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Final report

Risk Assessment for the Use of PAS100 Green Composts in Scottish Livestock Production

A quantitative risk assessment that examines the potential for any harm to animal, human health or the environment, resulting from the application of PAS100:2011 source segregated green waste (SSGW) compost products within the Scottish livestock supply chain

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Front cover photography: Spreading compost ahead of crop establishment

Executive Summary

Overall conclusion

Within the limitations of available information, source-segregated green waste (SSGW) compost (and by extension, green compost produced to the PAS100 specification) was found to pose no more risk to grazing livestock, or the environment, than other commonly-used soil amendments such as livestock manures. In many situations, SSGW compost was found to pose less risk than other commonly-used soil amendments.

Introduction

This report outlines the findings of work commissioned by WRAP (Waste & Resources Action Programme). The project incorporated the views and inputs of a wide range of stakeholders as part of a technical advisory group (TAG, Appendix A) and was undertaken by the James Hutton Institute to produce a quantitative risk assessment that establishes the potential for harm to animal, human health or the environment, resulting from the application of PAS100:2011 source-segregated green waste (SSGW) compost products for certain agricultural uses. The agricultural uses examined were:

- Grazing land;
- Land used to grow grain crops for animal consumption;
- Land used to grow root crops for animal consumption;
- Land used to grow leaf crops for animal consumption.

Where possible, this assessment considered SSGW compost that had been produced to the PAS100:2011 specification. However, data sources identifying SSGW compost as having originated from a PAS100 accredited process are not common, and to facilitate the risk assessment process it was necessary to consider data for non-PAS100 SSGW composts from countries such as Germany or the USA. Activities outside of the scope of the PAS100 specification, such as unauthorized contamination of compost feedstocks or illegal use of composts have not been considered. This assessment examines the potential for harm from a specific product, and therefore does not make predictions about system failure, potential bypass, or illegal activities.

The approach taken within this study followed a classical and widely accepted approach to risk assessment, whichhas been adopted by a number of agencies including Department for Environment, Food & Rural Affairs (DEFRA) and the Institute of Environment and Health; however, it is worth nothing that this approach has the usual limitation that it considers single potentially hazardous agents in isolation from each other. In reality, animals and humans are exposed to a complex mixture of chemicals which do not act in isolation. This limitation is accepted and factors – including a precautionary approach to risk assessment – have been built in to try and deal with these uncertainties.

The two main exposure scenarios considered within the project can be summarised as follows:

- *Surface application to grazing land* – compost spread evenly on the surface of the land and not incorporated into the soil at 25 t ha^{-1} fw (typical application rate) and 50 t ha^{-1} fw (realistic maximum application rate, outside a nitrate vulnerable zone, NVZ) forming a layer 0.4-0.8 cm thick at the base of the grazed sward. Animals were allowed to graze immediately. Soil ingestion rates from the literature were entirely substituted with compost ingestion rates on a dry matter for dry matter basis, calculated from mean available data. Realistic worst-case ingestion rates were taken to equate to the 95 %ile of the mean data for all groups or sub-groups reported in each study, whilst extreme worst-

case ingestion rates were taken to equate to the worst observed mean soil ingestion rate reported by the studies. Realistic worst-case rates were modelled as daily compost ingestion over a period of six years (sheep) and twenty years (cattle). For extreme worst-case rates it was assumed that for three months in every twelve over these lifetimes, livestock ingested compost at the extreme rate.

- *Incorporation of compost in soil and subsequent fodder crop production* – A series of 'dilutions' were applied to the concentrations identified for any agent present in the SSGW compost to represent the impact of application, ploughing into the soil, uptake by the fodder crop and the process to produce animal feed. A number of existing models were used to facilitate this.

Summary of risk assessment findings

Plant-derived toxic compounds

For plant toxins, PAS100 compliant green compost presents a negligible risk to grazing animals. This conclusion is based on the assumption that the feedstock contains roughly 1 % fresh material of those toxic plants that were considered to present a realistic hazard. For a number of the plants, this is likely to be an over-estimation. However, there are no data describing the composition, in terms of plant species, of green waste feedstock material to improve the accuracy of this assumption. It should be highlighted that no degradation data were available for ligustrin (privet) and digitoxin (foxglove). If degradation of these compounds does occur during the composting process, then the relative risks would decrease even further.

Organic pollutants

Reflecting the wide range of organic compound contaminants that are present in the environment, a wide range of these contaminants has been measured in SSGW compost, the majority of which are present at levels not considered to pose an appreciable risk to animals, humans, or the environment. Risk assessment of literature values indicated that a few organic compound contaminants are reported to have been present in SSGW samples at concentrations that may warrant further investigation. However, when SSGW compost is spread, the direct exposure to grazing livestock of any such contaminants of concern is likely to be low. Under the modelling scenarios adopted here, the compound 1,2,3,4,6,7,8-HpCDD may represent a risk to grazing sheep, but this compound was also reported as having been present in a range of livestock manures and other common soil amendments. A more complete understanding of its origins would facilitate further risk reduction for this contaminant.

A risk to sensitive broad-leaved plants was identified from the herbicide clopyralid. Plant material treated with this herbicide is prohibited from composting, but it may be difficult to manage levels of clopyralid entering SSGW from users of this herbicide unaware of this prohibition. However, PAS100 compliant compost does require a tomato plant bioassay that should identify excessive concentrations of this compound.

Potentially Toxic Elements (PTEs)

None of the PTEs were considered to present a significant risk at the levels present in PAS100 green compost. When PAS100 green composts are ploughed into soils, the resulting elevation in concentrations of PTEs in the soil is minimal. As a result, modelled uptake by the majority of crop types is relatively low. However, the models used in this study suggest that uptake of Cd by leaf crops may require further investigation to ensure the sustainability of long-term, repeat applications of green compost containing Cd at the PAS100 limits.

Pathogens
SSGW materials should, by their nature, have relatively low pathogen content prior to composting, and it is important to consider them in comparison not only with other composted or treated products but also in comparison with any risk associated with the land to which they will be applied, since the receiving environment is arguably likely to be no less contaminated than the original SSGW. The pathogens of concern are therefore those that might increase in numbers during the composting process, rather than those which may remain viable but relatively unchanged quantitatively. The key pathogens of concern identified in some samples of SSGW compost are enteric bacteria such as verotoxigenic *E. coli* and *Salmonella*, spore formers (such as Clostridia and Bacilli) and pathogenic fungi such as *Aspergillus fumigatus*. The PAS100 specification limits numbers of *E coli* and does not tolerate any occurrence of Salmonella. It was not possible to complete a full risk assessment for the remaining organisms, but in the context of other commonly-applied soil amendments (such as livestock manures and slurries), it is not thought that SSGW composts pose an additional risk to livestock, particularly when they are incorporated into soils by tilling or ploughing. A thorough examination of potential pathogen risks to grazing livestock through exposure to composts derived from catering (kitchen/food) waste is presented elsewhere (WRAP 2016a).

Invasive weeds
Although the literature is minimal, and for a number of the plants considered indicates that propagules should not survive the composting process, there is still a small theoretical risk (not characterised by this study) that Japanese Knotweed propagules could pass through the composting process – for example, if windrow turning processes are not optimised. PAS100:2011 recognises this and seeks to manage the residual risk through quality testing of the final compost product, which has zero tolerance for any germinating weed seeds or weed propagule growth.

Physical contaminants
Although the potential for contamination of green compost feedstocks with physical contaminants is large, the screening processes required to meet PAS 100:2011 reduces the likelihood of these substances being present in final compost at a size or volume likely to cause an unacceptable risk to livestock, humans or the environment, particularly when composts are incorporated into soil by tilling or ploughing.

Other Environmental Hazards
Although a number of hazards (such as plant nutrients) are present in green compost at levels that could cause harm to the environment, there is a negligible risk of harm if composts are applied to soils according to best agricultural practice.

Comparative risk assessment
The results of the risk assessment carried out for SSGW compost were compared, where appropriate, to risks associated with the following comparator materials:

- Dairy cattle slurry, pig slurry;
- Cattle farmyard manure, pig farmyard manure;
- Laying hen manure, broiler litter.

It was not the intention to repeat the main risk assessment exercise for each of the comparator materials. Instead, published concentrations of agents of concern present in the comparator materials were used in the exposure models developed for SSGW. Where published material was limited, advice was sought from relevant technical experts in the appropriate fields.

The results of the comparative risk assessment suggest that SSGW compost poses no more risk to grazing livestock than other commonly-used soil amendments. SSGW compost has been found to contain slightly higher concentrations of organic contaminants than farmyard manure or slurry based amendments. Even so, levels are not thought to pose an unacceptable risk.

Contents

Glossary

95%CI	95 % Confidence Interval (or limit)
95 %ile	95th percentile
A	Acute soil ingestion rate (Table 2-3)
ABP	Animal By-Product
ACDP	Advisory Committee on Dangerous Pathogens
AD	Anaerobic Digestion
ADD	Average daily dose, mg kg^{-1} d^{-1}
As	Arsenic
ATSDR	Agency for Toxic Substances and Disease Registry
MRL	Minimal Risk Level
B	Boron
BW	Body weight, kg
B[a]A	Benzo-a-anthracene
B[a]P	Benzo-a-pyrene
B[b]f	Benzo-b-fluoranthene
B[k]f	Benzo-k-fluoranthene
BFR	Brominated flame retardant
BOD	Biological Oxygen Demand
C	Carbon
C	Chronic soil ingestion rate (Table 2-3)
Cd	Cadmium
CHR	Chrysene
Co	Cobalt
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
COM / COT	Committees on Mutagenicity / Toxicity of Chemicals in Food, Consumer Products and the Environment
Cr	Chromium
C_s	Concentration (mg kg^{-1}) of the specific agent in the exposure medium
Cu	Copper
DEFRA	Department of the Environment, Food & Rural Affairs
DETR	Department of Environment, Transport and the Regions
DM	Dry matter
ED	Expected dose
Exp	Exposure
F	Fractional time, d
FAO	Food and Agriculture Organisation of the United Nations
FW/fw	Fresh weight
H	High application rate, 50 t ha^{-1} (Table 2-3)
HA	High application rate, 50 t ha^{-1}, Acute soil ingestion rate (Table 2-3)
HACCP	Hazard Analysis and Critical Control Point
Hg	Mercury
IPY	Indeno(1,2,3-cd)pyrene
K	Potassium
k_1,k_2	Empirical, metal-specific constants from the Freundlich equation
L	Low application rate, 25 t ha^{-1} (Table 2-3)

LAS	Linear alkylbenzene sulphonates
LC	Low application rate, 25 t ha^{-1}, Chronic soil ingestion rate (Table 2-3)
LOAEL	Lowest observed adverse effect level
$LOAEL_5$	Lower 95 % confidence interval of the LOAEL
LOI	Loss on ignition
MAFF	Ministry of Agriculture Fisheries and Food
Mn	Manganese
Mo	Molybdenum
MSW	Municipal Solid Waste
N	Nitrogen
NA	Not applicable/not available
NAP	Naphthalene
n_F	Power term from the Freundlich equation
Ni	Nickel
NO_3^-	Nitrate
NOAEL	No observed adverse effect level
NP	Nonylphenol
NVZ	Nitrate Vulnerable Zone
OR	Odds ratio
P	Phosphorus
PAH	Polycyclic Aromatic Hydrocarbons
PAS	Publicly available Specification
Pb	Lead
PCB	Polychlorinated biphenyls
PCDD/F	Polychlorinated bibenzo-dioxins and-furans
PEPFAA	Prevention of Environmental Pollution from Agricultural Activity
PFAS	Perfluorinated alkylated substances
PO_4^{3-}	Phosphate
PTE	Potentially Toxic Element
PVC	Polyvinyl Chloride
QMS	Quality Meat Scotland
QRA	Quantitative risk assessment
Ref Dose	Reference Dose
RfD	Reference dose, mg kg^{-1} d^{-1}
Rin	Ingestion rate of exposure medium, kg d^{-1}
RR	Relative Risk
Se	Selenium
SEPA	Scottish Environment Protection Agency
SSGW	Source Segregated Green Waste
TAG	Technical Advisory Group
TEF	Toxic Equivalency Factor
TEQ	Toxic Equivalents
UF	Uncertainty factor
USEPA	United States Environmental Protection Agency
V	Vanadium
WHO	World Health Organisation
WRAP	Waste & Resources Action Programme
Zn	Zinc

1.0 Introduction

1.1 What is green waste compost and what is it used for?

The continued need to reduce the quantities of biodegradable waste sent to landfill has increased interest in other methods of waste management such as composting followed by application to land. Source-segregated green waste (SSGW) compost is a solid, particulate, sanitized and stabilized organic material produced from garden waste (prunings, trimmings, clippings) segregated from non-biodegradable wastes by householders (source-segregated) and other sources of plant waste such as cuttings from landscape operations and amenity grassland (Slater & Frederickson, 2001). Input material for composting is first shredded and a mixture of leafy and woody materials is prepared to ensure sufficient porosity and moisture, as well as the appropriate carbon to nitrogen ratio for rapid aerobic composting.

The final or finished composted green waste material is deemed to be safer and more stable for soil application than fresh residues. Compost has demonstrable benefits to soil fertility, relieving structural degradation of soils and enhancing carbon stocks. In terms of soil improvement compost has multiple benefits. It can be used to improve soils physically, by enhancing moisture retention, protecting against erosion, improving root penetration and reducing compaction and enhancing aeration. Its application to soils low in organic matter and N, P and K can boost their capital of each and, furthermore, compost can provide a foodsource and habitat for a range of soil fauna. Compost may also reduce soil's albedo and protect crops against frost damage.

However, there are potential risks associated with the application of composted green wastes to agricultural soils. Potentially toxic elements and compounds that are ubiquitous in the environment can also be present in green wastes (Brändli et al., 2005; Brändli, 2006; Taubner & Tippkötter, 2003; Amlinger et al., 2004) and there have been occasional reports of other hazards such as toxic compounds derived from plants and pathogens such as *Legionella* (e.g. Potter & Pitman, 1995; Pitman, 1995; Pravinkumar et al., 2010). Furthermore, application of composts can stimulate microbial priming and mineralization (Kuzyakov et al, 2000), and enhanced degradation of stable carbon stocks, whilst soluble organic carbon leached from green waste compost can co-mobilise residual contaminants in soils and render them available for uptake by receptors such as crop plants (Beesley & Dickinson, 2010). Previous studies have shown that compost may also mobilize certain metalloids by increasing soil pH, an effect that can be evident in the years following greenwaste compost application (Clemente et al. 2010) and may enhance uptake to edible plant parts. However, greenwaste compost has also been found to decrease quantities of Cu and Pb mobile in soil pore water (Karami et al., 2011). In general, compost may reduce Cu and Pb, but may increase exchangeable Zn (Bernal et al. 2009).

There is a range of economic, social and environmental benefits associated with composting. For example, because compost contains organic matter (which is made up partly of carbon) in a stabilised form, when compost is applied to land, much of that carbon is sequestered (or fixed) into the soil. This is why it is estimated that each tonne of garden waste composted and used in agriculture, rather than disposed of in a landfill site, leads to a reduction of between 90 and 230 kg of carbon dioxide equivalent emissions. Some other uses for compost (for example as a component of manufactured topsoils or growing media) could offer even greater savings, since these materials – offset through the use of compost – have higher carbon footprints.

1.2 Application of compost to agricultural land

Maximizing the potential benefits of compost in agriculture requires an assessment of how composts interact with the environment. At the time of writing, the authors are unaware of any formal risk assessment of its use under different agricultural scenarios in the UK. The increased production and use of composts in agriculture has resulted in increased interest in their benefits, but also an increased interest in any disbenefits that might be associated with their use. Interest in the latter aspects of compost has arisen particularly within Scotland's farm assurance sector, which exercises a great deal of influence on Scottish agricultural practices to ensure consumer confidence in the quality of Scottish produce. Particular issues raised around the quality of compost have included: The apparent lack of information on how toxic plants (such as ragwort) degrade during the composting process, and whether toxic compounds are reduced to a sufficient degree during composting so as not to pose a risk to livestock grazing on land to which composts derived from these plants has been applied; The potential for harm from physical contaminants that might be present in composts applied to the surface of grazing land; The potential for harm from potentially toxic elements (such as lead or cadmium) either to livestock that might directly ingest surface-applied compost, or to livestock consuming fodder crops grown on land to which compost has been applied. A separate range of issues have been raised around the quality of food-derived composts, and the probity of applying such materials to land to which livestock might subsequently have access – these are not addressed in this report, which focusses instead on composts derived from 'green' (botanical) wastes only.

1.3 Risk and regulation

The risks of applying composted green waste to land surround both what is present in compost, which may be directly released into the soil upon degradation, and also the effects of substances released from compost on pollutants in soils (through complexation and co-mobilisation). As a quality assurance mechanism, the Publicly Available Specification (PAS) 100 (BSI, 2011) outlines requirements for the selection of input materials, the process of composting, the minimum quality of composted materials, and the storage, labelling and traceability of compost products. It was originally developed by the Composting Association in conjunction with WRAP (Waste & Resources Action Programme) and the British Standards Institution, and published in 2002. PAS100 acts as a baseline specification for the manufacture of composts from source-segregated biodegradable feedstock materials (those that have been separately collected from non-biodegradables, and that have not been mixed, combined or contaminated with other potentially polluting wastes, products or materials).

The minimum quality requirements in PAS100 specify upper limits for faecal indicator pathogens, potentially toxic elements (PTEs), microbial respiration rate (stability), physical contaminants, stones, and weed propagules. They also specify minimum plant response in a germination and growth test as a means of screening for potentially phytotoxic contaminants such as herbicides. The PAS does not specify tests for specific or indicator plant pathogens due to a lack of validated methods. It should be noted that PAS100 is not a regulatory instrument, although composts compliant with this specification may be regarded as recovered or recycled (ie, no longer wastes, even if they are derived from wastes) in Scotland. Where statutory instruments cover specific aspects of compost production and use, these take precedence over the PAS. One example of this is the Animal By-Products Regulations. Table 1-1 summarises the key minimum quality limits set within the PAS and gives a range of concentrations of PTEs found in some green waste composts.

This risk assessment should be read in conjunction with two others commissioned by WRAP to address concerns raised not only by Scottish farm assurance schemes, but a wider range of stakeholders representing sectors as diverse as malting barley and ready-to-eat crops. These other risk assessments include a re-examination of the 2002 Defra Catering Waste

risk assessment (Gale 2002), and a comprehensive examination of the potential risks associated with both green and food-derived composts when used in a number of cropping scenarios. Where possible, these risk assessments have been based on the use of composts produced to the PAS100 specification, since this was felt to offer the most appropriate quality baseline for assessment (WRAP 2016a and 2016b).

1.4 Pathogens in compost

A pathogen is any organism capable of producing disease through infection (Drew et al, 2010). It has been common practice for thousands of years to dispose of human and animal excreta on land, and the intensification of agriculture, the growth of the human and farm animal population and the popularity of organic farming methods may exacerbate the presence of pathogens. In composting, if animal excreta are introduced to the process, pathogens may be present in the resulting compost. In addition, materials such as green compost may become contaminated by organisms such as *Clostridium perfringens* which are common inhabitants of soil, but which only occasionally cause disease in humans or animals. Other organisms which may contaminate compost inputs in the UK include bacteria such as *Salmonella*, *Campylobacter*, *E. coli* (including enteropathogenic and enterohaemorrhagic types such as O157:H7), *Pasteurella*, *Listeria*, *Erysipelothrix*, *Staphylococcus aureus*, *Leptospira*, *Serpulina hyodysenteriae*, mycobacteria including perhaps *M. bovis* and *M. paratuberculosis* (Johne's disease), spore-formers such as *C. tetani* and rickettsias such as *Coxiella burnettii* (Q fever).

The PAS:100 2011 specification for composted material recommends for green-waste compost a temperature of at least 65°C for 7 days with a moisture content of around 50% by weight and with at least two turnings of the material. This has been shown to eradicate most plant pathogens including bacteria (except some spore-formers), fungi (including club root, *Plasmodiophora brassicae*), viruses (including tobacco mosaic virus), protozoa and nematodes (potato cyst nematode, *Globodera rostochiensis*) (Singh et al, 2006; Noble and Roberts, 2003). For most bacterial pathogens such as Salmonella a temperature of 55°C for 4 hours gives a million-fold destruction (in other words it kills 99.9999% of the pathogens) (Gale, 2002). Recent research has indicated that the highly pathogenic avian influenza virus H5N1 is likely also to be rapidly inactivated by the composting process.

Table 1-1 Summary of key upper limits included in PAS100:2011 and example range of PTEs in samples of PAS100 green waste compost

Parameter	Unit	Upper Limit	Range reported in PAS100 green waste composts (n = 18)*
Pathogens *(human and animal indicator species)*			
Salmonella ssp	25g fresh mass	Absent	Absent
Escherichia coli	CFU g^{-1} fresh mass	1000	< 10 - 425
Potentially toxic elements			
Cadmium (Cd)	mg kg^{-1} dry matter	1.5	0.25 - 0.73
Chromium (Cr)	mg kg^{-1} dry matter	100	17 - 89
Copper (Cu)	mg kg^{-1} dry matter	200	31 - 122
Lead (Pb)	mg kg^{-1} dry matter	200	46 - 211
Mercury (Hg)	mg kg^{-1} dry matter	1.0	0.1 - 0.17
Nickel (Ni)	mg kg^{-1} dry matter	50	10 - 17
Zinc (Zn)	mg kg^{-1} dry matter	400	171 - 487
Stability/maturity			
Microbial respiration rate	mg CO_2 g^{-1} organic matter day^{-1}	16	
Plant response			
Germination and growth test	Reduction in germination of plants is amended compost as % of germinated plants in peat control	20	
	Reduction in plant mass above surface in amended compost as % of plant mass above surface in peat control	20	
	Description of any abnormalities	No abnormalities	
Weed seeds and propagules			
Germinating weed seeds or propagule regrowth	Mean number per litre of compost	0	
Physical contaminants			
Total glass, metals plastic and any "other" non-stone fragments >2mm	% mass/mass of "air-dry" sample	0.25 (of which 0.12 is plastic)	
Stones			
Stones >4mm in grades other than "mulch"	% mass/mass of "air-dry" sample	8	
Stones >4mm in "mulch" grade		10	

* WRAP, 2011

1.5 Background to the present work

Reducing waste is now recognised as a major environmental priority. In Europe and the UK, legislation and technical guidance have been developed to address these factors. Specific waste management strategies have been written for England and Wales, Scotland and Northern Ireland. Scotland's Zero Waste Plan (Scottish Government, 2010) sets target levels to:

- Achieve 40% recycling and composting of municipal waste by 2010
- Achieve 60% recycling and composting of municipal waste by 2020
- Achieve 70% recycling and composting of municipal waste by 2025

These targets, and the legal obligations to meet the targets of the EU Landfill Directive (1999/31/EC), mean that the roles of waste reduction together with potentially more sustainable methods of waste management such as recycling, composting and other biowaste treatment technologies including Anaerobic Digestion (AD) are becoming increasingly important. The perceived and actual environmental benefits, as well as associated economic penalties on the local authorities if they fail to divert their waste from landfill make these options increasingly attractive. As a consequence, increasing quantities of compost are being produced – particularly green waste compost, as more local authorities segregate, collect and process biodegradable garden and landscaping wastes.

There are potential risks associated with the application of composted green wastes to agricultural land. Potentially toxic elements and compounds that are ubiquitous in the environment can also be present in green wastes and hence the resulting composts. There have also been occasional reports of other hazards. Different stakeholders have sought clarity around the potential for uptake of toxins and/or pathogens into the food chain (including to milk and meat products) resulting from the use of composts on soils. Additionally, clarity has been sought relating to the presence and possible spread of toxic plants, such as ragwort, through the use of composts. The evidence base to substantiate these concerns is, however, limited. However, if stakeholder and consumer confidence is to be improved, the risks associated with compost application to land need to be assessed and where possible quantified.

This risk assessment was procured by WRAP following concerns raised by Quality Meat Scotland over the safety of composts used in agriculture in Scotland. These concerns were raised in spite of the numerous regulatory and voluntary controls already in place that covered compost production and use. Surveys of the composting industry indicate that agricultural markets are seen as particularly valuable for the long term use of composts, and WRAP wished to commission research that would build end-user confidence in the quality of composts (especially those processed to the PAS100 specification) as well as highlighting issues where further research might be necessary to maximize this confidence. WRAP seeks to develop sustainable markets for composts and to promote the use of composts into markets where it is appropriate to do so.

Particular issues raised around the quality of compost included: The apparent lack of information on how toxic plants (such as ragwort) degraded during the composting process, and whether toxic compounds were reduced to a sufficient degree during composting so as not to pose a risk to livestock grazing on land to which composts derived from these plants had been applied; The potential for harm from physical contaminants that might be present in composts applied to the surface of grazing land; The potential for harm from potentially toxic elements (such as lead) either to livestock that might directly ingest surface-applied compost, or to livestock consuming fodder crops grown on land to which compost had been applied. A separate range of issues were raised around the quality of food-derived composts, and the probity of applying such materials to land to which livestock might subsequently

have access – these are explored in other risk assessments undertaken as part of the 'Confidence in Compost' programme and are not covered here (WRAP 2016a and 2016b).

This risk assessment should be read in conjunction with two others commissioned by WRAP to address concerns raised not only by Quality Meat Scotland, but a wider range of stakeholders representing sectors as diverse as malting barley and ready-to-eat crops (WRAP 2016a and 2016b). These other risk assessments include a re-examination of the 2002 WRc Animal By-Products risk assessment for Defra (Gale, 2002), and a comprehensive examination of the potential risks associated with both green and food-derived composts when used in a number of cropping scenarios. Where possible, these risk assessments have been based on the use of composts produced to the PAS100 specification, since this was felt to offer the most appropriate quality baseline for assessment.

The Publicly Available Specification (PAS) 100 outlines requirements for the selection of input materials, the process of composting, the minimum quality of composted materials, and the storage, labelling and traceability of compost products. It was developed by the Composting Association in conjunction with WRAP and the British Standards Institution prior to first publication in 2002, and acts as a baseline specification for the manufacture of composts from source-segregated biodegradable feedstock materials. Adherence to PAS100 is regarded as conferring a degree of confidence in the quality of composts, and differentiates them from composts produced outwith the framework of an accredited system. It specifies requirements for a quality management system (QMS) for the production of composts to ensure they are consistently fit for their intended use. The QMS requires Hazard Analysis and Critical Control Point (HACCP) planning. PAS100 is for biodegradable materials that have been separately collected from non-biodegradables, and that have not been mixed, combined or contaminated with other potentially polluting wastes, products or materials. It does not permit the inclusion of sewage sludge or its derivatives in compost feedstocks.

The requirements for the minimum quality of composts specify upper limits for human and animal pathogen indicator species, potentially toxic elements (PTEs), microbial respiration rate (stability), physical contaminants, stones, and weed propagules. They also specify minimum plant response in a germination and growth test. The PAS does not specify tests for specific or indicator plant pathogens due to a lack of validated methods. It should be noted that PAS100 is not a regulatory instrument, although composts compliant with this specification may be regarded as recovered (ie, regarded as non-wastes even if they are derived from waste inputs) in Scotland. Where statutory instruments cover specific aspects of compost production and use, these take precedence over the PAS. One example of this is the Animal By-Products Regulations. Table 1-1 summarises the key minimum quality limits set within the PAS.

This report outlines the findings of work commissioned by WRAP. The project incorporated the views and inputs of a wide range of stakeholders as part of a technical advisory group (TAG, Appendix A) and comprised the development of a generalised quantitative risk assessment that seeks to establish the potential for harm to animal, human health or the environment, resulting from the application of PAS100:2011 green composts for certain agricultural uses within the context of livestock production in Scotland. The agricultural uses examined were:

- Grazing land
- Land used to grow grain crops for animal consumption
- Land used to grow root crops for animal consumption
- Land used to grow leaf crops for animal consumption

2.0 General Methodology

This section provides an overview of the methodology used within this generalised Quantitative Risk Assessment (QRA). Specific details and assumptions for individual potentially hazardous agents are described further in Section 3.0.

The aim of this work was to undertake a quantitative risk assessment that establishes the potential for harm to animal or human health or to the environment, resulting from the use of PAS100:2011 green compost products, including the manner in which they were processed and used as shown in Table 2-1. Where appropriate, the risks determined for PAS100 green composts were compared with those determined for other common agricultural amendments such as livestock manures and slurries.

Table 2-1 Summary of green compost products and uses covered by this report

Input Materials	Treatment Method	Output Material	End Use Parameters
• Source-segregated biodegradable plant materials as defined in BSI PAS 100:2011, including plant wastes from parks, gardens and other landscaping activity; cardboard; paper; fruit and vegetable processing wastes (non Animal By-Product (ABP)); biodegradable packaging (PAS100 compliant); untreated wood; seaweed	• Outdoor turned windrow • In vessel	• 0 – 40mm screened compost product(s)	• Agriculture (grazing land) • Agriculture (land used to grow grain crops for animal consumption) • Agriculture (land used to grow root crops for animal consumption) • Agriculture (land used to grow leaf crops for animal consumption)

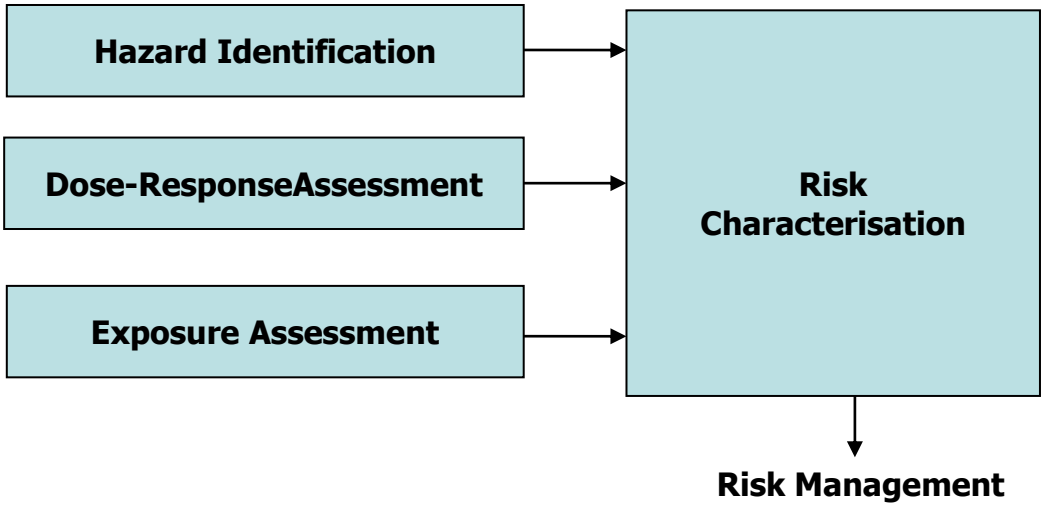
It must be emphasised that this assessment only considered green compost that has been produced to the PAS100:2011 specification. Under certain conditions, SEPA (Scottish Environment Protection Agency) consider composts produced to this specification to be regarded as fully recovered, which means that waste regulatory controls may no longer apply and the compost can be considered a product (SEPA, 2004). Activities outside of this specification, including unauthorized contamination of feedstocks and illegal use of compost have not been considered. This assessment examines potential risks associated with a specific product, and therefore does not make predictions about system failure, bypass of processing systems, or illegal activities.

The work was undertaken using the 'classical model' for QRA. This approach has been adopted by a number of agencies including the Department of the Environment, Food & Rural Affairs (DEFRA) and the Institute of Environment and Health (Defra, 2002)

The standard QRA model involves four key stages, namely hazard identification, dose-response assessment, exposure assessment, and risk characterisation (Figure 2-1). Briefly, the hazard identification comprises a literature-based review to identify which hazards, if any, are of most concern/most likely to be a risk; the dose-response assessment to characterise the magnitude of effect caused by specific doses of specific hazards, the exposure assessment to determine to what extent receptors are exposed to the hazards of concern, and finally, the risk characterisation to quantify the level of risk, i.e. the probability

that a specific hazard will result in a specific adverse outcome. The risk characterisation may then be used to inform 'risk management', i.e. management of risk factors in order to reduce impacts of particular causative agents.

Figure 2-1 The four stages of the 'Classical Model of Risk Assessment'



For this project, seven categories of potentially hazardous agents listed in Table 2-2 were considered. The risks posed by each of these categories under different feedstock, treatment methods, output types, and end uses (listed in Table 2-1) were investigated. For full lists of the agents considered see Appendix B.

Table 2-2 Categories of potentially hazardous agents that might be associated with SSGW compost

Categories of Potentially Hazardous Agents (for full list of agents considered see Appendix B; see Glossary for definitions of terms)	
1	**Toxic compounds present in plants** including Yew (*Taxus baccata*); Ragwort (*Senecio jacobaea*); Bracken (*Pteridium aquilinum*); Rhododendron (*Rhododendron* spp.); Cherry laurel (*Prunus laurocerasus*); Box (*Buxus sempervirens*); Beech (*Fagus sylvatica*); Privet (*Ligustrum* spp.)
2	**Organic pollutants** including PAHs; LAS; NP; PCBs; Antibiotics; Pesticides; Disinfectants; Inks; Residual chlorophenols
3	**Potentially toxic elements** including Zn; Cu; Ni; Cd; Pb; Hg; Cr; As
4	**Animal pathogens and other organisms** including Enterobacteriaceae (*E. coli* O157); *Salmonella* spp.; *Campylobacter* spp.; *Listeria* spp.; *Staphylococcus aureus*; *Clostridium botulinum*; *Cryptosporidium parvum*; Enteroviruses; Enteric organisms such as *Giardia*
5	**Invasive weeds and exotic (i.e., non-farmland) species** such as those that may transfer from gardens to farmland or vice versa including Ragwort (*Senecio jacobaea*); Japanese Knotweed (*Fallopia japonica*); Giant Hogweed (*Heracleum mantegazzianum*)
6	**Physical contaminants** – as listed in Table 3 of PAS100:2011 (glass; metal; plastic; non-stone fragments; stones; sharps)
7	**Other Environmental hazards** including nitrate; phosphate; effects on Biological Oxygen Demand (BOD) of water

In the following sections, the four stages of the QRA method are described in more detail.

2.1 Hazard identification and screening

The approach adopted for this stage of the QRA was adapted from Pollard et al. (2008a). It was considered important by the Technical Advisory Group (TAG) that the assessment should demonstrate that all potentially hazardous agents had been considered where practicable. It was considered neither feasible nor necessary to carry out a full QRA on each potentially hazardous agent identified. Instead, a series of filters was applied to the long list of hazards in order to produce a short list for further quantification. This filtering process has been used effectively in previous projects (Pollard et al., 2008a; Department of Health, 2001).

Initially, for each of the categories listed in Table 2-2, a comprehensive set of potentially hazardous agents were identified. As stipulated by the TAG, information derived from peer-reviewed literature was used as primary source material. Potentially hazardous agents were included in the list if:

- They had been identified or measured in SSGW compost, or
- Evidence was available that specific agents could enter the SSGW composting process assuming 'typical practice' was adhered to. (Typical practice was defined as PAS100 compliant (BSI, 2011) and controlled under a waste management licence or under a paragraph 12 exemption from waste management licensing).

As peer-reviewed data for PAS100 accredited compost are limited, the identification of potentially hazardous agents included other relevant information on source-segregated composts from UK, EU, and North American SSGW composts.

The agents to be considered were organized into the major groupings outlined in Table 2-2. A series of successive, defined, filters were then applied to each grouping to identify those agents considered most likely to present a potential risk to animals, humans, or the environment (Figure 2-2). These filters are discussed in more detail below.

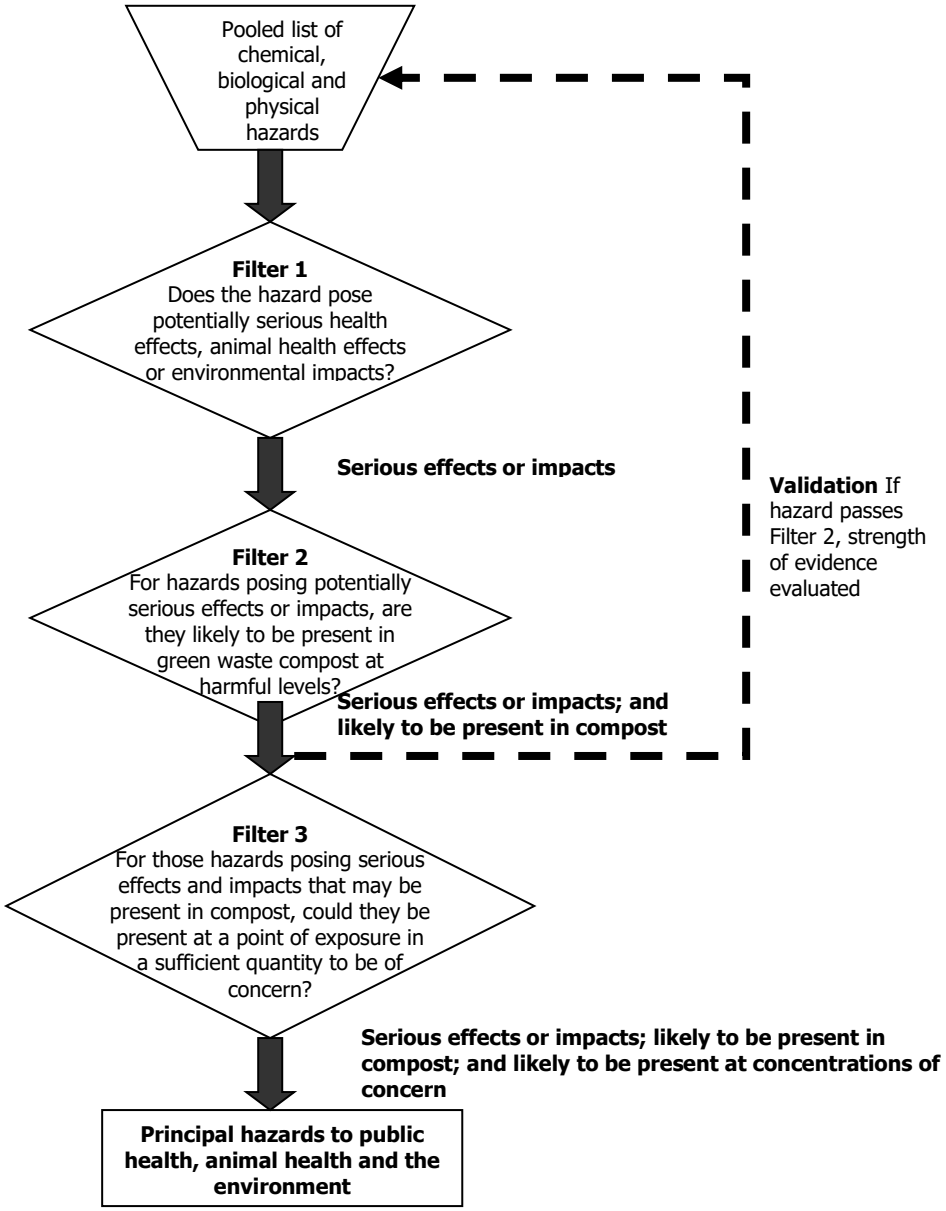
2.1.1 Filter 1

Filter 1 asks whether the agent under consideration has a *potentially serious effect* on animal or human health, or on the environment. This filter does not consider whether exposure is likely to occur, or if exposure would occur at a dose of concern, since these factors are considered in the subsequent filters. A *potentially serious effect* was defined according to the definition used by the European Commission Enterprise and Industry Directorate (European Commission 2005):

"'Serious' means a hazard that could result in death, could be life-threatening, could result in significant disability or incapacity, could be a congenital anomaly/birth defect, or which could result in hospitalisation or permanent or prolonged signs in exposed humans or animals, or which could realistically cause these effects where the product enters the environment."

All other effects were defined as being either 'mild' (i.e. readily reversible causing little/no short-term deleterious effects) or 'moderate' (i.e. reversible, but likely to cause some minor short-term deleterious effects). Where agents under consideration were associated with little or no effect, or where knowledge was insufficient, this was noted. No attempt was made to examine positive or protective effects of agents under consideration as this was considered outside the scope of this study. Only those agents considered to have a potentially serious effect were passed through Filter 1.

Figure 2-2 Flow chart for identifying principal animal health, public health, and environmental hazards from the application of source-segregated green waste compost



2.1.2 Filter 2

Filter 2 considers if each agent is likely to be present in commercially-produced SSGW compost at a level or concentration likely to cause harm to animals, humans, or the environment. This filter is important when considering the composting process and storage of compost. For example, a compound found to be present at a quantity of concern in compost does not necessarily pose a risk to grazing livestock or the environment until the compost has been spread. Further, grazing animals are not likely to ingest a diet of 100% compost, when compost has been spread according to current agricultural practice and other operational constraints (the potential for the compound to pose a risk once the SSGW has been spread is considered in Filter 3). This filter does however highlight agents that could become an issue if good agricultural practice is not adhered to and receptors are exposed to pure SSGW compost.

For some agents, numerous estimates of harmful levels are available. Where this was the case, the level of each agent considered to cause harm was determined using the concept of 'Principle Source Documents' adopted by the Environment Agency (Defra and Environment Agency, 2002). These are set out below in descending order of priority:

1 Authoritative bodies in the UK (DEFRA), Scottish Government, Scottish Environment Protection Agency (SEPA), Environment Agency (EA))
2 European Commission Committees
3 Other national organisations (e.g. United States Environmental Protection Agency (USEPA))
4 Reports produced by authoritative organisations, but for different purposes

Measured concentrations in SSGW compost were then compared to the 'harmful level' identified using the 'Principle Source Documents' concept. Where measured concentrations exceeded the harmful level, these agents passed on to Filter 3 (see below). Where a measured concentration in compost was not available, it was sometimes possible to find measured values for SSGW feedstock. In situations where little data were available describing degradation/hazard attenuation during the composting process a 'worst case' scenario of no degradation was assumed, and the agent passed through to the next stage of filtering.

Any agent that reached Filter 2, and was considered to be present in quantities of concern by virtue of documentary evidence, or potentially present in quantities of concern (where documentary evidence is lacking), was then validated. As stated previously, not all of the literature was related to compost that had been produced to the PAS100 specification. Consequently, the validation process involved further examination of the reliability and appropriateness of the source of information. This included comparability with PAS100 compost, experimental design, and analytical procedures (including provision for Quality Assurance/ Quality Control). Where information was considered unreliable or inappropriate, these concerns were presented to the TAG and wider advisory group and its advisors to reach a consensus as to whether it would be appropriate to consider this particular agent further.

2.1.3 Filter 3

Filter 3 assesses only those agents that have remained after the first two filters have been applied. This filter is concerned with exposure once the product has been spread in accordance with current agricultural practice. This process is further described below.

2.2 Exposure assessment

In consultation with the TAG, the primary exposure of concern was direct ingestion of compost by livestock. Due to this, our assessment was weighted towards modelling this exposure. However, where potential risks to the environment or human health were highlighted, these were also investigated.

The aim of the exposure assessment was to estimate the Average Daily Dose (ADD; mg kg^{-1} d^{-1}) of a specific agent (e.g plant toxin, organic contaminant) to a specific receptor (cow, sheep). In general terms the exposure model can be simplified to the following equation:

$$ADD = \left(\frac{C_s R_{in}}{BW} \right) F \qquad (2.1)$$

Where C_s is the concentration (mg kg^{-1}) of the specific agent in the exposure medium (e.g. surface of soil/pasture); R_{in} is the rate of ingestion (kg d^{-1}) of the exposure medium, BW is the body weight (kg) of the receptor (e.g. sheep, cattle, juvenile, adult), and F is the fractional time of exposure.

In order to satisfy the requirements of Table 2-1, exposure models were developed for the following scenarios utilising SSGW composts: (i) surface application to grazing land; (ii) incorporation into soil for growing grain crops for animal consumption; (iii) incorporation into soil for growing root crops for animal consumption; (iv) incorporation into soil for growing leaf crops for animal consumption. Scenarios ii to iv were combined into a single approach to estimate uptake of identified potentially toxic agents by various crop types. As agreed with the TAG, the exposure models developed simulated the 'realistic worst case scenario' given operational constraints.

2.2.1 Exposure model (i): Surface application to grazing land

In this exposure scenario it was assumed that compost would be spread in a single annual application on the surface of the land and not incorporated into the soil. In contravention of good agricultural practice (but not in contravention of regulations) animals were allowed to graze immediately. Animals would therefore ingest a mixture of herbage, compost, and soil. Therefore, the dose (mg agent/kg body weight/unit time) experienced by individual animals is related to the concentration of a given agent in the compost, the application rate, the ingestion rate, and the body weight of the animal.

Due to the extremely high soil intakes that were modelled (see below) it was agreed with the TAG that this scenario could serve as a proxy 'worst case' for exposures to animals from silage crops grown with SSGW composts. Commentary on potential exposures to animals from fodder crops grown with SSGW compost is included in Section 3.2.6.

After discussions with the TAG, a range of application rates was agreed: 25 t ha^{-1} fw (typical application rate) to 50 t ha^{-1} fw (realistic maximum application rate, outside a nitrate vulnerable zone, NVZ). The compost was assumed to have a bulk density of 0.6 kg L^{-1} fw (The Composting Association, 2005), and would therefore result in spreading depths of 0.4 and 0.8 cm for the two application rates. This assumes all compost was spread evenly. A further assumption was that such a thin layer of compost would settle towards the base of the sward, allowing continued access to the herbage for grazing animals. For modelling purposes, it was assumed that compost ingestion directly replaced soil ingestion (as identified in the literature, and discussed below).

If the stocking density is considered to be a constant, grazing cattle could be assumed to consume 12.5 kg DM d^{-1} (Hodgson et al., 1971; Waddington & Cooke, 1971; Greenhalgh & Reid, 1968, 1969). Using a similar basis, sheep were assumed to consume 4.32 kg DM d^{-1} (Black & Kenney, 1984). From a precautionary standpoint, the bodyweights of livestock were assumed to be relatively low. To achieve realistic bodyweights, average values for older (i.e. more historic) breeds were used. Cattle were therefore assumed to weigh an average of 450 kg, while sheep were assumed to weigh 40 kg (Spector, 1956).

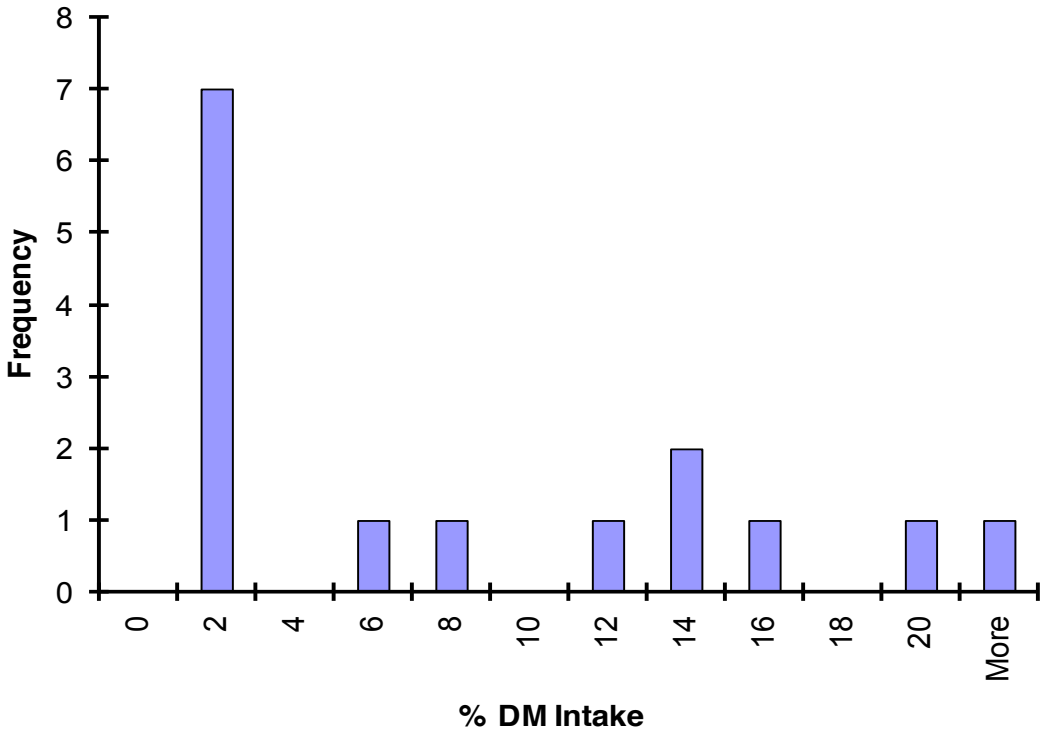
Under the assumptions of this model, soil ingestion becomes a key exposure parameter. It was agreed with the TAG that two scenarios would be modelled: (i) long term soil ingestion at realistic worst-case rates; (ii) short term soil ingestion at maximum mean reported rates.

