PCBs uptake by carrots after sludge composts application: worst-case and operational practice in greenhouse conditions

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Abstract

Polychlorinated biphenyls (PCBs) are classified as priority pollutants by American and European environmental agencies. The most important problem with PCBs is their potential for transmission within the food chain. In France, sewage sludge composts which answer to the French norm NFU 44-095 are applied on arable crops and could be applied on market gardening.

A study on PCBs behaviour in a sand/soil - plant system was conducted with the reclamation of sewage sludge compost for market gardening in mind. It was carried out in a temperature and humidity regulated greenhouse. Soil, compost and carrot samples were analyzed. PCBs uptake was followed into carrots core, peel and leaves.

First, carrot plants (*Daucus carota* var. *Amsterdam Bejo*) were grown on sand + PCBs pure substances in order to study transfer pathways. Two pathways by which PCBs can enter a carrot were identified: (1) uptake and transport in oil channels (2) foliar uptake of vapour from surrounding air.

Secondly, carrot plants were grown on amended sand and sandy soil under operational practice. No PCBs uptake was observed from the real operational practice experiment. Indeed, PCBs levels in carrots were lower than the limit of quantification in all cases.

Key words: priority pollutants; organic waste products; plant growth; chemical analysis; food chain

1. INTRODUCTION

Polychlorinated biphenyls (PCBs) are the most important class of ubiquitous priority pollutants whose mutagenic/carcinogenic and endocrine disrupting effects on biota have been reported [1-3]. They have been included in the "priority pollutants" listings implemented by the United State Environmental Protection Agency and by the European Commission. PCBs general formula is $C_{12}H_{(10-n)}Cl_n$ where n is the number of chlorine atoms, from 1 to 10 [4]. These molecules have an extremely low solubility in water especially the more chlorinated members [5]. They are soluble in oils and most organic solvents and moreover have a very high environmental mobility due to their high vapour pressure [6]. Starting in the thirties, PCBs were widely synthesized as part of different industrial compounds such as plastifying agents, inks or resins and in dielectric or coolant fluids [7]. They were available for sale mixed, under such trade names as Arochlor, Kanechlor, Clophen, Phenachlor, Pyralene. Although gradually banned since the eighties due to their toxicity, they are still present in the environment owing to their high physical, chemical and biological stability and the continued presence of various sources. According to Mhiri and Tandeau de Marsac [8], 400 000 tons of PCBs would have been spread in the environment. The most important problem with PCBs is their potential for transmission within the food chain [9-10]. They are carried in mammalian milk and accumulate in adipose tissues, increasing the risks of bioaccumulation and transfer along food chains [11]. However, plants are the first step in the food chain.

Organic-farmed crops are grown in soils that may be contaminated with persistent organic pollutants at low concentrations from past applications of agrochemicals or by-products, or from atmospheric deposition of volatile and semi-volatile organic compounds. In France, the production of sewage sludge composts is around 430 000 tons dry matter [12]. The compost which follows the norm NFU 44-095 [13] can be recycled on arable crops where wheat and maize may be cultivated. However, sewage sludge compost could be applied soon on market gardening and notably carrots. In Europe, PCBs levels (Σ 7 PCBs) from 0.03 to 0.11 $mg.kg^{-1}$ dry matter in sewage sludge composts were reported [14-15].

There are a lot of studies on PCBs uptake by terrestrial plants after sewage sludge land application [3] [16] but only few after compost application [17]. A lack of quantitative data was identified. Moreover, the most part of publications were focused on trace metal elements and not on trace organic compounds [18]. Numerous publications deal with the efficiency of this type of compost to improve organic matter and fertilizing elements contents of market gardening soils [19-20]. Therefore, knowledge on PCBs behaviour in environment and plants is essential in elucidating their potential bioaccumulation in the food chain.

Accordingly, the objective of this study was to investigate potential PCBs transfer from organic amendment (sewage sludge composts) amended sand/soil into a food-chain crop under real operational practice. Carrots (*Daucus carota* L. var. Amsterdam A.B.K. Bejo) were chosen as the test crop because they have been reported to be the crop having the greatest potential for organic uptake due to their high lipid content [21]. In addition, carrots can be easily separated in peel, core and leaves which allow the determination of the organic compounds transfer path.

