Dioxins, furans, PCBs and PAHs in eastern Canada compost

Elisabeth Groeneveld, biologist, M.Sc.[1]
Marc Hébert, agronomist, M.Sc.[2]

Ministère de l'Environnement du Québec
Direction du milieu rural
Service de l'assainissement agricole et des activités de compostage
675 boul. René-Lévesque est, 8e étage, Québec, Qc, G1R 5V7
fax : (418) 528-1035

[1]telephone : (418) 521-3829 #4833
e-mail : elisabeth.groeneveld@menv.gouv.qc.ca

[2] telephone : (418) 521-3829 #4826
e-mail : marc.hebert@menv.gouv.qc.ca

Abstract

There is currently no Canadian national standard for levels of dioxins and furans in compost. The CAN/BNQ and CCME compost criteria are now under revision, and the need for a dioxin/furan criteria is being evaluated. This study presents data on the levels of dioxins/furans, dioxin-like PCBs and PAHs in 14 composts made in the provinces of Québec and Nova-Scotia. Levels of dioxins and furans were low, with an average of 9.7 ng I-TEQ/kg dry weight, and a range of 1.0 to 31 ng I-TEQ/kg. All composts met the Québec C2 criteria for dioxins and furans of 50 ng I-TEQ/kg or less, and 86 % met the C1 criteria of 17 ng I-TEQ/kg or less. Dioxin/furan levels of all composts were between 10 and 300 times lower than the risk based limit of 300 ng TEQ_{DFP} originally proposed by the U.S. Environmental Protection Agency (USEPA). On average, dioxin-like PCBs represent less than 20 % of the TEQ_{DFP} total. Levels of PAH were generally low, over 96 % of all analyses were below either the detection or quantification limit. Based on these results, the inclusion of dioxins/furans, PCBs, or PAHs as parameters of concern in the CAN/BNQ or the CCME compost criteria do not appear to be justified.

Introduction

More than 500 000 metric tons of industrial and municipal organic residuals are composted every year in Québec (Charbonneau et al., 2000). The composts produced must meet stringent quality criteria. When the composts are destined for application to agricultural land, composts must either be certified by the Bureau de normalisation du Québec (BNQ) according to the Canadian standard (CAN/BNQ, 1997) or in accordance with a Certificate of approval (CA) issued by the Ministry of the Environment (MENV, 2002). Currently four different types of composts are certified by the BNQ in accordance with the Canadian standard. In Nova Scotia, composts must meet the Canadian council of Ministers of the Environment criteria (CCME, 1996).

The Canadian standard (CAN/BNQ, 1997), the CCME criteria (1996), and the MENV (2002) criteria are harmonized for inorganic contaminants and pathogens. However, unlike the MENV, the CAN/BNQ and CCME standards do not include criteria for polychlorinated dibenzodioxins (dioxins) and polychlorinated dibenzofurans (furans). The decision to not include dioxins and furans was based on an analysis of feedstocks generally composted in Canada in the mid 1990s. The CAN/BNQ and CCME criteria are now under revision, in collaboration with the Canadian Food Inspection Agency. The question still remains: are analyses and criteria for dioxins and furans in Canadian composts necessary? We also wanted to know if other organic contaminants, such as polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) (including benzo(a)pyrene) were present in composts in significant amounts.

To help answer these questions, different types of composts were sampled from Québec and Nova-Scotia composting facilities.

Materials and methods

A total of 25 composting companies operating under a CA in the province of Québec were inventoried. Of these, eleven sites operated by nine different companies were visited, and a total of twelve compost samples were taken by MENV representatives. One of the composts sampled was made in Québec with municipal biosolids from Ontario. Two composts produced in Nova Scotia were also sampled, by a private consultant. See Table 1 for more details on the compost types sampled.

Samples were collected from 18-20 November 2002 in Québec, and 18 December 2002 in Nova-Scotia. Each sample was a composite made of at least eight sub-samples, taken at least 30 cm deep in the pile. Between each sample, clean gloves were used, and instruments were washed in the following sequence: soapy water, tap water, acetone, hexane, acetone, and finally distilled deionised water. Samples were stored in a cooler, in one liter (L) amber bottles until shipped to the lab. All analyses were performed by the Centre d'expertise en analyse environnementale du Québec (CEAEQ). For each sample, the following compounds were analysed: 17 dioxin/furan compounds, 15 PCB congeners, and 44 PAH compounds.

Results presented for samples #3 and #8 are the average of two distinct composite samples, except where stated otherwise. All other results are from single composite samples. The total for dioxins/furans was calculated in two ways: 1) non-detects set to half the detection limit, detected but not quantified set to detection limit, 2) non-detects and detected but not quantified set to zero. On average, there is less than 0.2 ng TEQ/kg dry weight difference between the two calculation methods. In the following text, results using the first calculation method are reported. For more details, see Appendix 1.

Results and discussion

<u>Types of compost represented by the sampling</u>

More than half the composts sampled were produced from domestic residuals. These residuals represented varying levels of source separation, from yard & garden clippings to source separated organics and mixed municipal solid waste (Table 1). Two composts were made from municipal biosolids and three composts were made of pulp and paper mill residuals. Only one compost was made from manure. The compost samples tested in this study are therefore more heavily representative of urban or industrial residuals than of farm residuals. The latter were sampled less intensely based on the hypothesis that farm feedstocks are less likely to contain high levels of dioxins (NEBRA, 2001).

