Summary report

Compost quality and safety for agriculture

This report summarises the findings of three separate projects commissioned by WRAP to investigate the safety of composts meeting the PAS 100 quality specification, when used in agriculture and field horticulture. A wide range of hazards were considered – including microbiological, chemical and physical – and risks from compost use were considered to be low or negligible in all scenarios examined.

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Front cover photography: Spreading compost

Contents

Acknowledgements

This summary report is derived from three source documents, the authors of which are gratefully acknowledged:

- *Risk assessment for the use of PAS100 green composts in Scottish livestock production*. Written by: Rupert Hough*, Philippa Booth, Lisa Avery, Jeff Bacon, Stewart Rhind, Mads Troldborg, Luke Beesley and Colin Campbell (The James Hutton Institute, Aberdeen). WRAP project OAV021-004
- *Composts derived from catering wastes containing meat: Assessment of residual pathogen risks to livestock.* Written by: Paul Gale*, Animal and Plant Health Agency (APHA, New Haw). WRAP project OAV025-003
- *Risk assessment for the use of source-segregated composts in UK agriculture*. Written by: Phil Longhurst*, Raffaella Villa, Sean Tyrrel, Shaomin Wu and Simon Pollard (Cranfield University, Cranfield), Rupert Hough (The James Hutton Institute, Aberdeen), Paul Gale (APHA, New Haw), Brian Chambers and Matt Taylor (ADAS, Gleadthorpe). WRAP project OAV025-004

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- Professor Kevin Jones, University of Lancaster

Additional thanks are due to the members of the various steering and technical advisory groups who informed the direction of the research summarised here, amply voiced their concerns and questions around compost safety, and contributed significantly to the overall value of this work.

To obtain copies of any of these reports, please contact WRAP via risk.assessments@wrap.org.uk, quoting the report name and WRAP project number.

1.0 Compost and composting in the UK

1.1 What is compost?

Compost is both a soil conditioner and a source of major plant nutrients, including readily available potash, made from the controlled biological decomposition of either solely green waste (e.g. lawn clippings, prunings, woody material) or from a mix of green waste and food waste, in the presence of oxygen. Compost usually contains little readily available nitrogen, although soil nitrogen supply can be increased over the long term following its repeated use (WRAP, 2016a).

Many of the beneficial properties of compost relate not to its nutrient content – but its organic matter content. This has significant value in improving soil quality through interaction with soil mineral particles. Thus, water retention can be increased in light soils, whilst drainage can be improved (by opening-up the structure) in heavy soils. Improvements in soil physical structure over time enhance the rooting environment for crops, allowing them to better access any conventional nutrients that are applied – leading to savings in the medium to long term. Since the source materials from which composts are derived have not historically been applied to cropped land (being instead discarded to landfill, or prior to this, disposed in domestic compost heaps or similar), they can be regarded as a 'new' source of organic carbon. As such, increases in soil organic matter resulting from compost use can be regarded as a form of carbon sequestration, adding additional environmental benefit and value to the material (Powlson et al., 2012).

1.2 Compost production in the UK

Excluding manures, slurries and sewage sludges, the quantity of biodegradable wastes in the UK is estimated to be approximately 25 million tonnes (WRAP, 2008b) half of which is collected as municipal (household or similar) solid waste. The split of biodegradable material suitable for composting is roughly even between food wastes and garden wastes, and around 3.5 million tonnes of compost are produced every year (WRAP, 2012). Market assessments of the value of compost estimate it to be worth around £5 per tonne (WRAP, 2008b).

1.3 The importance of agriculture

The agricultural sector represents the principal market for compost, accepting around 60% of all output. 43% of composting sites supply material for use ahead of cereals and other combinable crops, with 15% supplied for application ahead of other arable crops such as sugar beet (WRAP, 2012). Continued confidence in the use of source-segregated composts in UK agriculture is essential to maintaining the effective use of these resources.

1.4 About this summary report

Whilst the agronomic value of compost cannot be disputed, its perceived origins from 'waste' materials can prove problematic in the market place. Compost is produced and used under a range of regulatory constraints, whether it has been made from materials including food waste or not (WRAP, 2016a). However, despite this, and the widespread adoption of the BSI PAS 100 specification for compost quality (BSI, 2011), key market stakeholders have raised questions around the quality, safety and usability of composts – both on land used to grow crops for human consumption, and land grazed by livestock. As a result of this, WRAP initiated a 'Confidence in Compost' programme to understand and address stakeholder concerns. The resulting portfolio of projects included three comprehensive risk assessments devoted to different types of compost in different uses:

1. Green compost used on land where livestock are grazed, or fodder grown;
2. Green/food compost used on land where livestock are grazed; and
3. Green and green/food compost used on land where crops are grown for human consumption.

These reports are summarised in Section 2.0, Section 3.0 and Section 4.0, respectively. The overall conclusions of each study are presented in Section 2.2, Section 3.2 and Section 4.2, respectively.

The conclusions from this research underpin WRAP's 'Renewable Fertiliser Matrix', which clearly illustrates cropping and grazing situations where green and green/food composts can be safely used. The accompanying good practice guidance provides agronomic advice for compost use (WRAP, 2016a).

2.0 Risk assessment for the use of PAS100 green composts in Scottish livestock production

2.1 Introduction

A quantitative risk assessment (QRA) was undertaken to establish the potential for harm to animal, human health or the environment, resulting from the application of PAS100:2011 source-segregated green waste (SSGW) compost in 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; and
- Land used to grow leaf crops for animal consumption.

