

SUMMARY

Objectives and methods

This report is the result of a study carried out on behalf of the Directorate-General for the Environment of the European Commission in the context of the European waste management policy and work on the biological treatment of biodegradable waste.¹

The objectives of the study were as follows:

- 1.) Identification of the pollutants (heavy metals, organic compounds) likely to be found in foodstuffs for human consumption.
- 2.) Evaluation of the concentration of most representative pollutants in compost produced from biowaste that is separately collected and from unsorted waste and/or residual municipal waste across the Community.
- 3.) Assessment of the influence of the different sampling techniques and analytical methods that are used in Member States for determining the concentration of pollutants in compost and stabilised biowaste. Identification of the applied ISO, CEN or other international or national standards.
- 4.) Elaboration of a scientific concept for limiting the amount of pollutants in compost and stabilised biowaste with a view to long term soil protection in the Community.

The study aimed to evaluate background concentrations of relevant pollutants (potential toxic elements (PTEs); organic pollutants (OPs)) in the areas of (in brackets, the relevant section of the report were the reader will find detailed information)²:

- 1.) Food and feeding stuff (chapter 2)
- 2.) Soils as receptors of waste derived organic fertilisers (chapter 3)
- 3.) Specific source materials for composting and other biological treatments (chapter 4)
- 4.) Materials intended as organic fertiliser or soil amendment (chapters 4 and 5)
 - i. Compost from source separated collection schemes and sludge
 - Biowaste compost (BWC) from organic household waste including kitchen waste
 - Green compost (GC) from garden and park waste materials (grass clippings, bush and tree cuttings, leaves, flowers etc.)
 - ii. Mixed municipal solid waste-derived compost (MSWC) or the stabilised organic waste fraction from mechanical biological treatment plants (MBTC)
- 5.) Other organic fertilisers or soil amendments such as manure, organic soil amendments and growing media, mineral fertilisers (chapter 6)

This study examined the literature (scientific publications, reports as well as original datasets provided by research institutes or local authorities). The data found include regional and temporal variations and the comparison with existing threshold and limit values.

The study conducted a comparative survey of *sampling and analytical methods* of composts, the variability of analytical results on the basis of inter-laboratory trials and specific investigations, as well

¹ The content of this report does not necessarily reflect an official position of the European Commission.

² In this context PTEs are defined as chemical elements that have the potential to cause toxicity to humans, flora and/or fauna, depending on concentration, bio-availability and bio-accumulation. The definition of "PTEs" commonly refers to heavy metals; in contrast to OPs they are not of organic nature, and they may not be degraded by microbial activity or chemico-physical impacts. The latter can – in general terms – be addressed as "persistent" and have to be considered when assessing toxicological effects in time.

as statistical rules for admissible deviations within national standards (chapter 7). The review of existing proposals for the definition of the quality of organic fertilisers and composts (chapter 8) resulted in the presentation of a possible *framework for the use of waste derived composts as organic fertilisers in agriculture* with the goal of ensuring the long term multifunctional productivity of agricultural soils (chapter 9).

Potential toxic elements (heavy metals) in food and feeding stuff (chapter 2.3.1)

The variation in reported concentrations of PTEs for each type of foodstuff was considerable. Such variability may result from:

- i. *Spatial variation*: the overall uptake of heavy metals may be affected by the nature and type of particular soils and the pattern of industrial sources in different districts.
- ii. *Temporal variation*: analyses have been carried out at different times and this may be linked, in turn, to all other affecting factors, such as new test methods, development of local industrial activities, etc.
- iii. *Heterogeneity of sampling and test methods* (in most cases surveys specify neither the sampling nor the test method).
- iv. *Intra- and inter-laboratory variations*.

A comprehensive assessment of the literature relating to PTEs concentrations in foodstuffs leads to the conclusion that these elements are found in the food chain to various extents, in particular:

- Leafy vegetables and vegetables (one of the basic components in daily diet throughout Europe) tend to show a higher concentration of PTEs than cereals.
- Lower concentrations found in cereals are affected by plant physiology, which tends to concentrate PTEs more in the shoot and leaves than in the seeds.
- Fish tend to accumulate relatively high concentrations of PTEs such as As, Cd, Cr, Pb. Arsenic, in particular, has been reported by some authors at high concentrations, though it may be affected by one or more of the aforementioned factors causing variation

Data were lacking for many types of foodstuff, particularly for milk products and eggs.

Organic pollutants in food and feeding stuff (chapter 2.3.4)

The most investigated compounds are *dioxins*, *polychlorinated biphenyls (PCBs)*, *polychlorinated hydrocarbons (PAHs)*, and the pesticides *hexachlorbenzene (HCB)*, *DDT*, *Aldrin* and *Dieldrin*. Factors affecting organic pollutant distribution included spatial variation, i.e., climatic and soil variations, proximity to local sources of pollution, and concentration in foodstuffs during preparation.

It is likely that the ongoing improvements in environmental legislation, and particularly new threshold values for air emissions, (e.g. as set for incineration in Directive 2000/76/EC), may reduce concentrations of organic pollutants in foodstuffs produced at farm sites near point sources. Arguably, this may also have positive implications on the future quality trends of organic waste materials used as fertilisers. A similar trend is likely to occur for sludge, if Programmes for the Prevention of Pollution were to be introduced in the Sewage Sludge Directive 86/278/EEC.

