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## Hazard to man and the environment posed by the use of urban waste compost: a review

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### Abstract

This review presents the current state of knowledge on the relationship between the environment and the use of municipal waste compost in terms of health risk assessment. The hazards stem from chemical and microbiological agents whose nature and magnitude depend heavily on the degree of sorting and on the composting methods. Three main routes of exposure can be determined and are quantified in the literature: (i) The ingestion of soil/compost mixtures by children, mostly in cases of pica, can be a threat because of the amount of lead, chromium, cadmium, PCDD/F and fecal streptococci that can be absorbed. (ii) Though concern about contamination through the food chain is weak when compost is used in agriculture, some authors anticipate accumulation of pollutants after several years of disposal, which might lead to future hazards. (iii) Exposure is also associated with atmospheric dispersion of compost organic dust that convey microorganisms and toxicants. Data on hazard posed by organic dust from municipal composts to the farmer or the private user is scarce. To date, microorganisms are only measured at composting plants, thus raising the issue of extrapolation to environmental situations. Lung damage and allergies may occur because of organic dust, Gram negative bacteria, actinomycetes and fungi. Further research is needed on the risk related to inhalation of chemical compounds.

**Keywords:** Municipal wastes; Compost; Organic pollutants; Inorganic pollutants; Microorganisms; Ingestion; Food chain; Inhalation

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### Résumé

Cette revue tend à évaluer les relations entre l'environnement et l'utilisation des composts urbains en terme d'évaluation des risques pour la santé. Les dangers concernent des agents chimiques et microbiologiques dont la

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nature et la teneur dans les composts sont dépendantes du tri préalable des ordures et de la méthode de compostage. On a pu qualifier et quantifier trois principales voies d'exposition: (i) L'ingestion directe de mélange sol/compost représente un risque pour les enfants, notamment en cas de pica, dû aux concentrations des composts en plomb, en chrome, en cadmium, en PCDD/F et en streptocoques fécaux. (ii) Lors de l'utilisation agricole, la transmission des polluants par la chaîne alimentaire est faible, mais certains auteurs ont envisagé des dangers futurs par l'accumulation des polluants dans les sols, suite à un amendement répété. (iii) Une exposition atmosphérique existe par la dispersion dans l'air de poussières organiques des composts, véhiculant des microorganismes et des toxiques. Les données recueillies sur le terrain évaluant le danger pour les utilisateurs (fermier ou utilisateur privé) sont rares. Actuellement les microorganismes ont été essentiellement mesurés sur le site de compostage ne permettant qu'une extrapolation discutable aux situations environnementales. Des affections pulmonaires et des allergies peuvent être dues aux poussières organiques, aux bactéries Gram<sup>+</sup>, aux actinomycètes et aux champignons. D'autres recherches sont nécessaires pour évaluer les risques liés à l'inhalation des composés chimiques.

*Mots-clés:* Déchets urbains; Compost; Polluants organiques; Polluants inorganiques; Microorganismes; Ingestion; Chaîne alimentaire; Inhalation

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## 1. Introduction

In the management of household wastes, the sorting-composting approach presents many advantages: (i) Sorting not only provides for the selection of recyclable and compostable materials, it also reduces the volume of waste to be treated by incineration. Hence, the putrefiable part represents 50–70% of the weight of the entire municipal solid waste (MSW) [1,2]. (ii) The volume of the putrefiable portion will be reduced during the composting process. (iii) Compost is widely utilized in agriculture, especially in Europe [3] and its use is also strongly encouraged in the USA [4–6]. Depending on its degree of maturity and quality, it can be used in vine yards, for mushroom farming (fresh compost), in horticulture (hot-beds with fresh compost), silviculture, country-side planning (flower beds), preparation of sports fields, or golf courses, maintenance of public or private parks, maintenance of motor-way embankments to cover waste discharge systems, or in the rehabilitation of sites such as mines and sand pits [7–12]. The chemical components play important roles in the physical and chemical properties of the soil [13,14]. Amendment is more interesting for the improvement of soil characteristics than for the fertilizer value of the compost [15]. Indeed, the use of municipal solid waste (MSW) influences the water retention capacity, resistance to erosion, density, pH, conductivity and the nutrient content of the soil [15,16].

There are three main methods for composting: gathering of waste in windrows that are turned at regular intervals, static piles of waste that are aerated by deliberate passage of air within the mass (aerated static piles), and finally by gathering waste materials in a totally enclosed and controlled environment, that is, in a reactor [2,17–20].

Many organic waste products are used for compost: yard wastes (YW), sewage sludge (SS), municipal solid wastes (MSW), industrial and agricultural (wood, animal droppings, etc.) [21]. In the present work, we have only studied domestic waste in single composts or accompanied with SS or YW.

The compost is not a harmless product; MSW may contain a number of contaminants with health or environmental risks. These chemical or biological contaminants may expose different populations to health hazards, ranging from the composting plant workers to the consumer of vegetable products treated with compost fertilizers. For example, the humus part of composts consists of numerous ligands, some of which are more or less irreversibly bound to metallic elements [22]. The metals may be released in the soil, when a change in environmental conditions such as pH occurs during application of the compost [23]; released metals then become bioavailable for plants. Among the toxic elements found in composts, arsenic, asbestos, hexavalent

chromium, nickel or PCB have been classified as carcinogens or potential carcinogens [24]. Finally, composts could be potentially hazardous through the presence of microorganisms [25].

In France, out of 20 500 000 tons of MSW per year, 7% (1 435 000 t) are treated and transformed into 640 000 tons of compost [26]. Due to the diversity of the populations exposed to the use of compost, the huge mass of products involved, and the potential risk of contamination, it is interesting to evaluate the public health and environmental risks arising from the utilization of compost originating from MSW. Based on literature surveys, the state of present knowledge with regard to the type and the quantity of contaminants is discussed. The different populations at risk through various routes of contamination are also discussed.

## 2. Method

In the preparation of this review, various comparable literature data on MSW from Europe, North America and Japan were collected [27,28]. All the articles were selected on composts of MSW origin. On account of the similarity of the problems encountered, our literature review also covered compost made from sediment wastes from water treatment stations and green wastes (gardens, parks, forests, etc.). For the same reasons, some articles that treated non-composted SS were considered.

## 3. Qualitative results

### 3.1. Contamination of composts

The quality of a compost determines its sales [29] and a hazard-free utilization, which may be viewed from two points: the agronomic value and the absence of contaminants. Many authors have written on the agronomic quality of composts [1,30–34].

The contamination of the finished product may come from the primary material, that is, essentially from the content of our garbage bins as well as other composted wastes (YW or SS). Metals, for example, are provided by plastics (pigments

and stabilizers), batteries (torch and radio), car batteries, electronic components, electric bulbs and their sockets, leather materials, glassware or ceramics [28,35,36]. Asbestos is found in household refuse because of insulation materials [37]. A number of organic compounds (solvents, grease, pesticides, etc.) find their way into our garbage bins as residues. These are also found in YW (lindane, PCB, PCDD, PCDF), and in SS (PAH, pesticides, halogenated hydrocarbons, phthalates, esters, PCB) [38–43].

Sorting of MSW is increasingly used and has proved to be very effective in reducing the contamination of the finished product. Mercury, lead, chromium, cadmium, zinc and copper are mostly derived from batteries, glassware, plastics and ferrous materials. Elimination of these recyclable components before making the compost leaves not more than 50% of lead and copper, 25–30% of zinc and nickel, which persists in papers/cardboards and is more or less strongly bound to organic materials [27]. Sorting may be carried out at the source by the producer or at the waste disposal plant, implemented manually or automatically by special machines, especially in the case of small amounts of plastics and metals, or after composting [18,31,44–46]. Early sorting ensures lower contamination with organic and inorganic pollutants [28,44,47].

Biological contamination is also encountered in MSW. Pathogenic microorganisms are likely to come from dirty discarded cloth, faeces of domestic animals, sanitary tissue papers or putrefying foods [25,48]. As a result of their origin, contamination exists in SS where one can easily find many strains of bacteria, viruses, fungi and other parasites (Table 1) [49].