2. EXPERIMENTAL

2.1. Materials

Plant

The experiment was conducted on carrot (*Daucus carota*) Amsterdam *A.B.K.* Bejo variety. This variety was chosen because: (1) It is fully developed after two and a half months, (2) The carrots are dwarf carrots commonly used for human consumption, (3) It is a model plant, identified as having the greatest absorption potential of trace organic compounds due to its high lipid content [22].

Sand and soil substrat

Crops were grown on sand and soil, in order to compare the influence of substrate on transfer. Sand was chosen because it has no organic matter content, thus applied organic compounds may be more bio-available. So a root crop growing in sand can be considered the worst-case scenario to study the PCBs behaviour [23]. The quartz-siliceous sand used (medium diameter 0.5 mm) was carefully washed in order to release organic matter (hydrochloric acid and demineralised water). A density of 1.6 $kg.L^{-1}$ was calculated and 3 kg of sand per pot were used. The water holding capacity of sand, that is to say the mass percentage of water which keeps sand, is around 15 %. The water holding of sand + compost mixtures in different application rates remains included between 12 and 14 %.

The soil came from a field belonging to an organic farmer with no fertilizers application since 1996. Geographically, this field is located between Saint Suplice-sur-Lèze (31, France) and Lézat-sur-Lèze (09, France) (Longitude: 01°20'24" E; Latitude: 43°18'17" N). The soil was sampled in the upper horizon (0-20 cm), air-dried and sieved at 5 mm diameter in order to fill the pots. The soil had a loamy texture and slimy-loamy type: clay (< 2μm) 36% ; fine loam (2-20 μm) 30% ; rude loam (20-50 μm) 18% ; fine sand (50-200 μm) 12% ; rude sand (200-2000 μm) 5%. The soil was rather basic with an alkalinity degree rather low (pH 8.3). This soil showed a good level of organic matter (23.2 $g.kg^{-1}$ dry matter). It was also rich in major elements. Trace metal elements levels were less than limit values (table 1). Soil density was 1.1 $kg.L^{-1}$ and 2 kg fresh matter of soil was put in containers. The water holding capacity of soil is higher than sand, in the order of 18 %.

Organic amendment

The sludge compost (Compost) was obtained from a composting facility processing sewage sludge mixed with crushed green waste and riddling refusal. The sampling of compost was accomplished following norm NF EN 12579 [24]. Then, the sample was sieved at 5 mm before use. Table 1 presents information about nutrient composition and PCBs concentrations. The acquired compost answers the norm NF U 44-095 [13].

PCBs standards

PCBs standards (PCBs in pure form) were introduced for the pure substances experiments: tri-, tetra-, penta-, hexa-, hepta-chlorinated biphenyls (IUPAC numbers: PCB28, PCB52, PCB101, PCB118, PCB138, PCB153, PCB180) at 10 $mg.L^{-1}$ in acetone from Cluzeau Info Labo (France).

2.2. Experimental set-up

A total of 42 pots were used for the experiment (table 2). Four treatments were applied to carrots: (1) carrots grown in sand with added PCBs pure substances; (2) carrots grown in

sand with an agronomic compost application (25 t/ha), which corresponds to the classical application dose of compost in gardening, (3) carrots grown in sand with an extreme compost application (60 t/ha), (4) carrots grown in soil with an agronomic compost application (25 t/ha). Soil cultures closer to reality were carried out in order to evaluate the real impact on transfers of an agronomic use of organic waste products. Control pots specific for each treatment (mineral content) were added to check growth conditions.

