Jones, K.C., 2006. Measurement of DDT fluxes
846 from a historically treated agricultural soil in Canada. Environ. Sci. Technol. 40, 4578-4585.
847 Kusmierz, M., Oleszczuk, P., Kraska, P., Palys, E., Andruszczak, S., 2016. Persistence of polycyclic
848 aromatic hydrocarbons (PAHs) in biochar-amended soil. Chemosphere 146, 272-279.
849 Labana, S., Pandey, G., Paul, D., Sharma, N.K., Basu, A., Jain, R.K., 2005. Pot and field studies on
850 bioremediation of p-nitrophenol contaminated soil using Athrobacter protophormiae RKJ100. Environ.
851 Sci. Technol. 39, 3330-3337.
852 Lan, J.C., Sun, Y.C., Shi, Y., Xu, X., Yuan, D.X., Hu, N., 2014. Source and contamination of
853 polycyclic aromatic hydrocarbons in surface soil in Karst underground river basin. Environ. Sci. 35,
854 2937-2943 (in Chinese).
855 Lang, Y.H., Li, G.L., Yang, W., Wang, X.M., Peng, P., 2014. Ecological risk and health risk assessment
856 of dioxin-like PCBs in Liaohe Estuarine Wetland Soils, China. Polycycl. Aromat. Comp. 34, 425-438.
857 Lei, P., Zhang, H., Shan, B., Zhang, B., 2016. Distribution, diffusive fluxes, and toxicity of heavy
858 metals and PAHs in pore water profiles from the northern bays of Taihu Lake. Environ. Sci. Pollut.
859 Res. Int. 23, 22072-22083.

860 Li, F. and Zhu, L.Z., 2014. Surfactant-modified fatty acid composition of Citrobacter sp SA01 and its
861 effect on phenanthrene transmembrane transport. Chemosphere 107, 58-64.
862 Li, F., Zhu, L.Z., Wang, L.W., Zhan, Y., 2015a. Gene Expression of an arthrobacter in
863 surfactant-enhanced biodegradation of a hydrophobic organic compound. Environ. Sci. Technol. 49,
864 3698-3704.
865 Li, F., Zhu, L.Z., Zhang, D., 2014. Effect of surfactant on phenanthrene metabolic kinetics by
866 Citrobacter sp SA01. J. Environ. Sci. 26, 2298-2306.
867 Li, J., Jiang, L., Xiang, X., Xu, S., Wen, R., Liu, X., 2013a. Competitive sorption between 17α-ethinyl
868 estradiol and bisphenol A/4-n-nonylphenol by soils. J. Environ. Sci. 25, 1154-1163.
869 Li, J., Zhang, G., Qi, S.H., Li, X.D., Peng, X.Z., 2006. Concentrations, enantiomeric compositions,
870 and sources of HCH, DDT and chlordane in soils from the Pearl River Delta, South China. Sci. Total
871 Environ. 372, 215-224.
872 Li, J.S., Chen, Y.Q., Wu, X.P., Hu, J., Huang, Y., 2008a. Studies on residues of organochloride
873 pesticides in the soils of Hunan province. R. Environ. Sci. 21, 85-90 (in Chinese).
874 Li, Q.B., Zhang, H., Luo, Y.M., Song, J., Wu, L.H., Ma, J.M., 2008b. Residues of DDTs and their
875 spatial distribution characteristics in soils from the Yangtze River Delta, China. Environ. Toxicol.
876 Chem. 27, 24-30.
877 Li, Q.L., Wang, Y., Luo, C.L., Li, J., Zhang, G., 2015b. Characterization and risk assessment of
878 polychlorinated biphenyls in soils and rice tissues in a suburban paddy field of the Pearl River Delta,
879 South China. Environ. Sci. Pollut. R. 22, 11626-11633.
880 Li, S., Liu, X., Chen, C., Dong, F., Xu, J., Zheng, Y., 2015c. Degradation of fluxapyroxad in soils and
881 water/sediment systems under aerobic or anaerobic conditions. Bull. Environ. Contam. Toxicol. 95,

882 45-50.

883 Li, T.C., Li, W., Yuan, C.Y., Tao, S., 2014b. Distribution of polycyclic aromatic hydrocarbons in
884 surface soils of Yinchuan Plain and surrounding areas. J. Agri-Environ. Sci. 33, 2136-2142 (in
885 Chinese).

886 Li, X., Zhou, J.Y., Wu, W.C., Li, X.S., Li, Y.B., Cai, X.D., 2015d. Evaluation of PAEs pollution of
887 farmland soil in Gaozhou. Chinese J. Soil Sci. 46, 991-996 (in Chinese).

888 Li, X.R., Zhao, T.K., Zhang, C.J., Li, P., Li, S.J., Zhao, L.P., 2013b. Source apportionment of
889 polycyclic aromatic hydrocarbons in agricultural soils of Yanqing County in Beijing, China. Environ.
890 Forensics 14, 324-330.

891 Li, Y., Zhang, H.B., Li, Q.B., Zhou, Q., Chen, X.B., Tu, C., Luo, Y.M., Christie, P., Hu, X.F., Li, L.Z.,
892 2016. Characteristics of residual organochlorine pesticides in soils under different land-use types on a
893 coastal plain of the Yellow River Delta. Environ. Geochem. Hlth. 38, 535-547.

894 Li, Y.F., Cai, D.J., Shan, Z.J., Zhu, Z.L., 2001. Gridded usage inventories of technical
895 hexachlorocyclohexane and lindane for china with 1/6 degrees latitude by 1/4 degrees longitude
896 resolution. Arch. Environ. Con.Tox. 41, 261-266.

897 Li, Y.F., Harner, T., Liu, L.Y., Zhang, Z., Ren, N.Q., Jia, H.L., Ma, J.M., Sverko, E., 2010.
898 Polychlorinated biphenyls in global air and surface soil: Distributions, air-soil exchange, and
899 fractionation effect. Environ. Sci. Technol. 44, 2784-2790.

900 Li, Y.T., Li, F.B., Zhang, T.B., Yang, G.Y., Chen, J.J., Wan, H.F., 2007. Pollution assessment,
901 distribution and sources of PAHs in agricultural soils of Pearl River Delta - The biggest manufacturing
902 base in China. J. Environ. Sci. Heal. A 42, 1979-1987.

903 Li, Z.Y., Kong, S.F., Chen, L., Bai, Z.P., Ji, Y.Q., Liu, J.W., Lu, B., Han, B., Wang, Q.W., 2011.

904 Concentrations, spatial distributions and congener profiles of polychlorinated biphenyls in soils from
905 a coastal city - Tianjin, China. Chemosphere 85, 494-501.
906 Liang, X., Zhu, L., Zhuang, S., 2015. Sorption of polycyclic aromatic hydrocarbons to soils enhanced
907 by heavy metals: perspective of molecular interactions. J. Soil. Sediment. 16, 1509-1518.
908 Lim, M.W., Von Lau, E., Poh, P.E., 2016. A comprehensive guide of remediation technologies for oil
909 contaminated soil - Present works and future directions. Mar. Pollut. Bull. 109, 14-45.
910 Limmer, M. and Burken, J., 2016. Phytovolatilization of organic contaminants. Environ. Sci. Technol.
911 50, 6632-6643.
912 Lin, Z.B., Tang, L.N., Chen, J.B., Fang, L., Chen, D.K., Lan, A.J., 2013. Residues characteristics of
913 organochlorine pesticides in the soil of rice in FuJian of northwest. Chinese Agr. Sci. Bull. 29,
914 158-160 (in Chinese).
915 Liu, B., Li, A.M., Zhang, Q., He, X.M., 2016a. Study on the pollution of OCPs in vegetable soils from
916 Hubei. Environ. Monit. China 32, 87-91 (in Chinese).
917 Liu, B.L, Ma. L., Dong, W.H., Hua, X.Y., Dong, D.M., Wang, B.B., 2013. Organochlorine pesticides
918 (OCPs) residues in farmland soils in the North and Centre of Jilin Province. J. Jilin Univ. Sci. Edit. 51,
919 1187-1192 (in Chinese).
920 Liu, G.Q., Yu, L.L., Li, J., Liu, X.A., Zhang, G., 2011. PAHs in soils and estimated air soil exchange in
921 the Pearl River Delta, South China. Environ. Monit. Assess. 173, 861-870.
922 Liu, G.Y., Chen, Z.S., Shi, Y.H., Wang, G.Y., Li, W., Li, C.Q., 2006. The levels and compositions of
923 PCBs in Beijing soil. Acta Sci. Circum stantiae 26, 2013-2017 (in Chinese).
924 Liu, H., Liang, H.C., Liang, Y., Zhang, D., Wang, C., Cai, H.S., Shvartsev, S.L., 2010. Distribution of
925 phthalate esters in alluvial sediment: A case study at JiangHan Plain, Central China. Chemosphere 78,