Dioxins, furans, and dioxin-like PCB's

All composts met the Québec C2 dioxin and furan quality criteria of 50 ng TEQ/kg for residuals that are applied on agricultural land (Table 1). Moreover, 86% of the composts (12 of 14) met the C1 highest quality criteria of 17 ng TEQ/kg. This latter criteria was derived from a German criteria based on a «best achievable approach» for yard and garden clippings (Frick et al., 1996).

Table 1: Dioxins, furans and PCBs Canadian composts.

No.	Compost type *(based on main ingredient)*	Dioxins and furans[1] *TEQ (ng/kg)*		Dioxin-like PCBs[2] *TEQ (ng/kg)*	
		ND=½ DL DNQ=DL	ND=0 DNQ=0	ND=½ DL DNQ=DL	ND=0 DNQ=0
1	Yard and garden clippings	4.0	3.4	2.3	0.8
2	Yard and garden clippings	6.2	6.2	0.4	0.4
3	Source separated organics[3]	9.9	9.6	0.7	0.2
4	Source separated organics	6.6	6.5	0.3	0.1
5	Source separated organics	6.4	6.3	1.9	0.9
6	Source separated organics	7.9	7.7	3.1	0.5
7	Source separated organics	11.7	11.6	2.8	0.7
8	Mixed municipal solid waste	31.1	31.1	12.4	2.3
9	Municipal biosolids	12.0	11.6	4.9	1.8
10	Municipal biosolids	2.4	2.3	0.6	0.4
11	Pulp & paper mill biosolids	1.9	1.6	1.1	0.6
12	Pulp & paper mill biosolids	1.0	0.9	0.1	0.1
13	Pulp & paper mill biosolids	4.9	4.9	1.8	1.2
14	Manure	27.2	27.1	0.2	0.0
Mean		9.5	9.3	2.3	0.7
Median		6.5	6.4	1.5	0.5
Maximum value		31.1	31.0	12.4	2.3
Minimum value		1.0	0.9	0.1	0.0

Criteria in various jurisdictions	
Québec Interim Criteria (all compost types applied on agricultural land)[4]	C1: 17 – C2: 50
USEPA (proposed for municipal biosolids)[5]	300
Baden-Württemburg, Germany (composted domestic residuals)[6]	17

[1]ND = non-detected. DNQ = detected, not quantified. DL = detection limit. International toxic equivalents (NATO/CCMS, 1988).
[2]The Toxic equivalents (TEQ) are from the World Health Organization (van den Berg et. al, 1988).
[3]Source separated organic residuals from households
[4]Sum of 17 PCDD&PCDF compounds, using the International Toxic Equivalency Factor (I-TEF) (NATO/CCMS, 1988). The criteria applies to all fertilising residuals that may be used in agriculture, but the analysis is required only in certain cases. For more details, refer to MENV (2002).
[5]Sum of 17 PCDD/PCDF compounds and 12 PCB congeners (TEQ_{DFP}-WHO_{98}). Also applies to composted municipal biosolids. For more details, refer to USEPA (2002).
[6]Maximum permitted concentration of 17 ng I-TEQ/kg dry weight for compost derived from biowaste and garden waste, established in 1994 (Fricke et al., 1996).

The observed levels of dioxins, furans, and dioxin-like PCBs in Québec and Nova-Scotia composts are between 10 to 300 times less than the risk based criteria of 300 ng TEQ/kg proposed by USEPA (2002) for municipal biosolids products, including biosolid composts. In fact, all compost types from the USA and Europe, as noted in Table 2, have dioxin/furan contents well below the USEPA proposed limit. Note that USEPA may decide not to establish a final standard for these constituents in biosolids products, including compost, because current Agency analysis suggests the risks are relatively low.

Dioxin-like PCBs contribute little in terms of TEQ in composts, representing on average less than 20 % of the TEQ_{DFP} total. This finding parallels Bennett and Wescott (2001), who found that coplanar PCBs added little to the overall TEQ_{DFP} (mean: 13%). When non-detects are set to ½ the detection limit, and detected but not quantified are set to the detection limit, the average TEQ_{PCB} is more than tripled over cases where non-detects and detected but not quantified are set to zero; this is because in many cases, the laboratory detection limit is relatively high. The total TEQ_{PCB} must therefore be interpreted cautiously, and regarded as an upper estimate rather than an absolute value.

In terms of toxicity, the most prevalent dioxin and furan compounds in all but two composts were 1234678-H7CDD and OCDD. Dioxin/furan congener signatures for the various composts were similar, suggesting a common contamination source. Figure 1 shows dioxin/furan congener signatures for 4 different types of compost.

When we look at differences in dioxin/furan concentrations between compost types, we observe the following trend:

Yard and garden clippings < source separated organics < mixed MSW

This suggests that residuals separated closer to the source (at the consumer level) are likely to be less contaminated, as found by Cook and Beyea (1998).

