ORGANIC POLLUTANTS IN SOURCE- SEPARATED COMPOST

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Introduction

Composting (i.e. aerobic degradation) of crude organic kitchen and green waste represents an important and well established part of waste management in Europe. Digestion (i.e. anaerobic degradation with or without subsequent aerobic process) has been promoted in recent years due to increasing efforts to combine recycling of organic materials with energy production. About 9.3×10^6 tonnes of compost and digestate are produced per year in the 25 European Union member states [1] and most of it is applied to agricultural soil. These recycling fertilizers can have positive effects on physical, chemical and biological soil parameters. However, little is known about organic pollutants in source-separated compost and digestate (i.e. not containing sewage sludge, municipal solid waste etc.), as has been shown in a recent compilation [2]. Information on digestate is completely lacking. This is problematic from a risk assessment point of view. Our study inventories the content of a wide range of today's most concerning organic pollutants in compost and digestate from Switzerland: PAHs (Σ16 polycyclic aromatic hydrocarbons as defined by the US EPA), polychlorinated biphenyls (PCBs, including three chiral PCBs), dioxin-like PCBs (DL-PCBs), polybrominated diphenyl ethers (PBDE), hexabromocyclododecane (HBCD), tetrabromobisphenol A (TBBPA), per- and polyfluorinated alkyl substances (PFAS), pesticides, phthalates, nonylphenol and chlorinated paraffins (CP). Most of theses compounds were analysed for the first time in compost.

Materials and Methods

Over 80 samples of composts and digestates derived from source separated green and kitchen waste were collected from 39 commercial composting and digestion plants in Switzerland. Sample selection accounted for factors that were hypothesised to be key determinants for organic pollutant content in these recycling fertilizers [2]: different input materials (green waste with and without organic kitchen waste; small amounts of organic waste materials of industrial origin included in some products were of minor importance), different origin of input material (urban versus rural), different season of input material collection (spring/summer, autumn, winter), and different maturity of compost and digestate. For sampling procedure, sample preparation and analytical methods see Brändli et al. 2006 [3], Bucheli et al. 2006 [4] and Brändli et al in preparation [5]. PAHs and PCBs were analysed in all 80 samples, whereas the remaining organic compounds and pesticides were only determined in a subset of samples (n = 3-18). A linear model was applied to the entire dataset to determine significant factors influencing PAH and PCB concentrations in compost and digestate, whereas for the small dataset the Mann-Whitney-U-Test was used. Some special cases (e.g. compost with manure in the input material) had to be excluded for evaluation.

Results and Discussion

PAHs

Median PAH concentration (Σ15 PAHs, Dibenzo(a,h)anthracene could not be determined due to analytical difficulties) was at 3010 μg/kg dry weight (dw) with a minimum at 600 μg/kg dw and a maximum at 12470 μg/kg dw (Figure 1, n=69). These values were higher than the median from the literature (1870 μg/kg dw [2]).

Median PAH concentrations in Swiss soils were lower by a factor 6 to 40 (arable soils: Σ 16 PAHs 66 µg/kg dw, permanent and pasture grassland: 142 µg/kg dw, urban soils: 451 µg/kg dw [6]). Additionally, the trend of concentration in soil was estimated, assuming a starting level in soil of 225 µg/kg dw [6], an aerial deposition of 1.6 g/ha/a [7] and a compost application rate of 10 t dw/ha/a as only inputs of PAHs to soil. As a simplified, conservative approach, once in soil, the compounds were assumed to be non-degradable and immobilized. The estimated time span to exceed the Swiss guide value for PAHs in soil (Ordinance relating to Impacts on the Soil, 1 mg/kg dw) would be less than 50 years. At this PAH level, the Swiss law calls for actions to prevent further increase of the PAH levels in soil, possibly prohibiting compost application.