926 382-388.
927 Liu, J., He, X.X., Lin, X.R., Chen, W.C., Zhou, Q.X., Shu, W.S., Huang, L.N., 2015a. Ecological
928 effects of combined pollution associated with e-waste recycling on the composition and diversity of
929 soil microbial communities. Environ. Sci. Technol. 49, 6438-6447.
930 Liu, J.Y. and Schnoor, J.L., 2008. Uptake and translocation of lesser-chlorinated polychlorinated
931 biphenyls (PCBs) in whole hybrid poplar plants after hydroponic exposure. Chemosphere 73,
932 1608-1616.
933 Liu, L.Y., Ma, W.L., Jia, H.L., Zhang, Z.F., Song, W.W., Li, Y.F., 2016b. Research on persistent
934 organic pollutants in China on a national scale: 10 years after the enforcement of the Stockholm
935 Convention. Environ. Pollut. 217, 70-81.
936 Liu, M.X., Yang, Y.Y., Yun, X.Y., Zhang, M.M., Wang, J., 2015b. Occurrence and assessment of
937 organochlorine pesticides in the agricultural topsoil of Three Gorges Dam region, China. Environ.
938 Earth Sci. 74, 5001-5008.
939 Liu, Y., Li, S., Ni, Z., Qu, M., Zhong, D., Ye, C., Tang, F., 2016c. Pesticides in persimmons, jujubes
940 and soil from China: Residue levels, risk assessment and relationship between fruits and soils. Sci.
941 Total Environ. 542, 620-628.
942 Long, Y.Y., Fang, Y., Zhang, C., Du, Y., Shentu, J., Shen, D.S., 2015. Degradation of polychlorinated
943 biphenyls by sequential anaerobic–aerobic composting. Water Air Soil Poll. 226.
944 Lu, H.X. and Liu, W.G., 2015. Vertical distributions of organochlorine pesticides and polychlorinated
945 biphenyls in an agricultural soil core from the Guanzhong Basin, China. Environ. Monit. Assess. 187.
946 Lv, J.G., Bi, C.J., Chen, Z.L., Zhou, J.C., 2011. Characteristics of organochlorine pesticide residues in
947 agricultural soil of Chongming Island in Shanghai. Environ. Sci. 32, 2455-2461 (in Chinese).

948 Lv, J.G., Shi, R.G., Cai, Y.M., Liu, Y., Wang, Z.H., Feng, J.M., Zhao, M., 2010. Assessment of 20
949 organochlorine pesticides (OCPs) pollution in suburban soil in Tianjin, China. B Environ. Contam.
950 Tox. 85, 137-141.
951 Lv, J.T., Zhang, S.Z., Wang, S.S., Luo, L., Cao, D., Christie, P., 2016. Molecular-scale investigation
952 with ESI-FI-ICP-MS on fractiination of dissolved organic matter induced by adsorption on iron
953 oxyhydroxides.
954 Ma, L.L., Chu, S.G., Wang, X.T., Cheng, H.X., Liu, X.F., Xu, X.B., 2005. Polycyclic aromatic
955 hydrocarbons in the surface soils from outskirts of Beijing, China. Chemosphere 58, 1355-1363.
956 Ma, L.L., Chu, S.G., Xu, X.B., 2003. Organic contamination in the greenhouse soils from Beijing
957 suburbs, China. J. Environ. Monitor. 5, 786-790.
958 Ma, T.T., Luo, Y.M., Christie, P., Teng, Y., Liu, W.X., 2012. Removal of phthalic esters from
959 contaminated soil using different cropping systems: A field study. Eur. J. Soil Biol. 50, 76-82.
960 Ma, W.L., 2007. Study on PCBs, PAHs and OCPs in soils in Harbin city. Harbin Institte of
961 Technology. Environ. Sci. Technol. 50, 2328-2336.
962 Ma, W.L., Liu, L.Y., Tian, C.G., Qi, H., Jia, H.L., Song, W.W., Li, Y.F., 2015. Polycyclic aromatic
963 hydrocarbons in Chinese surface soil: occurrence and distribution. Environ. Sci. Pollut. R. 22,
964 4190-4200.
965 Ma, X.X., Ran, Y., Gong, J., Zou, M.Y., 2008. Concentrations and inventories of polycyclic aromatic
966 hydrocarbons and organochlorine pesticides in watershed soils in the Pearl River Delta, China.
967 Environ. Monit. Assess. 145, 453-464.
968 MaliszewskaKordybach, B., 1996. Polycyclic aromatic hydrocarbons in agricultural soils in Poland:
969 Preliminary proposals for criteria to evaluate the level of soil contamination. Appl. Geochem. 11,

121-127.

Manz, M., Wenzel, K.D., Dietze, U., Schuurmann, G., 2001. Persistent organic pollutants in agricultural soils of central Germany. Sci. Total Environ. 277, 187-198.

Mao, X.X., Ding, Z.Y., Ma, Z.L., Ma, J.M., Huang, T., Gao, H., Guo, Q., Tian, H., 2013. Typical organochlorine pesticides residues in topsoils and ecological risk of Lanzhou surrounding areas,China. Environ. Chem. 32, 466-474 (in Chinese).

Martinez, J.L., 2009. Environmental pollution by antibiotics and by antibiotic resistance determinants. Environ. Pollut. 157, 2893-2902.

Master, E.R., Lai, V.W.M., Kuipers, B., Cullen, W.R., Mohn, W.W., 2002. Sequential anaerobic-aerobic treatment of soil contaminated with weathered aroclor 1260. Environ. Sci. Technol. 36, 100-103.

Meade, T. and D'Angelo, E.M., 2005. [C-14]Pentachlorophenol mineralization in the rice rhizosphere with established oxidized and reduced soil layers. Chemosphere 61, 48-55.

Meerts, I.A.T.M., Assink, Y., Cenijn P.H., van den Berg, J.H.J., Weijers, B.M., Bergman, A., Koeman, J.H., Brouwer, A., 2002. Placental transfer of a hydroxylated polychlorinated biphenyl and effects on fetal and maternal thyroid hormone homeostasis in the rat. Toxicol. Sci. 68, 361-371.

Meng, J., Wang, T.Y., Wang, P., Giesy, J.P., Lu, Y.L., 2013. Perfluorinated compounds and organochlorine pesticides in soils around Huaihe River: a heavily contaminated watershed in Central China. Environ. Sci. Pollut. R. 20, 3965-3974.

Nadal, M., Marques, M., Mari, M., Domingo, J.L., 2015. Climate change and environmental concentrations of POPs: A review. Environ. R. 143, 177-185.

National Bureau of Statistics of China, 2017. China Statistical Yearbook. China Statistic Press, Beijing.

993 Ni, H.G., Cao, S.P., Ji, L.Y., Zeng, H., 2011. Incidence of organochlorine pesticides in soils of
994 Shenzhen, China. J. Environ. Monitor. 13, 951-956.
995 Ni, H.W., Zhou, W.J., Zhu, L.Z., 2014. Enhancing plant-microbe associated bioremediation of
996 phenanthrene and pyrene contaminated soil by SDBS-Tween 80 mixed surfactants. J. Environ. Sci. 26,
997 1071-1079.
998 Niu, L.L., Xu, Y., Xu, C., Yun, L.X., Liu, W.P., 2014. Status of phthalate esters contamination in
999 agricultural soils across China and associated health risks. Environ. Pollut. 195, 16-23.
1000 Nwaichi, E.O., Frac, M., Nwoha, P.A., Eragbor, P., 2015. Enhanced phytoremediation of crude
1001 oil-polluted soil by four plant species: Effect of inorganic and organic bioaugumentation. Int. J.
1002 Phytoremediat. 17, 1253-1261.
1003 Odukkathil, G., and Vasudevan, N., 2016. Residues of endosulfan in surface and subsurface
1004 agricultural soil and its bioremediation. J. Environ. Manage. 165, 72-80.
1005 Ogunseitan, O.A., Schoenung, J.M., Saphores, J.D.M., Shapiro, A.A., 2009. The electronics
1006 revolution: From e-wonderland to e-wasteland. Science 326, 670-671.
1007 Pan, S.W., Wu, Y.X., Luo, J.H., Li, L., 2011. Residual of organochlorine pesticides and distribution
1008 characteristics in the vegetable soils from Chengdu region of Sichuan province,China. Ecol. Environ.
1009 Sci. 20, 538-543 (in Chinese).
1010 Pandey, P., Patel, D.K., Khan, A.H., Barman, S.C., Murthy, R.C., Kisku, G.C., 2013. Temporal
1011 distribution of fine particulates (PM2.5, PM10), potentially toxic metals, PAHs and Metal-bound
1012 carcinogenic risk in the population of Lucknow City, India. J. Environ. Sci. Health A Tox. Hazard.
1013 Subst. Environ. Eng. 48, 730-745.
1014 Peng, C., Wang, M.E., Zhao, Y., Chen, W.P., 2016. Distribution and risks of polycyclic aromatic
1015 hydrocarbons in suburban and rural soils of Beijing with various land uses. Environ. Monit. Assess.

188.

Pies, C., Yang, Y., Hofmann, T., 2007. Distribution of polycyclic aromatic hydrocarbons (PAHs) in floodplain soils of the Mosel and Saar River. J. Soil. Sediment. 7, 216-222.

Qu, C.K., Qi, S.H., Yang, D., Huang, H.F., Zhang, J.Q., Chen, W., Yohannes, H.K., Sandy, E.H., Yang, J.H., Xing, X.L., 2015. Risk assessment and influence factors of organochlorine pesticides (OCPs) in agricultural soils of the hill region: A case study from Ningde, southeast China. J. Geochem. Explor. 149, 43-51.