Where possible, this assessment considered SSGW compost that had been produced to the PAS100 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 were not considered.

2.2 Overall conclusions

Within the limitations of available information, source-segregated green waste (SSGW) compost (and by extension, green composts 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. SSGW 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.

2.3 Methods

The approach taken within this study followed a classical and widely accepted approach to risk assessment, which has been adopted by a number of agencies including Defra and the Institute of Environment and Health. However, it is worth noting 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 – were built-in to try and deal with these uncertainties.

2.3.1 Range of hazards considered

Seven categories of potentially hazardous agents were considered:

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 (Polycyclic Aromatic Hydrocarbons); LAS (Linear alkylbenzene sulphonates); NP (Nonylphenol); PCBs (Polychlorinated biphenyls); Antibiotics; Pesticides; Disinfectants; Inks; Residual chlorophenols;
3. Potentially toxic elements including Zn (Zinc); Cu (Copper); Ni (Nickel); Cd (Cadmium); Pb (Lead); Hg (Mercury); Cr (Chromium); As (Arsenic);
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 including glass; metal; plastic; non-stone fragments; stones; sharps; and
7. Other Environmental hazards including nitrate; phosphate; effects on Biological Oxygen Demand (BOD) of water.

2.3.2 Shortlisting hazards for assessment

It was considered important 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 quantitative risk assessment (QRA) on each potentially hazardous agent identified. Instead, a series of filters was applied to the initial list of hazards to produce a short list for further investigation. The approach adopted for this stage was adapted from Pollard *et al.* (2008).

Initially, for each of the categories listed in Section 2.3.1, a comprehensive set of potentially hazardous agents was identified. Information derived from peer-reviewed literature was used as primary source material, and potentially hazardous agents were included 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 America.

The hazards were then filtered. Only those passing through these filters were subjected to quantitative risk assessment:

1. Filter 1 asked whether the agent under consideration has a potentially serious effect on animal or human health, or on the environment.

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."

Only those agents considered to have a potentially serious effect were passed through Filter 1.

2. Filter 2 considered whether 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.

Hazards passing these two filters (and for which relevant data were considered to be available) were subject to quantitative risk assessment, as described below.

2.4 Risk characterisation

The 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 SSGW on agricultural land, an individual animal or environmental receptor would experience deleterious health effects or reduction in meat/milk quality from either direct grazing of compost-treated land or ingestion of fodder crops post-harvest from land that had been treated with compost.

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}) (Equation 1). If the ADD exceeds the RfD, we might expect to see deleterious effects on animal health, or on meat/milk quality.

$$RR = \frac{ADD}{RfD} \qquad (1)$$

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' ($RR \leq 1.0$) or 'potentially requiring further investigation' ($RR > 1.0$).

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 No Observable Adverse Effect Level (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 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 or sheep, this UF was not applied. The second factor was used to account for variability within receptor populations, e.g. differences in the amount of compost consumed, or differences in the inherent susceptibility of different members of the herd (Barnes and Dourson, 1988).

2.5 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 farmyard manure
Pig slurry	Laying hen manure
Cattle farmyard manure	Broiler litter

Where published information for comparator materials was limited, advice was sought from relevant technical experts in the appropriate fields. 'Typical' values (average values reported in review studies) for the concentrations of plant toxins, organic contaminants and PTEs were sought. 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 those materials.

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 (Defra, 2010), 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 estimated reference doses, to determine risks to animal health.

2.5.1 Assumptions for compost applied to the surface application to grazing land

Compost was spread evenly on the surface of the land and not incorporated into the soil at 25 t ha^{-1} fresh weight and 50 t ha^{-1} fresh weight. These rates were felt to reflect realistic typical and maximum application rates outside nitrate vulnerable zones (NVZs). Rates would be likely to be lower within NVZs due to constraints on loadings of total nitrogen. These application rates would form a layer of compost 0.4-0.8 cm thick at the base of the grazed sward.

Normal agronomic practice would be to exclude stock from treated land for a number of weeks – to allow the grass sward to utilise the nutrients applied in the compost. In contrast, this risk assessment assumed that animals were allowed to graze immediately.

Rates of soil ingestion normally associated with grazing were entirely substituted with compost ingestion rates on a dry matter for dry matter basis, calculated from mean available data. Realistic worse-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 worse-case ingestion rates were taken to equate to the worst observed mean soil ingestion rate reported by the studies.

Realistic worse-case rates were modelled as daily compost ingestion over a period of six years (sheep) and twenty years (cattle). For extreme worse-case rates it was assumed that for three months in every twelve over these lifetimes, livestock ingested compost at the extreme rate (Table 2-1).

Table 2-1 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)

These rates of ingestion were so high that the potential for risks associated with animal ingestion of soil adhering to fodder (root) crops did not have to be considered. Such adhesion rates are likely to be much lower than those modelled for direct ingestion during grazing. For example, Gale & Stanfield (2001) assume only 2% w/w of the consumed crop to be soil, while recent data for sugar beet identified that 6.2% of the weight of the crop was soil (NFU, 2009).

2.5.2 Approach where compost was incorporated into soil ahead of subsequent fodder crops production

A number of models were used to estimate how agents / hazards present in SSGW compost might be modified in practical use. These allowed the impacts of ploughing, uptake by the fodder crop and the processes used to produce animal feed to be considered.