The composting procedure is very important. The parameters that must be controlled during this process are: the composition of the mass, aeration, temperature, humidity, carbon/nitrogen (C/N) ratio and pH. Some components such as keratinous wastes, papers and cardboards are not easily composted [50]. Depending on the method of compost formation that is chosen, the parameters may be controlled to a reasonable extent [50–52]. Anaerobic conditions may provoke an increase in the duration of composting and, more

Table 1

Pathogens that may be found in sewage sludge and in municipal solid wastes.(49, 80, 110, 122, 124)

<b>Virus</b>	<b>Bacteria</b>	<b>Fungi</b>
Enterovirus	<i>Arisona hinshawii</i>	<i>Aspergillus fumigatus</i>
Poliovirus	<i>Aeromonas</i> sp	<i>Candida albicans</i>
Coxsachivirus	<i>Bacillus anthracis</i>	<i>C. guilliermondii</i>
Echovirus	<i>Bacillus cereus</i>	<i>C. krusei</i>
Myxovirus	<i>Brucella</i> sp	<i>C. tropicalis</i>
Adenovirus	<i>Campylobacter perfringens</i>	<i>Cryptococcus neoformans</i>
Astrovirus	<i>Campylobacter jejuni</i>	<i>Epidermophyton</i> sp.
Calicivirus	<i>Citobacter</i> sp	<i>Geotrichum candidum</i>
Coronavirus	<i>Clostridium botulinum</i>	<i>Microsporium</i> sp
Parvovirus	<i>Enterobacteriaceae</i>	<i>Phialophora richardsii</i>
Reovirus	<i>Escherichia coli</i>	<i>Trichosporon cutaneum</i>
Rotavirus	<i>Klebsiella</i> sp	<i>Tricophyton</i> sp
Norwalk virus	<i>Leptospira icterohaemorrhagiae</i>	
Hépatitis A virus	<i>Listeria monocytogenes</i>	<b>Helminthes</b>
Hépatitis E virus	<i>Mycobacterium tuberculosis</i>	<i>Ankylostoma duodenale</i>
	<i>Pasteurella pseudotuberculosis</i>	<i>Ascaris lumbricoides</i>
	<i>Proteus</i> sp	<i>Echinococcus granulosus</i>
<b>Protozoa</b>	<i>Providencia</i> sp	<i>Echinococcus multilocularis</i>
<i>Acanthamoeba</i>	<i>Pseudomonas aeruginosa</i>	<i>Enterobium vermicularis</i>
<i>Dientamoeba fragilis</i>	<i>Salmonella</i> spp	<i>Hymenolepis nana lumbricoides</i>
<i>Entamoeba histolytica</i>	<i>Serratia</i> sp	<i>Necator americanus</i>
<i>Giardia intestinalis</i>	<i>Shigella</i> spp	<i>Strongyloides stercoralis</i>
<i>Giardia lamblia</i>	<i>Staphylococcus aureus</i>	<i>Taenia solium</i>
<i>Isopora belli</i>	<i>Streptococcus</i> spp	<i>Taenia saginata</i>
<i>Naegleria fowleri</i>	<i>Vibrio parahaemoliticus</i>	<i>Toxocara cati</i>
<i>Palantidium coli</i>	<i>Vibrio cholerae</i>	<i>Toxocara canis</i>
<i>Sarcocystis</i> spp	<i>Yersinia enterocolica</i>	<i>Trichuris trichura</i>
<i>Toxoplasma gondii</i>		

importantly, an adverse sanitary condition if the temperature conditions are not fulfilled. A hygienic compost is free of the pathogens that it might have contained. There is an inherent risk in the use of unhygienic composts [8,53–56]. It is possible to disinfect them by monitoring the temperature during composting.

As can be seen in Table 2, the destruction of the pathogens depends on the temperature reached and the duration of the oxidation process. Temperatures of about 55–60°C for at least 3 days are recommended [50,57,58]. This has proved effective against *Salmonella* spp. and other parasites [59,60]. Unfortunately, these conditions are

Table 2

Level of temperature and length of time necessary to destroy some pathogens present in primary products of composts (180).

Organisms	Lethal temperature and necessary time
<i>Salmonella</i> spp	15–20 min at 60°C; 1 h at 55°C
<i>Escherichia coli</i>	15–20 min at 60°C; 1 h at 55°C
<i>Entamoeba histolytica</i>	68°C; time not given
<i>Taenia saginata</i>	5 min at 71°C
<i>Necator americanus</i>	50 min at 45°C
<i>Shigella</i> spp	1 h at 55°C

Note: the typical range of composting temperature is 55–65°C

not always fulfilled because temperature is dependent upon the degree of oxidation of the entire mass of compost. Control of temperature and aeration is not possible for the entire mass of wastes windrow composting. The compost is therefore not always disinfected by this method. The use of windrow presents, in addition, the risk of contaminating clean areas with unclean wastes from other parts of the heap infected during turning [31,51,61,62]. It should be noted however that these pathogens are not in their natural environment, that is, in their hosts. This does not favor their survival. If fungi and bacteria strains have the possibility to multiply, viruses and other parasites can at best acquire a form of resistance. The pathogens are forced to compete with other microorganisms which are in their natural environment. These are mostly bacterial strains at the beginning of the composting process, but turn to fungi and actinomycetes by the end, as a result of selection pressure due to increased temperature [61,63].

The method of composting permits both improvement of the hygienic conditions of the compost and promotes chemical decontamination. During the degradation of the primary wastes, the chemical contaminants are often implicated in the process of transformation. This is supported by laboratory results which show that chlorpyrifos, isofenphos, diazinon (insecticides) and pendimethalin (herbicide) found in plant wastes are totally degraded by composting [64]. Other studies have reported a degradation of 6% of chlorinated pesticides and 45% of PCB [38]. The phenomenon is widespread and it has been tried for the rehabilitation of soils by composting [65]. Only pollution by organic wastes can be treated by this approach. By contrast, mineral contaminants tend to concentrate during composting by reduction in volume.

The process used must encourage a good maturity of compost. Maturity refers to the degree of biological, chemical and physical stability of the compost. It can be measured in several ways [11,66–74]. There is a meeting point between the two terms maturity and stability. While maturity defines such aspects of the compost like color, friability and odor, stability on the other hand is

based on all the physical, chemical and biological evaluations [74]. The use of an immature compost may present an agronomic problem since it may become toxic to plants [11,63]. The degradation of the wastes continues in the soil after application of the compost, with several toxic intermediate metabolites being present, such as phenols, ammonia, acetic, propionic, butyric and isobutyric acids [32,75].

On the other hand, when immature composts are used, the risks inherent in increasing soil temperature, the competition between plants and microorganisms for available soil nitrogen and a reduction in the level of soil oxygen are equally important unfavorable factors for plant growth. The maturity of compost is also important because of its ability to create nuisance when used. The decomposition of immature compost is completed in the soil under anaerobic conditions, resulting in odor [63]. Furthermore, the bioavailability of heavy metals is a function of the degree of maturity of the compost, since the humic material is capable of binding them. Experiments have shown that metals become less bioavailable with increasing maturity. This condition, in turn, limits the risk of spreading and hence contamination of the food chain (via plants) and the entire environment [72,76–79].

The parameters discussed above are controlled and described differently in laboratory experiments or when field measurements are taken, making a summary of such diverse data difficult. The quantitative data that have been considered in this review are the highest and the lowest values encountered in composts and not averages, since there is a wide variability between data from each article. In addition, the values of the parameters that determine the level of contamination in each compost are not always described in each article.

### 3.2. *Routes of contamination and population at risk*

Man and his environment are exposed to contaminants from composts during processing, storage and utilization. Fig. 1 summarises the different means of contamination and their risk implication. There is limited literature data on

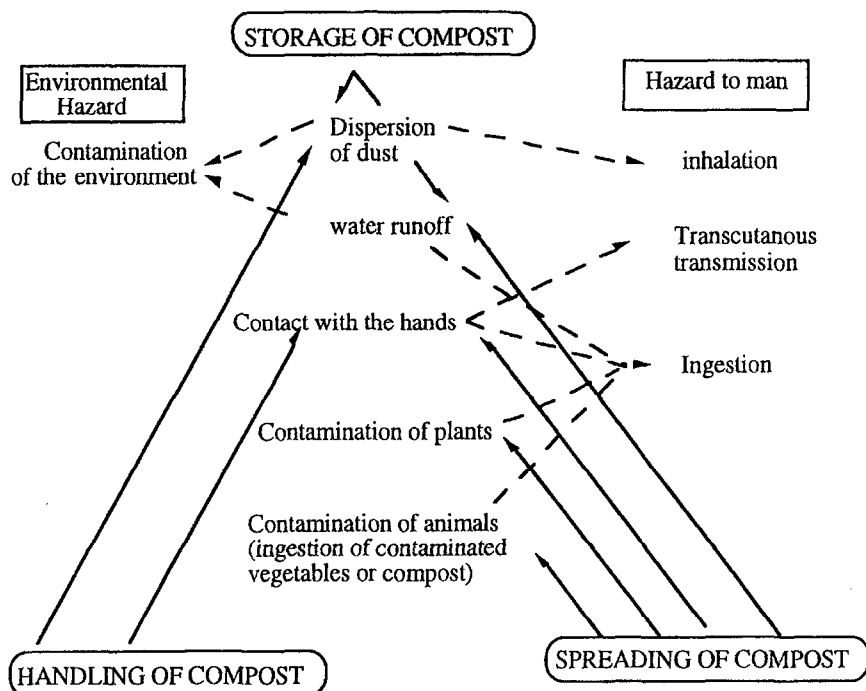


Fig. 1. Theoretical pathways of contamination and population at risk during production and utilization of municipal composts (adapted from [80,81]).

routes of contamination and on the populations at risk.