Soil ingestion data were collated from the available peer-reviewed literature. Under the concept of principal source documents (Section 2.1.2), data were included where studies were performed in the EU. Nine studies providing 14 estimates of mean soil ingestion by sheep, and 19 estimates of mean soil ingestion by cattle were included (Figure 2-3). In all cases mean soil ingestion from groups or sub-groups of animals were presented. It was further agreed with the TAG that realistic worst case ingestion rates would equate to the upper 95 %ile of the mean data for all groups or sub-groups reported in each study. Suitably precautionary timescales for exposure were considered to be 6 years for commercial sheep and 20 years for commercial cattle (which is beyond the lifespan of the majority of farmed

cattle). Extreme worst case soil ingestion rates would equate to the greatest observed mean ingestion rate reported by the studies (Table 2-3), with exposure at these rates for a period of three months in every calendar year over the timescales indicated above (6 years for sheep and 20 years for cattle), and exposure for the remaining nine months of every calendar year set at the upper 95%ile of reported values.

Figure 2-3 Histogram of literature-derived EU data for A) mean soil ingestion by sheep, B) mean soil ingestion by cattle (Abrahams & Steigmejer, 2003; Beresford & Howard, 1991; Fleming, 1986 Thornton & Abrahams, 1983; McGrath et al., 1982; Thornton, 1974; Field & Purves, 1964; Bob Mays, personal communication). All data presented as % dry matter intake

A



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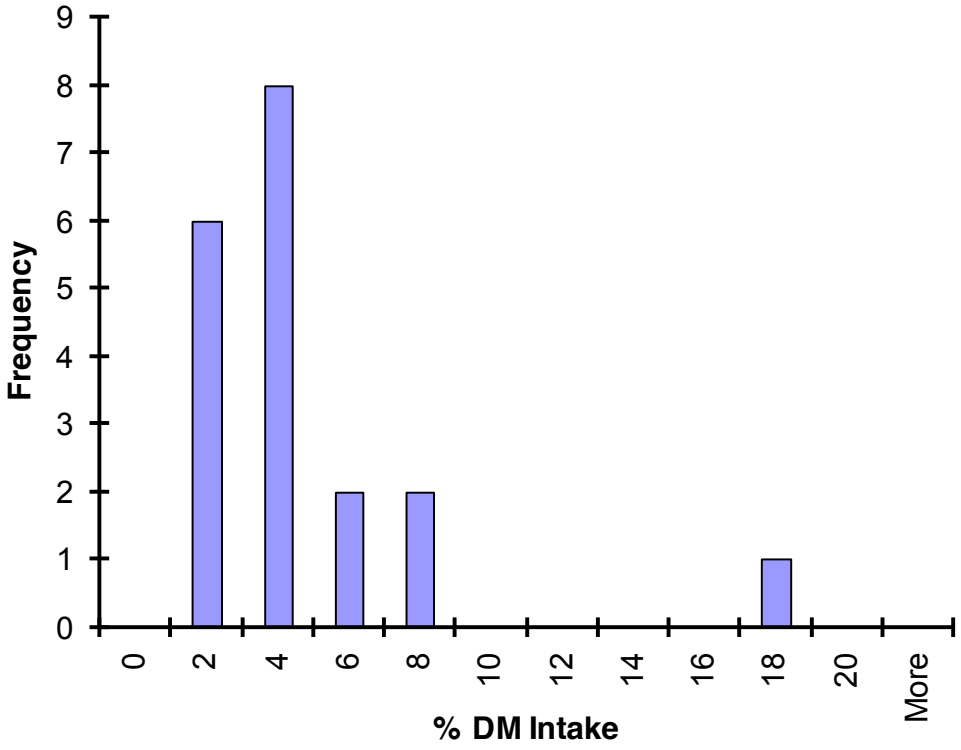


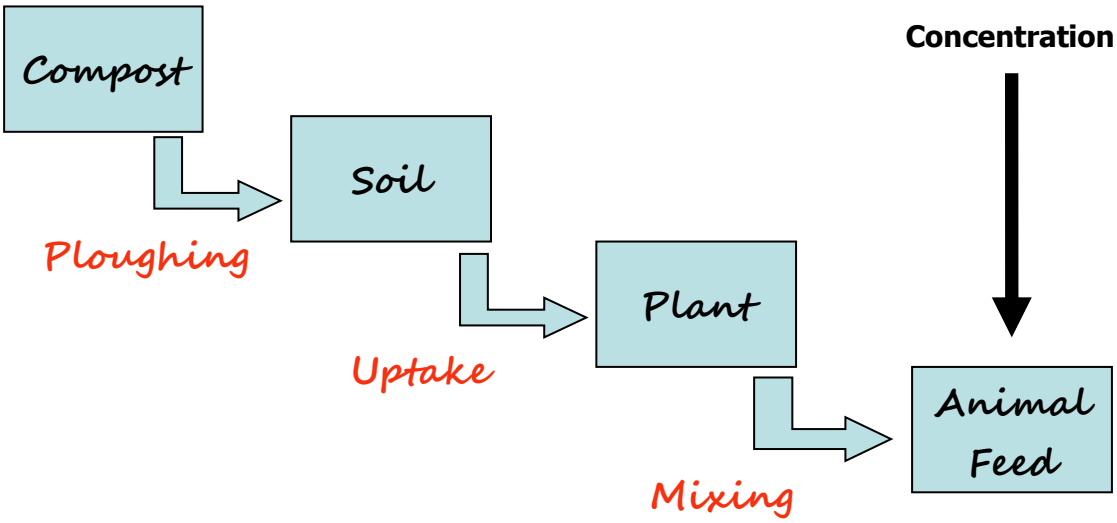
Table 2-3 Soil ingestion rates (realistic and extreme worst case exposure), % of dry matter intake (kg day^{-1})

	Cattle	Sheep
Realistic worst case (95 %ile). For ingestion during nine months of every modelled year.	9.0% (1.13kg)	16% (0.691kg)
Extreme worst case (maximum observed). For ingestion during three months of every modelled year.	18% (2.25kg)	25% (1.08kg)

2.2.2 Exposure model (ii – iv): Incorporation of compost into soil and subsequent fodder crop production

These exposure pathways are further characterised by a series of 'dilutions', whereby the concentration of any agent present in SSGW compost is reduced by application and ploughing into soil, uptake by fodder crops, and processing to produce animal feed (Figure 2-4). In this assessment, the first two dilution factors of ploughing and plant uptake are estimated.

Figure 2-4 Exposure pathway of incorporation of SSGW compost into soil and subsequent production of fodder crops: Reduction in concentration of any agents present in SSGW compost would be expected through the stages of ploughing, plant uptake, and animal feed processing



For incorporation into soil, a plough depth of 25 cm was assumed. If even mixing is assumed, the ratio of the volume of compost applied to the volume of soil can be used to estimate the final concentration of potentially toxic agents in the soil matrix. This concentration is therefore dependent on application rate (Table 2-4).

Table 2-4 Application rates of SSGW compost (t ha^{-1}) and subsequent dilution factors assuming even mixing to 25 cm

Application rate, t ha^{-1}	Dilution Factor
25	166-fold
30	139-fold
35	119-fold
40	104-fold
45	93-fold
50	83-fold

2.2.3 Uptake of Potentially Toxic Elements, PTEs

Plant uptake of inorganic agents (i.e. PTEs) was estimated using models previously developed by the authors (Hough et al., 2004; Hough et al., 2003; Hough, 2002). The uptake of PTEs by plants is highly dependent on soil chemical properties such as pH. Uptake also varies according to crop type, even cultivar. To estimate uptake, it is important to understand the biologically available 'pools' of PTEs in the soil, and how analytical measurements reflect these 'pools'. Broadly speaking, we can categorize analytical measurements of PTEs as measures of quantity, capacity and intensity. Quantity relates to the 'total' amount of PTE in soil which is most often a poor predictor of plant uptake. Capacity is a measure of the potential of the soil to re-supply a particular pollutant when it is

depleted by uptake or leaching or other loss. Lastly, intensity is a measure closer to the pool of pollutant likely to be taken up by plants, such as the soil pore water. The intensity of a pollutant in soil or compost may be very different to its capacity, but both are analogues of bioavailability (Figure 2-5). However, routine measurement of activity say in the soil pore water is not usually undertaken. Therefore it is necessary to predict activity from the principal parameters that control sorption phenomena.

Models based upon a pH-dependent Freundlich relationship can be used to describe metal solubility in soils (Jopony and Young 1994). This approach can be used to predict free metal ion activity in the soil pore water (M^{2+}; 'Activity II' in Figure 2-5) from total soil metal content, which is assumed to be adsorbed on humus, [M_C], (mg of a specific metal per kg of soil organic carbon) and soil pH (Equation 2.2):

$$p(M^{2+}) = \frac{p[M_c] + k_1 + k_2\, pH}{n_F} \qquad (2.2)$$

Where k_1, and k_2 are empirical, metal-specific constants and n_F is the power term from the Freundlich equation.

Metal uptake by vegetables is often characterised by a soil to plant concentration ratio, CR. This concept may be adapted to describe the quotient of metal concentration in the plant [M_{plant}] (mg kg^{-1}) to metal ion activity in soil pore water (M^{2+}) (mol L^{-1}) derived from Equation 2.2 (Equation 2.3):

$$CR = \log \frac{[M_{plant}]}{(M^{2+})} \qquad (2.3)$$

Equations 1 and 2 were combined into a single expression relating [M_{plant}] to pH and [M_C] (Equation 2.4):

$$\log[M_{plant}] = C + \beta_1[pH] + \beta_2 \log[M_C] \qquad (2.4)$$

Where C, β_1 and β_2 are empirical metal- and vegetable-specific coefficients.

The use of [M_C] in Equation 2.4 requires values for organic carbon content (% C). Where values for 'loss on ignition' (% LOI) were reported, these were converted to % C by assuming % C = 0.58 LOI (Rowell 1997). This assumption can lead to over-estimation of soil carbon content at small values of % LOI due to losses of hygroscopic water in clay during the assay of % LOI. However, studies of the relationships between % C and % LOI (e.g. Howard and Howard 1990; Wang et al.1996) have provided only soil-specific conversion equations that cannot be applied generically.

These models have been parameterised to estimate uptake of PTEs by 18 different fruit, vegetable, and cereal crops (Hough 2002) with relatively good results. As an example, Figure 2-6 compares the predicted uptake of Cd by different crops using these models compared to observed values.

Figure 2-5 Relationship between the concentration of zinc in ryegrass and various measures of zinc in soil. Measures of quantity and capacity provide relatively weak associations with uptake of zinc by ryegrass. Measures of activity provide much stronger associations with uptake of zinc by ryegrass (adapted from Hough et al., 2005)

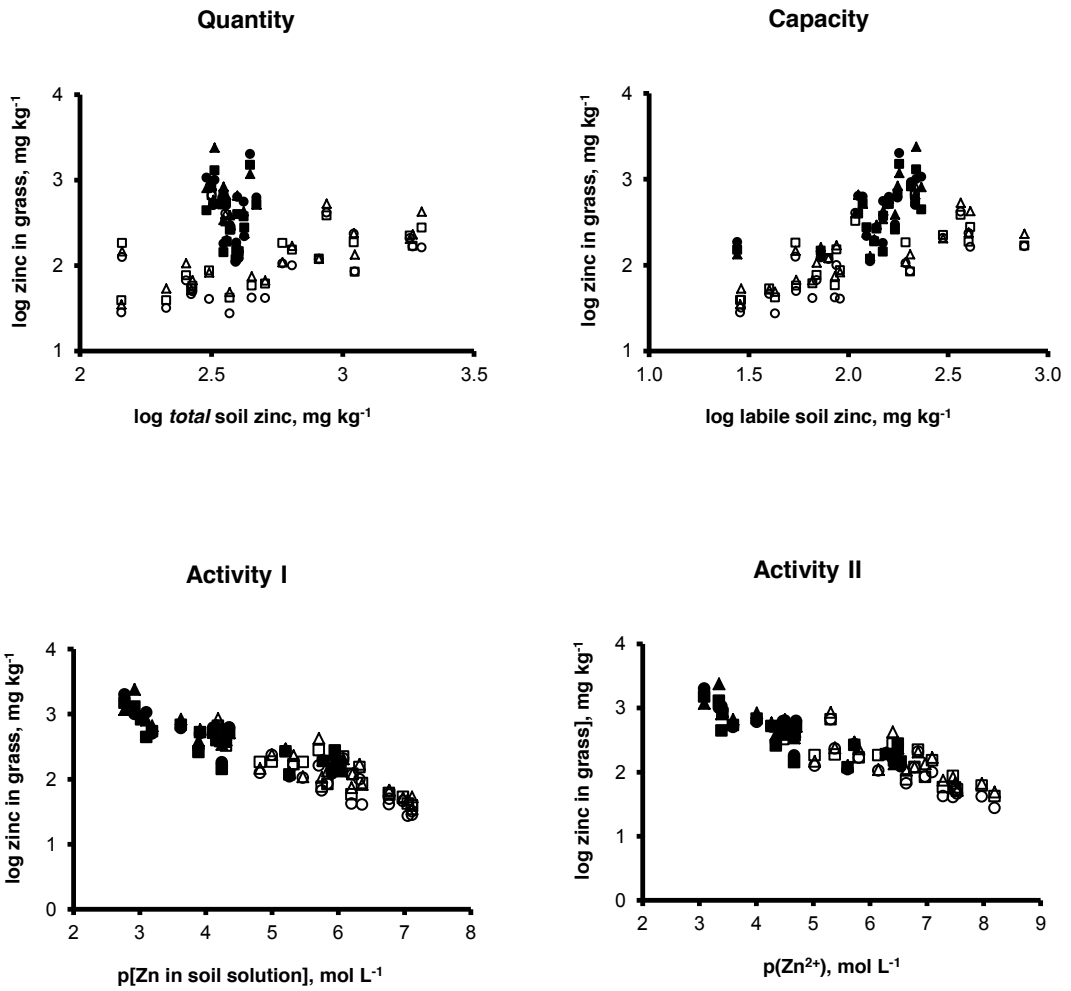
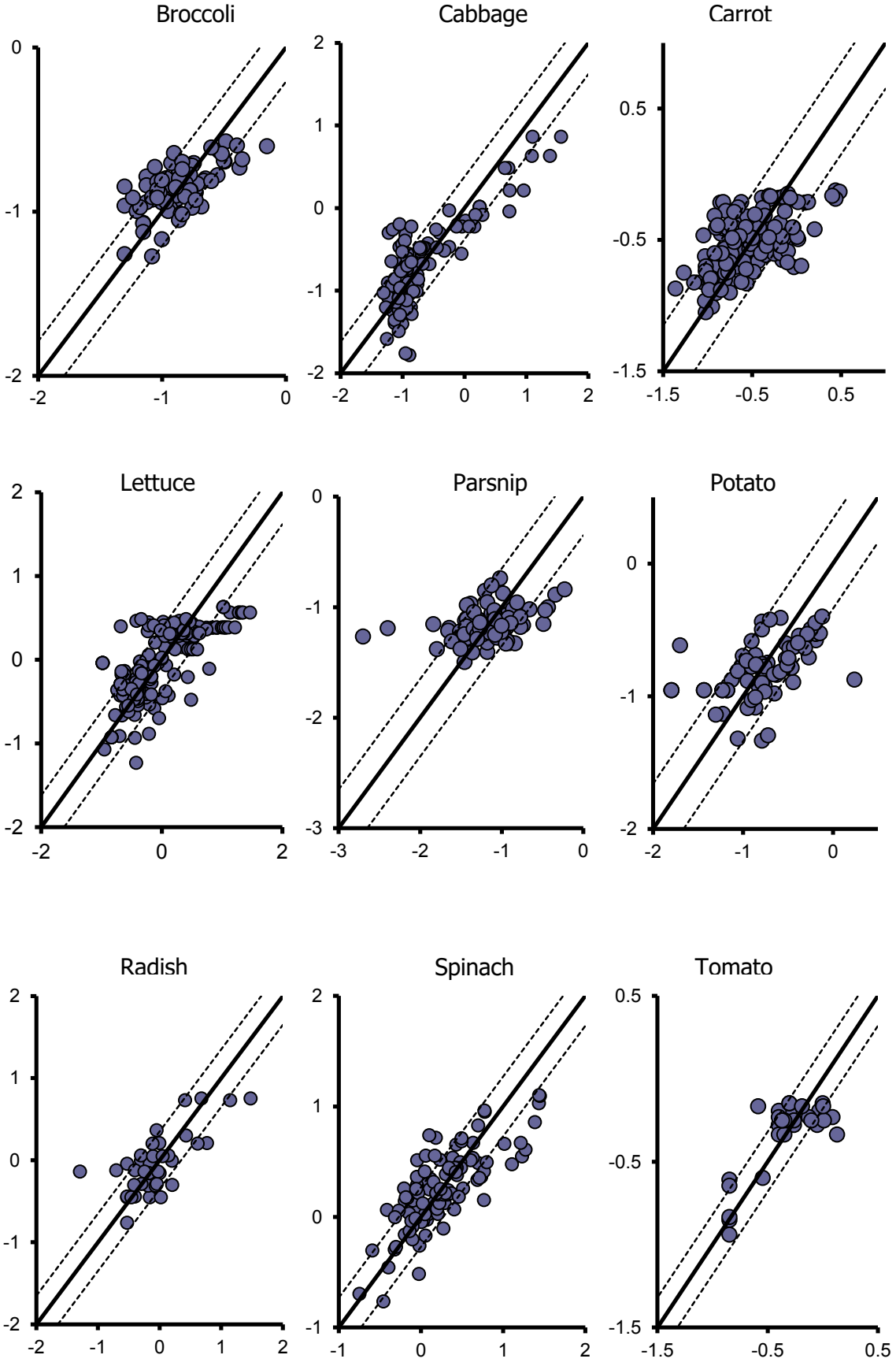


Figure 2-6 Cd uptake by vegetables: predicted (y-axis, log mg kg-1) and observed values (x-axis, log mg kg-1). The upper and lower lines represent 1 RSD from model



2.2.4 Uptake of organic compounds

Uptake of organic agents by crop plants presents various challenges. There are few data describing the uptake of organic contaminants by crop plants and therefore there is limited ability to evaluate the influence of soil chemistry on plant uptake.

Organic contaminants may enter crop plants through several pathways. The main uptake processes include i) uptake with soil water, ii) diffusion from soil or air, and iii) deposition of soil or airborne particles. The importance of the different pathways depends on both the contaminant-specific and plant-specific properties (Trapp and Legind, 2011). Experiments and model simulations have shown that that persistent, polar (log K_{ow}< 3) and non-volatile (dimensionless Henry's constant < 10^{-6}) contaminants generally have the highest potential for accumulation from soil into plants. Concentrations in roots and leaves may even exceed the concentrations in soil (in some cases by several orders of magnitude), which among other things is because the water content in roots (up to 95%) usually is higher than in soils (about 30%). Volatile contaminants have a low potential for accumulation, because they quickly escape to air (Trapp and Legind, 2011).

The crop type is decisive for which uptake processes are more likely to be dominant. For example, the accumulation of contaminants from soil will be higher for root crops than for tree fruits, while the accumulation by uptake from air is higher for fruits. The degree to which physiological plant-specific parameters such as leaf area, transpiration rate, water and lipid contents as well as growth rate affect the uptake is highly dependent on the properties of the contaminant of interest. For example, will water soluble contaminants be rapidly translocated from soil to leaves, and the accumulation in leaves will in this case almost entirely be decided by transpiration rate (Trapp and Legind, 2011).

The uptake of contaminants by plants can be estimated in different ways. A simple way of doing this is through bioconcentration factors (BCFs), which express the ratio of contaminant concentration in an organism (here, the crop plant) to contaminant concentration in the surrounding medium. Measurements of concentrations in plant tissues and concentrations in soil will yield a BCF plant to soil, given by:

$$BCF = \frac{C_{plant}}{C_{soil}} \qquad (2.5)$$

Where C_{plant} is the concentration in plant tissue and C_{soil} is the concentration in soil. Equation 2.5 is analogue to Equation 2.3 for PTEs. BCFs (or regression equations relating BCF to contaminant-specific properties) are usually determined through controlled experiments in the laboratory or in the field. It is important to note that BCFs will only be valid for the exact conditions under which they are estimated, i.e. for the specific contaminant and soil type used for the determination.

A range of mechanistic models cable of simulating plant uptake of organic contaminants furthermore exists (e.g., Fujisawa, 2002; Hung and Mackay, 1997; Passuello et al., 2010; Paterson et al., 1994; Rein et al., 2011; Trapp et al., 1994; Trapp, 2004; Trapp and Matthies, 1995). These models vary in complexity and usually aim at determining either the steady-state or dynamic uptake for specific crop types. Many of these models are based on a multimedia modelling principle; where mass balances are set up and combined for the different compartments considered (e.g., soil, roots, and leaves). Assuming equilibrium partitioning, this leads to relatively simple ordinary differential equations that can be solved analytically. These models are then capable of simulating the partitioning, transfer, and fate of chemical pollutants within and between the different compartments. The actual processes and their parameterization depend on the type of crop and the contaminant properties.

Here, we will apply the standard plant uptake model described in Trapp and Legind (2011), which considers uptake from soil and air into plants. The model includes the compartments soil, roots and leaves (or grains) and is cable of accounting for (Trapp and Legind, 2011): i) continuous and/or pulse input to all compartments, ii) uptake into roots with the transpiration water, iii) translocation from roots to leaves/grains with the transpiration stream, iv) loss from leaves to air, v) deposition from air to leaves, vi) transport to leaves with attached soil, vii) growth dilution, degradation and metabolism in roots and viii) loss from soil due to degradation, leaching, run-off and plant uptake.

However, in order to maintain the precautionary approach, only the steady-state solution for a continuous source concentration is applied here. We furthermore assume that no removal of contaminants occurs due to degradation, infiltration and volatilization. Finally, deposition of particles on the surfaces of leaves or grains is neglected and uptake from air is assumed solely by diffusive exchange in the gas phase. The steady-state expressions are given by:

$$C_{roots} = \frac{Q}{\frac{Q}{K_{rw}} + k_r M_r} C_{w,soil} \qquad (2.6)$$

$$C_{plant} = \frac{\frac{Q_p}{K_{pw}} C_{roots} + A_p g_p C_{air}}{\frac{H}{K_{pw}} A_p g_p + k_p M_p} \qquad (2.7)$$

Where C_{roots} and C_{plant} are the concentrations in the roots and plant (here: leaves or grains), $C_{w,soil}$ and C_{air} are the concentrations in soil water and air, respectively, H is the dimensionless Henry's constant, and k_r and k_p are first-order growth rates of the roots and leaves/grains, respectively. K_{rw} and K_{pw} are the equilibrium partition coefficients between roots and water and between leaves/grains and water, respectively. These can be determined through the following empirical expression:

$$K_{xw} = W_x + 1.22 L_x (K_{ow})^b \qquad (2.8)$$

where W_x and L_x are the water and lipid content of either roots, leaves or grains and b is a correction factor for differences between solubility in octanol and sorption to plant lipids. Based on previous studies, b can be assumed to be 0.77 for roots and 0.95 for leaves/grains (Trapp and Legind, 2011). The remaining plant-specific parameters and inputs used for the calculation are shown in Table 2-5.

Table 2-5 Generic plant-specific input data for the plant uptake modelling (normalised to 1 m^2 area of field). From Trapp and Legind (2011)

Symbol	Input [unit]	Value
Roots		
W_r	Water content of roots [L/kg]	0.89
L_r	Lipid content of roots [L/kg ww]	0.025
Q	Transpiration stream [L/d]	1
M_r	Root mass [kg ww]	1
k_r	First-order growth rate [1/d]	0.1
Leaves/grains		
A_p	Area of leaves [m^2]	5
	Area of grains [m^2]	1
W_p	Water content of leaves [L/kg]	0.8
	Water content of grains [L/kg]	0.15
L_p	Lipid content of leaves/grains [L/kg ww]	0.02
M_p	Mass of leaves/grains [kg ww]	1
ρ_p	Density of leaves/grains [kg ww/L]	1
g_p	Conductance of leaves/grains [m/d]	86.4
k_p	First-order growth rate for leaves/grains [1/d]	0.035
Q_p	Transpiration stream for leaves [L/d]	1
	Transpiration stream for grains [L/d]	0.2

As seen from the above equations, the concentrations of the contaminant in soil water and air are needed in order to estimate the accumulated concentrations in roots and leaves/grains. Here, fugacity modelling (based on adjusted pressures and tendency to move as liquid or volatile phase) (Mackay 2001) was used to estimate the propensity of various organic compounds to partition between the various phases of the soil matrix (i.e. air, water, soil mineral matter, soil organic matter). The fugacity modelling is, like the plant uptake model, based on an equilibrium assumption.

The SOIL model (Mackay, 2001) comprises four environmental compartments: air, water, soil mineral matter and soil organic matter. Densities, volumes, areas and depths of soil are user-specified, enabling total volumes and masses to be calculated, from which individual fugacities and environmental concentrations are derived (Mackay, 2001). The SOIL model has been modified to account for the mixing of the soil with SSGW compost due to ploughing. Table 2-6 presents the soil-specific parameters used for the fugacity calculation. The modified SOIL model was used to estimate the propensity of each organic contaminant to enter the different phases of the soil matrix and the output was subsequently used as input for the plant uptake model.

Although more sophisticated plant uptake models capable of simulating the dynamic behaviour of the soil-plant system exist, we consider the above approach for estimating the uptake of organic contaminants into crop plants appropriate for the current purpose. The chosen plant uptake model is well-accepted, it is simple and relies on relatively few inputs. The use of the steady-state solution is likely to overpredict the concentrations in the crops by orders of magnitude, which is in line with the precautionary approach used throughout this project. In reality the source (concentrations in soil) is better described as a pulse injection. It should be noted that the plant uptake predictions are uncertain due to the large variations in both environmental and plant physiological conditions. Because of the limited data available, the calculations carried out here are therefore by necessity rather crude. Where available, the calculations will be supported by results and conclusions from the literature such as published bioconcentration factors.

Table 2-6 Soil specific input data for the fugacity and plant uptake modelling

Symbol	Input [unit]	Value
θ_w	Water content [L/kg]	0.2
θ_a	Air content [L/kg]	0.25
ρ_{bulk}	Bulk density [kg/L]	1.6
foc,s	Fraction of organic carbon in soil [g/g]	0.058
foc,c	Fraction of organic carbon in compost [g/g]	0.5

2.3 Dose-response assessment

Dose-response data can be described by a model where the dose response parameters are simply the observed frequency of responses (in the case of quantal data), or the observed average responses (in the case of continuous data) at each dose group (COT, 2007). Most data are derived from laboratory experiments where groups of animals, commonly rats, are exposed to a range of doses of the test material.

The majority of toxicity dose-response data relate to exposures, often orders of magnitude greater than environmental levels, to get an observable adverse response in a limited number of experimental animals. Hence care must be taken in extrapolating such data to environmentally relevant concentrations. There are a number of methodological approaches to carry out such extrapolations, including various mathematical curve-fitting models. Since 1995, many agencies, including the UK and the EU have started to use the benchmark dose method. The Benchmark dose (BMD) is defined as the dose associated with a prespecified (small) effect size (Crump 1984). It is estimated from a statistical model fitted to the dose-response data. To take the statistical uncertainties in the data into account, a confidence interval around the BMD is calculated. The lower 95% confidence limit is often termed the BMDL (COT,2007). Moreover, the BMDL may serve as a Reference Point (RP), or Point of Departure (PoD) for deriving a health-based guidance level for human exposure; e.g., Acceptable Daily Intake (ADI), Tolerable Daily Intake (TDI) or Reference Dose (RfD) (COT, 2007). It is considered that the BMD approach for deriving a PoD provides a more robust estimate than the traditionally used NOAEL.

The risk assessment of chemical carcinogens is dependent on the mechanism of carcinogenicity and the relationship between dose and tumour response. From what is known about the mechanism of action of genotoxic carcinogens, in the absence of mechanistic data to suggest a threshold for carcinogenicity, it is currently assumed that there is none (COC, 2012). For most non-genotoxic carcinogens, it is accepted that there is a threshold dose, below which no effect occurs. Many non-genotoxic carcinogens induce tumours as a secondary effect arising from an initial toxic effect, for which a 'threshold' dose may be identified (Ashby et al., 1996). It follows that these substances are unlikely to pose a carcinogenic risk at dose levels at and below the given threshold that does not produce the primary toxic effect (Williams, 2001). For example, although known carcinogens, the COT (2001) concluded there was sufficient information to assume a threshold existed for the effects of dioxins, and hence a tolerable daily intake could be established. COT therefore recommended that a tolerable daily intake of 2 pg WHO-TEQ per kg body weight per day be established, based upon effects on the developing male reproductive system mediated via the maternal body burden. A later re-evaluation of this by WHO-IPCS in 2005 (Van den Berg, 2006) was ratified by COT (2006) and resulted in slightly updated toxic equivalency factors (TEF) for dioxin and dioxin-like compounds. The result of this re-evaluation was a slight reduction in the estimated exposure of the UK populus to the activity of those compounds; Toxic Equivalency Factors (TEFs) are toxicity potency factors that are used by the World Health Organization (WHO) and regulators as a consistent method to evaluate the toxicities of highly variable mixtures of dioxin compounds. This approach was favoured by some

members of the TAG, including the Food Standards Agency. While TEQs are the standard approach, it was considered appropriate for this study to also assess each congener separately because: (i) published data on the levels of all congeners in SSGW compost were not available; (ii) there are differences in the extent to which different congeners move through the environment. In the present study, dioxins and dioxin-like PCBs were assessed both on an individual basis, and collectively using Toxic Equivalency Factors (TEFs) and Toxic Equivalents (TEQs); these can be found in Table Table 3-20.

For both organic pollutants and PTEs, estimates of exposure (ADD) could be compared directly to reference doses (RfD) published in the literature. However, for the plant-derived toxins, RfD values had to be estimated from reported NOAELs as there were no published RfDs. This was done following the method of the United States Environment Protection Agency (Equation 2.9; USEPA, 1996):

$$RfD = \frac{NOAEL_5}{UF_L UF_H} \qquad (2.9)$$

The RfD is considered to be a daily dose to which the receptor can be exposed without experiencing any deleterious effects. The RfD is determined by applying Uncertainty Factors (UF) to the NOAEL (Barnes & Dourson, 1988; Clegg et al., 1986). In this study, a maximum of two uncertainty factors were applied to the lower 95 % confidence interval of the NOAEL ($NOAEL_5$). The first UF (UF_L) was used to account for uncertainties associated with extrapolating from the experimental population to the population at risk. This UF was applied where species differences existed, e.g. extrapolating from an experimental rat population to a herd of cattle. Where toxicity data were available for cattle, this UF was not applied. The second factor (UF_H) was used to account for variability within receptor populations, e.g. differences in the amount of compost consumed, differences in the inherent susceptibility of different members of the herd (Barnes and Dourson, 1988). Following this standard approach, each UF was assigned a value of 10 (WHO, 1999). The reference doses for the different potentially hazardous agents are given in Appendix E alongside their associated uncertainty factors. In the EU/UK it is not standard practice to use RfD values; an Acute Reference Dose (ARfD) is generally calculated to 'estimate', on a bodyweight basis, exposure to a given chemical to which a human population can be exposed over a short period of time (24 hours or less), without an appreciable risk of deleterious effects during a lifetime.

EFSA has recently published a Scientific Report (2013) giving guidance on human risk assessment of combined exposures to multiple chemicals. This report deals comprehensively and gives advice on current best practice terminology, as well as a tiered approach which takes into account toxicity and exposure. It gives particular advice on how to deal with Modes of Action (MoA).

2.4 Risk characterisation

As agreed with the TAG, our primary focus was on characterising risks posed to grazing animals, although risks posed to the environment and human health were also considered where appropriate. 'Risk' was defined as the modelled probability that after spreading composted green waste on agricultural land, an individual animal or environmental receptor would experience deleterious health effects or reduction in meat/milk quality from either direct ingestion or ingestion of fodder crops post-harvest. This approach of calculating risk on an individual basis is the most appropriate because associated legislation, e.g. food safety, is based on individual meat/milk products, rather than on the market as a whole.

Risk was calculated as the ratio of the exposure (Average Daily Dose, ADD, mg kg^{-1} d^{-1}) to the appropriate reference dose (RfD, mg kg^{-1} d^{-1}) derived in Section 2.3 (Equation 2.10). If

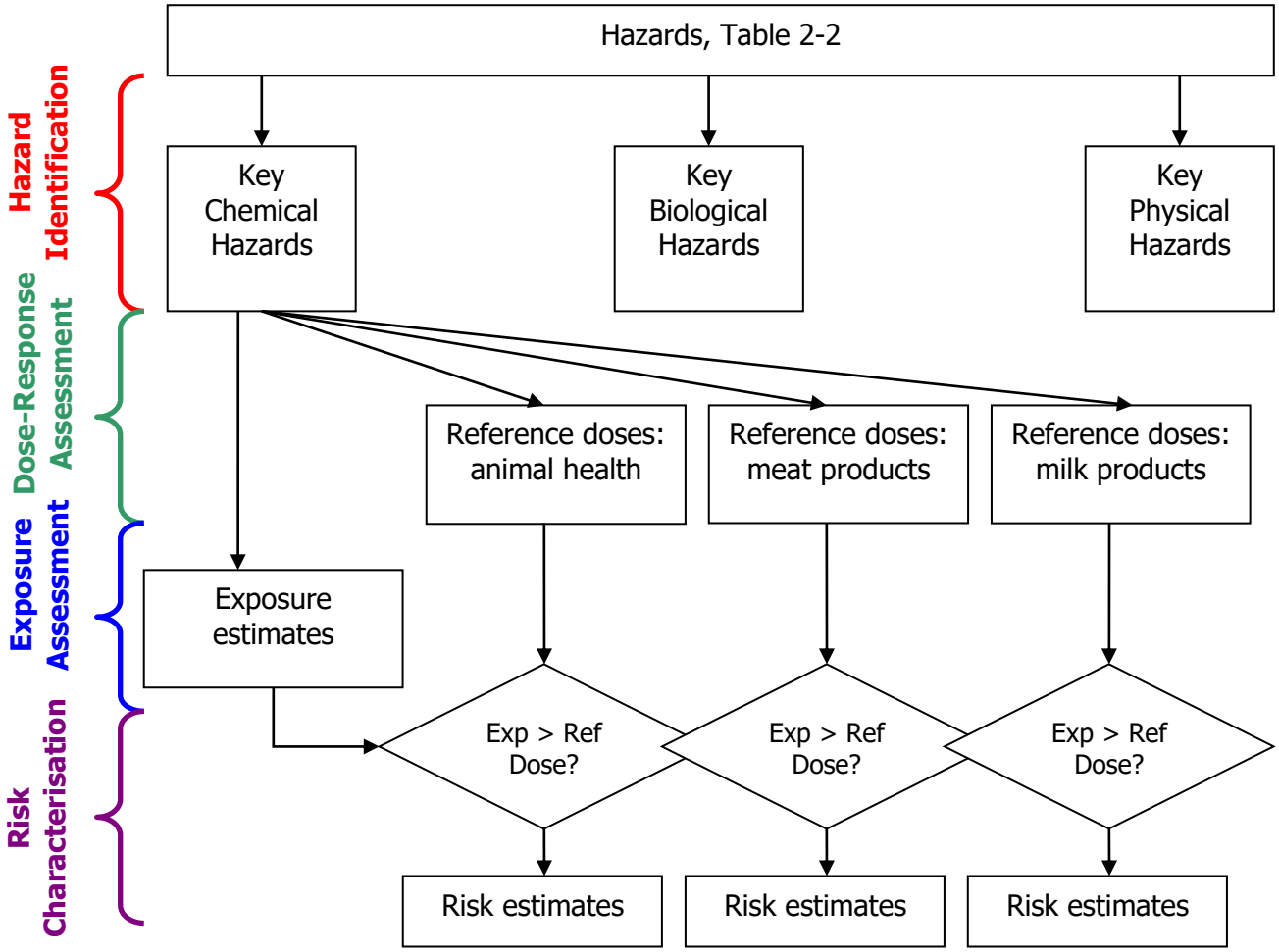
the ADD exceeds the RfD, we might expect to see deleterious effects on animal health, or on meat/milk quality. Fi

Figure 2-7 provides an overview of the process.

$$RR = \frac{ADD}{RfD} \qquad (2.10)$$

Due to the uncertainties associated with estimating risks, a Relative Risk (RR) greater than 1.0 indicates an issue that may require further investigation – but does not automatically imply a 'real' risk. RR less than or equal to 1.0 may be regarded as having negligible risk. For ease of interpretation, risk in this study was expressed either as 'negligible' (RR ≤ 1.0) or 'potentially requiring further investigation' (RR > 1.0).

Figure 2-7 Overview of risk characterisation process



2.5 Comparative risk assessment

The results of the risk assessment carried out for SSGW compost were compared, where appropriate, to risks associated with comparator materials identified in Table 2-7.

Table 2-7 Comparator materials

Comparator materials
Dairy cattle slurry
Pig slurry
Cattle farmyard manure
Pig farmyard manure
Laying hen manure
Broiler litter

It was not the intention to repeat the main risk assessment exercise for each of the comparator materials listed in Table 2-7. Instead, published concentrations of potentially toxic agents in the above comparator materials were used in the exposure models described in Section 2.2. Where published material was limited, advice was sought from relevant technical experts in the appropriate fields (see Appendix A and C).

Where appropriate, the exposure model was adjusted to take into account different management practices. Spreading rates of comparator materials were calculated based on the maximum permissible nitrogen level for soils with a low soil nitrogen supply status (MAFF, 2000), with other modelling parameters following the approach taken for compost (such as lack of grazing or harvest intervals after application). The resulting estimates of livestock exposures were compared to the reference doses collated during Section 2.3 of this project to determine risks to animal health.

'Typical' values (mean values reported in review studies) for the concentrations of plant toxins, organic contaminants and PTEs were collated. Data was considered if reported from UK, European, or North American studies. For PCBs there were few data for pig slurry, cattle and pig farmyard manure, so data from a study in Hong Kong were used as the closest available. No data on the concentrations of plant toxins present in the comparator materials was identified but it is unlikely these chemicals would be present in the comparator materials. Due to these reasons, plant toxins were omitted from the assessment. Sources of data are summarised in Table 2-8. The exposure scenario described in Section 2.2.1 was applied to each comparator material. In all cases, the application rate of each soil amendment was calculated from reported values of total nitrogen. The risk assessment for source-segregated green waste compost was re-run using mean values of each potentially hazardous agent in order to provide comparative estimates of risk.

Table 2-8 Sources of information used in the comparative risk assessment – full details can be found in Appendix E

Comparator materials	PAHs	PCBs	PCCD/Fs	PTEs	Nitrogen
Dairy cattle slurry	Berset & Holzer, 1995	Berset & Holzer, 1995; Ng et al., 2008	Stevens & Jones, 2003	Nicholson et al., 1999	Nicholson et al., 1999
Pig slurry	Berset & Holzer, 1995	Ng et al., 2008	Stevens & Jones, 2003	Nicholson et al., 1999	Nicholson et al., 1999
Cattle farmyard manure	Berset & Holzer, 1995	Ng et al., 2008	Stevens & Jones, 2003	Nicholson et al., 1999	Nicholson et al., 1999
Pig farmyard manure	Berset & Holzer, 1995	Ng et al., 2008	Stevens & Jones, 2003	Nicholson et al., 1999	Nicholson et al., 1999
Laying hen manure	-	-	Stevens & Jones, 2003	Nicholson et al., 1999; Faridullah et al., 2008	Nicholson et al., 1999
Broiler litter	-	-	Stevens & Jones, 2003	Nicholson et al., 1999	Nicholson et al., 1999

2.6 Scenario overview

Table 2-9 presents an overview of the different risk assessment scenarios that have been considered for each of the seven groups of hazardous agents. When possible and data permitted it, a QRA has been carried out following the approaches described in Section 2.1 to 2.4. However, for many of the scenarios the data were inadequate and did not allow for an actual QRA. In this case, the risk assessment consists of a commentary based on whatever evidence and information is available in the literature. Table 2-9 also shows for which groups of hazards it has been possible to carry out a comparative risk assessment. A detailed description of all the assumptions used in the QRA process is given in Appendix G.

Table 2-9 Overview of risk scenarios considered in the current study

Group of hazards	Waste type	End-use/pathway	Receptor	Type of risk assessment
Plant toxins	SSGW	Grazing	Animal	QRA*
	SSGW	Crops	Animal	Commentary**
Organic pollutants	SSGW	Grazing	Animal	QRA
	SSGW	Crops	Animal	QRA
	Comparator materials	Grazing	Animal	QRA
Potentially toxic elements	SSGW	Grazing	Animal	QRA
	SSGW	Crops	Animal	QRA
	Comparator materials	Grazing	Animal	QRA
Pathogens	SSGW		Animal	Commentary

Group of hazards	Waste type	End-use/pathway	Receptor	Type of risk assessment
	Comparator materials		Animal	Commentary
Weeds	SSGW		Animal	Commentary
Physical contaminants	SSGW		Animal	Commentary
Other environmental hazards	SSGW		Animal	Commentary

*QRA: Quantitative Risk Assessment based on the approaches described in Section 2.1 - 2.4.
**Commentary: When data are inadequate to support a QRA, a qualitative assessment consisting of a commentary based on evidence gathered during the initial hazard screening (Section 2.1; Appendix B) is presented.

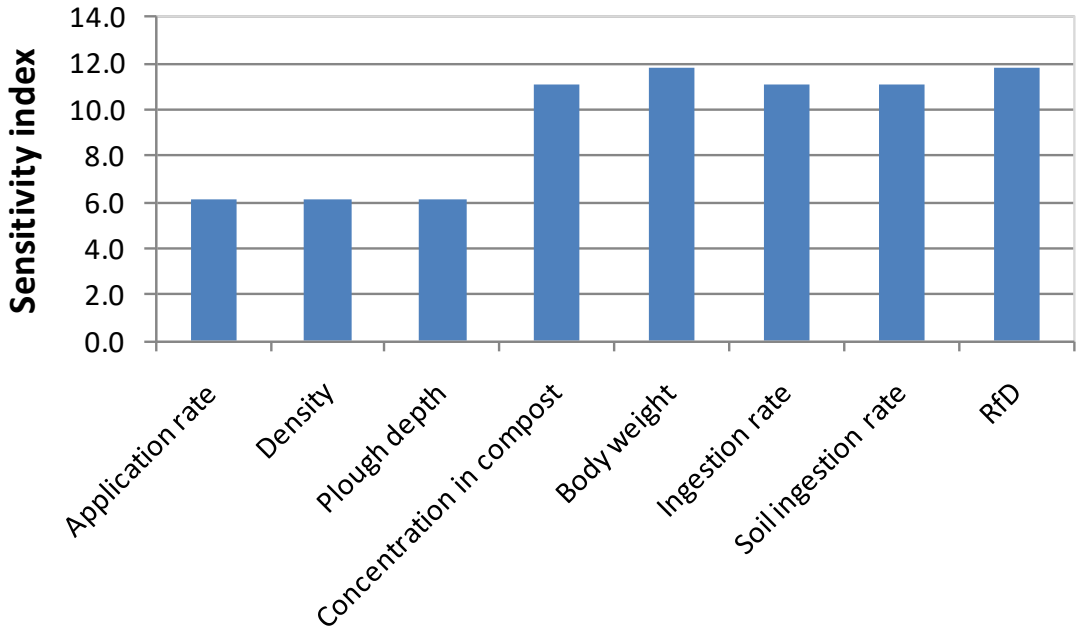
2.7 Sensitivity analysis

A simple point sensitivity analysis was conducted to identify which input parameters the risk assessment is most sensitive to and therefore are most important to characterise accurately in order to reduce the output uncertainty. A point sensitivity analysis investigates how the model output changes relative to the change in each input parameter while keeping all the other inputs at a fixed level. The sensitivity can be expressed in different ways. Here, the sensitivity of the model output, O, to a parameter i taking the value x_i is expressed through a normalised sensitivity index, SI, calculated as (Spitz and Moreno, 1996):

$$SI_i = \frac{|dO|}{\left(\frac{|dx_i|}{x_i}\right)}$$

where $|dO|$ is the absolute change in the model output following a change in the input parameter value dx_i, and x_i is the initial parameter value (i.e. in the base case).
This sensitivity approach was carried out for scenario in which SSGW was applied to the surface of grazing land. Figure 2-8 shows the calculated sensitivity index for each input parameter. These indices give an indication of which of the input parameters the estimated relative risks (RR) are most sensitive to. It is seen that the calculated risks are most sensitive to the concentration in compost, animal body weight, ingestion rate, percent soil ingestion rate and the RfD.

Figure 2-8 Calculated sensitivity indices for the direct application of SSGW to grazing land scenario



3.0 Results

The following subsections outline the findings of the risk assessment, divided into the agent categories identified in Table 2-2.

3.1 Toxic compounds present in plants

This part of the assessment focussed on poisonous plants either native to or commonly cultivated in the UK. The term 'poisonous plant' was defined as one that gives rise to a serious departure from normal health when a small quantity of its fruit, root or vegetation is eaten by a receptor susceptible to its effects (Forsyth, 1976).

During the hazard screening (Appendix B1; summarised in Table 3-1), 305 peer-reviewed articles were assessed and 89 agents were identified as being potentially harmful. Agents included alkaloids, glycosides, volatile oils, phyto-dynamic substances, and carcinogens. It was considered that 34 of these could have serious effects (as defined by European Commission, 2005). As there is a paucity of peer-reviewed measurements of plant toxins in SSGW compost (or measurements made in any other form of compost), and few data describing the degradation of these products, a precautionary approach was adopted. Where information was not available, it was assumed no degradation of the compound occurred during the composting process, after application to the surface of pasture, or when incorporated into the soil. A total of nine toxic compounds/groups of compounds eventually passed through Filter 2 (Table 3-1). However, during the lifetime of this project, new studies investigating the degradation of some of these compounds during composting were undertaken. This reduced the list to two toxic compounds eventually passing through Filter 2.

Table 3-1 Plant toxins present in commercially-produced SSGW compost at a level or concentration likely to cause harm to animals

Common Name	Scientific Name	Principal Toxins (Aniszewski, 2007)
Ragwort	*Senecio* spp.	Pyrrolizidine alkaloids
Rhododendron	*Rhododendron ponticum*	Gryanotoxins
Bracken	*Pteridium aquilinum*	Ptaquiloside
Privet	*Ligustrum* spp.	Ligustrin
Foxglove	*Digitalis purpurea*	Digitoxin
Laburnum	*Laburnum* spp.	Cytisine
Hemlock	*Conium maculatum*	Coniine
Yew	*Taxus* spp.	Taxine, Taxol
Monkshood	*Aconitum* spp.	Aconitine

Of these nine plants, ragwort, rhododendron, bracken, laburnum, hemlock, yew and monkshood were excluded from the final exposure assessment for the following reasons:

- Although **ragwort** has been reported as being present in 72 % of urban gardens in Sheffield, UK (Smith et al., 2006), recent experimental evidence demonstrated that pyrrolizidine alkaloids degrade completely within eight weeks of ragwort plants being pulled (Crews et al., 2009). Pyrrolizidine alkaloids have also been shown to degrade completely during the composting process (Hough et al., 2010).
- Grayanotoxins present in **rhododendron** have been shown to degrade significantly during composting (Hough et al., 2010)
- For **bracken**, ptaquiloside has been shown to degrade completely within three weeks of garden-scale composting (Potter & Pitman, 1995). Ptaquiloside has also been shown to degrade completely in the topsoil within 200 hours of application (Ovesen et al., 2008).

- **Laburnum** and **broom** both contain cytisine. Only 2% of urban gardens in Sheffield were reported to contain laburnum (Smith et al., 2006). Broom is a common weed, especially in the north of England and Scotland. Cytisine causes potentially serious effects (European Commission, 2005), but only when taken in relatively large doses.
- **Hemlock** contains the alkaloid coniine. A number of reports indicate that coniine does not degrade. Poisoning cases associated with dead plants pulled three years previous have been reported (Galey et al., 1992). Conversely, Keeler & Del Balls (1978) reported a 92.5 % reduction in coniine content within seven days of pulling. There is anecdotal evidence of dried stems being used as pea-shooters by children (Mabey, 1996). A recent study has demonstrated significant degradation of coniine during PAS100 composting (Michie et al., 2010).
- **Monkshood** contains aconitine. Heating in the presence of water for four hours degrades pure aconitine to non-lethal levels (Hikino et al., 1977). Monkshood is a wild plant, but may be locally common in gardens.

The remaining two plants (privet and foxglove) were put forward to the exposure assessment for the following reasons:

- **Privet.** No evidence was found describing the degradation of ligustrin during the composting process. Ligustrin is mainly present in the flowers and fruits of privet. Privet is an exceedingly common garden plant and very likely to enter the green waste stream. For this analysis, it was assumed that no degradation of ligustrin had occurred during the composting process.
- **Foxglove** is a very common garden plant (62 % of urban gardens in Sheffield were found to contain foxglove (Smith et al., 2006)). Although there is substantial evidence on the toxicity of the fresh plant (Appendix B1), there is no information on the degradation of digitoxin. For this analysis, it was assumed that no degradation of digitoxin had occurred during the composting process.

As there was no information on the proportion of each of the plants put forward to the exposure assessment in SSGW feedstock, two scenarios to represent the extremes were considered: compost that contained 1 % toxic plant material; and compost made entirely from the toxic plant in question. The proportion of each plant required to initiate further investigation (RR > 1.0) was also calculated. Initial toxin concentrations and RfD values for cattle and sheep are detailed in Table 3-2.