2.6 Results

2.6.1 Plant-derived toxic compounds

Only privet and foxglove passed hazard Filter 2 (Section 2.3.2) and were subjected to the exposure assessment. In the absence of evidence to the contrary it was assumed that no degradation of the active compounds (ligustrin and digitoxin for privet and foxglove, respectively) occurred during the composting process.

As there was no information on the proportions of privet and foxglove in typical SSGW feedstock, two scenarios were considered, to represent the extremes: compost that contained 1 % toxic plant material; and compost made entirely from the toxic plant in question. Table 2-2 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. None of the other species considered (including Ragwort, Rhododendron, Yew and Hemlock) passed Filter 2, since evidence was available to demonstrate that the toxins were either present at insufficient concentration to present a risk if they survived composting intact, or were sufficiently attenuated during the composting process.

Table 2-2 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%

Overall, for plant toxins, PAS100 compliant green compost presents a negligible risk to grazing animals.

2.6.2 Organic pollutants

Many organic pollutants are ubiquitous in the 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. 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.

2.6.2.1 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).

Following the exposure assessment, SSGW compost was considered to present a negligible risk to sheep and cattle from exposure to PAHs after surface-spreading to pasture. 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.

For these PAHs, SSGW compost was considered to present a negligible risk to sheep and cattle whether the compost was applied to grazed land or cropped land where forage crops were grown. Risks were also considered negligible for many of the PAHs in the various comparator materials.

2.6.2.2 PCBs

The following 11 PCB congeners were considered: PCB 28, PCB 52, PCB 95, PCB101, PCB 118, PCB 132, PCB 138, PCB 149, PCB 153, PCB 174 and PCB 180.

Modelling indicated that the PCBs had a strong propensity to become bound (sorbed) to soil and compost, offering limited potential for uptake into plants. While there was a potential risk from PCB 28 to sheep under the extreme worst case grazing scenario (with compost applied at 50t ha^{-1}), the overall conclusion was that SSGW compost was considered to present a negligible risk from exposure to PCBs.

Many of the comparator materials were assessed as presenting negligible risks, although all materials (including livestock manures) may require further investigation for specific PCBs. However, it must be remembered that this assessment used the same exposure scenario for all comparator materials, 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.

2.6.2.3 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.

None of the individual agents were found to cause a significant risk to grazing cattle. However, there was an apparent risk to 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. A more complete understanding of its origins would facilitate further risk reduction for this contaminant.

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. These results suggest that risks posed by other diffuse environmental contaminants are also likely to be negligible.

2.6.2.4 Pesticides and herbicides

Four compounds were evaluated in the exposure assessment: Clopyralid, Fenoxycarb, Imazalil, and Pentachlorophenol.

Only one compound – clopyralid – was considered to have the potential to present an exposure of concern. 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. potato). 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 the use of a bioassay that should identify excessive concentrations of this compound. 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).

2.6.3 Potentially Toxic Elements (PTEs)

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

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

Ten of these were considered to have potentially serious effects (European Commission, 2005) and were evaluated further. This analysis determined that four of these (Cu; Cd; Cr; Pb) could be present in compost at levels considered to cause serious effects, and these elements were considered in the exposure model.

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 low. However, the models used in this study suggest that uptake of cadmium by leafy crops may require further investigation to ensure the sustainability of long-term, repeat applications of green compost containing cadmium at the PAS100 limits.

2.6.4 Pathogens

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. In particular, 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).

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 in Section 3.0.

2.6.5 Invasive weeds

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, 2008):

- Japanese knotweed (*Fallopia japonica*)
- Rhododendron (*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*)

The Weeds Act 1959 made it an offence to allow the spread of these species, and the supply of compost containing propagules of these species is likely to be viewed as an offence. Under the Wildlife and Countryside Act (1981) it is illegal to permit the spread of Japanese Knotweed and Giant Hogweed.

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.

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 as to whether the frequency and number of tests undertaken for weed seeds/propagule reflects the heterogeneity of the compost heap.

2.6.6 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 itself (Dimambro *et al*., 2007; Barth 2005; Bexley Council & Enviros Consulting, 2004; Anon, 2000):

Glass	Masonry	Textile	Polystyrene foam
Metal	Concrete	PVC	Bones
Plastic	Tile	Fragments of PET*	Foil
Rubber	Carpet	Polyester	Partly degraded cardboard

*PET = polyethylene terephthalate

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 project 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.

2.6.7 Other Environmental Hazards

During the hazard screening, seven compost properties were identified as having the potential to cause harm to the environment: phosphate (P), nitrogen (N), alkalinity, salt, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and pH.

Data availability on the quantities of these “other environmental hazards” in SSGW compost and any 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. Based on this, it is considered that there is a negligible risk of harm if composts are applied to soils according to best agricultural practice.

3.0 Composts derived from catering wastes containing meat: Assessment of residual pathogen risks to livestock

3.1 Introduction

This section summarises the findings of a risk assessment that examined the fates during composting and subsequent land application of various pathogens of animal health interest that might be present in kitchen ('catering') waste sent for composting.

While safe for human consumption when cooked, some uncooked meats may contain pathogens that impact on animal health. For example, illegally imported meats could contain viable foot and mouth disease virus (FMDV), swine vesicular disease virus (SVDV), African swine fever virus (ASFV), classical swine fever virus (CSFV) and avian influenza virus. In 2001, Defra commissioned an independent assessment of the risks from such pathogens in compost produced from catering waste containing meat (Gale, 2002). Since this time, new information and data have become available that could be used to update the original risk assessment. For example, quantitative estimates of the amount of illegally imported meat have been produced (Hartnett *et al.* 2004). Furthermore, an extensive study of food waste (WRAP, 2008a) has enabled better estimates of the amount of meat discarded to catering waste at a livestock species level. The aim was to revise the original risk assessment (Gale, 2002) given the availability of new information, and to review the validity of the key assumptions made.