Spatial variation: OP background concentrations were compared at the following levels:

- i. Member States level (*geographic scale*) and
- ii. The *local level* addressing the OP content in food commodities in rural areas compared to industrial districts. However, the data collected was not sufficient to build a scenario covering the whole of Europe. Some case studies representing experiences and investigations carried out at local level are provided in this report.

Geographic scale: There is a general lack of information on several countries - in particular in Southern Europe - and, therefore, an analysis of *geographical trends* is not possible. Geographical variations can become blurred through the transportation of goods around Europe or imports of goods from outside the region. Care should, therefore, be taken in the identification of sources of these products before conclusions are drawn concerning sources of contamination.

Proximity to local pollution sources: Incinerators, petrochemical and metallurgical activities were generally identified as potential sources of organic pollutants. Many parameters influence the effect of the sources of organic pollutants on foodstuffs, the main ones being the type of industry, chemical identity and path through which the contaminant gets in touch with the foodstuff, distance from the industrial site, etc.

Temporal variation: The numbers reported show in most cases a decrease in detected concentrations over time. Arguably, these trends mainly depend on the implementation of technological improvements with particular reference to equipment to prevent formation and/or avoid dispersion of organic compounds dangerous for human health. As already remarked, enforcement of specific environmental legislation (as, for instance, Directive 2000/76/EC on the incineration of waste) may arguably be seen as a main driver for such technological improvements.

Effect of cooking on the OP concentration in food: Some studies indicate the general increase of concentrations of benzo(a)pyrene or polychlorinated hydrocarbons (PAHs) when food was cooked compared to uncooked foodstuffs. Those findings do not apply for PCBs, DDT or polychlorinated dibenzodioxins/furans (PCDD/F). Benzo(a)pyrene is formed through incomplete combustion of organic matter. Incomplete combustion mainly occurs during heating processes like grilling, barbecuing and roasting where foods are close in contact with the heat source (over an open flame). This includes drying with smoke, or by absorption during the smoking. The degree to which this process contributes to an undesirable increase in PAH concentrations in compost feedstock, and consequently in compost, depends on the proportion of cooked, grilled or smoked food residues in the overall feedstock composition.

Referring to the microbial degradation of PAH and the actually detected PAH concentration in compost, the report concludes that the effect of increased PAH concentration in cooked food residues is not likely to constitute a threat to the recycling of kitchen waste and its safe application via composting (see report, chapter 2.3.5).

Inorganic and organic pollutants in soil and factors influencing the content of pollutants in foodstuffs (chapter 3)

A number of interactive biotic and abiotic processes govern the behaviour of *heavy metals* in soils and define chemical speciation and bioavailability. The major factors driving the biogeochemical processes in soils are pH, cation-exchange-capacity (CEC) and redox potential.

Assessment of "total" PTE concentrations detected in soils after digestion with strong acids is the commonly agreed basis for the evaluation of conditions for long-term soil conservation. Aqua Regia (HCl_{conc.}: HNO₃ = 3 : 1) is still the first choice and was adopted as the preferred extracting agent for sludge, soil improver and growing media as well as soil.

Problems dealing with *background concentrations* arise from

- i. their great variability due to spatial variation of soil parent material and pedogenetic (weathering, decomposition, sedimentation, translocation and leaching processes) conditions,
- ii. the fact that "natural" soils (i.e. without any anthropogenic influence) are scarce due to historical land use patterns and diffuse emissions and
- iii. different sampling and analytical methods employed.

Ranges of so-called background concentrations from different authors, and a recently conducted study on behalf of the Joint Research Centre (Ispra), emphasise the great variance due to site and soil forming conditions and the obvious need for the harmonisation of sampling, analyses and interpretation.

The term “background” concentrations of *organic pollutants* refers more or less to anthropogenic pollution, since these compounds typically do not occur naturally in soils or soil parent materials. Consequently it differs from land use patterns related to soil management practice. Moreover, the varying susceptibility of the different organic compounds to bio-degradation under different soil conditions makes it difficult to identify reference concentrations. This could only be done with organic pollutants, which show a high persistency (such as PCBs, PCDD/F, PAH).

Potential toxic elements (PTEs) in compost (chapter 4)

In compost produced from separately collected organic household waste the PTE concentrations decreased by a factor 2 to 10 as compared to *municipal solid waste compost* or a stabilised organic waste fraction. Quality related regulations for composts have already reflected this development within the last 10 to 15 years in many EU Member States.

Potential source materials showed variability in PTE concentrations similar to that identified in foodstuffs. Cadmium, Copper and Zinc showed the highest concentrations in residues from food and semi-luxury food production as well as separately collected biowaste. Because of these pre-existing concentrations, it would seem difficult to comply with existing limit values for compost given the mineralisation of organic matter in the course of aerobic degradation. However, these particular high concentrations in some of the source materials did not seem to exert a major impact on the overall compost quality, as long as compost mixtures were coming anyway from source selected materials.

The proportion of physical impurities in the input wastes, did, however, have a measurable effect on their concentrations in the resultant compost. Final screening at the end of the composting process did not fully remove the pollutant input introduced by impurities in the raw material. For this reason collection at the doorstep (*door to door collection*) showed distinct advantages compared with collections using roadside containers, where the proportion of impurities was increased.