Qu, C.K., Qi, S.H., Zhang, L., Huang, H.F., Zhang, J.Q., Zhang, Y., Yang, D., Liu, H.X., Chen, W., 2013. Distribution characteristics of organochlorine pesticides in soil from Daiyun Mountain Range in Fujian, China. Environ. Sci. 34, 4427-4433 (in Chinese).

Ren, N.Q., Que, M.X., Li, Y.F., Liu, Y., Wan, X.N., Xu, D.D., Sverko, E., Ma, J.M., 2007. Polychlorinated biphenyls in chinese surface soils. Environ. Sci. Technol. 41, 3871-3876.

Rugner, H., Bittens, M., Finkel, M., 2008. Application of monitored natural attenuation in contaminated land management - A review and recommended approach for Europe. Consoil 2008: Theme a - Policies on Soil-Water Systems, 221-222.

Sepulveda, A., Schluep, M., Renaud, F.G., Streicher, M., Kuehr, R., Hageluken, C., Gerecke, A.C., 2010. A review of the environmental fate and effects of hazardous substances released from electrical and electronic equipments during recycling: Examples from China and India. Environ. Impact. Assess. Rev. 30, 28-41.

Shi, B.F., Wu, Q.L., Ouyang, H.X., Liu, X.X., Zhang, J.L., Zou, W.J., 2015. Distribution and source apportionment of polycyclic aromatic hydrocarbons in the surface soil of Baise, China. Environ. Monit. Assess. 187, 232

1038 Shi, R.G., Lv, J.G., Feng, J.M., 2011. Assessment of pesticide pollution in suburban soil in south
1039 Shenyang, China. B. Environ. Contam. Tox. 87, 567-573.
1040 Shi, R.G., Lv, J.G., Zhang, L.L., 2012. Content character and source analyses of PAHs in soils of
1041 Tianjin Suburbs. Environ. Monit. China 28, 1-5 (in Chinese).
1042 Shi, Y., Meng, F., Guo, F., Lu, Y., Wang, T., Zhan, H., 2005. Residues of organic chlorinated pesticides
1043 in agricultural soils of Beijing, China. Arch. Environ. Contam. Toxicol. 49, 37-44.
1044 Song, S., Zhu, L., Zhou, W., 2008. Simultaneous removal of phenanthrene and cadmium from
1045 contaminated soils by saponin, a plant-derived biosurfactant. Environ. Pollut. 156, 1368-1370.
1046 Su, G.Y., Liu, X.H., Gao, Z.S., Xian, Q.M., Feng, J.F., Zhang, X.W., Giesy, J.P., Wei, S., Liu, H.L., Yu,
1047 H.X., 2012. Dietary intake of polybrominated diphenyl ethers (PBDEs) and polychlorinated biphenyls
1048 (PCBs) from fish and meat by residents of Nanjing, China. Environ. Int. 42, 138-143.
1049 Sun, J., Pan, L., Su, Z., Zhan, Y., Zhu, L., 2016a. Interconversion between methoxylated and
1050 hydroxylated polychlorinated biphenyls in rice plants: An important but overlooked metabolic
1051 pathway. Environ. Sci. Technol. 50, 3668-3675.
1052 Sun, J., Wu, X., Gan, J., 2015. Uptake and metabolism of phthalate esters by edible plants. Environ.
1053 Sci. Technol. 49, 8471-8478.
1054 Sun, J.T., Pan, L.L., Tsang, D.C.W., Zhan, Y., Liu, W.X., Wang, X.L., Zhu, L.Z., Li, X.D., 2016b.
1055 Polychlorinated biphenyls in agricultural soils from the Yangtze River Delta of China: Regional
1056 contamination characteristics, combined ecological effects and human health risks. Chemosphere 163,
1057 422-428.
1058 Sun, J.T., Pan, L.L., Zhan, Y., Lu, H.N., Tsang, D.C.W., Liu, W.X., Wang, X.L., Li, X.D., Zhu, L.Z.,
1059 2016c. Contamination of phthalate esters, organochlorine pesticides and polybrominated diphenyl

1060 ethers in agricultural soils from the Yangtze River Delta of China. Sci. Total Environ. 544, 670-676.
1061 Sun, T.R., Cang, L., Wang, Q.Y., Zhou, D.M., Cheng, J.M., Xu, H., 2010. Roles of abiotic losses,
1062 microbes, plant roots, and root exudates on phytoremediation of PAHs in a barren soil. J. Hazard.
1063 Mater. 176, 919-925.
1064 Sun, X.J., Shi, C., Xu, S.Y., Pan, F.F., Wang, P.H., Ma, J.L., Liu, P., 2008. Concentration and sources
1065 of polycyclic aromatic hydrocarbons in surface soil of north suburban Shanghai, China. Res. Environ.
1066 Sci., 140-144 (in Chinese).
1067 Sun, Y., Qi, S.H., Li, H., Huang, H.F., Yang, D., Fan, Y.H., Min, Y., Qu, C.K., 2016d. Concentrations,
1068 sources and health risk assessment of polycyclic aromatic hydrocarbons in soils collected along the
1069 banks of Minjiang River, Fujian, China. China Environ. Sci. 36, 1821-1829 (in Chinese).
1070 Sweetman, A.J., Valle, M.D., Prevedouros, K., Jones, K.C., 2005. The role of soil organic carbon in
1071 the global cycling of persistent organic pollutants (POPs): interpreting and modelling field data.
1072 Chemosphere 60, 959-972.
1073 Tambo, E., Duo-Quan, W., Zhou, X.N., 2016. Tackling air pollution and extreme climate changes in
1074 China: Implementing the Paris climate change agreement. Environ. Int. 95, 152-156.
1075 Tang, X., Shen, C., Cheema, S.A., Chen, L., Xiao, X., Zhang, C., Liu, W., Li, F., Chen, Y., 2010.
1076 Levels and distributions of polycyclic aromatic hydrocarbons in agricultural soils in an emerging
1077 e-waste recycling town in Taizhou area, China. J. Environ. Sci. Heal. A 45, 1076-1084.
1078 Tao, S., Liu, W., Li, Y., Yang, Y., Zuo, Q., Li, B.G., Cao, J., 2008. Organochlorine pesticides
1079 contaminated surface soil as reemission source in the Haihe Plain, China. Environ. Sci. Tech. 42,
1080 8395-8400.
1081 Tao, S., Xu, F.L., Wang, X.J., Liu, W.X., Gong, Z.M., Fang, J.Y., Zhu, L.Z., Luo, Y.M., 2005.

1082 Organochlorine pesticides in agricultural soil and vegetables from Tianjin, China. Environ. Sci.
1083 Technol. 39, 2494-2499.
1084 Teng, M., Zhang, H.J., Fu, Q., Lu, X.B., Chen, J.P., Wei, F.S., 2013. Irrigation-induced pollution of
1085 organochlorine pesticides and polychlorinated biphenyls in paddy field ecosystem of Liaohe River
1086 Plain, China. Chinese Sci. Bull. 58, 1751-1759.
1087 Teng, Y., Luo, Y.M., Sun, X.H., Tu, C., Xu, L., Liu, W.X., Li, Z.G., Christie, P., 2010. Influence of
1088 arbuscular mycorrhiza and rhizobium on phytoremediation by alfalfa of an agricultural soil
1089 contaminated with weathered PCBs: A field study. Int. J. Phytoremediat. 12, 516-533.
1090 Teng, Y.G., Li, J., Wu, J., Lu, S.J., Wang, Y.Y., Chen, H.Y., 2015. Environmental distribution and
1091 associated human health risk due to trace elements and organic compounds in soil in Jiangxi province,
1092 China. Ecotox. Environ. Safe. 122, 406-416.
1093 Terashima, M., Tanaka, S., Fukushima, M., 2003. Distribution behavior of pyrene to adsorbed humic
1094 acids on kaolin. J. Environ. Qual. 32, 591-598.
1095 The Central People's Government of the People's Republic of China, 2016. Action plan of soil
1096 pollition control. (in Chinese) http://www.gov.cn/zhengce/content/2016-05/31/content_5078377.htm.
1097 Tian, Z.Y., Li, H.F., Xie, H.T., Tang, C., Han, Y., Wang, M.J., Liu, W.B., 2014. Polychlorinated
1098 dibenzo-p-dioxins and dibenzofurans and polychlorinated biphenyls in surface soil from the Tibetan
1099 Plateau. J. Environ. Sci. 26, 2041-2047.
1100 Tieyu, W., Yonglong, L., Yajuan, S., Hong, Z., 2005. Spatial distribution of organochlorine pesticide
1101 residues in soils surrounding guanting reservoir, people's republic of China. B. Environ. Contam. Tox.
1102 74, 623-630.
1103 UNEP (United Nations Environment Program) (2003) Regionally based assessment of persistent toxic

1104 substances. Global report. UNEP Chemicals, Geneva.