Table 2: Reported values of dioxins and furans in compost, worldwide

Source	Type of compost	N	Dioxins and furans[1] *TEQ (ng/kg)*
Schriftenreihe Umwelt 1997	**Switzerland**. Vegetable matter compost		Mean: 15 Range: 10-20
Zethner G., Götz B., Amlinger F. 2001	**Austria**. Kitchen waste and garden waste composts (urban and rural)	34	Median: 6.4 Max: 87
Krauss et al. 1994 and Fricke et al. 1996. Cited in Danish EPA, 1997.	**Germany**. Garden compost		Mean: 11
	Germany. Composted household waste		Mean: 38
Paulsrud et al, 1998.	**Norway**. Composted source separated household waste, including diapers, and kitchen waste (estimated from graph)	9	Mean: 4 Range: 1-11
Bennett, J. and Wescott, H., 2001	**USA** (Washington). Composted yard waste, biosolids, or both.	7	Mean: 21.4 Range: 4.0-39.6
Cook and Beyea, 1998 (various sources based on a literature review)	Source separated composts	21	Mean[2]: 21 Range: 1-65
	Mixed municipal solid waste composts	6	Mean: 39 Range: 18-96
AMSA 2001	**USA**. Composted municipal biosolids.	11	Mean: 41 Range: 13-113
As quoted in NEBRA 2001	Cow manure compost	4	Mean: 3.4

[1] Non-detects set to 0.5 of the detection limit. As quoted in NEBRA: original source of data uncertain, TEF scheme not-specified. Bennett and Wescott: USEPA TEFs. All other values use International TEF scheme (I-TEQ) (NATO/CCMS, 1988).
[2]Weighted arithmetic mean, by compost facility

Levels of dioxins and furans in composted mixed municipal solid waste (#8) were similar to those observed in the United States by Cook and Beyea (1998) and Germany (Danish EPA, 1997) for similar compost types.

Levels of dioxins and furans in composted municipal biosolids were much lower than those reported in the USA (AMSA, 2001; Bennett and Wescott, 2001). Composts derived from pulp and paper mill biosolids also had low levels. Some environmental activists have expressed concern that pulp and paper mill biosolids and municipal biosolids may contain high or dangerous levels of dioxins and furans (Priesnitz, 1997; Crittenden, 2002). Composting has been hypothesized to increase the amounts of dioxins and furans over the feedstock (Danish EPA, 1997), so the final compost product could potentially contain more of these contaminants than the original feedstock material. However, we found that compost made from pulp and paper mill biosolids and municipal biosolids contained insignificant amounts of dioxins and furans; in fact levels were less than those found in source separated organics.

The most surprising value occurred with the “manure compost” #14, which showed levels of dioxins and furans almost 10 times those reported by NEBRA for composted cow manure and Schriftenreihe Umwelt (1997) for solid manure and slurry (Table 2). It is difficult to draw conclusions from this single and apparently abnormal value. However the compost remains safe for use and well under both the Québec C2 limit and USEPA proposed criteria.

At two test sites, two distinct composite samples were taken from the same lot of compost, in order to evaluate the sampling and laboratory variability (composts #3 and #8, Table 3). Variability was much lower for the source separated organics than for the municipal solid wastes, for both dioxins and furans and for PCBs. However, for both test sites, we consider the variability to be acceptable.

Table 3: Compost sample variability for dioxins and furans

No.	**Dioxins and furans** *TEQ (ng/kg)*	**% variation**[1]
3a	9.8	1
3b	9.9	
8a	26.7	29
8b	35.6	

[1] % variation: absolute value of (sample a – sample b)/ mean (sample a, sample b) x 100

Polycyclic aromatic hydrocarbons (PAHs)

The European Union has undertaken an initiative to improve the management of land-applied municipal biosolids (EU, 2000). They have proposed a limit value of 6 mg/kg for PAHs in these residuals, which include sewage, septic and industrial treated sludge, as well as sludges that have been mixed with other residuals or products. The limit value refers to the sum of 9 PAHs: acenapthene, benzo(a)pyrene, benzo(b+j+k)fluoranthene, benzo(g,h,i)perylene, flouranthene, fluorene, indeno(1, 2, 3-c,d)pyrene, phenanthrene, and pyrene. However, the scientific basis for this criteria is not mentioned.

In the present study, 44 different PAH compounds were analysed, including the 9 proposed for regulation by the European Union. Levels of PAH were generally low: over 96% of all analyses were below either the detection or quantification limit. For thirteen composts, the sum of the nine compounds was well below the proposed EU limit of 6 mg/kg (Table 4). One compost, the mixed municipal solid waste compost #8, was slightly over the limit: however, given that the total is an estimate (see Table 4, note 2), this slightly elevated value is not likely to be statistically significant.