National investigations indicated that *green waste compost (GC)* tended to have slightly lower PTE concentrations than *biowaste compost (BWC)*. This difference showed a fairly marked pattern following the order: Cu > Zn >> Hg > Pb with differences between 20 and 50 % under well defined standard collection conditions. Cr, Cd and Ni gave an indifferent or heterogeneous picture with no clear trend observed. However, these differences should not lead to the exclusion of biowaste composts from the use as organic fertiliser and soil improver, as long as final PTE concentrations would still not lead to an unacceptable pressure to soil quality under good practice application schemes (see concept of chapter 9 in the report and below).

The difference between *urban and rural biowaste composts* was not as evident as could have been expected. Typical *pedogenic* metals like Cr and Ni tended to be higher in composts from rural areas compared to urban areas. Elements typically associated with *human (industrial)* activities such as Cu, Pb, Zn and Hg show relatively higher levels in urban than in rural areas. This was identified both in local and national surveys in Germany and in Austria.

Temporary and seasonal variation for Hg, Ni and Zn was reported to be lower than for Pb, Cd, and Cu in a German investigation in Baden-Württemberg. No evidence for a systematic differentiation of *winter* and *summer* compost was found. The comparison of mean PTE concentrations in biowaste compost and green compost investigated over a period of eleven and ten years in Germany and Switzerland respectively, show a similar outcome. The copper content increased (+ 45 % and + 30 % respectively), Zn remained on the same level or increased slightly (11 %), whereas all the other metals indicated a relative decrease of concentrations of -17 % to -38 %.

With the exception of copper, in many countries PTE concentrations in sewage sludge have constantly decreased within the last 20 years. This development increases the possibility to use sewage sludge as a

feedstock for the production of compost complying with precautionary quality standards. Notwithstanding, on average, sewage sludge composts (SSC) still contained distinctly higher concentrations of Cd, Cu, Hg and Zn than biowaste compost and green compost.

It can be further noted that

- regional and seasonal variations of PTEs in biowaste compost and green compost were based on unavoidable background concentrations in soils and caused by atmospheric deposition and the individual fluctuation even at similar collection schemes and purity level;
- countries in the early phases on implementing separate collection systems showed 10 to 50 % higher PTE concentrations in biowaste compost and green compost than it is found in long established schemes. But this has to be considered in the light of (i) the still limited data set and (ii) in some cases the difficulty of distinguishing between facilities producing compost only from bio and greenwaste and those also including sludge;
- when sewage sludge or animal manure is used as source material, Cu and Zn usually reach higher concentrations. However, the choice of high quality manure and sludge would also match quality standards set in member states for biowaste and green waste compost. This would be dependent on the source of the material: for example, in the case of sewage sludge the district served by the wastewater treatment plant and for manure on the use of feed additives containing Cu and Zn.

Organic pollutants in compost (chapter 5.2)

Selection criteria for the evaluation of organic pollutants were set based on their potential occurrence in compost, the availability of published data, knowledge of physico-chemical properties and feasibility of chemical analysis. The compounds considered were: Polychlorinated biphenyls (PCB), polychlorinated dibenzodioxins and dibenzofurans (PCDD/F), polycyclic aromatic hydrocarbons (PAHs), chlorinated pesticides and adsorbable organic halogen (AOX) (*Aldrin, Biphenyl, o-Phenylphenol Chlordane, Dieldrin, Endrin, Heptachlor, DDT [1,1,1-trichlor-2,2-bis(p-chlorophenyl)ethan], lindane, HCH-isomers [hexachlorcyclohexan], hexachlorobenzene, hexachlorobenzol, heptachlor, pentachlorophenol pyrethroides, Thiabendazole*), linear alkylbenzene sulphonates (LAS), nonylphenol (NPE), di (2-ethylhexyl) phthalate (DEHP), butylbenzyl phthalate (BBP), dibutyl phthalate (DBP).

Accumulation scenarios were only performed for PCBs, PCDD/F and PAHs, since these compounds are the best documented and show comparatively high persistency.

Conclusions for the key substances covered by reliable literature data in the area of organic waste and its recycling via composting were:

PCB: Since PCBs have been excluded from industrial processes since the 1980s a continuous reduction in their occurrence in the environment can be expected. In general, they were detected in higher concentrations in composts stemming from urban areas. Some, but not all investigations reviewed showed higher concentrations in biowaste than in green compost. PCB content in composts from mixed municipal solid waste is approximately 50 to 100-fold higher than that found in compost from source separated bio and green waste.

The observed reduction of PCBs during composting was up to a maximum of 45 % through either biodegradation or volatilisation. However, there are considerable uncertainties since, given the concurrent mineralisation/volatilisation of part of the organic substrate, generally higher concentrations attended to be found in compost than in feedstock. Degradation occurs mainly for congeners with lower chlorination.

Input of PCBs to soil from compost was considerably less than atmospheric deposition rates. Assuming a half-life ($t_{1/2}$) of 12 years reported in literature, and average concentrations in composts, no accumulation in soils can be expected. Even in a worst-case scenario ($t_{1/2}=50$ years) the soil precautionary reference value of the German Soil Protection Ordinance (0.05 mg kg^{-1}) would not be reached within 100 years also assuming a comparatively high PCB concentration of 0.1 mg kg^{-1} d.m. in compost.