3.2 Overall conclusions

Overall, this study concludes that current statutory composting process parameters and statutory grazing bans are sufficiently robust to ensure that risks to livestock are acceptably minimised. It also highlights that prevention of process by-pass remains a critical control point in preventing pathogens from re-entering the food chain.

3.3 Scope of risk assessment

3.3.1 Hazards considered

The hazards included in this risk assessment were selected to cover a wide range of pathogens and other organisms of importance to British livestock. The following were subjected to quantitative risk assessment:

African Swine Fever Virus (ASFV)	Newcastle Disease Virus (NDV)
Classical Swine Fever Virus (CSFV)	*Toxoplasma gondii*
Swine Vesicular Disease Virus (SVDV)	Classical and Atypical Scrapie
Foot and Mouth Disease Virus (FMDV)	BSE

Rather than quantitative risk assessment, an overview of the risks was collated for some faecal-oral bacteria, H5N1 Highly Pathogenic Avian Influenza Virus (HPAIV), and for *Clostridium botulinum*. Brief reviews of the data available for possible future risk assessment were also conducted for porcine circovirus, porcine parvovirus and MRSA (Methicillin-resistant *Staphylococcus aureus*).

3.3.2 Geographical scope

The quantitative risk assessments focus on GB. This is because available estimates for amounts of illegally imported meat infected with ASFV, CSFV, SVDV and FMDV are for GB (Hartnett *et al.*, 2004), as are estimates of the amount of scrapie and BSE infectivity entering the food chain (Adkin *et al.*, 2010). The risks for NDV and HPAIV are also estimated for GB, based on assumptions on the numbers of infected chicken carcasses that might enter the GB food chain. To correspond, therefore, the theoretical total amount of compost produced annually from catering waste in GB is used (Table 3-1). The risks for *Toxoplasma gondii* are calculated for the UK using data for number of cats in the UK, together with an estimate for the total amount of compost produced annually from catering waste in the UK.

Although of interest to stakeholders (particularly those who specify the use of composts on land where livestock might be grazed) ascarids (roundworms) are not considered here because in Quarter 3 of 2008, helminthiasis was diagnosed only twice in outdoor pigs across the whole of GB (VLA and SAC, 2008), and furthermore there is evidence that eggs from the helminth *Ascaris suum* are inactivated rapidly at temperatures from 49 to 55°C (Aitken *et al.,* 2005). These temperatures are below the minimum required during composting of catering waste.

3.3.3 Transfer of disease/infection between animals

This risk assessment considers the risk of incursion or the first infected animal (index case) through exposure to compost. Transfer of the disease to additional cases is beyond the scope of the risk assessment. Although some diseases, such as bluetongue virus serotype 8, can be transmitted through the placenta, this is a function of the disease itself and is not related to compost. With regard to exotic viruses, once the index case has been detected, the country is required to take procedures to prevent further spread and eradicate.

Although environmental or maternal transmission is not a significant route of infection for BSE, transmission of scrapie may occur via these routes, although this is not considered here. Animal-to-animal transmission could occur with faecal-oral pathogens particularly in cattle and pigs, and quantitative risk assessments for such exposures have not been undertaken here due to the lack of appropriate dose-response data. Commercial poultry operations are often “all-in/all-out”, so all poultry in each batch are of the same generation and are slaughtered at the same time. There is therefore no scope for trans-generational transfer in such poultry.

3.4 Risk assessment methodology and terminology

3.4.1 Overview

A deterministic approach to microbiological risk assessment was adopted, using the arithmetic mean to accommodate variation (see Gale, 2003). This approach has been previously described in detail (Gale, 2001; 2003; 2004; 2005a; 2005b). Rather than addressing uncertainties, worst-case estimates for modelling parameters are used, so that the overall predicted risk represents an upper estimate, and readers can be confident that the actual risks will be lower. A list of key assumptions is summarised in Table 3-1.

Table 3-1: Summary of new parameters and data sources for the risk assessment, and comparison with parameters from the original (2002) risk assessment

Variable	Values from original risk assessment	Updated values based on more recent evidence	Source of updated values
Estimate of percentage of raw meat discarded to waste and going to compost	1%	Poultry (2.8%) Pig meat (1.39%) Beef (0.8%) Lamb (1.09%)	WRAP (2008a)
Bone marrow weight in pigs	5.46 kg (10% of carcass weight)	0.546 kg estimated as 1% (w/w) of the dressed carcass	Sellers (1971) reports bone marrow in pig femur to be 0.011 kg. Pig bone marrow in long bones estimated at 0.315 kg. Below 0.546 kg total viral loading estimated in carcass is little affected by amount of bone marrow
Amount of infected meat illegally imported to GB per annum	(kg / year) 620,000 (FMD) 620,000 (CSFV) 62,000 (ASFV) 620,000 (SVDV)	(kg / year) – 95th percentile 565 (FMDV) 794 (CSFV) 0.14 (ASFV) 0.021 (SVDV)	Hartnett *et al.* (2004)
Soil consumption	(kg/animal/day) 0.41 pigs Chicken – not included 0.20 sheep 0.41 cattle	Maximum values found (kg/animal/day) 0.392 pigs 0.032 chicken 0.69 sheep – 95th percentile from WRAP (2016c) 1.125 cattle – 95th percentile from WRAP (2016c)	Smith (1996); Hoffman *et al.* (2002); Thornton and Abrahams (1983); Peterson *et al.* (1974); Commission of the European Communities (1996); van der Meulen *et al.* (2008)
Compost application rates	10 tonnes (dry solids)/ha	20 tonnes dry solids (tds)/ha	Defra (2010)
Total compost produced from catering waste per year	500,000 tonnes	6,522,000 (GB) and 6,700,000 (UK) tonnes wet weight; equivalent to 3,913,200 tds (GB); 4,020,000 tds (UK)	WRAP (2008a) and assuming compost is 60% dry matter