Table 4: Sum of 9 PAH compounds in eastern Canada composts (mg/kg, dry weight)

PAH compound	Compost #													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Acenaphthene	< 0.02	< 0.1	< 0.09	< 0.1	< 0.1	< 0.1	< 0.1	< 0.3	< 0.08	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
Benzo (a) pyrene	< 0.08	0.6	DNQ	< 0.1	DNQ	< 0.1	DNQ	DNQ	DNQ	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
Benzo (b,j) fluoranthene	DNQ[1]	1	0.4	DNQ	DNQ	DNQ	DNQ	DNQ	DNQ	< 0.1	< 0.08	< 0.2	DNQ	< 0.03
Benzo (g,h,i) prylene	< 0.08	0.4	DNQ	< 0.1	DNQ	< 0.1	< 0.1	DNQ	DNQ	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
Benzo (k) fluoranthene	< 0.08	0.4	DNQ	< 0.1	< 0.1	< 0.1	DNQ	< 0.3	DNQ	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
Fluoranthene	0.1	1.1	DNQ	DNQ	DNQ	DNQ	0.6	1.8	0.5	< 0.1	< 0.08	< 0.2	DNQ	< 0.03
Fluorene	< 0.02	< 0.1	< 0.09	< 0.1	< 0.1	< 0.1	< 0.1	< 0.3	< 0.08	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
Indeno (1,2,3 cd) pyrene	< 0.08	0.6	DNQ	< 0.1	DNQ	DNQ	< 0.1	DNQ	< 0.08	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
Phenanthrene	DNQ	DNQ	< 0.09	DNQ	< 0.1	< 0.1	DNQ	1.8	0.3	< 0.1	< 0.08	< 0.2	DNQ	DNQ
Pyrene	0.1	1	DNQ	DNQ	DNQ	DNQ	DNQ	1.4	0.3	< 0.1	< 0.08	< 0.2	DNQ	DNQ
Total[2]	0.5	5.3	1.1	0.7	0.8	0.7	1.3	6.6	1.5	0.5	0.4	1.0	0.7	0.2
Mean: 1.5 **Range**: 0.2 – 6.6														

[1] DNQ = Detected but not quantified.
[2] This is the estimated total. To calculate the total: Values less than the detection limit (preceded by "<" sign) set to 1/2 detection limit. DNQ values set to the detection limit. The detection limit for DNQ values was not supplied with the laboratory results: the value was estimated by averaging all the DL values for a given sample.

For detailed dioxin & furan, PCB, and PAH analysis results, see Appendices 1, 2, and 3.

Conclusions

The followings observations were made:

- The fourteen composts sampled for this study are representative of commercial composts made with domestic/urban residuals in eastern Canada.
- The maximum recorded dioxin/furan value found in this study was 31.1 ng TEQ/kg in a mixed MSW compost.
- Source separation of domestic residuals appears to strongly reduce dioxin content in composts.
- Dioxin/furan concentrations were either comparable or less than values reported for similar composts in the USA or Europe, and all were well under the risk based criteria of 300 ng TEQ/kg proposed by the USEPA (2002).
- The contribution of dioxin-like PCBs to the overall TEQ_{DFP} in compost is less than 20 %.
- In over 96% of the analyses, the measured concentrations of PAHs were below the detection limit or the quantification limit. In thirteen compost samples, concentrations of PAHs were below European Union proposed criteria, and only slightly over the limit for one compost sample.

Other factors must be taken into account when determining the necessity of a dioxin and furan criteria for compost:

- Levels of dioxins and furans in organic residuals have been decreasing over the last decades in North America and in Europe, and are expected to continue on this downward trend in the future (Bright et al., 2003; USEPA, 2000; Schriftenreihe Umwelt, 1997).
- The same is also expected for other contaminants such as PCBs, whose manufacture and use have been banned in North America since 1977 (USEPA, 2000; Canada, 2002).
- Under the USEPA (2002) proposal (which may or may not be eventually adopted), yearly monitoring would be required for municipal biosolids with a dioxin content ranging from 30 to 300 ppt TEQ; and monitoring every five years would be required in other cases (e.g. < 30 ppt TEQ).
- The main risk pathway for the human food chain is the ingestion of beef and dairy products following application of contaminated residuals to pasture or forage crops (USEPA, 2002; Rideout et al., 2002).
- In Québec, only a small proportion of the composts produced are used in agriculture, because of the availability of other cheaper organic amendments.
- A risk assessment based on 100 years use of residuals containing between 27 and 50 ng I-TEQ/kg applied at maximum agronomic rates predicts that the resulting dioxin and furan accumulation in soils would be lower than the CCME soil criteria of 4 ng I-TEQ/kg (CCME, 2001; Van Coïllie and Laquerre, 2003).
- As mixed MSW composts are expected to be higher in metals (CCME category B), this would limit the quantities applied, and thus indirectly limit the loading of dioxins and furans.

For these reasons, and in light of the data presented in this article, inclusion of dioxin as a parameter of concern in the CAN/BNQ Canadian standard or the CCME compost criteria does not appear to be justified. Following similar research, the Norwegian and Austrian authorities have made similar recommendations (Paulsrud et al.; Zethner et al., 2001). USEPA is also considering this option.

However, due to a lack of data for certain compost types, and following MENV (2002) and Zethner et al. (2001), we recommend that dioxin/furan analyses for composts made with the textile plant or tannery residuals. We also suggest banning the use of PCP contaminated wood as a compost feedstock.

We do not recommend further analysis of dioxin-like PCBs and PAHs for any type of compost, as both were low in most composts sampled, and PAHs are unlikely to accumulate in soil due to their relatively short half-life (< 180 days in soils).