Table 3-2 Initial toxin concentrations in composted plant material and related reference doses (RfD) for cattle and sheep

Plant/Toxin	Mean concentration composted* plant material mg kg^{-1}	Max concentration composted* plant material mg kg^{-1}	RfD Cattle mg kg^{-1} d^{-1}	RfD Sheep mg kg^{-1} d^{-1}
Privet/ Ligustrin	425 [a]	650[a]	20.0[b]	20.0[b]
Foxglove/ Digitoxin	45.0[c]	60.0[c]	0.56[d]	0.56[d]

[a]Yin & Chan, 2007
[b]Singh et al., 1992
[c]Hagimori et al., 1984; Dzyuba et al., 1971; Sellwood, 1956
[d]Hagimori et al., 1984
*In all cases, concentrations of plant toxins were derived from fresh, non-composted material.

The two toxins detailed in Table 3-2 were entered into the exposure models described in Section 2.2: (i) surface application on pasture followed by immediate grazing. These compounds were also considered for exposure models ii - iv incorporation into soil and subsequent cultivation of fodder crops. Two application rates (25 and 50 t ha^{-1}, Section 2.2.1) and two soil ingestion rates (realistic and extreme worst case, Table 2-3) were used.

3.1.1 Surface application to pasture and subsequent grazing

The results of the assessment, considering 1% and 100% of feedstock material, are presented in Table 3-3. Table 3-4 provides an estimation of the proportion of total feedstock required for each individual toxic plant to present an appreciable risk to either cattle or sheep.

Table 3-3 Estimated relative risks (RR, Equation 2.10) associated with surface spreading of SSGW compost to grazing land and subsequent immediate grazing by either sheep or cattle. In this analysis two different application rates (25 t ha^{-1}; 50 t ha^{-1}) and two different soil ingestion scenarios (Table 2-3) were explored for different proportions (1 % and 100 %) of the potentially toxic plant within the SSGW compost

Plant-derived toxin (Source plant)	Exposure Scenario															
	Sheep								Cattle							
	LR		LE		HR		HE		LR		LE		HR		HE	
	1%	100%	1%	100%	1%	100%	1%	100%	1%	100%	1%	100%	1%	100%	1%	100%
Ligustrin (Privet)																
Digitoxin (Foxglove)																

L = Low application rate (25t ha^{-1})
H = High application rate (50t ha^{-1})
R = Realistic worst case soil ingestion rate (Table 2-3)
E = Extreme worst case soil ingestion rate (Table 2-3)
1% = Compost made from feedstock containing 1% of plant material
100% = Compost made from feedstock containing 100% of plant material

Negligible risk (RR ≤ 1.0)

May require further investigation (RR > 1.0)

Table 3-4 Percentage of total feedstock required for each individual toxic plant to generate a RR > 1.0 for either cattle or sheep for an application rate of 50 t ha^{-1}, at two rates of soil ingestion (Realistic and Extreme worst case)

Plant	Cattle		Sheep	
	Realistic	Extreme	Realistic	Extreme
Privet	>100%	>100%	>100%	>100%
Foxglove	73%	36%	>100%	71%

3.1.2 Incorporation into soil and subsequent production of fodder crops

As explained in Section 2.2.2, the incorporation of SSGW compost into soil by ploughing has a large dilution effect (Figure 3-1), hence reduces the concentration of plant-derived toxins available for uptake by plants. There are no data available to estimate the uptake of these chemicals by crop plants. However, due to the chemical nature of these compounds, it would be expected that they would remain strongly sorbed to the compost itself. This would result in insignificant uptake by crop plants.

Incorporation will also reduce concentrations of plant-derived toxins in surface soils comparative to surface spreading. For example, at an application rate of 50 t ha^{-1}, the concentration of all plant-derived toxins in surface soil would be diluted 83-fold. Even assuming no degradation of the toxic compounds occurs, this dilution effect reduces risk estimates across the board (Table 3-5).

Table 3-5 Estimated relative risks (RR, Equation 2.10) associated with incorporation of SSGW compost ahead of grassland conversion grazing by either sheep or cattle. In this analysis two different application rates (25 t ha^{-1}; 50 t ha^{-1}) and two different soil ingestion scenarios (Table 2-3) were explored for different proportions (1 % and 100 %) of the potentially toxic plant within the SSGW compost

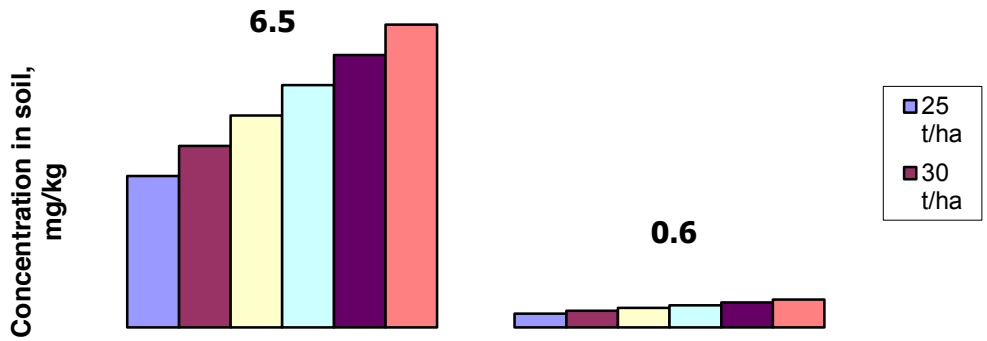
Plant-derived toxin (Source plant)	Exposure Scenario															
	Sheep								Cattle							
	LR		LE		HR		HE		LR		LE		HR		HE	
	1%	100%	1%	100%	1%	100%	1%	100%	1%	100%	1%	100%	1%	100%	1%	100%
Ligustrin (Privet)																
Digitoxin (Foxglove)																

L = Low application rate (25t ha^{-1})
H = High application rate (50t ha^{-1})
R = Realistic worst case soil ingestion rate (Table 2-3)
E = Extreme worst case soil ingestion rate (Table 2-3)
1% = Compost made from feedstock containing 1% of plant material
100% = Compost made from feedstock containing 100% of plant material

Negligible risk (RR ≤ 1.0)

May require further investigation (RR > 1.0)

Figure 3-1 Concentration of potentially toxic compounds from plants in soil in relation to the range of application rates presented in Table 2-4. Numbers above each category of data represent the initial concentration of each compound in SSGW compost prior to incorporation



3.1.3 Comparative risk assessment

No data on the concentrations of toxic compounds present in plants in the comparator materials were identified but it is unlikely these chemicals would be present in the comparator materials. Due to these reasons, plant toxins were omitted from the assessment.

3.1.4 Conclusions

For plant toxins, PAS100 compliant green compost presents a negligible risk to grazing animals. This conclusion is based on the assumption that the feedstock contains roughly 1 % fresh material. For a number of the plants, this is likely to be an over-estimation. There are no data describing the composition, in terms of plant species, of green waste feedstock material to improve the accuracy of this assumption.

Sheep tend to be more susceptible to the toxins of concern than cattle. This is in part due to their lower bodyweight and tendency to ingest a greater proportion of soil, as well as some toxicological differences. It should be highlighted that no degradation data were available for ligustrin (privet) and digitoxin (foxglove). If degradation of these compounds does occur during the composting process, then the relative risks reported in Table 3-3 would decrease further. Where risk ratios were estimated at >1 (Table 3-3), these were for composts derived from more than 35% foxglove inputs (Table 3-4), and where no degradation of digitoxin was modelled to occur during or after composting. Both of these are considered extremely unlikely, and lead to the conclusion presented below (3.1.5).

3.1.5 Options for risk management

- The risk estimates presented in this report suggest that risks posed by toxic compounds present in plants are negligible.

3.2 Organic pollutants

The assessment focussed on organic pollutants that have been recorded as being measured in SSGW feedstock or compost output materials in scientific and grey literature.

Data were included in the assessment if they were: (i) derived from SSGW feedstock material; and/or (ii) derived from SSGW output material that had undergone windrow or in-vessel composting; (iii) derived from samples obtained from commercial composting operations; and (iv) reported concentrations of single compounds on a dry weight basis.

Data were excluded if they were: (i) derived from feedstock or output material from non-SSGW sources such as mixed-waste composts or MSW composts; (ii) derived from samples from pilot-scale, experimental, or laboratory investigations; (iii) reported organic pollutants as classes or groupings of chemicals, rather than on an individual compound basis.

Many organic pollutants are ubiquitous in our environment. This is reflected in the long list of compounds that have been measured in compost and other similar derived materials. The initial hazard screening identified a total of 253 organic pollutants that had been measured in SSGW compost products. These were grouped into polycyclic aromatic hydrocarbons (PAHs), polychlorinated byphenols (PCBs), polychlorinated dibenzo –dioxins and -furans (PCDD/Fs), linear alkylbenzene sulphonates (LASs), chlorinated paraffins, brominated flame retardants (BFRs), phthalates, perfluorinated alkylated substances (PFASs), nonylphenols (NPs), pesticides, and other chlorinated hydrocarbons (Appendix B2). Numerous peer reviewed articles were assessed and a thorough internet search undertaken to identify grey literature. A significant proportion of the information was obtained from a thesis by Brändli (2006) and the associated papers, which reviewed over 98 field studies on organic pollutants in compost and its feedstock. The thesis provided a comprehensive overview of organic contaminants in compost and described factors that may influence them.

3.2.1 Polycyclic Aromatic Hydrocarbons, PAHs

The following PAHs were entered into the exposure assessment: Naphthalene (NAP), benzo-a-anthracene (B[a]A), chrysene (CHR), benzo-b-fluoranthene (B[b]f), benzo-k-fluoranthene (B[k]f), benzo-a-pyrene (B[a]P) and indeno(1,2,3-cd)pyrene (IPY). Data sources included in the analysis are summarised in Table 3-6, those excluded are detailed in Table 3-7. An overall summary of the data used in the exposure assessment is provided inTable 3-8.

Table 3-6 Sources of data on PAH concentrations in SSGW included in the exposure assessment. NR = not reported

Country of origin	Catchment	Season of sampling	n	mean ΣPAH mg kg^{-1}	max ΣPAH mg kg^{-1}	Reference
Germany	NR	All Year	4	2.66	5.84	Krauss (1994)
Switzerland	Urban	NR	1	2.49	2.49	Berset & Holzer (1995)
Germany	Urban	Spring	1	3.31	3.31	Hund et al (1999)
Austria	Urban / Rural	All Year	13	0.77	2.18	Zethner et al (2000)
France	NR	NR	1	1.67	1.67	Verge-Leviel (2001)
Switzerland	NR	NR	3	2.60	2.67	Schleiss (2003)

Table 3-7 Sources of data on PAH concentrations in SSGW excluded from the exposure assessment, including the reasoning for their exclusion

Country of origin	Reference	Reasoning
Germany	Kummer (1996)	PAH not specified
Germany	van Raaij et al (1996)	Graphical data reporting only; PAH assayed in feedstock, not in compost.
Germany	Breuer et al (1997)	Mean concentrations & ranges reported only
USA	McGowin et al (2001)	Mean concentrations & ranges reported only
Denmark	Petersen & Hansen (2002)	Mean concentrations & ranges reported only; PAH not specified
Germany	Marb et al (2003)	Sums reported only

Table 3-8 Summary of data used in the exposure assessment of PAHs

PAH	Mean concentration (mg kg^{-1})	Standard deviation	Max concentration (mg kg^{-1})
CHR	0.31 (n=56)	0.19	1.10
IPY	0.20 (n=56)	0.14	0.96
B[a]A	0.23 (n=56)	0.16	0.81
B[b]f	0.27 (n=56)	0.16	0.89
B[k]f	0.14 (n=56)	0.09	0.48
B[a]p	0.17 (n=56)	0.11	0.62
NAP	0.02 (n=56)	0.02	0.14
Tot PAH	2.25 (n=23)	0.89	5.84

3.2.1.1 Surface application to pasture and subsequent grazing

Following the exposure assessment (Section 2.2), SSGW compost was considered to present a negligible risk to sheep and cattle from exposure to PAHs post surface spreading to pasture (Table 3-9). Closer inspection of risk estimates reveals that, while still negligible, sheep tend to have a higher RR compared with cattle. This reflects their lower bodyweight combined with greater soil ingestion than cattle (Figure 3-2).

Table 3-9 Estimated relative risks (RR, Equation 2.10) for PAHs associated with surface spreading of SSGW compost to grazing land and subsequent immediate grazing by either sheep or cattle. In this analysis two different application rates (25 t ha^{-1}; 50 t ha^{-1}) and two different soil ingestion scenarios (Table 2-3) were simulated

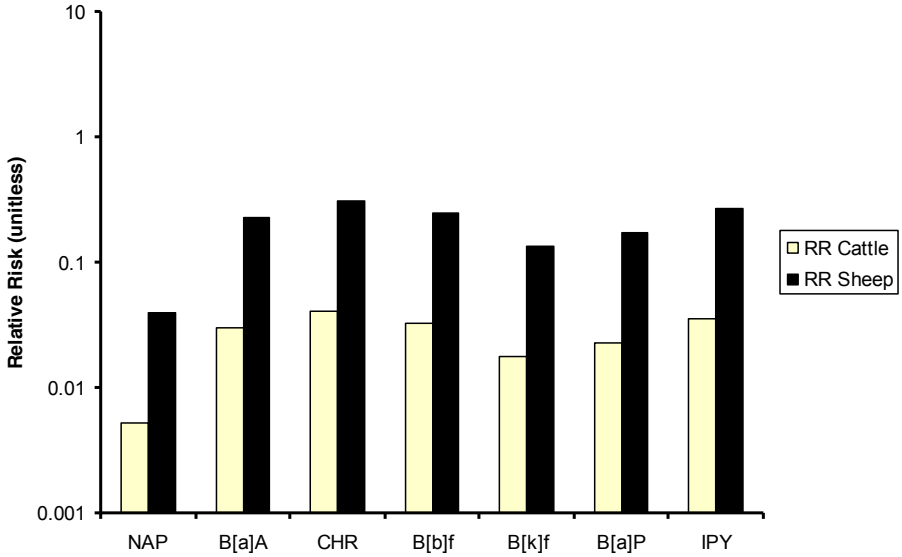
Potentially Toxic Agent	Exposure Scenario							
	Sheep				Cattle			
	LR	HR	LE	HE	LR	HE	LE	HE
NAP								
B[a]A								
CHR								
B[b]f								
B[k]f								
B[a]P								
IPY								

L = Low application rate (25t ha^{-1})
H = High application rate (50t ha^{-1})
R = Realistic worst case soil ingestion rate (Table 2-3)
E = Extreme worst case soil ingestion rate (Table 2-3)

Negligible risk (RR ≤ 1.0)

May require further investigation (RR > 1.0)

Figure 3-2 Relative risk (RR) to grazing cattle and sheep from PAHs in SSGW compost (realistic worst case soil ingestion rate, Table 2-3; high application rate, 50 t ha^{-1}). A value of RR > 1.0 indicates an issue that may require further investigation



3.2.1.2 Incorporation into soil and subsequent production of fodder crops

As most of the polycyclic aromatic hydrocarbons (PAHs) are very lipophilic (log K_{ow} ranging from 5 to 7) and have a very low water-solubility, the uptake into crop plants with transpiration water is considered unlikely (Trapp and Legind, 2011). This was confirmed through the plant uptake modelling following Section 2.2.3. The fugacity modelling using the adapted version of SOIL model (Section 2.2.2) indicated that the PAHs had a strong propensity to remain sorbed to the soil and SSGW compost, and therefore limited availability for uptake into plants, i.e. insignificant partitioning to the water and air phases of the soil matrix (Table 3-10). However, contamination of plants can also potentially occur via attached soil particles or from air, while uptake from soil into the outer layers of some root crops (such as carrots) may also occur (Trapp and Legind, 2011).

Table 3-11 shows the estimated relative risks (RR) for PAHs associated with using crops, which have been grown on land amended with SSGW compost, for animal consumption. Despite the conservative nature of the risk assessment approach used here, the calculated RR values for all of the PAHs are well below 1, and the risks are therefore considered negligible. Generally, the highest RR values were obtained for sheep consuming leaf crops.

These findings agree with the results published in the literature. In a recent study by Passuello et al. (2010), the risk of accumulating persistent organic pollutants (including the two PAHs, benzo(a)pyrene, and dibenzo(a,h)anthracene) in the food chain following application of sewage sludge to agricultural land was assessed. They found low risk to humans through oral intake (i.e. RR $\leq$ 1).

Table 3-10 Predicted partitioning behaviour of PAHs (%) amongst phases of the soil matrix

PAH	Phase		
	Soil + compost	Water	Air
NAP	99.6	<1	<1
B[a]A	100	<1	<1
CHR	100	<1	<1
B[b]f	100	<1	<1
B[k]f	100	<1	<1
B[a]P	100	<1	<1
IPY	100	<1	<1

Table 3-11 Estimated relative risks (RR, Equation 2.10) for PAHs associated with using crops grown on land amended with SSGW compost for animal consumption. In this analysis two different application rates (25 t ha^{-1}; 50 t ha^{-1}) were simulated. The maximum concentrations reported in Table 3-8 were used

Potentially Toxic Agent	Exposure Scenario			
	Sheep		Cattle	
	L	H	L	H
NAP				
B[a]A				
CHR				
B[b]f				
B[k]f				
B[a]P				
IPY				

L = Low application rate (25t ha^{-1})
H = High application rate (50t ha^{-1})

Negligible risk (RR ≤ 1.0)

May require further investigation (RR > 1.0)

3.2.2 Polychlorinated Biphenyls, PCBs

The following 11 PCB congeners were considered in the exposure assessment: PCB 28, PCB 52, PCB 95, PCB101, PCB 118, PCB 132, PCB 138, PCB 149, PCB 153, PCB 174 and PCB 180. Data sources included in the analysis are summarised inTable 3-12, those excluded are detailed in Table 3-13. An overall summary of the data used in the exposure assessment is provided in Table 3-14.

Table 3-12 Sources of data on PCB concentrations in SSGW included in the exposure assessment. NR = not reported

Country of origin	Catchment	Season of sampling	n	mean ΣPCB mg kg^{-1}	max ΣPCB mg kg^{-1}	Reference
Germany	NR	All Year	20	0.03	0.05	Krauss (1994)
Germany	Urban	Summer / Winter	6	0.06	0.08	Aldag & Bischoff (1995)
Germany	Urban / Rural	NR	8	0.07	0.09	Bayerisches Laudesamt fur Umweltschutz (1995)
Switzerland	Urban	NR	1	0.03	0.03	Berset & Holzer (1995)
Germany	Urban	Spring	1	0.04	0.04	Hund et al (1999)
Germany	NR	NR	5	0.03	0.05	Marb et al (2001)
France	NR	NR	1	0.06	0.06	Verge-Leviel (2001)
Austria	Urban / Rural	All Year	13	0.01	0.03	Zethner et al (2000)

Table 3-13 Sources of data on PCB concentrations in SSGW excluded from the exposure assessment, including the reasoning for their exclusion

Country of origin	Reference	Reasoning
USA	Hegberg et al (1991)	Mean concentrations & ranges reported only
USA	Lisk et al (1992a)	PCB measured as Aroclor 1254
USA	Lisk et al (1992b)	PCB measured as Aroclor 1254
USA	Miller et al (1992)	Mean concentrations & ranges reported only
USA	Malloy et al (1993)	PCB not specified
Germany	Kummer (1996)	PCB not specified
Germany	Breuer et al (1997)	Mean concentrations & ranges reported only
Germany	Kerst et al (2003)	Median values reported only
Germany	Marb et al (2003)	Sum of PCBs reported only

Table 3-14 Summary of data used in the exposure assessment of PCBs in (a.) individual and (b.) total basis.

a. Individual	Mean concentration (mg kg^{-1})	Max concentration (mg kg^{-1})	Standard deviation
PCB 28	0.010 (n=3)	0.02	0.010
PCB 52	0.003 (n=64)	0.03	0.003
PCB 95	0.004 (n=60)	0.03	0.004
PCB 101	0.006 (n=64)	0.07	0.009
PCB 118	0.006 (n=64)	0.13	0.016
PCB 132	0.004 (n=60)	0.07	0.009
PCB 138	0.007 (n=64)	0.13	0.016
PCB 149	0.006 (n=60)	0.08	0.010
PCB 153	0.009 (n=64)	0.14	0.017
PCB 174	0.002 (n=60)	0.02	0.002
PCB 180	0.005 (n=64)	0.06	0.007

b. Total	Mean concentration (mg kg^{-1})	Max concentration (mg kg^{-1})
	0.062	0.78

3.2.2.1 Surface application to pasture and subsequent grazing

Following the exposure assessment (Section 2.2), SSGW compost was considered to present a negligible risk from exposure to PCBs in the majority of cases (Table 3-15). Again, sheep tend to have a relatively higher risk compared to cattle, with estimated risks being associated primarily with the high application rate/acute soil ingestion scenarios. The only significant risk was recorded for PCB 28 for sheep, based on a 50 t ha^{-1} application rate, and acute soil ingestion of 25 % of dry matter intake.

Table 3-15 Estimated relative risks (RR, Equation 2.10) for PCBs associated with surface spreading of SSGW compost to grazing land and subsequent immediate grazing by either sheep or cattle. In this analysis two different application rates (25 t ha^{-1}; 50 t ha^{-1}) and two different soil ingestion scenarios (Table 2-3) were simulated

Potentially Toxic Agent	Exposure Scenario							
	Sheep				Cattle			
	LR	LE	HR	HE	LR	LE	HR	HE
PCB 28								
PCB 52								
PCB 95								
PCB 101								
PCB 118								
PCB 132								
PCB 138								
PCB 149								
PCB 153								
PCB 174								
PCB 180								

L = Low application rate (25t ha^{-1})
H = High application rate (50t ha^{-1})
R = Realistic worst case soil ingestion rate (Table 2-3)
E = Extreme worst case soil ingestion rate (Table 2-3)

Negligible risk (RR ≤ 1.0)

May require further investigation (RR > 1.0)

3.2.2.2 Incorporation into soil and subsequent production of fodder crops

Polychlorinated biphenyls (PCB) are generally considered persistent, semi-volatile and lipophilic. They are thus very unlikely to enter crop plants via uptake with transpiration water, while attached soil particles can lead to contamination of plants (Mikes et al., 2009; Trapp and Legind, 2011). This was again confirmed through the plant uptake modelling following Section 2.2.3. The fugacity modelling based on the adapted version of the SOIL model (Section 2.2.3), indicated that the PCBs had a strong propensity to remain sorbed to the soil and the SSGW compost, while partitioning to the water and air phases of the soil matrix was insignificant (Table 3-16). PCBs are therefore expected to have limited availability for uptake into plants.

Table 3-17 shows the estimated relative risks (RR) for PCBs associated with using crops, which have been grown on land amended with SSGW compost, for animal consumption. The RR values are again well below 1 indicating that the risks from this exposure scenario are negligible. These findings agree with results published previously in the literature. For example, Passuello et al. (2010) found that the risk of PCB 180 contaminating the food chain following application of sewage sludge to agricultural land was very low (i.e. RR << 1). In Appendix G BCFs (= C_{plant}/C_{soil}) for various PCBs reported in the literature are listed and range from 0.05 - 0.5. These BCF values are all lower than the BCF values we can determine based on our plant uptake modelling approach. This confirms that the approach we are using here is indeed precautionary.

Table 3-16 Predicted partitioning behaviour (%) of PCBs amongst phases of the soil matrix

PCB	Phase		
	Soil + compost	Water	Air
PCB 28	99.4	<1	<1
PCB 52	99.9	<1	<1
PCB 95	99.9	<1	<1
PCB 101	99.9	<1	<1
PCB 118	99.8	<1	<1
PCB 132	99.8	<1	<1
PCB 138	99.8	<1	<1
PCB 149	100	<1	<1
PCB 153	100	<1	<1
PCB 174	100	<1	<1
PCB 180	100	<1	<1

Table 3-17 Estimated relative risks (RR, Equation 2.10) for PCBs associated with using crops, which have been grown on land amended with SSGW compost, for animal consumption. In this analysis two different application rates (25 t ha^{-1}; 50 t ha^{-1}) were simulated. The maximum concentrations reported in Table 3-14 were used

Potentially Toxic Agent	Exposure Scenario			
	Sheep		Cattle	
	L	H	L	H
PCB 28				
PCB 52				
PCB 95				
PCB 101				
PCB 118				
PCB 132				
PCB 138				
PCB 149				
PCB 153				
PCB 174				
PCB 180				

L = Low application rate (25t ha^{-1})
H = High application rate (50t ha^{-1})

Negligible risk (RR ≤ 1.0)

May require further investigation (RR > 1.0)

3.2.3 Polychlorinated dibenzo-dioxins and -furans (PCDD/Fs)

A total of seven PCDD/Fs were evaluated in the exposure assessment: 2,3,7,8-TeCDD, 1,2,3,7,8-PeCDD, 1,2,3,4,6,7,8-HpCDD, 2,3,4,7,8-PeCDF, 1,2,3,4,7,8-HxCDF, 1,2,3,6,7,8-HxCDF, and 2,3,4,6,7,8-HxCDF. Data sources included in the analysis are summarised in Table 3-18, those excluded are detailed in Table 3-19. An overall summary of the data used in the exposure assessment is provided in Table 3-20 which includes both individual and total PCDD/F data.

Table 3-18 Sources of data on PCCD/F concentrations in SSGW included in the exposure assessment. NR = not reported

Country of origin	Catchment	Season of sampling	n	mean ΣPCDD mg kg^{-1}	max ΣPCDD mg kg^{-1}	Reference
Germany	Urban / Rural	NR	9	2.5E-03	3.6E-03	Kummer (1990)
USA	Rural	Spring / Autumn / Winter	13	2.1E-02	2.6E-02	Harrad et al (1991)
USA	Peri-urban	Spring / Autumn / Winter	7	2.1E-02	3.3E-02	Malloy et al (1993)
Germany	NR	All Year	20	1.6E-03	3.8E-03	Krauss (1994)
Germany	Urban	Summer	5	1.2E-05	1.4E-05	Aldag & Bischoff (1995)
Germany	NR	NR	8	2.4E-03	1.1E-02	Bayerisches Laudesamt fur Umweltschutz (1995)
Germany	NR	NR	1	1.1E-05	1.1E-05	Kummer (1996)
Austria	Urban / Rural	All Year	13	5.1E-06	2.4E-05	Zethner et al (2000)
Germany	NR	NR	5	9.1E-06	1.2E-05	Marb et al (2001)
Germany	NR	NR	2	5.8E-04	8.3E-04	Kuhn & Arnet (2003)
Switzerland	NR	NR	13	5.6E-06	2.1E-05	Brandli et al (2005)

Table 3-19 Sources of data on PCDD/F concentrations in SSGW excluded from the exposure assessment, including the reasoning for their exclusion

Country of origin	Reference	Reasoning
Germany	Hagenmeier et al. (1990)	Individual congeners not specified
Germany	Fricke et al. (1992)	Individual congeners not specified, median values reported only
USA	Malloy et al. (1993)	Individual congeners not specified
Germany	Kummer (1996)	Individual congeners not specified
Germany	Sihler et al. (1996)	Individual congeners not specified
USA	Eitzer et al. (1997)	Ranges reported only

Table 3-20 Summary of data used in the exposure assessment of PCDD/Fs (a.) on an individual and (b.) total basis.

a. Individual PCDD/F	TEF	Mean concentration (mg kg^{-1})	Max concentration (mg kg^{-1})	Standard deviation
2,3,7,8-TeCDD	1	3.6E-07 (n=13)	1.2E-06	3.3E-07
1,2,3,7,8-PeCDD	1	1.7E-06 (n=13)	8.8E-06	2.5E-06
1,2,3,4,7,8-HxCDD	0.1	1.2E-06 (n=13)	5.0E-06	1.5E-06
1,2,3,6,7,8-HxCDD	0.1	2.8E-06 (n=13)	9.1E-06	2.6E-06
1,2,3,7,8,9-HxCDD	0.1	1.7E-06 (n=13)	5.9E-06	1.8E-06
1,2,3,4,6,7,8-HpCDD	0.01	5.4E-05(n=13)	1.2E-04	3.5E-05
OCDD	0.0001	3.9E-04(n=13)	8.2E-04	4.1E-05
2,3,7,8-TeCDF	0.1	2.1E-06(n=13)	4.4E-06	1.1E-06
1,2,3,7,8-PeCDF	0.05	2.1E-06(n=13)	8.4E-06	2.3E-06
2,3,4,7,8-PeCDF	0.5	2.7E-06(n=13)	1.1E-05	2.9E-06
1,2,3,4,7,8-HxCDF	0.1	3.6E-06 (n=13)	1.5E-05	4.0E-06
1,2,3,6,7,8-HxCDF	0.1	3.2E-06(n=13)	1.6E-05	4.5E-06
1,2,3,7,8,9-HxCDF	0.1	5.2E-07(n=13)	1.5E-06	5.0E-07
2,3,4,6,7,8-HxCDF	0.1	3.2E-06(n=13)	1.4E-05	4.0E-06
1,2,3,4,6,7,8-HpCDF	0.01	1.4E-05(n=13)	5.5E-05	1.6E-05
1,2,3,4,7,8,9-HpCDF	0.01	1.5E-06(n=13)	5.3E-06	1.5E-06
OCDF	0.0001	1.3E-05(n=13)	2.7E-05	7.2E-06

b. Total PCDD/F	TEF	Mean concentration (mg kg^{-1})	Max concentration (mg kg^{-1})
	3.38	4.9E-04(n=96)	1.13E-03

3.2.3.1 Surface application to pasture and subsequent grazing

Following the exposure assessment (Section 2.2), SSGW compost was considered to present a negligible risk from exposure to PCDD/Fs in the majority of cases (Table 3-21). None of the individual agents were found to cause a significant risk to grazing cattle. However, there was an apparent risk towards grazing sheep from 1,2,3,4,6,7,8-HpCDD at an application rate of 50 t ha^{-1}. The compound 1,2,3,4,6,7,8-HpCDD is generated as a by-product of industrial bleaching processes and combustion, and it should be noted that literature values for the same compound also predict an apparent risk from cattle farmyard manure and pig slurry from this same hazard (Table 3-28). Within this context, the possible presence of 1,2,3,4,6,7,8-HpCDD in SSGW compost represents no greater risk than other, commonly used, soil amendments. In general these results suggest that risks posed by other diffuse environmental contaminants are also likely to be negligible.

Table 3-21 Estimated relative risks (RR, Equation 2.10) for PCDD/Fs associated with surface spreading of SSGW compost to grazing land and subsequent immediate grazing by either sheep or cattle. In this analysis two different application rates (25 t ha^{-1}; 50 t ha^{-1}) and two different soil ingestion scenarios (Table 2-3) were simulated

Potentially Toxic Agent	Exposure Scenario							
	Sheep				Cattle			
	LR	LE	HR	HE	LR	LE	HR	HE
2,3,7,8-TeCDD								
1,2,3,7,8-PeCDD								
1,2,3,4,6,7,8-HpCDD								
2,3,4,7,8-PeCDF								
1,2,3,4,7,8-HxCDF								
1,2,3,6,7,8-HxCDF								
2,3,4,6,7,8-HxCDF								
∑PCDD/F								

L = Low application rate (25t ha^{-1})
H = High application rate (50t ha^{-1})
R = Realistic worst case soil ingestion rate (Table 2-3)
E = Extreme worst case soil ingestion rate (Table 2-3)

Negligible risk (RR ≤ 1.0)

May require further investigation (RR > 1.0)

3.2.3.2 Incorporation into soil and subsequent production of fodder crops

Polychlorinated dibenzo-p-dioxins and -furans (PCDD/F) are generally considered persistent, semi-volatile and lipophilic, and they are therefore very unlikely to enter plants via uptake with transpiration water. Uptake of these compounds into crops is more likely to occur via air and/or from attached soil particles (Muller et al., 1993; 1994; Trapp and Legind, 2011). This was again confirmed through the plant uptake modelling following Section 2.2.3. The fugacity modelling based on the adapted version of the SOIL model (Section 2.2.3), indicated that the PCDD/Fs had a strong propensity to remain sorbed to the soil and the SSGW compost, while partitioning to the water and air phases of the soil matrix was insignificant (Table 3-22). They therefore have limited availability for uptake into plants.

Table 3-23 shows the estimated relative risks (RR) for PCDD/Fs associated with using crops, which have been grown on land amended with SSGW compost, for animal consumption. As for the PAHs and the PCBs, the risks are found to be negligible. The findings agree with published results in the literature. Of the organic contaminants considered by Passuello et al. (2010), 2,3,7,8-TCDD was found to pose the greatest risk of contaminating the food chain, but the estimated RR-values were still low (approximately 0.02). The BCF values calculated based on plant uptake modelling approach are well above BCF values reported in the literature (see Appendix G), which again confirm the conservative nature of our risk approach.

Table 3-22 Predicted partitioning behaviour (%) of PCDD/Fs amongst phases of the soil matrix

PCDD/F	Phase		
	Soil + Compost	Water	Air
2,3,7,8-TeCDD	100	<1	<1
1,2,3,7,8-PeCDD	100	<1	<1
1,2,3,4,6,7,8-HpCDD	100	<1	<1
2,3,4,7,8-PeCDF	100	<1	<1
1,2,3,4,7,8-HxCDF	100	<1	<1
1,2,3,6,7,8-HxCDF	100	<1	<1
2,3,4,6,7,8-HxCDF	100	<1	<1

Table 3-23 Estimated relative risks (RR, Equation 2.10) for PCDD/Fs associated with using crops, which have been grown on land amended with SSGW compost, for animal consumption. In this analysis two different application rates (25 t ha^{-1}; 50 t ha^{-1}) were simulated. The maximum concentrations reported in Table 3-20 were used for the calculations.

Potentially Toxic Agent	Exposure Scenario			
	Sheep		Cattle	
	L	H	L	H
2,3,7,8-TeCDD				
1,2,3,7,8-PeCDD				
1,2,3,4,6,7,8-HpCDD				
2,3,4,7,8-PeCDF				
1,2,3,4,7,8-HxCDF				
1,2,3,6,7,8-HxCDF				
2,3,4,6,7,8-HxCDF				
∑PCDD/F				

L = Low application rate (25t ha^{-1})
H = High application rate (50t ha^{-1})

Negligible risk (RR ≤ 1.0)

May require further investigation (RR > 1.0)

3.2.4 Pesticides and herbicides

Four compounds were evaluated in the exposure assessment: Clopyralid, Fenoxycarb, Imazalil, and Pentachlorophenol. Table 3-24 summarises the data sources used in this analysis.

Table 3-24 Sources of data on pesticide and herbicide concentrations in SSGW included in the exposure assessment

Pesticide/ Herbicide	n	Mean concentration (mg kg^{-1})	95th %ile concentration (mg kg^{-1})	Max concentration (mg kg^{-1})	Reference
Clopyralid	4	$7.25x10^{2}$	$1.24x10^{3}$	$1.30x10^{3}$	Van der Voort et al., 1997
Fenoxycarb	1	$1.11x10^{-3}$	$1.11x10^{-3}$	$1.11x10^{-3}$	Brändli, 2006
Imazalil	11	$2.61x10^{-2}$	$1.01x10^{-1}$	$1.03x10^{-1}$	Brändli, 2006
Pentachloro phenol	4	$4.10x10^{-3}$	$1.21x10^{-2}$	$1.40x10^{-2}$	Reddy & Michel, 1999 Brändli et al., 2005

After exposure assessment only one compound – clopyralid – was considered to have the potential to present an exposure of concern post-spreading (Table 3-25). The concern relates to the potential impact on the environment, since it is of low toxicity to animals and wildlife, but high toxicity to certain plants (e.g. tomato). Clopyralid may have a half life of 6 – 66 days in compost, with an average of 22 days (Krieger 2004).

Clopyralid levels are highly dependent on feedstock and can be managed. A range of label guidance is provided to minimize exposure to sensitive crops (Whitehead, 2008).

Clopyralid is present in a number of herbicide products used in both domestic and amenity settings in the UK. Amenity uses are likely to produce significant quantities of treated plant material and are likely to be responsible for the greatest concentrations measured in green waste composts, even though some formulations (such as clopyralid and 2,4-D and MCPA) that are approved for control of broad-leaved species in amenity turf provide the label warning "Do not use any treated plant materials for composting or mulching" (Whitehead, 2008). Clopyralid itself is released from plant material as it decomposes. It may then be taken up by broad-leaved plants. Although it has a low toxicity to humans and larger animals such as sheep and cattle, it is very toxic to a number of broad-leaved plants and aquatic insects, and should not be applied in the root zone of plants belonging to the Compositae or Leguminosae (Whitehead, 2008). A leaching model could be used to estimate concentrations in soil within the rooting zone and/or concentrations of Clopyralid entering groundwater. Elliott et al. (1998) modelled leaching of Clopyralid after an autumn application (worst case). They found 12 days after application, 93 % of the applied Clopyralid was still present in the rooting zone. This had reduced to 12 % by day 30, with 3.5 % entering groundwater.

Assuming even leaching to 30 cm, a surface application of 0.2 cm compost containing 1300 mg kg^{-1} Clopyralid, would result in a concentration of 9.1 mg Clopyralid kg $soil^{-1}$ in the rooting zone 12 days after application. This is below the concentration considered toxic to broad-leaved plants, although concentrations within the root zone prior to day 12 would be

significantly greater. For example, if even leaching is assumed, by day 6 concentrations within the root zone could still be as high as 18.2 mg kg^{-1}.

Table 3-25 Estimated relative risks (RR, Equation 2.10) for pesticides associated with incorporation of compost into land that is subsequently sown with susceptible plant species

Potentially Harmful Agent	Exposure Scenario	
	Susceptible broad-leaved plants	
	L	H
Clopyralid		
Fenoxycarb		
Imazalil		
PCP Pentachlorophenol		

L = Low application rate (25t ha^{-1})
H = High application rate (50t ha^{-1})

Negligible risk (RR ≤ 1.0)

May require further investigation (RR > 1.0)

Aminopyralid, an herbicide with a similar chemical structure to Clopyralid, had a high profile in the British press during summer 2008, when the produce of a number of gardens and allotments was adversely affected by application of manure originating from farms where the herbicide had been sprayed on fields. The Observer reported in June 2008 (Davies 2008) that the contamination came from grass treated 12 months before. Experts, were reported in The Observer to say the grass was probably made into silage, and then fed to cattle during the winter months. The herbicide remained present in the silage, passed through the animal and into manure that was later sold. Horses fed on hay that had been treated were also reported as a possible channel (Davies 2008). Aminopyralid is popular with farmers, who spray it on grassland because it controls weeds such as docks, thistles and nettles without affecting the grass around them. It binds itself to the 'woody' tissue in the grass and only breaks down when exposed to bacteria in the soil (Davies 2008). The use of aminopyralid is now subject to strict stewardship to ensure that any treated grass (or resulting manure) does no leave the treated field. No recorded evidence of its presence in green compost has been found (The Composting Association 2008).

The Organics Recycling Group (formerly The Composting Association) advises UK biowaste processors not to knowingly compost any materials that have been treated with clopyralid or aminopyralid. Each biowaste processor should, as far as practicable, check with each supplier whether any product that contains clopyralid or aminopyralid has been applied to the material. Although the Organics Recycling Group recognise that this recommendation is not feasible for material collected from households, local authorities can help to minimise risks by reminding householders to read herbicide product labels carefully before deciding whether to purchase a product, using it and deciding what to do with any garden plant

wastes treated with the herbicide (The Composting Association 2008). Further information on clopyralid can be found in Appendix D.

3.2.5 Comparative risk assessment

A full description of the data used in this comparative risk assessment may be found in Appendix E.

Risks were considered negligible for many of the PAHs in the various comparator materials (Table 3-26).

For PCBs, many of the comparator materials were assessed as presenting negligible risks, although all materials (including livestock manures) may require further investigation for particular PCBs. (Table 3-27). However, it must be remembered that this assessment has used the same exposure scenario for all comparator materials (Section 2.2), inasmuch as it was assumed that animals were allowed to graze the land immediately after surface spreading of the various amendments. In reality, a livestock-clear period would be implemented post spreading – for all of the materials under consideration.

For the dioxins (PCCD/Fs), pig slurry, cattle farmyard manure and chicken manure all posed risks that were significantly greater than those associated with SSGW compost (Table 3-28). In all cases 1,2,3,4,6,7,8-HpCDD was found to pose the greatest risk. The other dioxins assessed presented negligible risk.

Table 3-26 Estimated relative risks (RR, Equation 2.10) for PAHs associated with surface spreading of comparator materials to grazing land and subsequent immediate grazing by either sheep or cattle. In this analysis two different soil ingestion scenarios (Table 2-3) were simulated

Comparator Material	Sheep (Realistic worst case ingestion rate)							Sheep (Extreme worst case ingestion rate)						
	NAP	B[a]A	CHR	B[b]f	B[k]f	B[a]P	IPY	NAP	B[a]A	CHR	B[b]f	B[k]f	B[a]P	IPY
SSGW Compost														
Dairy cattle slurry														
Pig slurry														
Cattle FYM														
Pig FYM														
	Cattle (Realistic worst case ingestion rate)							Cattle (Extreme worst case ingestion rate)						
	NAP	B[a]A	CHR	B[b]f	B[k]f	B[a]P	IPY	NAP	B[a]A	CHR	B[b]f	B[k]f	B[a]P	IPY
SSGW Compost														
Dairy cattle slurry														
Pig slurry														
Cattle FYM														
Pig FYM														

Negligible risk (RR ≤ 1.0)

May require further investigation (RR > 1.0)

Table 3-27 Estimated relative risks (RR, Equation 2.10) for PCBs associated with surface spreading of comparator materials to grazing land and subsequent immediate grazing by either sheep or cattle. In this analysis two different soil ingestion scenarios (Table 2-3) were simulated

Comparator Material	Sheep (Realistic worst case ingestion rate)											Sheep (Extreme worst case ingestion rate)									
PCB	28	52	95	101	118	132	138	149	153	174	180	28	52	95	101	118	132	138	149	153	174	180
SSGW Compost																						
Dairy cattle slurry																						
Pig slurry																						
Cattle FYM																						
Pig FYM																						
	Cattle (Realistic worst case ingestion rate)											Cattle (Extreme worst case ingestion rate)									
PCB	28	52	95	101	118	132	138	149	153	174	180	28	52	95	101	118	132	138	149	153	174	180
SSGW Compost																						
Dairy cattle slurry																						
Pig slurry																						
Cattle FYM																						
Pig FYM																						

Negligible risk (RR ≤ 1.0)

May require further investigation (RR > 1.0)

Table 3-28 Estimated relative risks (RR, Equation 2.10) for PCDD/Fs associated with surface spreading of comparator materials to grazing land and subsequent immediate grazing by either sheep or cattle. In this analysis two different soil ingestion scenarios (Table 2-3) were simulated

Comparator Material	Sheep (Realistic worst case ingestion rate)							Sheep (Extreme worst case ingestion rate)						
PCDD/F	2,3,7,8-TeCDD	1,2,3,7,8-PeCDD	1,2,3,4,6,7,8-HpCDD	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	2,3,7,8-TeCDD	1,2,3,7,8-PeCDD	1,2,3,4,6,7,8-HpCDD	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF
SSGW Compost														
Dairy cattle slurry														
Pig slurry														
Cattle FYM														
Pig FYM														
Chicken manure														

	Cattle (Realistic worst case ingestion rate)							Cattle (Extreme worst case ingestion rate)						
PCDD/F	2,3,7,8-TeCDD	1,2,3,7,8-PeCDD	1,2,3,4,6,7,8-HpCDD	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	2,3,7,8-TeCDD	1,2,3,7,8-PeCDD	1,2,3,4,6,7,8-HpCDD	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF
SSGW Compost														
Dairy cattle slurry														
Pig slurry														
Cattle FYM														
Pig FYM														
Chicken manure														

Negligible risk (RR ≤ 1.0)

May require further investigation (RR > 1.0)

3.2.6 Conclusions

Although a wide range of organic contaminants have been measured in SSGW compost, the majority of these are present at levels that pose a negligible risk to animals, humans, or the environment. A few contaminants may be present in SSGW product at concentrations that exceed the calculated references doses under the modelled parameters. Only 1,2,3,4,6,7,8-HpCDD may require further investigation, although the same dioxin has been shown to present a theoretical risk for a range of other materials, including cattle farmyard manures, pig slurry and chicken manures. In the context of these other materials, the risks from SSGW compost may be viewed as manageable, but as this dioxin is associated with the industrial bleaching of paper, it might be that reducing paper and card levels in compost feedstocks could reduce concentrations of this dioxin still further.

The potential for risks associated with animal ingestion of soil adhering to fodder crops was not considered, since such adhesion rates are likely to be much lower than those modelled for direct ingestion during grazing (Table 2-3). For example, Gale & Stanfield (2001) assume only 2% w/w of the consumed crop to be soil, while recent data for sugar beet identify that 6.2% of the weight of the crop was soil (NFU 2009).

A potential risk to sensitive broad-leaved plants has been identified from the herbicide clopyralid (Table 3-25); although some studies report that concentrations of the compound drop to below threshold levels within a few weeks post application. The compound can also be toxic to aquatic insects, and Codes of Practice should be followed to ensure that compost is not applied within recommended distances from water courses. It may be difficult to manage levels of clopyralid entering SSGW in contaminated feedstock. However, PAS100 compliant compost does require a tomato seed germination and growth bioassay that should protect against negative effects associated with clopyralid residues by preventing their occurrence in certified compost at concentrations that could harm crop or ornamental plants.

3.2.7 Options for risk management

- There is a lack of PAS100-specific data for levels of organic contaminants in SSGW compost. This must be borne in mind when interpreting the assessment presented here.
- The specific source of 1,2,3,4,6,7,8-HpCDD in SSGW compost (or other common agricultural amendments in which this compound was also identified) is unknown, which means that it is difficult to manage any associated risks. This compound has been shown to be present in other common agricultural amendments, including cattle farmyard manure, and its apparent ubiquity may not therefore be cause for concern. However, since industrial bleaching of paper is known to be a source for this dioxin, screening of excessive volumes of paper from compost feedstocks may offer an additional degree of management.
- Similarly, it is difficult to manage risks from clopyralid by limiting feedstock from amenity grassland – even though clopyralid-treated grass should not be sent for composting. Feedstocks need to comprise roughly 7 % treated grass to result in a RR > 1. Also, the tomato seed germination bioassay, which is part of PAS100 compliance, should protect against the risks associated with such herbicide residues.
- Raising awareness of the potential problem in itself should help reduce risks and this could be undertaken within the composting industry specifically. Recent general concern about the use of clopyralid in agriculture has resulted in clearer labelling and indeed some products have been withdrawn. As a result, levels of clopyralid in compost products are likely to decline in the future.

3.3 Potentially Toxic Elements (PTEs)

Many soil amendments contain heavy metals and other potentially toxic elements in varying amounts. Animal exposure is principally through ingestion of treated soil, but consumption of herbage grown on treated soils is also a route that needs to be considered. If present in sufficient quantity, human health could also be impacted by these elements when they are taken up by crops, by grazing animals, through surface run off or from leaching to ground water. The primary route of exposure will therefore be through ingestion, and the dose (and therefore risk) will depend on the concentrations of the elements in the food or water and the degree of repeated exposure over time.

A total of 14 PTEs were identified as having been measured in SSGW compost:

- Arsenic (As)
- Boron (B)
- Cadmium (Cd)
- Chromium (Cr)
- Cobalt (Co)
- Copper (Cu)
- Lead (Pb)
- Mercury (Hg)
- Manganese (Mn)
- Molybdenum (Mo)
- Nickel (Ni)
- Selenium (Se)
- Vanadium (V)
- Zinc (Zn)

Ten of these were considered to have potentially serious effects (European Commission, 2005) and were evaluated further. Four of these (Cu; Cd; Cr; Pb) could be present in compost at levels considered to cause serious effects and were entered into the exposure model. These are detailed in Table 3-29.

Copper (Cu)

Cu is used in the manufacture of batteries, welding, soldering and also as a fungicide and an insecticide.

Cu is one of the most important essential micronutrients for plants and animals. Issues of deficiency in animals are more prevalent than those of toxicity but are confined to grazing cattle and sheep due to levels of Cu in forage which are below the minimum concentrations required for livestock diets. This is particularly the case in the presence of elevated levels of molybdenum which is an antagonist and inhibits enzymes in which Cu is a co-factor. In addition, Cu is used as a growth promoter in pigs and poultry so ingestion via compost for these receptors is unlikely to be an issue. The application of pig slurries and distillery wastes, both rich in Cu, to land has been considered beneficial in order to improve the Cu status of soils. Sheep, however, are particularly sensitive to Cu and in theory could be at some risk when grazing on pasture amended with pig slurry. Copper salts are traditionally used as fungicides within organic production systems, and these uses remain permitted (EC 2008).

Concentrations of Cu in plants typically fall in the range 5-20 mg kg^{-1} (Kabata Pedias and Pendias, 2000). As accumulation varies according to plant species, it is not possible to give single concentration values for Cu deficiency or toxicity. Soil biological activity is sensitive to Cu inputs (Sherameti and Varma, 2009) and is probably the main limitation to amendment of soil with copper-containing wastes.