1105 Vergani, L., Mapelli, F., Zanardini, E., Terzaghi, E., Di Guardo, A., Morosini, C., Raspa, G., Borin, S.,

1106 2017. Phyto-rhizoremediation of polychlorinated biphenyl contaminated soils: An outlook on

1107 plant-microbe beneficial interactions. Sci. Total Environ. 575, 1395-1406.

1108 Vidali, M., 2001. Bioremediation-An overview. Pure Appl. Chem. 73, 1163-1172.

1109 Wang, B.B., Wu, C.F., Liu, W.X., Teng, Y., Luo, Y.M., Christie, P., Guo, D., 2016a. Levels and

1110 patterns of organochlorine pesticides in agricultural soils in an area of extensive historical cotton

1111 cultivation in Henan province, China. Environ. Sci. Pollut. R. 23, 6680-6689.

1112 Wang, C.F., Gong, P., Wang, X.P., Yao, T.D., 2016b. Distribution，environmental behavior，and health

1113 risks of polychlorinated biphenyls in the Tibetan agricultural soil and crops. Asian J. Ecotox. 11,

1114 339-346 (in Chinese).

1115 Wang, C.F., Wang, X.P., Gong, P., Yao, T.D., 2016c. Residues, spatial distribution and risk assessment

1116 of DDTs and HCHs in agricultural soil and crops from the Tibetan Plateau. Chemosphere 149,

1117 358-365.

1118 Wang, C.H., Wu, S.H., Zhou, S.L., Wang, H., Li, B.J., Chen, H., Yu, Y.N., Shi, Y.X., 2015a.

1119 Polycyclic aromatic hydrocarbons in soils from urban to rural areas in Nanjing: Concentration, source,

1120 spatial distribution, and potential human health risk. Sci. Total Environ. 527, 375-383.

1121 Wang, F., Jiang, X., Bian, Y.R., Yao, F.X., Gao, H.J., Yu, G.F., Munch, J.C., Schroll, R., 2007a.

1122 Organochlorine pesticides in soils under different land usage in the Taihu Lake region, China. J.

1123 Environ. Sci-China 19, 584-590.

1124 Wang, F., Yao, J., Sun, K., Xing, B.S., 2010a. Adsorption of dialkyl phthalate esters on carbon

1125 nanotubes. Environ. Sci. Technol. 44, 6985-6991.

1126 Wang, H., An, Q., Dong, Y.H., Li, D.C., Velde, B., 2010b. Contamination and congener profiles of
1127 polychlorinated biphenyls from different agricultural top soils in a county of the Tailake Region,
1128 China. J. Hazard. Mater. 176, 1027-1031.
1129 Wang, J., Yang, J.B., Han, C.R., Cai, L.W., Li, X.B., Bukkens, S.G.F., Paoletti, M.G., 1999. Pesticide
1130 residues in agricultural produce in Hubei province, PR China. Crit. Rev. Plant Sci. 18, 403-416.
1131 Wang, L.W., Li, F., Zhan, Y., Zhu, L.Z., 2016d. Shifts in microbial community structure during in situ
1132 surfactant-enhanced bioremediation of polycyclic aromatic hydrocarbon-contaminated soil. Environ.
1133 Sci. Pollut. R. 23, 14451-14461.
1134 Wang, P., Zhang, H.D., Fu, J.J., Li, Y.M., Wang, T., Wang, Y.W., Ren, D.W., Ssebugere, P., Zhang,
1135 Q.H., Jiang, G.B., 2013a. Temporal trends of PCBs, PCDD/Fs and PBDEs in soils from an E-waste
1136 dismantling area in East China. Environ. Sci. Proc. Impacts 15, 1897-1903.
1137 Wang, P., Zhang, Q.H., Wang, Y.W., Wang, T., Li, X.M., Li, Y.M., Ding, L., Jiang, G.B., 2009a.
1138 Altitude dependence of polychlorinated biphenyls (PCBs) and polybrominated diphenyl ethers
1139 (PBDEs) in surface soil from Tibetan Plateau, China. Chemosphere 76, 1498-1504.
1140 Wang, T.Y., Tan, B., Lu, Y.L., 2012a. HCHs and DDTs in soils around Guanting Reservoir in Beijing,
1141 China: Spatial-temporal variation and countermeasures. Scientific World J. 2012, 628216.
1142 Wang, X., Ren, N.Q., Qi, H., Ma, W.L., Li, Y.F., 2009b. Levels, distributions, and source
1143 identification of organochlorine pesticides in the topsoils in Northeastern China. J. Environ. Sci. 21,
1144 1386-1392.
1145 Wang, W.T., Simonich, S.L.M., Xue, M.A., Zhao, J.Y., Zhang, N., Wang, R., Cao, J., Tao, S., 2010c.
1146 Concentrations, sources and spatial distribution of polycyclic aromatic hydrocarbons in soils from
1147 Beijing, Tianjin and surrounding areas, North China. Environ. Pollut. 158, 1245-1251.

1148 Wang, X.L., Lin, Q.X., Wang, J., Lu, X.G., Wang, G.P., 2013b. Effect of wetland reclamation and
1149 tillage conversion on accumulation and distribution of phthalate esters residues in soils. Ecol. Eng. 51,
1150 10-15.
1151 Wang, X.P., White, J.C., Gent, M.P.N., Iannucci-Berger, W., Eitzer, B.D., Mattina, M.J.I., 2004.
1152 Phytoextraction of weathered p, p'-DDE by zucchini (Cucurbita pepo) and cucumber (Cucumis
1153 sativus) under different cultivation conditions. Int. J. Phytoremediat. 6, 363-385.
1154 Wang, X.Q., Hua, R.M., Pan, J.Y., Gao, Q., Li, X.D., Cao, H.Q., Wu, X.W., Tang, J., 2011a.
1155 Distribution and composition of organochlorine pesticides in farmland top soils of Anhui Province.
1156 Chinese J. Appl. Ecol. 22, 3285-3292 (in Chinese).
1157 Wang, X.T., Chen, L., Wang, X.K., Lei, B.L., Sun, Y.F., Zhou, J., Wu, M.H., 2015b. Occurrence,
1158 sources and health risk assessment of polycyclic aromatic hydrocarbons in urban (Pudong) and
1159 suburban soils from Shanghai in China. Chemosphere 119, 1224-1232.
1160 Wang, X.X., Sun, L.N., Wu, H., Wang, H., Chen, S., Li, H.C., 2016e. In-site experiment on
1161 surfactants-enhanced for biodegradation of DDTs-contaminated farmland soils by *Arthrobacter*
1162 *globiformis*. Chinese J. Environ. Eng. 10, 6768-6774 (in Chinese)
1163 Wang, X.Y., Zhao, M.K., Pan, W.W., 2009c. Investigation on organochlorine pesticides (OCPs)
1164 pollution in soil from Jiaozuo in Henan Province. Chinese J. Soil Sci. 40, 415-419 (in Chinese).
1165 Wang, Y., Luo, C.L., Li, J., Yin, H., Li, X.D., Zhang, G., 2011b. Characterization and risk assessment
1166 of polychlorinated biphenyls in soils and vegetations near an electronic waste recycling site, South
1167 China. Chemosphere 85, 344-350.
1168 Wang, Y., Luo, C.L., Wang, S.R., Liu, J.W., Pan, S.H., Li, J., Ming, L.L., Zhang, G., Li, X.D., 2015c.
1169 Assessment of the air-soil partitioning of polycyclic aromatic hydrocarbons in a paddy field using a

1170 modified fugacity sampler. Environ. Sci. Technol. 49, 284-291.
1171 Wang, Y., Tian, Z.J., Zhu, H.L., Cheng, Z.N., Kang, M.L., Luo, C.L., Li, J., Zhang, G., 2012b.
1172 Polycyclic aromatic hydrocarbons (PAHs) in soils and vegetation near an e-waste recycling site in
1173 South China: Concentration, distribution, source, and risk assessment. Sci. Total Environ. 439,
1174 187-193.
1175 Wang, Y., Wang, S.R., Luo, C.L., Xu, Y., Pan, S.H., Li, J., Ming, L.L., Zhang, G., Li, X.D., 2015d.
1176 Influence of rice growth on the fate of polycyclic aromatic hydrocarbons in a subtropical paddy field:
1177 A life cycle study. Chemosphere 119, 1233-1239.
1178 Wang, Z., Chen, J.W., Qiao, X.L., Yang, P., Tian, F.L., Huang, L.P., 2007b. Distribution and sources of
1179 polycyclic aromatic hydrocarbons from urban to rural soils: A case study in Dalian, China.
1180 Chemosphere 68, 965-971.
1181 Wei, H., Hu, D., Cheng, X.L., Li, K.B., 2015. Residual levels of organochlorine pesticides and heavy
1182 metals in the Guanzhong Region of the Weihe Basin, North-western China. J. Residuals Sci. Tech. 12,
1183 31-36.
1184 Wei, Z.Q., Liu, C.Q., Liang, X.B., Wang , F.S., Wang, S.F., 2007. Residue of PCBs and OCPs in the
1185 paddy soil from Hongfeng reservoir area, Guizhou, China. Environ. Sci. 28, 255-260 (in Chinese).
1186 White, J.C., 2002. Differential bioavailability of field-weathered p,p '-DDE to plants of the Cucurbita
1187 and Cucumis genera. Chemosphere 49, 143-152.
1188 White, J.C., 2001. Plant-facilitated mobilization and translocation of weathered 2,2-bis
1189 (p-chlorophenyl)-1,1-dichloroethylene (p,p'-DDE) from an agricultural soil. Environ. Toxicol. Chem.
1190 20, 2047-2052.
1191 White, J.C., Ross, D.W., Gent, M.P.N., Eitzer, B.D., Mattina, M.I., 2006. Effect of mycorrhizal fungi