PCDD/F: The level of PCDD/F in composts mainly depended on the background concentrations in the soil and the source material following diffuse emissions in the catchment area of the composting plant. A differentiation between urban and rural areas could not be clearly identified. Mean values of several investigations demonstrated a trend towards lower values in green compost than in biowaste compost. A trend of continuous decrease of PCDD/F levels over time in composts was observed. PCDD/F content in composts from mixed municipal solid waste was typically 50 to 100 times higher than in compost from source separated bio- and green waste.

In general PCDD/F tended to concentrate during the degradation process, mostly due to the mass loss during mineralisation of organic matter. Biowaste and green waste feedstocks showed generally lower concentrations than the finished composts. The reported initial generation during the rotting process only contributes to a negligible degree to dioxin content in composts and only occurs with temperatures > 70°C and in the presence of primary substances such as *trichlorophenol* and *pentachlorophenol*. Here it is important to say that properly managed processes keep temperatures in the range of 45 to 60°C. Higher temperatures are sought only for a short period to ensure sanitisation, although many regulations just mandate 55 to 60 °C to be reached for hygienisation. Most tests conducted during the composting process of biowaste showed an increase of hepta- and octa- PCDD. On the other hand, the content of low chlorinated PCDD/PCDF decreased during the composting process (thereby leading to a decrease in overall toxicity). Furans also generally diminished.

PCDD/F input by regular compost application can be estimated to be in the same range as or slightly higher than mean atmospheric deposition rates. However, in none of the scenarios when modelling the long term change of soil PCDD/F status accumulation was thought to occur (this holds true even if no further decay in soil is assumed). In most of the cases a considerable decrease in soil concentration was found, due to the half-life of these substances, which overcompensates for input through deposition and compost application.

PAHs: The relevant spatial and temporal variability of PAH may be explained by seasonal differences in the composition of the raw material, by different collection capture areas or individual contamination with extraneous materials (e.g. ashes). From the literature considered, higher concentrations for urban areas than for rural areas can be assumed. There was only a slight trend indicating higher values in biowaste compost than in green compost. PAH concentrations in organic wastes were higher than in compost. PAH content in composts from mixed municipal solid waste was typically 1 to 10 times higher than in compost from source separated bio- and green waste.

Though PAHs show a high persistency in soils they undergo an effective reduction under aerobic degradation conditions by up to 70 %. This includes volatilisation as well as bio-degradation and performs more effectively during the maturation stage of composting.

Though a certain accumulation of PAHs may occur in soils with low background concentrations (ca. < 0.5 mg kg⁻¹ d.m.) precautionary soil threshold values would not be touched even in the long term.

Conclusions for PCBs, PCDD/F and PAHs:

Concentrations of PCBs, PCDD/F and PAHs in BWC and GC were similar to background concentration in soils. This lead to the conclusion that regular measurements of PCBs, PCDD/F and PAHs and the establishment of limit values for these compounds are not required for the safe use of compost derived from source separated organic waste materials.

Due to the comparatively much higher concentrations found in mixed waste compost they should be measured, instead, when mixed waste compost is used as amendment. The authors recommend to restrict the use of mixed waste compost to limited non-food areas such as land reclamation of brown fields and surface layers on landfill sites or on noise protecting walls aside roads or railways.

AOX and Pesticides: Even though most of the chlorinated pesticides are now banned in the EU they may be found in very low amounts in composts. Generally biowaste compost tended to show higher

concentrations than green compost. Organochlorine pesticides, Pyrethroides and Thiabendazole were found to be below related limit values for fertiliser regulations or even close to the lowest detection limit.

The variety of compounds within the group of *chlorinated pesticides* and *absorbable organic halogens* gives a wide range of properties and related behaviour during composting.

Comparisons of the pesticide concentrations in feedstock versus the end composted products showed that composting tends to substantially decrease the concentrations of most compounds. Frequently, thermophilic process conditions were favourable to breakdown the investigated substances.

Specific case studies on *chlorophenols* consistently indicated their high degradability during composting. Therefore they are not considered as substances with priority for analysis in compost or digestate from anaerobic treatment.

In general, the patterns of pesticide degradation in composting parallel the patterns found in soil, but in several studies, pesticide compounds disappeared faster during composting than they typically do in soils, as indicated by their soil half-life values.

From the literature reviewed it can be concluded that there is no indication for the need for regular analyses of AOX or specific pesticides. This is mainly based on general low background concentrations as well as degradation behaviour during composting.

However, given the high persistence/toxicity of compounds used and by means of precaution, pesticide treated wood should be excluded from the production of marketable compost products or any recycling in agriculture.

LAS, NPE, DEHP: The Danish Decree for the agricultural use of sewage sludge and waste derived composts was the only regulation that specifies limit values for LAS, NPE, DEHP. Those compounds are all rapidly degraded under aerobic composting conditions. Extremely low concentrations were found in the literature examined. Thus there is no evidence of a need for general threshold or limit values.

Sampling and analytical methods examined for PTEs (chapter 7)

The study examined sampling frequencies, sampling methods and analytical procedures together with statistical variability in compost testing on the basis of existing compost standards, case studies and inter-laboratory trials.