Variable	Values from original risk assessment	Updated values based on more recent evidence	Source of updated values
Total area of land to which compost is applied	50,000 ha (England and Wales)	195,660 ha (GB only) of which 58.2% (113,897 ha) is grassland for grazing	Calculated as number of ha covered at 20 tds/ha by 3,913,200 tonnes (dry weight), assuming 58.2% of land is grassland (Anon, 2010)
Compost dilution in soil	150-fold dilution due to leaching to 10 cm depth	Depth tilled into soil 0 cm – Surface application giving no dilution 10 cm – minimum tillage giving 75-fold dilution 25 cm – plough depth giving dilution of 187.5-fold	Based on expert and stakeholder feedback, including Prof. Brian Chambers (Pers. Comm. 2008), discussion with WRAP, Gale and Stanfield (2001)
Livestock numbers exposed to compost-treated soil	England/Wales Cattle 42,800 Pigs 33,417 Sheep 157,100	GB, using England livestock densities for Scotland and Wales Cattle 181,096 Pigs 318,912 Sheep 580,875	Based on maximum livestock densities (see below) in England from Defra (2005, 2006a, 2006b) and application of compost to 195,660 ha in GB of which 58.2% used for grazing. Note that using the maximum density will provide an over-estimate for any risks, since for the purpose of calculating the number of livestock exposed, the arithmetic means should be used. These arithmetic mean data are not currently available.
Livestock densities	Cattle 0.86/ha Pigs 0.67/ha Sheep 3.14/ha	Cattle 1.59/ha Pigs 2.8/ha Sheep 5.10/ha	Defra (2005; 2006a, b) Cronin (1996)

Variable	Values from original risk assessment	Updated values based on more recent evidence	Source of updated values
BSE source term for GB	57.6 bovine oral ID_{50} units (28.8 from UK plus 28.8 imported) based on oral ID_{50} being 0.1 g of bovine brain.	95th percentile of 260.23 bovine oral ID_{50} estimated to leave abattoir in GB to food chain in 2008	Adkin *et al*., 2010
Number of cats in UK	7.5 million	9.2 million	Cats' Protection website
Percentage of cat litter discarded to green/catering waste	10%	1% as a worst-case	Valorgas (2012) found no cat litter in 1,000 food waste collection bags sampled in UK
Virus destruction by composting	4.7-log	4.61 log	WRAP, 2016b
Newcastle disease virus dose-response	Chicken oral ID_{50} = 10,000 EID_{50}	Chicken oral ID_{50} = 80 EID_{50}	Preliminary analysis of unpublished data from APHA
Newcastle disease virus soil decay data	--	-0.095 log EID_{50} per day at 21 – 27°C converted to -0.0125 log EID_{50} per day at 3 to 6°C	Analysis of data for decay on grain from Echeonwu *et al.* (2008) and soil survival times of Olesiuk (1951)
Decay rates for pathogens in soil. Note for exotic viruses decay data in slurry was used as a surrogate for soil.	Log per day CSFV (-0.05459) FMDV (-0.04847) ASFV (-0.029) *T. gondii* (-0.0119)		Liquid manures, Haas *et al.* (1995) Using data of Olson *et al.* (1999) for 1 log decay of *Cryptosporidium* in 84 days soil as a surrogate
Avian influenza virus (AIV) dose response	--	H5N1, Chicken oral ID_{50} = 1,000 EID_{50}	Unpublished data from APHA
AIV decay data	--	-0.006 log per day for virus in wildfowl wintering ground in winter	Breban *et al.* (2009)
H5N1 avian influenza virus in meat	--	10^6 EID_{50} per gram	Thomas and Swayne (2007)

3.4.2 Using a 'worst-case' approach to address modelling uncertainties

Worst-case estimates for modelling parameters were used, so that the overall predicted risk represents an upper estimate, and readers can be confident that the actual risks will be lower:

- The risk assessment assumes that all the meat discarded in GB through catering waste over a period of one year goes to compost.
- On the grassland to which catering waste-derived compost is applied, livestock graze all year at maximum livestock densities recorded in the 2005 Defra Census for England.
- 95th percentiles for soil consumption by cattle and sheep are used, and the maximum in the case of pigs.
- In the case of surface-applied compost, livestock ingest compost to the complete exclusion of soil, every day for a period of one year. There is thus no dilution of the compost in the soil for surface-applied compost. Under this approach, 6.8% of the catering waste-derived compost produced each year is assumed to be ingested by farm animals when surface applied.
- 95th percentiles are used for the amounts of BSE and scrapie infectivity entering the food chain. For exotic viruses, loadings are calculated on the basis of the infected carcasses being at the highest viraemic state together with 95th percentiles for the amount of infected meat estimated to be illegally imported into GB.
- It is assumed there is no inactivation of BSE by composting and just 0.69-log inactivation of scrapie infectivity. Recent experiments suggest composting and mesophilic anaerobic digestion, in particular, may remove significant amounts of scrapie infectivity.
- The risk assessments presented here for NDV and AIV assume 10,000 infected carcasses enter GB per year illegally. This is 15 tonnes of infected chicken meat and 20 tonnes of infected duck meat for NDV and AIV, respectively. Estimates of the amounts of pig meat infected with exotic pig viruses and illegally imported into GB are in the order of a few hundred kilograms per year. Actual amounts of illegally imported poultry meat infected with AIV and NDV would presumably be of similar magnitude.
- The number of *T. gondii* cases is calculated assuming that all 596,728 sheep grazing at 5.1 sheep/ha on the 117,005 ha of grassland (UK) treated with compost at 20 tds/ha are pregnant ewes, and that grazing ewes are pregnant all year.
- Although decay and dilution of pathogens in the soil are accommodated, no allowance is made for leaching of those pathogens to lower soil layers, beyond the reach of grazing livestock.
- Decay data were taken from experiments performed during winter months or at low temperatures for which pathogen decay rate is lower than might be expected when compost is applied during the main grass growing season.
- No decay in soil was allowed for BSE, scrapie or SVDV.
- No more than 5-log decay was allowed on land over period of one year.

3.4.3 Precision in the risk assessment model

One criticism of the quantitative approach to risk assessment used here has been that the inputs and hence the outputs are over-precise, given the likely uncertainties, and that this may give rise to over-interpretation of the outputs and a false confidence in the results. It should be remembered that the numerical final results, although precise in themselves, are only a guide to the magnitude of the risks.

The key findings of this revised risk assessment are that there is no need for tightening current composting process parameters or the length of the grazing bans, and that prevention of process by-pass, whether intrinsic or extrinsic, remains a critical control point.

3.5 Summary of results

The individual risks for CSF, ASF, FMD, SVD, NDV, AIV, *T. gondii*, scrapie and BSE are set out in Table 3-2. The predicted number of years between infections in livestock is set out in Table 3-3 for each pathogen. For scrapie the number of infections predicted per year is set out in Table 3-4.

Table 3-2: Overall summary of the individual risks of disease (risk per head per year). *Note predicted individual risks apply to an animal spending all day, every day for 1 year on land to which compost has been applied once at 20 tds/ha

Pathogen	**Surface applied (no dilution in soil)**		**Minimum tillage to 10 cm depth**	
Grazing ban	**None**	**2 month**	**None**	**3 week**
CSF	0.92 x 10^{-6}	0.76 x 10^{-9}	1.22 x 10^{-8}	0.88 x 10^{-9}
ASFV	1.1 x 10^{-10}	1.7 x 10^{-12}	1.4 x 10^{-12}	3.4 x 10^{-13}
FMDV cattle[1]	0.4 x 10^{-9}	0.52 x 10^{-12}	0.5 x 10^{-11}	0.5 x 10^{-12}
SVDV	3.7 x 10^{-15}	3.7 x 10^{-15}	4.9 x 10^{-17}	4.9 x 10^{-17}
NDV	5.3 x 10^{-7}	9.1x 10^{-8}	7.0 x 10^{-9}	3.8 x 10^{-9}
AIV	5.7 x 10^{-8}	ND	ND	ND
T. gondii[2]	8.9 x 10^{-5}	1.7 x 10^{-5}	1.2 x 10^{-6}	0.67 x 10^{-6}
Classical scrapie (95th percentile)	1.34 x 10^{-4}	1.34 x 10^{-4}	1.8 x 10^{-6}	1.8 x 10^{-6}
Atypical scrapie (95th percentile)	1.65 x 10^{-5}	1.65 x 10^{-5}	2.2 x 10^{-7}	2.2 x 10^{-7}
BSE	0.8 x 10^{-6}	0.8 x 10^{-6}	1.1 x 10^{-8}	1.1 x 10^{-8}

[1] Highest risk amongst livestock categories considered (cattle, sheep and pigs) reflecting amount of soil ingested

[2] abortion in pregnant sheep

ND, not done as grazing ban and tilling in to 10 cm difficult to enforce for backyard poultry

Table 3-3: Overall summary of results. Predicted number of years between cases of disease in GB

Pathogen	**Surface applied (no dilution in soil)**			**Minimum tillage to 10 cm depth**	
Grazing ban	**None**	**3 week**	**2 month**	**None**	**3 week**
CSF	3.4	48	4,110	256	3,579
ASFV	29,574	123,400	1,858,000	2,218,000	9,254,000
FMDV sheep	7,773	80,771	5,392,000	583,000	6,058,000
SVDV	8.6 x 10^{8}	8.6 x 10^{8}	8.6 x 10^{8}	6.4 x 10^{10}	6.4 x 10^{10}
T. gondii‡	0.019	0.335	0.1	1.4	2.5
BSE	7	7	7	511	511

[‡] abortion in pregnant sheep for UK

Table 3-4: Overall summary of results for scrapie. Predicted number of infections in GB per year

Pathogen	**Surface applied (no dilution in soil)**			**Minimum tillage to 10 cm depth**	
Grazing ban	**None**	**3 week**	**2 month**	**None**	**3 week**
Classical scrapie (95th percentile)	14.7	14.7	14.7	0.195	0.195
Atypical scrapie (95th percentile)	9.6	9.6	9.6	0.13	0.13
Total (classical and atypical)	24.3	24.3	24.3	0.325	0.325

3.6 Results for other hazards

3.6.1 Endemic faecal-oral bacteria

Due to the lack of dose-response data for faecal-oral bacterial pathogens in livestock, full quantitative risk assessments could not be performed. The approach therefore was to compare predicted loadings of *E. coli* O157 in compost with those predicted in stored manures (3 months' storage).