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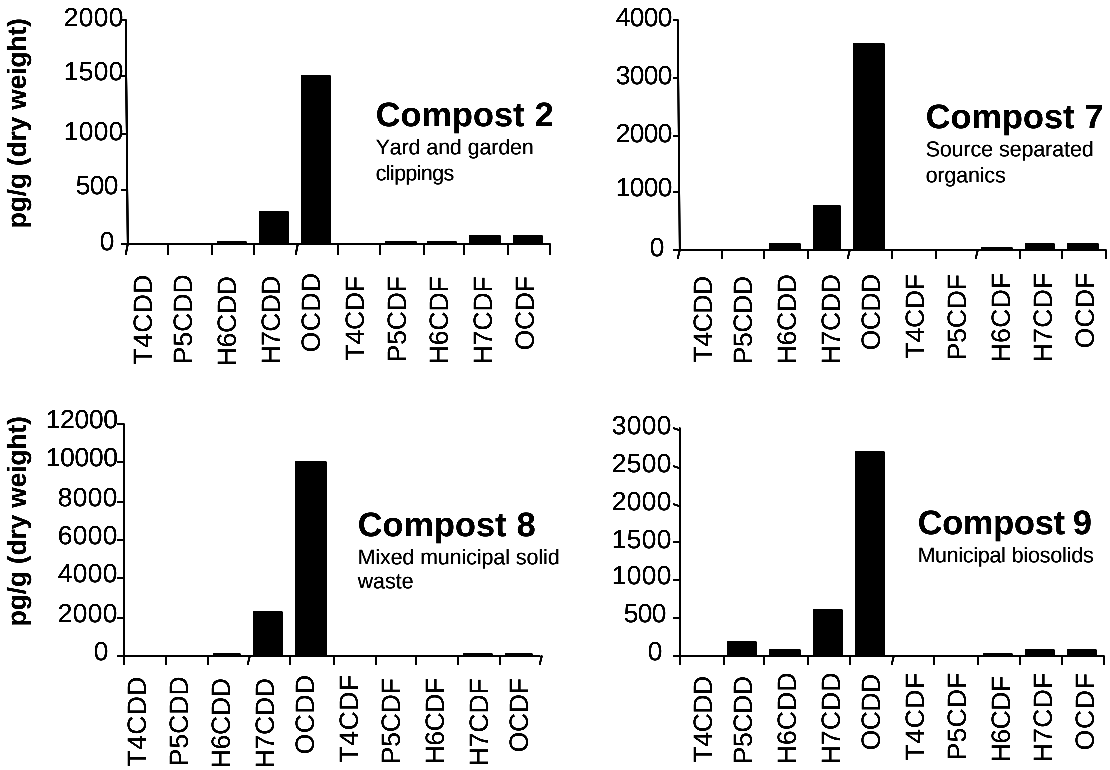

Figure 1: Comparison of dioxin/furan signatures in eastern Canada composts, by homologue group. Note that the vertical scales differ.

Appendix 1: Levels of dioxins and furans in eastern Canada composts.