1192 on the phytoextraction of weathered p,p-DDE by Cucurbita pepo. J. Hazard Mater. 137, 1750-1757.
1193 Wong, M.H., Wu, S.C., Deng, W.J., Yu, X.Z., Luo, Q., Leung, A.O.W., Wong, C.S.C., Luksemburg,
1194 W.J., Wong, A.S., 2007. Export of toxic chemicals - A review of the case of uncontrolled
1195 electronic-waste recycling. Environ. Pollut. 149, 131-140.
1196 World Wide Found (WWF), 2005. Stockholm Convention "New POPs": screening additional POPs
1197 candidates. April, 2005, 38.
1198 Wu, D.M., Chen, S.S., Deng, X., Qu, C.Y., Li, Q.F., 2014. Residues and eco-risk evaluation of
1199 organochlorine pesticides in agricultural soils from typical vegetable produce areas of Hainan
1200 Province, China. J. Agr. Resour. Environ. 31, 343-348 (in Chinese).
1201 Wu, W., Hu, J., Wang, J.Q., Chen, X.R., Yao, N., Tao, J., Zhou, Y.K., 2015. Analysis of phthalate
1202 esters in soils near an electronics manufacturing facility and from a non-industrialized area by gas
1203 purge microsyringe extraction and gas chromatography. Sci. Total Environ. 508, 445-451.
1204 Wu, X. and Zhu, L.Z., 2016. Evaluating bioavailability of organic pollutants in soils by sequential
1205 ultrasonic extraction procedure. Chemosphere. 156, 21-29.
1206 Xie, W.J., Chen, A.P., Li, J.Y., Liu, Q., Yang, H.J., Wu, T., Lu, Z.H., 2012. Topsoil
1207 dichlorodiphenyltrichloroethane and polychlorinated biphenyl concentrations and sources along an
1208 urban-rural gradient in the Yellow River Delta. J. Environ. Sci. 24, 1655-1661.
1209 Xie, Z.D., Ding, Y., 2013. Distribution of residues of DDTs and HCHs in paddy soil from Poyang lake
1210 area, Jiangxi Province. Resour. Surv. Environ. 34, 199-204 (in Chinese).
1211 Xing, X.L., Qi, S.H., Zhang, Y.A., Yang, D., Odhiambo, J.O., 2010. Organochlorine pesticides (OCPs)
1212 in soils along the Eastern sope of the Tibetan Plateau. Pedosphere 20, 607-615.
1213 Xu, G., Li, F.H., Wang, Q.H., 2008. Occurrence and degradation characteristics of dibutyl phthalate

1214 (DBP) and di-(2-ethylhexyl) phthalate (DEHP) in typical agricultural soils of China. Sci. Total
1215 Environ. 393, 333-340.
1216 Xu, S.S., Liu, W.X., Tao, S., 2006. Emission of polycyclic aromatic hydrocarbons in China. Environ.
1217 Sci. Technol 40, 702-708.
1218 Xu, Y., Guo, C., Luo, Y., Lv, J., Zhang, Y., Lin, H., Wang, L., Xu, J., 2016. Occurrence and
1219 distribution of antibiotics, antibiotic resistance genes in the urban rivers in Beijing, China. Environ.
1220 Pollut. 213, 833-840.
1221 Yang, D., Qi, S.H., Zhang, J.Q., Tan, L.Z., Zhang, J.P., Zhang, Y., Xu, F., Xing, X.L., Hu, Y., Chen, W.,
1222 Yang, J.H., Xu, M.H., 2012. Residues of organochlorine pesticides (OCPs) in agricultural soils of
1223 Zhangzhou City, China. Pedosphere 22, 178-189.
1224 Yang, D., Qi, S.H., Zhang, J.Q., Wu, C.X., Xing, X.L., 2013a. Organochlorine pesticides in soil, water
1225 and sediment along the Jinjiang River mainstream to Quanzhou Bay, southeast China. Ecotox.
1226 Environ. Safe. 89, 59-65.
1227 Yang, G.Y., Zhang, T.B., Gao, S.T., Guo, Z.X., Wan, H.F., Gao, Y.X., 2007a. Source and distribution
1228 characteristics of polycyclic aromatic hydrocarbons in agricultural soils in the Pearl River Delta.
1229 Environ. Sci. 28, 2350-2354 (in Chinese).
1230 Yang, G.Y., Zhang, T.B., Gao, S.T., Guo, Z.X., Wan, H.F., Luo, W., Gao, Y.X., 2007b. Distribution of
1231 phthalic acid esters in agricultural soils in typical regions of Guangdong Province. Chinese J. Appl.
1232 Ecol. 18, 2308-2312 (in Chinese).
1233 Yang, H.J., Xie, W.J., Liu, Q., Liu, J.T., Yu, H.W., Lu, Z.H., 2013b. Distribution of phthalate esters in
1234 topsoil: a case study in the Yellow River Delta, China. Environ. Monit. Assess. 185, 8489-8500.
1235 Yang, X.L., Wang, S.S., Bian, Y.R., Chen, F., Yu, G.F., Gu, C.G., Jiang, X., 2008. Dicofol application

1236 resulted in high DDTs residue in cotton fields from northern Jiangsu province, China. J. Hazard.
1237 Mater. 150, 92-98.
1238 Yu, H.Y., Li, F.B., Yu, W.M., Li, Y.T., Yang, G.Y., Zhou, S.G., Zhang, T.B., Gao, Y.X., Wan, H.F., 2013.
1239 Assessment of organochlorine pesticide contamination in relation to soil properties in the Pearl River
1240 Delta, China. Sci. Total Environ. 447, 160-168.
1241 Yu, X.Z., Gao, Y., Wu, S.C., Zhang, H.B., Cheung, K.C., Wong, M.H., 2006. Distribution of
1242 polycyclic aromatic hydrocarbons in soils at Guiyu area of China, affected by recycling of electronic
1243 waste using primitive technologies. Chemosphere 65, 1500-1509.
1244 Yuan, H.M., Li, T.G., Ding, X.G., Zhao, G.M., Ye, S.Y., 2014. Distribution, sources and potential
1245 toxicological significance of polycyclic aromatic hydrocarbons (PAHs) in surface soils of the Yellow
1246 River Delta, China. Mar. Pollut. Bull. 83, 258-264.
1247 Yuan, S.Y., Liu, C., Liao, C.S., Chang, B.V., 2002. Occurrence and microbial degradation of phthalate
1248 esters in Taiwan river sediments. Chemosphere 49, 1295-1299.
1249 Yue, Q., Guan, Y.F., Tu, X.Y., Wu, H.H., 2012. Residual and distribution of organochlorine pesticides
1250 in agricultural soils from the upper watershed of Beijiang River in Guangdong province, China. Ecol.
1251 Environ. Sci. 21, 321-326 (in Chinese).
1252 Zeng, F., Cui, K.Y., Xie, Z.Y., Wu, L.N., Liu, M., Sun, G.Q., Lin, Y.J., Luo, D.L., Zeng, Z.X., 2008.
1253 Phthalate esters (PAEs): Emerging organic contaminants in agricultural soils in peri-urban areas
1254 around Guangzhou, China. Environ. Pollut. 156, 425-434.
1255 Zhai, G.S., Lehmler, H.J., Schnoor, J.L., 2013. Sulfate Metabolites of 4-Monochlorobiphenyl in whole
1256 poplar plants. Environ. Sci. Technol. 47, 557-562.
1257 Zhan, H. and Jiang, Y., 2015. Metal oxide nanomaterials for the photodegradation of phenol. Anal.