Under normal conditions, Cu is benign to humans. However, ingestion of excess Cu by humans can cause renal tubular abnormalities while inhalation of Cu dust or fumes can result in metal fume fever (reported in welders). Exposure to Cu sulphate solution used as a fungicide by vineyard sprayers has resulted in interstitial pulmonary disease (ATSDR, 1990).

Cadmium (Cd)
No Cd ores exist as such, and Cd occurs in nature associated with Zn. It is a relatively recent environmental contaminant with over 50% of Cd used in industry being produced since 1970 (Hutton, 1987), but phosphate fertilizers are widely regarded as the most ubiquitous source of cadmium contamination in agricultural soils. In field experiments, phosphatic fertilisers containing 3-8 mg kg^{-1} Cd contributed 2 g Cd ha^{-1} yr^{-1} to an arable soil and 7.2 g Cd ha^{-1} yr^{-1} to soil under permanent grassland (Jones et al., 1987). These levels were however, lower than those resulting from large annual applications (35 t FW ha^{-1}) of farmyard manure (0.3 - 1.8 mg kg^{-1} Cd). The maximum allowable annual loading limits under various sewage sludge regulations are 0.0015 (Finland) to 1.9 (USA) kg Cd ha^{-1} yr^{-1} (Alloway, 1995). The current EU limit is 0.15 kg Cd ha^{-1} yr^{-1}.

The principal uses of Cd are in the electroplating of steel, in various alloys, in pigments (for plastics, enamels and glazes), in nickel cadmium dry-cell batteries, as a plastic stabilizer and other miscellaneous uses such as photovoltaic cells and control rods for nuclear reactors (Alloway, 1995).

Cd has no essential biological function and is highly toxic to both plants and animals. Food is the main route by which cadmium enters humans. The EFSA recommends a tolerable weekly intake (TWI) of 2.5 µg/kg-1 body weight.

The major hazard to human health from Cd is chronic accumulation in the kidneys where it can cause dysfunction (Jarup, 2003). Cadmium accumulation can also occur in the liver. Cd has also been linked with carcinogenicity in the human body (Waalkes, 2003) and is a cause of so-called "hard-metal disease" in exposed workers, a form of emphysema (Nemery, 1990). In exposed workers a form of osteomalacia has also been described (itai itai disease, Chalkley et al., 1998). Studies of non-occupational exposures have also reported outcomes such as brittle bones (Staessen et al., 1999) and lung cancer (Nawrot et al. 2006).

Chromium (Cr)
Cr is used in metallurgic and chemical applications. It increases hardness when mixed with steel or wrought iron. Cr chemicals have many uses including the manufacture of pigments, dyeing, and leather tanning, as a wood preservative and in glass making.

Cr is an essential element and with normal dietary intakes at <200 µg d^{-1} (McGrath, 1995) deficiency is more likely a problem than toxicity. Indeed, there have been studies on increasing the Cr content of crops in order to supplement the diet (Cary et al., 1977a, 1977b). In general, there is minimal uptake of chromium from soil by plants because trivalent Cr is present in most soil and organic rich materials such as sewage sludge and this is relatively insoluble (Kabata Pendias and Pendias 2000).

The toxicity of Cr depends on its chemical form, hexavalent Cr being especially toxic both in terms of development of asthma and carcinogenicity in humans. Contact dermatitis has been widely reported following exposure to chromium. Chronic low-level exposure to the hexavalent form can result in asthma, gingivitis, eye lesions, conjunctivitis, bronchitis, sinusitis and it has carcinogenic properties (Cohen & Costa, 1998).

Lead (Pb)
Environmental Pb can be found in water, soil and in air although the predominant store of Pb is in surface soils as a result of historical deposition of Pb from the atmosphere. Since the introduction of the Clean Air Act and the abolition of leaded petrol, airborne Pb levels have fallen dramatically and the overall contribution to the total Pb burden from air, although still detectable, is now small. Pb and its compounds tend to accumulate in soils where they remain almost indefinitely.

One of the main uses of Pb is in manufacturing batteries with other uses being for production of pigments, plastics, cable sheathing and ammunition (Thornton et al. 2001).

Under current EU sewage sludge regulations, no more than 15 kg ha^{-1} yr^{-1} of Pb can be added to soil (Thornton et al. 2001).

Both occupational and non-occupational exposure of humans to Pb is of concern especially Pb toxicity in children. Toxicity is also dependent on the solubility of the Pb compound (Thornton et al. 2001). Pb poisoning is a chronic disease as a result of gradual accumulation of lead within the body, leading to effects on the nervous system (headache, dizziness, sleep disturbances, memory deficit, kidneys (renal dysfunction), cardiovascular system (anaemia, hypertension), gastrointestinal tract (nausea, weight loss), locomotor system (joint pains) and the reproductive system (teratogenic effects on fertility in males and females, spontaneous abortion) (Fischbein, 1998). The EFSA report that there is no evidence for a threshold for lead-induced critical effects (EFSA, 2010)

Table 3-29 Initial toxin concentrations in composted plant material and related reference doses (RfD) for cattle and sheep. PAS100 limits shown for comparison

PTE	Mean concentration in compost mg kg^{-1}	Max concentration in compost mg kg^{-1}	PAS100 limits mg kg^{-1}	RfD Cattle mg kg^{-1} d^{-1}	RfD Sheep mg kg^{-1} d^{-1}
Cu	44.9[a]	300[a]	200	10.0[b]	2.50[b]
Cd	0.41[a]	4.00[a]	1.50	0.50[b]	0.50[b]
Cr	19.7[a]	117[a]	100	10.0[b]	10.0[b]
Pb	43.1[a]	263[a]	200	10.0[b]	5.00[b]

[a] Brändli, 2006; Barth, 2005; Petrell et al., 2003; Greenway & Song, 2002; Whittle & Dyson, 2002 & SMA, 1998.
[b]National Research Council, 1980

3.3.1 Surface application to pasture and subsequent grazing

Following the exposure assessment (Section 2.2), PAS100 green compost was considered to present a negligible risk from exposure to PTEs (Table 3-30). Modelling of maximum copper concentrations in non-PAS100 green composts identified that such composts may present a risk to grazing sheep if surface applied at a rate of 50t ha^{-1} immediately prior to grazing.

Table 3-30 Estimated relative risks (RR, Equation 2.10) for PTEs associated with surface spreading of PAS100 green composts to grazing land and subsequent immediate grazing by either sheep or cattle. In this analysis two different application rates (25 t ha^{-1}; 50 t ha^{-1}) and two different soil ingestion scenarios (Table 2-3) were simulated

Potentially Toxic Agent	Exposure Scenario							
	Sheep				Cattle			
	LR	LE	HR	HE	LR	LE	HR	HE
Cu								
Cd								
Cr								
Pb								

L = Low application rate (25t ha^{-1})
H = High application rate (50t ha^{-1})
R = Realistic worst case soil ingestion rate (Table 2-3)
E = Extreme worst case soil ingestion rate (Table 2-3)

Negligible risk (RR ≤ 1.0)

May require further investigation (RR > 1.0)

3.3.2 Incorporation into soil and subsequent production of fodder crops

Uptake of PTEs into various crop plants was modelled using the approach outlined in Section 2.2.3. As expected, incorporation of SSGW compost into the soil reduced the concentration of all PTEs (Figure 3-3). Uptake by wheat, forage maize, root crops, and leaf crops were estimated for six different application rates (Figure 3-4 to to Figure 3-7). To maintain comparability, soil organic carbon was held at 5.9 % and soil pH was held at 6.33. In both cases, these were the mean values from the parameterisation dataset described in Hough (2002). The influence of soil pH and soil organic content on metal uptake is illustrated in Figure 3-8 and Figure 3-9.

Figure 3-3 Concentration of PTEs in soil in relation to the range of application rates presented in Table 2-4. Initial concentrations of each compound in SSGW compost prior to incorporation were assumed to equal current PAS100 limits (Table 3-29)

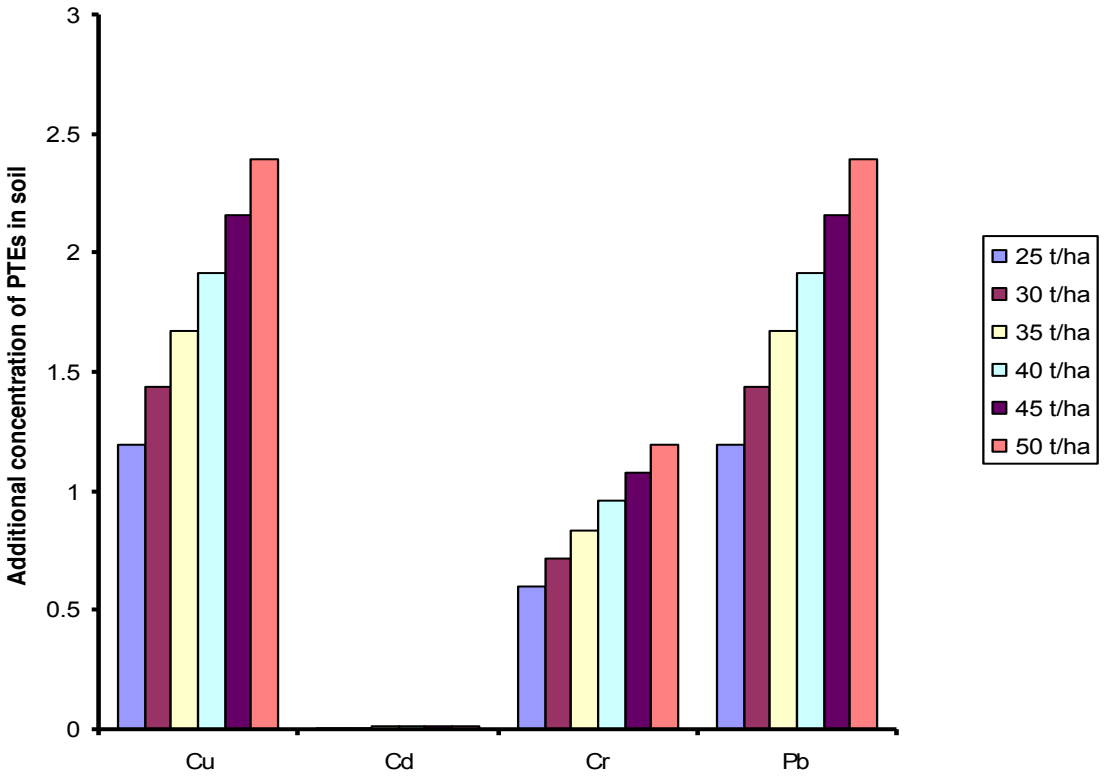


Figure 3-4 Predicted uptake of Cu by crop plants as a function of application rate

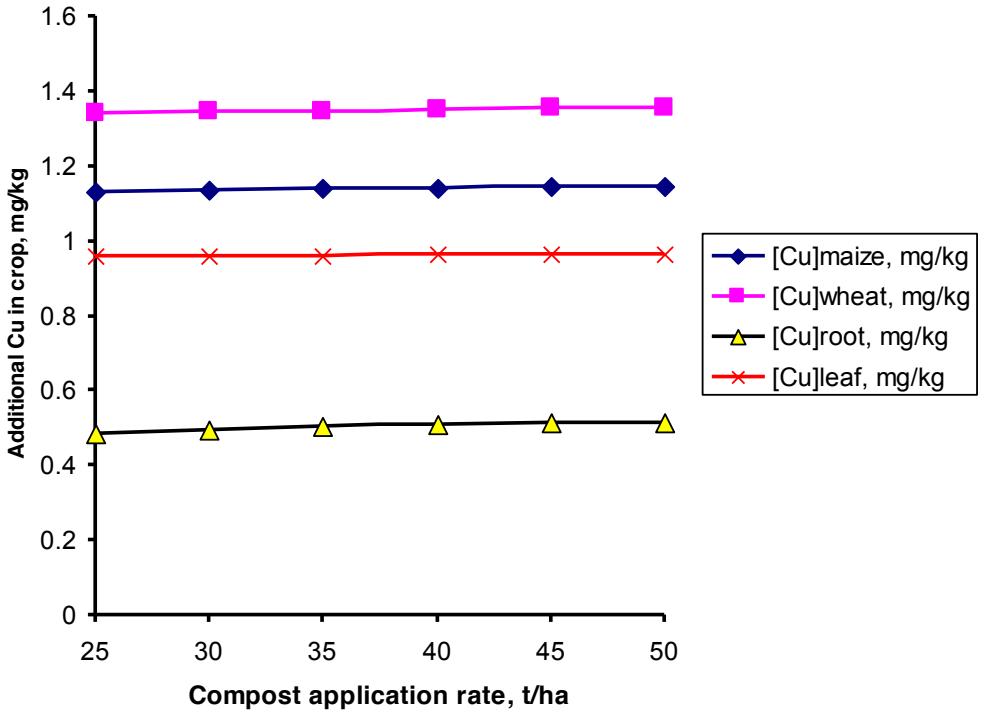


Figure 3-5 Predicted uptake of Cd by crop plants as a function of application rate

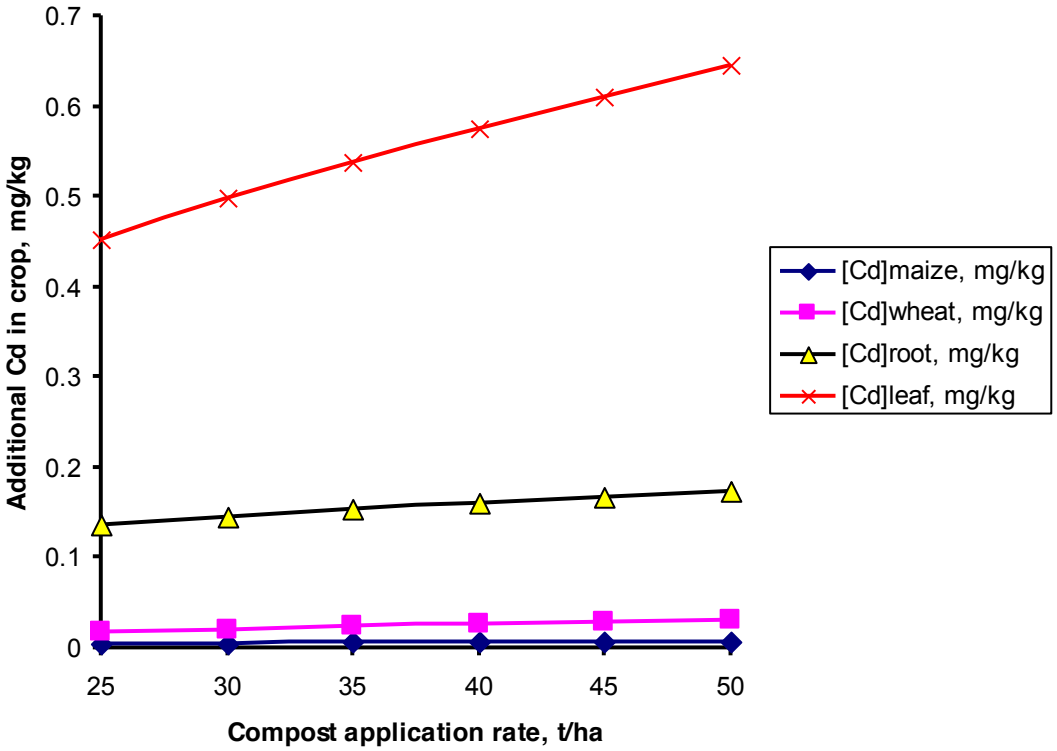


Figure 3-6 Predicted uptake of Cr by crop plants as a function of application rate

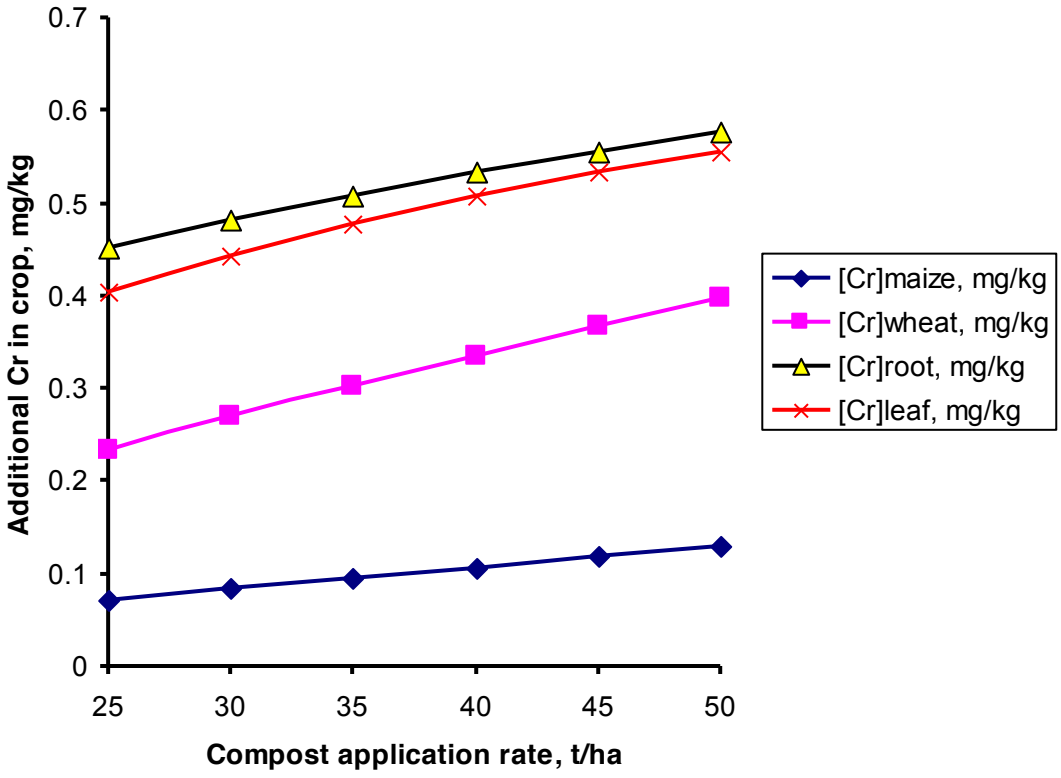


Figure 3-7 Predicted uptake of Pb by crop plants as a function of application rate

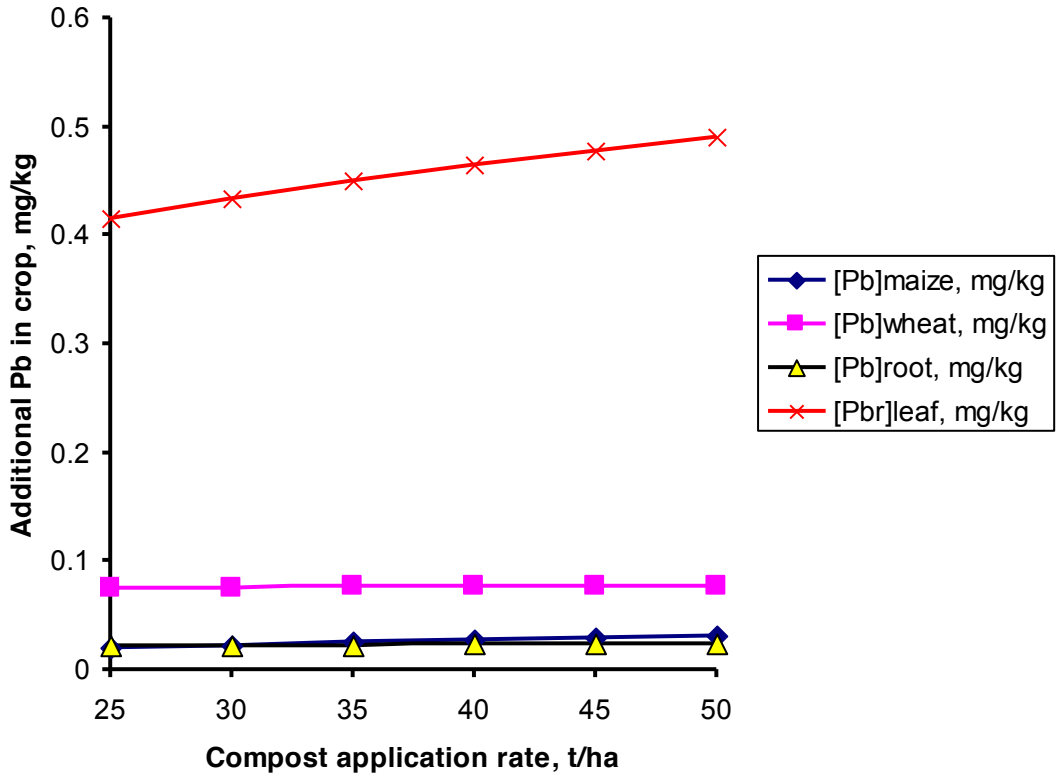


Figure 3-8 Influence of soil pH on the uptake of Cd by crop plants. An application rate of 50 t ha^{-1} and soil organic carbon content of 5.9 % was used for this illustration

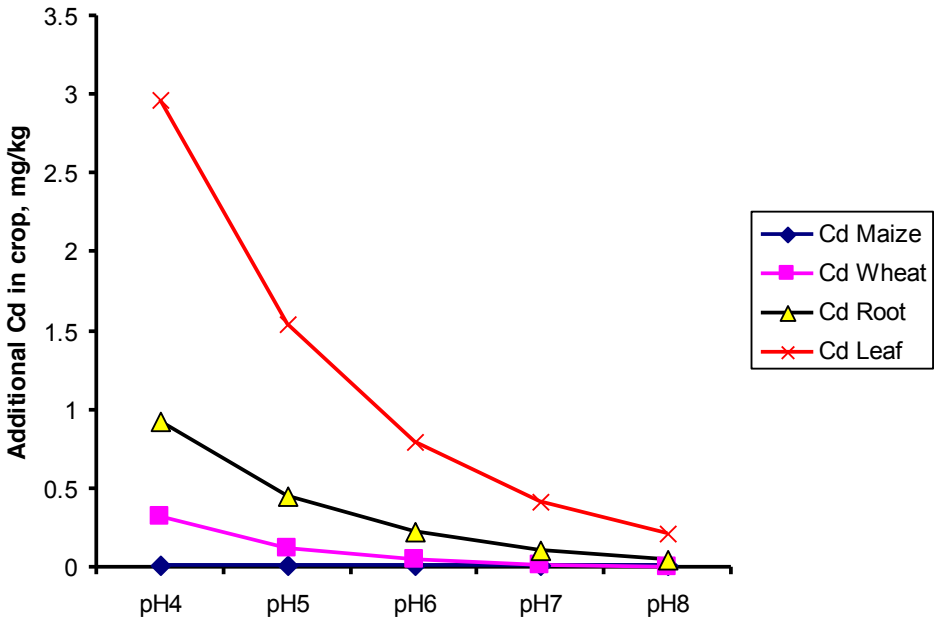
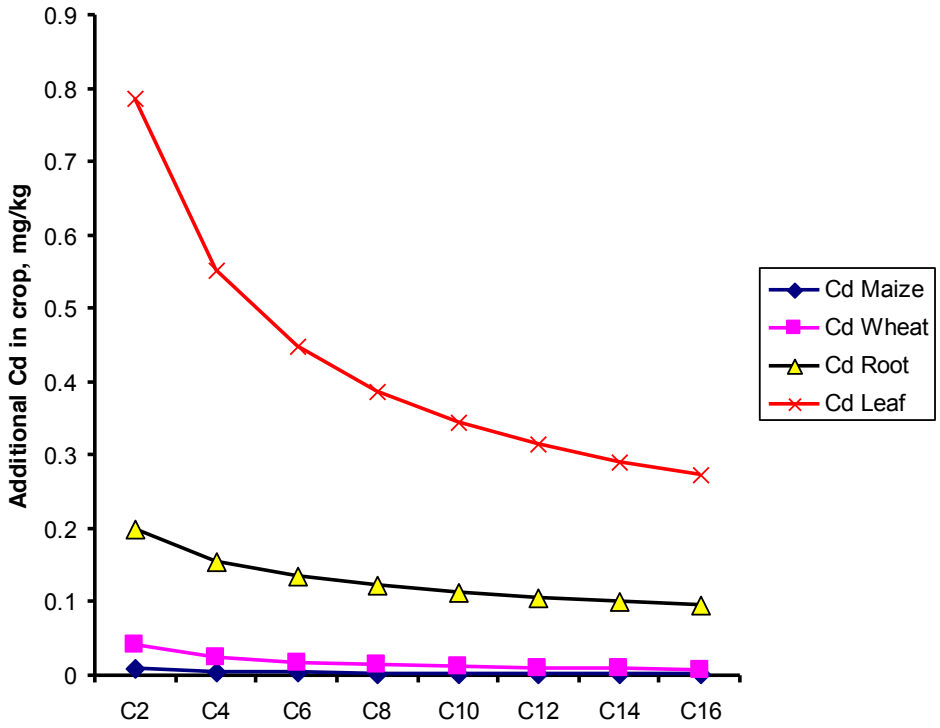


Figure 3-9 Influence of soil organic carbon on the uptake of Cd by crop plants. 'C2' represents a soil with 2 % organic carbon, 'C16' a soil with 16 % organic carbon. An application rate of 25 t ha^{-1} and pH of 6.33 were used for this illustration. It is unlikely for compost to be applied to soil with a C content > 10%



The uptake models were used to estimate the maximum allowable concentration of each PTE in soil in order to achieve ≤1.00 mg Cd kg^{-1} dry weight in the final crop. Cadmium was investigated in this way because this element is covered by the animal feed regulations, which allow a maximum of 1 mg Cd kg^{-1} in feed (assuming 12 % moisture content).

Table 3-31 presents the results of this analysis for both the maximum concentration of Cd reported in SSGW compost in the literature (4.00 mg kg^{-1}), and for the PAS100 limit (1.50 mg kg^{-1}). This analysis indicates that relatively few annual (maximum) applications of SSGW compost would be required for soil Cd levels to exceed limits at which foliar uptake of Cd presents a risk to livestock. While this initially indicates that further investigation is warranted, it is worth noting that the maximum permissible concentration of Cadmium in agricultural soils of pH ≥ 5.0 is 3.0 mg kg^{-1} dry solids (OPSI, 1989) – almost ten-times the back-calculated theoretical maximum for soils in which leafy crops are grown for animal feed. This emphasizes the extremely conservative nature of the modelling approach, but suggests that it would be appropriate to monitor foliar Cd concentrations to ensure that thresholds are not met.

Table 3-31 Maximum concentrations of Cd in soil that may result in animal feed exceeding legislative limits (1.00 mg Cd kg^{-1}; 12 % moisture content) and the number of applications of SSGW compost required to reach these levels. This assessment relates to additional cadmium only

Crop	Theoretical modelled maximum allowable in soil, mg/kg	No. applications to reach max @ 50 t/ha maximum PTE compost	No. applications to reach max @ 50 t/ha PAS100 limits
Maize	17.0	353	941
Wheat	6.00	125	332
Root	10.0	208	553
Leaf	0.33	6.23	16.6

Negligible risk (RR ≤ 1.0)

May require further investigation (RR > 1.0)

3.3.3 Comparative risk assessment

Within the scenarios modelled, potential risks to grazing sheep were associated with potentially toxic elements in dairy and pig slurry, pig farmyard manure, and cattle farmyard manure (Table 3-32). These risks were primarily associated with elevated concentrations of copper, to which sheep are particularly sensitive. Again it must be noted that under normal practice a livestock-clear period (good practice advice is to allow a 3-4 week 'no graze' period (ADAS, 2001)) would be implemented post spreading which would reduce the risks (to maintain comparability, the exposure model used for each comparator material remained the same, with no 'graze-free' periods).

Table 3-32 Estimated relative risks (RR, Equation 2.10) for PTEs associated with surface spreading of comparator materials to grazing land and subsequent immediate grazing by either sheep or cattle. In this analysis two different soil ingestion scenarios (Table 2-3) were simulated

Comparator Material	Sheep (Realistic worst case ingestion rate)				Sheep (Extreme worst case ingestion rate)			
PTE	Cu	Cd	Cr	Pb	Cu	Cd	Cr	Pb
SSGW Compost								
Dairy cattle slurry								
Pig slurry								
Cattle FYM								
Pig FYM								
Chicken manure								
	Cattle (Realistic worst case ingestion rate)				Cattle (Extreme worst case ingestion rate)			
PTE	Cu	Cd	Cr	Pb	Cu	Cd	Cr	Pb
SSGW Compost								
Dairy cattle slurry								
Pig slurry								
Cattle FYM								
Pig FYM								
Chicken manure								

Negligible risk (RR ≤ 1.0)

May require further investigation (RR > 1.0)

3.3.4 Conclusions

Potentially toxic elements in PAS100 green compost present a negligible risk to grazing animals, even when surface applied at high rates with no livestock lay-off period. Sheep are four times more susceptible to copper than cattle, with risks from non-PAS100 SSGW composts possible under high application rate/acute soil ingestion scenarios. Post-ploughing, additional concentrations of PTEs in soil are low. As a result, uptake by the majority of crop types is relatively low. However, the levels of uptake do depend on soil chemistry with low pH, low organic carbon soils associated with higher rates of uptake. The conservative models used in this study suggest that uptake of Cd by leaf crops might be an issue for long-term application of SSGW compost, and monitoring of foliar Cd concentrations is recommended to ensure that critical limits are not met.

3.3.5 Options for risk management

- The PAS100 limits for PTEs are adequate to protect against medium- to long-term build-up of PTEs in soils. It should be stressed that these results are based on PTEs added to a 'clean' soil. Therefore, it may be sensible to adjust application rates according to pre-application levels of PTEs in a given soil, especially if leaf crops are to be grown.

3.4 Pathogens

During composting, pathogen reduction is achieved through thermal destruction, but also through competitive interactions between microorganisms, nutrient depletion and by-product toxicity, and natural die-off. SSGW compost does not originate from sources expected to have a significant burden of microbial pathogens (Anon 1999-2000). However, it is possible that microbial contamination may occur and it is essential to assess the likelihood of increased human and animal pathogen burdens in soils to which SSGW composts have been applied. Previous work has already examined the potential for composting to control plant pathogens, concluding that, of the numerous pathogens indentified as concerns by compost users, only Tobacco Mosaic Virus (TMV) was likely to survive the composting process. The authors state that this agent was unlikely to be of major significance in the UK, as previously susceptible crops are now bred with TMV resistance (Noble et al., 2004).

The aim of this work was to:

- identify microorganisms that could enter SSGW compost
- determine whether they would pose a significant health risk to humans and animals
- determine whether they would survive the composting process
- determine the longevity after application to soil/pasture of those likely to survive composting
- determine the likelihood of human/animal infection arising from these organisms.

The steps taken to evaluate the microbial contamination of SSGW are elucidated and discussed in the following sections.

Step 1 - Identification of microorganisms in SSGW feedstocks

There are a vast array of microorganisms present on plant surfaces and in the attached soils, therefore rather than using Filter 1 to identify health effects of any microorganisms present, it was decided to begin with a list of pathogenic microorganisms. The Advisory Committee on Dangerous Pathogens (ACDP) list (ACDP 2004) of category II, III and IV organisms was selected for this purpose as it was considered to encompass all important human pathogens, providing an appropriate starting point. Hazard Group I organisms were considered to pose negligible risks. Definitions of each group are as follows:

- *Hazard Group I* - A biological agent that is unlikely to cause human disease.
- *Hazard Group II* - A biological agent that can cause human disease and may be a hazard to employees; it is unlikely to spread to the community and there is usually an effective prophylaxis or effective treatment is usually available.
- *Hazard Group III* - A biological agent that can cause severe human disease and presents a serious hazard to employees; it may present a risk of spreading to the community but there is usually effective prophylaxis or treatment available.
- *Hazard Group IV* - A biological agent that causes severe human disease and is a serious hazard to employees; it is likely to spread to the community and there is usually no effective prophylaxis or treatment available.

Step 2 - Cross-check with a list of important animal pathogens not already present in the "human" list

DEFRA's A-Z of animal pathogens under *Disease surveillance & control: Animal Pathogens*was checked for additional pathogens of livestock not considered in the ACDP list.

Step 3 - To determine which of the organisms in steps 2 and 3 were likely to enter SSGW feedstock

The assumption was made that the following would be included in SSGW:

It was considered possible for bacteria, fungi, protozoa and viruses to enter SSGW via the following processes:

- Association with plant material comprising clippings and materials from public and private parks and gardens, other amenity areas, grass verges etc;
- Small quantities of soil associated with plant material;
- Small amounts of faecal material associated with any of the above e.g. through dogs/other pets/wildlife (e.g. birds, rodents, small ruminants, badgers, foxes and deer).
- Farm livestock manures and associated microorganisms were not considered to be likely to enter SSGW directly, although composting is often recommended as a measure to reduce pathogen loadings in manures (Food Standards Agency, 2009).

Initially a broad review of information was made using ISI Web of Science and internet searches to check for any references linking pathogens listed in steps 1 and 2 with soil, plant material/compost or bird/animal faeces. References were not listed at this stage but organisms were simply eliminated from the list where there was no evidence of the organism having been found in those matrices.

This provided a list of human and animal pathogens that could be associated with soil, plant material, animal faeces or compost, but did not account for sources, geographical limitations or prevalence.

A second, more in-depth search was then performed for the organisms remaining on the list, to locate reliable references documenting their association/isolation/presence in the above matrices. These references were recorded. In some cases there was an abundance of literature while in others there was little or none. In general only one example was provided for the latter.

Step 4 - Application of filter 1

Filter 1 (for microbial contamination) was to determine the likelihood of the identified agents entering SSGW. This permitted the removal of organisms that were not directly relevant (e.g. tropical climates, paddy fields, association with livestock animal faeces unlikely to enter SSGW etc.) as "Unlikely to enter SSGW". Where references were sparse or raised uncertainty about the prevalence or frequency of isolation from relevant matrices, the organism was filtered as "Unknown likelihood of entry into SSGW"

In addition to those organisms listed in Appendix B4ii as passing through filter 1; *Legionella longbeachae* was also considered further as there have been reports of "potting mixtures" being a source of infection. Note that potting mixtures can be mixture of various organic substrates (including SSGW compost, peat, coir fibre, bark fines and others) with soil. In our risk assessment it did not pass through filter 1 as at the time of writing there were no reports of its isolation from compost or soil in the UK. The organism has been reported principally in Australia and the US (Steele et al, 1989; O'Connor et al 2007). Only three infection cases of *L. longbeachae* have been reported in Scotland to date and the source of infection was only identified positively in one case. In this case the source was attributed to potting compost which was handled prior to coming to Scotland (Scottish Parliament, 2009). In one of the other cases it was, however, thought to have arisen through use of commercial potting compost (Madeley, 2008) but it is not clear if this was simply because it is a recognised source of infection in the US and Australia (O'Connor et al 2007). There is currently no evidence to associate this organism with SSGW in the UK but it should be noted

that commercial composts in Australia carry warning labels and advice on how to minimize exposure to this potential hazard.

Step 5 - Quantification of pathogenic microorganisms entering the SSGW composting process

In order to carry out a quantitative risk assessment for microbial pathogens within the SSGW composting process, it is necessary first of all to have data to determine the dose of each organism entering the composting process. At this point it was necessary to deviate from the original protocol due to lack of available data.

Data are at best scarce and generally non-existent concerning the role of soil, let alone parkland and garden plants, as carriers or reservoirs of enteric infections for humans and animals, and there is little or no information on prevalence or numbers of pathogenic microorganisms in soil, plants or even animal and bird faeces. The literature is much better populated for livestock systems and manures; however these are not relevant as sources of SSGW composting materials (although such manures are acceptable inputs to a PAS100 compliant composting process, and composting is recognized as a route for controlling enteric agents in livestock manures (Food Standards Agency, 2009)). Santamaria and Toranzos (2003) highlighted in their review a similar issue for soils. In the absence of such data, it is impossible to carry out a quantitative risk assessment of the dangers posed by these organisms through the SSGW composting process. Appendix B4ii provides information on numbers of some of the key organisms in soils.

Further research is required to elucidate the prevalence of the organisms listed in Appendix B4i Filter 1 in SSGW material.

However, in the absence of such data, Appendix B4i Filter 1 presents the most likely candidates for entry into SSGW compost and Appendix B4i Filter 2 begins to identify some aspects of their physiology and behaviour which may render them more or less susceptible to inactivation during the composting process. Data have been drawn from the literature where possible. Where data were not obtained, the organism is filtered as "Uncertain", denoting insufficient information.

Step 6 - Health Effects

All of the microorganisms listed can have potentially severe health implications for humans and or animals (livestock). The full assessment of health effects is not included since all were selected as important human/animal pathogens in the Step 1.

Step 7 - Survival during the composting process

Most of the available data refers to composting of materials such as cattle manure or sewage sludge and tends to focus on coliforms and indicator microorganisms. While providing insight into faecal contamination, these are not necessarily good analogues for all of the potential pathogens. Coliforms and other enteric pathogens tend to be susceptible to the chemical and microbiological environment within composts as well as to thermal inactivation. Conditions are sub-optimal for the growth of enteric bacteria although growth of *E. coli* has been reported during composting of some wastes (Wichuk & McCartney 2007) including in SSGW (Brown et al 2000). This growth appears to occur prior to the onset of the thermophilic stage of composting (sanitization phase) during which die-off occurs (Brown et al 2000). In general, sustained temperatures over 55°C should kill off most enteric bacteria. Indeed, Noble et al (2004) suggested that green compost processes should achieve temperatures ≥ 65°C for seven days to provide appropriate kill of plant pathogens, and this recommendation is made in the PAS100 specification (BSI, 2011). It is likely that such temperatures and duration will also eliminate many other pathogens (Gale, 2002). Where die-off does not occur at seemingly appropriate temperatures, this is thought to be due to

the heterogeneity of compost windrows and difficulty in guaranteeing uniformly high temperatures. The frequent turning recommended in PAS 100 is intended to ensure that the cooler outside areas of the windrow are incorporated into the centre of the stack. Few published data are available to determine the efficacy of windrow turning in reducing pathogen load, although temperature profiling in windrows has been subject to intensive research, and models developed to calculate the number of turns required to ensure that all material achieves the required temperatures are available (Notton, 2005).

Composting does generally lead to a decline in enteric bacteria (Appendix B4i, Filter 2). For example, Nell et al, 1983 (cited in Wichuk & McCartney 2007) reported that *E. coli* in sewage sludge compost was not detectable after five weeks, while *Salmonella* spp. were not detectable after two weeks composting in a full scale windrow. A number of studies indicate that provided a temperature of 55°C is maintained for 3 days, *Salmonella* should be inactivated. In contrast, other studies indicate variability, particularly spatial differences throughout the windrows, and viable counts of *Salmonella* spp. were recorded despite maintainance of a temperature of 55°C. However, most of these studies refer to sewage sludge or manure composting, which is likely to have a much greater pathogen burden than SSGW. PAS100 has zero tolerance for the presence of *Salmonella* in sub-samples of finished compost product (BSI, 2011).

Wichuk & McCarntey (2007) reviewed a range of studies of inactivation of *E. coli*. The verotoxigenic form (*E. coli* O157:H7) was eliminated in a windrow compost within 25 days at less than 55°C. Reported temperatures for elimination of *E. coli* ranged between 45°C and 55°C. Larney et al. (2003) reported 99.9% elimination of total coliforms and *E. coli* organisms from beef feedlot manures in the first 7 days of composting when average windrow temperatures ranged from 33.5 to 41.5°C, illustrating that there is considerable variability, likely to be attributable at least in part to differences in the compost feedstock materials. Larney also reported the inactivation of *Listeria* spp., *M. paratuberculosis*, and *Salmonella* spp. in composted cattle manure after 3 days at temperatures comparable to full-scale windrows (55-65°C).

Spore-forming bacteria such as *Bacillus* spp. and *Clostridium* ssp. are likely to survive during the composting process for prolonged periods of time and may not be inactivated (Wichuk & McCartney 2007). This is evident from the studies of Brown et al (2000) in which clostridia were evident throughout the composting process and increased in numbers by approximately half a log unit over the course of eight weeks. When windrows of SSGW mixed with anaerobically digested sewage sludge were compared with those containing just SSGW, the mixed feedstocks yielded more clostridia (Brown et al 2000). The authors took this to indicate that clostridia were not killed during anaerobic digestion (which is perhaps not surprising for a spore-forming anaerobic organism). Therefore, in terms of clostridial contamination, SSGW is likely to pose a lower risk than anaerobically digested sewage sludge when applied to land. This may also be the case for *Bacillus* species, although Schloss et al. (2004), investigating the microbial community dynamics of compost noted that *Bacillus* species increased in abundance during the composting period.

Fungi are not considered in compost regulations in the US (USEPA 1999) due to their non-enteric origins and due to risks being primarily to compost facility workers (i.e. occupational exposure), rather than the general public (i.e. environmental exposure).

Although there is a substantial body of literature developing with regard to the widespread occurrence of *Aspergillus fumigatus* in compost, measurements of materials during and after composting seem to be rare and in general, studies are concerned with spore counts in aerosols around windrows or composting sites (e.g. Taha et al. 2007) and do not provide input and output data for the process for use in a quantitative risk assessment of the type

presented here. However, the measurement of *Aspergillus* spores around windrow and composting sites demonstrates their presence, and consideration should be given to post-process handling of SSGW to minimise aerosols.

Although enteric viruses carried by domestic animals or wild/domestic birds and other wildlife are capable of persisting in the environment and could potentially enter source separated SSGW through incidental inclusion of soil and or faecal material, they do not possess the ability of bacteria and fungi to replicate outside the host cells. Therefore, multiplication of viruses could not occur during the composting process (Anon 2003). In general, virus die-off occurs within typical windrow composting temperatures (Wichuk & McCartney 2007). Given the small quantities of such material likely to be incorporated into SSGW, along with the fact that some die off is inevitable during the composting process, viruses remaining once spread onto land would be unlikely to reach infective doses required to pose a threat to animal or human health. It also seems much more likely that such agents would be deposited directly on soils from source animals than via a composting route. There is no clear route by which non-enteric viruses could enter SSGW, and even if this were possible the above limitations to risk would apply.

There are no studies of protozoal survival during SSGW composting. Studies considering other source materials have detected *Giardia* cysts and *Cryptosporidium* oocysts after composting, however in the only study to take into account viability of the cysts, they were found to have declined to non-detectable levels in a full scale windrow composting beef feedlot manure after 12-26 days at a temperature of 55°C or more (Wichuk & McCartney 2007).

Step 8 - Survival following application to land

It is difficult to predict post-application persistence of pathogens from green waste without appropriate data for source terms (concentrations of each pathogen entering SSGW or present post-processing) and pathway terms (survival during composting). There is a substantial body of literature reporting the survival of key bacteria (e.g. *E. coli* (and O157), *Salmonella*, *Clostridia*, *Campylobacter*) in a range of other organic wastes (animal manures, slurries, a human sewage sludge). Appendix B4ii provides a collation of literature data (not exhaustive) for die-off of some key enteric pathogens in soils and animal wastes (combined and separate). This provides some indication of environmental longevity of these organisms. However, it could be unwise to extrapolate directly from these data as numerous factors influence the survival of pathogens.

In a risk assessment for the pathogens *Salmonella* spp., *Listeria monocytogenes*, *Campylobacter*, *Cryptosporidium*, *E. coli* O157, *Giardia* and enteroviruses in biosolids, the authors stated that there was no clear consensus on the behaviour of pathogens over the 10, 12 or 30 month harvest intervals specified by the Safe Sludge Matrix, although they further stated that decay may be assumed (Gale, 2003). However, detailed consideration of these organisms was undertaken to develop guidance for the use of livestock manures in the production of ready to eat crops, and the guidance suggests that composting of manures over a period of three months (during which temperatures in excess of 55°C should be achieved for three days) is sufficient to allow the composted manures to be applied ahead of ready to eat crops at any time prior to drilling or planting (Food Standards Agency, 2009). Pathogen survival in organic wastes depends upon the interaction of biotic (microbial composition) and abiotic factors (temperature, moisture content, ammonia content, pH, nutrient availability, soil type, weather, timing and nature of application etc.) (Gagliardi and Karns, 2000; Jiang et al 2002; Kudva et al 1998; Franz et al 2003). For example, in an experimental study, *E. coli* O157 applied in either cattle manure or ovine gut contents to the surface or rhizosphere of perennial rye grass differed significantly in rate of decline (Avery et al, 2004). Indigenous microbial communities will also vary significantly between different

waste types (Beauchat, 2002). On the whole, enteric pathogens appear to survive better in soil than in manures/slurries and tend to survive better at lower temperatures (Guan and Holley, 2003). However, where conditions allow, growth may occur at warmer temperatures (i.e. below temperatures at which thermal stress begins to be induced). Thus it is clear from the literature that the nature of those organic wastes can influence subsequent behaviour in the environment and that extrapolating from application of other organic waste materials is not a robust approach.

The application process itself will influence the longevity of remaining pathogens. For example, Hutchison et al (2004) found that leaving manure on the soil surface for longer led to a greater decline in pathogenic bacteria (*E. coli* O157*, Salmonella, Listeria and Campylobacter*) than when wastes were incorporated more rapidly. The opposite effect was observed by Avery et al (2004) where *E. coli* O157 survived better overall following surface application compared to subsurface injection of wastes. Gerba and Smith (2005) suggested that the common maxima for survival of bacterial pathogens in soil and on plants were two and one month respectively; that for viruses this was three months and one month respectively, and that for protozoa two days for both soil and plants.

3.4.1 Comparison against background concentrations of pathogens in soils

Nicholson et al (2005) commented that there are few data on typical numbers of specific pathogens in soils, and this is still the case. The variability in soils (and faecal inputs to soils which influence their pathogen content) is also vast, and even where data are available they are unlikely to be representative as a "guide" for pathogen starting densities entering SSGW in soil adhered to plants. Appendix B4ii provides some evidence of background pathogen numbers in soils; however, the range cannot be verified due to the paucity of data. Agricultural soils are routinely subject to inputs of pathogens via other organic wastes (manures, slurries, faecal deposits from wildlife etc) and therefore we would suggest that addition of SSGW instead of faecally-derived wastes would be unlikely to pose a greater health threat when considering enteric organisms present in those faecally-derived wastes. As it is not possible to provide specific guidance in relation to pathogens for green waste, it would be prudent to follow guidance, including "cattle clear" periods that have been adopted for the application of other wastes.

3.4.2 Comparative risk assessment

Many of the pathogens identified as potentially entering SSGW can be described as being of faecal origin, whether directly (principally through wildlife inputs) or indirectly, through plant materials and adhered soil contaminated with faecal material from wild and domestic animals or use of materials such as manures likely to carry faecal microorganisms. When compared against other organic wastes used as agricultural or domestic fertilisers, it is reasonable to consider that SSGW is unlikely to have a higher faecal pathogen burden. In view of this, and in the absence of data for SSGW, following guidelines for other organic wastes would provide a degree of protection in the interim. However, it should be remembered that the prevalence and spectrum of pathogens entering and surviving composting in SSGW will differ from other wastes and therefore no certainty can be attached to the use of guidelines for other wastes, these would simply inform a best practice approach.

3.4.3 Conclusions

For unrestricted use of compost, it is generally accepted that pathogens must be rendered undetectable in the finished product in order to minimise the risk (USEPA 1999). However, particularly with SSGW materials which should by their nature have relatively low pathogen contents to begin with, it is important to consider them in comparison not only with other composted or treated products but also in comparison with any risk associated with the land to which they will be applied. To clarify, the pathogens of concern should be those which are likely to increase in numbers during the composting process, rather than those which may

remain viable but relatively unchanged quantitatively. The key pathogens in SSGW are enteric bacteria such as verotoxigenic *E. coli* and *Salmonella*, spore formers such as clostridia and *Bacillus*, and fungi such as *Aspergillus fumigatus*. These organisms are those most likely to increase in numbers at some stage during the composting process which, if they do not decline prior to completion of composting, may be present in higher concentrations than are already present on the land to which they will be applied. However, the receiving environment is arguably likely to be no less contaminated than the original SSGW, particularly when that environment has received livestock manures, which are known to harbour populations of *E. coli* O157, pathogenic *Listeria, Salmonella* spp, *Campylobacter, Giardia* and *Cryptosporidium* (Hutchison et al, 2004).

3.4.4 Options for risk management

- SSGW composts are unlikely to pose pathogenic risks to grazing livestock, but given the paucity of data on the occurrence of a number of pathogenic agents in SSGW composts, it is recommended that a precautionary approach be adopted and that pathogen management guidance developed for other soil amendments be followed. Specifically, that compost should be incorporated after application (as recommended by the Food Standards Agency, 2009). Where incorporation is not possible (for example, following application to pasture), then no-graze intervals should be adopted.
- Awareness raising with general public to further reduce possible faecal contamination (manure, dog faeces, bird guano) of SSGW.