**Storage of compost.** Oral contamination through contaminated hands is possible for biological and chemical contaminants. This risk is particularly pronounced for children. Studies have shown that a child may ingest as much as 100 mg/day of dust from the soil, and when the child suffers from geophagy — or pica — (pathologic exaggeration of the hand-mouth behaviour) this may increase up to 5 g [82,83]. Environmental contamination may result from open air storage of compost or under bad or inadequate protection which exposes it to rain. Pollutants are then washed by rain and carried along by water run-off or spread by percolation into the soil. Wind may also disperse inadequately stored composts. The storage of immature compost also provokes the emanation of a nauseating odor.

**Application.** The applicator may be wounded if sharp objects are left in the compost. Compost generates dusts and many particles are suspended in the air during spreading. Their inhalation may

be dangerous to health since they adsorb both biological and chemical contaminants. Dispersion of these dusts and their components in the ecosystem may also constitute an environmental risk.

**Spread compost.** Composts add chemical or biological pollutants to the soil. These pollutants exist either in a free state or are bound to humus components of the soil. The free chemical contaminants are said to be bioavailable and may be assimilated by plants. There is therefore a potential risk of contamination of the food chain through plants cultivated on such soils and to animals which are fed with these plants as well as to their predators. The external parts of plants are in contact with treated soil. A consumer who does not wash or peel edible materials is thus exposed to the risk of either chemical or biological contamination. The consumption of animals fed with such plants might lead to hazard. Under this condition, meat transmits essentially chemical contaminants and parasites.

From a different point of view, the free chemi-

cal and biological contaminants may be washed along by flowing water or rain and may percolate down to groundwaters. This is a means of dispersion in the environment and a threat to man if these infiltrations reach groundwater used as drinking water.

#### 4. Quantitative results

##### 4.1. Chemical risk

The concentration of contaminants in composts, their bioavailability, the recovery rate in plants cultivated on compost-treated soils and in compost sewage systems will now be described.

Bioavailability of contaminants may be evaluated in different ways using different agents for extraction or binders. Bioavailability is calculated from the ratio of the weight of the extract and the quantity of the compound in the compost or treated soil. This knowledge helps in the estimation of the free fraction of metals that may be assimilated by plants or capable of contaminating water bodies or soils.

Odor resulting from soil treatment with immature compost will not be dealt with here because of the very limited amount of research done in this area [63,84].

##### 4.1.1. Inorganic compounds

Only a certain number of compounds selected according to their known toxicity will be discussed in the following section. Their general characteristics as well as those of other contaminants are presented in Table 3.

**Cadmium.** The amount in compost ranges from 0.26 ppm to 11.7 ppm (Fig. 2, graph A) (unless otherwise stated, all data are in dry weights), although the minimum level is much lower, since about 10 observations did not reach the detection level with the analytical method used [85,86]. Although there is no statistical difference in the quantity of cadmium in compost of diverse origins ( $P = 0.57$ ), uncomposted sewage sludge contains higher levels (5–2450 ppm) [87–89]. Bioavailability varies from about 0 to 52% (Fig. 2, graph A). The results depend on the pH of the soil from which the samples come from (respectively 8.1

[77] and 5.2 [94]). Bioavailability is much higher in respect of uncomposted sewage sludge and may reach 92% in the case of highly contaminated sewage [90]. Studies on leachates have shown that a liter of leachates collected from compost made up of a mixture of MSW and SS contains 0.17 mg of Cd [91], while SS composted alone gives about 0.1–0.014 mg/l [92]. For the record, the acceptable maximum concentration of Cd in potable water in France is 5  $\mu\text{g/l}$ . One does not detect it in leachates originating from compost constituted from plant materials [86].

Several authors have considered the assimilation of Cd by plants as a result of treatment of soils with compost [88,93–95]; Cd content of 1.75 ppm was therefore found in beetroot [93]. A Cd range from 0.5 ppm to 1.7 ppm was found in beetroot cultivated on soils treated with SS composts or YW. Table 4 indicates that assimilation depends on the plant and the level of metals in the soils. Similar results have been obtained in other studies carried out in fields treated with uncomposted SS. One month after planting, tobacco plants assimilated 7–10% of Cd present in the soil while maize took in only 5% [88]. The effects are long lasting. For example, on a soil treated for 7 years, 0.9–32 ppm Cd was observed in beetroot several years after treatment was stopped [95]. A concentration of 50–70 ppm was found in the leaves of maize 14 years after a treatment with SS was stopped [88].

**Lead.** The levels of lead in compost of MSW range from 10.6 ppm to 13 212 ppm (Fig. 2, graph B) with a statistically significant difference between composts made partially or completely of MSW and those without MSW ( $P = 10^{-5}$ ). The latter contains much lower levels of Pb. This may attain 200–20 000 ppm in non-composted sewage sludge [28,87–89]. Its bioavailability is from 4.1% to 75.4% (Fig. 2, graph B). These two extreme values have been measured in two mixtures of soil/compost of urban wastes. The methods of extraction were similar but the pH of both soils was very different. The lowest bioavailability was measured in a soil of pH 8.1 [77] while that of pH 5.2 [94] gave a very high bioavailability value. The release of Pb in SS is known to be low [96]. Experiments carried out with lysimeters gave con-



Table 3  
Literature dealing with 14 compounds present in urban compost(\*: when a difference in concentration due to the origin of the compost. Only the MSW compost value are given)

Compounds	Results obtained from literature on compost				General literature on metals				References
	Concentration	Bioavailability %	Present in plants	Present in leachates	Quantity in natural environment		Necessary for life	Adult daily intakes (mg)	
					Earth crust	Sea water			
Ag	12 ppm	—	no	no	0.1 ppm	0.15 ppb	no	0.1	166,167
Al	2–20%*	—	no	no	8%	3–2400 ppb	no	45	86,85,166–168
As	7–9 ppm	—	no	no	2 ppm	5 ppb	?	0.2–1	27,102
B	27.4–81.3 ppm*	—	no	yes	—	—	no	1.3	85,86,88,98,167,168,269
Ba	39 ppm	—	no	no	450 ppm	0.03 ppm	no	0.2	166
Cd	0.26–11.7 ppm	near 0–52	yes	yes	0.05 ppm	0.3 ppb	no	0.050	86,88,91–95,167
Co	1.5–9.6 ppm	1.5–7.7	no	no	22 ppm	0.1 ppb	yes	0.06–0.1	85,86,101,168,167
Cr	8.4–403 ppm	0.2–37.3	yes	no	200 ppm	1–2.5 ppb	yes	—	3,10,28,76,77,78,85
Cu	0.12–1143 ppm	3–81.3	yes	yes	4.5 ppm	1.25 ppb	yes	4.5	86,89,91,94,99,100–102,105,166–168,170–172
Fe	0.22–8% 16%	0.05–28.3	no	yes	5%	3.5 ppm	yes	12–15	3,28,33,77–79,85,86,88,90–92
Hg	0.9–23.3 ppm	—	no	yes	0.5 ppm	0.03 ppb	no	0.02	170–173,175
Mg	0.14–2.37%	—	no	yes	2%	0.13%	yes	24	77,79,85,86,88,91,92,101,105
Mn	125–1206 ppm	3.5–67.3	yes	yes	1000 ppm	1 ppb	yes	2–9	130,166–170,172,174
Mo	0.08–7.79 ppm*	—	no	no	1 ppm	12–16 ppb	yes	0.1–0.3	3,28,85,101,102,167,168,173
Na	0.12–1%*	—	yes	yes	2.8%	1.05%	yes	5000–15000	85,86,99,105,130,167–169
Ni	0.8–1220 ppm	1.4–67.3	yes	yes	80 ppm	2–5 ppb	yes	0.6–0.6	77,79,85,86,88,99,100,102
Pb	10.6–1312 ppm*	4.1–75%	no	yes	15 ppm	5 ppb	no	0.45	166–170,175
Se	0.1–8.8 ppm*	—	yes	no	0.09 ppm	4 ppb	yes	0.060–0.150	85,167,168,170
Ti	0.09%	—	no	no	4400 ppm	1–9 ppb	no	0.85	86,167
V	0.4–37.4 ppm	—	no	no	300 ppm	5 ppb	yes	0.002	85,137,168,170
Zn	75–2427 ppm*	1.3–60.3	yes	yes	605 ppm	9–21 ppb	yes	8–15	3,28,33,76–79,81,85–88,91,92