2.3. Cultivation technique

Carrot plants were grown on sand or soil in pots. The culture was conducted under greenhouse conditions (day: mean temperature 24°C, 14 hours light, 50% relative humidity / night: temperature 19°C, 10 hours light, 50% relative humidity). Carrot seeds were germinated on filter paper moistened with deionised water for 5 days at 23°C in the dark. Carrot seedlings were transplanted into glass pots (2 L volume ; 15 10^{-2} m high ; 13 10^{-2} m diameter) with bottom hole. Six pots, each containing 7 carrots, per treatment were used. Pots were randomly arranged in the greenhouse. All plants were watered with nutrient solution (KNO_3 5, KH_2PO_4 2, $Ca(NO_3)_2$ 5, $MgSO_4$ 1.5 mM for macronutrients, and Fe 268.6, Mn 8.9, Cu 0.9, Zn 1.7, Mo 0.1, B 24.1 µM for micronutrient). The drain water contained in the saucer under the pots is poured back onto the sand. Carrots were irrigated daily to maintain the moisture content at 66% of the field capacity. Carrots were harvested after 90 days, carefully washed, divided into peel, core and leaves and weighted.

2.4. Analytical procedure

No standard reference material (SRM) was available for PCBs quantification in carrots. The analytical procedure evaluation was performed with control carrot (spiked concentration 10 µL PCBs at 10 ng.µL^{-1} acetone). Seven PCB isomers (IUPAC codes: 28, 52, 101, 118, 138, 153 and 180) were determined.

The plant matter was freeze-dried and ground up using a household grinder. 2 g sample, 1 g Fontainebleau sand (particle size 150-300 µm) to control boiling, 1g powdered Florisil (Florisil PR particle size 60-100 mech) to adsorb grease and the extraction standard PCB209 (10 µL of a solution at 200 µg.mL^{-1} in *n*-hexane (Cluzeau Info Labo, France)) were introduced in cellulose extraction cartridge (30 x 100 cm) (Schleicher & Schuell, France). An extraction with 100 mL of *n*-hexane Suprasolv (VWR, France) for 3 hours (2 hours in boiling mode and 1 hour in rinsing mode) is performed with a Soxtec System HT 1045 (Tecator, France). Then, a rotary evaporator (Rotavapor, Büchi) and a 30°C temperature controlled bath were used to concentrate the sample down to 10 mL. Concentration of the extract to 1 mL before purification was performed by a nitrogen stream (Alpha 1, Air Liquide, France). Clean up is done by 1g Florisil Solid Phase Extraction cartridges (Supelco, France) placed on a manifold (Supelco, France) and rinsed with 10 mL of *n*-hexane. A 10 mL graduated tube is placed under the manifold to collect the extract coming out of the cartridge. The 1 mL concentrated extraction sample is placed at the top of the cartridge. An elution at a rate of 1-2 drops per second is carried out with 8 mL of *n*-hexane to recover the PCBs. Each purified extract is then concentrated to 1 mL in a stream of nitrogen.

PCBs were analyzed by high resolution gas chromatography coupled with low resolution mass spectrometry (HRGC-LRMS) on electron impact mode. The apparatus is a Finnigan Trace 2000 series with a quadrupole type analyzer, entirely computer-controlled with data acquisition and processing using XCalibur software. The chromatograph is fitted with a Restek RTX-5MS (5% diphenyl; 95% dimethylpolysiloxane) column 30 meters long, 0.25 mm in diameter and 0.25 µm film thickness. Helium (Alpha 2, Air Liquide, France) carrier gas is used at a flow rate 1.2 mL.min^{-1}. A 1 µL sample is injected into the split/splitless inlet in splitless mode at 250°C. The temperature of the HRGC-LRMS interface is 250°C, and