3.5 Invasive weeds and exotic species

This part of the assessment looked at those plants identified as invasive weeds and exotic (i.e. non-farmland) species that may be transferred to farmland from gardens and vice versa. The Scottish Government identifies four non-native species currently causing a problem in Scotland (Scottish Government, 2008a):

- Japanese knotweed (*Fallopia japonica*)
- Rhododendron ponticum (*Rhododendron ponticum*)
- Himalayan Balsam (*Impatiens glandulifera*)
- Giant Hogweed (*Heracleum mantegazzianum*)

Ragwort, although commonly thought of as an invasive weed, was classified as a native species in the new Atlas of British and Irish Flora. It is however one of five injurious weeds covered by the Weeds Act 1959:

- Common Ragwort (*Senecio jacobaea*)
- Spear Thistle (*Cirsium vulgare*)
- Creeping or Field Thistle (*Cirsium arvense*)
- Curled Dock (*Rumex crispus*)
- Broad-leaved Dock (*Rumex obtusifolius*)

Although the potential for the toxins associated with these plants to pass through the composting process was considered to be low (Section 3.1), the potential for the actual weeds to pass through the composting process has not yet been considered. This part of the assessment considers this potential.

All of the weeds identified above adversely affect the environment and have a negative impact on biodiversity, through one or all of the following: encouraging the development of a monoculture; supporting a much narrower range of species; acting as a host for parasites and diseases (e.g. Giant Hogweed is a host for both carrot fly (Degen et al 1999) and the disease *Sclerotinia sclerotiorum* (Farr et al 2005), both of which attack many horticultural and arable crops); toxicity to wildlife and plants; and affecting soil erosion (e.g. Japanese knotweed leads to river bank erosion problems (Parrott, 2008)).

For this element of the risk assessment the focus was on whether propagules (seeds and other parts of plants necessary for their reproduction) could be present in final compost product. Very little literature was identified to aid this process. That found is summarised in Table 3-33.

Table 3-33 Scientific literature available on potential for weed propagules to pass through composting process

Weed	Literature
Ragwort	Scottish Government allows composting of ragwort by sites achieving BS PAS 100:2005 (Scottish Government 2008 b) Good practice composting that complies with the guidelines in the DEFRA Code of Practice for Common Ragwort and PAS100 should destroy weeds and their propagules (The Composting Association 2004).
Japanese Knotweed	Ward (2003) showed that under laboratory conditions, pieces of Japanese Knotweed rhizome (the crowns and runners), did not regenerate if exposed to temperature of 55°C or greater for one week or more. However, Ward (2003) identified there was still a small risk as sections of rhizome as small as 0.7 grams or smaller than a one penny piece, can grow into a new plant. However, the research was done under controlled, static conditions in the laboratory. The Composting Association (2004) suggests that due to its re-growth potential it should be incinerated or sent to a landfill site licensed to accept it. Japanese Knotweed should not be composted. Environment Agency (2003) states that Japanese Knotweed will survive composting
Giant Hogweed	Environment Agency (2003) Allows onsite composting of spoi.l
Himalayan Balsam	Environment Agency (2003) Allows onsite composting of spoil unless seeds are present.
Spear thistle	Good practice composting that complies with the guidelines in the DEFRA Code of Practice for Common Ragwort and PAS100 should destroy weeds and their propagules (The Composting Association 2004). Gardening websites recommend that thistle seed heads should not be composted as there is a risk that they will survive (e.g. http://www.enjoygardening.com/?p=84), although home composting usually takes place at far lower temperatures than are found in commercial systems.
Creeping (or field) thistle)	
Curled dock	Good practice composting that complies with the guidelines in the DEFRA Code of Practice for Common Ragwort and PAS100 should destroy weeds and their propagules (The Composting Association 2004). When examining the composting of farmyard manure, temperatures within the heap of 55°C or higher have been shown to destroy the seeds of Rumex spp. (Dierauer & Stöppler-Zimmer,1994) there are indications that it is not only higher temperatures during composting that are responsible for decreased Rumex germination, but also the presence of antagonistic non-thermophilic microorganisms (J G Zaller, unpubl. Obs. cited in Zaller 2004).
Broad-leaved dock	Seeds buried in cattle farmyard manure (maximum temperature 63 °C) for one month results in 28% germination; 2 months 0% germination. No germination after 4 months in vermicompost (max temp 35°C) (Zaller, 2007) Skinner (2005) results indicate composting of docks could be a viable, effective and useful method and should be researched

Weed	Literature
	in more detail in the future. In addition, in Skinner's personal past experience they found that well composted docks contain no viable seed or root fragments. (Skinner, 2005) Also see Curled dock.
Rhododendron ponticum	No literature on propagule survival.

The Organics Recycling Group, formerly the Composting Association (The Composting Association, 2004) states that the destruction of weed propagules occurs in composting heaps that reach and sustain temperatures of 55 – 75°C, are maintained with adequate air and moisture and are thoroughly mixed during the process. These conditions are in line with the requirements of PAS100:2011.

3.5.1 Comparative risk assessment

No data on the populations of invasive weeds in the comparator materials was identified but it is unlikely these weed propagules would be present. Due to these reasons, and the lack of data on invasive weeds in green compost, a comparative risk assessment was not undertaken.

3.5.2 Conclusions

The literature is minimal, and for a number of the plants considered indicates that propagules should not survive the composting process. However, there is still a small risk (not assessed by this study), particularly for Japanese Knotweed passing through the composting process. The Organics Recycling Group comments that Japanese Knotweed should not be composted (The Composting Association 2004). PAS100:2011 recognises this issue and seeks to manage it through quality testing of the final compost product by not allowing any germinating weed seeds or propagule re-growth in finished composts. The test is obligatory for all compost uses identified in PAS100:2011 apart from use as mulch (although mulch materials will still have been subject to the sanitization and stabilization phases required by PAS100:2011).

PAS100:2011 is supported by legislation which should prevent these weeds entering composting streams including:

- *The Weed Act 1959* made it an offence to allow the spread of the noxious weeds considered. The supply of compost containing propagules from noxious weeds is likely to be viewed as an offence.
- *The Wildlife and Countryside Act 1981* made it illegal to permit the spread of Japanese Knotweed and Giant Hogweed. Any polluted soil or plant material that is discarded, intended to be discarded or is required to be discarded is classed as controlled waste and should be accompanied by appropriate Waste Transfer documentation

In relation to Japanese Knotweed the Organics Recycling Group (The Composting Association 2004) provides the following advice to minimize the risk of weeds propagules entering compost product:

- *Hauliers* - Prior to accepting waste material for transfer or disposal, hauliers should inspect it for Japanese Knotweed contamination. If present, the load must be taken to a licensed landfill site. Hauliers should not haul waste containing this contaminant unless they can ensure its appropriate disposal.
- *Large scale composting* - Recommend that it is important to carry out a HACCP assessment of the feedstock types, composting process and compost end-uses. All composting facilities should have a written operating procedure covering control of

identified hazards, and all relevant staff should be trained accordingly. In an example provided by the Organics Recycling Group (The Composting Association, 2004), the inspection of the load or identification of noxious weeds should be identified as a critical control point. It is likely to be impractical and not cost effective to thoroughly remove Japanese Knotweed contamination from a load. Therefore, if it is found present in a load, the entire load should be rejected and sent for disposal. Should any noxious weeds still remain in the feedstock (not found during inspection), the composting conditions (temperature, moisture and oxygen) and the duration they are maintained for will be important. Composting conditions should be frequently monitored and recorded. This is another critical control point (The Composting Association 2004). As noted earlier, advice given by local authorities to householders is not always consistent and further awareness-raising of this issue to prevent this route of entry would be beneficial.

3.5.3 Options for risk management

- The present recommendations for hazard analysis and control, and the continuation of the strict no-tolerance limit for weeds propagules in PAS100:2011 are already highly protective. However, it is recommended that more information be provided to householders and other sources of compost feedstock to increase awareness of those weeds which should not enter the composting stream. Further consideration may be required of whether the frequency and number of tests undertaken for weed seeds/propagule reflects the heterogeneity of the compost heap.

3.6 Physical contaminants

The initial hazard screening identified 16 physical contaminants that have been recorded in the scientific and grey literature as being found in the green waste collected for composting or green compost (Dimambro *et al.*, 2007; Barth 2005; The Composting Association, 2005; Bexley Council & Enviros Consulting, 2004; Anon, 2000) (Appendix B.6, summarised in Table 3-34). However, it is recognised that the list of physical contaminants with the potential to enter the green waste stream is potentially very long and ever increasing. A number of organisations and individuals were also approached to obtain information on the potential physical contaminants within green compost (Appendix C includes a summary of those contacted and the responses received).

Table 3-34 Physical contaminants identified in green compost

Physical contaminant		
Glass	Masonry	Fragments of PET
Metal	Concrete	Polyester
Plastic	Tile	Polystyrene foam
Rubber	Carpet	Bones
Insufficiently biodegraded cardboard	Textile	Foil
	PVC	

(Dimambro et al 2007; Barth 2005; The Composting Association, 2005; Bexley council & Enviros Consulting 2004; MEL Research 2000; Anon 2000)

Information on the levels of physical contamination in feedstock and final compost is currently extremely limited. The compost specification PAS100:2011 does however provide prescriptive upper limits for the maximum content and size of physical contaminants:

- Total glass, metal, plastic and any "other" non-stone fragments >2mm – 0.25% mass/mass of "air-dry" sample (of which 0.12% is plastic)
- Stones >4mm in grades other than "mulch" – 8% mass/mass of "air-dry" sample
- Stones >4mm in "mulch" grade - 10% mass/mass of "air-dry" sample

These maximum limits allow assumptions to be made on the potential maximum size and volume of physical contaminants present in compost products produced to these standards.

The majority of the physical contaminants that could be found in green compost have the potential to present serious health effects to mammals and other animals though skin abrasion and damage to internal organs and processes i.e. intestinal damage and choking. However, compost that has been treated using visual and automated screening, to a suitable standard to meet PAS100:2011 limits should pose negligible risk to humans, livestock and the environment. Review of both the scientific and grey literature and consultation with members of the Steering Group support this conclusion, as no reported cases of negative impact relating to physical contamination of green compost were identified. Even so, where composts are intended for use as a top dressing on pasture, a zero-tolerance approach to man-made physical contaminants may be advisable.

3.6.1 Comparative risk assessment

No data on the concentrations of physical contaminants present in the comparator materials was identified but it is unlikely these contaminants would be present in the comparator materials. Due to these reasons, physical contaminants were not subjected to comparative assessment.

3.6.2 Conclusions

Although the potential for contamination of green compost feedstocks with physical contaminants is significant, the screening processes required to meet PAS 100:2011 reduce the likelihood of these substances being present in final compost at a size or volume likely to cause risks to livestock, humans or the environment.

3.6.3 Options for risk management

- Incorporation of composts into soils (as recommended for other hazards) would minimize any residual risks from the presence of physical contaminants in SSGW composts
- Where incorporation is not possible (for example, compost application to pasture), then a zero-tolerance policy to man-made physical contaminants in compost should be considered

3.7 Other Environmental Hazards

This part of the assessment focussed on identifying other attributes of compost and its content that have not been included in the other categories considered i.e. the nutrient and salt content and the chemical and biological attributes of green compost e.g. effects on Biochemical Oxygen Demand (BOD) in waters.

During the hazard screening, seven compost properties were identified as having the potential to cause harm to the environment. These included: phosphate (P) content, nitrogen (N) content, alkalinity, salt, BOD, Chemical Oxygen Demand (COD) and pH (Appendix B7). It was considered that six of these had the potential to be present at values that could have significant effects on the environment as defined by European Commission, 2005.

Data availability on the quantities of the identified "other environmental hazards" in SSGW compost is limited, especially for situations after SSGW compost has been applied to land. Therefore, conclusions within this section draw on the general knowledge of literature relating to each of these agents and their behaviour once applied to soil.

The levels of the pH, alkalinity and salinity in SSGW compost can pose a risk to some plants, particularly when used as growing media (Saebo & Ferrini, 2006, Watson, 2003, Rengel 2002, Tester 1990, Tisdale et al 1985). High concentrations of soluble salts and different pH values can adversely affect germination and plant growth and can ultimately cause plant death. Different plant species have different preferences and tolerance levels (Saebo & Ferrini 2006). The pH and alkalinity level of composts may also affect the bioavailability and leaching of some elements e.g. trace elements required for good plant growth, and PTEs (WRc 2000). Quality parameters over and above those required by PAS100 are designed to minimize such risks when SSGW composts are used in growing media (Paul Waller Consulting 2004).

The pH of composts typically range from 6.8 to 7.3 (Alexander 1994), but can vary significantly depending on feedstock. The impact of compost on soil pH is dependent on the pH of the soil, its buffering capacity, the pH of the compost, how much is used, how thoroughly it is mixed with the soil, and how rapidly the compost breaks down in the soil environment (Watson, 2003). Pickering and Sheppard (2000) found that the pH of the compost was not a good indicator of how it affects soil pH. Saebo and Ferrini (2006) reported that the application of mature compost to soils is likely to have a limited impact on soil pH, due to the low buffering capacity of compost. Composts with a high liming value may limit the availability of micronutrients to plants when applied in excess, especially on plants which prefer acid soils (Saebo & Ferrini 2006).

Feedstock influences the level of soluble salts within the final compost (Saebo & Ferrini 2006, Watson 2003). Generally, composts with electrical conductivity (EC) of less than 3.5 dS/m are considered suitable for general use (although specifications for the use of composts in landscaping recommend an upper limit of 3.0 dS/m (Landscape Institute 2003)). More careful management is required where salt levels are between 5.0 and 6.4 dS/m. Above this, soluble salt concentrations should be reduced prior to application (Warncke & Krauskopf 1983, Watson 2003). When conductivity is higher than 5 dS/m, the incorporation rate with soils should be no more than 20% when salt-sensitive species are to be established (Alexander 2001). The impact of the soluble salt content of the compost will be influenced by the soil, plant tolerance and the amount and frequency of irrigation water or rainfall (Watson 2003).

When considering the application scenarios outlined in this report it is believed that application of SSGW compost will not have a significant impact on soil pH or soluble salt levels due to the limited rates of application that are permitted by codes of good agricultural practice, NVZ Regulations and other instruments.

Primary concerns for BOD, COD, N and P are the potential for them to reach ground and surface water through leaching and runoff (Richard, 1996). The quantities of BOD/COD, P and N within SSGW compost (as with other 'organic manures') have the potential to pose a risk to the environment by causing eutrophication if they directly enter ground or surface water. The analysis of risk posed to the water environment can be simplified by considering the risk arising from two main processes:

1. *Pollution arising from spreading of compost under inappropriate conditions or at inappropriate rates, leading to more-or-less direct routing of composted material components to surface and field drainage water*

In this scenario, any pollutants present within the composted material will generate a risk, since little retention or transformation of any pollutants will occur post-application. This process is responsible for the majority of the risk of pollution associated with BOD, and P pollution of surface water.

For this rapid transport category, there is risk of contamination by all potential associated hazards and risk minimisation involves mainly the application of good practice standards that are already in place. Land which is most vulnerable to pollution pathways of this type could have a steep slope, topographic complexity, flood risk and a high groundwater table. All of these identify a pathway (e.g. steeply sloping ground) or a receptor (e.g. groundwater) that would contribute to the likelihood of environmental damage from direct transport of applied green compost.

Following good practice application and storage guidelines should minimise the likelihood of pollution via this pathway. Therefore, if compost operations are in accordance with current guidelines then it can be concluded that the content of "other hazards" within green compost do not pose an exposure of concern to the water environment via this pathway.

2. *Pollution associated with transport of compost components after their interaction with the soil matrix*

This scenario principally includes processes leading to leaching to groundwater and field drainage systems, following the retention, sorption, degradation and transformation processes known to occur in soils.

For this category of pollutant hazard, the principal contaminants of concern are nutrients (N and P). The assessment of risk for this type of pollution involves assessment of the risk of leaching of pollutants to ground and surface waters, in the light of environmental quality standards, and application rates.

N can be found in two significant forms in compost, namely inorganic or organic. The majority of the N in compost is organic and bound within organic molecules. The inorganic forms of nitrogen are immediately available for uptake by plants or leaching, whilst the availability of organic forms of N is dependent on how quickly compost is broken down by microbes in the soil. Within green compost nitrogen availability is low, with greater than 90% of total N bound within organic molecules (Hadas & Portnoy 1994).

The lack of available nitrogen means the risk of N leaching is low, with numerous authors reporting no significant N leaching or reduced N leaching when using appropriate application techniques. Despite these findings, care should be taken if considering the application of high amounts of compost in one or repeated applications, particularly on well drained soils (Amlinger et al 2003, Gerke et al 1999, Berner et al. 1995, Diez et al. 1995)

Assuming the application rate of compost is limited to that stipulated by the SRUC technical notes, N leaching risk should be minimal.

The potential for P to leach to drainage or groundwater is dependent on the degree of phosphorus saturation, which is influenced by the extractable (by oxalate) P and aluminium (Al) within soil horizons (Schouwmans and Groenedijk, 2000). Work previously completed by the James Hutton Institute (Towers et al 2008a, b) looking at sewage sludge application for forestry and land reclamation, indicated that for the vast majority of soils, the recommended application rates based on N levels should be well below those permitted when the risk of phosphorus leaching is considered. Sewage sludge has a greater P content and is applied in greater volumes for land reclamation and forestry than SSGW compost in agriculture (although baseline P levels are likely to be greater in agricultural soils than in land reclamation and forestry soils). Comparing the content of phosphorus of SSGW compost, the likely soil properties and the application scenario, it can also be concluded that the application rates for SSGW compost based on N levels should also be well below those permitted when phosphorus leaching is considered. Good practice also requires that the soil P index should be determined before application of amendments such as SSGW compost, further minimizing any risk.

Repeated compost applications over long time periods can lead to a gradual increase in the soil organic matter content. While this is often seen as a benefit (especially on low organic matter soils) it may increase the inherent soil potential for nitrogen mineralization and increase the risk of groundwater contamination by nitrate leaching (Gerke et al 1999, Körschens et al., 1998). This needs to be considered in areas where compost has been applied in higher application rates over long periods, or where other supplements are applied to the area in addition to compost which may influence the soil organic matter content. Routine testing for soil nutrient indices would minimize any risk from excess nutrient supply, and it should also be considered that supplying concentrations of soil nutrients that are greater than those required by the growing crop would represent a reduction in potential profit by the farmer/grower.

Pickering and Sheppard (2000) found that the C:N ratio of compost was a good indicator of the amount of N which is likely to be released to the growing crop in the season of application. The total concentrations of P and potassium (K) in compost should also be taken into account when calculating the fertiliser value of these nutrients in compost, where soil P and K status is moderate or higher, since much of the P and K present in compost will enter the soil P and K pools. When calculating crop fertiliser requirements for P and K in soils where P or K status is lower than moderate, only 30% of the P and 90% of the K present in the compost should be taken into account, since only these amounts are likely to be released from green compost in the year of application (Pickering and Sheppard 2000).

3.7.1 Comparative risk assessment

Data availability on the quantities of the identified "other environmental hazards" in SSGW compost and associated leachate is limited, especially for after SSGW compost is applied to land. It was not considered possible to carry out a full comparative risk assessment, although the low available nutrient contents of SSGW when compared with common amendments such as cattle slurry imply lower environmental risk from SSGW use – particularly when applied in accordance with good practice.

3.7.2 Conclusions

Although a number of agents are present in green compost at levels that could potentially cause harm to the environment, consideration of the potential pathways if good practice is applied indicates that these agents do not present an exposure, and therefore any risk, of concern.

3.7.3 Options for risk management

- Risks from hazards identified in this section would be negligible if good practice (such as GAEC (Good Agricultural and Environmental Condition) or COGAP (Codes of Good Agricultural Practice)) is followed.
- Users should request that compost liming potential, N, P and K contents be determined, so that compost applications can be best matched to soil and crop requirements.

4.0 Conclusions

Within the limitations of available information, source-segregated green waste compost was found to pose no more risk to grazing livestock, or the environment, than other commonly-used soil amendments, such as livestock manures, paper mill and sewage sludges. In many situations, SSGW compost (and by extension, PAS100 green compost) was found to pose even lower risks than other commonly-used soil amendments.

Where risks were identified, they were greater to sheep than cattle due to their smaller body weight, and their propensity to consume a greater proportion of soil in their diet. However, risks associated with uptake of potentially hazardous compounds into fodder crops, and subsequent use of those crops as animal feed, were negligible due to the various dilutions in this exposure pathway.

The risk assessment highlighted specific hazards in PAS100 green compost:

- Under extreme modelling scenarios (composts are applied at 50t ha^{-1} to the surface of pasture and sheep subsequently ingest compost to the exclusion of soil every day for six years) 1,2,3,4,6,7,8-HpCDD – a dioxin associated with industrial bleaching processes – has been measured in SSGW compost at levels that could cause a risk to grazing sheep. A potential risk from the same compound was also identified for pig slurry and cattle farmyard manure, suggesting that this contaminant may be ubiquitous. However, it would be beneficial to examine the concentrations of 1,2,3,4,6,7,8-HpCDD in PAS100 composts, particularly those derived from feedstocks including heavily-bleached paper.
- The herbicide clopyralid was modelled as posing a risk to susceptible broad-leaved plants at levels measured in some SSGW composts. This herbicide is associated primarily with amenity grassland management, and on-label warnings preclude the composting of treated plant materials. The PAS100 specification also includes a compulsory plant response test, relying on tomato plants to detect such phytotoxic contaminants as herbicide residues. It would be beneficial to demonstrate that this test is sufficiently sensitive to detect herbicides at relevant concentrations in composts intended for application to agricultural land.

The results of the comparative risk assessment suggest that source-segregated green waste compost poses no more risk to grazing livestock, and in many situations, SSGW compost was found to pose even less risk than other commonly-used soil amendments. Source-segregated green waste compost has been found to contain slightly higher concentrations of some organic contaminants than farmyard manure or slurry based amendments. Even so, levels are not thought to pose an unacceptable risk.

4.1 Risk assessment methodological caveats

The risk assessment methodologies were judged to be the best available methods given the data available for SSGW compost. This risk assessment considered the risks posed by 497 potentially hazardous agents that could be associated with source-segregated commercially-produced green waste compost. These potentially hazardous agents were grouped into the following categories: toxic compounds present in plants, organic contaminants, potentially toxic elements, pathogens, physical contaminants, and other contaminants. A hazard screening approach was used to rationalise this long list into a number of key potentially hazardous agents that were entered into an exposure assessment model. Estimates of exposure were compared to reference doses derived from dose-response data available from peer-reviewed and grey literature sources. However, there are a number of inherent limitations to the approach used that are discussed here that must be taken as caveats to any conclusions.

The approach taken within this study has followed the classical approach of considering single potentially hazardous agents in isolation from each other, except in the case of dioxins. In reality, animals and humans are exposed to a complex mixture of chemicals which may not act in isolation. Toxicological studies, often involving a range of concentrations of compounds and including some very high doses, are important because they contribute to understanding of mechanisms of action. However, they can only partially inform the assessment of risk because in practice, unlike in the laboratory, exposure normally involves thousands of compounds at the same time, usually at very low levels, and often throughout life. The dose-response methodology described in Section 2.3, and the use of uncertainty factors factors to extrapolate from laboratory studies to the exposure scenario described in Section 2.2, is one paradigm for coping with these uncertainties.

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Appendix A Members of the Technical Advisory Group

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Phil Thomas	Artilus
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Simon Pollard	Cranfield University
Mel Keenan	Keenan Recycling
Scott Henderson	Quality Meat Scotland
Charlotte Maltin	Quality Meat Scotland
Kathy Peebles	Quality Meat Scotland
Steve McGrath	Rothamsted Research
Audrey Litterick	Scottish Agricultural College
Alex Sinclair	Scottish Agricultural College
Ewan Swaffield	Scottish Government
David Alexander	Food Standards Agency
Jacqui McElhiney	Food Standards Agency
Will Munro	Food Standards Agency
Sarah Macnaughton	WRAP
Nina Sweet	WRAP
David Tompkins	WRAP

Appendix B Sift for principal agents

B1: Toxic compounds present in plants

Volatile oils: (mustard oil, horseradish, wild radish)
n-propyl disulphate (Wild Garlic, *Allium ursinum*, & other onions)
Mercurialine (Dog's Mercury, *Mercurialis perennis*; Annual Mercury, *Mercurialis annua*)
Tetrahydrocannabinols (Cannabis, *Cannabis sativa*)
Protoanemonin (Wood Anemone, *Anemone nemerosa*; Buttercup, *Ranunculus* spp.)

Tannins:
Tannic acid (Oak, *Quercus* spp.; Bracken, *Pteridium aquilinum*; broomrape)

Alkaloids:
Aconitine (Monkshood/Wolf's-bane, *Aconitum napellus*)
Ajacine/Ajaconiine (all delphiniums)
Aquaticine (*Senecio aquaticus*)
Atropine, hyoscyamine, hyoscine (Deadly Nightshade, *Atropa belladonna*; Henbane, *Hyoscyamus niger;* Thorn-apple, *Datura stramonium*)
Berberine (Barberry, *Berberis* spp.)
Bryonicine (White Bryony, *Bryonia dioica*)
Buxine (Box, *Buxus sempervirens*)
Chelidonine/homochelidonine/chelerythrine/sanguinarine (Celandines, *Chelidonium majus*; horned or sea poppy)
Colchicine, colchiceine (Meadow Saffron, *Colchicum autumnale*)
Coniine, methylconiine, coniceine, conhydrine (Hemlock, *Conium maculatum*; fool's parsley)
Cynapine (Fool's parsley)
Cytisine (Laburnum, *Laburnum anagyroides;* broom)
Ephedrine (Monkswood, *Aconitum napellus*; Yew, *Taxus baccata*)
Imperialine (fritillary)
Isatadine (*Senecio isatadeus*)
Jacobine, jacodine, jaconiine (all Ragwort, *Senecio* spp.)
Lobeline (lobelias)
Lupinine, lupinidine, *l*-lupanine, *dl*-lupanine, hydroxylupanine (Lupins, *Lupinus* spp.)
Lycorine, galanthamine (Daffodil, *Narcissus* spp.)
d-lysergic acid amide or ergine (Morning Glory, *Ipomoea* spp.)
Morphine (Opium Poppy, *Papaver somniferum*)
Nicotine (tobacco inc. ornamental varieties)
Palustrine (Horsetails, *Equisetum* spp.)
Rhoeadine (Field Poppy, *Papaver rhoeas*)
Solanine, solanein, solanidine (Woody Nightshade, *Solanum dulcamara*; Black/Garden Nightshade, *Solanum nigrum*; Potato foliage & green potato, *Solanum tuberosum*; tomato foliage)
Solanocapsine (Christmas Cherry, Solanum capsicastrum and Solanum pseudocapsicum)
Sparteine (broom)
Taxine (Yew, *Taxus baccata*)
Temuline (darnel)

Glycosides:
Aesculin (Horse Chestnut, *Aesculus hippocastanum*; Ash, *Fraxinus excelsior*)
Amygdalin, glycoside + emulsion, enzyme = hydrocyanic acid (kernals of apple, pear, plum, cherry, peach, apricot, almond & leaves of Cherry Laurel, *Prunus laurocerasus*)
Bryonin (White Bryony, *Bryonia dioica*)
Convallotoxin, Convallamarin, convallarin convalloside (Lilly of the valley, *Convallaria majalis*)
Cyanogenetic glycosides (Marsh & Sea arrow grass)
Cyclamin (Cyclamins)
Digitoxin, digitalin (Foxglove, *Digitalis purpurea*; water figwort)
Emodin (Buckthorn, *Rhamnus cathartica*; Alder)
Euonymine (Spindle Tree, *Euonymus europaeus*)
Helleborein/Helleborin (Hellebores, *Veratrum* spp.)
Ilicin (Holly, *Ilex aquifolium*)
Iridin/Irisin (Irises, *Iris* spp.)
Linamarin (glycoside and goitrogen)

Ligustrin (Privet, *Ligustrum* spp.) Lotaustralin (white clover) Narthecin (Bog Asphodel, *Narthecium ossifragum*) Paridin (herb paris) Phytolaccin, phytolaccatoxin (Pokeweed, *Phytolacca americana*) Prunasin (Bracken, Pteridium aquilinum; Cherry Laurel, Prunus laurocerasus) Ranunculin (Wood Anemone, *Anemone nemorosa*; Traveller's Joy, *Clematis vitalba*; Buttercup, *Ranunculus* spp.) Saponin(s) (chickweed; corn cockle; pinks & carnations; fat hen, *Chenopodium album*; nightshade; herb paris; Ivy, *Hedera helix*; Dog's Mercury, *Mercurialis perennis*; Annual Mercury, *Mercurialis annua*; Lily of the Valley, *Convallaria majalis*; Bog Asphodel, *Narthecium ossifragum*; Solomon's Seal, *Polygonatum multiflorum*) Scillarens (Bluebell, *Hyacinthoides non-scripta*) Scoparin (broom) Scillaine (Daffodil, *Narcissus* spp.) Similacin (Scarlet pimpernel) Sinigrin (Horse Radish, *Armoracia rusticana*)
Phyto-dynamic substances: (buckwheat; St. John's wort; Bog Asphodel, *Narthecium ossifragum*; yellow trefoils) Furocoumarins (Giant Hogweed, *Haracleum mantegazzianum*) Hypericin (St. John's Wort, *Hypericum perforatum*)
Proteins, peptides & amino acids: Ricin (Caster Oil Plant, *Ricinus communis*) Viscotoxin A & B (Mistletoe, *Viscum album*)
Enzymes: linamarase (Flax) Thiaminase (destroys vit B1; Horsetails, *Equisetum* spp.; Bracken, *Pteridium aquilinum*)
Carcinogens: Ptaquiloside (Bracken, *Pteridium aquilinum*)
Oxalic acid and soluble oxalates: (fodder beets & mangles; wood sorrels; Docks & sorrels; rhubarb; water pepper; knotweed; peachwort) Ca Oxylate crystals (Cuckoo Pint, *Arum maculatum*; Black Bryony, *Tamus communis*) Ca Oxylate sap (Dumb Cane, *Dieffenbachia* spp.; Cheese Plant, *Monstera deliciosa*; Elephant's Ear, *Philodendron* spp.; Arum Lily, *Zantedeschia* spp.) Oxalates (Fat Hen, *Chenopodium album*; Rhubarb, *Rheum rhaponticum*)
Others/not able to group: Hydrocyanic acid (apricot, cherry, peach & plum kernels; apple & pear pips; cherry laurel; linseed; millet; sorghums; wild white clover; juncus; yew) Thiouracil, and other goitrogens (cabbages, esp. kale) Aflatoxin Molybdenum, 'teart pastures' Potassium nitrate/nitrites (taken up by fodder crops inc. oats, beet, turnips, kale, rape) Dicoumarol (from breakdown of coumarin in damaged clover) Mezerein, daphnetoxin (Mezereon, *Daphne mezereum*; Spurge Laurel, *Daphne laureola*) Cicutoxin (Cowbane, *Cicuta virosa*) Oenathotoxin (Hemlock Water Dropwort, *Oenanthe crocata*) Euphorbiosteroid (Spurges inc. dog's mercury & annual mercury) Diterpene esters (Sun and Petty Spurge, *Euphorbia helioscopia* and *Euphorbia peplus*; Poinsettia, *Euphorbia pulcherrima*) Lantadene A (Lantana, *Lantana* spp.) Andromedotoxin or acetylandromedol (Rhododendrons, azaleas & kalmias; Pieris, *Pieris* spp.) Fagin, Beech, *Fagus sylvatica*
Limited info: Glycoside, Oleander, *Nerium oleander* Alkaloids, Comfrey, *Symphytum officinale* Cyanide-producing glycoside, Elder, *Sambucus* spp. Snowberry, *Symphoricarpos rivularis* Cypress, *Cupressus* spp.

Filter 1: Does agent have potentially serious effect (animal/human/environment)?

Potential serious effects if exposed (including moderate or serious illness, death)	**Some effects** (potential to cause mild to moderate illness)	**Little or no effects** (little or no chance of becoming ill)
Mercurialine – death of sheep (Vet. Rec. 27:485-489; Watson, 1998)	Mercurialine – case report in Man (Rugman et al., 1983)	Aconotine – chronic exposure → weight gain & decreased body temperature (Wada et al. 2006)
Tannic acid – Oak poisoning of cattle (Hume, 2006; Deroo & de Kruif, 2003; Sharma et al., 2001; Singh et al., 2000; Meiser et al., 2000; Garg et al., 1992; Basden & Dalvi, 1987; Kasari et al., 1986; Neser et al., 1982; Sandusky et al., 1977)	Cannabinols – movement impairment in dogs (Wolf et al., 2006)	Aconotine – chronic exposure → increased blood pressure (Miao et al., 2004)
Tannic acid – Oak poisoning of birds (Kinde, 1988)	Protoanemonin – Imparement of root growth in Zea mays (Erickson & Rosen, 1949)	Aconotine – chronic exposure → neurological effects in humans (Ameri, 1998; Chan, 1994; Chan et al., 1994)
Tannic acid –poisoning of sheep (Zhu & Filippich, 1995)	Aconotine – Disruption of Ca homeostasis →cardiac problems/arrhythmia (Fu et al., 2006; Moroz & Lipnitskii, 2006; Shan et al., 2006; Sheikh-Zade et al., 2000)	Atropine – Chronic exposure → effects on breathing in goats (Bonis et al., 2007)
Aconitine – Human deaths/murder (Van Landeghem et al., 2007; Pullela et al., 2006; Elliott, 2002; Ohno, 1998)	Ajacine – Effects on CNS of mice (Stegelmeier et al., 2003) D-R data for mice, hamsters, rats & sheep (Olsen & Sisson, 1991)	Muscle twitching in buffalo from d-lysergic acid from Ipomea (Barbosa et al., 2005)
Aconitine – cattle deaths (Puschner et al., 2002)	Transfer of pyrrolizidine alkaloids to eggs (Edgar & Smith, 2000)	Tremors in goats from d-lysergic acid from Ipomea (Medeiros et al., 2003; Schumaher-Henrique et al., 2003)
Ajacine – cattle deaths from Delphinium (Pfister et al., 2003; 1999; 1994)	Chronic pyrrolizidine alkaloid poisoning of cattle (Sanches et al., 2000; Braun et al., 1999)	Slight elevation of rectal temperature in cattle from Hypericin (Bourke & White, 2004)
Atropine – Horse deaths from Datura in hay (Binev et al., 2006; Gerber et al., 2006; Naude et al., 2005)	Transfer of pyrrolizidine alkaloids to milk (Panariti et al., 1997; Synge & Stephen, 1993)	
Atropine – Human deaths from Datura (Boumba et al., 2004; Steenkamp et al., 2004)	Oxidative stress from pyrrolizidine alkaloid in cattle (Bondan et al., 2005)	
Atropine – Canine deaths from Datura (Thiermann et al., 2996)	Emaciation & weakness in goats from d-lysergic acid from Ipomea (Armien et al., 2007; Dantas et al., 2007)	

Potential serious effects if exposed (including moderate or serious illness, death)	**Some effects** (potential to cause mild to moderate illness)	**Little or no effects** (little or no chance of becoming ill)
Bryonicine – Canine poisoning from White bryony (Whur, 1986)	Nicotine poisoning in cat (Sommer & Mischke, 2007) in goat (Vijayakumar et al., 2002) in dog (Vig, 1990)	
Colchicine – Canine deaths (Wagenaar, 2004)	Solanine and cerebral degeneration of cattle by potato (Verdes et al., 2006)	
Colchicine – Cattle deaths from crocus bulbs (Yamada et al., 1998; Frayha et al., 1984)	Solanine and skeletal changes of cattle (Dammrich et al., 1975)	
Colchicine – poisoning of pigs (Lohner & Gindele, 1989)	Taxine and anaemia in lambs & meat quality (Smit, 1992)	
Colchicine – Human deaths/poisoning (Sundov et al., 2005; Brvar et al., 2004a; 2004b Gabrscek et al., 2004; Klintschar et al., 1999)	Digitalin –cardiac problems/arrhythmia in horses (Wijnberg wt al., 1999)	
Coniine – Human and livestock poisoning & deaths from Hemlock (Reynolds, 2005; Vetter, 2004; Downs et al., 2002; Lopez et al., 1999)	Phytolacca poisoning of sheep by pokeweed → diarrhoea (Peixoto et al., 1997)	
Coniine poisoning in cattle & sheep (Tokarnia et al., 1985) Congenital malformations in cattle (Edmonds et al., 1972) In pig (Hannam, 1985; Markham, 1985) In rabbit (Short & Edwards, 1989)	Bracken toxicity in rodent models (Ngomuo & Jones, 1996)	
Cytisine – abortions in cattle sheep & goats from broom (Gardner et al., 1999)	Bracken poisoning → bright blindness in sheep (Hirono et al., 1993; Sunderman, 1987)	
Cytisine – poisoning in dogs from laburnum (Leyland, 1981; Clarke et al., 1971)	Saponin poisoning → phytosensitivity in horses (barbosa et al., 2006)	

Potential serious effects if exposed (including moderate or serious illness, death)	**Some effects** (potential to cause mild to moderate illness)	**Little or no effects** (little or no chance of becoming ill)
Pyrrolizidine alkaloid poisoning in cattle (Barros et al., 2007; Moyano et al., 2006; Karam et al., 2004; van Wuijckhuise & Mars 2003; Tokarnia et al., 2002; 1990; Vos et al., 2002; Borsberry, 1999; Harrison, 1999; Brodrick, 1997; Taggart, 1995; Noble et al., 1994; Odriozola et al., 1994; Debarros et al., 1992; 1987a; 1987b Driemeier & Barros, 1992; Mendez et al., 1990; 1987; Habermehl et al., 1988; Nazario et al., 1988; Monaghan & Sheaham, 1987; Tokarnia & Dobereiner, 1984)	Saponin poisoning → deminished menace response, halitosis, bad gait in goats (McKeough et al., 2005; Aslani et al., 2004)	
Pyrrolizidine alkaloid poisoning in horses (de Lanux-Van Gorder, 2000; McDowell, 1999; Gregory, 1998; O'Scanaill, 1998; Gava & Barros, 1997; Milne et al., 1990; Dewes & Lowe, 1985; Leyland, 1985; Giles, 1983; Gopinath et al., 1972)	Saponin poisoning → deminished menace response, halitosis, bad gait in sheep (Aslani et al., 2003)	
Pyrrolizidine alkaloid poisoning in sheep (Ilha et al., 2001; Barros et al., 1989)	Furocoumarin poisoning → phytosensitivity in pigs (Lopez et al., 1997)	
Pyrrolizidine alkaloid poisoning in yaks (Winter et al., 1994)	Hypericin poisoning → phytosensitivity in sheep (Bourke, 2003)	
Pyrrolizidine alkaloid poisoning in chicks (Mendez et al., 1990)	Thiouracil poisoning from cabbages → anaemia in sheep and cattle (Helclova, 1996; Taljaard, 1993; Semalulu & Rousseaux, 1989; Mason & Lucas, 1983; Smith, 1980)	

Potential serious effects if exposed (including moderate or serious illness, death)	**Some effects** (potential to cause mild to moderate illness)	**Little or no effects** (little or no chance of becoming ill)
Lobeline poisoning of sheep (Lopez et al., 1994; Raegor, 1979)	Lantana poisoning of cattle & sheep (Brito et al., 2004; Reddy et al., 2002; Thirunavukkarasu et al., 2001; Tokarnia et al., 1999; Ide & Tutt, 1998; Ali et al., 1995; McKenzie, 1991; McLennan & Amos, 1989; Stewart et al., 1988; Pass, 1986; Black & Carter, 1985; Frisch et al., 1984; Pass & Stewart, 1984; Rietcorrea et al., 1984; Tokarnia et al., 1984; McSweeney et al., 1983; Uppal & Paul, 1982; Sastry & Singh, 1979; Pass & Heath, 1977; Seawrigh & Allen, 1972; Aluja, 1970)	
Solanine poisoning of dog by Black Nightshade (Davies, 1972)	Grayanotoxin poisoning → tremors in goats from Azalea (Puschner et al., 2001; Miller, 1981)	
Solanine poisoning of horse by potato (Owen, 1985)	Oleander poisoning in horse (Hughes et al., 2002)	
Solanine poisoning & death of cattle by potato (Rech et al., 2006; Gimeno et al., 2000; Anon, 1998; Debarros S.S. et al., 1987; Dobereiner et al., 1975)	Oleander poisoning in guinea pig (Ewringmann et al., 1999)	
Solanine poisoning & death of cattle by egg plant (Bizimenyera, 2003)	Oleander poisoning in cattle (Mahin et al., 1984; Bors et al., 1971)	
Solanine poisoning of pigs (Done et al., 1976)	Cypress poisoning in cattle (O'Scanaill, 1986)	
Taxine poisoning & death of horses (Tiwary et al., 2005; Cope et al., 2004; Kite et al., 2000; Parkinson, 1996; Lowe et al., 1970)		
Taxine poisoning & death of emus (Fiedler & Perron, 1994)		
Taxine poisoning & death of cattle (Hare, 1998; Panter et al., 1993; Casteel & Cook, 1985; Thomson & Barker, 1978)		

Potential serious effects if exposed (including moderate or serious illness, death)	**Some effects** (potential to cause mild to moderate illness)	**Little or no effects** (little or no chance of becoming ill)
Taxine poisoning & death of deer (Wacker, 1983)		
Taxine poisoning & death of sheep (Rae & Binnington, 1995)		
Taxine poisoning & death of dogs (Evans & Cook, 1991)		
Taxine poisoning & death of humans (Locket, 1971)		
Hydrocyanic acid poisoning of cattle from cherry (Malik, 2005; Kumar & Jindal, 1995; Sargison et al., 1996; Rao et al., 1991; Krishna & Katoch, 1989; Vogel et al., 1987; Cran, 1985 Stauffer, 1970)		
Hydrocyanic acid poisoning of goat from cherry (Gough, 1995; Prasad et al., 1977)		
Hydrocyanic acid poisoning of sheep (Gajendragad et al., 1992; Prasad et al., 1977)		
Convallotoxin poisoning of goat by Lilly of the Valley (Gibb & Taylor, 1987)		
Digitalin poisoning in cattle (Thomas et al., 1987)		
Digitalin poisoning in deer (Corrigall et al., 1978)		
Digitalin poisoning & death in horses (Woods et al., 2004)		
Digitalin poisoning in dog (Carmichael, 1987)		
Digitalin poisoning in humans (Simpkiss & Holt 1983)		
Emodin poisoning in horses from Alder (Vandendikkenberg & Holtkamp, 1987)		
Veratrum poisoning in humans (?) (Kulig & Rumack, 1982a, b; Hruby et al., 1981)		
Privet poisoning (Parkinson, 1986)		

Potential serious effects if exposed (including moderate or serious illness, death)	**Some effects** (potential to cause mild to moderate illness)	**Little or no effects** (little or no chance of becoming ill)
Clover poisoning & death of cattle (Peer et al., 2003; Puschner, 1998; Nation, 1989; Hsu, 1986; Alstad et al., 1985; Blakley, 1985; Moran, 1982; Traub et al., 1982; Wasko, 1981; White, 1970)		
Clover poisoning & death of horses (Colon et al., 1996; Nation 1991)		
Clover poisoning & congenital abnormality in sheep (Jagun & Nuru, 1991)		
Narthecin poisoning & deaths of cattle by bog asphodel (Malone et al., 1992; Suzuki et al., 1985)		
Phytolacca poisoning & deaths of horses by pokeweed (Griess et al., 1994)		
Phytolacca poisoning & deaths of cattle by pokeweed (Storie et al., 1992)		
Phytolacca poisoning & deaths of chickens by pokeweed (Storie et al., 1992)		
Bracken poisoning & deaths of cattle (Souto et al., 2006; Cranwell, 2004; Gava et al., 2002; Twoomy et al., 2002; Xu, 1992; Burns, 1986; Hirono et al., 1984; Evans et al., 1983; Evans et al., 1982; Grimshaw, 1978; Yamane et al., 1975a, b, c; Kitahara, 1971; Kohanawa, 1971; Iwata, 1970; Kohanawa, 1970; Konishi, 1970)		
Bracken poisoning & deaths of humans (Alonso-Amelot & Avendano, 2002)		
Bracken poisoning & deaths of pigs (Vuillaume et al., 1989; Harding, 1972; Evans et al., 1972)		

Potential serious effects if exposed (including moderate or serious illness, death)	**Some effects** (potential to cause mild to moderate illness)	**Little or no effects** (little or no chance of becoming ill)
Bracken poisoning & deaths of horses (Kelleway & Geovjian, 1978)		
Ranunculin poisoning & deaths of sheep by buttercup and Clematis (Olsen et al., 1983; Yarris, 1983; Moore, 1971)		
Ranunculin poisoning & deaths of hourses by buttercup (Griess & Rech, 1997)		
Saponin poisoning of deer by Ivy (Bromel & Zettl, 1986)		
Saponin poisoning & deaths of sheep (Brum et al., 2007)		
Saponin poisoning & deaths of dogs from Solomon's Seal (Baxter, 1983; Rohrbach, 1983)		
Similacin poisoning of sheep by Scarlet Pimpernel (Rothwell & Marshall, 1986)		
Furocoumarin poisoning of goat by Giant Hogweed (Andrews et al., 1985; Giles, 1985)		
Hypericin poisoning from St. John's Wort (Van Wuijckhuise et al., 2002)		
Ricin poisoning (experimental) from Castor Oil Plant (Cook et al., 2006; Brito et al., 2001; Brito & Tokarnia, 1997; Tokarnia & Dobereiner, 1997; Armien et al., 1996; Elbadwi et al., 1992; Spyker et al., 1982a, b; Derezende et al., 1981; Dobereiner et al., 1981; Malizia et al., 1977)		
Ricin poisoning & death in dog from Castor Oil Plant (Soto-Blanco et al., 2002)		
Ricin poisoning & death in ducks from Castor Oil Plant (Jensen & Allen, 1981)		
Aflatoxin poisoning & death cattle (Melo et al., 1999; Cockcroft, 1995)		
Mezerein poisoning & death of cattle (Pernthaner & Langer, 1993)		

Potential serious effects if exposed (including moderate or serious illness, death)	**Some effects** (potential to cause mild to moderate illness)	**Little or no effects** (little or no chance of becoming ill)
Cowbane poisoning & deaths of livestock (Anon., 2004)		
Grayanotoxin poisoning & deaths of sheep from Pieris (Power et al., 1991)		
Grayanotoxin poisoning & deaths of goats from Pieris (Hollands & Hughes, 1986; Smith, 1979; 1978)		
Grayanotoxin poisoning & deaths of goats from Rhododendron (Puschner et al., 2001; Thiemann, 1991; Casteel & Wagstaff, 1989; Humphreys et al., 1983)		
Grayanotoxin poisoning & deaths of alpacas from Rhododendron (Crawford, 1999)		
Grayanotoxin poisoning & deaths of kangaroo from Rhododendron (Hough, 1997)		
Grayanotoxin poisoning & deaths of dogs from Rhododendron (Frape & Ward, 1993)		
Grayanotoxin poisoning & deaths of sheep from Rhododendron (Black, 1991; Casteel & Wagstaff, 1989; Hosie et al., 1986; Higgins et al., 1985; Shannon, 1985)		
Grayanotoxin poisoning & deaths of circus elephants from Rhododendron (Schaller, 1983)		

Filter 2: Is there a pathway?
Potentially serious effect (animal/human/environment)
AND is hazard likely to evade destruction if contamination not contained during composting process?