Random sampling is commonly agreed to be a suitable procedure for testing compost quality approval processes. In line with existing national standards, one sample per 1,000 to 2,000 tonnes of treated biowaste with a maximum of 12 analyses per year can be considered as reliable sampling frequency. However, higher sampling frequencies are required in the commissioning phase applied by external quality assurance systems (QAS).

A minimum of ten consecutive analyses at one composting facility has been recognised as a reliable forecaster of the range and mean values of PTE concentrations, which can be estimated with statistical methods. This figure can then also be used as a reference for possible reduction in the number of normally required analyses. This case-by-case reduction of standard sampling frequencies can be granted by the competent authority or a recognised quality assurance organisation in the frame of a product certification scheme. By statistical evaluation at facility level, expected upper values at a given confidence interval (e.g. 95 %) may give the margin for the identification of facility specific outliers. If an outlier was identified, repeated sampling should be carried out, and if confirmed, specific measures of quality management and a cause study should be applied.

Sample taking: The portions sampled have to be in the same condition as the compost batches used or marketed under the same specification. The minimum number of increments in national regulations and standards range from 4 to 30 from heaps to stocks, depending on the size of the sampled batch. Based on a statistical evaluation of standard errors, a minimum number of 9 incremental samples independent of

the batch size has been singled out as needed. *Sampling points must be distributed evenly* over the volume of the sampled stock.

Repeated sampling and measurements – system of tolerances: In principle we have to distinguish between two types of tolerances for an analytical result:

- 1.) tolerance which refers to the standard error of the analytical procedure in order to estimate the *true value* of a single measurement
- 2.) tolerance which refers to an analytical result *relative to given quality classes* or limit values

In the case of *sampling on behalf of the compost producer* the experience of investigations on parallel sampling of batches led to the conclusion that it may be advisable to carry out parallel, distinct sampling from one sampled batch. This would tackle the lack of homogeneity of compost materials better than a repeated testing of one single combined laboratory sample.

As a consequence, coefficients of variability of parallel sampling procedures have to be considered. On the basis of the examined studies, as well as of the repeatability factors laid down in analytical standards, for composts a coefficient of variability of $\pm 30\%$ would be a reliable maximum value for all elements. In this case the number of parallel samples shall be limited to six and after exclusion of statistically identified outliers, the mean value of the repeated measurements has to meet a given threshold value.

Furthermore, a system of tolerances for an individual measurement result in a series of compost batches should be considered. Making reference to the German Biowaste Ordinance one sample out of four (25 %) may exceed the limit value by 25 %, but the sliding mean value of the most recent four samples must still be below the limit value.

When it comes to a *control measurement on behalf of the competent authority* the overall variability of composting processes as well as the sampling and analytical procedure and the coefficient of variation between individual laboratories have to be considered.

Therefore it is recommended to establish an additional tolerance relative to the set limit values regarding the recognition of a *control sample*. The evaluation coefficients of variation (CVs) of inter-laboratory trials (ILTs) and the batch related CV led to the conclusion that a tolerance of 50 % is accepted in the case of an external controlling procedure on the market place.

Extraction method for PTEs: Since the *aqua regia* method was adopted by the CEN Technical Committees³ and as the majority of experience with compost is based on this extraction method, it seems to be a reasonable way forward to refer to EN 13650 for greater consistency.

Concepts of quality definitions for waste derived organic fertilisers (chapter 8)

Three basic options are available in order to determine "safe" limit values for potential toxic elements (PTEs). They vary according to the viewpoint adopted:

- 1.) Risk based assessment such as the No Observable Adverse Effect Levels (NOAEL) concept
- 2.) Mass balance or No Net Accumulation (NNA) in relation to the concentration of contaminants in the soil (precautionary approach)

There are two options for a NNA concept:

- i. Limiting **PTE/OP concentrations** in fertilisers and soil amendments to the same level of soil background concentrations ("*same to same*" or "*similar to similar*")

³ "Sewage Sludge" (CEN TC 308; EN 13346 "Characterisation of sludges – Determination of trace elements and phosphorus – Aqua regia extraction methods") and "Soil improvers and growing media" (CEN/TC 223; EN 13650 "Soil improvers and growing media - Extraction of aqua regia soluble elements").

- ii. Limiting the **PTE/OP load** so that it matches the amount of tolerable exports from soil via harvested crops, leaching or erosion (“*import = export*”)
- 3.) Between those two polarities manifold hybrid systems and indicators such as the assessment of predicted environmental concentration (PEC) in comparison with the predicted no effect concentration (PNEC) are discussed.

A long-term sustainable strategy will always seek for a combination of measures, which fulfil both:

- i. the maximisation of benefits of recovering organic matter (and nutrients thereto linked), and
- ii. the minimisation of inputs of contaminants that may adversely affect soil functions and human, animal and plant health.

The **Risk assessment based on No Observable Adverse Effect Levels (NOAEL)** is discussed using the example of the *US EPA Part 503 Risk Assessment* for the use of sewage sludge where 14 different pathways were assessed for risks associated with each of the pathways. The key arguments of published criticisms relate to the *non-protective aspects* of the assumptions and the underlying approach. For example, this may be underlined by the fact that *Part 503* allows a yearly Cd load through the use of *bag sludge* (this is the higher quality of sludges defined under Part 503) of 1,900 g ha⁻¹, resulting in an estimated increase of the soil Cd concentration of 0.63 mg Cd kg⁻¹ soil d.m. year⁻¹. As a consequence soil is considered as a sink for PTEs as long as no harm occurs within the food chain, but long-term sustainability of soil management tends to be overlooked. This is why Europe has historically adopted and enforced an approach aimed at preserving soil safety in many regulatory provisions. Such an approach is reflected in both of the following concepts.