the oven temperature program starts at 60°C for 2 minutes. Then, the temperature increases to 230°C at 16°C.min^{-1}, reaches 282°C at 5°C.min^{-1} and levels off at this temperature for 1 minute. The full scan electron impact data is obtained under the following conditions: solvent delay 5 minutes, electron impact energy 70 eV, source temperature 250 °C, emission current 150 µA, detector voltage 350 V. Separation has been set up using a standard mixture of 7 PCBs at 10 µg.mL^{-1} in isooctane. Tetrachlorometaxylene (TCMX at 20 µg.mL^{-1} of acetone), an organo-chloride is used as internal standard and is added to the purified extract just before the gas chromatography analysis. Quantification is performed in Multiple Ion Monitoring (MIM) mode. Seven retention time windows have been used, each corresponding to the ions selected per compound: (1) 9.0-12.5 min m/z = 244 ; 178 (2) 13.0-13.5 min m/z = 256 ; 186 (3) 13.5-14.5 min m/z = 292 ; 220 (4) 14.5-16.4 min m/z = 326 ; 184 (5) 16.4-18.0 min m/z = 360 ; 290 ; 254 (6) 18.0-22.0 min m/z = 394 ; 324 (7) 22.0-24.0 min m/z = 498 ; 428. Figure 1 shows a chromatogram for a standard mixture of 7 PCBs, the internal standard (TCMX) and the extraction standard (PCB 209). Each extract has been analyzed three times.

2.5. Analytical quality assurance

Analytical quality control and quality assurance programs were run in the laboratory during sample analysis in order to get reliable data [25]. Internal calibration curves have been obtained for each compound by linear regression of the peak area against the concentration injected. In each case, the regression coefficient ranged from 0.990 to 0.996. The calibration range of PCBs scans the concentrations from 10 to 100 ng.mL^{-1}.

Limit of detection (LOD) and limit of quantification (LOQ) were evaluated from standard deviation of ten replicates of carrot sample spiked. LOD (3 standard deviations) is 0.3 µg.kg^{-1} fresh mater for each PCB and LOQ (10 standard deviations) is 1 µg.kg^{-1} fresh mater for each PCB. These values are compatible with the levels found in plants tissues [26].

The repeatability, expressed as the relative standard deviation (in %), is an evaluation of the overall extraction - purification - analysis procedure. It is calculated from 5 replicates of 5 carrot peel samples and was less than 5% per compounds.

The HRGC-LRMS apparatus gives concentration results in µg.L^{-1}. Knowing the mass of the sample and taking into account all the analytical steps, the results can be expressed in terms of µg.kg^{-1} of fresh matter (Figure 2).

2.6. Statistics

Variance analysis of data and a Newman-Keuls multiple range test at 0.05 probability level were performed (Statistical Software, Sigma Stat 2.00). The same letter in a column means that there is not significant difference at a probability equal to 0.05. On the other hand, a different letter means that there is a significant difference between control and treatments.

3. RESULTS AND DISCUSSION

3.1. Biomass production

For each modality, carrot fresh weight of controls and treatments were compared (Table 3). Plant masses were comprised between 7.5 and 53.0 g fresh matter according to compartments and experiment. No phytotoxicity symptoms were observed for plants regardless of the PCB concentration in pot. First, there is not significant difference between treatments and control in terms of the number of carrots per pot and the average number is always between 6 and 7. Secondly, there were no significant differences in growth between the carrots on the sand only (C1) and those on the sand with PCBs pure substances (T1). Concerning the compost experiment, a decrease in peel production was observed in treatment pots whatever dose of compost applied.

3.2. PCBs distribution in the pure substance experiment

PCBs average levels in peel, core and leaves of the carrots were calculated. PCBs were grouped according to chlorine number in the molecule: tri-chlorinated biphenyls (PCB28), tetra- chlorinated biphenyls (PCB52), penta-chlorinated biphenyls (PCB101 and PCB118), hexa-chlorinated biphenyls (PCB138 and PCB153), hepta-chlorinated biphenyls (PCB180). Distribution percentages of PCBs in carrot compartment were calculated according to equation presented in figure 3. Distribution profiles in the different compartment, presented in figure 4, clearly show that PCBs accumulated in carrot peel: 85% of ΣPCBs transferred were found in the peel. This result is consistent with other studies showing more than 80% of PCBs contamination was associated with peels [16] [27]. This behaviour can be explained with partition phenomena between lipophilic properties of PCBs and high lipid content of carrots peel (presence of oil channels). Moreover, root parts (peel + core) have absorbed 7 till 10 times more PCBs than the foliar parts. Besides, we observed that the more PCB is chlorinated, the more PCB is fixed in peel. Indeed, lipophilic properties of PCBs which are correlated to octanol-water partition coefficient (Kow) increase with the chlorine atoms number. The more lipophilic the chemical is, the greater is the association with the root.