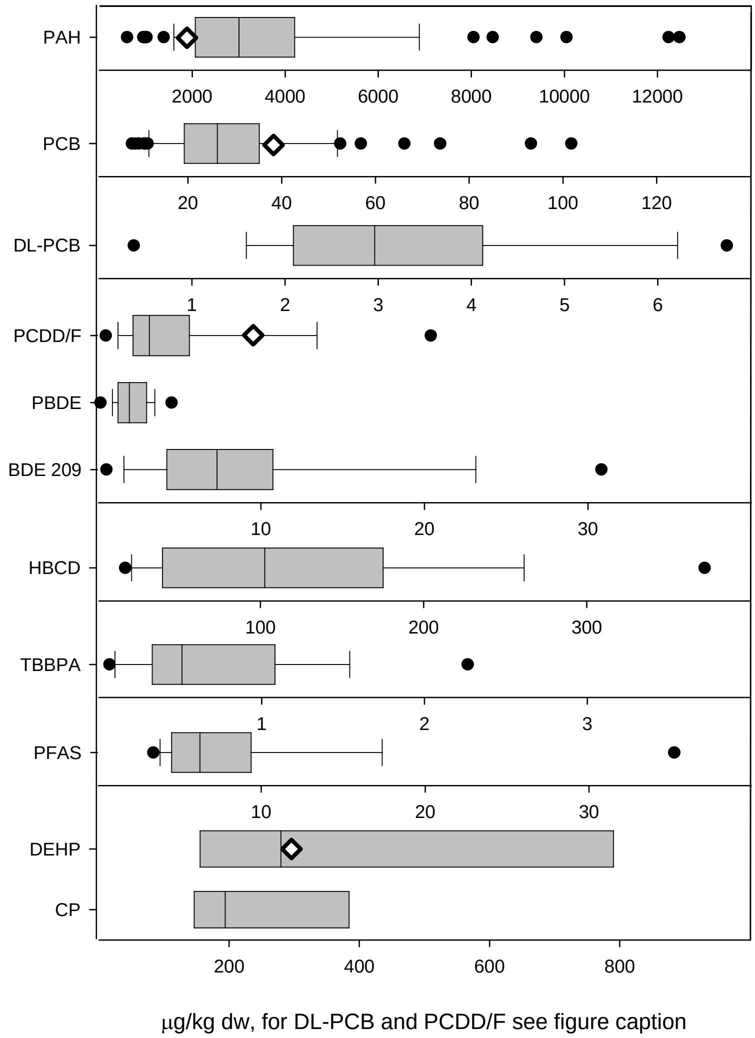

Figure 1: Concentrations of organic pollutants in compost and digestate (line: median; box: 25th and 75th percentile; lines with whiskers 10th and 90th percentile, dots: outliers, diamond: median literature value [2]; where missing: not available), PAH (Σ of 16 PAHs defined by the US EPA, except Dibenzo(a,h)anthracene in µg/kg dry weight (dw), n=69), PCB (Σ of PCB 28, 52, 101, 118, 138, 153, 180, in µg/kg dw, n=69), PCDD/Fs (Σ17PCDD/Fs in ng I-TEQ/kg dw, n=18), DL-PCBs (Σ of PCB 77, 81, 105, 114, 118, 123, 126, 156, 157, 167, 169, #189 in ng WHO-TEQ/kg dw, n=18), PBDE (Σ of BDE28, 47, 99, 100, 153, 154, 183, in µg/kg dw, n=18), BDE 209 (n=18), HBCD (n=18) and TPPBA (n=18) in µg/kg dw, PFAS (Σ of 21 compounds in µg/kg dw, n=18), DEHP in µg/kg dw (n=6), CP (Σ of short and medium chain chlorinated paraffins in µg/kg dw, n=3)

PCBs and dioxin-like PCBs (dl-PCBs)

Median PCB concentration (ΣPCB 28, 52, 101, 118, 138, 153, 180) in Swiss compost and digestate was 26.3 µg/kg dw ranging from 8.1 µg/kg dw to 102 µg/kg dw (Figure 1, n=69). These concentrations were lower than in the literature (38 µg/kg dw for 6 indicator PCBs [2]), possibly reflecting the general decreasing PCB levels in the environment [8]. Median concentration of the DL-PCBs (ΣPCB 77, 81, 105, 114, 118, 123, 126, 156, 157, 167, 169, 189) accounted for 3.0 ng WHO-TEQ/kg dw (n=18), ranging from 0.4 to 6.8 WHO-TEQ/kg dw. Urban samples had significantly higher PCB concentrations than rural composts. The other factors did not influence PCB concentration significantly. Concentration of DL-PCBs (in WHO-TEQ) was about equal to the PCDD/F concentration (in I-TEQ, see below), and therefore it would be useful to include DL-PCBs if PCCD/Fs in compost are assessed. Enantiomeric fractions of chiral PCBs (95, 132, 149) varied little and were very close to 0.5 in compost, indicating no significant enantioselective degradation during composting.