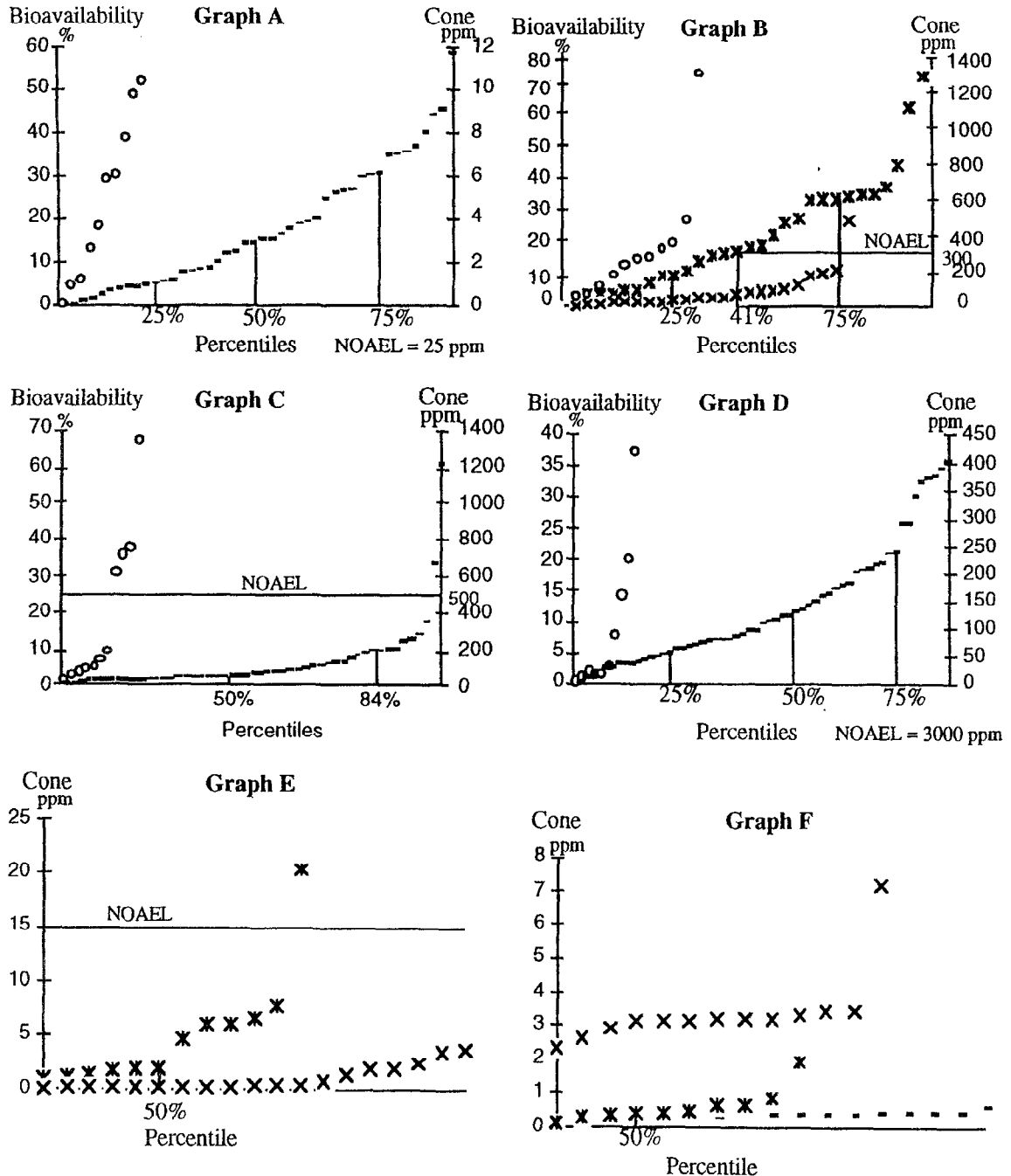


Fig. 2. Concentration and bioavailability of six metals in composts according to the origin of the composts (percentiles correspond to the distribution of MSW composts; where applicable, a NOAEL is indicated [3]). (A) Cadmium: —, concentrations in composts from all sources ( $n = 44$ ); ○, bioavailability ( $n = 9$ ). (B) Lead: \*, concentrations in MSW composts ( $n = 28$ ); ×, concentrations of composts from other sources ( $n = 23$ ); ○, bioavailability ( $n = 10$ ). (C) Nickel: —, concentrations in composts from all sources ( $n = 51$ ); ○, bioavailability ( $n = 11$ ). (D) Chromium: —, concentrations in composts from all sources ( $n = 58$ ); ○, bioavailability ( $n = 10$ ). (E) Mercury: \*, concentrations in MSW composts ( $n = 12$ ); ×, concentrations of composts from all sources ( $n = 19$ ). (F) Selenium: \*, concentrations in MSW composts ( $n = 10$ ); —, concentrations in yard waste compost ( $n = 17$ ); ×, concentrations in sewage sludge compost ( $n = 13$ ).

centrations in leachates of 15–512  $\mu\text{g}/\text{l}$  Pb for MSW [97], 0.01–0.3 mg/l for a compost from a mixture of MSW and SS [91] and 0.01 mg/l for compost formed from plant wastes [86]. None of the articles we examined dealt with the assimilation of Pb in plants cultivated in fields treated with compost from MSW, though it is known that Pb is only very slightly assimilated by plants [98].

**Nickel.** The usually observed level of nickel in composts, 0.8–1220 ppm, is only slightly dependent on the original primary materials from which the composts were formed ( $P = 0.17$ ), though the highest values are obtained in composts containing SS (Fig. 2, graph C).

The extreme values of bioavailability range from 1.4% to 58.6% (Fig. 2, graph C). The highest values was obtained with a compost of MSW and SS with soil of low pH (pH 5.7). This situation is rare since the majority of the observations do not exceed a bioavailability value of 37% [94]. Because of low rate, the methods of analysis are not effective for the detection of Ni in leachates of composts of plant wastes [86]. On the other hand, a concentration of 0.3 mg/l has been found in a compost of MSW and SS [91]. The French standard for drinking water is 50  $\mu\text{g}/\text{l}$ .

Several studies have shown the absorption of

Ni in plants, especially in vegetables, following the application of composts [81,88,94,99,100]. Values ranging from 6.8 ppm to 61.1 ppm have been found in the aerial parts of wheat [99,100] and 15.5 ppm in the entire seedling of soya. Studies on soils treated with uncomposted SS have shown that maize contains 2–17 ppm of Ni [88].

**Chromium.** The lowest (8.4 ppm) amount of chromium is found in a compost of SS [85], while the highest (403 ppm) occurs in a MSW compost [77] (Fig. 2, graph D). In spite of these observations, there is no statistical difference between compost of MSW origin and the other types ( $P = 0.56$ ). The bioavailability values are between 0.2% [101] and 37.3% [99] (Fig. 2, graph D). The latter represents an extreme value; most fall below 20%. As for other metals, this value is obtained from experiments carried out with soil at low pH (pH 5.27). Leachates of farmyard waste composts do not contain significant amounts of chromium and only 0.1 mg/l was found in mixed composts of MSW and SS [86,91]. The maximum acceptable concentration in potable water in France is 50  $\mu\text{g}/\text{l}$ .

Some authors have described the assimilation of chromium in plants cultivated on soils amended with composts [89,94,100,101]. Wheat seedlings

Table 4  
Concentration (ppm) of metals in various plants according to dilution of compost in the soil [94]

	Cd	Cr	Cu	Ni	Zn
Substrate					
100% compost	7.3	80.6	148	28.3	330
50% compost	4.6	69	99	28	223
Lettuce (leaves)					
100%	6.5	6.6	19.8	10.2	250
50%	6	3.3	6.1	5.7	123
Carrot (root)					
100%	1.5	1.6	4.4	3.3	85
50%	1.3	1.1	0.3	2.3	30
Tomato (fruit)					
100%	1.9	2	6.5	2.8	25
50%	1	1.3	6.1	2.9	52
Herb (whole plant)					
100%	2.3	2.2	10.9	8.7	130
50%	2.1	2.5	2.3	6.4	41

may assimilate about 13 ppm of chromium [100] which is accumulated essentially in the roots and very little in the leaves and fruits [89].

**Mercury.** The only available information deals with the mercury content of composts. No author, to the best of our knowledge, has been interested in its bioavailability and its presence in plants as a result of the application of composts or in leachates. The quantity found in a compost depends on the origin of the compost and there is a significant difference between composts of different origins ( $P = 0.05$ ). Composts of MSW have the highest level of mercury which range from 0.9 ppm to 20.3 ppm (Fig. 2, graph E).

**Selenium.** The selenium content of composts varies from 0.1 ppm to 8.8 ppm with a difference as a function of their origins ( $P = 0.01$ ) which may be explained by a high contamination with SS (Fig. 2, graph F). YW and MSW composts have similar concentrations of selenium but data are scarce.

Beetroot grown on soils treated with a MSW compost may contain about 0.04 ppm to 0.17 ppm of selenium depending on the origin of the compost [93]. We have no information on selenium in leachates of composts.

**Arsenic.** Very little information on the measurements of arsenic in compost has been found in the course of this research. The values range from 7 ppm to 9 ppm. The application of MSW compost for more than 30 years did not increase the arsenic content of plants cultivated in sites [27,102].

