Phthalate esters and organochlorine pesticides in agricultural soils and vegetables from fast-growing regions: a case study from eastern China

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ABSTRACT

The present study investigated phthalate esters (PAEs) and organochlorine pesticides (OCPs) in

agricultural soils and vegetables from eastern China. The concentrations of PAEs ranged from 109 to 5560 ng/g in soils and 60.1 to 2390 ng/g in cabbages, with average concentrations of 946 and 601 ng/g, respectively. The concentrations of OCPs ranged from <0.1 to 662 ng/g in soils and <0.1 to 42.8 ng/g in cabbages, with average concentrations of 134 and 11.6 ng/ g, respectively. OCPs were mainly in the 0–30 cm surface soil layers, while PAEs could infiltrate in deep soil profiles to 70– 80 cm layer. Potential source analysis traced the occurrence of OCPs to both historical application and current usage, where- as building materials and agricultural plastic film were possible input sources of PAEs in the ambient environment. OCPs showed no apparent effect on soil microbial communities, whereas significant negative relationship was observed be- tween PAEs and fungi in soils ($R = -0.54$, $p < 0.01$). Human health risk assessment data revealed marginal noncarcinogenic risks and low carcinogenic risks in these soils. Notably, PAEs posed a comparable or higher risk level compared with that of OCPs. This study suggests the need for better regulation on pollution control and management of PAE-elevated sites to protect soil quality and food safety.

INTRODUCTION

In recent years, soil pollution in China has become a significantly environmental issue due to the population growth, eco- nomic development, and accelerated urbanization (Li et al. 2015; Teng et al. 2014). A large number of fast-growing regions were potential pollution hotspots to the surrounding environment. The intensified farming and industrial activities in these regions may lead to the elevated levels of various contaminants in the environment (Cai et al. 2008; Zhong and Zhu 2013). Organic pollutants in agricultural soils could influence microbial activities and enter the food chain through bioaccumulation, thus disturbing the ecosystem and impairing human health (Fang et al. 2015).

Organochlorine pesticides (OCPs) such as dichlorodiphenyl-trichloroethanes (DDTs) and hexachlorocyclohexanes (HCHs) were produced and extensively used in agriculture of China dur- ing the 1950s–1980s (Liu et al. 2015b). Although the production and agricultural use of DDTs and HCHs have been

phased out over the past three decades, the historical usage of these persistent OCPs has resulted in widespread pollution of agricultural soils and vegetation in China (Tao et al. 2008; Wang et al. 2016).

Phthalate esters (PAEs) are widely used plasticizers and additives in a variety of products, including building materials, home furnishings, food packaging, and polyvinylchloride (PVC) resins (Ma et al. 2015). Numerous studies have demonstrated that some PAEs are endocrine disrupting compounds, with adverse effects on metabolism and reproduction (Li and Ko 2012). As a result, some phthalates have been classified as priority pollutants by the US Environmental Protection Agency (USEPA). In China, the production of plastic has reached 74 million tons by 2013, which accounts for approximately 24.8 % of the global production (PlasticsEurope 2015), and PAEs are gradually released into the environment from PAE-containing products during their manufacture, use, and disposal (Wang et al. 2013). Yang et al. (2013a) observed the high concentrations of PAEs in densely anthropo- genic activities areas (such as the urbanization and industrialization), and agriculture influenced district.

The concentrations of PAEs have reached milligrams per kilogram in most agricultural soils across China (Chen et al. 2012; Niu et al. 2014; Zeng et al. 2008). However, there is no available soil quality standard for PAEs in China. More studies on the contamination of PAEs and associated environmental effects are required to better understand the potential risk of these chemicals in soil environments.

Our recent study has revealed that the agricultural soils in the Yangtze River Delta (YRD) of China were widely contaminated with various organic pollutants (Sun et al. 2016). The border of Jiangsu province and Shanghai Municipality is such a pollution hotspot. A large number of industrial and commercial enterprises does not only contribute to economic development but also possibly pose a serious threat to the environmental quality. It is important to elucidate the soil- plant interactions with high-density sampling to assess the pollution of OCPs and PAEs in agricultural fields and their associated impact on the environmental quality and human health. This is crucial for managing environmental risks and developing effective remediation and abatement strategies.

In the present study, DDTs, HCHs, and six priority control PAEs were determined in soils and vegetables

collected from the agricultural fields at the border of Jiangsu province and Shanghai Municipality in eastern China. The objectives were to: (i) characterize the contamination status of OCPs and PAEs in agricultural topsoils and soil profiles; (ii) analyze bioaccumulation of OCPs and PAEs by plants; (iii) identify the correlations among soil microbiota, soil properties, and organic contaminants; and (iv) evaluate the potential human health risks due to exposure to OCPs and PAEs in agricultural soils. The results can provide important baseline information for soil quality assessments in fast-growing regions, especially in China.