Dioxins/furans	I-TEF[1]	Compost 1			Compost 2			Compost 3			Compost 4			Compost 5			Compost 6			Compost 7		
		pg/g[2]	TEQ[3]	TEQ[4]	pg/g	TEQ[3]	TEQ[4]	pg/g	TEQ[3]	TEQ[4]	pg/g	TEQ[3]	TEQ[4]	pg/g	TEQ[3]	TEQ[4]	pg/g	TEQ[3]	TEQ[4]	pg/g	TEQ[3]	TEQ[4]
2378-TCDD	1	ND	0.00	0.15	DNQ	0.00	0.04	ND	0.00	0.10	0.6	0.60	0.60	ND	0.00	0.05	ND	0.00	0.05	ND	0.00	0.05
12378-P5CDD	0.5	0.7	0.35	0.35	0.94	0.47	0.47	0.75	0.38	0.38	0.4	0.20	0.20	0.8	0.40	0.40	ND	0.00	0.05	0.7	0.35	0.35
123478-H6CDD	0.1	DNQ	0.00	0.08	1.9	0.19	0.19	2.5	0.25	0.25	ND	0.00	0.01	1.1	0.11	0.11	0.9	0.09	0.09	1.9	0.19	0.19
123678-H6CDD	0.1	3.5	0.35	0.35	5.3	0.53	0.53	6.35	0.64	0.64	8	0.80	0.80	3.8	0.38	0.38	5.5	0.55	0.55	9	0.90	0.90
123789-H6CDD	0.1	3.6	0.36	0.36	4.4	0.44	0.44	5.3	0.53	0.53	4.5	0.45	0.45	3	0.30	0.30	3.1	0.31	0.31	4.9	0.49	0.49
1234678-H7CDD	0.01	100	1.00	1.00	180	1.80	1.80	390	3.90	3.90	180	1.80	1.80	120	1.20	1.20	270	2.70	2.70	450	4.50	4.50
OCDD	0.001	880	0.88	0.88	1500	1.50	1.50	3150	3.15	3.15	1400	1.40	1.40	1400	1.40	1.40	3100	3.10	3.10	3600	3.60	3.60
2378-T4CDF	0.1	ND	0.00	0.04	1	0.10	0.10	DNQ	0.00	0.05	6.5	0.65	0.65	4.2	0.42	0.42	2	0.20	0.20	2.2	0.22	0.22
12378-P5CDF	0.05	ND	0.00	0.01	0.48	0.02	0.02	DNQ[5]	0.00	0.00	0.8	0.04	0.04	0.8	0.04	0.04	ND	0.00	0.01	0.4	0.02	0.02
23478-P5CDF	0.5	DNQ	0.00	0.10	0.5	0.25	0.25	DNQ[6]	0.00	0.04	0.4	0.20	0.20	1.9	0.95	0.95	ND	0.00	0.08	0.9	0.45	0.45
123478-H6CDF	0.1	ND	0.00	0.05	1.8	0.18	0.18	1.45	0.15	0.15	1	0.10	0.10	2.3	0.23	0.23	2.1	0.21	0.21	2.2	0.22	0.22
123678-H6CDF	0.1	DNQ	0.00	0.10	1.1	0.11	0.11	1.05	0.11	0.11	0.8	0.08	0.08	1.2	0.12	0.12	DNQ	0.00	0.04	1.1	0.11	0.11
234678-H6CDF	0.1	ND	0.00	0.05	1.7	0.17	0.17	2.15	0.22	0.22	1	0.10	0.10	2	0.20	0.20	1.6	0.16	0.16	1.7	0.17	0.17
123789-H6CDF	0.1	ND	0.00	0.05	ND	0.00	0.01	ND	0.00	0.02	DNQ	0.00	0.01	ND	0.00	0.02	ND	0.00	0.03	ND	0.00	0.01
1234678-H7CDF	0.01	16	0.16	0.16	31	0.31	0.31	25	0.25	0.25	7.5	0.08	0.08	39	0.39	0.39	28	0.28	0.28	30	0.30	0.30
1234789-H7CDF	0.01	28	0.28	0.28	1.5	0.02	0.02	DNQ	0.00	0.01	1.1	0.01	0.01	1.4	0.01	0.01	DNQ	0.00	0.01	1.7	0.02	0.02
OCDF	0.001	41	0.04	0.04	80	0.08	0.08	76	0.08	0.08	32	0.03	0.03	160	0.16	0.16	60	0.06	0.06	80	0.08	0.08
Total I-TEQ$_{DF}$		**1077**	**3.4**	**4.0**	**1812**	**6.2**	**6.2**	**3662**	**9.6**	**9.8**	**1645**	**6.5**	**6.6**	**1742**	**6.3**	**6.4**	**3475**	**7.7**	**7.9**	**4187**	**11.6**	**11.7**

Dioxins/furans	I-TEF[1]	Compost 8			Compost 9			Compost 10			Compost 11			Compost 12			Compost 13			Compost 14		
		pg/g	TEQ[3]	TEQ[4]	pg/g	TEQ[3]	TEQ[4]	pg/g	TEQ[3]	TEQ[4]	pg/g	TEQ[3]	TEQ[4]	pg/g	TEQ[3]	TEQ[4]	pg/g	TEQ[3]	TEQ[4]	pg/g	TEQ[3]	TEQ[4]
2378-TCDD	1	ND	0.00	0.10	DNQ	0.00	0.10	ND	0.00	0.05	ND	0.00	0.15	ND	0.00	0.05	ND	0.00	0.01	ND	0.00	0.05
12378-P5CDD	0.5	1.65	0.83	0.83	2	1.00	1.00	0.4	0.20	0.20	ND	0.00	0.03	ND	0.00	0.03	0.62	0.31	0.31	NDR	0.00	0.03
123478-H6CDD	0.1	2.95	0.30	0.30	2.3	0.23	0.23	ND	0.00	0.01	DNQ	0.00	0.04	ND	0.00	0.01	0.63	0.06	0.06	1.9	0.19	0.19
123678-H6CDD	0.1	17.5	1.75	1.75	11	1.10	1.10	2.1	0.21	0.21	2	0.20	0.20	0.5	0.05	0.05	3.3	0.33	0.33	18	1.80	1.80
123789-H6CDD	0.1	9.35	0.94	0.94	7.5	0.75	0.75	1.1	0.11	0.11	1.2	0.12	0.12	0.4	0.04	0.04	2.1	0.21	0.21	6.3	0.63	0.63
1234678-H7CDD	0.01	1300	13.00	13.00	420	4.20	4.20	41	0.41	0.41	57	0.57	0.57	12	0.12	0.12	150	1.50	1.50	1300	13.00	13.00
OCDD	0.001	10000	10.00	10.00	2700	2.70	2.70	440	0.44	0.44	540	0.54	0.54	49	0.05	0.05	1400	1.40	1.40	10000	10.00	10.00
2378-T4CDF	0.1	8.1	0.81	0.81	2.9	0.29	0.29	4.8	0.48	0.48	DNQ	0.00	0.05	5.9	0.59	0.59	3.5	0.35	0.35	DNQ	0.00	0.02
12378-P5CDF	0.05	1.55	0.08	0.08	DNQ	0.00	0.03	0.5	0.03	0.03	ND	0.00	0.00	ND	0.00	0.01	NDR	0.00	0.00	0.3	0.02	0.02
23478-P5CDF	0.5	3.4	1.70	1.70	DNQ	0.00	0.25	0.6	0.30	0.30	ND	0.00	0.03	DNQ	0.00	0.05	0.39	0.20	0.20	DNQ	0.00	0.05
123478-H6CDF	0.1	7.15	0.72	0.72	2.9	0.29	0.29	0.7	0.07	0.07	0.8	0.08	0.08	ND	0.00	0.01	1.2	0.12	0.12	2.7	0.27	0.27
123678-H6CDF	0.1	2.5	0.25	0.25	1.7	0.17	0.17	0.5	0.05	0.05	DNQ	0.00	0.02	ND	0.00	0.01	DNQ	0.00	0.03	1.6	0.16	0.16
234678-H6CDF	0.1	4.1	0.41	0.41	2.7	0.27	0.27	NDR	0.00	0.01	0.7	0.07	0.07	ND	0.00	0.01	1.1	0.11	0.11	2.2	0.22	0.22
123789-H6CDF	0.1	ND	0.00	0.03	ND	0.00	0.01	ND	0.00	0.01	ND	0.00	0.01	ND	0.00	0.01	ND	0.00	0.02	ND	0.00	0.03
1234678-H7CDF	0.01	NDR	0.00	0.02	50	0.50	0.50	ND	0.00	0.00	ND	0.00	0.00	ND	0.00	0.00	20	0.20	0.20	69	0.69	0.69
1234789-H7CDF	0.01	ND	0.00	0.03	1.7	0.02	0.02	ND	0.00	0.00	ND	0.00	0.00	ND	0.00	0.00	1.1	0.01	0.01	3.2	0.03	0.03
OCDF	0.001	195	0.20	0.20	75	0.08	0.08	25	0.03	0.03	15	0.02	0.02	2.1	0.00	0.00	88	0.09	0.09	50	0.05	0.05
Total I-TEQ$_{DF}$		**11559**	**31.0**	**31.1**	**3281**	**11.6**	**12.0**	**517**	**2.3**	**2.4**	**619**	**1.6**	**1.9**	**71**	**0.9**	**1.0**	**1672**	**4.9**	**4.9**	**11456**	**27.1**	**27.2**