**Asbestos.** The presence of asbestos has been studied in different experiments [10,37]. In eight samples of MSW composts, fibres were found in all, while 13 observations were positive out of 22 carried out with non-MSW composts.

#### 4.1.2. Organic compounds

In contrast to metals, organic contaminants may be metabolized by microorganisms during the process of composting [38]. Only the very stable compounds may persist in the composts because of the length of time of compost formation, the presence of microorganisms and the high temperature. Hence, pesticides such as diazinon which

has a life span of 12 weeks were not found in compost [64], while pentachlorophenol which may persist for 5 years in the soil is found in compost [103]. Few studies have been made on pollution with organic contaminants, but many compounds have been measured (Table 5). For the sake of a summary, these substances will be examined in groups, adding also specific examples. The major families treated have been chosen based on their relative resistance to biological degradation, or their toxicity to man, animals and plants, and on their tendency to accumulate in the food chain [104]. Unlike the inorganic compounds, organic compounds may be transmitted to plants in two ways: by classical routes through the roots, and through the air into the leaves during vaporization of some of the compounds [104].

**PAH.** Their half-life in the soil is long and they are stable even when metabolized in the plants. Total PAH content in composts ranges from 1 ppm to 250 ppm. For each element, the values range from 0.0006 ppm to 49.3 ppm (Table 5).

**Pesticides.** Though many organochlorinated pesticides have been banned, they are often found in the environment. Composts made of wastes that are sorted early contain very little organochlorinated pesticides [38]. Pesticides detected are in the range of 0.007 ppm to 2.2 ppm (Table 5).

**Chlorinated hydrocarbons.** The different substances gathered in this family of compounds range from 0.02 to 1.1 ppm. Volatile solvents are among the most important since they are found at a concentration as high as 0.1 ppm.

**PCDD / F.** They are lower in composts of MSW that have been sorted early and range from 0.1 to 7 ppm. Very small quantities are found in SS (in the order of ppb) [104].

**PCB.** The quantity of PCB found in composts is about 0.5–5 ppm (Table 5). In SS, this may vary from 0.5 to 5 ppm.

**Natural substances.** In contrast to pollutants (exogenous compounds), natural substances (endogenous compounds) are derived from the compost itself. For example, microorganisms produce fatty acids and methylated esters, but in quantities that do not add more than 0.025–0.05 ppm to

Table 5  
Range of concentration of organic contaminants in composts

Compounds	Concentration (ppm)	References	Compounds	Concentration (ppm)	References
<b>PAH</b>	4.4	38	<b>Pesticides</b>		
Acenaphthene	9.1	146	aldrin/dieldrin	0.002	124
Acenaphthylene	0.5	146	carbaryl	2.2	39
Anthracene	0.006–6.7	124, 146	DDT + DDD + DDE	0.007	124
Benzo[ <i>a</i> ]anthracene <sup>a</sup>	0.205	124	endrine	0.002	124
Benzo[ <i>a</i> ]pyrene <sup>a</sup>	0.009–0.04	41, 124			
Benzo[ <i>b</i> ]fluoranthene <sup>a</sup>	0.067	124	<b>Chlorinated hydrocarbon</b>		
Benzo[ <i>b</i> ]fluoranthene	0.18,	124	chlorobenzene	0.006	42
Benzo[ <i>e</i> ]pyrene	0.08	124	heptachlorocyclohexane	< 0.01	124
Benzo[ <i>g</i> ]perylene	0.03–0.04	41, 124	heptachlore/ heptachloroepoxide	< 0.002	124
Benzo[ <i>k</i> ]fluoranthene <sup>a</sup>	0.042	124	hexachlorobutadiene	nd	124
Benzo[ <i>fluoranthene</i>	27.6	146	1,2,4-trichlorobenzene	nd	124
Chrysene <sup>a</sup>	0.15–0.5	124, 146	hexachlorobenzene	< 0.002	124
Dibenzo[ <i>iac</i> ]anthracene	0.06	41	pentachlorophenol	nd–0.013	42, 124
Dibenzothiophene	42.8	146	trichloromethane	< 0.1	124
Dibenzo[ <i>ah</i> ]anthracene <sup>a</sup>	0.03	41	tetrachloromethane	< 0.1	124
Dibutylnaphtalene	nd	146	trichloroethylene	< 0.1	124
Fluoranthene	0.079	124	tetrachloroethylene	< 0.1	124
Fluorene	17.4	146			
Indeno[ <i>123-ed</i> ]pyrene <sup>a</sup>	0.083	124	<b>PCDD/F</b>	0.1–7.3	38, 42
Methoxyphenanthrene	nd	146	PCDD	7	42
Naphtalene	41	146	PCDF	0.3	42
Napthothiophene	49.3	146			
Perylene	0.007–0.025	41,124	<b>PCB</b>	0.0007–5	41, 38, 85, 124, 168
Phenanthrene	0.224–45.9	39, 124, 146			
Pyrene	0.1–9.4	124, 146			

(nd: not detectable); PCDD: polychlorinated dibenzodioxine; PCDF: polychlorinated dibenzofurane; PCB; polychlorinated biphenyls; PAH: polynuclear aromatic hydrocarbons; Origin of composts: [124, 146, 41, 38] = OM; [42] = Yard wastes; [39] = Sewage sludge; [85, 168] = Diverse.

<sup>a</sup>Carcinogen to man.

the soils during application. These quantities are considered not to be dangerous [105]. The excess soluble organic materials from composts may constitute a nuisance, particularly for flowing water. Successive leachates might introduce organic matter into water and may pose a risk of ecological disequilibrium. In a study over 3 years [106], a decrease of COD (chemical oxygen demand) from 5000 mg/l to 200 mg/l (corresponding to 600 mm of leachates) was observed after 2 years, and BOD (biological oxygen demand) represented 10% of COD.

#### 4.2. Biological risk

Given the diversity of the references as to the type of microorganisms and the method of composting, it is difficult to summarize the literature. The aim of this work, therefore, is simply to find a base from which the microbiological risks associated with composting can be evaluated. Those who wish more details may go through the original papers.

Two types of microorganisms are envisaged. First, the pathogens present in raw materials

meant for composting and liable to disappear during the composting process (Tables 1,2). These agents are representative of the microorganisms present in the digestive tract. Secondly, there are microorganisms which develop during the process of compost formation and which play a role in the degradation of organic matter. These are fungi and mesophilic and thermophilic bacteria. There are several obligatory and facultative pathogens [61]. The organism as well as its spore or toxin (endotoxins of Gram negative bacteria), may be implicated in the pathogenicity. Hazard essentially occurs through the respiratory system and these germs constitute a potential risk for workers at the composting site and for users of composts, whether workers or private users. Table 6 summarises the concentrations of these germs found in the literature, according to their route of penetration (ingestion or inhalation).

Air measurements have been carried out in tunnels of a mushroom culture house or in composting sites, near mounds of mature compost. The latter will be used, in this review, as an index for the risk resulting from the use of composts because no other data on atmospheric measurements during compost disposal are available.

Microorganisms which constitute a potential respiratory hazard are more frequent than those which follow the digestive route. These are Gram positive (including actinomycetes) and Gram negative bacteria and fungi. The microorganisms are essentially bound to dusts produced by composts, especially during turning [117]. About 50–85% of particles in suspension in the atmosphere about composts can be inspired because of their small diameter ( $< 5 \mu\text{m}$ ), and can therefore reach pulmonary alveoli [12,116,126].

In parallel to the microbiological hazard through inhalation, there is also a physical risk due to the deposition of dust in the lungs. In a study among workers, concentrations of  $10.6\text{--}80 \text{ mg/m}^3$  of dust ( $n = 4$ ) were measured in the atmosphere at a composting site [12,116,117]. These values are higher than the occupational standard of  $10 \text{ mg/m}^3$  [12]. Very few studies have been done on organic dusts from composts.

Table 6

Evaluation of microorganisms and of their metabolites in composts. ( $n$  = number of experiments)

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#### Organisms associated with the digestive track

*Salmonella*: ( $n = 108$ ) detected four<sup>a</sup>. (61, 62, 108, 109, 110, 111).

*Escherichia coli*: ( $n = 9$ ), 0–158 organisms/g (62, 110, 111)

Total coliforms:  $1.5 \times 10^6$  to  $5.6 \times 10^6$  CFU/g ( $n = 3$ ), from 79 to organisms/g ( $n = 3$ ) (107, 110)

Fecal coliforms:  $4.1 \times 10^2$  to  $4 \times 10^6$  CFU/g ( $n = 3$ ),  $9.1 \times 10^1\text{--}2.5 \times 10^2$  organisms/g ( $n = 8$ ) (61, 107).