MATERIALS AND METHODS

Sample collection

The studied region was located at the border of Shanghai Municipality and Jiangsu province, eastern China. The 26 sampling sites were based in Jiading District of Shanghai, Kunshan, and Taicang cities of Jiangsu. As shown in Fig. 1, there were nine sampling sites in area BA^, which comprised an industrial park and nearby villages. There were seven sampling sites in area BB^, which comprised several villages and vast areas of farmland. There were five sampling sites in area BC^, where several residential areas were under construction and many greenhouses were in use. A sampling site in each of the three areas (i.e., A, B, and C) was included in our previous survey (Sun et al. 2016). These three areas have different industry and agriculture types, and represent the different levels of rapid economic development. The other areas including D, E, F, G, and H contained only one sampling site each. These five areas are evenly distributed along the border of Jiangsu province and Shanghai Municipality. More detailed sampling locations are presented in the Supporting information (SI).

In November 2014, a total of 26 pairs of topsoil (depth, 0– 20 cm) and cabbage (*Brassica chinensis*) were collected from the study region. Each composite sample consisted of five subsamples. In addition, three vertical soil profiles were obtained. The soil profiles were excavated to a depth of 90 cm. Soil samples were collected from the front of the soil trenches at 10-cm intervals. All the samples were packed in aluminum foil and freeze-dried before being ground, homogenized, and stored at −20 °C until analysis.

Sample preparation and analysis

The target compounds in the analysis of the present study included α-HCH, β-HCH, γ-HCH, δ-HCH, *p,p′*-DDT, *o,p′*- DDT, *p,p′*-DDD, *o,p′*-DDD, *p,p′*-DDE, *o,p′*-DDE, dimethyl phthalate (DMP), diethyl phthalate (DEP), dibutyl phthalate (DnBP), benzyl butyl phthalate (BBP), *bis*(2-ethylhexyl) phthalate (DEHP), and di-*n*-octyl phthalate (DnOP).

The sample preparation and analysis procedures for OCPs and PAEs were adapted from the reported methods (Wang et al. 2007, 2015). Briefly, 5 g of soil or 1 g of plant material was extracted with 30 mL of a 1:1 (*v/v*) mixture of hexane and dichloromethane in an ultrasonic bath for 60 min twice. Surrogate standards PCB-209 (20 ng) and deuterium-labeled DnBP (DnBP-D4) (20 ng) were added prior to extraction. The two extracts were combined, concentrated to 1–2 mL and cleaned up by passing through a multilayer column containing, from bottom to top, alumina oxide (6 g), neutral silica gel (12 g), and anhydrous sodium sulfate (2 g). The column was eluted with 60 mL acetone/hexane (1:4, *v/v*). Then the eluent was reduced to 0.5 mL with a gentle nitrogen flow.

PAEs were determined by an Agilent 7890B/5977A gas chromatography/mass spectrometry (GC/MS) equipped with a DB-5 MS fused silica capillary column (30 m, 0.25 mm i.d.,
0.25 μm film thickness) for chromatographic separation. The initial oven temperature was 90 °C, and then increased at 15 °C/min to 220 °C and further to 260 °C at 1 °C/min. The post-run was set at 300 °C and kept for 3 min. The analysis of OCPs was carried out on an Agilent 6890N GC with a DB-5 column (30 m, 0.25 mm i.d., 0.25 μm film thickness) and an electron capture detector (ECD). The oven temperature was held at 80 °C for 2 min and programmed to increase at 10 °C/min to 140 °C, increase again at 4 °C/min to 280 °C, and held for 5 min

Quality assurance and quality control

A procedural blank, spiked blank, and sample duplicate were processed simultaneously with every batch of

ten samples. Trace DnBP and DEHP were detected in procedural blanks, though contact with plastics was avoided throughout the experiment. The concentrations of PAEs were all blank corrected. The recovery rates of PAEs and OCPs in the spiked samples ranged from 77.6 to 108.5 % and from 81.5 to 93.1 %, respectively, where relative standard deviation (RSD) was <10 % (n = 3). The measured concentration variations of pollutants in duplicates were <15 % (n = 3). The recovery rates of surrogate standards DnBP-D4 and PCB-209 were 84.5 ± 12.2 and 88.7 ± 14.6 %, respectively. Five-point standard calibration curves were used for quantitative analysis. The limits of detection (LODs) were calculated as three times the signal-to- noise ratio and fell in the range of 0.20–0.40 and 0.10–0.45 ng/g for PAEs and OCPs, respectively. Statistical analyses were per- formed using SPSS 18.0, R, and Origin 8.0. Statistical significance was considered as $p < 0.05$.