Proxy processes, e.g. Hay/silage/temperature:

Agent	**Uncertain**	**Likely to evade destruction**	**Likely to be destroyed/ negated**
	(livestock disease resulting from pathway/agent not fully understood)	(normal best practice/agricultural measures or nature will not destroy or negate agents)	(normal best practice/agricultural measures or nature should destroy or negate agents)
		Ragwort (hay & silage): (Dewes and Lowe 1985) **Ensiled** – (Borsberry 1999)	
		Rhododendron (mulch):	

Agent	Uncertain	Likely to evade destruction	Likely to be destroyed/ negated
		(Frape and Ward 1993)	
		Bracken (dried): (Evans et al. 1972, Roberts et al 1949, Evans et al 1982) **Boiling water extract** – Hirono et al 1984; Evans et al 1958)	**Autoclaved bracken** no effect on rats (Thomas & Walker 1949; Evans & Evans 1949; Evans eta l 1982)
		Privet (old clippings): Parkinson 1986)	
		Foxglove (dried): (Barnikol & Hoffman 1973)	
		Laburnum (3 month old stick): (Clarke et al 1971)	
		Hemlock (hay): Hemlock (hay): Kubik et al 1980, Panter et al 1988, Galey et al 1992, Vetter 2004)	Hemlock (dried in sun for 7 days): Significant reduction in toxicity (Keeler andBalls 1978, Lopez et al 1999)
		Alsike clover (in hay) – exposure must be at least 1 year: Nation 1989 Schofield 1932 Morgan & Jacob 1905	
		Yew (old clippings): (Rae and Binnington 1985, Thomson and Baker 1978) Burnt clippings: (Parkinson 1986)	
			Aflatoxin: Reduced >40% @ 40°C for 5 d (Faraj et al 1993) Reduced 57.6 % after drying in sunlight (UV) 14 h @ 25 – 37 °C (Gowda et al, 2007)
			Tannins: 20 % reduction at 37°C for 18 h at pH 8 (Makkar and Becker 1996)
		Aconotine (boiled): (Van Landeghem et al 2007)	

Outdoor-turned windrow:

Agent	Uncertain	Likely to evade destruction	Likely to be destroyed/ negated
	(livestock disease resulting from pathway/agent not fully understood)	(normal best practice/agricultural measures or nature will not destroy or negate agents)	(normal best practice/agricultural measures or nature should destroy or negate agents)
Ptaquiloside			Bracken: Ptaquiloside likely to be destroyed in normal composting

			(Taylor & Thomson 1998 Potter & Pitman 1995 Pitman 1995)

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Appendix B2 Sift for principal agents – Organic pollutants

1. PAHs[1]
Acenapthene
Acenaphthalene
Anthracene,
Chrysene/Triphenylene
Fluoranthene
Indeno[*123-ed*]pyrene
Naphthalene,
Phenanthrene,
Pyrene
Benz[*a*]anthracene
Benzo[*a*]pyrene
Benzo[*b*]fluoranthene
Benzo[*k*]fluoranthene
Benzo[*bkj*]fluoranthene
Benzo[*e*]pyrene
Benzofluoranthene
Benzoperylene
Benzo[*ghi*]perylene
Dibenz[*a,h*]anthracene
Dibenzo[ia*c*]anthracene
Dibenzothiophene
Perylene
Fluorene
2. PCBs[2]
2,4,4'-Trichlorobiphenyl (PCB-28)
2,2',5,5'-Tetrachlorobiphenyl (PCB-52)
PCB 77
PCB 81
2,2',4,5,5'-Pentachlorobiphenyl (PCB-101)
PCB 105
PCB 114
PCB 118
PCB 123
PCB 126
2,2',4,4',5,5'-Hexachlorobiphenyl (PCB-153)
PCB 156
PCB 157
PCB 167
PCB 169
2,2',3,4,4',5,5'-Heptachlorobiphrnyl (PCB-180)
PCB 189
2,2',3,4,4',5'-Hexachlorbiphenyl (PCB-138)
3. PCDD/F[3]
2,3,7,8-TeCDD
1,2,3,7,8-PeCDD
1,2,3,4,7,8-HxCDD
1,2,3,6,7,8-HxCDD
1,2,3,7,8,9-HxCDD
1,2,3,4,6,7,8-HpCDD
OCDD

[1] Source: Incomplete combustion processes - important sources are domestic heating, open fires, diesel and other engine combustion, combined heat and power plants, waste incineration plants, aluminium works and abrasion from asphalt and tires (European Communities 2001 cited in Brandhli 2006[1])

[2]Source: dielectric fluid in transformers, capacitors, heat exchangers, in hydraulic machinery, in lubrication and cutting oils as plasticizer in sealants, adhesives, lacquers endpoints (Borja et al 2005 cited in Brandli 2006)

[3]Source: (by-products from the production of certain chemicals and are formed under combustion and incineration processes (WHO 1989 cited in Brandli 2006)

2,3,7,8-TeCDF
1,2,3,7,8-PeCDF
2,3,4,7,8-PeCDF
1,2,3,4,7,8-HxCDF
1,2,3,6,7,8-HxCDF
1,2,3,7,8,9-HxCDF
2,3,4,6,7,8-HxCDF
1,2,3,4,6,7,8-HpCDF
1,2,3,4,7,8,9-HpCDF
OCDF
4. LAS
C9-LAS
C10-LAS
C11-LAS
C12-LAS
C13-LAS
C14-LAS
C15-LAS
5. Chlorinated paraffins[4]
6. Brominated flame retardants (BFR)
PBDE (Polybrominated diphenyl ether)
HBCD (hexabromocyclododecane)
TBBPA (tetrabromobisphenol A)
BDE 28
BDE 47
BDE 99
BDE 100
BDE 153
BDE 154
BDE 183
BDE 209
7. Phthalates
DEHP
8. Perfluorinated alkyl substaces (PFAS)[5]
9. NP[6]
10 PFAS
6:2 fluorotelomer sulfonate (6:2 FTS),
fluorotelomer carboxylates (FT(U)CA),
perfluorinated sulfonates (PFS)
perfluorinated carboxylates (PFCA
fluorooctane sulfonamides (FOSA)
fluorooctane sulfonamidoethanols (FOSE))
11. Natural substances
12. Pesticides (herbicides, fungicides and insecticides)
2,4,5-T (2,4,5-Trichlorophenoxyacetic acid) (Herbicide)
2,4-D (2,4-Dichlorophenoxyacetic acid) (Herbicide)
alachlor (herbicide)
Aldrin (insecticide)
atrazine (Herbicide)
azoxystobin (fungicide)
benfluralin (herbicide)
Bensulide (herbicide)
Benomyl (fungicide)
biphenyl (fungicide predominately used in citus fruits)

[4]Source: additives in metal working fluids, flame retardants, plasticizers, additives in paints, coatings and sealants
[5] Source: stain and water replellents for surface treatment of textiles, carpets, leather and paper products, used in fire fighting foams, lubricants and insecticides
[6] Source: break down product of NPnEO, surfactant, emulsifier in pesticide formulations (Guenther et al 2002 cited in Branli 2006))

Bitertanol (fungicide)
Carbaryl (Insecticide)
captan (fungicide)
Chlordane
Chlorpyrifos (acaricides, insecticide, nematicides)
chlorthalonil (herbicide)
clopyralid (herbicide)
cyanazine (herbicide)
cyfluthrin (insecticide)
cyproconazole (fungicide)
cyprodinil (fungicide)
DCPA (herbicide)
DCP dichlorophenol (pesticide)
Dieldrin (insecticide)
deltamethrin (insecticide)
Diazinon (Insecticide)
dicamba (herbicide)
Dichlobenil
Dichlorprop (herbicide)
difenoconazole (fungicide)
Dinosep (herbicide)
dimethomorph (fungicide)
dodemorph (fungicide)
Endrin (avicides, insecticides)
Endosulfan
epoxiconazole (fungicides)
etaconazole (fungicide)
fenbuconazole (fungicide)
fenhexamide (fungicide)
Fenoxycarb
Fenpropathrin
fenpropimorph
Fenpyroximat
flurprimidol (herbicide)
Flusilazole
Flutolanil
Fonofos
HCB (Hexachlorobenzene) (fungicide)
Heptachloroepoxid
Imazalil
isofenphos (insecticide)
Lindane
Malathion (Insecticide)
MCPA ((4-Chloro-2-methylphenoxy)acetic acid) (herbicide)
mecopop
metamitron (herbicide)
Methoxychlor
Metolachlor
myclobutanil (fungicide)
oryzalin (herbicide)
oxadiazon (herbicide)
oxadixyl (fungicide)
parathion (acaricides, insecticides)
o-phenyl-phenol (Fungicide for citrus fruit)
PCB_z pentachlorobenzene (Precursor to pesticide)
PCP Pentachlorophenol (Wood-protection product, with fungicide and bactericide propoerties)
pendimethalin (herbicide)
propazine (tiazine herbicide)

propiconazole (fungicide)
propoxur (acaridides, insecticide)
pyridaben (acaridides, insecticide)
pyrifenox (fungicide)
pyriproxyfen (insecticide)
tebuconazole (fungicide)
tebufenpyrad (acaridides, insecticide)
terbuthylazine-2-hydroxy (herbicide)
thiabendazole (fungicide)
triadimefon (fungicide)
triclopyr (herbicide)
trifluralin (herbicide)
thiophanate ethyl (fungicide)
toxaphene (insectacide)
triadimenol (fungicide)
triasulfuron (herbicide)
13. DDT
DDD
DDE
DDT
14. Chlorinated hydrocarbon
chlorobenzene
heptachlorocyclohexane
heptachloroepoxide
hexachlorobutadiene
1,2,4-trichlorobenzene
hexachlorobenzene
trichloromethane
TCB_z tetrachlorobenzene (Precursor to pesticide)
tetrachloromethane
trichloroethylene
tetrachloroethylene
HCH
HCHl
Heptachlor
TCP tetrachlorophenol
TrCP trichlorophenol
15. Identified as tested for but no information on whether found
2,4-DB (herbicide - auxin))
3,5-DCA
4-nonylphenol
atraton (herbicide)
Bisphenol A
bormacil
butachlor (herbicide)
butylate (herbicide)
casoron
cichlorovos
cimethaot
chlorpropham (herbicide)
chlozoli
cycloate (herbicide)
dalapon (herbicide)
DBP dibutylphhalate (insect repellent)
Dibutyltin
Dichlorvos (acaricides, insecticides)
dicofol (acaricdes)
Dimethonate

Dioctyltinv
Diphenamid (herbicidie)
dittocypermethrin
dursban
EPTC (herbicide)
ethoprop (insecticide, nematicides)
fenarimol (fungicides)
fenvalerate (acaricides, insecticides)
fluridone (herbicide)
l-cyhalothrin (insecticide)
hexazinome (herbicide)
iprodione (fungicide)
metalaxyl (fungicide)
methidathion (insecticide)
methiocarb (acaricides, bird repellents, insecticides, molluscicides)
methyl metolachlor
metribuzin (herbicide)
mevinphos (acaricides, insecticides)
Monobutyltin
Monooctyltin
Musk xylol
napropamide (herbidie)
norflurazon (herbicide)
paraoxon
pebulate (herbicide)
permethrin (acaricides, insecticides)
phenothrin (insecticides)
phosalon (acaricides, insecticides)
procymidon (fungicide)
prometon (herbicide)
pronamide (herbicide)
propachlor (herbicide)
propamocarb (fungicide)
pyrazophos (fungicides, insecticides)
Silvex (herbicide, plant growth regulators)
Simazine (algicides, herbicides)
simetryn (herbicides)
stirofos (acaricides, insecticides)
tebuthiuron (herbicides)
terbutryn (algicies, herbicide)
Tetrabutyltin
Tributyltin (fungicide, molluscicides)
tricyclazole (fungicide)
Tricychlohexyltin (acaricides)
Triphenyltin (algicide, antifeedants, fungicides, molluscicides)
vernolate (herbicide)
vinclozolin (fungicide)

Filter 1: Does hazard have potentially serious effect (animal/human/environment)?

Potential serious health effects (including moderate or serious illness, death)	**Some health effects** (potential to cause mild to moderate illness)	**Little or no effects** (little or no chance of becoming ill)	**Insufficient knowledge**
PAH			
Chrysene/Triphenylene US EPA IRIS *Probable Human carcinogen* - no human data but sufficient data from animal bioassays (carcinomas and malignant lymphoma in mice after intraperitoneal injection and skin carcinomas in mice following dermal exposure. Chromosomal abnormalities in hamsters and mouse germ cells after gavage exposure, positive responses in bacterial gene mutation assays and transformed mammalian cells exposed in culture.	Fluoranthene Significant *adverse influence on photosynthesis* – inhibition biomass and content photosynthetic pigments faba bean and sunflower after 22 days cultivation in nutrient solution (Kummerova at al 2001) Short term exposure to spring barley (Kummerova et al 1997) US EPA 1988 – Mice exposed to 250 and 500 mg/kg/day had statistically increased SGPT values and increased absolute and relative liver weights US EPA IRIS - Data from skin-painting bioassays was judged inadequate because no increases in tumor incidences were observed and the group sizes tested were small.	Acenaphtene US EPA IRIS - Rats fed 2 grams for 32days (long term) had changes in their blood and some damage to the liver, kidney and lungs. Confidence in study low as observed effects adaptive and not considered adverse	Benzofluoranthene Scorecard not recognised as human or environmental toxicant.
Indeno[123-ed]pyrene – carcinogenic mammals US EPA IRIS *Probable human carcinogen* no human data but sufficient data from animal bioassays. Produced tumours in mice following lung implants subcutaneous injection and dermal exposure. Positive in bacterial gene mutation assays. Component of mixtures that have been associated with human cancer .e.g. coal tar, soots, coke oven emissions and cigarette smoke	Fluorene US SEPA IRIS – Gastorintestinal or liver toxicant – Decreased red blood cells, packed cell volume and hemoglobin mice (125mg/kg/day NOAEL) No human data carcinogenicity and inadequate data from animal bioassays. WMPT Ecosystem risk score top 10% of hazardous chemicals	Acenaphthalene US EPA IRIS - No human carcinogenicity data. Inadequate data animal carcinogenicity. No tumours observe din lifetime study, 25% applied to the skin of mice study flawed and limited detail	Benzoperylene

Potential serious health effects (including moderate or serious illness, death)	**Some health effects** (potential to cause mild to moderate illness)	**Little or no effects** (little or no chance of becoming ill)	**Insufficient knowledge**
Benz[*a*]anthracene US EPA IRIS – *probable human carcinogen.* No human data but sufficient animal bioassays. Produced tumours in mice exposed by gavage; intraperitoneal, subcutaneous or intramuscular injection; and topical application. Produced mutations in bacteria and in mammalian cells, and transformed mammalian cells in culture. Component of mixtures that have been associated with human cancer. These include coal tar, soots, coke oven emissions and cigarette smoke.		Anthracene US EPA (1989) range oral doses to mice up to 1000mg/kg/day for at least 90 days. No treatment-related effects were noted. Schmahl (1955) rats daily dosage 5-15mg up to total dose of 4.5g. No treatment effects noted. US EPA IRIS - several studies no carcinogenic impact Exposure to high doses for a short time *can cause damage to the skin*. It can cause burning, itching and edema, a build up of fluid in tissues. Humans exposed experienced *headaches, nausea, loss of appetite, inflammation or swelling of the stomach and intestines*. In addition, their *reaction time slowed* and they felt weak.	Dibenzo[iac]anthracene
Benzo[*a*]pyrene US EPA IRIS - *human carcinogen* – increased incident of bladder cancer and related deaths in exposed workers Mice 308ppm in food for 10 days (short term exposure) off spring with birth defects (EPA) Mice 923 ppm in food for a period of months problems in the liver and blood (EPA)		Phenanthrene US EPA IRIS – not classifiable as to human carcinogenicity. No human data and inadequate data from rat and mice study Harmful if swallowed. May be harmful if inhaled or absorbed through the skin. *Skin, eye and respiratory irritant. Causes photosensitivity*.	Dibenzothiophene
Benzo[*b*]fluoranthene US EPA IRIS – *probable human carcinogen.* No human data but sufficient animal bioassays tumours in mice after lung implantation, intraperitoneal or subcutaneous injection, and skin painting.		Benzo[*e*]pyrene IARC - Available evidence inadequate to permit an evaluation of the carcinogenecy to experimental animals – limited evidence Phytotoxic LT50 (mean survival time until the death of 50% of the test organisms) for Dapnia magna (water flea) was 15.36 hours at a concentration of 0.7 ug/L (ppb) (Irwin et al 1997)	Perylene

Potential serious health effects (including moderate or serious illness, death)	**Some health effects** (potential to cause mild to moderate illness)	**Little or no effects** (little or no chance of becoming ill)	**Insufficient knowledge**
Benzo[*k*]fluoranthene US EPA IRIS – *probable human carcinogen.* No human data but sufficient animal bioassays. Produced tumours after lung implantation in mice and when administered with a promoting agent in skin-painting studies. Equivocal results have been found in a lung adenoma assay in mice. Mutagenic in bacteria.			
Dibenz[*a,h*]anthracene US EPA IRIS – *probable human carcinogen.* No human data but sufficient animal bioassays. Produced carcinomas in mice following oral or dermal exposure and injection site tumours in several species following subcutaneous or intramuscular administration. Induced DNA damage and gene mutations in bacteria as well as gene mutations and transformation in several types of mammalian cell cultures.			

Potential serious health effects (including moderate or serious illness, death)	**Some health effects** (potential to cause mild to moderate illness)	**Little or no effects** (little or no chance of becoming ill)	**Insufficient knowledge**
Naphthalene EU EC Directive 67/548 Category 2 may cause cancer IARC[7] Group 2B possibly carcinogenic to humans Human toxicity low dose, chronic exposures, lens of eye and lungs most sensitive (Stohs et al 2002) US EPA IRIS Human experience with acute accidental exposures identifies the development of hemolytic anaemia and cataracts. US SEPA IRIS - classified as a possible human carcinogen. Inadequate data of carcinogenicity in humans exposed via the oral and inhalation routes, and the limited evidence of carcinogenicity in animals via the inhalation route - suggestive evidence (observations of benign respiratory tumors and one carcinoma in female mice only exposed to by inhalation [NTP, 1992]). Additional support includes increase in respiratory tumors associated with exposure to 1-methylnaphthalene. 10% decrease in body weight rats following 90 day average exposure 200mg/kg-day not associated with decrease food intake (BCL 1980a) Shopp et al (1984) significant decrease absolute weight brain, liver and spleen slight but significant increase hemoglobin high-dose female mice. Kock et al 1976 development of cataract – studies have included rats and rabbits (Murano et al 1993, Selzer et al 1991)			
PCB			
2,4,4'-Trichlorobiphenyl (PCB-28) Know human and animal carcinogen (Proposition 65, 2004)			

Potential serious health effects (including moderate or serious illness, death)	**Some health effects** (potential to cause mild to moderate illness)	**Little or no effects** (little or no chance of becoming ill)	**Insufficient knowledge**
2,2',5,5'-Tetrachlorobiphenyl (PCB-52) Know human and animal carcinogen (Proposition 65, 2004)			
PCB 77 Know human and animal carcinogen (Proposition 65, 2004)			
PCB 81 Birth or developmental effects, Brain and nervous system, Cancer, Endocrine system, Immune system (including sensitization and allergies), Persistent and bioaccumulative, Reproduction and fertility			
2,2',4,5,5'-Pentachlorobiphenyl (PCB-101) Birth or developmental effects, Brain and nervous system, Cancer, Endocrine system, Immune system (including sensitization and allergies), Persistent and bioaccumulative			
PCB 105 Birth or developmental effects, Brain and nervous system, Cancer, Endocrine system, Immune system (including sensitization and allergies), Persistent and bioaccumulative, Reproduction and fertility			
PCB 114 Birth or developmental effects, Brain and nervous system, Cancer, Endocrine system, Immune system (including sensitization and allergies), Persistent and bioaccumulative, Reproduction and fertility			
PCB 118 Birth or developmental effects, Brain and nervous system, Cancer, Endocrine system, Immune system (including sensitization and allergies), Persistent and bioaccumulative, Reproduction and fertility			

Potential serious health effects (including moderate or serious illness, death)	**Some health effects** (potential to cause mild to moderate illness)	**Little or no effects** (little or no chance of becoming ill)	**Insufficient knowledge**
PCB 123 Birth or developmental effects, Brain and nervous system, Cancer, Endocrine system, Immune system (including sensitization and allergies), Persistent and bioaccumulative, Reproduction and fertility			
PCB 126 Birth or developmental effects, Brain and nervous system, Cancer, Endocrine system, Immune system (including sensitization and allergies), Persistent and bioaccumulative, Reproduction and fertility			
2,2',4,4',5,5'-Hexachlorobiphenyl (PCB-153) Known carcinogen and developmental toxicant (Proposition 65, 2004), endocrine toxicant (BKH 2000), gastrointestinal or liver toxicant (RTECS)			
PCB 156 Carcinogen and developmental toxicant (Proposition 65, 2004), birth or developmental effects, Brain and nervous system, Cancer, Endocrine system, Immune system (including sensitization and allergies), Persistent and bioaccumulative, Reproduction and fertility			
PCB 157 Birth or developmental effects, Brain and nervous system, Cancer, Endocrine system, Immune system (including sensitization and allergies), Persistent and bioaccumulative, Reproduction and fertility			
PCB 167 Birth or developmental effects, Brain and nervous system, Cancer, Endocrine system, Immune system (including sensitization and allergies), Persistent and bioaccumulative, Reproduction and fertility			

Potential serious health effects (including moderate or serious illness, death)	**Some health effects** (potential to cause mild to moderate illness)	**Little or no effects** (little or no chance of becoming ill)	**Insufficient knowledge**
PCB 169 Carcinogen and developmental toxicant (Proposition 65, 2004), endocrine toxicant (BKH 2000), gastrointestinal or liver toxicant (RTECS)			
2,2',3,4,4',5,5'-Heptachlorobiphrnyl (PCB-180) Birth or developmental effects, Brain and nervous system, Cancer, Endocrine system, Immune system (including sensitization and allergies), Persistent and bioaccumulative, Reproduction and fertility			
PCB 189 Birth or developmental effects, Brain and nervous system, Cancer, Endocrine system, Immune system (including sensitization and allergies), Persistent and bioaccumulative, Reproduction and fertility			
2,2',3,4,4',5'-Hexachlorbiphenyl (PCB-138) Carcinogen and developmental toxicant (Proposition 65, 2004)			
PCDD/F			
2,3,7,8-TeCDD causes chloracne in humans, a severe acne-like condition. It is known to be a developmental toxicant in animals, causing skeletal deformities, kidney defects, and weakened immune responses in the offspring of animals exposed during pregnancy. Human studies have shown an association between 2,3,7,8-TeCDD and soft-tissue sarcomas, lymphomas, and stomach carcinomas. EPA has classified it as a probable human carcinogen (Group B2).			

Potential serious health effects (including moderate or serious illness, death)	**Some health effects** (potential to cause mild to moderate illness)	**Little or no effects** (little or no chance of becoming ill)	**Insufficient knowledge**
1,2,3,7,8-PeCDD Birth or developmental effects, Cancer, Immune system (including sensitization and allergies), Persistent and bioaccumulative			
1,2,3,4,7,8-HxCDD In rats and mice there was a dose-related toxic hepatitis consisting of degenerative liver changes and necrosis. A significant dose-related increase in incidence of hepatocellular carcinomas or neoplastic nodules was noted in male rats (EPA)			
1,2,3,6,7,8-HxCDD In rats and mice there was a dose-related toxic hepatitis consisting of degenerative liver changes and necrosis. A significant dose-related increase in incidence of hepatocellular carcinomas or neoplastic nodules was noted in male rats (EPA)			
1,2,3,7,8,9-HxCDD Birth or developmental effects, Cancer, Immune system (including sensitization and allergies), Persistent and bioaccumulative			
1,2,3,4,6,7,8-HpCDD Birth or developmental effects, Cancer, Immune system (including sensitization and allergies), Persistent and bioaccumulative			
OCDD Birth or developmental effects, Cancer, Immune system (including sensitization and allergies), Persistent and bioaccumulative			
2,3,7,8-TeCDF Birth or developmental effects, Cancer, Immune system (including sensitization and allergies), Persistent and bioaccumulative			
1,2,3,7,8-PeCDF Birth or developmental effects, Cancer, Immune system (including sensitization and allergies), Persistent and bioaccumulative			

Potential serious health effects (including moderate or serious illness, death)	**Some health effects** (potential to cause mild to moderate illness)	**Little or no effects** (little or no chance of becoming ill)	**Insufficient knowledge**
2,3,4,7,8-PeCDF Birth or developmental effects, Cancer, Immune system (including sensitization and allergies), Persistent and bioaccumulative			
1,2,3,4,7,8-HxCDF Birth or developmental effects, Cancer, Immune system (including sensitization and allergies), Persistent and bioaccumulative			
1,2,3,6,7,8-HxCDF Birth or developmental effects, Cancer, Immune system (including sensitization and allergies), Persistent and bioaccumulative			
1,2,3,7,8,9-HxCDF Birth or developmental effects, Cancer, Immune system (including sensitization and allergies), Persistent and bioaccumulative			
2,3,4,6,7,8-HxCDF Birth or developmental effects, Cancer, Immune system (including sensitization and allergies), Persistent and bioaccumulative			
1,2,3,4,6,7,8-HpCDF Birth or developmental effects, Cancer, Immune system (including sensitization and allergies), Persistent and bioaccumulative			
1,2,3,4,7,8,9-HpCDF Birth or developmental effects, Cancer, Immune system (including sensitization and allergies), Persistent and bioaccumulative			
OCDF Birth or developmental effects, Cancer, Immune system (including sensitization and allergies), Persistent and bioaccumulative			
LAS			

Potential serious health effects (including moderate or serious illness, death)	**Some health effects** (potential to cause mild to moderate illness)	**Little or no effects** (little or no chance of becoming ill)	**Insufficient knowledge**
	The available data indicate that LAS exhibits slight acute toxicity. Oral LD50 values for rats range from 1,080 to 1,980 mg/kg bw. Oral LD50 values for mice are 2,160 and 2,250 mg/kg bw for males and females, respectively. The rat dermal LD50 value was greater than 2,000 mg/kg bw. The oral and dermal acute toxicity data for LAS generally indicate low hazard potential when all studies are considered together. Acute inhalation toxicity data indicate that LAS is moderately toxic, with mortality occurring at respirable particle concentrations of 310 mg/m3 (MMAD = 2.5 microns). (SIDS 2005)		

Chlorinated paraffins			
The June 2002 Marketing and Use Directive relating to SCCPs came into force in January 2003 to address concerns relating to environmental release. Under the amended Marketing and Use Directive (76/679/EEC), SCCPs may not be marketed or used in concentrations greater than 1% for metalworking and leather finishing. EU member countries are required to adopt regulations to comply with the EU Directive by January 2004. Other uses such as paints, coatings and flame retardants are not affected.		Long-chain chlorinated paraffins (LCCPs) are not included on the EU priority list. The UK, however, issued a draft national environmental risk assessment for LCCPs in November 2002. The risk assessment concluded that the risk to surface water, waste water and the atmosphere from LCCPs with chain lengths greater than C_{20} (those typically manufactured in the US) was low.	A draft EU risk assessment for mid-chain chlorinated paraffins (MCCPs), prepared by the United Kingdom (UK), was posted on the European Chemical Bureau website in August of 2002. The draft assessment included a provisional recommendation that MCCPs be classified as dangerous for the environment because of concerns relating to toxicity to aquatic organisms. The CEFIC Chlorinated Paraffins Sector Group, which represents the European producers of chlorinated paraffins, is working with the UK and participating in the relevant EU Technical Meetings to promote a reasonable assessment. Additional testing of MCCPs is underway to provide necessary clarification of effects.
Brominated flame retardants (BFR)			
	PBDEs There is no definite information on health effects of PBDEs in people. Rats and mice that ate food with moderate amounts of PBDEs for a few days had effects on the thyroid gland. Those that ate smaller amounts for weeks or months had effects on the thyroid and the liver. Large differences in effects are seen between highly-brominated and less-brominated PBDEs in animal studies. Preliminary evidence suggests that high concentrations of PBDEs may cause neurobehavioral alterations and affect the immune system in animals. (ATSDR)		

Perfluorinated alkyl substances (PFAS)			
	The toxicological properties of perfluorinated compounds are presently not well understood, but different length (perfluorinated) carbon chains and functional groups are likely to influence toxicity. It is not clear at this time whether the hazard concerns of PFAS can be extrapolated to other perfluorinated compounds except under circumstances where the compound may degrade to PFAS. PFAS is reported to be persistent, bioaccumulative and toxic to mammalian species. Repeated exposure results in hepatotoxicity and mortality. In addition, PFAS has been shown to cause hepatocellular adenomas and thyroid follicular cell adenomas in rats; the hepatocellular adenomas do not appear to be related to peroxisome proliferation. Epidemiological studies have shown an association of PFAS exposure and the incidence of bladder cancer; further work is needed to understand this association. PFAS appears to be of low to moderate toxicity to aquatic organisms but there is evidence of high acute toxicity to honey bees. No information is available on effects on soil- and sediment-dwelling organisms		

Pesticide			
Clopyralid– (sunflower, legume crops and solanaceous plants including tomatoes and potatoes – effects at 10 parts per billion)	Bensulide WHOII moderately hazardous	Alachlor[7] US EPA 1996 classified L2 carcinogen likely at high dose but not likely at low does EU EC Directive 67/548 Category 3 Possible Risk of irreversible effects EU[9] Category 1 Endocrine disruptor, at least one study providing evidence in an intact organism. Included German EA priority list EDCs	
Fenoxycarb USEPA 1996 classified L1 Likely to be carcinogenic to humans, available tumour effects and other key data are adequate to demonstrate carcinogenic potential for humans EU[9] Category 2 Potential EDC	Captan US EPA 1986 classified B2 sufficient evidence of carcinogen effect in animals and inadequate of no evidence in humans EU EC Directive 67/548 Category 3 Possible Risk of irreversible effects IARC[7] Group 3 Not classifiable as to carcinogenicity in humans	Aldrin US EPA 1996 classified L2 carcinogen likely at high dose but not likely at low does EU EC Directive 67/548 Category 3 Possible Risk of irreversible effects IARC[8] Group 3 Not classifiable as to carcinogenicity in humans EU[9] Category 2 Potential EDC Included UK EA and WWF list EDCs	
Imazalil WHOII moderately hazardous USEPA 1996 classified L1 Likely to be carcinogenic to humans, available tumour effects and other key data are adequate to demonstrate carcinogenic potential for humans	Carbaryl WHOII moderately hazardous US EPA 1999 classified 2 Likely to be carcinogenic to humans EU EC Directive 67/548 Category 3 Possible Risk of irreversible effects IARC[9] Group 3 Not classifiable as to carcinogenicity in humans EU[9] Category 1 Endocrine disruptor, at least one study providing evidence in an intact organism.	Atrazine IARC[7] Group 3 Not classifiable as to carcinogenicity in humans EU[9] Category 1 Endocrine disruptor, at least one study providing evidence in an intact organism. Included UK EA, German EA , OSPAR and WWF list EDCs	

[7] *IARC – International Agency for Research on Cancer*
[8] *IARC – International Agency for Research on Cancer*
[9] *Community Strategy for Endocrine Disruptors*

PCP Pentachlorophenol WHO 1b highly hazardous EU[9] Category 1 Endocrine disruptor, at least one study providing evidence in an intact organism.	Chlordane WHOII moderately hazardous US EPA 1986 classified B2 sufficient evidence of carcinogen effect in animals and inadequate of no evidence in humans EU EC Directive 67/548 Category 3 Possible Risk of irreversible effects IARC[7] Group 2B possibly carcinogenic to humans EU[9] Category 1 Endocrine disruptor, at least one study providing evidence in an intact organism. Included German EA , OSPAR and WFF list EDCs		
	Chlorpyrifos WHOII moderately hazardous	Benfluralin EU EC Directive 67/548 Category 3 Possible Risk of irreversible effects	
	Chlorothalonil US EPA 1986 classified B2 sufficient evidence of carcinogen effect in animals and inadequate of no evidence in humans EU EC Directive 67/548 Category 3 Possible Risk of irreversible effects IARC[7] Group 2B possibly carcinogenic to humans	Benomyl US SEPA 1986 Group C Possible Human Carcinogen WFD suspected EDC	
	Cyanazine WHOII moderately hazardous US SEPA 1986 Group C Possible Human Carcinogen EU[9] Category 2 Potential EDC	Dacthal (DCPA) US SEPA 1986 Group C Possible Human Carcinogen IARC[7] Group 3 Not classifiable as to carcinogenicity in humans	
	Cyfluthrin WHOII moderately hazardous	Difenoconazole US SEPA 1986 Group C Possible Human Carcinogen	
	Cyproconazole US EPA 1986 classified B2 sufficient evidence of carcinogen effect in animals and inadequate of no evidence in humans	Dinosep US EPA 1986 Group C Possible Human Carcinogen	
	Deltamethrin WHOII moderately hazardous IARC[10] Group 3 Not classifiable as to carcinogenicity in humans EU[9] Category 1 Endocrine disruptor, at least one study providing evidence in an intact organism. Included WWF list EDCs	Endrin IARC[7] Group 3 Not classifiable as to carcinogenicity in humans EU[9] Category 2 Potential EDC. Included UKEA and WWF list EDCs	

[10] *IARC – International Agency for Research on Cancer*

	Diazion WHOII moderately hazardous EU[9] Category 2 Potential EDC	Epoxiconazole US EPA 1999 classified 2 Likely to be carcinogenic to humans EU EC Directive 67/548 Category 3 Possible Risk of irreversible effects	
	Dieldrin US EPA 1986 classified B2 sufficient evidence of carcinogen effect in animals and inadequate of no evidence in humans EU EC Directive 67/548 Category 3 Possible Risk of irreversible effects IARC[11] Group 3 Not classifiable as to carcinogenicity in humans EU[9] Category 2 Potential EDC. Included UKEA, OSPAR and WWF list EDCs	Fenbuconazole US EPA 1986 Group C Possible Human Carcinogen	
	Endosulfan WHOII moderately hazardous EU[9] Category 2 Potential EDC. Included UKEA, OSPAR and WWF list EDCs	Malathion US EPA 1999 classified as 3 suggestive evidence of carcinogenicity, but not sufficient to assess human carcinogenic potential IARC[7] Group 3 Not classifiable as to carcinogenicity in humans EU[9] Category 2 Potential EDC	
	Fenpropathrin WHOII moderately hazardous	Methoxychlor IARC[7] Group 3 Not classifiable as to carcinogenicity in humans EU[9] Category 1 Endocrine disruptor, at least one study providing evidence in an intact organism. Included OSPAR, WWF list EDCs	
	Lindane WHOII moderately hazardous US EPA 1999 classified as 3 suggestive evidence of carcinogenicity, but not sufficient to assess human carcinogenic potential IARC[7] Group 2B possibly carcinogenic to humans EU[9] Category 1 Endocrine disruptor, at least one study providing evidence in an intact organism. Included UK EA, Ger EA, OSPAR, WWF list EDCs	Oxadiazon US EPA 1986 Group C Possible Human Carcinogen	

[11] *IARC – International Agency for Research on Cancer*

	Metolachlor WHOII moderately hazardous	Oxadixyl US EPA 1986 Group C Possible Human Carcinogen	
	Oryzalin US EPA 1999 classified 2 Likely to be carcinogenic to humans	Propazine US EPA 1986 Group C Possible Human Carcinogen EU EC Directive 67/548 Category 3 Possible Risk of irreversible effects	
	Pentachlorophenol US EPA 1986 classified B2 sufficient evidence of carcinogen effect in animals and inadequate of no evidence in humans EU EC Directive 67/548 Category 3 Possible Risk of irreversible effects	Tebuconazole US EPA 1986 Group C Possible Human Carcinogen	
	Propiconazole WHO II moderately hazardous US EPA 1986 Group C Possible Human Carcinogen	Tebufenpyrad US EPA 1999 classified as 3 suggestive evidence of carcinogenicity, but not sufficient to assess human carcinogenic potential	
	Propoxur WHO II moderately hazardous US EPA 1986 classified B2 sufficient evidence of carcinogen effect in animals and inadequate of no evidence in humans	Triadimefon US EPA 1986 Group C Possible Human Carcinogen EU[9] Category 2 Potential EDC.	
	Toxaphene US EPA 1986 classified B2 sufficient evidence of carcinogen effect in animals and inadequate of no evidence in humans IARC[7] Group 2B possibly carcinogenic to humans	Triadimenol US EPA 1986 Group C Possible Human Carcinogen EU[9] Category 2 Potential EDC.	
		Trifluralin US EPA 1986 Group C Possible Human Carcinogen EU EC Directive 67/548 Category 3 Possible Risk of irreversible effects EU[9] Category 2 Potential EDC. Included on UK EA & WFD EDCs list	
DDT			
	DDD US EPA 1986 classified B2 sufficient evidence of carcinogen effect in animals and inadequate of no evidence in humans		

	DDE US EPA 1986 classified B2 sufficient evidence of carcinogen effect in animals and inadequate of no evidence in humans		
	DDT WHOII moderately hazardous US EPA 1986 classified B2 sufficient evidence of carcinogen effect in animals and inadequate of no evidence in humans EU EC Directive 67/548 Category 3 Possible Risk of irreversible effects IARC[7] Group 2B possibly carcinogenic to humans EU[9] Category 1 Endocrine disruptor, at least one study providing evidence in an intact organism. Included UK EA, German EA , OSPAR and WWF list EDCs		
Chlorinated hydrocarbon			
	Heptachlor US EPA 1986 classified B2 sufficient evidence of carcinogen effect in animals and inadequate of no evidence in humans EU EC Directive 67/548 Category 3 Possible Risk of irreversible effects IARC[7] Group 2B possibly carcinogenic to humans EU[9] Category 2 Potential EDC.		
	Hexachlorobenzene US EPA 1986 classified B2 sufficient evidence of carcinogen effect in animals and inadequate of no evidence in humans EU EC Directive 67/548 Category 3 Possible Risk of irreversible effects IARC[7] Group 2B possibly carcinogenic to humans EU[9] Category 1 Endocrine disruptor, at least one study providing evidence in an intact organism. Included German EA , OSPAR and WWF list EDCs		

	TrCP trichlorophenol US EPA 1986 classified B2 sufficient evidence of carcinogen effect in animals and inadequate of no evidence in humans EU EC Directive 67/548 Category 3 Possible Risk of irreversible effects		
Identified as tested for but no information on whether found			
Butachlor USEPA 1996 classified L1 Likely to be carcinogenic to humans, available tumour effects and other key data are adequate to demonstrate carcinogenic potential for humans	Dichlorvos US EPA 1999 classified as 3 suggestive evidence of carcinogenicity, but not sufficient to assess human carcinogenic potential IARC[7] Group 2B possibly carcinogenic to humans UK EA list of EDCs	Bormacil US EPA 1986 Group C Possible Human Carcinogen	
Ethoprop USEPA 1996 classified L1 Likely to be carcinogenic to humans, available tumour effects and other key data are adequate to demonstrate carcinogenic potential for humans	Dimethonate WHOII moderately hazardous US EPA 1986 Group C Possible Human Carcinogen EU[9] Category 2 Potential EDC. Included on UK EA & WFD EDCs list	Dicofol US EPA 1986 Group C Possible Human Carcinogen EU[9] Category 2 Potential EDC. Included on OSPAR & WFD EDCs list	
Iprodione USEPA 1996 classified L1 Likely to be carcinogenic to humans, available tumour effects and other key data are adequate to demonstrate carcinogenic potential for humans EU EC Directive 67/548 Category 3 Possible Risk of irreversible effects EU[9] Category 2 Potential EDC.	EPTC WHOII moderately hazardous	Methidathion US EPA 1986 Group C Possible Human Carcinogen	
Methiocarb WHO 1b highly hazardous	Fenvalerate WHO II moderately hazardous IARC[7] Group 3 Not classifiable as to carcinogenicity in humans	Norflurazon US SEPA 1986 Group C Possible Human Carcinogen	
Propachlor USEPA 1996 classified L1 Likely to be carcinogenic to humans, available tumour effects and other key data are adequate to demonstrate carcinogenic potential for humans	Metribuzin WHOII moderately hazardous EU[9] Category 1 Endocrine disruptor, at least one study providing evidence in an intact organism.	Pendimethalin US EPA 1986 Group C Possible Human Carcinogen	

	Pebulate WHOII moderately hazardous	Simazine US EPA 1986 Group C Possible Human Carcinogen EU EC Directive 67/548 Category 3 Possible Risk of irreversible effects IARC[7] Group 3 Not classifiable as to carcinogenicity in humans EU[9] Category 2 Potential EDC. Included UK EA and WFD list EDCs	
	Permethrin WHO II moderately hazardous US EPA 1999 classified as 3 suggestive evidence of carcinogenicity, but not sufficient to assess human carcinogenic potential IARC[7] Group 3 Not classifiable as to carcinogenicity in humans	Terbutryn US EPA 1986 Group C Possible Human Carcinogen	
	Procymidon US EPA 1986 classified B2 sufficient evidence of carcinogen effect in animals and inadequate of no evidence in humans		
	Pronamide US EPA 1986 classified B2 sufficient evidence of carcinogen effect in animals and inadequate of no evidence in humans EU EC Directive 67/548 Category 3 Possible Risk of irreversible effects		
	Pyrazophos WHO II moderately hazardous		
	Tricyclazole WHO II moderately hazardous		
	Triphenyltin US EPA 1986 classified B2 sufficient evidence of carcinogen effect in animals and inadequate of no evidence in humans EU EC Directive 67/548 Category 3 Possible Risk of irreversible effects		

Filter 2: Is there a pathway?
Potentially serious effect (animal/human/environment)
AND is hazard likely to evade destruction if contamination not contained during composting process?

Outdoor-turned windrow:

Agent	Uncertain	Likely to evade destruction	Likely to be destroyed/ negated
	(livestock disease resulting from pathway/agent not fully understood)	(normal best practice/agricultural measures or nature will not destroy or negate agents)	(normal best practice/agricultural measures or nature should destroy or negate agents)
PCB 28		These PCBs have been measured in SSGW compost (Krauss (1994), Aldag & Bischoff (1995), Bayerisches Laudesamt fur Umweltschutz (1995), Berset & Holzer (1995), Hund et al (1999), Strom (2000), Marb et al (2001), Verge-Leviel (2001), Zethuer et al (2000))	
PCB 52			
PCB 95			
PCB 101			
PCB 118			
PCB 132			
PCB 138			
PCB 149			
PCB 153			
PCB 174			
PCB 180			
NAP		These PAHs have all been measured in SSGW compost (Krauss (1994), Bewset & Holzer (1995), Hund et al (1999), Verge-Leviel (2001), Zethuer et al (2000), Schleiss (2003))	
B[a]A			
CHR			
B[b]f			
B[k]f			
B[a]P			
IPY			
2,3,7,8-TeCDD		These PCCD/Fs have all been measured in SSGW compost (Kummer (1996, 1990), Harrad et al (1991), Malloy et al (1993), Krauss (1994), Aldag & Bischoff (1995), Bayerisches Laudesamt fur Umweltschutz (1995), Zethuer et al (2000), Marb et al (2001), Kuhn & Arnet (2003))	
1,2,3,7,8-PeCDD			
1,2,3,4,6,7,8-HpCDD			
2,3,4,7,8-PeCDF			
1,2,3,4,7,8-HxCDF			
1,2,3,6,7,8-HxCDF			
2,3,4,6,7,8-HxCDF			
Clopyralid		These pesticides/herbicides have all been measured in SSGW compost (CIWBM)	
Fenoxycarb			
Imazalil			
PCP Pentachlorophenol			

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Appendix B3 Sift for principal agents – Potentially toxic elements

Arsenic (As) Boron (B) Cadmium (Cd) Chromium (Cr) Cobalt (Co) Copper (Cu) Lead (Pb)	Mercury (Hg) Manganese (Mn) Molybdenum (Mo) Nickel (Ni) Selenium (Se) Vanadium (V) Zinc (Zn)

Filter 1: Does hazard have potentially serious effect (animal/human/environment)?

Potential serious health effects (including moderate or serious illness, death)	**Some health effects** (potential to cause mild to moderate illness)	**Little or no effects** (little or no chance of becoming ill)
As - associated with skin, kidney, bladder cancer, even at low level exposure (Leonardi et al, 2012)	**V** – Arthritis, aching joins bones & teeth, ear ache, chronic colds, gastrointestinal problems, trabecular bone loss	**Ni** – Some allergic effects (Reilly 1991)
Cu – Environmental level exposures associated with Haemolytic anaemia (Ivanovich et al 1969)		**Co** – usually not of concern as toxicity does not develop from normal consumption of food/beverages or environmental-level exposures
Cd - environmental exposures associated with kidney and bone disorders in humans (Oliver, 1997; Reilly, 1991; Tsuchiya 1976), various studies showing toxicity to aquatic organisms, accumulation in liver/kidney of animals.		**B** – Inhibits formation of starch from sugars in plants & reduce yields. Difficult to attain toxic levels in humans or larger animals from environmental exposures
Pb - environmental exposures shown to cause neurological disorders in humans (Orfilia 1817, Lin-Fu 1992) also anorexia, dyspepsia, constipation, colic, paroxysmal abdominal pain (Millstone, 1997, Reilly 1991). Long-term intakes of 'non-toxic' levels shown to have adverse effects (Davies & Wixson 1987)		**Cr** – Skin contact with Cr(VI) or Cr(III) can cause skin ulcers or other allergic reactions
Cr – Shown to increase risk of cancer in rats, increased risk of lung cancer in humans exposed to Cr fumes (less relevant for composting situation) (ATSDR 2000)		**Mo** – Skin eruptions, itchy skin, joint diseases/irritations
Hg – Severe corrosive gastroenteritis, acute tubular necrosis, chronic neurologic and renal dysfunction (Diner 2007)		
Mn – Co-requirement for tumour development from a number of other agents such as alcohol, cannabis, viral infections, etc.		
Se – Nerve degradation, osteoporosis, cystadenoma, shingles, hair loss, abnormal nails, tooth decay, garlic smelling breath, death		
Zn – Interferes with Cu absorption causing hair damage & anaemia (Fox & Jacobs 1985), interferes with reproduction of humans and animals (Peereboom-Stegeman, 1987), may impair embryo growth (Oliver 1997)		

Filter 2: Is there a pathway?
Potentially serious effect (animal/human/environment)
AND is hazard likely to evade destruction if contamination not contained during composting process?

Proxy processes, e.g. Backyard composting:

Agent	Uncertain	Likely to evade destruction	Likely to be destroyed/ negated
	(livestock disease resulting from pathway/agent not fully understood)	(normal best practice/agricultural measures or nature will not destroy or negate agents)	(normal best practice/agricultural measures or nature should destroy or negate agents)
As		Concentrations remain stable during composting (Evans and Tan 1998)	
Cd			
Cr		Concentrations remain stable during composting (Evans and Tan 1998)	
Pb			
Hg			
Se			
V		Concentrations remain stable during composting (Evans and Tan 1998)	
Zn		Concentrations shown to decrease ~20 % during composting (Evans and Tan 1998)	

Outdoor-turned windrow:

Agent	Uncertain	Likely to evade destruction	Likely to be destroyed/ negated
	(livestock disease resulting from pathway/agent not fully understood)	(normal best practice/agricultural measures or nature will not destroy or negate agents)	(normal best practice/agricultural measures or nature should destroy or negate agents)
As		Availability does not significantly change during composting process (Greenway and Song 2002) 2 mg kg^{-1} measured in greenwaste compost (Petrell et al 2003) 12.1 mg kg^{-1} max. measured in greenwaste compost (SMA 1998) 11.7 mg kg^{-1} measured in greenwaste compost (Greenway and Song 2002)	

Agent	Uncertain	Likely to evade destruction	Likely to be destroyed/ negated
Cd		Availability does not significantly change during composting process (Greenway and Song 2002) Concentrations shown to increase ~50 % during windrow composting of greenwaste to 1.46 mg kg^{-1} (Whittle and Dyson 2002) 0.3 mg kg^{-1} measured in greenwaste compost (Petrell et al 2003) 1.5 mg kg^{-1} measured in greenwaste compost (The Composting Assoc. 2008) 0.6 mg kg^{-1} max. (SMA 1998) 1.5 mg kg^{-1} (Greenway and Song 2002) 0.95 mg kg^{-1} max. (Informa 2005)	
Cr		Concentrations shown to decrease ~40 % to 3.7 mg kg^{-1} (Whittle and Dyson, 2002) 24 mg kg^{-1} (Petrell et al 2003) 73.7 mg kg^{-1} max (The Composting assoc. 2008) 39.3 mg kg^{-1} max (SMA 1998) 23.9 mg kg^{-1} max (Greenway and Song 2002) 59.3 mg kg^{-1} max (Informa 2005)	

Agent	Uncertain	Likely to evade destruction	Likely to be destroyed/ negated
Cu		Concentrations shown to decrease ~50 % (Whittle and Dyson, 2002) 43.7 mg kg^{-1} max. measured in greenwaste compost (SMA 1998) 200 mg kg^{-1} max. measured in greenwaste compost (The Composting Assoc. 2008) 50.2 mg kg^{-1} measured in greenwaste compost (Greenway and Song 2002) 67.4 mg kg^{-1} max. (Informa 2005)	Availability decreases during composting process (Greenway and Song 2002)
Pb		15 mg kg^{-1} measured in greenwaste compost (Petrell et al. 2003) 200 mg kg^{-1} max. measured in greenwaste compost (The Composting Assoc. 2008) 95 mg kg^{-1} max (SMA 1998) 117.2 mg kg^{-1} (Greenway and Song 2002) 87.7 mg kg^{-1} max (Informa 2005)	Concentrations shown to decrease >90 % during windrow composting. (Whittle and Dyson, 2002) Availability decreases during composting process (Greenway and Song 2002)
Hg		<1 mg kg^{-1} measured in greenwaste compost (Petrell et al 2003) 1 mg kg^{-1} max. (THe Composting Assoc. 2008) <0.1 mg kg^{-1} measured in composted greenwaste (SMA 1998) 0.31 mg kg^{-1} max. (Informa 2005)	
Mn		560 mg kg^{-1} max. measured in greenwaste compost (SMA 1998)	
Mo		6.2 mg kg^{-1} max. measured in greenwaste compost (SMA 1998)	

Agent	Uncertain	Likely to evade destruction	Likely to be destroyed/ negated
Ni		45.8 mg kg^{-1} max. measured in greenwaste compost (The Composting Assoc. 2008) 27 mg kg^{-1} max. measured in greenwaste compost (SMA 1998) 15 mg kg^{-1} measured in greenwaste compost (Greenway and Song 2002) 55.4 mg kg^{-1} max. (Informa 2005)	
Se		0.5 mg kg^{-1} max. measured in greenwaste compost	
V			
Zn		Availability does not significantly change during composting process (Greenway and Song 2002) Concentrations shown to decrease ~20 % to 108 mg kg^{-1} (Whittle and Dyson, 2002) 79 mg kg^{-1} (Petrell et al 2003) 400 mg kg^{-1} max (The Composting Assoc. 2008) 173 mg kg^{-1} max (SMA 1998) 220.4 mg kg^{-1} (Greenway and Song 2002) 284 mg kg^{-1} max. (Informa 2005)	

In Vessel Composting:

Agent	Uncertain	Likely to evade destruction	Likely to be destroyed/ negated
	(livestock disease resulting from pathway/agent not fully understood)	(normal best practice/agricultural measures or nature will not destroy or negate agents)	(normal best practice/agricultural measures or nature should destroy or negate agents)
As			
Cd		0.5 mg kg^{-1} measured in in-vessel composted greenwaste (Informa 2005)	
Cr		24.1 mg kg^{-1} measured in in-vessel composted greenwaste (Informa 2005)	
Co			
Cu		52.9 mg kg^{-1} measured in in-vessel composted greenwaste (Informa 2005)	
Pb		50.5 mg kg^{-1} measured in in-vessel composted greenwaste (Informa 2005)	

Hg		0.2 mg kg^{-1} measured in in-vessel composted greenwaste (Informa 2005)	
Mo			
Ni		13.8 mg kg^{-1} measured in in-vessel composted greenwaste (Informa 2005)	
Se			
V			
Zn		190.5 mg kg^{-1} measured in in-vessel composted greenwaste (Informa 2005)	

References: Appendix B3

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Appendix B4i Sift for principal agents – Pathogens

Filter 1. Which pathogens identified as being associated with soil, animal faeces or plant material are likely to enter Green Waste?