Fecal *Streptococcus*: ( $n = 12$ )  $10^2$  to  $1.9 \times 10^9$  organisms/g, ( $n = 4$ ).  $10^2$  to  $4.7 \times 10^6$  CFU/g (61, 62, 107, 111)

Eggs of *Ascaris lumbricoides*: 0–90 eggs/g (59, 110)

#### Organisms associated with the respiratory track

*Aspergillus fumigatus*:  $10^6$  FVP/ $\text{m}^3$  and from 670 to  $1.1 \times 10^6$  CFU/ $\text{m}^3$  ( $n = 10$ ) (108, 113, 116, 117, 118).

Bacteria Gram negatives:  $1.3\text{--}69.8 \times 10^3$  CFU/ $\text{m}^3$  ( $n = 7$ ) (12, 116, 118)

Bacteria Gram negatives and *actinomycetes*:  $10^6$  CFU/ $\text{m}^3$  (12)

Endotoxin: 0.01–0.014  $\mu\text{g}/\text{m}^3$  (116)

Bacteria *actinomycetes*: 8870 to  $10^9$  organisms/ $\text{m}^3$  (114, 117)

Fungus: 3110 particles of microorganisms/ $\text{m}^3$  and from 0.2 to  $10^6$  CFU/ $\text{m}^3$  ( $n = 13$ ) (12, 113, 114, 117, 118, 119)

Yeasts:  $1.2 \times 10^{-3}$  to  $16 \times 10^{-3}$  CFU/ $\text{m}^3$  (118)

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<sup>a</sup>On two occasions, the authors suggested a sampling error. The two assays, depending on the method used (Most Probable Number), only give a qualitative identification, i.e.,  $< 0.2$  organism/g.

## 5. Discussion and risk evaluation

This review deals with a limited number of contaminants because not all have been studied in compost. The risk associated with ingestion of dust from an amended soil depends on its use. For farming, especially for vegetables and potted farm crops, 50 t/ha of compost is used while 300

t/ha is spread in public places (gardens and green playgrounds). Composts are usually mixed with a depth of soil of approximately 30 cm [127]. If the density of soil and compost are comparable, the dilution of the compost in the soil is, depending on the quantities that are disposed, in a fraction of one-hundredth or one-tenth. The level of exposure of an individual depends on the quantity of soil ingested. The best estimate of ingestion of telluric dust by a normal child is about 100 mg and about 60 mg for an adult while a child suffering from geophagy may absorb up to 5 g/day [82,83]. This route of exposure is, however, modest because the use of compost for soil treatment by private owners or for public gardens and parks currently represents only 2–5% of the total compost production [127]. The hypothesis that an individual is in permanent contact with an amended soil is theoretically possible, but this is not very likely to occur. The maximum quantity of contaminants that are absorbed daily may thus be estimated as:

$$Q \text{ absorbed } (\mu\text{g}) = \text{Maximum concentration of toxicant observed in composts (C; ppm)} \times \text{Dilution of compost in ground} \times \text{Amount soil ingested (g)} + \text{amount compost dust in the air} \times C \times \text{Amount air inspired (l)}.$$

As a first approach, aerial contamination may be ignored due to relatively low exposure. Compost is dispersed in the air essentially during manipulation. This is a minor route of exposure for the general population. On the other hand, however, this route is not negligible for the workers of the compost production and manipulation sites.

The ingested fraction (EDA: Estimated Daily Absorption) will hereafter be the main route of exposure considered in this review. Its intake will be compared with the Acceptable Daily Intake (ADI) for each substance. Exposure by ingestion may occur through contamination of the food chain from plants and animals raised on soils treated with composts (animals bred on open fields may ingest soil up to 6% of their daily food ration) [128]. The contamination of underground water by products from amended soils may equally

present a human health hazard or an environmental nuisance when the ground water is not used for potable water.

### 5.1. Chemical hazard

Table 7 summarizes results which help comparisons for inorganic compounds' ADIs and estimation of the maximum potential exposure associated with compost. The contribution of the ingestion of a mixture of soil and composts to the ADIs of an adult is shown to range from  $1.5 \times 10^{-3}$  to 4%. It is therefore negligible for all metals.

For a normal child, the risk is higher for chromium and lead in the case of direct contact with treated public gardens and parks. The contribution of this type of soil may rise up to 1–4%. In the case of pica, four contaminants may be dangerous. For Cd, EDA may amount to 23% of the ADI, 40% for Cr and 73% for Pb. These are extreme values estimated from the most contaminated composts, and are unusual (Fig. 2).

The US-EPA assessed the risk associated with the use of SS and considered all the possible routes of contamination. It estimated a corresponding NOAEL (No Observed Adverse Effect Level) for some pollutants [3]. According to the data in the literature, only Pb occurs in composts at quantities that are frequently higher than the NOAEL (59% of samples described in the literature) (Fig. 2, graph B).

In view of the possible dilution in the environment, the concentration of metals encountered in leachates does not suggest a significant risk of contamination of the environment or of drinking water. The nuisances that concern soil, fauna and flora after treatment with composts are not well known, but they are unlikely to yield important risks. Only Pb is suggested to have an impact on invertebrate fauna in the soil through which the food chain of wild life may be contaminated [98,129].

Though the risks indicated in this review seem to be of little importance, it must be remembered that composts persist in the soil for several years [16,130] and that repeated applications may lead to an accumulation of pollutants [88,102]. The

Table 7

Potential contribution of composts to the contamination of the soil (based on the estimation of 1/10 for the compost/soil volume ratio).

Metals	As	Cd	Cr	Hg	Ni	Pb	Se
Baseline concentration in natural soils (ppm) (3, 132, 167)	1–2	0.01–1	23–200	0.1–0.5	3–300	2.6–16	0.001–0.1
Maximum concentration observed in composts (ppm)	9	11.7	403	23.3	1220	1312	8.8
Maximum concentration in soils after application (ppm) (excess relative to the highest percent)*	~ 3 (90)	2.1 (17170)	240 (275)	2.8 (2300)	422 (4000)	147 (5000)	0.8 (880)
Standard values in soils (ppm) (most severe–less severe) (144)							
—Agricultural soil	7–50	0.8–5	50–1000	0.2–50	35–200	50–1000	1–10
—Residential soil	7–30	0.8–5	50–1000	0.2–2	35–100	50–500	1–10
—Public spaces (park, garden)	7–80	0.8–15	50–600	0.2–20	35–250	50–100	1–10
—Non agricultural ecosystems	40–60	5–10	200–500	10–50	100–200	10 <sup>3</sup> –210 <sup>3</sup>	5–10
Estimated Daily Absorption (EDA) (μg)**							
—Adult (60 mg/day)	5.4 10 <sup>-2</sup>	7.10 <sup>-2</sup>	2	0.1	7	7	5.3.10 <sup>-2</sup>
—Infant (100 mg/day)	9 10 <sup>-2</sup>	0.1	4.3	0.2	12	13	8.8.10 <sup>-2</sup>
—Geophagy (pica) (5 g/day)	4.5	5.8	200	11	610	650	4.4
ADI*** (μg/day)(132, 135, 181, 182)							
—Adult (60 kg)	3000	601	50–200	42	na	214	na
—Child (25 kg)	1250	25	50–200	42	na	89	na
EDA/ADI(%)							
—Adult	1.5.10 <sup>-3</sup>	0.1	1–4	0.2	—	3	—
—Child	7.2.10 <sup>-3</sup>	0.4	2–8	0–0.5	—	14	—
—Geophagy (pica)	0.35	23	100–400	26	—	730	—
NOAEL for use of SS****(ppm) (3)	100	25	3000	15	500	300	na

na: Information non available

\* Maximum quantity: concentrations in the most polluted soil after treatment with the most contaminated compost excess relative to the highest %; percentage increase in the concentration of contaminants after soil amendment = (Concentration in the least contaminated soil + the most contaminated compost)/(Concentration in the least contaminated soil)

\*\* The risk associated with the absorption of agricultural soil is not considered

\*\*\* Acceptable Daily Intake

\*\*\*\* No Observed Adverse Effect Level.

fate of pollutants in treated agricultural soil was studied bi-annually in Holland for 30 years, showing an increase in the quantity of Cd (3.4 times the baseline level), of As and of Cr ( $\times 1.5$ ), Ni ( $\times 3.7$ ), Hg and Pb ( $\times 4$ ). In spite of this, no increases were observed in the levels of Cd and Ni in cultivated crops. Rather, a decrease in the quantity of As was observed while Cr and Pb increased only by 15% in carrots, beetroot, turnip, pears and beans. However, in another 8-year study

of the fate of Cd and Ni in soils amended annually with SS and of their transfer to the leaves of maize plants, a strong increase in the quantities of both metals were observed (50–105%) for Cd and 40% for Ni in comparison with the levels measured after the first application [88].