Soil microbiological and physicochemical analysis

Extraction and analysis of microbial phospholipid fatty acids (PLFA) were performed by GC fitted with MIDI Sherlock microbial identification system with reference to the reported method (He et al. 2013). The biomasses of bacteria, fungi, actinomycetes, gram-positive bacteria, and gram-negative bacteria were quantified, respectively. Soil pH was measured using a pH meter with a soil/water ratio of 1:2.5. The total organic carbon (TOC), total nitrogen, and total phosphorus were analyzed by the reported methods (Liu et al. 2015a).

Health risk assessment

The noncarcinogenic and carcinogenic risks of OCPs and PAEs to human were evaluated using the methods recommended by the USEPA (1997), which have been widely adopted in the literature (Islam et al. 2015; Niu et al. 2013; Wang et al. 2015). Among the studied pollutants, DEP, DnBP, BBP, DEHP, DnOP, α-HCH, β-HCH, γ-HCH, and *p,p′*-DDT were regarded as noncarcinogenic compounds with respect to human health, while BBP, DEHP, α-HCH, β-HCH, γ-HCH, *p,p′*-DDT, *p,p′*-DDD, and *p,p′*-DDE present carcinogenic risk. Risks through nondietary (including soil ingestion, inhalation and dermal contact) and

dietary (i.e., intake of agricultural products harvested from the soils) pathways were all involved. The average daily intake dose was estimated by the equations presented in SI. The noncarcinogenic risks of pollutants were presented as hazard index (HI). The local residents are considered to be exposed to noncarcinogenic risks if HI > 1. The carcinogenic risks are considered very low if the value of risk is less than 10^{-6}, low in the range of 10^{-6}–10^{-4}, moderate in the range of 10^{-4}–10^{-3}, high in the range of 10^{-3}–10^{-1}, and very high if the value exceeds 10^{-1}.

RESULTS AND DISCUSSION

OCPs residues in topsoils

A summary of the concentrations (ng/g dry weight) of OCPs in topsoil samples is presented in Table 1. The concentrations of total HCHs in the agricultural soils ranged from <0.1 to 92.0 ng/ g, with a mean of 14.4 ng/g and a detection rate of 84.6 % in all the soil samples. The HCH levels found in this study were higher than those in agricultural soil collected across China (0.146–23.9 ng/g) (Niu et al. 2013), and those in soil collected in the YRD region (0.376–30.3 ng/g) in our previous study (Sun et al. 2016). The total concentrations of DDTs and their metabolites in the agricultural soils ranged from <0.1 to 659 ng/g, with a mean of 120 ng/g and a detection rate of 88.5 %. The overall DDT concentrations in the present study were comparable with or higher than those in agricultural soil from other regions of China (Tao et al. 2008; Zhang et al. 2012). The mean values of total DDTs in the study area were higher than those in soil col- lected in the YRD region (mean of 56.2 ng/g) in our previous study (Sun et al. 2016). The agricultural soils in the study area may have been subjected to relatively high levels of OCP pollu- tion. However, it has been reported that the OCP residues in the environment were gradually decreasing after many years of for- bidden for application for agriculture in China (Hu et al. 2010; Nakata et al. 2002).

Higher levels of OCPs were found in the sites located in area A, which probably reflected the presence of point source pollution in this area. A large number of chemical factories within and surrounding the villages may contribute to the OCPs pollution (Tang et al. 2016). In addition, local practices of pesticide

applications with respect to pest control needs may be another input source. Comparing with the industrial area A, the natural and agricultural area B possessed much lower OCP residues. The concentrations of DDTs in only one soil sample collected in site A1 exceeded less stringent grade II limits in Environmental Quality Standard for Soil (GB-15618-1995) (China National Environmental Protection Agency 1995). The concentrations of HCHs in all the samples complied with this environmental quality standard.