Biological	Source/Reservoir (of relevance to green waste)	Unlikely to enter Green Waste	Unknown likelihood of entry into Green Waste
Bacteria:			
Actinomadura madurae	Widely distributed in soil (Holt 1994) Mainly in tropical and subtropical areas (Holt 1994, Foltz and Fallat 2004).	Unlikely to be in temperate soils	
Actinomadura pelletieri	Present in soil – mainly found in Africa (Holt 1994). Soil is primary reservoir for infection through feet.	Unlikely to be in temperate soils	
Actinomyces bovis	Commonly present mucosal membranes especially in mouth (cattle)	Unlikely to enter environment where no cattle	
Actinomyces israelii	Commonly present mucosal membranes especially in mouth (humans)	Unlikely to be in environment Transmission via soils/plant material unlikely.	
Actinomyces other spp.	Endogenous to human/animal mucosal membranes.	Transmission via soils/plant material unlikely.	
Alcaligenes spp.	Occurs in water and soils and is a common inhabitant of GI tract invertebrates & isolated from urine/faeces (Holt 1994), soil – ubiquitous (Dworkin et al 200a7)		
Bacillus anthracis	Common in soil (Holt 1994)		
Bacillus cereus	Common in soil/rhizosphere (Dworkin et al 2007b)		
Bacteroides fragilis	Soil/ GI tract & faeces animals and birds (Dworkin 2007b)		
Bacteroides other spp.	Main habitat is caecum but found in soil/ faeces (Dworkin 2007b, Holt 1994)		
Bordetella bronchisepta	May be a soil reservoir (Stavely et al 2003) and references theirin).		No citations found for *Bordetella bronchisepta* and relevent environmental matrices
Bordetella parapertussis *Bordetella pertussis*	Respiratory tract pathogens of animals and humans – no direct evidence for an environmental		No citations found for *Bordetella parapertussis/pertussis* and relevent environmental

Biological	Source/Reservoir (of relevance to green waste)	Unlikely to enter Green Waste	Unknown likelihood of entry into Green Waste
	reservoir (Parton 1999)		matrices
Brucella abortus *Brucella suis*	Animal and human hosts, primarily catle, pigs etc - thought to survive outside hosts in soils (Public Health Agency of Canada (unknown) – evidence poor).	*B. abortus* eradicated in UK (DEFRA unkonwn). May be in livestock associated soils but not vegetation/soils from gardens/public places	Little clear evidence for survival in soils etc.
Burkholderia cepacia	Common in rhizosphere and bulk soil – opportunistic pathogens (Jacobs et al 2008)		
Campylobacter fetus *Campylobacter jejuni* *Camylobacter* other spp.	Present in wild/domestic avian and animal faeces (Jones 2001) inc dogs (Moyaert 2008), can survive in soil (Ross and Donnison 2006)		
Cardiobacterium hominis	Part of natural flora of upper respiratory tract in humans (e.g. Malani et al 2006)		No relevent references found.
Chlamydida pneumoniae	Human pathogen (Vanrompay et al 1993)		No relevent references found.
Chlamydia abortus (psittaci) *Chlamydia trachomatis*	Can be found in faeces of birds (Vanrompay et al 1993)		
Clostridium botulinum	Common in soil although prevalence varies (Gessler and Bohnel 2006)		
Clostridium perfringens	Common in soil (Singleton and Sainsbury 2001) and domestic animal faeces (Sinha et al 1975)		
Clostridium tetani	Common in soil (Singleton and Sainsbury 2001)		
Clostridium other spp.	Common in soil (Singleton and Sainsbury 2001) *C. difficile* in dog & cat faeces (Marks et al 2002, Weber et al 1989). Clostridia isolated from Green Waste windrows (Health and Saftey Executive 2005)		
Corynebacterium diptheriae	No reference on WoS to *C. diptheriae* and soil/plants/faeces	Unlikely to enter Green Waste	
Corynebacterium psuedotuberculosis	Can be present in/survive environmental matrices after contamination from infected animals (sheep, goats, horses,		Uncertain – probably low prevalence

Biological	Source/Reservoir (of relevance to green waste)	Unlikely to enter Green Waste	Unknown likelihood of entry into Green Waste
	others) (Yeruham et al 2003, Augustine 1986, Fontaine and Baird 2008) but not clear how prevalent it is.		
Coxiella burnetii	Primary reservoir goats, cattle, sheep (DEFRA unkown). Also cats (Pinsky et al 1991), wild rabbits (Marrie et al 1986), manure brought into urban environment from farms (Salmon et al 1982)		Uncertain – unlikely to be present in plant or soil material or faeces as an organism present in reproductive fluid or raw milk, yet farm manure in urban garden implicated in a case.
Enterobacter aerogenes (cloacae)	Ubiquitous in environment (soil and on plants) (Hoffman and Roggenkamp 2003) Isolated from Green Waste compost (Brown et al 2000).		
Enterobacter other spp.	Common in soil and on plants (Singleton and Sainsbury 2001).		
Enterococcus spp.	Ubiquitous in nature (Shimoji 2000, Singleton and Sainsbury 2001)		
Erysipelothrix	Isolated from green waste compost (Brown et al 2000)		
Escherichia coli	Isolated from green waste windrows (Brown et al 2000). Present in animal and bird faeces + frequently isolated from soil (Singleton and Sainsbury 2001)		
Escherichia coli verocytotoxigenic strains	Cattle are main reservoir but isolated from wide range wild and domestic animal & bird faeces, soil etc. (Jones 1999)		
Chryseobacterium (Flavobacterium) meningosepticum	No relevant citations for this organism in comjuctions with compost, plants, soil or faces on WoS. Nosocomial infections. Not common in healthy people outside hospital infections (Lu et al 2004).	Unlikely to enter Green Waste	
Fluoribacteria bozemonae	See *Legionella* other species		
Francisella tularensis	May survive in environmental matrices but unknown – essentially tick-borne (Steele et al 1990)		Uncertain
Fusobacterium necrophorum	Livestock/wild animal faeces	Unlikely to enter Green Waste as not commonly	

Biological	Source/Reservoir (of relevance to green waste)	Unlikely to enter Green Waste	Unknown likelihood of entry into Green Waste
	(Smith and Thornton 1993). Primarily present in throat of humans/animals but implicated in livestock footrot via contact with shed faces – but thought not commonly shed in faces (Nagaraja et al 2005)	shed in faeces.	
Helicobacter pylori	Isolated from cat faeces (Fox et al 1996) No clear non-human reservoirs, but some evidence it can be isolated from environment (Sasaki et al 1999). No references to isolation from soil or compost in WoS.		Uncertain
Klebsiella spp.	Common in soil and associated with plants (Dong et al 2003, Chelius and Triplett 2000, Brassard et al 1999; Singleton and Sainsbury 2001)		
Legionella pneumophila	Principle reservoir is small wild mammals but isolated from soil, dust water, potting mixes (Dworkin et al 2007a, Wallis and Robinson 2005)		
Legionella other spp.	Livestock/wild animal faeces (Dworkin 2007b) soil, potting mixes (Steele et al 1990)		
Leptospira (added to list from another source)	Rat urine (Health & Safety Executive 2005)		
Listeria ivanovii	Human and animal faeces, soil, dust, air water, grain, fruit, vegetables (Dworkin 2007b, Holt 1994, Moshtaghi et al 2003).		
Listeria monocytogenes	Widely distributed in environment (Holt 1994) manure, plants, soil (Dowe et al 1997, Weis and Seeliger 1975)		
Morganella morganii	Present in environment (O'Hara et al 2000). Can be present in cattle species and survive in soil (Britova 1985).		
Mycobacterium spp	Removed.		
Mycoplasma caviae		Pet bedding should not enter Green Waste	
Mycoplasma other spp.	Primarily plant pathogens		

Biological	Source/Reservoir (of relevance to green waste)	Unlikely to enter Green Waste	Unknown likelihood of entry into Green Waste
Neisseria gonorrhoeae	No relevant refs on WoS	Unlikely to enter Green Waste	
Neisseria meningitidis	No relevant refs on WoS	Unlikely to enter Green Waste	
Nocardia asteroides	Present in soil, (Yamamura 2003, Singleton and Sainsbury 2001)		
Nocardia brasiliensis	Present in soil (Singleton and Sainsbury 2001)		
Nocardia farcinica	Present in soil (Singleton and Sainsbury 2001)		
Nocardia nova	Present in soil (Singleton and Sainsbury 2001)		
Nocardia otitidiscaviarum	Present in soil (Singleton and Sainsbury 2001)		
Pasteurella multocida	Obligate cellular parasite. No clear evidence of survival or reservoir in soils etc. (Blanchong et al 2006, Backstrand and Botzier 1986. Hundt and Ruffolo 2005)	Unlikely to enter Green Waste	Uncertain
Pasteurella other spp.	No clear evidence for prevalence in soil		Uncertain
Peptostreptococcus anaerobius	No references associated with soil, plants, compost etc.		Uncertain
Peptostreptococcus other spp.	No clear evidence of presence or prevalence in relevant matrices		
Plesiomonas shigelloides	May be prevalent in soils (Abbey et al 1993) but primarily isolated from aquatic env. In subtropical and tropical areas (Pilar and Rodriguez De Garcia 1997)	Unlikely to enter Green Waste	
Prevotella spp.	Common in ruminant gut and therefore faeces e.g. (Fogarty and Voytek 2005) but others are mammalian sources (Ueki et al 2007) main pathogenic species appear to be those carried in human oral tract etc.		Uncertain
Proteus mirabilis & other spp.	Widely distributed in environment (O'Hara et al 2000), proposed as an indicator		

Biological	Source/Reservoir (of relevance to green waste)	Unlikely to enter Green Waste	Unknown likelihood of entry into Green Waste
	organism in composting process (Gaby et al 1970)		
Providencia spp.	Ubiquitous in environment (O'Hara et al 2000); survives in soil (Dhiaf and Bakhrouf 2008)		
Pseudomonas aeruginosa *Pseudomonas mallei* *Pseudomonas pseudomallei*	Pseudomonads common in soil and on plants (Singleton and Sainsbury 2001; Hirano and Upper 2000) and present in composted fruit, vegetables and garden waste (Termorshuizen et al 2003)		
Rhodococcus equi	Present in soil from equine stud farms (Cohen et al 2008) but thought likely to be a soil rather than GI tract organism (Barton and Hughers 1982)		
Salmonella sp.	Present in animal and bird faeces (Singleton and Sainsbury 2001) & isolated from Green Waste compost (Brown et al 2000)		Uncertain
Serpulina spp.	Intestinal bacterium isolated from dogs & birds (inc water birds) (& livestock) (Oxberry et al 1998). Limited literature.		
Shewanella putrefaciens	Wide distribution inc. soil (Bulut et al 2004 Singleton and Sainsbury 2001)		
Shigella spp.	Little evidence for presence in soil, primarily human-human. Carried by primates (ESR Ltd 2001)	Unlikely to enter Green Waste	
Staphylococcus aureus	Primarily a skin commensal/pathogen (Singleton and Sainsbury 2001). Little evidence for a soil reservoir in literature although believed able to survive in soil (Papaconstantinou et al 1979).		Uncertain
Streptobacillus moniliformis	N/A – from bites/bedding small animals No evidence on WoS searches for this bacterium in soil	Pet bedding should not enter Green Waste	
Streptococcus pneumoniae	Little evidence on WoS searches for this bacterium in soil – only ref was (Papaconstantinou et al 1979)	Unlikely to enter Green Waste as primarily respiratory pathogen	

Biological	Source/Reservoir (of relevance to green waste)	Unlikely to enter Green Waste	Unknown likelihood of entry into Green Waste
Streptococcus pyogenes	No evidence on WoS searches for this bacterium in soil		Uncertain
Streptococcus suis	Can be found in domestic animal faeces, wild/domestic birds or soil.	Unlikely to enter Green Waste as associated with pig tonsils (111).	
Streptococcus other spp.	Indicators of faecal contamination(Singleton and Sainsbury 2001; Papaconstantinou et al 1979, Sasaki et al 2004, rinkinen et al 2004, Vancannyet et al 2004, Herdt et al 1994)		
Vibrio cholerae	Primarily aquatic environments (Colwell and Spire 1992) One ref found indicates good survival in soil (Khan 1990)		Uncertain – non-aquatic prevalence unclear
Vibrio spp.	Little info on other vibrios in relevant matrices on WoS – isolated from aquatic birds in Japan & US (Miyasaka et al 2006, Buck1990)		Uncertain – may enter if aquatic birds locally but prevalence unclear
Yersinia enterocolitica	Can be present in soil and dog faeces (Botzler et al 2008, Nastasi et al 1986, Jentzen and Hellmann 1980))		
Yersinia pestis	Can be present in soil (Eisen et al 2008)		Uncertain
Yersinia pseudotuberculosis / other spp.	No reference to other Yersinia spp. In relevant matrices on WoS.		
Fungi:			
Aspergillus fumigatus	Commonly isolated from composts including leaf/grass composting facilities (Browne et al 2001, Fischer et al 1999, oliver 1994)		
Aspergillus niger	Likely to be present in composts as associated with rotting vegetation (Ozer & Koycu 2006)		
Cladophialophora bantiana (*Cladosporium bantianum*)	Ubiquitous worldwide in soil and plant debris (Werlinger & Moore 2005).		
Coccidioides immitis	Isolated from subtropical /arid soils (Greene et al 2000, Anon 2004; Bowman et al 1992)	Unlikely to enter UK Green Waste as subtropical/arid areas	

Biological	Source/Reservoir (of relevance to green waste)	Unlikely to enter Green Waste	Unknown likelihood of entry into Green Waste
Cryptococcus neoformans	Isolated from soil, plants and bird/animal faeces (bohlm et al 1970, Emmons 1951, Jesenska 1995).		
Emmonsia parva var *parva*	Primarily found in rodents but has been isolated from soil (Peterson & Sigler 1998).		
Epidermopyton floccosum	Present in soils (Sberna et al 1993) (atheletes foot)		
Fonsecaea compacta	Soil fungus (little in literature) (University of Adelaide, unknown)		
Fonsecaera pedrosoi	Soil/decomposing forest vegetation (little in literature) (University of Adelaide, unknown)		
Histoplasma capsulatum	Thought to be worldwide, assoc'd with bird and bat excrement (Bowman et al 1992) but Isolated from soil in areas where it is endemic (Spitzer 1989).		
Histoplasma var *duboisii*	Isolated from soil (Fadulu et al 1969)		
Histoplasma var *farcinimosum*	No refs associated with relevent matrices on WoS.		Uncertain
Microsporium spp.	Soils, birds nests (Singleton and Sainsbury 2001)		
Neotestudina rosatii	Tropical/temperate soils (Sivanesan 1998)		
Paracocidiodes brasiliensis	Isolated from soils in S. America (Tercarioli et al 2007)	Unlikely to enter UK Green Waste as only isolated in S. America	
Penicillium marneffei	Geographically restricted to S.E. Asia (Dend et al 1988).	Unlikely to enter UK Green Waste as only isolated f ro soils in SE Asia	
Scedosporium apiospermum	Has been isolated from soil (Williamson et al 2001) but natural habitat unknown (Guarro et al 2006).		Unclear whether this MO is prevalent in UK soils
Sporothrix schenkii	Ubiquitous in soil (Pang et al 2004).		
	Ubiquitous in soil (Bowman et		

Biological	Source/Reservoir (of relevance to green waste)	Unlikely to enter Green Waste	Unknown likelihood of entry into Green Waste
Trichophyton rubrum	al 1992)		
Trichophyton other spp.	Soils, birds' nests (Singleton and Sainsbury 2001)		
Stachybotrys atra (from additional source)	Saprophyte on decaying vegetation (Sorenson et al 1987)		
Memnoniella echinata (from additional source)	Isolated in compost (ryckeboer et al 2003, Tuomela et al 2000) MMWR for a case		
Protozoa *Cryptosporidium*	Principle reservoir is sheep/cattle but common in domestic pets too (Thompson et al 2008)		
Giardia	Principle reservoir is sheep/cattle but common in domestic pets too (Thompson et al 2008)		
Toxoplasma gondii (added from another source)	Domestic animals (cats), birds (DEFRA unknown)		

Filter 2: Is there a pathway?
Potentially serious effect (animal/human/environment)
AND is hazard likely to evade destruction if contamination not contained during composting process?

Agent	Uncertain	Likely to evade destruction	Likely to be destroyed/ negated
These organisms are either likely to enter Green Waste due to their uniquity in relevant matrices (soil, plant material, domestic pet or wildlife faeces) or have been isolated from these matrices and therefore are likely to enter green waste at least occasionally	(livestock disease resulting from pathway / agent not fully understood)	(normal best practice/agricultural measures or nature will not destroy or negate agents) These organisms are spore formers or have particularly resistant characteristics	(normal best practice/agricultural measures or nature should destroy or negate agents)
Bacteria: *Alcaligenes* spp.			No growth over 60°C (optimum temperature 20-37°C) therefore likely to be destroyed/reduced by composting temperatures (Holt 1994). A. eutrophicus completely destroyed above 55°C (destroyed after only 2 mins at 60°C) – (Rocher et al 1999)
Bacillus anthracis		Spore former (potential to evade inactivation)	
Bacillus cereus		Spore former (potential to evade inactivation) Spore former, great longevity in soil etc. Survive pasteurisation 80°C 10 min. 60°C for 60 min may induce spore germination to a heat – sensitive cells (Dworkin et al 2007a)	
Bacteroides fragilis	x		
Bacteroides other spp.	x		
Burkholderia cepacia	x		
Campylobacter fetus			See *C. jejuni*
Campylobacter jejuni			*Campylobacter jejuni* is destoyed in milk by pasteurization e.g. D values 48°C 7.2-12.8 mins; 55°C <1min; mean approx. 6 mins @ 50 °C; <1min 60°C. (Jacobs-Reitsma 2000) and is heat sensitive, therefore should be eliminated during composting*
Camylobacter other spp.			See *C. jejuni*

Agent	Uncertain	Likely to evade destruction	Likely to be destroyed/ negated
Chlamydophila abortus (*Chlamydia psittaci*)	x		
Chlamydia trachomatis	x		
Clostridium botulinum		Spore former (potential to evade inactivation) Can survive 100°C 2h (Wichuk & McCartney 2007)	
Clostridium perfringens		Spore former (potential to evade inactivation) Can survive 100°C 2h (Wichuk & McCartney 2007) Approx. 0.5-log increase in GW composting windrow (Brown et al 2000).	
Clostridium tetani		Spore former (Singleton & Sainsbury 2001) - potential to evade inactivation	
Clostridium other spp.		Spore former (Singleton & Sainsbury 2001) - potential to evade inactivation	
Enterobacter aerogenes (*cloacae*)	x		
Enterobacter other spp.	x		
Enterococcus spp.		Still detectable in some locations of a windrow after 55°C for an extended period.	Destruction at 55°C for 34h in-vessel
Erysipelothrix	x		
Escherichia coli			Likely to grow then die off to some degree at high temps. Approx overall 1-log decrease over 8 weeks (Brown et al 2000) Destroyed between 45 and 55°C (Wichuk & McCartney 2007)
Escherichia coli verocytoxigenic strains			Likely to follow similar pattern to E. coli although may be slightly more resistant. Complete kill was acheived at 60°C for ten mins in abattoir wastes (Avery et al., unplublished data) Destroyed between 45 and 55°C (Wichuk & McCartney 2007)
Klebsiella spp.	x		
Legionella pneumophila			Composting at 43°C or greater should destroy *Legionella* (Wichuk & McCartney 2007)
Legionella other spp.			See above

Agent	Uncertain	Likely to evade destruction	Likely to be destroyed/ negated
Leptospira	x		
Listeia ivanovi	x		
Listeria monocytogenes			Destroyed by pasteurisation therefore can be expected to die off during composting.
Morganella morganii	x		
Mycobacterium spp			Destruction within 10 days in a windrow mean temperature min 60°C (Wichuk & McCartney 2007)
Nocardia asteroides	x		
Nocardia brasiliensis	x		
Nocardia farcinica	x		
Nocardia nova	x		
Nocardia otitidiscaviarum	x		
Proteus mirabilis & other spp.	x		
Providencia spp.	x		
Pseudomonas aeruginosa	x		
Pseudomonas mallei	x		
Pseudomonas pseudomallei Rhodococcus equi	x		
Salmonella sp.			Likely to grow then die off to some degree at high temps
Shewanella putrefaciens	x		
Streptococcus other spp.			1.5-2=-log decrease in faecal Streptococci over 8 weeks in GW. No growth (Brown et al 2000).
Yersinia enterocolitica			Destroyed by pasteurization therefore can be expected to die-off during composting.
Yersinia pestis	x		
Fungi			
Aspergillus fumigatus	x		
Aspergillus niger	x		
Cladophialophora bantiana (*Cladosporium bantianum*)	x		
Cryptococcus neoformans	x		
Emmonsia parva var *parva*	x		
Epidermopyton floccosum	x		
Fonsecaea compacta	x		
Fonsecaera pedrosoi	x		
Histoplasma capsulatum	x		
Microsporium spp.	x		
Neotestudina rosatii	x		
Sporothrix schenkii	x		
Trichophyton rubrum	x		
Trichophyton other spp.	x		
Stachybotrys atra	x		

Agent	Uncertain	Likely to evade destruction	Likely to be destroyed/ negated
Memnoniella echinata	x		
Protozoa			
Cryptosporidium			Likely to be destroyed – shown to be destroyed over 7 weeks in (Brown et al 2000) .Inactivated in 12-26 days at a temperature of 55°C (Wichuk & McCartney 2007)
Giardia			Inactivated in12-26 days at a temperature of 55°C (Wichuk & McCartney 2007).
Toxoplasma gondii	X		

*NB – Campylobacter is one of the key pathogens associated with bird faeces, therefore re-entry of the organism via birds later during the composting process may lead to viable counts being detected.

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Appendix B4ii

Pathogen numbers in soils

Pathogen	Source	CFU/MPN/g	Reference
C. botulinum	Misc. soil Former cattle ground Swedish coast soil Swedish Misc. soil Norway shores soil Norway coast soil Denmark Misc soil Iceland soil Faroe Islands soil	0.002 0.0066 0.410 0.03 0.007 0.071 0.015 0.003 <0.003	Dodds, K.L. (1993)
C. perfringens	Clay loam (uncultivated field) Black loam (creek bank) Sandy garden loam Clayey garden loam Sandy soil and decaying vegetation Soil underlying turf	1090 56700 1730 110 1530 1150 1200	DeSpain Smith, L. and Gardner, M.V. (1949)
E. coli	Garden compost Garden soil Moorland soil	<1 0.5 <1	Evison and James (1973). Van Donsel et al (1967).
Coliforms	Garden compost Garden soil Moorland soil	90 42 <1	Evison and James (1973).
Faecal streptococci	Garden compost Garden soil Moorland soil	14 23 <1	Evison and James (1973). Van Donsel et al (1967)

Longevity of pathogens in soils

Pathogen	Source	CFU/MPN/g	Reference
E. coli	Soil (summer) Soil (autumn)	T_{90} 3.3 days T_{90} 13.4 days	Van Donsel et al (1967).
E. coli O157:H7	Soil (cold 4-6°C) Soil (warm 20-30°C)	99 days 56 days	Bolton et al (1999) Mubiru et al (2000)
Faecal streptococci	Soil (summer) Soil (winter)	T_{90} 2.7 days T_{90} 20.1 days	
Salmonella spp.	Pasture soil Garden soil Moist soil Sand loam and clay (0.6°C) Sand loam and clay (3.2°C) Sand loam and clay (14°C) Sand (8°C) Sand (20°C) Garden soil (8°C) Garden soil (20°C)	120 days 280 days T_{99} 45 days 46.8 days 32 days 3.3 days 131 days 102 days 96 days 54 days	Morse and Duncan (1974). Guo et al (2002) Platz (1980) Tamasi (1981)

Yersinia enterocolitica	Soil (20-30°C)	10 days	Chao et al (1988)
Campylobacter	Soil (cold 4-6°C) Soil (warm 20-30°C)	20 days 10 days	Guan and Holley (2003); references therein.
Giardia	Soil (frozen -4°C) Soil (cold 4-6°C) Soil (warm 20-30°C)	<7 days 49 days 7 days	Guan and Holley (2003); references therein.
Cryptosporidium	Soil (frozen -4°C) Soil (cold 4-6°C) Soil (warm 20-30°C)	>54 days 56 days 28 days	Guan and Holley (2003); references therein.

Longevity of pathogens in wastes

Pathogen	Matrix/conditions	Measure of survival	Reference
E. coli O157	Bovine faeces 37°C Bovine faeces 22°C Bovine faeces 5°C	42-49 days 49-56 days 63-70 days	Wang et al. (1996).
	Manure heaps: Bovine Aerated ovine Non-aerated ovine	 47 days 4 months 21 months	 Kudva et al (1998).
	Bovine Manure (4, 20 and 37°C) Bovine Slurry (fresh: 4, 20 and 37°C) Bovine Slurry (old: 4, 20 and 37°C)	DRT 3.6-21.6 DRT 3.2-21.5 DRT 2.3-38.8	Himathongkham et al. (1999).
	Cattle manure (20-30°C)		
S. typhimurium *Salmonella* spp.	Bovine Manure (4, 20 and 37°C) Bovine Slurry (fresh; 4, 20 and 37°C) Bovine Slurry (old: 4, 20 and 37°C)	DRT 1.7-24.7 DRT 2.4-16.4 DRT 2.52-65.8	Himathongkham et al. (1999).
	Avian faeces Bovine Manure	28 months 30months	Morse and Duncan (1974)
Campylobacter	Cattle manure (frozen -4°C or -20°C) Cattle manure slurry or liquid (4, 20 or 37°C)	3 days 3 days	Guan and Holley (2003); references therein.
Giardia	Cattle manure (cold 4-5°C) Cattle manure warm (20-37°C	7 days 7 days	Guan and Holley (2003); references therein.
Cryptosporidium	Cattle manure (cold 4-5°C) Cattle manure warm (20-37°C	56 days 28 days	Guan and Holley (2003); references therein.

Longevity of pathogens in soils amended with wastes

Pathogen	Matrix/conditions	Measure of survival	Reference
E. coli O157:H7	Manure-amended autoclaved soil: 5°C 15°C 21°C	 77 days >226 days 231 days	Jiang et al (2002).
Salmonella spp.	Cattle slurry application to land	300 days	Jones (1886)
	Sandy loam with liquid hog manure (summer; 5-30°C)	27 days	Cote and Quessy (2005)
	Loamy sand with liquid hog manure (summer; 5-30°C)	54 days	Nicholson et al (2005)
	Sandy loam/ clayey loam with cattle slurry (summer)	30 days	Gessel et al (2004)
	Fine loam with contaminated hog manure slurry (10-16°C)	7 days	Dazzo et al (1973)
	Fine sand only	DRT 2 days	Chandler and Craven (1981)
	Fine sand with dairy manure slurry	DRT 3.5-6 days	
	Sandy clay loam with hog manure	8 months	Baloda et al (2001)
	Agricultural soil with hog slurry (natural conditions)	14 days	Islam et al (2004)
	Agricultural soil with hog slurry (lab conditions)	299 days	
	Agricultural soil with cattle manure compost (natural conditions)	203-231 days	Hutchison et al (2004)
	Agricultural sand loam with hog slurry (average of summer and winter)	56 days	
	Agricultural sand loam with hog manure (average of summer and winter)	120 days	
	Clay with cattle manure (5°C)	63 days	Zibilske and Weaver (1978)
	Clay with cattle manure (22°C)	42 days	
	Clay with cattle manure (39°C)	3 days	
	Sandy loam with cattle manure(5°C)	42 days	
	Sandy loam with cattle manure(22°C)	42 days	
	Sandy loam with cattle manure(39°C)	21 days	
	Loamy sand	119 days $T_{99.9}$ 63 days	Natvig et al (2002)
	Sheep manure application (natural conditions; summer)	42 days	Tannock and Smith (1972)
L. monocytogenes	Sewage sludge cake mixed with agricultural soil	3-5 weeks	Al-Ghazali and Al-Azawi (1990)
*L. innocua**	Soil with composted bovine manure (lab;20°C)	Rate of decrease: -0.324 to -0.243 log/day	Girardin et al (2005).

*C. sporogenes**	Soil	16 months; Rate of decrease: -0.007 log/day	

* Pathogen surrogate utilised for field trials

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Appendix B5 Sift for principal agents – Invasive weeds and exotic species

- 1 Ragwort (*Senecio jacobaea*)
- 2 Japanese Knotweed (*Fallopia japonica*)
- 3 Giant Hogweed (*Heracleum mantegazzianum*)
- 4 Himalayan Balsam (*Impatiens glandulifera*)
- 5. Spear thistle (identified as injurous weed Weed Act 1959) (*Cirsium vulgare*)
- 6. Creeping (or field) thistle (identified as injurous weed Weed Act 1959) (*Cirsium arvense*)
- 7. Curled dock (*Rumex crispus*) identified as injurous weed Weed Act 1959)
- 8. Broad-leaved dock (*Rumex obtusifolius*) (identified as injurous weed Weed Act 1959)

Further analyses undertaken, considering whether propagules (seeds and other parts of plants necessary for their reproduction) are present in final compost product

Filter 1: Does hazard have potentially serious effect (animal/human/environment)?

Potential serious health effects	Some health effects	Little or no effects	Insufficient knowledge
1) Ragwort – poisonous to most vertebrates as contains pyrrolizidine alkaloids which produces toic products when broken down by the liver. Alkaloids do not accumulate within the body of an animal (excreted in 24-48 hours), but damage casued to the liver cells can, if sufficient ragwort is donsumed at each dose by cumulative to the point of death – 5-25% body weight for horses and cattle, 125% and 404% for goats (Stewart & Steenkamp 2001, Chojkier 2003) Goeger et al 1982)			
2.) Japanese knotweed – impacts on biodiversity, only supporting a narrow range of species, far less than native species (Compost association 2004), Bank erosion problems, lower quality riparian habitat for fish and wildlife			
3 Giant Hogweed Human health - plant exudes a clear watery sap which sensitizes the skin to ultraviolet radiation. This can result in severe burns to the affected areas resulting in severe blistering and painful dermatitis. These blisters can develop into purplish or blackened scars. Plants - Giant hogweed is also a host for both carrot fly and the disease *Sclerotinia sclerotiorum*, both of which attack many horticultural and arable crops. Animals - risk that the mouths and			

tongues of the grazing animals may be susceptible to painful blisters.			
4 Himalayan Balsam			
5. Spear thistle (identified as injurous weed Weed Act 1959)			
6. Creeping (or field)thistle (identified as injurous weed Weed Act 1959)			
7. Curled dock(identified as injurous weed Weed Act 1959) – likely pushes out native species once established – seeds and vegetation of docks can be toxic to animals (Royer and Dickinson 1999)			
8. Broad-leaved dock (*Rumex obtusifolius)* (identified as injurous weed Weed Act 1959)			

- Legally the majority of these weeds should not be collected/ sent to composting plants – the majority of councils will not take them.
- *The Weed Act 1959* makes it an offence to allow the spread of the noxious weeds considered. The supply of compost containing propagules from noxious weeds is likely to be viewed as an offence.
- *The Wildlife and Countryside Act 1981* made it illegal to permit the spread of Japanese Knotweed and Giant Hogweed. Any polluted soil or plant material that is discarded, intended to be discarded or is required to be discarded is classed as controlled waste and should be accompanied by appropriate Waste Transfer documentation
- The weed act applies to: 1) Common Radwort (*Senecio jacobaea*); 2) Spear Thistle (*Cirsium vulgare*); 3) Creeping or Field Thistle (*Cirisium arvense*); 4) Curled Dock (*Rumex crispus*); 5) Broad-leaved Dock (*Rumex obstusifolius*)

Filter 2: Is there a pathway?
Potentially serious effect (animal/human/environment)
AND is hazard likely to evade destruction if contamination not contained during composting process?

Outdoor-turned windrow

Agent	Uncertain	Likely to evade destruction	Likely to be destroyed/ negated
	(livestock disease resulting from pathway/agent not fully understood)	(normal best practice/agricultural measures or nature will not destroy or negate agents)	(normal best practice/agricultural measures or nature should destroy or negate agents)
1. Ragwort			Scottish Government allows composting of ragwort by sites achieve BS PAS 100:2005 (Scottish Government 2008) – similar defra guidance
2. Japanese Knotweed		Conditions required for Japanese Knotweed to regrow showed that under laboratory conditions, pieces of Japanese Knotweed rhizome (the crowns and	

Agent	Uncertain	Likely to evade destruction	Likely to be destroyed/ negated
		runners), did not regenerate if exposed to temperature of 55 °C or greater for one week or more (Ward 2003). Still a small risk (Ward 2003). This piece of research was done under controlled, static conditions in the laboratory. However, Sections of rhizome as small as 0.7 grams or smaller than a one pence piece, can grow into a new plant. Fragmenting the rhizome stimulates the production of small red buds, which grow into new plants. Due to Japanese Knotweed's re-growth potential it should be incinerated or sent to a landfill site licensed to accept it. Japanese Knotweed should not be composted. (The Composting Association 2004) Environment Agency (2003). Will survive composting	
3 Giant Hogweed (*Heracleum mantegazzianum*)			Environment Agency (2003) Allows onsite composting of spoil
4 Himalayan Balsam (*Impatiens glandulifera*)		Environment Agency (2003) Allows onsite composting of spoil unless seeds are present	
5. Spear thistle		Don't compost thistle seed heads – there's too much risk that they'll survive the composting process and return to plague your garden when you work the compost into your soil.	
6. Creeping (or field) thistle		Don't compost thistle seed heads – there's too much risk that they'll survive the composting process and return to plague your garden when you work the compost into your soil.	
7. Curled dock			Composting of farmyard manure- temperatures within the heap of 55^0C or higher have been shown to destroy the seeds of Rumex spp. (Dierauer & Stöppler-Zimmer, 1994) there are indications that not only higher temperatures during composting are responsible for decreased Rumex

Agent	Uncertain	Likely to evade destruction	Likely to be destroyed/ negated
			germination but also antagonistic non-thermophilic microorganisms during composting (J G Zaller, unpubl. obs.). Composting docks is a promising option that should be researched in more detail in the future. The results of treatment 3 indicate that this is a viable, effective and useful method. In personal past experience it has been found that docks well composted should contain no viable seed or root fragments. (Skinner 2005)
8. Broad-leaved dock (*Rumex obtusifolius)*			Seeds buried in cattle farmyard manure (maximum temp 63 degrees C) one month 28% germination 2 months 0% germination – no germination after 4 onths in vermicompost (max temp 35 degrees C) (Zaller, 2007) - composting of farmyard manure- temperatures within the heap of 55^0C or higher have been shown to destroy the seeds of Rumex spp. (Dierauer & Stöppler-Zimmer, 1994) there are indications that not only higher temperatures during composting are responsible for decreased Rumex germination but also antagonistic non-thermophilic microorganisms during composting (J G Zaller, unpubl. obs. cited in Zaller 2004).

In Vessel composting:

Agent	Uncertain	Likely to evade destruction	Likely to be destroyed/ negated
	(livestock disease resulting from pathway/agent not fully understood)	(normal best practice/agricultural measures or nature will not destroy or negate agents)	(normal best practice/agricultural measures or nature should destroy or negate agents)
1. Ragwort			SurreyCC - Composting can only be carried out using a fully contained system. This involves ragwort being composted in a container where draining liquid is contained, and where weather can't affect the process. The British Standards PAS 100:2005 specification for composted materials must be met. Trotting down ragwort is likely to be a more practical solution than composting is for horse-keepers. It involves using a standard composting bin with a lid to allow small quantities of ragwort to biodegrade. Adding grass cuttings on top of the fresh ragwort will help the decomposing process and some water may need to be added to keep the material moist. To help ensure ragwort seeds and roots are killed, the plants should be left for 12 months (with no new plant matter added) before the compost bin is emptied.
1. Japanese Knotweed			Conditions required for Japanese Knotweed to regrow showed that under laboratory conditions, pieces of Japanese Knotweed rhizome (the crowns and runners), did not regenerate if exposed to temperature of 55 °C or greater for one week or more (Ward 2003). This piece of research was done under controlled, static conditions in the laboratory. However, Sections of rhizome as small as 0.7 grams or smaller than a one pence piece, can grow into a new plant! Fragmenting the rhizome stimulates the production of small red buds, which grow into new plants.

Agent	Uncertain	Likely to evade destruction	Likely to be destroyed/ negated
			Due to Japanese Knotweed's re-growth potential it should be incinerated or sent to a landfill site licensed to accept it. Japanese Knotweed should not be composted. (The Composting Association 2004)
3 Giant Hogweed (*Heracleum mantegazzianum*)			Environment Agency (2003) Allows onsite composting of spoil
4 Himalayan Balsam (*Impatiens glandulifera*)		Environment Agency (2003) Allows onsite composting of spoil unless seeds are present	
5. Spear thistle		Don't compost thistle seed heads – there's too much risk that they'll survive the composting process and return to plague your garden when you work the compost into your soil.	
6. Creeping (or field) thistle		Don't compost thistle seed heads – there's too much risk that they'll survive the composting process and return to plague your garden when you work the compost into your soil.	
7. Curled dock			Composting of farmyard manure- temperatures within the heap of 55^0C or higher have been shown to destroy the seeds of Rumex spp. (Dierauer & Stöppler-Zimmer, 1994) there are indications that not only higher temperatures during composting are responsible for decreased Rumex germination but also antagonistic non-thermophilic microorganisms during composting (J G Zaller, unpubl. obs. cited in Zaller 2004).
8. Broad-leaved dock (*Rumex obtusifolius)*			Seeds buried in cattle farmyard manure (maximum temp 63 degrees C) one month 28% germination 2 months 0% germination – no germination after 4 onths in vermicompost (max tmep 35 degrees C) (Zaller, 2007) - composting of farmyard manure- temperatures within the heap of 55^0C or higher have been shown to destroy the seeds of Rumex spp.

Agent	Uncertain	Likely to evade destruction	Likely to be destroyed/ negated
			(Dierauer & Stöppler-Zimmer, 1994) there are indications that not only higher temperatures during composting are responsible for decreased Rumex germination but also antagonistic non-thermophilic microorganisms during composting (J G Zaller, unpubl. Obs. cited in Zaller 2004).

Filter 3: Is exposure likely As above AND is final exposure quantity of concern?

No agents carried forward to this filter as only considering environmental risk, toxicity considered under plant toxins.

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Appendix B6 Sift for principal agents –Physical contaminants

- 1. Glass
- 2. Metal
- 3. Plastic
- 4. Rubber
- 5. Insufficiently biodegraded cardboard
- 6. Masonry
- 7. Concrete
- 8. Tile
- 9. Carpet
- 10. Textiles
- 11. Fragments of PET
- 12. Polyester
- 13. Polystyrene Foam
- 14. Twine
- 15. Foil
- 16. PVC

(Dimambro et al 2007, Barth 2005, The Composting Association, 2005, Bexley Council & Enviros Consulting 2004 MEL Research 2000, unknown 2000)

Filter 1: Does hazard have potentially serious effect (animal/human/environment)?

Potential serious health effects	**Some health effects**	**Little or no effect**	**Insufficient knowledge**
(including moderate or serious illness, death)	(potential to cause mild to moderate illness)	(little or no chance of becoming ill)	
1. Glass Can be swallowed cutting mouths and intestines of animals or birds leading to injury or death. May also cut human hands when handling the compost (Watson 2003) or the feet of animals		13. Polystyrene Foam Believed to simply pass through wildlife when ingested (Eckhardt 1998)	
2. Metal Can be swallowed cutting mouths and intestines of animals or birds leading to injury or death. May also cut human hands when handling the compost or the feet of animals			
3. Plastic Potential to be swallowed and lead to choking or intestinal problems resulting in death. (EPA 1990). Accumulations of film plastics in the cultivated layer of the soil can become a moisture barrier and can wrap in tillage implements (Watson 2003).			
4. Rubber			

Potential serious health effects	Some health effects	Little or no effect	Insufficient knowledge
Potential to be swallowed and lead to choking or intestinal problems resulting in death. (Lucadou-Wells 2008)			
5. Insufficiently biodegraded cardboard Potential to be swallowed and lead to choking or intestinal problems resulting in death.			
6. Masonry (<5mm once processed) Potential to be swallowed and lead to chocking or intestinal problems resulting in death.			
7.Concrete Potential to be swallowed and lead to choking or intestinal problems resulting in death.			
8. Tile (<5mm once processed) Potential to be swallowed and lead to chocking or intestinal problems resulting in death.			
9. Carpet Potential to be swallowed and lead to chocking or intestinal problems resulting in death.			
10. Textiles Potential to be swallowed and lead to choking or intestinal problems resulting in death.			
11. Fragments of PET Potential to be swallowed and lead to choking or intestinal problems resulting in death.			
12. Polyester Potential to be swallowed and lead to choking or intestinal problems resulting in death. (EPA 1990)			
14. Twine Long pieces of twine eaten by animals may cause intestinal problems resulting in death. Maybe used as a nesting material and the parent birds or nestlings may become entagled (Gibons Wildlife (http://www.gibsonswildlifere habcentre.org/wildinfo.html))	.		
15. Foil Potential to be swallowed and lead to choking or intestinal problems resulting in death.			
16. PVC Potential to be swallowed and lead to choking or intestinal			

Potential serious health effects	Some health effects	Little or no effect	Insufficient knowledge
problems resulting in death. (EPA 1990)			

No direct literature was found relating to the adverse impact of physical contaminants in compost adversely impacting the livestock, humans or the environment. References were taken from wildlife and rubbish literature and logical extrapolation of the information available to similar substances.

Filter 2: Is there a pathway? Potentially serious effect (animal/human/environment) AND is hazard likely to evade destruction if contamination not contained during composting process?

Outdoor-turned windrow:

Agent	Uncertain	Likely to evade destruction	Likely to be destroyed/ negated
	(livestock disease resulting from pathway/agent not fully understood)	(normal best practice/agricultural measures or nature will not destroy or negate agents)	(normal best practice/agricultural measures or nature should destroy or negate agents)
			1. Glass (<2mm once processed)
			2. Metal (<2mm once processed)
			3. plastic (<2mm once processed)
			4. Rubber (<2mm once processed)
			5. Insufficiently biodegraded cardboard (<2mm once processed)
			6. Masonry (<5mm once processed)
			7.Concrete (<5mm once processed)
			8. Tile (<5mm once processed)
			9. Carpet
			10. Textiles
			11. Fragments of PET
			12. Polyester
			14. Twine
			15. Foil
			16. PVC
Physical contaminants liable to be reduced to minimal levels during screening process required to achieve PAS 100:2011			

In-vessel composting:

Agent	Uncertain	Likely to evade destruction	Likely to be destroyed/ negated
	(livestock disease resulting from pathway/agent not fully understood)	(normal best practice/agricultural measures or nature will not destroy or negate agents)	(normal best practice/agricultural measures or nature should destroy or negate agents)
			1. Glass (<2mm once processed)
			2. Metal (<2mm once processed)
			3. plastic (<2mm once processed)
			4. Rubber (<2mm once processed)
			5. Insufficiently biodegraded cardboard (<2mm once processed)
			6. Masonry (<5mm once processed)
			7.Concrete (<5mm once processed)
			8. Tile (<5mm once processed)
			9. Carpet
			10. Textiles
			11. Fragments of PET
			12. Polyester
			14. Twine
			15. Foil
			16. PVC
Physical contaminants liable to be reduced to minimal levels during screening process required to achieve PAS 100:2011			

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Appendix B7 Sift for principal agents – Environmental Hazards

- BOD
- COD
- Phosphate
- Nitrogen (Nitrate, Ammonia)
- pH
- Alkalinity
- Salts

Filter 1: Does hazard have potentially serious effect (animal/human/environment)?

<table>
<tr><th>Potential serious health effects</th><th>Some health effects</th><th>Little or no effects</th><th>Insuff. knowledge</th></tr>
<tr><td>(including moderate or serious illness, death)</td><td>(potential to cause mild to moderate illness)</td><td>(little or no chance of becoming ill)</td><td></td></tr>
<tr><td>1and 2) BOD and COD
Runoff and leaching or direct entry to surface water leads to oxygen depletion in water courses leading to death of fish, other animals and plants and environmental degradation (Moss 1998)</td><td rowspan="2">5) pH
Some plants are sensitive to pH (Rengel 2002)
ph can influence the mobility and toxicity of other substances such as heavy metals. (WRc 2000),
pH influences the availability of nutrients to plants (Saebo & Ferrini 2006, Tester 1990, Tisdale et al 1985)</td><td>6) alkalinity
Increases toxicity and impact of other components of compost (Saebo & Ferrini 2006)</td><td></td></tr>
<tr><td>3) Phosphate
Human - Severe phosphate toxicity can result in hypocalcemia, and in various symptoms resulting from low plasma calcium levels. Moderate phosphate toxicity, occurring over a period of months, can result in the deposit of calcium phosphate crystals in various tissues of the body (Domico et al 2006)
Plants - The result of phosphate over-fertilizing is leaf chlorosis. Phosphorus is known to compete with iron and manganese uptake by roots, and deficiencies of these two metal micronutrients causes interveinal yellowing. In urban landscapes many plants are believed to be suffering indirect iron (or manganese) deficiency from over application of phosphorus. Moreover, it has been experimentally demonstrated that high levels of phosphorus are detrimental to mycorrhizal health and lower the rate of</td><td></td><td></td></tr>
</table>

Potential serious health effects	Some health effects	Little or no effects	Insuff. knowledge
mycorrhizal infection of root systems (Chalker-Scott, unknown, Aitken et al 1992). **Environment -** phosphate will induce algal blooms (eutrophication). Such blooms are followed by increased bacterial activity, resulting in lowered oxygen levels and the eventual death of fish and other animals (Moss 1998).			
4) Nitrogen (Nitrate, Ammonia) **Livestock -** The level of nitrate that causes toxicity in ruminants varies depending on rate of intake, diet, acclimation to nitrate and nutritional status. As a rule, forage containing less than 5,000 ppm NO_3 on a dry matter basis is safe. Forage containing 5,000 to 10,000 ppm NO_3 is considered potentially toxic when provided as the only feed. Forage containing over 10,000 ppm NO_3 is considered dangerous but often can be fed safely after proper dilution with other feeds. (Stanton & Whittier 2006) **Humans** - Nitrate, is rapidly converted to nitrite by the naturally occurring bacteria residing on the tongue, as well as in the intestines, and then absorbed into the bloodstream. The amount of nitrate that is supplied by leafy vegetables and in drinking water is generally about 100-170 mg/day. The amount of nitrite supplied by a typical diet is much less, that is, than 0.1 mg nitrite/day. Poisoning by nitrite, or nitrate after its conversion to nitrite, results in the inability of hemoglobin to carry oxygen throughout the body. This condition can be seen by the blue color of the skin. Adverse symptoms occur when over 30% of the hemoglobin has been			

Potential serious health effects	Some health effects	Little or no effects	Insuff. knowledge
converted to methemoglobin, and these symptoms include cardiac arrhythmias, headache, nausea and vomiting, and in severe cases, seizures. The Environmental Protection Agency (EPA) has set the Maximum Contaminant Level (MCL) of nitrate as nitrogen (NO3-N) at 10 mg/L (or 10 parts per million) for the safety of drinking water. Nitrate levels at or above this level have been known to cause a potentially fatal blood disorder in infants under six months of age called methemoglobinemia or "blue-baby" syndrome **Environment** – Eutrophication (Moss 1989)			
7) Salt Plants High concentrations of soluble salts are detrimental to germinating seeds and to plant growth. High concentrations can result in plant death (Watson 2003) Humans and animals Sodium salt Oral toxicity (The Registry of Toxic Effects of Chemical Substances, 1986): Human; TDLo: 12,357 mg/kg/23 D-C Mouse; LD50: 4,000 mg/kg Rat; LD50: 3,000 mg/kg Rabbit; LDLo: 8,000 mg/kg Acute aquatic toxicity (U.S. EPA 1988): *Rana breviceps* (frog); No observed effect concentration (NOEC): 400 mg/L. *Daphnia pulex* 48-hour LC50 or EC50: 1,470 mg/L *Daphnia magna* (water flea); 48 hour EC50: 3,310 mg/L *Myriophyllum spicatum* (water milfoil); Phytotoxicity (EC50 for growth): 5,962 mg/L *Pimephales promealas* (fathead minnow); 69-hour LC50: 7,650 mg/L *Lepomis macrochirus* (Bluegill) LC50 or EC50:			

Potential serious health effects	Some health effects	Little or no effects	Insuff. knowledge
7,846 mg/L *Anguilla rostrata* (American eel) 48-hour LC50 or EC 50: 13,085 mg/L Pottassium salt Acute oral toxicity of KCl in mammals is low (LD50 = 3020 mg/kg bw). In humans, acute oral toxicity is rare because large single doses induce nausea and vomiting, and because KCl is rapidly excreted in the absence of any pre-existing kidney damage. Short-term acute toxicity tests with fish, daphnia and algae : *Ictalurus punctulus* 48h-LC50 = 720 mg/l; *Ceriodaphnia dubia*: 48h-LC50 = 630 mg/l; *Nitzschia linearis:* 120 h-EC50 = 1337 mg/l. All the studies compiled on the acute and chronic aquatic toxicity were => 100 mg/L, and KCl is considered not hazardous to freshwater organisms. (http://www.jetoc.or.jp/HP_SIDS/pdffiles/7447-40-7.pdf)			

Potential negative impacts derived from literature not directly relating to compost.