1258 Lett. 49, 855-866.
1259 Zhang, A.P., Chen, Z.Y., Ahrens, L., Liu, W.P., Li, Y.F., 2012a. Concentrations of DDTs and
1260 enantiomeric fractions of chiral DDTs in agricultural soils from Zhejiang Province, China, and
1261 correlations with total organic carbon and pH. J. Agric. Food Chem. 60, 8294-8301.
1262 Zhang, D. and Zhu, L.Z., 2012. Effects of Tween 80 on the removal, sorption and biodegradation of
1263 pyrene by Klebsiella oxytoca PYR-1. Environ. Pollut. 164, 169-174.
1264 Zhang, D., Zhu, L.Z., Li, F., 2013a. Influences and mechanisms of surfactants on pyrene
1265 biodegradation based on interactions of surfactant with a Klebsiella oxytoca strain. Bioresource
1266 Technol. 142, 454-461.
1267 Zhang, F.J., He, J., Yao, Y.P., Hou, D.K., Jiang, C., Zhang, X.X., Di, C.X., Otgonbayar, K., 2013b.
1268 Spatial and seasonal variations of pesticide contamination in agricultural soils and crops sample from
1269 an intensive horticulture area of Hohhot, North-West China. Environ. Monit. Assess. 185, 6893-6908.
1270 Zhang, H., Luo, Y., Teng, Y., Wan, H., 2013c. PCB contamination in soils of the Pearl River Delta,
1271 South China: levels, sources, and potential risks. Environ. Sci. Pollut. Res. Int. 20, 5150-5159.
1272 Zhang, H.B., Li, X.H., Luo, Y.M., Li, Q.B., 2011a. Depth distribution of polychlorinated biphenyls in
1273 soils of the Yangtze River Delta region, China. Geoderma 160, 408-413.
1274 Zhang, H.B., Luo, Y.M., Li, Q.B., 2009. Burden and depth distribution of organochlorine pesticides in
1275 the soil profiles of Yangtze River Delta Region, China: Implication for sources and vertical
1276 transportation. Geoderma 153, 69-75.
1277 Zhang, H.B., Luo, Y.M., Teng, Y., Wan, H.F., 2013d. PCB contamination in soils of the Pearl River
1278 Delta, South China: levels, sources, and potential risks. Environ. Sci. Pollut. R. 20, 5150-5159.
1279 Zhang, H.B., Luo, Y.M., Wong, M.H., Zhao, Q.G., Zhang, G.L., 2006. Distributions and

1280 concentrations of PAHs in Hong Kong soils. Environ. Pollut. 141, 107-114.
1281 Zhang, J.J., 2016a. Residues and environmental effectcs of organochlorine pesticides in peri-urban
1282 soil-vegetable system in major cities of Jilin Provonce. Northeast Institute of Geography and
1283 Agroecology, Chinese Academy.
1284 Zhang, J.J., Liu, J.S., Yu, R., Liu, Q., Wang, Y., 2016b. Pollution assessment of organochlorine
1285 pesticides in urban agricultural soils of Jilin City, China. Hum. Ecol. Risk Assess. 22, 792-801.
1286 Zhang, J.Q., Qi, S.H., Tan, L.Z., Zhang, J.P., Xing, X.L., 2011b. Distribution characteristics of
1287 organochlorine pesticides in soil samples from the northern Wuyi Mountains, Fujian, Southeast China.
1288 China Environ. Sci. 31, 662-667 (in Chinese).
1289 Zhang, J.Q., Qi, S.H., Xing, X.L., Tan, L.Z., Chen, W., Hu, Y., Yang, D., Wu, C.X., 2012b.
1290 Concentrations and classification of HCHs and DDTs in soil from the lower reaches of the Jiulong
1291 River, China. Front. Env. Sci. Eng. 6, 177-183.
1292 Zhang, J.Q., Qi, S.H., Xing, X.L., Tan, L.Z., Gong, X.Y., Zhang, Y., Zhang, J.P., 2011c.
1293 Organochlorine pesticides (OCPs) in soils and sediments, southeast China: A case study in Xinghua
1294 Bay. Mar. Pollut. Bull. 62, 1270-1275.
1295 Zhang, J.Y., Qiu, L.M., He, J., Liao, Y., Luo, Y.M., 2007. Occurrence and congeners specific of
1296 polychlorinated biphenyls in agricultural soils from Southern Jiangsu, China. J. Environ. Sci. 19,
1297 338-342.
1298 Zhang, Q., Chu, L., Cao, J., 2010. Residual levels and chiral signatures of organochlorine pesticides in
1299 soil and plants in Tianjin,China. J. Agro-Environ. Sci. 29, 2346-2350 (in Chinese).
1300 Zhang, X., Cui, Y., Zhang, G.X., He, Q.S., Qianr, T.W., 2014. Distribution characterisitcs of polycyclic
1301 aromatic hydrocarbons in agricultural soils in Taiyuan Basin. J. Taiyuaan Univ. Sci. Technol. 35,

231-235 (in Chinese).

Zhang, Y., Liang, Q., Gao, R.T., Hou, H.B., Tan, W.B., He, X.S., Zhang, H., Yu, M.D., Ma, L.N., Xi, B.D., Wang, X.W., 2015. Contamination of phthalate esters (PAEs) in typical wastewater-irrigated agricultural soils in Hebei, North China. Plos One 10.

Zhang, Y.X. and Tao, S., 2009. Global atmospheric emission inventory of polycyclic aromatic hydrocarbons (PAHs) for 2004. Atmos. Environ. 43, 812-819.

Zhang, Z., Liu, L.Y., Li, Y.F., Wang, D.G., Jia, H.L., Harner, T., Sverko, E., Wan, X.N., Xu, D.D., Ren, N.Q., Ma, J.M., Pozo, K., 2008. Analysis of polychlorinated biphenyls in concurrently sampled Chinese air and surface soil. Environ. Sci. Technol. 42, 6514-6518.

Zhao B,Q., 2013. The anslysis of the space-time difference of applying pesticide content. Issue Agr. Res. 28 (in Chinese).

Zhao, L., Hou, H., Shangguan, Y.X., Cheng, B., Xu, Y.F., Zhao, R.F., Zhang, Y.G., Hua, X.Z., Huo, X.L., Zhao, X.F., 2014. Occurrence, sources, and potential human health risks of polycyclic aromatic hydrocarbons in agricultural soils of the coal production area surrounding Xinzhou, China. Ecotox. Environ. Safe. 108, 120-128.

Zhong, Y.C. and Zhu, L.Z., 2013. Distribution, input pathway and soil-air exchange of polycyclic aromatic hydrocarbons in Banshan Industry Park, China. Sci. Total Environ. 444, 177-182.

Zhou, B.H., Zhang, C.Z., Jiang, J.L., Ma, W.L., Yang, Z.L., 2012. Characteristics and sources of PAHs in Top-soil Xi'an City. Environ. Sci. Technol. 35, 97-100 (in Chinese).

Zhou, Q., Wang, J.J., Meng, B.D., Cheng, J.Q., Lin, G.P., Chen, J.C., Zheng, D., Yu, Y.H., 2013a. Distribution and sources of organochlorine pesticides in agricultural soils from central China. Ecotox. Enviro. Safe. 93, 163-170.

1324 Zhou, W. and Zhu, L., 2008. Influence of surfactant sorption on the removal of phenanthrene from
1325 contaminated soils. Environ. Pollut. 152, 99-105.
1326 Zhou, Z.Y., Tang, H.L., Liu, Y.S., 2013b. Source and distribution characteristics of polycyclic
1327 aromatic hydrocarbons in agricultural soils in Beijing suburbs. Environ. Chem. 32, 874-880 (in
1328 Chinese).
1329 Zhu, L., Lou, B., Yang, K., Chen, B., 2005. Effects of ionizable organic compounds in different
1330 species on the sorption of p-nitroaniline to sediment. Water Res. 39, 281-288.
1331 Zhu, S.Y., Niu, L.L., Aamir, M., Zhou, Y.T., Xu, C., Liu, W.P., 2017. Spatial and seasonal variations in
1332 air-soil exchange, enantiomeric signatures and associated health risks of hexachlorocyclohexanes
1333 (HCHs) in a megacity Hangzhou in the Yangtze River Delta region, China. Sci. Total Environ. 599,
1334 564-272.
1335 Zhu, X., Tsang, D.C., Chen, F., Li, S., Yang, X., 2015. Ciprofloxacin adsorption on graphene and
1336 granular activated carbon: kinetics, isotherms, and effects of solution chemistry. Environ. Technol. 36,
1337 3094-3102.
1338 Zhu, Z.C., Chen, S.J., Zheng, J., Tian, M., Feng, A.H., Luo, X.J., Mai, B.X., 2014. Occurrence of
1339 brominated flame retardants (BFRs), organochlorine pesticides (OCPs), and polychlorinated
1340 biphenyls (PCBs) in agricultural soils in a BFR-manufacturing region of North China. Sci. Total
1341 Environ. 481, 47-54.
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Figure legend:

Fig. 1: National distributions of OCPs, PAHs, PCBs, and PAEs in agricultural soils of China. The average concentrations were calculated from the data in literatures of the same province. The name of province/city where only one paper was published was given in the map.

Fig. 2: Concentrations of organic pollutants in agricultural soils of different regions. The primary regions include East China (e.g., Shandong, Anhui, Jiangsu, Shanghai, and Zhejiang), South China (e.g., Fujian, Guangdong, Hainan, and Guangxi), North China (e.g., Inner Mongolia, Shanxi, Hebei, Beijing, and Tianjin), Central China (e.g., Jiangxi, Hunan, Hubei, and Henan), Northeast China (e.g., Heilongjiang, Jilin, and Liaoning), Southwest China (e.g., Guizhou, Yunnan, Chongqing, Sichuan, and Tibet), and Northwest China (e.g., Xinjiang, Qinghai, Gansu, Ningxia, and Shaanxi). The bars represent mean values. The error lines represent the maximum.

Fig. 3: Temporal trends of organic pollutants in the agricultural soils of China.