In the **mass balance / no net accumulation concepts** soil itself is the first subject of protection. Precautionary limit values are designed to safeguard soils against future impacts. In its pure interpretation, the precautionary approach may be regarded as avoiding any increases of soil PTE concentrations above current values. This means that additions of PTEs from soil improvers, fertilizers and the atmosphere should equal the losses via leaching, plant uptake and erosion. Two general options for integrating this concept at the operational level have been formulated: (i) avoidance and/or decrease of pollutant input to zero; no change of given background concentrations and (ii) limiting inputs to (provisionally) tolerable outputs (zero balance; critical-load-concept). A restrictive limitation following a “no net accumulation” policy may, for instance, lead to a maximum compost application of about 2-3 tonnes ha⁻¹y⁻¹ and would therefore preclude the benefits of humus management even with high quality composts in agriculture.

The report discusses in detail different *critical load* or *no net accumulation* concepts designed for an unique evaluation of all types of fertilisers, which have mainly been brought up on the background of the German Soil Protection Ordinance. Here the key disadvantages and critical aspects of those concepts are indicated:

- Maximum PTE loads are non science based arbitrary settings.
- Results often depend on the assumed phosphorus content in organic fertilisers, which shows a considerable variation even for composts (0.4 – 1.2 % P₂O₅ d.m.).
- The organic matter supply especially with composts is underestimated.
- The rigour of some of the concepts would exclude 100 to 50 % of produced compost based on qualities achievable under the condition of source separation of organic waste.
- The concepts are not based on the reality of achievable PTE concentrations, even with proper strategies for source separation of clean feedstocks, considering (i) the background contamination from diffuse sources (this makes the approach typically an “end-of-pipe” solution) and (ii) necessary tolerances due to local, seasonal and analytical deviations.
- None of the concepts questions the factual effect of the application system to the soil at least on a mid term scale. But this would be the key element in order to estimate the environmental impact and the maintenance of soil functions in the agro-eco system.

Hybrid systems have therefore been developed in order to overcome the shortcomings of both previous approaches. Similarly to concepts focused on “no net accumulation”, hybrid systems focus on the long-term preservation of quality of soils; anyway, in order to avoid any “end-of-pipe” solution, these systems consider the quality achievable through source separation (which tends to exclude from the composted stream the “avoidable” load of pollutants) and check the profile of accumulation in time. The definition of threshold limits therefore allows for slow, provisionally tolerable accumulation, if this is kept well within “safe” thresholds for the soil itself, in order to benefit from organic matter and nutrients vectored by compost onto soils, whilst allowing for a time window long enough to work effectively on further reduction of pollution at industrial and other sources. However the key element of such a concept is the proper and science based derivation of so-called *soil precautionary values*. This would have to take into account the following:

- i. Proportions for different pathways [soil-plant-groundwater-food chain, etc.],
- ii. the balance of additional inputs in the range between background and precautionary values from different sources based on total contents within a long term time frame (e.g. 200 years) and a soil use specific depth,
- iii. mobile fractions and threshold concentrations which would lead to a measurable effect on the environment and
- iv. site-specific differentiation regarding current pollutant status.

Based on this it has to be taken into account that organic matter cannot be given up, and related hazards have to be tackled at the source (improving industrial processes, decreasing diffuse contamination). The application is therefore beneficial and environmentally sustainable as long as the quality of materials is high (primarily due to separate collection schemes for feedstocks) and as a consequence, the accumulation profile allows for a long enough time frame to solve the problem of diffuse contamination at source. Any soil managed within such framework will therefore fulfil the requirement of multifunctionality if

- i. ecotoxicological effect thresholds (balanced with data on background values) are not exceeded, even once a certain “safety factor” is considered to reduce the threshold,
- ii. there is no evidence of unwanted or hazardous effects on plants and groundwater at this concentration level,
- iii. there is an adequate distance (safety factor) to the trigger values proposed for the pathway “soil to humans”.

Recommendation for a step-wise concept for the sustainable use of compost (chapter 9)

An important element of a comprehensive concept is that the assessment of benefits derived from Good Agricultural Practice (GAP) requirements and the potential adverse effects of contaminants are performed independently in a step by step manner, rather than linking or weighing the desirable and undesirable effects through arbitrary balance equations (e.g. the relation between P and Cd content). This approach guarantees the acknowledgement of the full range of beneficial effects intended through the application of organic fertilisers.

The authors have therefore adopted a crosscutting step-wise approach to check the effects of the accumulation of PTEs in soil; according to this approach, unit loads (tonnes ha⁻¹ dry matter) assumed as the input load in scenario calculations have been singled out after a thorough evaluation of possible limiting factors or, conversely, agronomic needs for the application of compost.

