Occurrence and distribution of organophosphorus esters in soils and wheat plants in a plastic waste treatment area in China

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Organophosphate esters (OPEs) are widely used as flame retardants and plasticizers in various consumer products, particularly after the regulation to phase-out of polybrominated diphenyl ethers in many countries in recent years[1]. In most applications, OPEs are used additively in products, which results in their easily leaching out from the materials to the environment[2]. Therefore, their occurrence and fate in the environment has attracted increasing attentions from both public and researchers[3]. Up to date little research has been focused on OPEs in the soil-plant system, and only three reports related to OPEs in soils are available with the purpose to establish their analysis methods. Disposal and recycling of plastic wastes have been reported to cause the release of contaminants such as PBDEs to the environment[4]; however whether such activities also cause contamination of OPEs in the environment is unknown. Therefore in the present study, soil and wheat (*Triticum aestivum* L.) samples collected from a plastic waste recycling area in northern China were determined for the contamination levels of OPEs in the soil–plant system.

A total of 28 soil samples were collected from the areas of plastic wastes disposed and treated and as well as from the farms nearby. Wheat samples including the aboveground parts and roots were also collected from the farmland. Eight of nine OPEs were found in the soil samples with the exception of TDCPP. The total concentrations of OPEs (ΣOPE) in the soils are listed in Table 1. The ΣOPE concentrations ranged from 37.8 to 1250.4 μg/kg dry weight (dw) in the soil samples (mean, 295.7 ± 326.6 μg/kg dw). Higher concentrations of the ΣOPE were found in the areas where open deposit and burning of plastic wastes presented with plastic debris and combustion residues existed, and lower concentrations of ΣOPEs were detected in the soils from farmlands around. Among non-chlorinated OPEs, TBEP exhibited the highest level with the concentration varying from 14.1 to 592.1 μg/kg dw (mean, 157.1 ± 189.3 μg/kg dw). TiBP and TCP had the similar mean concentrations but less detected. The levels of the two chlorinated OPEs, TCEP and TCPP, were in the range of 4.7 to 436.0 μg/kg dw (mean, 65.8 ± 102.3 μg/kg dw), and 2.2 to 52.0 μg/kg dw (mean, 17.2 ± 13.5 μg/kg dw), respectively. TBEP represented to be the most abundant OPEs and detected most frequently with TCEP followed.

Table 1. Concentration ranges of OPEs in the soils (μg/kg), n = 28

Compound	%detected	Range	Mean
TiBP	85.7	4.6~68.1	33.7 ± 23.4
TnBP	60.7	3.4~54.8	16.7 ± 14.0
TCEP	92.9	4.7~436.0	65.8 ± 102.3
TCPP	75.0	2.2~52.0	17.2 ± 13.5
TBEP	85.7	14.1~592.1	151.7 ± 189.3
TPHP	60.7	2.5~38.7	21.3 ± 18.0
EHDPP	64.3	1.8~60.0	11.3 ± 9.2
TCP	35.7	10.3~200.1	92.0 ± 64.7

Accumulation of OPEs in wheat plants collected in the farms in the sampling area was evidenced in this study, and the concentration ranges are given in Table 2. The ΣOPE concentrations in roots and the aboveground tissues were in the range of 8.6 to 41.8 and 10.6 to 50.8 μg/kg dw with the mean values of 23.1 ± 11.6 and 21.7 ± 12.3 μg/kg dw, respectively. Similar distribution profiles of OPEs in wheat roots were identified with those of the farmland soils, giving a hint that there might exist root uptake of OPEs from soils and further translocation upward to the aboveground parts of wheat.

Table 2. Concentration range of OPEs in wheat samples (μg/kg), n= 9

Compound	Roots			Aboveground tissues		
	%detected	Range	Mean	%detected	Range	Mean

TiBP	77.8	1.6~6.1	3.1 ±1.4	44.4	0.6~2.5	1.3 ±0.8
TnBP	22.2	1.4~3.4	2.4 ±1.4	22.2	0.6~4.6	2.6 ±2.8
TCEP	100.0	2.2~9.3	4.9 ±2.3	100.0	2.2~13.2	7.3 ±4.0
TCPP	55.6	3.4~6.4	4.6 ±1.7	66.7	2.5~6.5	4.0 ±1.4
TBEP	77.8	6.1~15.2	9.9 ±3.6	77.8	7.1~28.8	12.8 ±7.5
TPHP	33.3	0.9~6.3	3.2 ±2.8	ND	ND	ND
EHDPP	66.7	1.8~8.1	4.1 ±2.7	33.3	1.5~2.5	1.8 ±0.6
TCP	33.3	2.6~5.7	3.7 ±1.7	ND	ND	ND

To further confirm the above speculation, relationship between the concentrations of ΣOPE in plant tissues and soils were analyzed and a significant positive linear relationships existed between the concentrations of ΣOPE in the aboveground tissues of wheat and soils ($P<0.001$) as well as between the concentrations of ΣOPEs in the aboveground tissues and those of roots. However, the distribution of the OPEs in the aboveground tissues of wheat was somewhat different from that in roots. For example, the proportions of TBEP and TCEP were obviously higher in the aboveground tissues than in roots.

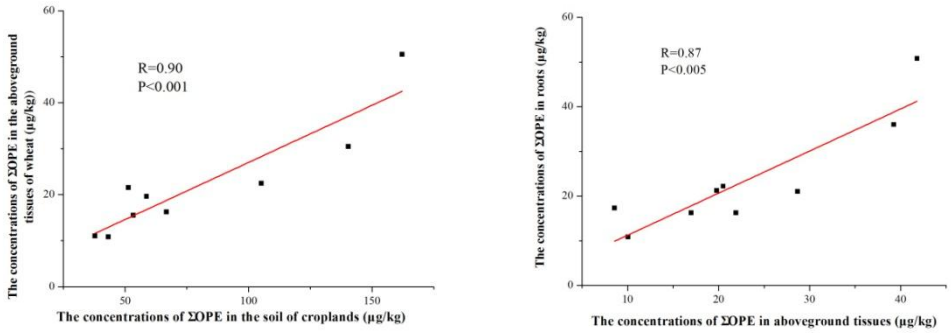

Figure 1 Relationships between the the concentrations of ΣOPE in the aboveground tissues of wheat and soils (right) and concentration of ΣOPE in wheat roots (left)

The present study has confirmed that plastic waste treatment causes OPE contamination in soils not only at the treatment sites but also in the nearby farmlands, which further led the accumulation of OPEs in wheat. The results of this study highlight the potential of OPEs for environmental contamination and threat to the food chain arising from contamination from primitive and crude plastic waste treatment.

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