Filter 2: Is there a pathway?
Potentially serious effect (animal/human/environment)
AND is hazard likely to evade destruction if contamination not contained during composting process?

Outdoor-turned windrow:

Agent	Uncertain	Likely to evade destruction	Likely to be destroyed/ negated
	(livestock disease resulting from pathway/agent not fully understood)	(normal best practice/agricultural measures or nature will not destroy or negate agents)	(normal best practice/agricultural measures or nature should destroy or negate agents)
1) BOD/COD		Best practice storage and application should negate this agent. No evidence of adverse impact outside of composting plants (which can be negated by best practice) identified (Richards unknown, Williams 1991)	

Agent	Uncertain	Likely to evade destruction	Likely to be destroyed/ negated
2) Phosphate		Best practice storage and application should negate this agent. Potential risk to the water environment through accumulation of P in soil after repeated application.	
3) Nitrogen (Nitrate, Ammonia)		Best practice storage and application should negate this agent. Potential risk to the water environment through accumulation of N in soil and subsequent mineralization of originally unavailable N dependent on C:N ratio. (Richards unknown, Williams 1991)	
6) Salt		Best practice application should negate this agent Saebo & Ferrini 2006, Watson 2003)	

In Vessel composting:

Agent	Uncertain	Likely to evade destruction	Likely to be destroyed/ negated
	(livestock disease resulting from pathway/agent not fully understood)	(normal best practice/agricultural measures or nature will not destroy or negate agents)	(normal best practice/agricultural measures or nature should destroy or negate agents)
1) BOD/COD		Best practice storage and application should negate this agent. No evidence of adverse impact outside of composting plants (which can be negated by best practice) identified (Richards unknown, Williams 1991)	
2) Phosphate		Best practice storage and application should negate this agent. Potential risk to the water environment through accumulation of P in soil after repeated application.	
3) Nitrogen (Nitrate, Ammonia)		Best practice storage and application should negate this agent. Potential risk to the water environment through accumulation of N in soil and subsequent mineralization of originally unavailable N dependent on C:N ratio. (Richards unknown, Williams 1991)	

6) Salt		Best practice application should negate this agent Saebo & Ferrini 2006, Watson 2003)	

Filter 3: Is exposure likely
As above AND is final exposure quantity of concern?

Agriculture (grazing land):

Agent (refer to Filter 2)	Uncertain	YES	NO
	(livestock disease resulting from pathway/agent not fully understood)	(amount and/or timing of exposure to agent could potentially cause a problem)	(amount and/or timing of exposure to agent is unlikely to cause a problem)
1) BOD/COD			Best practice storage and application should negate this agent. No evidence of adverse impact outside of composting plants (which can be negated by best practice) identified (Richards unknown, Williams 1991)
2) Phosphate			Best practice storage and application should negate this agent. Potential risk to the water environment through accumulation of P in soil after repeated application.
3) Nitrogen (Nitrate, Ammonia)			Best practice storage and application should negate this agent. Potential risk to the water environment through accumulation of N in soil and subsequent mineralization of originally unavailable N dependent on C:N ratio. (Richards unknown, Williams 1991)
6) Salt			Best practice application should negate this agent Saebo & Ferrini 2006, Watson 2003)

Agriculture (land used to grow grain crops for fodder):

Agent (refer to Filter 2)	Uncertain	YES	NO
	(livestock disease resulting from pathway/agent not fully understood)	(amount and/or timing of exposure to agent could potentially cause a problem)	(amount and/or timing of exposure to agent is unlikely to cause a problem)
1) BOD/COD			Best practice storage and application should negate this agent. No evidence of adverse impact outside of composting plants (which can be negated by best practice) identified (Richards unknown, Williams 1991)
2) Phosphate			Best practice storage and application should negate this agent. Potential risk to the water environment through accumulation of P in soil after repeated application.
3) Nitrogen (Nitrate, Ammonia)			Best practice storage and application should negate this agent. Potential risk to the water environment through accumulation of N in soil and subsequent mineralization of originally unavailable N dependent on C:N ratio. (Richards unknown, Williams 1991)
6) Salt			Best practice application should negate this agent Saebo & Ferrini 2006, Watson 2003)

Agriculture (land used to grow root crops for fodder):

Agent (refer to Filter 2)	Uncertain	YES	NO
	(livestock disease resulting from pathway/agent not fully understood)	(amount and/or timing of exposure to agent could potentially cause a problem)	(amount and/or timing of exposure to agent is unlikely to cause a problem)
1) BOD/COD			Best practice storage and application should negate this agent. No evidence of adverse impact outside of composting plants (which can be negated by best practice) identified (Richards unknown, Williams 1991)
2) Phosphate			Best practice storage and application should negate this agent. Potential risk to the water environment through accumulation of P in soil after repeated application.
3) Nitrogen (Nitrate,			Best practice storage and

Ammonia)			application should negate this agent. Potential risk to the water environment through accumulation of N in soil and subsequent mineralization of originally unavailable N dependent on C:N ratio. (Richards unknown, Williams 1991)
6) Salt			Best practice application should negate this agent Saebo & Ferrini 2006, Watson 2003)

Agriculture (land used to grow leaf crops for fodder):

Agent (refer to Filter 2)	Uncertain	YES	NO
	(livestock disease resulting from pathway/agent not fully understood)	(amount and/or timing of exposure to agent could potentially cause a problem)	(amount and/or timing of exposure to agent is unlikely to cause a problem)
1) BOD/COD			Best practice storage and application should negate this agent. No evidence of adverse impact outside of composting plants (which can be negated by best practice) identified (Richards unknown, Williams 1991)
2) Phosphate			Best practice storage and application should negate this agent. Potential risk to the water environment through accumulation of P in soil after repeated application.
3) Nitrogen (Nitrate, Ammonia)			Best practice storage and application should negate this agent. Potential risk to the water environment through accumulation of N in soil and subsequent mineralization of originally unavailable N dependent on C:N ratio. (Richards unknown, Williams 1991)
6) Salt			Best practice application should negate this agent Saebo & Ferrini 2006, Watson 2003)

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Appendix C Consultation Record

Name	Date of contact	Response	Action
LanGuard Vegetation Management	Email 11/06/08		
Carolyn Hedley, Scottish Golf Environment Group	Email 11/06/08	Practices vary amongst green keepers from my observations, some compost, some dispose of there green waste in other ways. To get an idea of what is the most prevalent method in Scotland I would recommend you speak to someone at the Institute of Green keepers at BIGGA www.bigga.co.uk They should be able to help you. We do promote composting as good practice and I've attached our Waste Management Toolkit publication for your info.	BIGGA contacted
Jonathan Smith, Golf Environment Europe	Email 12/06/08	Past email to David Lawson, Sports Turf Research Institute - Firstly, wirh regard to composting on the golf course, there is a wide range of practices. Some greenkeepers may simply spread cuttings on to fairway areas or, in some cases dump the cuttings on a spare area of land. However, there is a resurgence in interest in composting on-site and a number of golf courses are establishing facilities for the composting of grass cuttings along with other waste organic materials. It is also worth noting that on most golf courses the cuttings from the fairways are not collected. Although it may occur in a few cases, the likelihood of grass cuttings from golf greens being collected and transported to municpal or private composting facilities is extremely small. There is actually a greater interest in buying in good quality green waste compost for application to the golf course. With regard to pesticide use, fungicides are the principal chemicals used, as broadleaved weeds are not generally a major problem. However, clopyralid does have approval for use on amenity turf. The principal fungicides used would be azoxytstrobin, chlorothalonil and iprodione.	David Lawson contacted
Phil Wallace, Enviro centre	Email 12/06/08	I am aware of your research as I am a Director of the Composting Association. Golf courses are very unlikely to send their grass clippings off site for composting. I would say that it would never happen. They may pile it up and 'compost' it themselves or just use it around trees as a mulch. You could ask David Lawson at STRI to confirm this.	David Lawson contacted
Dr Jon Pickering, Organic Resource Agency	email 12/06/08	I understand you contacted us regarding composting golf course grass clippings. I would suggest that both on and off site composting of golf course grass clippings occurs - When I worked as a grounds man on a golf course we composted them with other shredded green waste on site. However I am sure that where golf courses have very large arisings of green waste, or use external contractors for maintenance work grass clippings may be taken off site for composting. You might try contacting the institute of groundsmanship for more details of current practice. PS I would be very interested to hear of the results of the risk assessment you are undertaking - will it be published, and if so could I obtain a copy? Any details on this would be much appreciated.	Response to thank and offer to keep updated. Institute of Groundmanship contacted

Name	Date of contact	Response	Action
Josef Barth	Email 12/06/08	Philippa, I have no idea on the real situation on golf courses but in some Member states composting is subject to waste treatment licensing even in small quantities which might be too much efforts for the golf courses operators to do composting by their own. Normally they can afford to send it to a central composting plants. In addition they will not dare to produce compost which might include some weed seeds - e.g. because of insufficient composting - and spread it again on the golf ground. So I suppose - but can't verify - that most material goes to central cites. Grass from golf courses occur in green waste compost plants normally in a very low percentage, less than 1 percent I suppose. So even if there are some golf course pesticide residues I doubt that they can be analysed in the final product or cause any risk. Nevertheless I will ask some German and Dutch colleagues who compost several million tonnes annually if there is any research available.	
Florian Amlinger	Email 12/06/08		
Enzo Favoino	Email 12/06/08		
Organic Recycling	email 17/05/08		
Institute of groundmanship	email 17/06/08		
David Lawson, Sports Turf Research Institute	email 13/06/08	Thank you for your enquiry regarding composting on golf courses. Your enquiry to Jonathan Smith at Golf Environment Europe was also passed to us. Firstly, with regard to composting on the golf course, there is a wide range of practices. Some greenkeepers may simply spread cuttings on to fairway areas or, in some cases dump the cuttings on a spare area of land. However, there is a resurgence in interest in composting on-site and a number of golf courses are establishing facilities for the composting of grass cuttings along with other waste organic materials. It is also worth noting that on most golf courses the cuttings from the fairways are not collected. Although it may occur in a few cases, the likelihood of grass cuttings from golf greens being collected and transported to municipal or private composting facilities is extremely small. There is actually a greater interest in buying in good quality green waste compost for application to the golf course. With regard to pesticide use, fungicides are the principal chemicals used, as broadleaved weeds are not generally a major problem. However, clopyralid does have approval for use on amenity turf. The principal fungicides used would be azoxytstrobin, chlorothalonil and iprodione.	
British Association Landscape Industries	email 17/06/08		
Amenity Forum	email 17/06/08		
Vitex	email 17/06/08		
Brian Chambers, ADAS	email 17/06/08		

Name	Date of contact	Response	Action
Harry Hoitink, Ohio State University	email 17/06/08	You may want to contact scientists who published on this topic from the Seattle region of the US. It has been found sporadically at low concentrations in composted yardwastes but it has posed herbicidal effects a few times and in the Pacific Northwest only I think. Even there it does not pose issues today although I seem to recall that this herbicide no longer is marketed to the green industry. It should be present in composted manures (twice as much compost screening equipment is sold to farmers today than all other markets combined with almost none used on farms 10yrs ago) sold widely now...and no reports of toxicity that I know off. Some "toxicity" data may have been due to N immobilization (10 yrs ago when solid maturity/stability data was less available) but some of the problems apparently were due to the herbicide. This pesticide was used here in the eastern US for years and never posed an issue in composts made with grass clippings. So...in spite of a lot of research I am not sure whether any one has a good handle on this. It certainly created havoc when it was an issue and lots of funds are being spent on routine residue testing.	
Dow Agro Sciences Ltd	email 17/06/08		
Sita UK	email 17/06/08		
Veolia Environmental Services (UK) Plc	email 17/06/08		
Freeland Horticulture	email 17/06/08		
Jim Frederickson, Open University	email 17/06/08	As you will know, the PAS100 laboratory test data collected over the last few years is the obvious source for the information you require and I don't know of any other large data bank that includes physical contaminants. You may need to do quite a bit of data processing to get the level of analysis you need. No doubt you have already contacted Emily Nichols from the Composting Assn. about this.	Emily Nichols contacted
Emily Nichols, The Composting Association	email 18/06/08		
Bigga	email 19/06/08		

Appendix C.2 Physical Contaminants

Name	Date of contact	Response	Action	Further Response
Organic Recycling	email 17/06/08			
Sita UK	email 17/06/08			

Name	Date of contact	Response	Action	Further Response
Veolia Environmental Services (UK) Plc	email 17/06/08			
Freeland Horticulture	email 17/06/08			
Enzo Favoino	email 17/06/08			
Joseph Barth	email 17/06/08	Up to date data available in Europe are only from plants in quality assurance schemes and they have to meet the physical contaminates thresholds of e.g. the for glass in the Netherlands with <0.2 % (> 2mm) and for glass, plastic and metals with <0.5 % (> 2 mm) in Germany. Stone thresholds are <5% (> 5mm) in Germany and Netherlands, while Germany skipped lately the stones thresholds because of no problem/relevance for the practice and the Netherlands deleted the heavy metals thresholds in compost this year because the nutrients are the really limiting factor there for the use. Both countries produce several million tons on green waste compost per year for the highest quality ranges of growing media with peat replacement rates of up to 70 %. So the quality of the material must be excellent. 78 % of the Dutch and 53 % of the German BIOcompost is used in agriculture and this for years without problems, so even this higher risky material compared to green compost can be used successfully. 50 % of the Austrian green and biowaste compost is produced on-farms (quality controlled) and used by farmers beneficially on arable and pasture land. Your list of physical contaminats looks very crasy and far away from the good composting practice. Material with ingredients like rubber, insufficiently biodegraded cardboard, masonry, concrete, tiles, carpet is not green waste. I would characterize such source materials as bulky or construction waste. Green waste comes from gardens and parks and not from the break down of houses. This types of contaminants can be easily managed by wheel loader drivers because they are optical visible at the point of delivery/reception. Element of all compost quality assurance schemes are requirements for intake control. Every composting plant which intends to sell the compost would reject the whole batch to the deliverer in order to avoid the risk to pollute the rest of the production. Practice in some bio-/foodwaste plants is the hand sorting/picking of the source material in sorting stations. I have never heard of the need of that for green waste composting plants. Intake control and screening is suffcient to get rit of the contaminants. Difficult impurities in green waste composting are plastic (people collect grass and branches in plastic bags) and, if the final product is sold to greenhouses, the glass, where ZERO glass it requested because people work with the hands in the material for planting. But even this can be managed reasonable with new screen types (wind shifting, ballistic separation, star screens) and the visual control of the input.	Contacted to thank and verify no literature available on adverse impact of contamination	I don't know any quotable research on adverse impacts of green waste compost in agriculture. Problems I have heard of referred to coloured plastic chips on the field (no effect on crop growing) especially in the corner/area where the rain water drainage will take place or the application of very fresh (uncomposted) material. There is the risk of spreading weed seeds or plant propagules. All the quality assurance schemes do not allow that because they require sanitisation and a certain level of compost maturity.

Name	Date of contact	Response	Action	Further Response
Jim Frederickson, Open University	email 18/06/08	As you will know, the PAS100 laboratory test data collected over the last few years is the obvious source for the information you require and I don't know of any other large data bank that includes physical contaminants. You may need to do quite a bit of data processing to get the level of analysis you need. No doubt you have already contacted Emily Nichols from the Composting Assn. about this.	Contact Emily Nichols	
Emily Nichols, The Composting association	email 18/09/08			

Appendix D Further research on clopyralid

The herbicide clopyralid is effective on a variety of weeds and causes damage at very low concentrations to sensitive plants, sometime below 10 parts per billion (ppb) in the growing medium for plants (Rynk 2002,2003). Sensitive agricultural and garden crops include tomatoes, potatoes, peppers, peas, beans, clover, alfalfa and sunflower (Rynk 2002, 2003). The level of clopyralid on grass the day of application is 10,000 to 50,000 ppb, therefore even a small amount of contaminated material entering a composting facility or directly applied to sensitive crops can cause major problems (Michel and Doohan unknown). A concern compounded by research on the persistence of Clopyralid during composting and in soil.

Lowest clopyralid concentrations in compost based growing mixes where herbicide effects were observed.

	Clopyralid Concentration (parts per billion)			
Plant Type	Day 14	Day 40	Day 72	Day 91
Grass, most ornamentals	>30000	>30000	>30000	>30000
Wheat	>300	>300	>300	
Sweet Basil	>300	>300	>300	
Japanese Buckwheat	>300	>300		
Cucumber	100	10		
Lettuce	10	10	10	
Tomato	3	3		
Peas, Beans	10	1		
Sunflower	1	1	3	
Red Clover	1	1	3	3

Source: W. Brinton, E. Evans, Composting News, April 2002. Taken from Michael and Doohan, (unknown)

Persistence, decay rate, and safe concentrations of commonly used herbicides that may be found in compost feedstocks and composts.

Pesticide	Trade Name	Reported Half Life in Soil (days)	Estimated Composting Half Life (days)	Plant Safe Conc. in Soil (ppb)
2,4-D	Weed-B-Gon, Hi-Dep® Weedar® 64 Weed RHAP A-4D®, Weed RHAP A	7	7-14	500
Atrazine	AAtrex®, Atratol®, Atrazine	100-300	21-50	nd
Clopyralid	Stinger®, Reclaim®, Transline®. Confront, Curtail, Millenium Ultra	15-287	1-2 years	3
Diazinon	Basudin, Dazzel, Gardentox, Kayazol, Knox Out, Nucidol, Spectracide, Diazinon	14-28	1-2	na
Dicamba	Banvel®, Banex®, Trooper®	7-42	nd	50
Glyphosate	Roundup®, Rodeo®, Accord®	3-130	nd	nd
MCPP	Kilprop, Mecopar, Triester-II, Mecomin-D, Triamine-II, Triplet TriPower, Trimec-Encore, U46 KV Fluid	< 60	nd	600
Pendimethalin	Prowl, AC 92553, Accotab, Go-Go-San, Herbadox, Penoxalin, Sipaxol, Stomp and Way-Up.	90	7-14	100
Picloram	Tordon®, Grazon®, Access®, Pathway	20-300	nd	10

Abbreviations: nd-no data, na-not applicable, a-limited data Taken from Michael and Doohan, (unknown).

The first instance where clopyralid in compost was associated with damage to plants grown in compost was in 2000 in eastern Washington. Further instances were then identified in Oregon (Rynk 2003). Problems have also been documented in Ohio, Pennsylvannia, New Jersey and California (Michel and Doohan unknown). Clopyralid contamination was first identified as a problem primarily from residential lawn clippings.

To protect the composting industry Washington, Oregon and California have all adopted a number of rules prohibiting the use of clopyralid in specific markets. In Ohio the rules prohibit the use of products containing clopyralid on residential lawns, commercial, and public turf, plantings, school grounds, parks or recreational areas other than golf courses. The rules continue to permit application of pesticides containing clopyralid to agriculture, forestry, rights of way, golf courses and cemeteries provided that grass clippings or other treated residues are not used to produce compost (ODEQ, 2003). In Washington the final rules were stricter, preventing the application of clopyralid products to cemeteries too (Rynk 2002). In Washington the applicator of herbicides on golf courses must also provide written

notice to the grounds keeper about the composting restriction. In Washington clopyralid products labelled for cereal grains, grass hay and lawns and turf can only be sold by licensed pesticide dealers to certified applicators (or their authorised agents) (Rynk 2002).

In California, the Californian Department of Pesticides Regulation (DPR) cancelled the registration of 15 herbicide products that contained clopyralid and were used on residential lawns (Rynk 2002). Rynk (2002) also reports on a bill progressing via the senate which requires the DPR to evaluate the presence of clopyralid in compost and either take regulatory action to prevent such contamination or state in writing why no action is required. The DPR is also given the task of imposing restrictions or cancelling the registration of any herbicide if it is found to persist in compost at levels that are "likely to cause damage to plants". In common with Washington State, clopyralid containing herbicides can only be sold by a licensed pesticide dealer. In addition, the bill limits lawn and turf applications of clopyralid to golf courses, with the same prerequisites required in Washington (Rynk 2002)

Present studies indicate that the restrictions employed in Washington and Oregon on the use of clopyralid have, on average, significantly reduced compost contamination levels (Musick 2004). Washington State Department of Agriculture (WSDA) reported an average 80% decline in clopyralid levels in commercial compost between 2001 and 2002 followed by an additional 9% decline in 2003. Oregan reported a 42% decrease between 2002 and 2003 from 12 operations tested however two facilities showed an increase in clopyralid contamination. Using the GC/MS analytical method the Oregon Department of Environmental Quality found clopyralid ranging from 4.3 to 37 ppb in 2003 compared to a range of 6.3 ppb to 94.3ppb in 2002. Average levels in eastern Washington dropped from 169.4ppb to 26.7 ppb between 2001 and 2002. An average increase was observed in 2003 from 26.7 to 29.4 ppb however this was primary caused by one facility where values increased from an average 5.7ppb in 2002 to 75ppb in 2003 due to a batch of compost made with livestock bedding, grass and hay feedstock that showed a level of 260ppb. In addition to this although another eastern compost facility showed an overall decline individual batches of compost made with grass clippings showed clopyralid levels of 87ppb and 66ppb in 2003 (Musick 2004). Clopyralid levels in compost from western Washington dropped from 80.9ppb 2001 to 1.1ppb in 2003.

The increase in clopyralid concentrations in eastern Washington implies that the problem still persists despite regulation. However, the higher levels in this area are believed to be associated with the inclusion of agricultural compost feedstocks where the application of clopyralid is not regulated and the requirement to avoid composting is voluntary (Musick 2004) and as such are not relevant when considering the risk from green compost in the UK.

Some individuals feel that continuing problems are due to improper use of compost. The compost in question is intended to be used as a blend rather than in its pure form for plant growth (Musick 2004).

Research by Miltner et al (2003) indicates that mowing treatment (bagging and removal of clippings or returning clippings into the plant canopy using a mulching mower) has no significant effect on clopyralid content of grass clippings. By 56 and 98 weeks after treatment with clopyralid, the concentration in clippings was 0.06 and 0.02 mg kg^{-1} respectively. Based on the results, and depending on feedstock dilution and composting conditions, a waiting period of up to one year after application of clopyralid could be necessary for treated grass clippings to be safely used as compost feedstock. This is supported by research by Vandervoot et al (1997) which detected clopyralid in grass cuttings after 365 days, with concentrations ranging from 0.1-1.3 mg kg^{-1}.

Several research projects are on-going into appropriate uses of compost tainted with clopyralid. Contaminated compost can be incorporated in soil or blended with clean compost to lower the clopyralid concentrations, or used for applications which do not include sensitive plants. Initial results of these studies indicate clopyralid contaminated compost can be used if the application rate is low or if the crops are not sensitive (as would be expected, even at high application rates) (Rynk 2002).

Bezdieck et al (2001) suggest that compost facilities should adopt a few preventative measures. Facility operators should become familiar with their sources of feedstock and inquire into the use of persistent herbicides. They suggested that a bioassay should be conducted on all feedstocks suspected of being treated with clopyralid, especially grass clippings as well as the finished compost. If herbicide damage is observed bioassays should be followed up with analytical tests (Bezdieck et al 2001). To ensure the reliability of the bioassay details of salinity, pH and maturity of the compost should also be verified to ensure any symptoms observed reflect only herbicide damage (Bezdieck et al 2001, Brinton et al 2006)

In relation to actual use of clopyralid in the UK and measures in place to control the risks to compost, the Minister of State, Department for Environment, Food and Rural Affairs (Lord Rooker) (reported in the Daily Hansard) provided the following written response to this question posed by Lord Lucas in June 2007:

Question: "Which formulations that include clopyralid are licensed for (a) garden use and (b) for use by contractors on municipal or institutional grasslands; and how they intend to alleviate any problems this chemical might cause for the composting of green waste by local authorities"

Answer: There are six pesticide products containing clopyralid licensed for garden use: Verdone extra (M13113);Verdone extra (M10635);Verdone extra ready-to-use (M11758);Verdone extra spot weeder (M10834);Vitax lawnclear 2 (M13508); Vitax lawnclear 2 ready-to-use (M13509); and five pesticide products licensed for institutional grasslands:Blaster (M10571);Blaster (M13267); Esteem (M12555);Greenor (Ml 0909); and Spearhead (M09941).

Because compost contaminated with clopyralid may harm some ornamental and vegetable crops, the labels of pesticide products containing it have a warning to avoid using any plant materials treated with the products for composting or mulching. Therefore, grass treated with clopyralid should not be composted or sent for composting.
The requirement not to compost grass treated with clopyralid forms part of the statutory labelling of products containing this compound. However, the ability to trace and sanction any parties who fail to follow this guidance is uncertain.

More information on this subject can be found in Gilbert *et al* (2010).

References: Appendix D

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Appendix E Comparative risk assessment data

	Paper mill sludges	Dairy Cattle Slurry	Pig Slurry	Cattle FYM	Pig FYM	Laying hen manure	Broiler litter	Sewage sluldge
Plant-derived toxins								
Grayanotoxins	ND	ND	ND	ND	ND	ND	ND	ND
Ligustrin	ND	ND	ND	ND	ND	ND	ND	ND
Digitoxin	ND	ND	ND	ND	ND	ND	ND	ND
Coniine	ND	ND	ND	ND	ND	ND	ND	ND
Taxine	ND	ND	ND	ND	ND	ND	ND	ND
PAHs								
NAP	2.4	0.029	0.007	0.029	0.007	ND	ND	0.115
B[a]A	0.1	0.013	0.016	0.013	0.016	ND	ND	1.124
CHR	0.1	0.033	0.044	0.033	0.044	ND	ND	1.585
B[b]f	0.1	0.029	0.01	0.029	0.01	ND	ND	1.067
B[k]f	0.1	0.011	0.005	0.011	0.005	ND	ND	0.718
B[a]P	0.1	0.013	0.008	0.013	0.008	ND	ND	0.921
IPY	0.1	0.015	0.007	0.015	0.007	ND	ND	0.821
PCBs								
PCB 28	2.50E-05	5.54E-04	5.54E-04	5.54E-04	5.54E-04	ND	ND	0.0331
PCB52	1.00E-05	2.82E-04	2.82E-04	2.82E-04	2.82E-04	ND	ND	0.052
PCB 95	1.00E-05	2.82E-04	2.82E-04	2.82E-04	2.82E-04	ND	ND	0.052
PCB 101	1.10E-04	1.12E-04	1.12E-04	1.12E-04	1.12E-04	ND	ND	0.1079
PCB 118	3.70E-05	1.90E-08	1.90E-08	1.90E-08	1.90E-08	ND	ND	0.078
PCB 132	3.70E-05	1.90E-08	1.90E-08	1.90E-08	1.90E-08	ND	ND	0.078
PCB 138	4.00E-06	3.15E-04	3.15E-04	3.15E-04	3.15E-04	ND	ND	0.1185
PCB 149	4.00E-06	5.08E-05	5.08E-05	5.08E-05	5.08E-05	ND	ND	0.1185
PCB 153	6.80E-05	4.33E-05	4.33E-05	4.33E-05	4.33E-05	ND	ND	0.1185
PCB 174	6.80E-05	4.33E-05	4.33E-05	4.33E-05	4.33E-05	ND	ND	0.1185
PCB 180	2.00E-06	1.33E-04	1.33E-04	1.33E-04	1.33E-04	ND	ND	0.054
Dioxins								
2,3,7,8-TeCDD	1.76E-07	4.00E-08	4.00E-08	4.30E-07	1.00E-08	1.00E-08	1.00E-08	1.35E-04
1,2,3,7,8-PeCDD	6.60E-08	8.00E-08	8.00E-08	1.60E-06	7.00E-08	4.00E-08	4.00E-08	7.00E-06
1,2,3,4,6,7,8-HpCDD	6.30E-08	3.00E-06	3.00E-06	8.50E-04	8.00E-07	1.40E-06	1.40E-06	2.66E-04
2,3,4,7,8-PeCDF	6.60E-08	1.30E-07	1.30E-07	6.90E-07	6.00E-08	1.20E-07	1.20E-07	8.00E-06
1,2,3,4,7,8-HxCDF	6.20E-08	2.50E-07	2.50E-07	1.50E-06	5.00E-08	1.50E-07	1.50E-07	1.10E-05
1,2,3,6,7,8-HxCDF	6.10E-08	2.70E-07	2.70E-07	1.50E-06	6.00E-08	7.00E-08	7.00E-08	5.00E-06
2,3,4,6,7,8-HxCDF	6.40E-08	1.90E-07	1.90E-07	2.10E-07	6.00E-08	1.40E-07	1.40E-07	1.00E-05

	Paper mill sludges	Dairy Cattle Slurry	Pig Slurry	Cattle FYM	Pig FYM	Laying hen manure	Broiler litter	Sewage sluldge
Pesticides								
Clopyralid	ND	ND	ND	ND	ND	ND	ND	ND
Fenoxycarb	ND	ND	ND	ND	ND	ND	ND	ND

Imazalil	ND	ND	ND	ND	ND	ND	ND	ND
PCP Pentachlorophenol	ND	ND	ND	ND	ND	ND	ND	ND
PTEs								
Cu	400	352	807	55.8	780	74.8	173	641
Cd	0.2	1.74	0.84	0.53	0.53	2.04	1.16	3.8
Cr	903	12.9	6.81	21.4	3.42	7.06	79.8	275
Pb	210	16.9	9.74	9.18	4.65	14.8	9.28	221

Appendix F Reference doses used in this assessment

Potentially	TEF	Safe Dose	Safety/	Safe Dose	Safety/

hazardous agent		Cattle (mg kg^{-1} d^{-1})	uncertainty factor	Sheep (mg kg^{-1} d^{-1})	uncertainty factor
Grayanotoxins	-	3.40×10^{0} (Wong et al., 2002)	100	3.40×10^{0} (Wong et al., 2002)	100
Lingustrin	-	2.00×10^{1} (Singh et al., 1992)	100	2.00×10^{1} (Singh et al., 1992)	100
Digitoxin	-	5.60×10^{-1} (Hagimori et al., 1984)	100	5.60×10^{-1} (Hagimori et al., 1984)	100
Coniine	-	3.30×10^{-1} (Lopez et al., 1999; Keeler & Del Balls, 1978)	10	3.00×10^{-2} (Keeler & Del Balls, 1978)	100
Taxine	-	1.00×10^{0} (Wilson et al., 2001)	10	1.00×10^{-1} (Wilson et al., 2001)	100
Naphthalene	-	2.00×10^{-2} (Shopp et al., 1984)	3000	2.00×10^{-2} (Shopp et al., 1984)	3000
Benzo[a]anthracene	-	1.40×10^{-3} (Hoogenboom et al., 2003)	3000	1.40×10^{-3} (Hoogenboom et al., 2003)	3000
Chrysene	-	1.4×10^{-2} (Hoogenboom et al., 2003)	3000	1.4×10^{-2} (Hoogenboom et al., 2003)	3000
Benzo[b]fluoranthene	-	1.40×10^{-3} (Hoogenboom et al., 2003)	3000	1.40×10^{-3} (Hoogenboom et al., 2003)	3000
Benzo[k]fluoranthene	-	1.40×10^{-3} (Hoogenboom et al., 2003)	3000	1.40×10^{-3} (Hoogenboom et al., 2003)	3000
Benzo[a]pyrene	-	1.40×10^{-4} (USEPA, 2002)	3000	1.40×10^{-4} (USEPA, 2002)	3000
PCBs	-	2.00×10^{-5} (Arnold et al., 1993a; 1993b; Tryphonas et al., 1989; 1991a; 1991b)	300	2.00×10^{-5} (Arnold et al., 1993a; 1993b; Tryphonas et al., 1989; 1991a; 1991b)	300
2,3,7,8-TeCDD	1 (Van Den Berg et al., 2006)	2.00×10^{-9} (COT, 2006)	9.6	2.00×10^{-9} (COT, 2006)	9.6
1,2,3,7,8-PeCDD	1 (Van Den Berg et al., 2006)	2.00×10^{-9} (COT, 2006)	9.6	2.00×10^{-9} (COT, 2006)	9.6
1,2,3,4,6,7,8-HpCDD	0.01 (Van Den Berg et al., 2006)	2.00×10^{-7} (COT, 2006)	9.6	2.00×10^{-7} (COT, 2006)	9.6
2,3,4,7,8-PeCDF	0.3 (Van Den Berg et al., 2006)	6.70×10^{-9} (COT, 2006)	9.6	6.70×10^{-9} (COT, 2006)	9.6
1,2,3,4,7,8-HxCDF	0.1 (Van Den Berg et al., 2006)	2.00×10^{-8} (COT, 2006)	9.6	2.00×10^{-8} (COT, 2006)	9.6
1,2,3,6,7,8-HxCDF	0.1 (Van Den Berg et al., 2006)	2.00×10^{-8} (COT, 2006)	9.6	2.00×10^{-8} (COT, 2006)	9.6
2,3,4,6,7,8-HxCDF	0.1 (Van Den	2.00×10^{-8}	9.6	2.00×10^{-8}	9.6

	Berg et al., 2006)	(COT, 2006)		(COT, 2006)	
Clopyralid	-	2.00×10^{3} (WSDOT, 2006)	100	2.00×10^{3} (WSDOT, 2006)	100
Fenoxycarb	-	5.60×10^{-2} (WSDOT, 2006)	100	5.60×10^{-2} (WSDOT, 2006)	100
Imazalil	-	1.30×10^{-2} (WSDOT, 2006)	100	1.30×10^{-2} (WSDOT, 2006)	100
Pentachlorophenol	-	3.00×10^{-2} (WSDOT, 2006)	100	3.00×10^{-2} (WSDOT, 2006)	100
Copper	-	4.00×10^{-2} (Hérbert, 1993)	100	4.00×10^{-2} (Hérbert, 1993)	100
Cadmium	-	1.00×10^{-4} (USEPA, 1995)	10	1.00×10^{-4} (USEPA, 1995)	10
Chromium (VI)	-	3.00×10^{-3} (MacKenzie et al., 1958)	300	3.00×10^{-3} (MacKenzie et al., 1958)	300
Lead	-	3.50×10^{-4} (Mushak et al., 1989)	100	3.50×10^{-4} (Mushak et al., 1989)	100

Appendix G Summary of all assumptions made in the risk assessment

Scenario i: Exposure of grazing animals to hazards potentially present in PAS100 green compost

In this scenario, composted source-segregated green waste is surface applied to grazing land on which sheep or cattle are immediately allowed to graze (Figure G1).

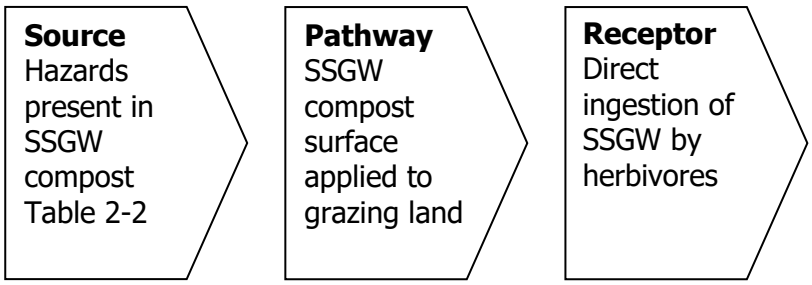

Figure G1: Source-pathway-receptor schematic of this scenario

Quantitative risk assessments were only carried out for plant toxins, PTEs and organic pollutants and are based on the assumptions listed in Table 1. For the remaining four hazard groups (pathogens, invasive weeds, physical contaminants and other environmental hazards), a commentary risk assessment has been carried out based on the hazard screening process described in Section 2.1.

Table G1: Specific assumptions for the QRA

Stage	Assumption	Commentary
SOURCE	PAS100 green compost	
General	The concentrations in SSGW of the different hazards considered are assumed to the maximum allowable under PAS100.	When PAS100 SSGW data were not available or inappropriate for use, data from non-PAS100 SSGW have been used.
Plant toxins	Two proportions of toxic plant material in SSGW feedstock are considered: i) 1% (WRAP, 2016a) ii) 100% (extreme scenario)	It is unlikely that any specific plant of interest would make up more than 1 % of SSGW feedstock, but as there were no data on this, a plant-specific content of 100 % was assumed as an extreme.
	Mean and maximum concentrations of plant toxins in SSGW compost are given in Table 3-2.	The concentrations are derived from fresh, non-composted material. Where information was not available, it was conservatively assumed that the compound would not degrade during the composting process, after application to the surface of pasture, or when incorporated into the soil.
Organic pollutants	Mean and maximum concentrations of organic pollutants in SSGW compost are given in Table 3-8 (PAHS), Table 3-13 (PCBs), and Table 3-18 (PCDD/Fs).	Concentrations are derived from literature data on PAH, PCBs and PCDD/Fs reported as being measured in SSGW compost. This included non-PAS100 SSGW compost, compost produced in Germany, Switzerland, and the USA. This assumption was made to minimise data selection bias.
PTE	Mean and maximum PTE concentrations	Concentrations of aqua regia-extractable PTEs were

	measured in SSGW compost as well as the maximum permissible PAS100 concentration for PTE in SSGW compost are given in Table 3-25.	equal to the total maximum permissible under PAS100 regulations. These concentrations have been used for the exposure assessment.
PATHWAY	Surface application of PAS100 SSGW	
General	Compost is spread in a single annual application on the surface and forms an even layer that settles towards the base of the sward.	
	The compost is not incorporated into the soil, i.e. no dilution effects.	
	Two application rates are considered: 25 t ha^{-1} fw (typical application rate) and 50 t ha^{-1} fw (maximum application rate, outside of Nitrate Vulnerable Zone)	NVZ compliant application rate would be roughly 30 t ha^{-1} (based on compost containing 8.3 kg N/fresh tonne).
	PAS100 green compost has a bulk density of 0.6 kg L^{-1} (The Composting Association, 2005)	
RECEPTOR	Grazing animals	
General	Animals are allowed to graze immediately after surface application of compost, i.e. there is not a 'no graze' period between compost application and the introduction of livestock.	This is a conservative assumption to ensure that the animals are exposed to the highest concentrations possible. Good practice advice is to allow a 3-4 week 'no graze' period (ADAS, 2001; Chambers et al., 2001).
	Body weights: Sheep: 40 kg (Spector, 1956) Cattle: 450 kg (Spector, 1956)	Relatively low body weight animals were assumed to maintain a precautionary approach. To achieve realistic bodyweights, average values for older (i.e. more historic) breeds were used.
	Consumption rates: Sheep: 4.3 kg DM d^{-1}, (Black & Kenney, 1984) Cattle: 12.5 kg DM d^{-1}, (Hodgson et al., 1971; Waddington & Cooke, 1971; Greenhalgh & Reid, 1968, 1969)	These consumption rates assume that the stocking density is constant.
	Soil ingestion is assumed as a proxy for direct ingestion of SSGW compost (WRAP 2016a).	This assumption represents an animal that spends all year in the field consuming a diet that consists of only compost and herbage. This is a significant over-estimation of exposure and is included to present a worst-case scenario.
	Two soil ingestion rates are considered (WRAP 2016a): i) *Realistic worst case* (assumed to be the upper 95 %ile ingestion rates): Sheep: 16 % dry matter intake as soil Cattle: 9 % dry matter intake as soil ii) Maximum soil ingestion: Sheep: 25 % dry matter intake as soil Cattle: 18 % dry matter intake as soil	Soil ingestion rates are based on 14 estimates of mean soil ingestion by sheep, and 19 estimates of mean soil ingestion by cattle.
	Long-term exposure timescale: Sheep: 6 years Cattle: 20 years Livestock are assumed to ingest compost at the realistic worst case rate over this timescale. As a	The long-term exposure timescale is conservatively set beyond the lifespan of the majority of farmed cattle.

	second (extreme worst case) scenario, it is assumed that livestock are ingesting compost at the maximum rate for a period of three months in every calendar year, while ingesting compost at the realistic worst case rate for the remaining nine months.	
	Reference dose (RfD) values for cattle and sheep are detailed in Table 3-2 (plant toxins), Table 3-8 (PAHS), Table 3-13 (PCBs), Table 3-18 (PCDD/Fs) and Table 3-25 (PTEs).	The RfD represents the dose an individual can experience for every day of their lifetime without experiencing any deleterious health effects. All RfD values are derived from animal data and have various margins of safety built into them (see Appendix F).

Scenario ii: Exposure of livestock to hazards in crops for animal consumption grown in soil amended with PAS100 green compost

In this scenario, PAS100 green compost is incorporated into soil for growing crops for animal consumption (Figure G2).

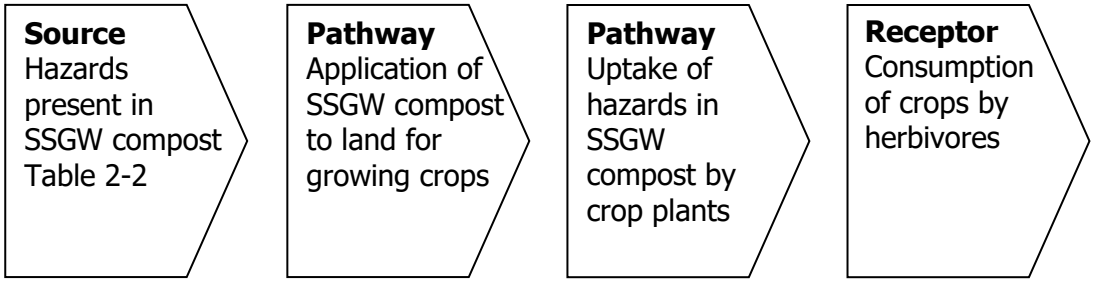

Figure G2: Source-pathway-receptor schematic of this scenario

Quantitative risk assessments were again only carried out for PTEs and organic pollutants and are based on the assumptions listed in Table G2. For the remaining four hazard groups (pathogens, invasive weeds, physical contaminants and other environmental hazards), a commentary risk assessment has been carried out based on the hazard screening process described in Section 2.1.

Table G2: Specific assumptions for the QRA

Stage	Assumption	Commentary
SOURCE: PAS100 green compost		
General	The concentrations in SSGW of the different hazards considered are assumed to the maximum allowable under PAS100.	Data from non-PAS100 SSGW have been used, when data were insufficient.
	The source concentrations are assumed constant with time.	
Plant toxins	Two proportions of toxic plant material in SSGW feedstock are considered: i) 1% (WRAP, 2016a) ii) 100% (extreme scenario)	It is unlikely that any specific plant would make up more than 1 % of SSGW feedstock, but as there were no data on this, a plant-specific content of 100 % was assumed as an extreme.
	Mean and maximum concentrations of plant toxins in SSGW compost are given in Table 3-2.	These concentrations are derived from fresh, non-composted material. Where information was not available on the fate of the compound, it was conservatively assumed that the compound would not degrade during the composting process, after application to the surface of pasture, or when incorporated into the soil.
Organic pollutants	Mean and maximum concentrations of organic pollutants in SSGW compost are given Table 3-8 (PAHs), Table 3-13 (PCBs), and Table 3-18 (PCDD/Fs).	Concentrations are derived from literature data on PAH, PCBs and PCDD/Fs reported as being measured in SSGW compost. This included non-PAS100 SSGW compost, compost produced in Germany, Switzerland, and the USA. This approach was adopted to minimise data selection bias.
PTE	Mean and maximum PTE concentrations measured in SSGW compost as well as the maximum permissible PAS100 concentration for PTE in SSGW compost are given in Table 3-25.	Concentrations of aqua regia-extractable PTEs were equal to the total maximum permissible under PAS100 regulations. These concentrations have been used for the exposure assessment.

PATHWAY: Surface application of PAS100 green compost		
General	Compost is spread in a single annual application on the surface and is evenly mixed with soil through ploughing. A plough depth of 25 cm is assumed.	This assumption ensures uniform concentration all over the field and results in a dilution of the concentrations that the crops are exposed to.
	Two application rates are considered: 25 t ha^{-1} fw (typical application rate) and 50 t ha^{-1} fw (maximum application rate, outside of Nitrate Vulnerable Zone)	NVZ compliant application rate would be roughly 30 t ha^{-1} (based on compost containing 8.3 kg N/fresh tonne).
	PAS100 green compost has a bulk density of 0.6 kg L^{-1} (The Composting Association, 2005)	
	Soil-air-water-compost equilibrium is assumed reversible and instantaneous.	After incorporating the compost into soil, the hazards present in compost will partition into the soil-water-air matrix and hereby be available for plant uptake.
PATHWAY: Uptake of hazards present in PAS100 green compost into fodder crops		
General	The concentrations in compost are constant with time and the soil-plant system is assumed in steady-state.	This assumption is likely to overestimate the concentrations in the crops significantly and presents a worst case scenario. In reality the source (concentrations in soil) is better described as a pulse injection.
	Plant-specific parameters are given in Table 2-5.	
Organic pollutants	The uptake of organic pollutants by crops is calculated with Eq. 2.6-2.8.	
	Removal of contaminants due to degradation, infiltration and volatilization is neglected.	This presents a worst case scenario. In reality, contaminant losses are likely due to degradation, leaching and run-off from soil as well as due to metabolism in plants.
	Deposition of particles on leaf/grain surfaces is neglected and uptake from air is assumed solely by diffusive exchange in the gas phase.	
	For comparison purposes, the following soil:plant bioconcentration factors (BCF) were used to describe the proportion of organic pollutants in the soil taken up by crops (Mikes et al 2009; Whitfield Åslund et al 2008; Inui et al 2008; 2009) PCB BCF PCB 28 0.42 PCB 52 0.54 PCB 95 0.08 PCB 101 0.08 PCB 118 0.175 PCB 132 0.06 PCB 138 0.06 PCB 149 0.07 PCB 153 0.07 PCB 174 0.06 PCB 180 0.06 PCDD/F BCF 2,3,7,8-TeCDD 0.025	Bioconcentration factors are derived by measuring the levels of organic pollutants in the soil and then measuring the concentrations in plants grown in that soil. It should be noted that these values are a broad estimation, since precise figures are likely to vary between different soils (i.e. different physical and chemical characteristics) and between different crop types. It should also be noted that reported bioconcentration factors may be over-estimates of PCB or PCDD/F uptake as contamination of the plant samples by soil is difficult to avoid. Therefore these values have been selected, in part, due to the precautionary approach being employed in this assessment.

	1,2,3,7,8-PeCDD 0.03 1,2,3,4,6,7,8-HpCDD 0.003 2,3,4,7,8-PeCDF 0.01 1,2,3,4,7,8-HxCDF 0.01 1,2,3,6,7,8-HxCDF 0.01 2,3,4,6,7,8-HxCDF 0.02	
PTEs	The uptake of PTEs by crops is calculated with Eq. 2.2 - 2.4.	
	pH-dependent equilibrium between soil, water and compost is assumed	
RECEPTOR: Livestock		
General	Animals are assumed only to eat crops grown on compost amended soil.	This is an unknown. The real value will be between 0 % and 100 %, so 100 % has been used as a high hazard scenario.
	Body weights: Sheep: 40 kg (Spector, 1956) Cattle: 450 kg (Spector, 1956)	Relatively low body weight animals were assumed to maintain a precautionary approach. To achieve realistic bodyweights, average values for older (i.e. more historic) breeds were used.
	Consumption rates: Sheep: 4.3 kg DM d^{-1} (Black & Kenney, 1984) Cattle: 12.5 kg DM d^{-1}, (Hodgson et al., 1971; Waddington & Cooke, 1971; Greenhalgh & Reid, 1968, 1969)	These consumption rates assume that the stocking density is constant.
	Long-term exposure timescale: Sheep: 6 years Cattle: 20 years	The long-term exposure timescale is conservatively set beyond the lifespan of the majority of farmed cattle.
	Reference dose (RfD) values for cattle and sheep are detailed in Table 3-2 (plant toxins), Table 3-8 (PAHS), Table 3-13 (PCBs), Table 3-18 (PCDD/Fs) and Table 3-25 (PTEs).	The RfD represents the dose an individual can experience for every day of their lifetime without experiencing any deleterious health effects. All RfD values are derived from animal data and have various margins of safety built into them (see Appendix F).

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