The ratios of selected compounds were useful for distinguishing whether the sources originated from the historical usage or fresh application on agricultural soils in recent years. In China, technical HCH (α-HCH 60–70 %, β-HCH 5– 12 %, γ-HCH 10–12 %, δ-HCH 6–10 %) was widely used for agriculture during the 1950s–1980s (Tao et al. 2008). Lindane (>99 % γ-HCH) was subsequently applied as a substitute (Li et al. 2001). The α-/γ-HCH ratios in soil samples ranged from 0 to 0.60 in this study, which indicated fresh application of lindane in recent years. The major source of DDT contamination in China was attributed to the agricultural application of technical DDTs and dicofol (Yang et al. 2013b). In this study, the ratio of (*p,p′*-DDE + *p,p′*-DDD)/*p,p′*-DDTwas greater than 1.0 in 73 % of the topsoils, suggesting DDT in soils originated mainly from historical usage. Furthermore, a ratio of *o,p′*- DDT/*p,p′*-DDT higher than 1.3 was indicative of dicofol source while a range of 0.20–0.30 was indicative of technical DDT source (Qiu et al. 2005). The *o,p′*-DDT/*p,p′*-DDT ratios ranged from 0 to 0.28, suggesting aged DDT as the prime source of DDTs in the study area.

PAEs residues in topsoils

A summary of the concentrations (ng/g dry weight) of PAEs in topsoil samples is presented in Table 2. The concentrations of six PAEs in the agricultural soils ranged from 109 to 5560 ng/ g, with a mean of 946 ng/g. The concentrations of PAEs in the study area were comparable with those in soils across China (75.0–6369 ng/g) (Hu et al. 2003; Niu et al. 2014). The mean values of total six PAEs in the study area were higher than those in soil collected from vast area of the YRD region (mean of 670 ng/g) in our previous study (Sun et al. 2016). It sug- gested that the agricultural soils have been widely contaminat- ed with PAEs in this region.

196 According to the commonly used soil cleanup objectives from the USEPA (2015), DEHP in the soil sample
197 collected from site C1 exceeded the allowable concentration (3900 ng/g). DEHP exhibited the highest
198 con- centration (mean, 796 ng/g) among the analyzed PAEs, followed by DnBP (mean, 91.8 ng/g). The
199 contribution of DEHP in total PAEs was in the range of 13.9 to 98.9 %. The average total contributions
200 of DMP, DEP, and BBP were 5.1 % to the total concentrations. The composition was similar to those
201 reported in other regions of China (Chai et al. 2014; Zhang et al. 2015b).

202 Higher levels of PAEs were found in the sites located in area C (mean of 2120 ng/g). Many new buildings
203 were under construction in this area. A wide range of new building materials could release PAEs to the
204 surrounding environment (Xia et al. 2011). The plastic used in greenhouses in this area may also be an
205 important source of PAEs pollution (Wang et al. 2015). The concentrations of PAEs found in Chinese farmland
206 soils were significantly higher than in other countries, such as the UK (Gibson et al. 2005) and Denmark
207 (Vikelsoe et al. 2002). The PAEs pollution in China was likely to become more serious in the near future
208 because of the increasing use for PAE- containing building materials, home furnishings, and PVC in the
209 process of rapid urbanization. In addition, facility agriculture (i.e., controlled environment agriculture) is
210 an important developing direction in China. A large amount of agricultural plastic films input and
211 greenhouses construction could be possible emission sources of PAEs (Wang et al. 2015). This should draw
212 more attention for strategic planning and regulation on pollution management of PAEs in China.

213 **Vertical distributions of OCPs and PAEs in soil profiles**

214 The vertical concentrations and distributions of OCPs and PAEs at different depths in three collected
215 agricultural soil profiles are shown in Fig. 2. Higher OCPs concentrations were observed in the 0–30-
216 cm surface layers relative to the subsurface soils, because the upper 30 cm of the soil was a plow layer
217 formed through frequent cultivation and plowing activities. A rapid decline of OCPs concentrations to
218 marginal level was observed when the soil depth was >30 cm. This indicated that OCPs in agricultural
219 soils were less likely to contaminate the groundwater and subsurface environments. In contrast, the
220 vertical distributions of PAEs in soil profiles were not regular. The relatively higher PAEs concentrations

were observed in the 0–20 cm surface layers of site C, and the 0–10-cm surface layer of site A. However, PAEs could be detected through each soil layer to a depth of 90 cm. In site B, the higher concentration was even found in the 70–80-cm layer of the soil profile. There was no obvious variation tendency for the vertical distribution of PAEs, in contrast to that of OCPs in soils. This suggested that PAEs may be easier to infiltrate into the soil profile, imposing potential risks to the subsurface soil and groundwater environments.