The following steps have been followed:

- I. Identify the benefits of the fertiliser/soil amendment to the agro system (e.g. relevant amounts of organic matter or plant nutrients);

- II. Identify potential pollutants which may have any adverse effects to the agro-ecosystem, to the environment or the food chain;
- III. Define the limiting factor – in terms of maximum applicable loads;
- IV. Calculate the response – in terms of accumulation of pollutants - to the outcome of step III. Incidentally, we have to remark that assessing the accumulation at maximum applicable loads depicts a “precautionary” approach, since any lower load would factually translate into a slower profile of accumulation.

The assumptions made for the calculated scenarios are based on the following:

- **Soil threshold values:**
 - The “precautionary” values of the German Soil Protection Ordinance for sandy and clayey soils; these values are regarded as one of the most stringent approaches to soil safety in Europe;
 - The proposal of the Joint Research Centre (JRC) for acidic to neutral soils ($6 < \text{pH} < 7$), which were suggested for a revision of the EC Sewage Sludge Directive on the basis of European soil surveys on PTEs.
- **Compost PTE concentrations**
 - A statistically weighted average of seven country-median (or mean) values and the 90th percentile values
- **PTE outputs from the system**
 - Average total export of heavy metals via harvest (cereals, maize, sugar beet, potatoes) and leaching taken from figures in Germany.
- **Scope**
 - 100 and 200 years as reference time frames for the accumulation of PTEs against the assumed soil threshold values in order to allow for a sufficiently long time-frame to address the issue of diffuse contamination at the source through improved technology in industrial processes, transport etc.
- **Soil depths and density**
 - 20 and 30 cm at 1.5 g cm^{-3} resulting in 3,000 and 4,500 t ha^{-1} respectively.
- **Soil background concentrations for PTEs**
 - Differentiated for sandy and clayey soils taken from average values of national surveys of three European countries (DK, FR, DE).
- **Yearly application of compost**
 - This is derived from a lower ($30 \text{ kg ha}^{-1}\text{y}^{-1}$) and higher ($60 \text{ kg ha}^{-1}\text{y}^{-1}$) phosphorus supply on the basis of P_2O_5 contents in biowaste compost (0.65 % d.m.). It resulted in 4.6 and 9.2 t d.m. compost $\text{ha}^{-1}\text{y}^{-1}$ respectively
- **Mineralisation rate of compost incorporated into the soil**
 - Some authors calculated that up to 8 % of the organic matter applied as compost would remain in the soil on a mid to long-term basis. In this model a more cautious approach was taken, and the retained OM was assumed to be 6 %;
 - The level of OM in composts was assumed to be 36 % d.m., which equals a mineralisation rate of 30 % relative to the total dry matter mass. Accordingly, the increase of soil mass was set to 70 % of the annually added compost dry matter mass. The calculated concentrations of PTEs are related to the soil mass at the assumed soil depth (20 or 30 cm) plus 70 % of the yearly applied compost mass. This equals 6.44 t in case of a yearly compost application of $9.2 \text{ t ha}^{-1}\text{y}^{-1}$.

Further, this study presents a *possible approach towards threshold values for composts used in agriculture* after considering both general accumulation scenarios and actual compost qualities. The approach takes into account the following:

- Temporal and regional variations as well as the variation within an individual composting plant, which goes beyond any effective control strategy (as for example effective source separation).
- The possibility that 90th percentile values may occur in individual facilities across Europe due to regional background concentrations in feedstock materials.
- Countries which are in the starting phase of source separation showed PTE concentrations 7 % (Cr) to 56 % (Ni) higher than EU average concentrations. Possible explanations for this result – probably more important than only the efficiency of source separation – are discussed in detail.
- Even allowing for 10 years of regular compost application on soil at the highest allowable PTE concentrations, increases caused by PTE accumulation would hardly be detectable by current analytical methods.

[A] Findings of the general accumulation scenario on the basis of actual compost qualities in Europe:

- Chromium will not reach the soil limits under any of the assumed scenarios.
- In the scenario for *clay soils* assumed soil thresholds will – with the exception of Zn (150 mg kg⁻¹ after 137 years) – not be exceeded up to 200 years of compost application.
- On sandy soils Cu, Hg (only at 20 cm soil depth) and Zn exceed the soil threshold values within 100 years (mainly with application rates of 9.2 t ha⁻¹y⁻¹ and at 90th percentile compost concentrations).
- In the case of sandy soils, Cu at high application rates (9.2 t ha⁻¹y⁻¹) and Zn even at the low application rates (4.6 t ha⁻¹y⁻¹) must be considered the most critical elements compared with achievable BWC quality. However, their function as trace elements essential for plant nutrition has to be taken into account in the overall fertiliser regime.
- Significantly higher concentrations in composts for the elements Cu and Zn (and to a lesser degree for Ni, Pb and Cd) than the 90th percentile assumed in the model calculation might require a site specific evaluation if such composts are to be used continuously on sensitive sandy soils in the long run.

[B] Scenario findings and justification of the proposed approach towards threshold values for composts used in agriculture:

- The regional and seasonal variations of Biowaste and Green Composts are based on unavoidable background concentrations, which fluctuate even in similar collection schemes and purity levels.
- It has to be recognised that due to specific regional background concentrations, the 90th percentile of country/Europe-wide produced composts may actually represent the average quality of composts achieved at a single composting plant in a certain region.
- Countries in the starting phase of separate collection systems show 10 to 50 % higher PTE concentrations in Biowaste Compost and Green Compost. This has to be considered in the light of (i) the still limited data set and the comparatively low reliability of sampling/testing methods (ii) the inability to distinguish between facilities producing compost from biowaste only and those also including sludge (frequently considered jointly in available statistics as “source selected materials”).
- Based on the evaluation of material specific, regional and temporal variability a 50 % tolerance was added to the 90th percentile value of European BWC [level 1] and the averaged 90th percentile of ES and UK composts as representatives for *starting phase countries* mentioned above [level 2]. Table S1 gives a comparison of the resulting concentrations with the proposed limit values of the Working Document “Biological treatment of biowaste” (2nd draft) and the averaged limit values for BWC in European countries.