The food chain is a potential route of human exposure because most of the composts produced are used in agriculture [127], but it is difficult to make a global assessment of the risk to the gen-



eral population since the overall agricultural land area where composts are applied is not well known. Some hypotheses will be made in order to set the risk scenario. It will be estimated that the dilution of compost in target and vegetable farm soils is about one-hundredth burden.

Under this assumption, each inorganic pollutants will be reviewed.

**Cadmium.** The body burden of Cd comes essentially from food, except among smokers [3,131]. Cd is very persistent in the human body, since its half-life is about 17–30 years [132,133]. The consequence of an intoxication with Cd is primarily renal and hepatic; the bones are also a target after very high contamination (the 'itai-itai' episode in Japan) [3,131,134,135]. Cd found in compost may strongly contaminate food because the relationship between the quantity of Cd in the soil and that in plants is linear without threshold [131,132]. A steeper gradient is found in lettuce (60%) than in Irish potatoes (3%) [131,136], showing that Cd accumulates differently according to the organ of the plants (leaves > roots > fruits and grains) [3,128].

The quantity of Cd in food also depends upon the use of the food. For instance, when wheat is transformed into flour, the quantity of Cd is reduced by about 46% due to elimination from the chaff [128]. Contamination of the food chain may also come through animals. Grass grown on soils with high concentrations of metals may contaminate animal feed. This hazard is apparently minimal for Cd because the quantities present in composts are not sufficient to yield high amounts in plants that might accumulate in the muscles of animals. With increasing daily intake, accumulation in the body is minor. A 40-fold increase in Cd daily intake in pig does not yield a significant increase in the quantity in the muscle [128,137]. Cd normally accumulates in the offal which represents only a small fraction of our food regime (0.3–0.5%). Only populations that abundantly eat liver or kidney are seriously exposed [128]. However, there is a direct potential risk for animals grazing on grounds treated with composts. During grazing, animals ingest 3–6% of soil with grass. An increase has been observed in muscular tissues for animals grazing in fields amended with

SS containing 8.8 ppm of Cd [128]. The concentration observed in compost is much lower (maximum 12 ppm) and the risk is therefore less than when SS is used, even after application for several decades [102].

The case of lettuce is interesting because its Cd content depends very strongly on the quantity in the soil [3]. The normal level of Cd in lettuce grown in normal agricultural land ranges between 50 and 60  $\mu\text{g}/\text{kg}$  (fresh wt.). Hence, lettuces cultivated on pure compost (a very unfavorable situation and very unlikely, except for experiments) may contain only 68  $\mu\text{g}/\text{kg}$  (fresh wt.) [135], which is very close to the normal value. Risks associated with food also depend on the frequency at which that food is consumed. A low contamination of a food item that is consumed frequently may be more deleterious than high contamination of food that is rarely eaten. Unfortunately, though there are data on the average food intakes and on the natural content of metals in food items [135], data from Cd contaminated zones are scarce [138].

**Lead.** Pb quantities in composts are apparently not high enough to represent a risk to animals through grazing. Furthermore, the risk of contamination to man through the consumption of such animals is low, since, as in the case of Cd, Pb does not accumulate in meat but in offal [137]. Pb is assimilated in small fractions by plants. Its penetration in grapes is poor but higher in maize and wheat. The risk of contamination of products made from these crops is reduced by the biological barriers in plants which prevent the penetration of Pb in the grains [98,139].

**Nickel.** Ni is found mainly in green vegetable [140]. There are poor data on the transfer of Ni to man through plants, and the existing data does not suggest any risk. Some studies seem to indicate that at the levels recovered, Ni may not pose any phytotoxicity problem [98]. However, this metal is toxic to crops before attaining the toxic dose for man [3].

**Chromium.** Data on the risk of Cr via food is also scarce; 60% of Cr in the food chain is found in plants and an increase in consumption might be dangerous [10]. Cr accumulates mostly in the roots of some vegetables [10,98].

**Mercury.** Hg is only slightly assimilated from the soil by higher plants (mineral mercury even less than methylated mercury) [98,141]; on the other hand, mushrooms accumulate Hg very easily [98,142]. In France, the use of urban compost in mushroom farms has decreased from 60 to 10% in 5 years, and an AFNOR standard has targeted a reduction from 10 to 5% which will further reduce the risk associated with such practice [127]. It has not been proved if Hg accumulates in animals fed on plants grown on compost amended soils [3].

**Selenium.** Fruits and vegetables contain on average 0.1–0.6 ppm Se [143]. One study on the assimilation of Se by plants cultivated on MSW compost amended soil did not indicate an increase compared to the normal level [93]. Paradoxically, a study on amendment of SS has shown in several species of fruits, vegetables and cereals, that the levels obtained are well below those measured in normal food (4.8–46 ppb) [141]. The maximum concentration observed in soil does not exceed the standard values for agricultural or residential areas (Table 7) [144].

**Arsenic.** There is only a limited amount of studies on the absorption of As by plants. However, available results suggest that assimilation takes place in the leaves and not through the roots [145]. As to the risk from arsenic, there is no adverse indication regarding the use of compost in agriculture.

The potential risks associated with organic compounds have been assessed to a lesser degree.

**PAH.** The international reference values for total PAHs range 1–50 ppm for gardens or residential areas [144]. Quantities found in compost may reach 200 ppm which, for a one-tenth dilution, give a non-negligible surplus; this increase is lower in the case of a one-hundredth dilution. These results are due to the high content of certain contaminants (phenanthrene, naphthalene, anthracene, pyrene, acenaphthalene and fluorene) but these compounds are not very toxic. Out of the seven PAHs that are well known carcinogens (Table 5) none was found above the standard in the soil after compost was applied. Agricultural use of SS (at levels comparable to

those of composts) gives only low concentrations of PAH in plants, even after a very long trial [104]. While PAHs penetrate into plants, they concentrate mainly in the underground teguments and only very little in the aerial parts. Peeling and washing before cooking helps to avoid contamination through the food chain [104]. However, the risks might increase during repeated applications. No accumulation of PAHs in agricultural soil was noticed after treatment with MSW composts for 3 years but the authors of the study admit the inadequacies of the data and the necessity to carry out experiments of longer duration [146]. As regards the risks associated with leachates of composts, 10% of PAHs are free in SS (and many thus percolate) [147]. If this fraction holds true in compost and taking into account future dilution, the chances of contamination of water is minute [147].

**PCDD/F.** Though WHO has recommended an ADI of 10 pg/day/kg for 2,3,7,8 TCDD [148], the ADI for complex mixtures of compounds is not known. The US-EPA has calculated an acceptable exposure dose to PCDD/F for a general population as  $6 \times 10^{-9}$  ng/kg/day [149]. This exposure should not provoke the occurrence of more than one cancer in a population of one million persons. If one considers the least contaminated compost (0.1 ppm) and depending on what the soil is used for, the daily absorbed doses by an adult, a normal child and a child with pica are 40–100 000 times the recommended dose. However, this result should be considered with care because there are only a very small amount of measurements on dioxins and furans in composts and it is not possible to assess whether the samples were representative. These compounds are sparingly soluble in water and are strongly adsorbed onto dust and soils. Therefore, they accumulate but have low availability [104]. Yet, a literature review shows that several surveys reported leaf assimilation of PCDD/F by plants due to their dispersion in air [150]. The transfer of PCDD/F by animals has been reported when grazing animals ingest dispersed contaminated SS [150]. Finally, PCDD/Fs are not easily bioavailable and, therefore, are not likely to concentrate in leachates.

**PCB.** The maximum quantities recommended in the soil range from 0.05 ppm to 0.5 ppm [144]. The concentrations observed in composts (0.0007–5 ppm), with a dilution of one-tenth, might lead to an increase of the amounts in the soil above standard values and represent a potential risk in the case of ingestion of soil, especially to children. Risks through crops are weaker. After dispersion of SS with a PCB level of 52 ppm in a trial including several crop species, it was recovered only from carrot [104]. On the other hand, fields amended with SS containing an average of 292 ppm PCB might represent a risk to farm animals by accumulation of the chemical [151]. It should be noted that PCBs are very persistent products and measures should be taken to control long-term uses.

**Pesticides.** The maximum acceptable quantities for pesticides such as aldrin, dieldrin or DDT for agriculture purposes without risk are 0.1 ppm for the first two and 0.75 ppm for DDT [104]. These values are higher than those found in composts. The contaminants often concentrate in the external teguments and peeling might reduce risk [104]. Plants possess metabolic pathways which, over a certain length of time, eliminate pesticides from the tissues [104]. Diazinon, isofenphos, chlopyrifos and pendimethalin (non organochlorinated) are less persistent and disappear during composting [64].

**CH.** The non-volatile CH accumulates only slightly in crops grown on compost amended soil, which eliminates the danger inherent in the consumption of these crops [152,153]. By contrast, the volatile ones (trichloromethane, chloroethylene) may pose a risk since marked C<sup>14</sup> indicated a non-negligible foliar assimilation [104]. Unfortunately, these works concern SS and there is no information on the volatilization of volatile organic compounds (VOC) in MSW compost during use [43]. It should be lower than during the application of SS since there are many occasions for loss during the process of composting (heat, turning of the windrow, duration of composting). Authors have shown that at the composting site, the highest levels of VOCs are found near fresh wastes [43].