Assuming as a worst-case that 4-log regrowth of *E. coli* O157 occurred in meat awaiting composting, it was estimated that the *E. coli* O157 total loadings were some 4,335–fold lower than for manures stored for 3 months. It is concluded that even allowing for regrowth in compost, the total loadings of faecal pathogens such as salmonellas, *E. coli* O157 and campylobacters present in composted catering waste do not exceed those of stored manure, which is currently used on 78% of farms.

There is recent evidence that *E. coli* O157 may lose virulence genes during manure storage, so presumably the same could happen during composting. Campylobacters require unusual conditions for growth and would not grow in raw meat or in the environment (Corry and Atabay, 2001). Overall it is concluded that the exposures to livestock of faecal-oral bacteria through composted catering waste are low compared to stored manures.

3.6.2 Clostridium botulinum

The risk of botulinum intoxication to cattle through compost would be low because composting, unlike silage production, is an aerobic process such that regrowth of any *Clostridium botulinum* bacteria present in the meat should not occur during composting. Also, at temperatures of 56°C – 60°C, any bacteria germinating from spores would be inactivated. Furthermore, any botulinum toxin is likely to be diluted during the composting and soil application processes, such that cattle exposures may be below the threshold dose, although this has not been formally assessed here.

It is concluded that the risks to grazing livestock from *C. botulinum* in compost which has been tilled into a depth of 10 cm are low. However, it cannot be ruled out that spores present in compost could not multiply up in anaerobic silages produced from grass.

3.6.3 Porcine parvoviruses

Pigs in acute phases of infection shed the virus in faeces (Mengeling, 1986), which could contaminate the meat, and high levels of viral DNA have been detected in heart, liver and kidneys of infected piglets (Wilhelm *et al.,* 2005). Thus, porcine parvovirus (PPV) is likely to be present in pig meat, although lack of information on loadings of infectivity prevents a quantitative risk assessment being undertaken here. However, significant inactivation (>4.0-log) of PPV occurs over the time scales of composting (48 hours) at temperatures of 55°C to 60°C.

Composting according to the Animal By-Product Regulations (2011) should greatly reduce the levels of any PPV in catering waste. Belschner and Love (1984) write that the main ways in which porcine parvovirus can be introduced are through pigs that are actively infected and excreting the virus and by faecal contamination of introduced pigs, clothing or boots of personnel. The inactivation of PPV by composting should minimise the risks from pig meat in catering waste-derived compost compared to these routes.

While the risks through compost are lower than through other routes, it cannot at this stage be demonstrated that the risks are negligible. The magnitude of the risk would reflect loadings of virus in pig meat in GB. A quantitative risk assessment cannot be undertaken at this stage because of lack of information on loadings of PPV infectivity in meat.

3.6.4 Porcine circoviruses

There is clear evidence that porcine circovirus 2 (PCV2) is present in pig tissues including muscle, bone marrow and mammary gland, and pig milk. Indeed Opriessnig *et al.* (2009) have demonstrated that uncooked pig meat products can infect naïve pigs through the oral route. The temperature inactivation data available for PCV2 suggest that composting (60°C for 48 h) could achieve some reduction in the risks, and could (with extrapolation of 1.33 log in 24 h at 60°C) achieve 2.66-log reduction over 48 hour periods. The time-temperature combination of 60°C for 48 h achieves >3.0-log reduction for porcine parvovirus and indeed, there is some evidence that PCV2 is inactivated more rapidly than parvoviruses (albeit at 70°C).

Although the risks of transmission of PCV2 to pigs through composted catering waste may be low relative to other routes, it cannot at this stage be demonstrated that the risks are negligible. The exact role of PCV2 in post-weaning multisystemic wasting syndrome (PMWS) is not clear, and a risk assessment for PMWS is not yet feasible.

3.6.5 Methicillin-resistant Staphylococcus aureus (MRSA)

Although *Staphylococcus aureus* may be more temperature resistant than *Salmonella enterica* serotypes, available evidence suggests that composting for 60°C for 2 x 48 hours (as set out in the Animal By-Products Regulations 2011) would achieve log reductions in *Staphylococcus aureus* comparable to those of salmonellas. The risk of colonisation of pigs through contact with scraps of MRSA-infected pig skin after composting of catering waste is likely to be remote in relation to the risks from direct contact between pigs during sales. This is because singeing and scalding during processing of the pig carcass together with destruction of the *Staphylococcus aureus* during composting will greatly reduce any risks of MRSA to pigs in composted catering waste. It is concluded that further consideration of the risks of MRSA through compost is not required.

4.0 Risk assessment for the use of source-segregated composts in UK agriculture

4.1 Introduction

A research consortium led by Cranfield University and including the James Hutton Institute, APHA (Animal and Plant Health Agency) and ADAS undertook a study examining the hazards present in compost feedstocks, and the resulting risks to receptors – including humans, animals, the environment and crops. The study aimed to provide a clear evidence base for compost quality and safety, through the use of robust, traceable risk assessment. A Technical Advisory Group (TAG) of stakeholders from across the farming and food chain provided input throughout the project.