OCPs and PAEs pollution in vegetables

A summary of the concentrations (ng/g dry weight) of OCPs and PAEs in plant samples is presented in Tables 1 and 2, respectively. Cabbage was selected as a bioindicator because it was commonly planted as food items for local residents in East and South China. Residues of OCPs in cabbages ranged from <0.1 to 15.0 ng/g for total HCHs and from <0.1 to 39.3 ng/g for total DDT-related compounds. However, the concentration of DDTs was comparable with that of HCHs in plants. It was probably because the higher vapor pressures and lower octanol-water coefficient (K_{ow}) of HCHs make them easier to accumulate in plants than DDTs (Walker et al. 1999). The concentrations of PAEs in cabbages ranged from 60.1 to 2390 ng/g, with a mean of 601 ng/g, of which DEHP was the predominant compound detected in most vegetable samples.

The concentrations of OCPs and PAEs in the plants were significantly correlated with the concentrations in soils (R = 0.72–0.91, p < 0.01), suggesting that OCPs and PAEs in cabbages originated mainly from the soil. However, both translocation from roots to aerial tissues and evaporation from soil to ambient air followed by foliar uptake were possible pathways of these pollutants entering the edible parts of cabbages. The bioconcentration factors (BCF) of compounds, i.e., the ratio of concentrations in the plant to corresponding con- centrations in soil, were in the range of 0–1.31 for total HCHs, 0–0.16 for total DDTs, and 0.29–1.23 for total PAEs, respectively. The BCF values of cabbages in the present study were lower than those of OCPs in tomatoes from the south- eastern region of Buenos Aires Province in Argentina (Gonzalez et al. 2003). This difference in soil-plant transfer might be caused by the short life cycle of

246 cabbages in the current study. In addition, cultivation methods, soil properties, and climate might be other key
247 factors contributing to the BCF values (Zhang et al. 2015a).
248
249 **Correlations among soil properties, microbiota, and pollutants**
250 Soil pollution could affect microbial community activity and the soil ecosystems (Brantner and Senko
251 2014). Soil proper- ties are important factors affecting the fate of pollutants and microbial community
252 composition. A matrix of correlation coefficients between pollutant residues, microbial community
253 characteristics, and soil properties are shown in Table 3. Significant relationships were observed between
254 PAEs and soil pH ($R = 0.49$, $p < 0.05$, $n = 26$); however, other soil physicochemical properties showed no
255 apparent relationships with the pollution levels of OCPs and PAEs. Soil TOC and total nitrogen seemed to
256 impose greater effects than OCPs and PAEs on the soil microbial communities. Negative relation- ships
257 were observed between PAEs and fungi in soils ($R = -0.54$, $p < 0.01$, $n = 26$), which suggested that
258 fungi are sensitive to environmental stress due to PAEs, and PAEs pollution may reduce the abundance of
259 soil fungi. In contrast, there was no significant correlation between OCPs and soil microbiota, suggesting
260 that OCPs in the soils showed no significant effect on the composition of microbial communities.
261
262 **Human health risk assessments**
263 The noncarcinogenic and carcinogenic risks of OCPs and PAEs to local villagers living close to the farmlands
264 through multiple pathways were assessed (Fig. 3). The average noncarcinogenic risks of PAEs (HI = 0.150 for
265 children and 0.084 for adults) was higher than the average noncarcinogenic risks of OCPs (HI = 0.123 for
266 children and 0.068 for adults). Among the measured PAEs, the average HI in soils was highest for DEHP,
267 while the noncarcinogenic risks of OCPs were mainly derived from *p,p′*-DDT and γ-HCH. The estimated intake
268 doses of PAEs and OCPs in all the samples were within acceptable levels (HI < 1). The average carcinogenic
269 risk of OCPs (3.28×10^{-6} for children and 7.85×10^{-6} for adults) was slightly higher than those of PAEs (2.99
270 $\times 10^{-6}$ for children and 7.26×10^{-6} for adults). DEHP and γ-HCH were the dominant contributors to the

carcinogenic risks of PAEs and OCPs, respectively. The estimated carcinogenic risk levels of OCPs and PAEs were all less than 10^{-4}, implying low or very low carcinogenic risks to both adults and children.

Intake of agricultural products is the primary exposure pathway and contributed to over 99 % of the total risks. The risks derived from the tightly controlled DDTs were in the acceptable range now, nevertheless, potential accumulation of PAEs in vegetables should receive more attention in future monitoring programs. The health risks due to both PAEs and OCPs pollution in soil were generally low based on the assessment in this study. However, the risks caused by PAEs reached a comparable level with those of OCPs. The elevated concentration of PAEs in the environment in China should arouse more stringent regulation (which is currently absent) to safeguard the soil environment and food quality.