Around 5% of ΣPCBs were found in the core. In theory, the lower the degree of chlorination is, the more the transfer in the core takes place (Iwata et al. 1976). In our case, this tendency is respected.

Around 10% of ΣPCBs were found in the leaves. The lower chlorinated biphenyls are generally reported to be more labile in soils, more soluble, less absorbed, more quickly degraded and more volatile than the higher chlorinated biphenyls. This phenomena is clear for leaves where more the degree of chlorination is weak, more the transfer takes place. We noticed that the lightest PCBs (tri- and tetra chlorinated) are found predominantly in the leaves. Volatilisation of these PCBs from the sand would allow explaining this presence [26]. This hypothesis was verified with experimentation without carrots (Figure 5). Tri and tetra-chlorinated PCBs are present at lower levels that high chlorinated PCBs in the upper part of the sand. The origin of these PCBs in leaves can be owned to a volatilisation and adsorption of PCB in the air. Indeed, Henry's law constant of these compounds are upper than 10^{-4} [28].

Two pathways by which PCBs can enter a carrot were identified: (1) uptake and transport in oil channels (2) foliar uptake from surrounding air.

3.3. PCBs uptake in the compost experiment

PCBs concentrations in sludge compost were comprised between 1 and 13 $\mu g.kg^{-1}$ fresh matter according to the congener (Table 1). PCBs concentrations in plants (leaves, core and peel) for treatments and controls pots were lower than the limit of quantification equal to 1 $\mu g.kg^{-1}$ fresh matter (Table 4). No correlation between concentration of PCBs in soil and

their uptake by carrots was observed. Apparently PCBs are so strongly adsorbed on organic matter from the soil or the compost indeed bioavailability of PCBs is independent of organic carbon. Moreover, a level of 1 $\mu g.kg^{-1}$ fresh matter do not give cause for concern in relation to the maximum EU tolerable daily intake limit of 10 $pg.kg^{-1}$.body $weight^{-1}.day^{-1}$ [29].

4. CONCLUSION

First, PCBs concentrations were determined in a pure substance experiment. Distribution of PCBs has shown that compounds with high octanol-water partition coefficient are most likely to be sorbed by the peel. They accumulate on root surface and remain there bound to lipids in cells walls. The trend for preferential contamination of leaves with more soluble and lower chlorinated biphenyls has been reported.

Then, uptake of polychlorinated biphenyls from compost amended soil was measured at real conditions: no PCBs uptake was observed. Indeed, PCBs levels were lower than the limit of quantification in all cases. Consequently, this experiment in real operational practice conditions shows that NFU 44-095 sludge compost could be applied on carrots culture even on sand substrate.

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Table 1. Physical and chemical characterisation of the compost and soil used in this study

	Unit	Number of repetitions	Compost	Soil
pH		5	8.3 ± 0.0	8.3 ± 0.0
Dry matter	% fresh matter	5	68.8 ± 0.0	82.9 ± 1.0
Organic matter	$g.kg^{-1}$ dry matter	5	538 ± 26	463 ± 4
Total nitrogen	$g.kg^{-1}$ dry matter	5	38.8 ± 1.1	-
C/N ratio	-	5	6.9 ± 0.1	-
P2O5	$g.kg^{-1}$ dry matter	5	60.7 ± 4.4	146 ± 10
K_2O	$g.kg^{-1}$ dry matter	5	-	400
MgO	$g.kg^{-1}$ dry matter	5	-	525
CaO	$g.kg^{-1}$ dry matter	5	-	11210
Cu	$mg.kg^{-1}$ dry matter	5	244 (300*)	28,24 (100*)
Zn	$mg.kg^{-1}$ dry matter	5	295 (600*)	86,13 (300*)
Cd	$mg.kg^{-1}$ dry matter	5	0,82 (3*)	0,32 (2*)
Cr	$mg.kg^{-1}$ dry matter	5	21,7 (120*)	33,71 (150*)
Hg	$mg.kg^{-1}$ dry matter	5	1,41 (2*)	0,042 (1*)
Ni	$mg.kg^{-1}$ dry matter	5	16,7 (60*)	28,74 (50*)
Pb	$mg.kg^{-1}$ dry matter	5	31,2 (180*)	19,98 (100*)
PCB 28	$\mu g.kg^{-1}$ fresh matter	5	<1	<1
PCB 52	$\mu g.kg^{-1}$ fresh matter	5	4.1 ± 1.7	<1
PCB 101	$\mu g.kg^{-1}$ fresh matter	5	6.4 ± 2.5	<1
PCB 118	$\mu g.kg^{-1}$ fresh matter	5	5,6 ± 5,9	<1
PCB 138	$\mu g.kg^{-1}$ fresh matter	5	8,5 ± 3,6	<1
PCB 153	$\mu g.kg^{-1}$ fresh matter	5	10,0 ± 2,7	<1
PCB 180	$\mu g.kg^{-1}$ fresh matter	5	1,7 ± 2,0	<1