Table 1 Concentrations of OCPs (ng/g) in agricultural soil of China

Location	Total concentrations of DDTs			Total concentrations of HCHs			Total concentrations of OCPs			References
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
East China										
Zhejiang/Shanghai/Jiangsu	0.13	3515	56.2	0.37	30.3	2.46	1.0	3520	59.3	(Sun et al., 2016c)
Shandong	3.88	79.55	26.51	0.41	9.67	4.01	5.07	87.77	32.58	(Geng et al., 2006)
Anhui	—	—	17.61	—	—	28.64	—	—	48.58	(Wang et al., 2011a)
Shanghai	0.14	77.89	15.80	1.14	22.43	4.52	3.11	117.47	26.25	(Lv et al., 2011)
Zhejiang	0.08	5.39	1.22	0.05	5.90	2.20	ND	41.3	—	(Feng et al., 2012)
Jiangsu	3.31	43.81	11.13	0.81	9.43	3.6	—	—	—	(Ge et al., 2006)
Jiangsu	6.3	1050.7	64.1	2.7	130.6	13.6	10.3	1059.6	77.6	(An et al., 2005)
Shandong	0.46	17.6	5.84	ND	7.11	1.49	—	—	—	(Li et al., 2016)
Jiangsu	ND	600	88.8	ND	99	3.23	—	—	—	(Hu et al., 2014)
Shandong	—	—	19.8	—	—	21.8	7.17	171	44	(Zhu et al., 2014)
Jiangsu	ND	184.02	23.33	ND	42.59	8.26	4.80	219.10	32.2	(Gao et al., 2013)
Zhejiang	4.0	529	82	—	—	—	4.0	529	82	(Zhang et al., 2012a)
Zhejiang				0.028	2.80	1.23				(Zhu et al., 2017)
Jiangsu	ND	600	88.8	ND	99	3.2	—	—	—	(Hu et al., 2011)
Shanghai	0.44	247.45	21.41	ND	10.38	2.41	3.16	265.24	—	(Jiang et al., 2009)
Jiangsu	0.46	484.24	28.87	0.28	17.93	3.23	—	—	—	(Zhang et al., 2009)
Jiangsu	4.2	678.6	99.81	—	—	—	4.2	678.6	99.81	(Yang et al., 2008)
Zhejiang/Shanghai/Jiangsu	0.57	302.73	36.49	—	—	—	0.57	302.73	36.49	(Li et al., 2008b)
Jiangsu	19	92.6	50.2	10.1	41.5	28.5	—	—	86.4	(Wang et al., 2007a)
Anhui	ND	211	23.7	1.51	14	4.69	3.63	227	29.7	(Meng et al., 2013)
South China										
Fujian	6.51	469.5	51.17	0.41	9.61	2.02	7.36	473.09	53.19	(Lin et al., 2013)
Fujian	0.01	107.99	7.48	1.05	25.07	3.98	—	—	—	(Zhang et al., 2011b)
Fujian	0.22	384.75	32.86	1.39	247.4	22.75	2.7	632.15	55.61	(Huang et al., 2014b)
Fujian	0.1	240.38	14.94	0.78	90.71	5.03	2.56	465.99	38	(Qu et al., 2013)
Guangdong	0	152.7	26.9	0	104.4	15.3	4.6	1021.5	113.4	(Hao et al., 2007a)
Hainan	0	12.38	1.25	0	2.23	0.16	ND	17.37	2.30	(Wu et al., 2014)
Guangdong	1.82	60.3	8.57	0	1.74	0.53	2.71	62.4	11.9	(Yue et al., 2012)
Fujian	0.51	241.3	29.61	0.45	151.21	14.51	3.66	658.42	78.83	(Qu et al., 2015)
Guangdong	ND	110	8.8	ND	62	3.4	—	—	—	(Yu et al., 2013)
Fujian	10.54	1.53	53.26	0.41	7.90	2.125	—	—	—	(Yang et al., 2013a)
Fujian	0.94	700.99	71.17	0.38	39.52	9.51	—	—	—	(Zhang et al., 2012b)
Fujian	0.64	78.07	3.86	0.72	30.16	9.79	—	—	—	(Yang et al., 2012)
Fujian	0.91	27.89	6.725	0.96	7.47	3.18	4.62	38.2	12.58	(Zhang et al., 2011c)
Guangdong	1.93	199	60.8	0.35	281	22	—	—	—	(Ni et al., 2011)
Guangdong	—	—	82.1	—	—	4.42	—	—	86.5	(Ma et al., 2008)
Guangdong	0.27	414	—	ND	24.1	—	—	—	—	(Li et al., 2006)
North China										
Tianjin	—	—	16.085	—	—	93.61	—	—	140.07	(Zhang et al., 2010)
Beijing	18.04	101.33	64.44	11.64	29.80	15.77	—	—	—	(Ma et al., 2003)
Beijing	ND	64.91	6.46	ND	14.97	0.73	—	—	—	(Wang et al., 2012a)
Tianjin	ND	616.98	—	ND	92.74	—	ND	690.9	62.78	(Lv et al., 2010)
Beijing	ND	116.74	6.64	ND	5.56	0.67	—	—	—	(Hu et al., 2010)
Tianjin	—	—	157.5	—	—	52.8	—	—	—	(Tao et al., 2005)
Beijing	ND	57.9	9.82	ND	7.33	0.69	—	—	—	(Tieyu et al., 2005)
Beijing	7.21	2910	381.3	2	760.3	32	—	—	—	(Shi et al., 2005)
Tianjin	0.7	972.2	56.0	—	—	—	—	—	—	(Gong et al., 2004)
Hohhot	ND	994.39	137.22	4.84	281.44	52.39	10.69	1384.12	184.87	(Zhang et al.,

										2013b)
Central China										
Jiangxi	0	43.04	7.11	0.37	7.52	1.66	—	—	—	(Xie and Ding, 2013)
Henan	—	—	135.3	—	—	89.0	—	—	—	(Wang et al., 2009c)
Hubei	8	570	68	4.9	27	11	21	590	88	(Liu et al., 2016a)
Hunan	0.33	2421	111.2	—	—	—	—	—	115.3	(Li et al., 2008a)
Henan	ND	206.1	54.9	2.9	56.4	20.3	85.0	1392.1	193	(Wang et al., 2016a)
Jiangxi	ND	1690	16.35	0	178	1.46	—	—	—	(Teng et al., 2015)
Hubei	0.31	5.36	1.80	0.23	3.77	1.27	1.26	22.15	6.49	(Liu et al., 2015b)
Hubei	ND	1198	151.56	ND	100.58	15.39	11.43	1253.3	196.59	(Zhou et al., 2013a)
Jiangxi	0.14	6.981	2.138	—	—	—	0.14	6.981	2.138	(He et al., 2013)
Northeast China										
Liaoning	1.6	21.55	6.67	0.7	2.61	1.42	—	—	—	(Teng et al., 2013)
Jilin	1.45	81.75	—	1.17	27.83	—	1.45	83.88	—	(Liu 2013)
Jilin	3.16	48.35	13.19	4.37	44.77	11.17	12.10	72.51	29.69	(Zhang et al., 2016b)
Jilin	0.94	107.81	16.59	0.89	98.29	11.62	2.44	177.06	31.95	(Zhang 2016a)
Liaoning	ND	40.25	—	ND	42.79	—	ND	51.32	6.86	(Shi et al., 2011)
Heilongjiang	0.72	28.2	5.430	0.136	51.8	7.12	—	—	—	(Wang et al., 2009b)
Heilongjiang	0.072	28.222	5.84	0.136	51.762	9.3	0.28	81.34	17.5	(Ma 2007)
Southwest China										
Sichuan	—	—	1.73	—	—	1.08	—	—	—	(Xing et al., 2010)
Guizhou	—	—	14.39	—	—	5.595	—	—	—	(Wei et al., 2007)
Yunnan	—	—		2.88	17.62	7.448	—	—	—	(He et al., 2010)
Chongqing	4.31	213.5	41.76	0.55	26.54	4.05	7.29	222.42	46.15	(Fu et al., 2012b)
Sichuan	—	—	53.89	—	—	5.01	20.18	104.33	61.46	(Pan et al., 2011)
Tibetan	ND	41.6	1.36	ND	8.36	0.349	—	—	—	(Wang et al., 2016c)
Sichuan	0.29	5.72	1.755	0.43	10.6	1.93	0.97	17.6	4.915	(Gai et al., 2014)
Northwest China										
Xinjiang	ND	40.03	18.51	ND	30.86	14.37	16.4	84.86	41.89	(Chen et al., 2014)
Lanzhou	0.141	120	16.9	0.0822	4.49	0.865	—	—	—	(Mao et al., 2013)
Gansu/Xinjiang/Qinghai/Ningxia	0.1	120.49	12.52	0.17	9.38	1.45	0.9	133.44	—	(Huang et al., 2014c)
Shaanxi	ND	80.9	7.65	0.01	86.16	2.22	0.33	130.34	11.05	(Wei et al., 2015)
Shaanxi	—	—	5.75	—	—	0.45	—	—	6.2	(Lu and Liu, 2015)