1) I-TEF. NATO/CCMS 1988. ND = non-detected. DNQ = detected but not quantified. NDR = detected but did not satisfy the isotopic report. **2)** Concentration, pg/g dry weight. For column totals, ND and NDR set to ½ DL, DNQ = DL. **3)** I-TEQ. ND, DNQ, NDR set to zero. **4)** I-TEQ. ND, NDR = 1/2 DL, DNQ = DL. **5)** Sample 3: Data show average of two samples. Sample a = NDR, sample B = DNQ **6)** Data shows average of two samples. Sample a = DNQ, sample B = ND

Appendix 2: Dioxin-like polychlorinated biphenyls in eastern Canada composts (pg/g, dry weight)

Congener		Compost #													
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Tetrachlorobiphenyls	IUPAC # 77	120	22	47.5	33	480	210	230	1500	360	54	160	34	540	26
Tetrachlorobiphenyls	IUPAC # 81	31	ND	7	ND	28	DNQ	ND	160	DNQ	DNQ	DNQ	ND	ND	DNQ
Pentachlorobiphenyls	IUPAC # 105	1500	250	370	220	1700	890	1300	4700	3000	700	1000	180	2300	100
Pentachlorobiphenyls	IUPAC # 114, #122	DNQ[1]	9	DNQ	DNQ	170	DNQ	DNQ	DNQ	260	28	39	9.8	200	DNQ
Pentachlorobiphenyls	IUPAC # 118, # 123	3600	560	855	540	3600	2000	3000	9250	7400	1700	2400	420	5100	230
Pentachlorobiphenyls	IUPAC # 126	ND[2]	3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Hexachlorobiphenyls	IUPAC # 156	390	66	145	69	310	300	440	1300	1000	200	360	38	570	22
Hexachlorobiphenyls	IUPAC # 157	81	14	30	13	64	55	84	225	200	38	75	7.1	110	4.3
Hexachlorobiphenyls	IUPAC # 167	120	26	49.5	14	71	71	88	420	220	65	100	12	130	8.9
Hexachlorobiphenyls	IUPAC # 169	ND	ND	ND	ND	ND	DNQ	ND	ND	ND	ND	ND	ND	ND	ND
Heptachlorobiphenyls	IUPAC # 170	330	110	205	210	500	540	590	2700	1500	290	450	64	1100	50
Heptachlorobiphenyls	IUPAC # 180	580	290	580	550	1300	1100	1500	7200	4200	880	1100	220	2500	120
Heptachlorobiphenyls	IUPAC # 189	11	3.7	8.4	5.9	15	19	22	84.5	54	9.6	16	2.3	31	1.6

[1] DNQ = detected but not quantified

[2] ND = non-detected

Appendix 3: Polycyclic aromatic hydrocarbons in eastern Canada composts (mg/kg, dry weight)