CONCLUSION

The agricultural soils and vegetable in the fast-growing areas in China have been subjected to relatively high levels of OCPs and PAEs pollution. DEHP and *p,p′*-DDT contributed to most of the detected PAEs and OCPs, respectively. Historical usage was regarded as the primary source of DDTs, whereas HCHs may originate from fresh application of lindane in recent years. A large number of new building materials and plastic used in greenhouses could release PAEs to the ambient environment. The OCPs residues were accumulated in the surface plow layer, while PAEs were easier to infiltrate in soil, resulting in potential risks to the deep soil layers and ground- water. The soil ecosystem function was not significantly influenced by PAE and OCP pollution. The human health risks due to both PAEs and OCPs pollution in soil were generally low based on the assessment in this study. However, given the increasing usage of PAEs in various products, continual monitoring, and environmental health risk assessments are needed in some pollution hotspot regions.

ACKNOWLEDGMENTS

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LIST OF TABLES AND FIGURES

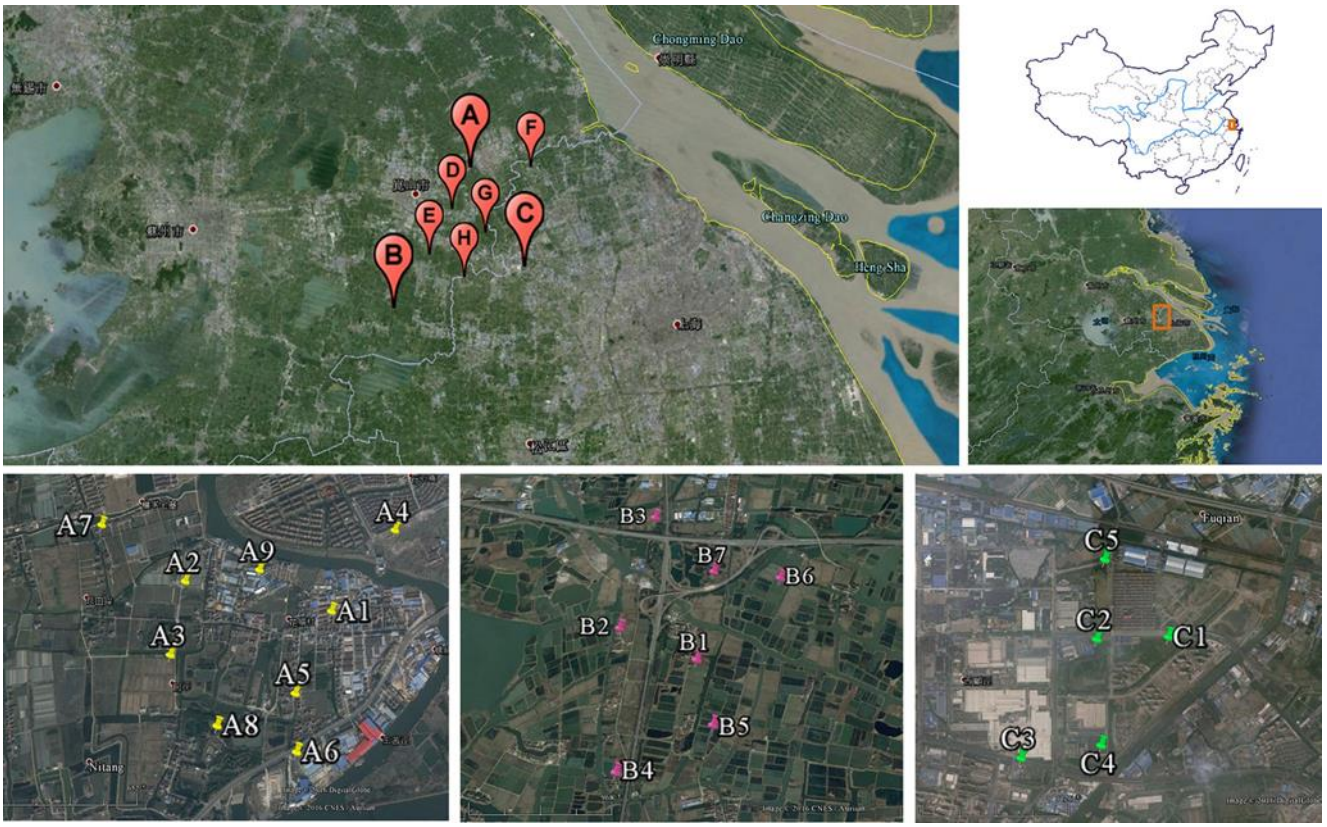

Fig. 1 Map showing the sampling sites in the border of Jiangsu province and Shanghai Municipality, eastern China. There were nine, seven, and five sites in A, B, and C, respectively. The three sampling sites with soil profiles are A1, B1, and C1