PCDD/Fs

Median PCDD/F concentration (Σ17 PCDD/F) in composts and digestates was 3.2 ng I-TEQ/kg dw ranging from 0.5 to 21.0 ng I-TEQ/kg dw (Figure 1, n=18). The median literature value was slightly higher (9.3 ng I-TEQ/kg dw [2]). The conservative time span until the Swiss guide value for PCDD/F in soil (5 ng I-TEQ/kg dw, Ordinance relating to Impacts on the Soil) would be exceeded was estimated 112 years, assuming a starting level of 2.4 ng I-TEQ/ kg dw [9] in soil, aerial deposition (deposition rate 22 mg/ha/a [10]) and regular compost application as only input sources, and no removal of PCDD/F due to degradation or other processes. However, the surface specific load (i.e. the load per hectare; g I-TEQ/ha/a) of aerial deposition was estimated to be only a factor two lower than input via compost application.

Brominated flame retardants

The median concentration of the sum of PBDE (ΣBDE 28, 47, 99, 100, 153, 154, 183) in composts and digestates was 2.0 µg/kg dw (0.2 - 4.5 µg/kg dw), BDE 209 accounted for 7.3 µg/kg dw (0.6 - 30.8 µg/kg dw, Figure 1, n=18). Median concentrations of pentaBDE and octaBDE calculated according to Morf et al. 2005[11] were at 1.9 µg/kg dw, and 0.2 µg/kg dw, respectively. Values in Swedish soils [12] were more than a factor ten lower than in compost. Median HBCD and TPPBA concentrations in compost were 100.6 and 0.51 µg/kg dw, respectively (Figure 1, n=18).

PFAS

The median for the sum of PFAS (Σ fluorotelomer sulfonate, four fluorotelomer carboxylates, four perfluorinated sulfonates, seven perfluorocarboxylates, three fluorooctane sulfonamides and two fluorooctane sulfonamidoethanols) was 6.3 µg/kg dw (Firgure 1, n=18). Values ranged from 3.4 to 35.2 µg/kg dw, which is between concentrations found in sludge and sediments. Relative contribution of 6:2 fluorotelomer sulfonate, perfluorobutane sulfonate, perfluorocarboxylic acids and perfluorooctane sulfonamide to the total sum of PFAS was similar in all samples. This may be an indication for the uniform distribution of these compounds irrespective of their emission from different industries, applications and diffuse sources.

Pesticides

Of the more than 270 pesticides and some of their metabolites (86 fungicides, 86 herbicides, 92 insecticides, 5 acaricide) analysed, 30 fungicides, 14 herbicides, eight insecticides, and one acaricide were detected in compost and digestate. Median concentration of the sum of all fungicides was 42.4 µg/kg dw (n=18), whereas for herbicides and insecticides the concentration was lower (4.1 and 1.1 µg/kg dw, n=18, respectively). Highest median concentrations were found for imazalil (9.0 µg/kg dw, detected in 14 out of 18) and thiabendazole (5.3 µg/kg dw, detected in 13 out of 18), two typical post-harvest fungicides applied on citrus fruit.

Phthalates, nonylphenol and CP

The median DEHP concentration in compost and digestate was 280 µg/kg dw (n=6), corresponding well with literature values (300 µg/kg dw[2] and being well below the of 50mg/kg dw of the Danish Statutory Order on application of waste products for agricultural purposes [13]. Even though detected at considerable concentrations in German apples and tomatoes [14], nonylphenol was not detected in compost. Possible reasons are relatively good degradability and high detection limit (1mg/kg dw). Concentration of CPs (short and medium chain CP) were between 86 and 285 µg/kg dw (n=3), which is comparable with Swiss soil data (personal communication, S.Iozza, University of Basel).

Synopsis

Nearly all of the today's most concerning organic pollutants could be quantified in compost and digestate at concentrations at or above levels found in background soil, the main recipient of these recycling fertilisers. On the one hand, total input of organic pollutants to the agricultural surface by compost application seemed to be limited relative to other sources in Switzerland. On the other hand surface specific loads (based on a standard fertilisation of 70kg P_2O_5, in g/ha/a) of organic pollutants to soil can account for equally or more important inputs, compared to aerial deposition, manure and sewage sludge application. This seemingly negative characteristic of compost and digestate needs to be counterbalanced with their apparent and well-documented beneficial aspects, such as soil improvement and the sustainable management of natural resources.

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