* Threshold value in compost and soil

Table 2. The various plant pots placed in the greenhouse

	Subtracts	By-product	Rate application	Plant	Number of pots
Pure substances experiment					
C1	Sand	-	-	carrots	3
T1	Sand	PCBs pure substances	300 g FM/ha	carrots	6
T1’	Sand	PCBs pure substances	300 g FM/ha	-	6
Compost experiment					
C2	Sand	-	-	carrots	3
T2	Sand	Compost	60 t FM/ha	carrots	6
C3	Sand	-	-	carrots	3
T3	Sand	Compost	25 t FM/ha	carrots	6
C4	Soil	-	-	carrots	3
T4	Soil	Compost	25 t FM/ha	carrots	6

Table 3. Fresh matter production per pot (g FM)

	Number of repetitions	Peel	Core	Leaves
Pure substances experiment				
C1	3	23.9 ± 2.9 a	53.0 ± 7.3 a	20.0 ± 2.0 a
T1	6	20.0 ± 5.3 a	44.4 ± 14.9 a	17.8 ± 1.7 a
Compost experiments				
C2	3	13,5 ± 3,1 a	20,2 ± 3,2 a	21,8 ± 1,3 a
T2	6	8,7 ± 1,1 b	18,3 ± 3,6 a	23,0 ± 2,4 a
C3	3	10,9 ± 1,4 a	11,7 ± 2,9 a	21,0 ± 1,1 a
T3	6	7,5 ± 0,9 b	11,4 ± 2,9 a	22,8 ± 2,0 a
C4	3	13,5 ± 3,1 a	20,2 ± 3,2 a	21,8 ± 1,3 a
T4	6	8,7 ± 1,1 b	18,3 ± 3,6 a	23,0 ± 2,4 a

Mean values of three (or six) replications followed by the same letter in a column are not significantly different at $P<0.05$; ± Standard Deviation (variance analysis).

Table 4. PCBs levels (µg.kg^{-1} fresh maater) in each compartment for the compost experiments

Treatment		Number of repetitions	Peel	Core	Leaves
C2	PCB 28	5	<1	<1	<1
	PCB 52	5	<1	<1	<1
	PCB 101	5	<1	<1	<1
	PCB 118	5	<1	<1	<1
	PCB 138	5	<1	<1	<1
	PCB 153	5	<1	<1	<1
	PCB 180	5	<1	<1	<1
C3	PCB 28	5	<1	<1	<1
	PCB 52	5	<1	<1	<1
	PCB 101	5	<1	<1	<1
	PCB 118	5	<1	<1	<1
	PCB 138	5	<1	<1	<1
	PCB 153	5	<1	<1	<1
	PCB 180	5	<1	<1	<1
C4	PCB 28	5	<1	<1	<1
	PCB 52	5	<1	<1	<1
	PCB 101	5	<1	<1	<1
	PCB 118	5	<1	<1	<1
	PCB 138	5	<1	<1	<1
	PCB 153	5	<1	<1	<1
	PCB 180	5	<1	<1	<1

Figure 1. Chromatogram of a standard solution (7 PCBs at 10 µg.mL^{-1}, the TCMX at 20 µg.mL^{-1}and PCB 209 at 1 200 µg.mL^{-1}) in SIM mode.