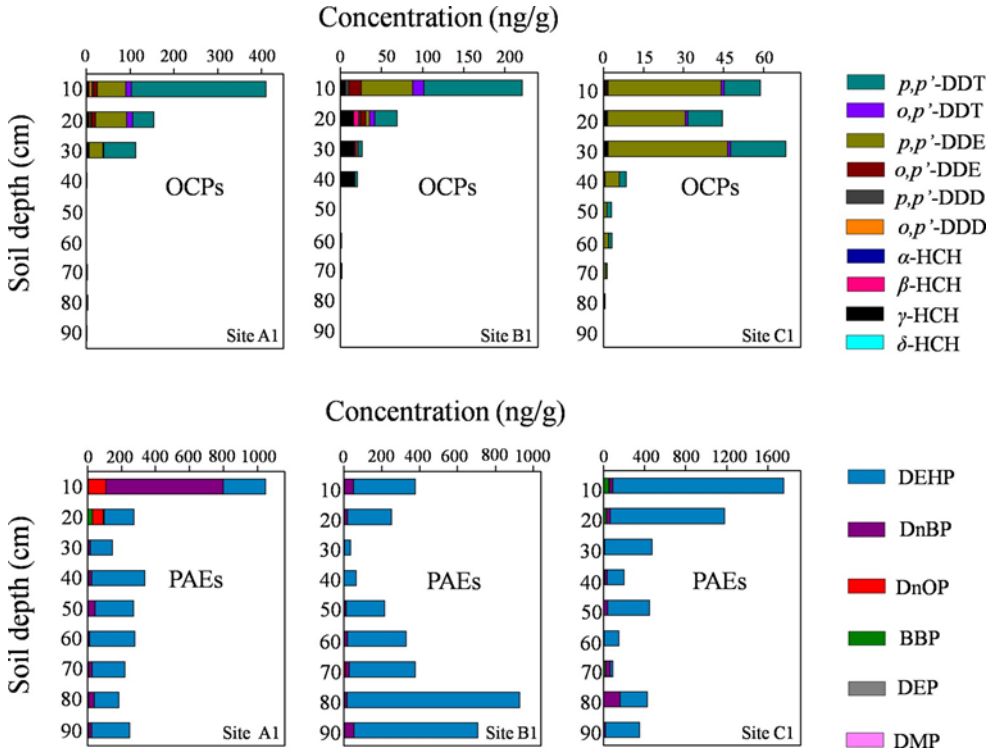

Fig. 2 Vertical distributions of the concentrations and compositions of organic contaminants in agricultural soils of the study area

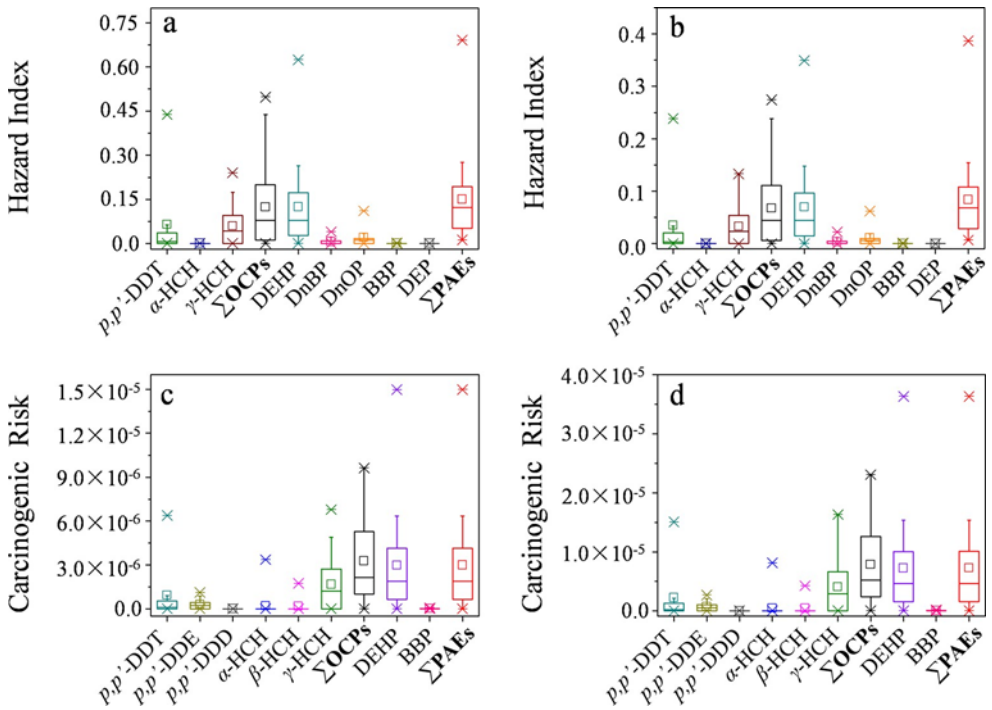

Fig. 3 Noncarcinogenic risks to a children and b adults and carcinogenic risks to c children and d adults through dietary and nondietary exposure pathways to different organic contaminants