Compound	Compost #													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Acenaphthene	< 0.02	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.3	< 0.08	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
Acenaphthylene	< 0.02	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.3	< 0.08	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
Anthanthrene	< 0.08	DNQ	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.3	< 0.08	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
Anthracene	< 0.02	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.3	< 0.08	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
Benzo(a)anthracene	< 0.08	DNQ	< 0.1	< 0.1	DNQ	< 0.1	DNQ	DNQ	0.3	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
Benzo(a)pyrene	< 0.08	0.6	DNQ	< 0.1	DNQ	< 0.1	DNQ	DNQ	DNQ	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
Benzo(b,j)fluoranthene	DNQ	1	0.2	DNQ	DNQ	DNQ	DNQ	DNQ	DNQ	< 0.1	< 0.08	< 0.2	DNQ	< 0.03
Benzo(e)pyrene	< 0.08	0.6	DNQ	< 0.1	DNQ	< 0.1	DNQ	DNQ	DNQ	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
Benzo(g,h,i)perylene	< 0.08	0.4	DNQ	< 0.1	DNQ	< 0.1	< 0.1	DNQ	DNQ	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
Benzo(k)fluoranthene	< 0.08	0.4	< 0.1	< 0.1	< 0.1	< 0.1	DNQ	< 0.3	DNQ	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
Benzo(c)acridine	< 0.08	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.3	< 0.08	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
Benzo(c)phenanthrene	< 0.08	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.3	< 0.08	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
Carbazole	< 0.02	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.3	DNQ	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
1-Chloronaphthalene	< 0.02	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.3	< 0.08	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
2-Chloronaphthalene	< 0.02	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.3	< 0.08	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
Chrysene	< 0.08	0.8	DNQ	< 0.1	DNQ	DNQ	DNQ	DNQ	DNQ	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
Coronene	< 0.08	DNQ	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.3	< 0.08	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
Dibenzo(a,c)+(a,h)anthracene	< 0.08	DNQ	< 0.1	< 0.1	< 0.1	< 0.1	DNQ	< 0.3	< 0.08	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
7H-Dibenzo (c,g) carbazol	< 0.08	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.3	< 0.08	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
Dibenzo(a,e)fluoranthene	< 0.08	DNQ	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.3	< 0.08	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
Dibenzo(a,e)pyrene	< 0.08	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.3	< 0.08	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
Dibenzo(a,h)acridine	< 0.08	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.3	< 0.08	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
Dibenzo(a,h)pyrene	< 0.08	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.3	< 0.08	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
Dibenzo(a,i)pyrene	< 0.08	DNQ	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.3	< 0.08	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
Dibenzo(a,j)anthracene	< 0.08	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.3	< 0.08	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
Dibenzo(a,l)pyrene	< 0.08	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.3	< 0.08	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
7,12-Dimethylbenzo(a)anthracene	< 0.08	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.3	< 0.08	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
1,3-Dimethylnaphthalene	< 0.02	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.3	DNQ	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
Fluoranthene	0.08	1.1	< 0.1	DNQ	DNQ	DNQ	0.6	1.8	0.5	< 0.1	< 0.08	< 0.2	DNQ	< 0.03
Fluorene	< 0.02	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.3	< 0.08	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
Indeno(1,2,3-cd)pyrene	< 0.08	0.6	DNQ	< 0.1	DNQ	DNQ	< 0.1	DNQ	< 0.08	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
2-Methyl chrysene	< 0.08	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.3	< 0.08	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
3-Methyl chrysene	< 0.08	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.3	< 0.08	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
4+5+6-Methyl chrysene	< 0.08	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.3	< 0.08	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
2-Methyl fluoranthene	< 0.02	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.3	< 0.08	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
3-Methylcholanthrene	< 0.2	< 0.2	< 0.2	< 0.3	< 0.3	< 0.2	< 0.3	< 0.6	< 0.2	< 0.2	< 0.2	< 0.3	< 0.3	< 0.06
1-Methylnaphthalene	< 0.02	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.3	< 0.08	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
2-Methylnaphthalene	< 0.02	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.3	< 0.08	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
Naphthalene	< 0.02	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	DNQ	< 0.08	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
1-Nitropyrene	< 0.3	< 0.4	< 0.4	< 0.6	< 0.6	< 0.4	< 0.6	< 0.9	< 0.3	< 0.5	< 0.3	< 0.6	< 0.6	< 0.09
Perylene	< 0.08	DNQ	< 0.1	< 0.1	< 0.1	< 0.1		< 0.3	< 0.08	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03
Phenanthrene	DNQ	DNQ	< 0.1	DNQ	< 0.1	< 0.1	DNQ	1.8	0.3	< 0.1	< 0.08	< 0.2	DNQ	DNQ
Pyrene	0.07	1	< 0.1	DNQ	DNQ	DNQ	DNQ	1.4	0.3	< 0.1	< 0.08	< 0.2	DNQ	DNQ
2,3,5-Trimethylnaphthalene	< 0.02	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.3	DNQ	< 0.1	< 0.08	< 0.2	< 0.1	< 0.03

[1] DNQ = Detected but not quantified. Values preceded by "<" sign are under the detection limit.