ND: Not detected

Table 2 Concentrations of PAHs (ng/g) in agricultural soil of China

Location	Total concentrations of Car-PAHs			Total concentrations of 16-PAHs			Total concentrations of PAHs			References
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	
East China										
Shandong	—	—	—	84.2	1076	289	120	1486	415	(Feng et al., 2013)
Anhui	—	—	—	—	—	—	58.2	437.8	216.8	(Gao et al., 2012)
Jiangsu	—	—	—	—	—	—	312.2	27580.9	4292.4	(Ge et al., 2006)
Shanghai	—	—	—	—	—	—	203.8	6753.9	1172.7	(Sun et al., 2008)
Jiangsu				—	—	—	45.6	2286.8	627.15	(Ding et al., 2007)
Zhejiang	4.9	355.2	75.1	22.6	757.6	179.1	22.6	757.6	179.1	(Hu et al., 2015)
Jiangsu	16.7	2330	747	—	—	—	21.5	3350	1060	(Wang et al., 2015a)
Shandong	—	—	—	—	—	—	27	753	118	(Yuan et al., 2014)
Shanghai	10.6	3040	402	18.8	6320	807	25.8	7380	976	(Wang et al., 2015b)
Shanghai	47.3	1159.5	428.6	92.2	2062.7	665.8	140.7	2370.8	756.8	(Jiang et al., 2011b)
Zhejiang	70.5	1254.1	282.8	—	—	—	262.6	3420.2	1118.2	(Tang et al., 2010)
South China										
Guangdong	ND	3125	124.8	—	—	—	3.3	4079	244.2	(Yang et al., 2007a)
Fujian	13.12	394.5	141.48	—	—	—	70.7	1667.83	480.28	(Sun et al., 2016d)
Guangdong	—	—	—	—	—	—	44.8	3206	582	(Yu et al., 2006)
Guangdong	ND	2400	585	—	—	—	160	3700	1480	(Cai et al., 2007)
Guangdong	—	—	—	—	—	—	22.1	1256.9	318.2	(Hao et al., 2007b)
Guangdong	—	—	—	—	—	—	58	3077	315.4	(Ma et al., 2008)
Guangdong	—	—	—	—	—	—	—	—	514.4	(Huang et al., 2014a)
Guangdong	ND	2773	147.5	—	—	—	ND	4079	316.4	(Li et al., 2007)
Guangxi	—	—	—	—	—	—	—	—	76.5	(Shi et al., 2015)
Hongkong	—	—	—	—	—	—	—	—	31.1	(Zhang et al., 2006)
Guangdong	309	473	—	—	—	—	562	934	—	(Wang et al., 2015d)
North China										
Beijing	—	—	—	—	—	—	1200	3350	1970	(Zhou et al., 2013b)
Beijing	—	—	—	—	—	—	48.4	381.6	140	(Li et al., 2013b)
Tianjin	—	—	—	—	—	—	20.1	4074.7	509.9	(Shi et al., 2012)
Shanxi	—	—	—	—	—	—	78	325	210	(Zhang et al., 2014)
Beijing	—	—	—	—	—	—	37.5	1245.9	219.2	(Peng et al., 2016)
Beijing	—	—	485	—	—	—	16	3884	1347	(Ma et al., 2005)
Beijing/Tianjin	8.6	658.6	128.8	—	—	—	31.6	1475	336.4	(Wang et al., 2010c)
Shanxi	ND	607	56	—	—	—	ND	782	202	(Zhao et al., 2014)
Tianjin	—	—	—	—	—	—	22.86	14722.14	957.825	(Chen et al., 2015)
Central China										
Jiangxi	ND	961	30.1	—	—	—	1.86	3810	195	(Teng et al., 2015)
Northeast										
Liaoning	—	—	—	—	—	—	—	—	223	(Wang et al., 2007b)
Liaoning	3	236	33.7	—	—	—	50	3309	390	(Cao et al., 2013)
Jilin	—	—	—	—	—	—	1572.4	4390.2	2954.9	(Chen et al., 2016)
Southwest										
Chongqing	72.08	1800.81	309.9	—	—	—	277.4	3301	752.6	(Lan et al., 2014)
Northwest										
Shannxi	92	7940	3816	—	—	—	125	9057	2727	(Zhou et al., 2012)
Ningxia	—	—	—	—	—	—	17.2	1199.3	190.6	(Li et al., 2014b)
Shannxi	—	—	—	—	—	—	48.4	440.01	141.34	(Han et al., 2015)
Xinjiang	22	288	102	—	—	—	331	2752	1742	(Chen et al., 2013)
Total China	—	—	—	—	—	—	9.9	5910	377	(Ma et al., 2015)

Car-PAHs: carcinogenic PAHs

16-PAHs: 16 kinds of PAHs which were on a priority control list by the USEPA

ND: Not detected

1371

1372

Table 3 Concentrations of PCBs (ng/g) in agricultural soil of China

Location	Total concentrations of DL-PCBs			Total concentrations of PCBs			References
	Min	Max	Mean	Min	Max	Mean	
East China							
Zhejiang/Jiangsu/Shanghai	0.41	65.8	9.37	0.41	73.5	15.2	(Zhang et al., 2011a)
Jiangsu	ND	3.791	0.352	0.016	3.791	1.071	(Wang et al., 2010b)
Jiangsu	—	—	—	1.18	29	12.74	(Hu et al., 2009)
Shandong	—	—	—	3.06	14.88	8.04	(Geng et al., 2006)
Zhejiang/Jiangsu/Shanghai	0	78.9	7.5	ND	130	20.2	(Sun et al., 2016b)
Jiangsu	—	—	—	ND	32.83	4.13	(Zhang et al., 2007)
Shandong	—	—	—	ND	87	2.6	(Xie et al., 2012)
South China							
Guangdong	—	—	—	18	130	66	(Wang et al., 2011b)
Guangdong	—	—	—	0.04	0.79	—	(Li et al., 2015b)
Guangdong	—	—	—	ND	32.79	0.42	(Jiang et al., 2011a)
Guangdong	0.15	61.2	9	0.3	202	18.4	(Zhang et al., 2013d)
North China							
Beijing				0.39	13	3.1	(Liu et al., 2006)
Tianjin	0.03	4.36	0.87	0.36	16.88	4.02	(Li et al., 2011)
Central China							
Jiangxi	—	—	—	ND	93	6.75	(Teng et al., 2015)
Northeast China							
Liaoning	0.36	1.36	0.77	0.36	1.36	0.77	(Lang et al., 2014)
Southwest China							
Guizhou	—	—	—	8.9	55.9	29.8	(Wei et al., 2007)
Tibet	—	—	—	0.0019	0.0132	0.0051	(Wang et al., 2016b)
Tibet	—	—	—	0.0471	0.4226	0.1856	(Wang et al., 2009a)
Tibet	—	—	—	0.0086	0.0391	0.0162	(Tian et al., 2014)
Sichuan	—	—	—	0.22	2.31	1.005	(Gai et al., 2014)
Northwest China							
Shannxi	—	—	—	—	—	0.67	(Lu and Liu, 2015)
Total China	—	—	—	0.138	1.14	0.424	(Ren et al., 2007)

DL-PCBs: dioxin-like PCBs

ND: Not detected

1378

Table 4 Concentrations of PAEs (ng/g) in agricultural soil of China

Location	Total concentrations of six PAEs			Total concentrations of PAEs			References
	Min	Max	Mean	Min	Max	Mean	
East China							
Shandong	716	16007	2219.5	794	19504	2385	(Yang et al., 2013b)
Zhejiang/Shanghai/Jiangsu	68	9330	—	167	9370	782	(Sun et al., 2016c)
Shandong/Zhejiang/Shanghai/Anhui	—	—	—	1340	7140	2282	(Hu et al., 2003)
South China							
Guangdong	3000	45670	21030	3000	45670	21030	(Cai et al., 2005)
Guangdong	ND	25900	670	ND	25990	670	(Yang et al., 2007b)
Guangdong	—	—	1984	—	—	1984	(Li et al., 2015d)
Guangdong	—	—	—	195	33600	2570.4	(Zeng et al., 2008)
Guangxi/Fujian/Guangdong	—	—	—	2930	6970	4353	(Hu et al., 2003)
North China							
Hebei	191	457	294	191	457	294	(Zhang et al., 2015)
Tianjin	50	10400	754	50	10400	754	(Kong et al., 2012)
Neimenggu/Beijing/Tianjin/Shanxi	—	—	—	17600	3780	2800	(Hu et al., 2003)
Beijing	ND	1360	310	20	2900	630	(Cheng et al., 2015)
Central China							
Hubei	5630	157620	19330	5630	157620	19330	(Wu et al., 2015)
Jiangxi	ND	22800	530	ND	22800	530	(Teng et al., 2015)
Henan/Hubei/Hunan	—	—	—	890	2250	1430	(Hu et al., 2003)
Northeast China							
Heilongjiang	—	—	—	—	—	109.2	(Wang et al., 2013b)
Heilongjiang/Liaoning	—	—	—	4410	10030	6713	(Hu et al., 2003)
Southwest China							
Sichuan/Yunnan/Guizhou	—	—	—	1850	2960	2220	(Hu et al., 2003)
Northwest China							
Gansu	—	—	—	—	—	2810	(Hu et al., 2003)
Total China	—	—	—	75	6369	1088	(Niu et al., 2014)

Six PAEs: PAEs which were classified as environmental priority pollutants by USEPA

ND: Not detected

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