## 5.2. Biological risk

There are two routes of exposure for pathogens or toxins: ingestion of a mixture of soil/compost and inhalation of microorganisms dispersed in the air during manipulation of composts. Microorganisms present in composts do not seem to compete with those in the soil. Therefore, spreading of composts is apparently without biological risk to the environment [119].

### 5.2.1. Risks associated with ingestion of microorganisms

Different authors and institutions have proposed standards for the microbial quality of composts using indicators of contamination as an index. This issue still provokes scientific controversy in terms of relevance [61,111]. The following have been proposed as limiting values:  $5 \times 10^3$  faecal *Streptococci*/g,  $5 \times 10^2$  enterobacteria/g, absence of *Salmonella* in 100 g, and absence of eggs of parasites [61]. *Salmonella* strains are rarely present in MSW compost but more often in compost of SS [125] while eggs of *Ascaris* are absent. With regards to faecal *Streptococcus* (Table 6), seven studies out of 16 which were screened in the literature showed higher concentrations than the recommended values. However, these results are inconsistent and these observations were made under different processes of composting. The slow methods of composting (such as turning of compost in windrow) are less efficient in sanitization of composts [61,62].

During storage or after application of composts, pathogens may disappear more or less rapidly. Survival of viruses depends on humidity, temperature and on the type of strain [122,154]. They do not seem to concentrate in leachates [122]. Some authors reported that it is possible for viruses to penetrate into the plant through the roots and to migrate into the stem [122]. The survival of enteric bacteria is also influenced by humidity and temperature. In the soil, they survive longer in the saturated zone. In an experiment, though no bacterial indicator was detected in the soil before amendment with SS, it took 7 months to eliminate the effect of  $6 \times 10^8$  *Strepto-*

*coccus*/g,  $1.3 \times 10^8$  total coliforms/g and  $0.37 \times 10^8$  faecal coliforms/g [80,122]. During this time span, the paradoxical phenomenon of recolonization of mixtures of soil and compost may take place especially after rain. Hence, a compost with a normal rate of indicators may undergo a sudden increase in their concentration (and reach values above the proposed norms) following changes in environmental conditions [155]. The survival of parasites is the longest. Eggs of *Ascaris* may persist 3 years during storage of mud and up to 78–107 days in the soil [122,59]. However, the US-EPA has shown that after 5 years of soil amendment with SS that were contaminated by parasites, *Toxocara* were isolated in 13% of the samples but no *Ascaris* was found [80].

Pathogens may be ingested by children through hand-mouth contact, which is an important route of exposure in cases of geophagy. The composts observed in this review did not contain adequate levels of *Salmonella* as to represent a risk, and parasites were rarely found. The infective dose of *E. coli* is about  $10^6$  [25] which should not be reached after ingesting a mixture of soil and compost. The infective dose of *Streptococcus* ( $10^9$ ), however, may be attained in case of pica.

Aflatoxin is produced mainly by *Aspergillus flavus* and *A. parasiticus*. This carcinogenic toxin is hazardous when ingested [156,157]. The impact of aflatoxin is difficult to evaluate because there is only qualitative information on its presence in composts.

### 5.2.2. Risk associated with inhalation of microorganisms

This route of contamination may be found during utilization of composts which cause air dispersal of microorganisms responsible of the process of composting. These are different from the faecal microorganisms which come from a contamination related to the nature of the composted material. Apparently, respiratory infection caused by enteric pathogens during air dispersion of composts is negligible. Studies on workers at sewage treatment plants (a highly exposed zone) have never shown evidence of disease due to

faecal pathogens through the inhalation route [108,158].

Among the most frequently studied organisms, *Aspergillus fumigatus* remains a controversial subject. The amounts measured in the air are often high but serological studies carried out on exposed workers did not indicate the presence of circulating antigens [156,159]. The infective dose of this fungus has not been assessed but was shown to be hazardous only to susceptible persons who are hypersensitive or immunodepressed [57,112,113,117,157].

By contrast, evidence of higher risks has been shown after exposure to dust containing Gram negative bacteria. Epidemiological studies carried out among workers in a MSW sorting factory, or in wastewater treatment plants, in farms, mushroom farms or in a composting plant have shown that symptoms of headache, diarrhea or eye problems are more frequent during massive exposure to factory dust [126,159–161].

Gram negative bacteria are pathogenic because of the endotoxin they produce. The activity of the endotoxin does not depend on the integrity of the bacterial cell because it relates to the lipopolysaccharides present in their wall. A fragment of the wall is as dangerous as the whole bacterial cell [115,162]. A security level of  $1000/m^3$  has been proposed for Gram negative bacteria [12], though some authors claimed that this concentration could provoke an allergic reaction [118]. When endotoxins are measured, several air measurements around composts ( $10\text{--}14\text{ ng}/m^3$ ) were comparable to the limit proposed by several authors as levels without effect [115,162].

The risk associated with actinomycetes is well known to workers in mushroom farms and is referred to as ‘mushroom farmers lung’ [114,159]. Those germs also cause the ‘farmers lung’ disease [163]. A massive ( $10^8/m^3$ ) and sudden exposure to these bacteria during utilization of composts may initiate a sensitization and an allergic reaction [163,118] with circulating antibodies being measurable [159]. It is therefore plausible that sensitized individuals develop allergic reactions to actinomycetes following exposure to mature compost. Some atmospheric measurements during

mature compost handling at composting plant gave results similar to those where allergic reactions were observed among exposed workers [126]. As an example, a 52-year-old urban planner was reported to have developed a pulmonary problem 12 h after he had manipulated farmyard waste composts. Retrospective reconstitution of his exposure provided the following data in the air:  $1.4 \times 10^6$ – $4.7 \times 10^8$  cfu/m<sup>3</sup> of fungi,  $6.3 \times 10^5$ – $7.7 \times 10^8$  cfu/m<sup>3</sup> of bacteria (with Gram negative bacteria in the majority) and  $1.3 \times 10^8$ – $3.7 \times 10^9$  spores/m<sup>3</sup> [164].

No hazardous yeast strain was found in this review. One of the most studied yeast, *Candida albicans*, was never encountered.

Extrapolation of these results obtained in the context of professional exposure to the general population using compost should be done with caution. Measurements taken at the composting sites are the only data available. Hence, the concentrations of the organisms are not necessarily representative of those obtained in natural conditions of use. The amounts that are measured at the plant site represent a mixture of emanations from the different stages of composting. At the beginning of composting, one essentially observes bacterial populations [165], which are subsequently replaced by fungal populations [53]. A study comparing just mature compost with composts at the salting point, has shown a big decline in Gram negative bacteria between the two locations. By contrast, the populations of actinomycetes remained constant [12]. To our knowledge, air measurements during application of composts were not made. Therefore, other studies should be made in order to assess this risk more precisely.

## 6. Conclusion

The hazard associated with chemical contamination of the food chain during agricultural use of composts seems very low. However, application of compost by individuals or during the amendment of public fields (parks, playgrounds) might pose a risk to health and these applications are likely to develop in the future. The risks that were

discussed in this review have been assessed using extreme concentrations of contaminants in composts — levels that were found in rare circumstances.

The most prominent risks are associated with hand-mouth contact and ingestion by children. A child with geophagy might ingest, under such hypotheses, 730% of the total Admissible Daily Intake (ADI) of lead, 400% and 23% for chromium and cadmium, respectively. For a normal child, the intake of lead through ingestion of compost poses a risk for lead, and to a lesser extent, for chromium. The same route of exposure might incur a significant hazard with PCDD/F and PCB but the data are too scarce to make conclusions. Repeated application of composts may cause accumulation of contaminants in the soil. This can be prevented by appropriate MSW management policies and by the extension of selective collection of MSW that should contribute to a reasonable reduction in the contamination of composts, hence reducing the risks.

The microbiological hazard arising from fecal contamination is apparently modest, although direct intake of soil contaminated by faecal *Streptococcus* present in the compost might represent a potential danger. Exposure to organisms responsible for the composting are difficult to control. Some of the fungi and bacteria are direct pathogens or can act through their toxins. The manipulation of composts triggers their aerial dispersion that can induce their inhalation, as shown among workers in composting plants or in mushrooms farms (fresh compost). It is presently difficult to extrapolate these results to populations that do not produce but use MSW composts. Future studies aimed at assessing the risk associated with inhalation of compost dust should also take into account the chemical hazard caused by molecules adsorbed on dusts. Such hazard has never been described to date.

The high dilution of composts and of their pollutants throughout the environment (water, air, soil) and the discontinuous exposure of the population create a low risk for use of MSW composts by the public. The health risk associated with composting seems to be occupational.

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