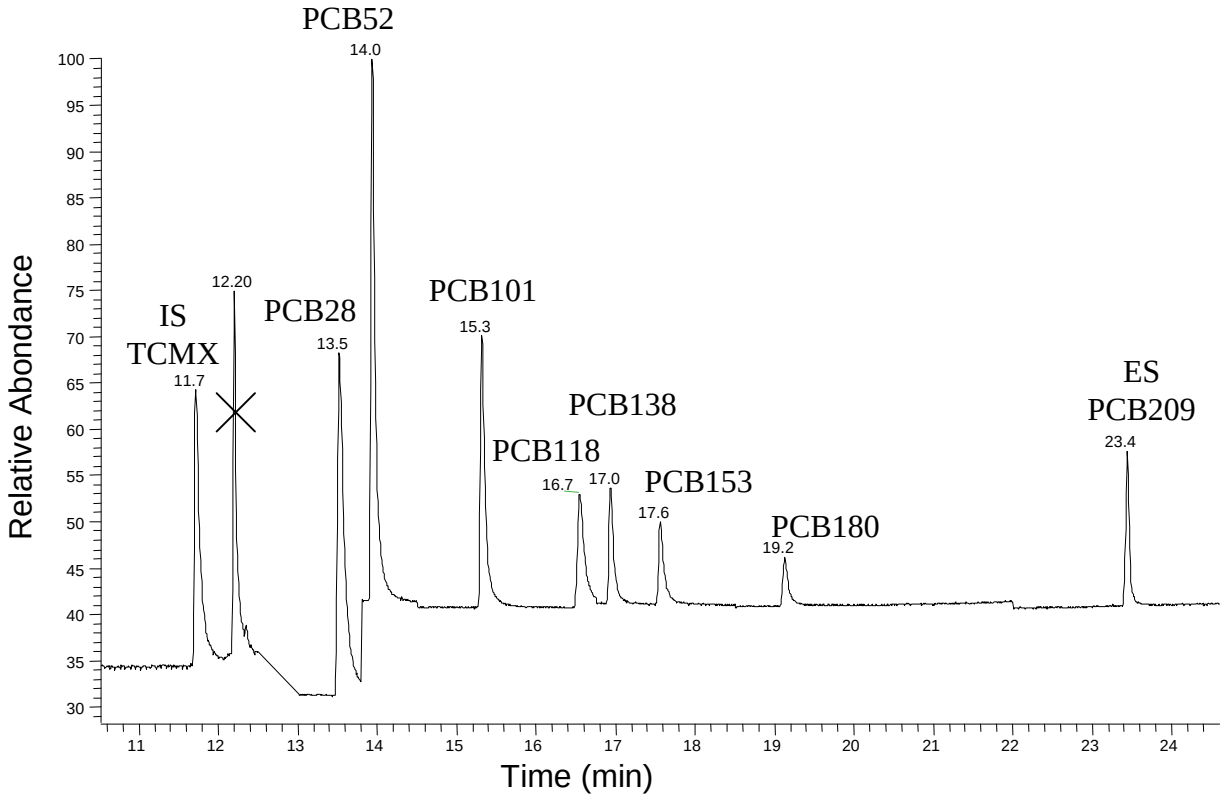

Figure 2. Equation to calculate the concentration of PCBs in the plant matter (µg.kg^{-1} fresh matter) as a function of the PCBs concentration in the extract in µg.mL^{-1} ($C_{extract}$), the initial volume of the extract in mL ($V_{initial}$), the final volume of the extract in mL (V_{final}), the mass of the plant matter introduced into the extraction cartridge in g fresh matter (m), the extraction yield (the extraction is considered to be valid when the extraction yield is > 80 %) and the concentration factor (= initial volume of extract / final volume of extract) (CF).