Table 1 Concentrations (ng/g, dry weight) of OCPs in agricultural soil and vegetable samples

Compound	Soil					Vegetable				
	Min.	Max.	Mean	SD	Detectable rate (%)	Min.	Max.	Mean	SD	Detectable rate (%)
α-HCH	ND	4.67	0.47	0.96	38.5	ND	1.12	0.06	0.24	7.7
β-HCH	ND	3.70	0.58	0.95	38.5	ND	2.05	0.20	0.59	11.5
γ-HCH	ND	84.2	12.8	21.8	76.9	ND	12.9	3.19	3.52	61.5
δ-HCH	ND	7.45	0.57	1.72	19.2	ND	2.14	0.26	0.60	19.2
o,*p*′-DDE	ND	18.7	1.73	3.96	30.8	ND	1.34	0.10	0.35	7.7
p,*p*′-DDE	ND	79.8	29.0	20.6	88.5	ND	6.85	1.86	1.89	69.2
o,*p*′-DDD	ND	7.33	0.78	2.05	15.4	ND	2.05	0.13	0.46	7.7
p,*p*′-DDD	ND	4.77	1.18	1.26	69.2	ND	ND	ND	ND	0.0
o,*p*′-DDT	ND	15.3	1.77	3.30	46.2	ND	1.52	0.15	0.43	11.5
p,*p*′-DDT	ND	613	85.7	156	88.5	ND	38.3	5.61	10.7	53.8
Total OCPs	ND	662	134	163	88.5	ND	42.8	11.6	11.8	88.5

SD standard deviation, *ND* non-detectable

Table 2 Concentrations (ng/g, dry weight) of PAEs in agricultural soil and vegetable samples

Compound	Soil					Vegetable				
	Min.	Max.	Mean	SD	Detectable rate (%)	Min.	Max.	Mean	SD	Detectable rate (%)
DMP	ND	28.4	10.6	8.99	76.9	ND	31.6	3.36	8.42	15.4
DEP	ND	19.6	3.40	4.57	61.5	ND	20.1	1.88	5.39	11.5
DnBP	ND	659	91.8	163	57.7	ND	720	99.6	178	42.3
BBP	ND	78.3	11.6	20.6	61.5	ND	81.4	10.4	18.1	46.2
DEHP	28.9	5520	796	1120	100	ND	2250	450	523	84.6
DnOP	3.26	167	32.6	42.2	100	ND	200	36.3	53.6	69.2
Total PAEs	109	5560	946	1130	100	60.1	2390	601	538	100

SD standard deviation, *ND* non-detectable

Table 3 Correlation coefficients (*R*, *n* = 26) between pollutant residues, microbial community characteristics, and soil properties

	OCPs	PAEs	Bacteria	Fungi	Actinomycete	F/B	GN/GP	TOC	pH	TP	TN
OCPs	1										
PAEs	0.17	1									
Bacteria	0.28	−0.35	1								
Fungi	0.06	−0.54**	0.74**	1							
Actinomycete	0.23	−0.34	0.90**	0.72**	1						
F/B	−0.14	−0.13	−0.47*	0.14	−0.40*	1					
GN/GP	0.22	−0.30	0.35	0.50**	0.37	0.30	1				
TOC	0.30	0.03	0.49*	0.09	0.56**	−0.56**	−0.03	1			
pH	0.26	0.49*	−0.22	−0.23	−0.23	0.12	0.21	−0.18	1		
TP	0.10	0.04	0.12	0.16	0.17	0.05	−0.14	0.22	−0.01	1	
TN	0.23	−0.10	0.52**	0.25	0.59**	−0.49*	0.16	0.54**	−0.26	0.15	1

F/B PLFAs ratio of fungi to bacteria, *GN/GP* PLFAs ratio of gram-negative bacteria to gram-positive bacteria, *TP* total phosphorus, *TN* total nitrogen

*Correlation is significant at the 0.05 level; **correlation is significant at the 0.01 level

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