Table S1. Possible approach for compost limit values derived from the accumulation scenarios for sandy soils (mg kg⁻¹ d.m.)

		Cd	Cr	Cu	Hg	Ni	Pb	Zn
90-percentile EU all		0.89	37.4	79.5	0.35	29.7	105.2	284.2
90-percentile UK & ES		1.27	42.8	113.1	0.43	42.1	133.4	314.0
Difference [(UK&ES)-EU]/EU (%)		+47	+7	+53	+43	+56	+52	+14
90-percentile EU + 50 %	[level 1]	1.3	60	110	0.45	40	130	400
90-percentile UK & ES + 50 %	[level 2]	1.9	64	170	0.65	63	200	470
Averaged limit values of EU countries		1.4	93	143	1.0	47	121	416
WD 2 nd Draft ¹⁾	class 1	0.7	100	100	0.5	50	100	200
	class 2	1.5	150	150	1	75	150	400

¹⁾ EU Commission, DG Environment. Working Document (WD), 2nd draft: "Biological treatment of biowaste"

- [level 1] can be recommended as general threshold for sustainable, regular use of compost in food and feeding stuff production as well as hobby gardening.
- In order to guarantee comparability between well "stabilised" or mineralised composts and "young" ones (in which concentration of PTEs due to the loss of *organic matter* has not fully occurred, yet) measured PTE concentrations should be standardised to a fixed organic matter content (e.g. 35 or 40 % d.m.). This would be a fair proof of compliance with set limit values and balances the sometimes highly varying degree of mineralisation in composted materials.
- In any case, the calculated increase of PTE concentrations in the soil due to annual compost applications is hardly detectable by analytical means prior to 10 years of application.
- The allowance of a transition period of about 10 to 15 years for the use of [level 2] composts (see Table S1) in food and feeding stuff production may be acceptable from the viewpoint of environmental and soil protection. This would be a viable way in order to
 - allow countries in the starting phase of separate collection systems to improve collection schemes and quality management during the implementation phase;
 - give enough time to improve sludge qualities from industrial and urban wastewater treatment for the use as feedstock of composting.
- However, when sewage sludge or animal manure (specifically pig manure) is used as source material, PTE concentrations of [level 2] could in some cases not be met in the case of Cu and Zn. This requires further efforts for improvement of quality at the source.
- In terms of practicability and a flexible application system, applied quantities may be seen as average yearly dosage within a time span of 20 years. In other words for land reclamation projects for the restoration of degraded soils a maximum incorporation of approximately 200 tonnes per hectare should be granted under consideration of all relevant environmental aspects (i.e. water conservation etc.)
- The graphs presented in chapter 9 of the study show that even at high application rates (9.2 t d.m. ha⁻¹) [level 1; see Table S1] composts would not lead to an accumulation beyond soil reference concentrations for clayey soils within 200 years. The JRC proposal would only be exceeded within 130 years in the case of Zn.
- Thus, for clayey soils, there is still a comparatively wide scope and flexibility for the use of compost. This might be of special importance where a distinct need for the amelioration of degraded soils is recognised (for example, in Mediterranean soils).

- The time span after which reference values for sandy soils would be exceeded when using composts of both proposed qualities [level 1 and 2] is shown in Table S2.

Table S2. Years until precautionary threshold values for sandy soils* are exceeded**

PTE concentration according to:	Cd	Cr	Cu	Hg	Ni	Pb	Zn
	<i>years</i>						
[Level 1]	103	237	60	74	122	97	44
[Level 2]	70	218	39	53	73	61	37

* taken from the German Soil Protection Ordinance

** at 9.2 t compost ha⁻¹y⁻¹

- It is worth noting that at the proposed levels of threshold concentrations, the limiting factor for compost application is still the phosphorus supply rather than the PTE loading. This is particularly true in Central and Northern European Countries, where specific regulatory provisions are being implemented on P supply.
- Some open issues for research and monitoring may be defined, along the following lines:
 - i. Soil concentrations of Cu, Hg and Zn should be regularly monitored on sandy soils, which show *high background concentrations* every 100 to 150 tons of compost application. The definition of high soil background concentration should be made by local authorities based on national soil surveys.
 - ii. Monitoring and research of PTE availability/solubility/mobilisation within pilot schemes with plots fertilised with compost is an important tool for further evaluation of potential impacts due to the input of contaminants by fertilisation systems. It would be of great advantage to establish a cooperative research and monitoring network which integrates existing as well as new field trials covering the most important climate, soil and management conditions for a better understanding of the dynamics of the elements and substances concerned in the soil-plant-groundwater system. In any case, the slow accumulation profile caused by the (comparatively) low thresholds made possible by source separation, allow for the possibility of even long-term research programmes, before any risk can be envisaged.