$$Concentration\ in\ plant = \frac{C_{extract} \times V_{initial}}{Yield \times m \times CF \times V_{final}}$$

Figure 3. Equation for the distribution percentages of PCBs in carrots

$$\text{Distribution (\%)} = \frac{\text{mass of nCl PCB in a carrot compartment (µg)}}{\text{mass of nCl PCB into the 3 carrot compartments (µg)}} \text{ x } 100$$

With:

- Mass of n-Cl PCB in a compartment (µg) = n-Cl PCB concentration in the compartment (µg.kg^{-1} MD) x mass of the compartment (kg DM)
- 3<n<7

Figure 4. PCBs distribution in peel, core and leaves of carrots as a function of chlorine numbers (pure substances experiment).

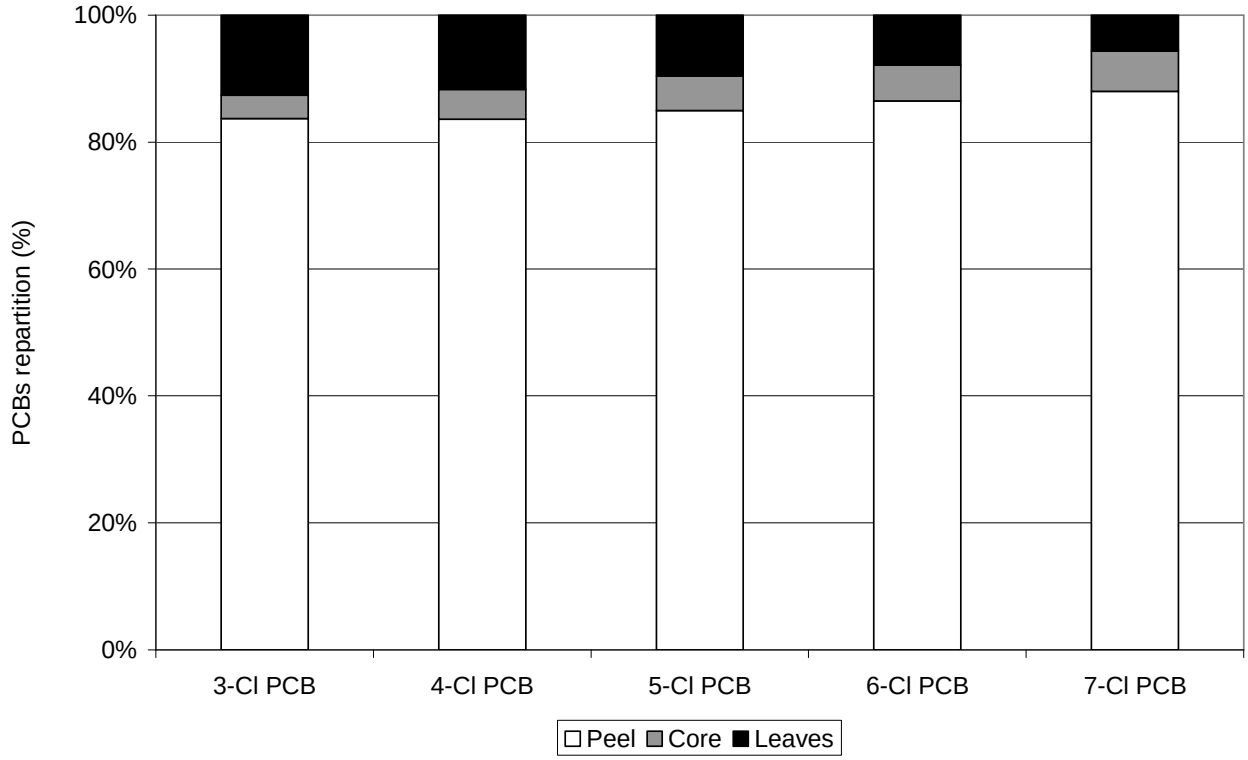

Figure 5. PCBs average levels in sand at the end of the experimentation (pure substances experiment without carrots)