The quantitative risk assessment reported here focussed principally on humans as the receptor. This was because other receptors had been considered elsewhere: livestock exposure to green compost (WRAP, 2016c) (Section 2.0); livestock exposure to green/food compost (WRAP, 2016b) (Section 3.0); Crop exposure to plant pests and diseases in compost (Noble & Roberts, 2003); Crop exposure to selected herbicide residues in compost (WRAP, 2009b). Environmental risks from compost have also been considered elsewhere, in the context of other common land-applied materials including livestock manures and slurries (WRAP, 2016c).

4.2 Overall conclusions

In conclusion, the risks associated with the use of PAS100 composts in agriculture and field horticulture were assessed to be negligible. The results presented provide evidence that users of composts can have confidence in their safety when used responsibly.

4.3 Risk assessment approach

Two risk principles underpin this research: exposure and potency.

- Firstly, for there to be a risk of harm, the receptor must be exposed to a hazard or hazardous agent. Without exposure, there can be no risk;
- Secondly, the dose at the point of exposure must be sufficient to cause harm to the receptor. Living organisms are routinely exposed to hazards, which they tolerate and resist (i.e., a tolerable risk).

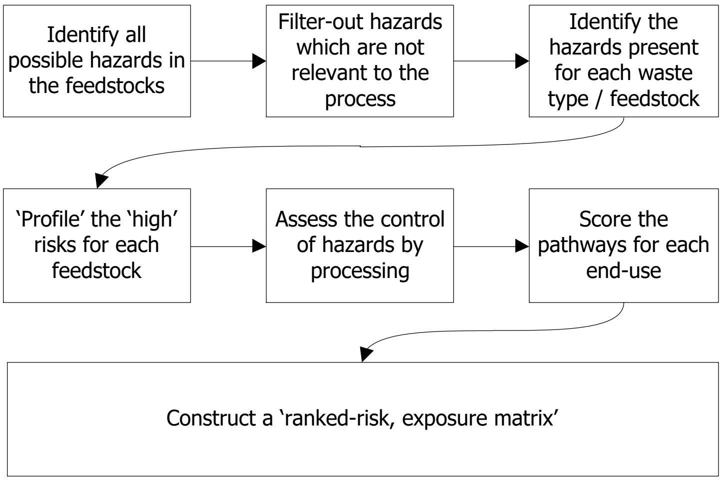
The work programme applied these principles in two stages:

- Semi-quantitative exposure assessment: which comprehensively identifies and prioritises all known hazards within PAS100-allowed feedstocks;
- Quantitative risk assessments: which analyse ‘worst case’ or ‘highest plausible hazard’ scenarios for selected hazards to assess their potency to vulnerable receptors.

4.4 Semi-quantitative exposure assessment

Figure 1 illustrates the main components of the semi-quantitative exposure assessment method.

Figure 1 Semi-quantitative exposure assessment components



4.4.1 High level findings of semi-quantitative exposure assessment

Observations from our analysis show that:

- Feedstocks with a high proportion of animal faeces were located at the top of the ranked exposure matrix. This confirms the assessment method as capable of identifying high risk feedstocks, since the presence of faecal pathogens in feedstocks results in a comparatively higher potential for hazards than other wastes, and thus a higher risk profile.
- Those pathways judged to present the greatest opportunity for exposure were: direct ingestion of compost; ingestion of soil; skin contact; and dust inhalation. Other highly available pathways were direct pathways to the environment: contamination of soil biota; contact of compost or dust from compost with plants; air contamination, e.g. bioaerosols; and water contamination. Such direct pathways of high availability have no significant barriers to exposure to certain hazards.

4.5 Quantitative risk assessment

The final selection of QRA scenarios was determined in agreement with the stakeholders. It was recognised that these represented the potential for significant harm to individual receptors and/or specific market concerns. In addition, examples were selected where the semi-quantitative exposure assessment indicated that there was a high probability of exposure. Table 4-1 lists the key parameters for the scenarios considered. A number of suggested scenarios were not modelled, since they had already been considered elsewhere (as summarised in Sections 2.0 and 3.0 of this report). Where data were not available to undertake a quantitative assessment, e.g. sharps, then a commentary on the implications for assessment and risk was added.

4.5.1 Toxicological (and physical) hazards: risk assessment approach

Where harm is assessed as a result of an increasing probability or concentration of exposure to a hazard, then this is calculated as a hazard quotient. Examples of this include exposure to increasing levels of a toxin or toxic elements, accumulated exposure to pollutants, or the chances of exposure to a harmful incident. Management approaches to such incidents are focused on reducing risks to as "as low as reasonably practicable" [ALARP], an approach often used in safety-critical systems. In the case of pathogens, the concept of infectious dose is used instead (Section 4.5.2).

The aim of the exposure assessment was to estimate the Average Daily Dose (ADD; mg kg^{-1} bodyweight d^{-1}) of a specific agent (plant toxin, organic contaminant) to a specific receptor (human, animal). To estimate exposure for each of the risk assessment scenarios, it was necessary to make a series of worst-case assumptions. This meant that where a range of values were available for a specific parameter, the extreme of the distribution was selected. For example, we estimated exposure for a person who is the 95 %ile vulnerable consumer of ready to eat crops, rather than for an average consumer.

4.5.1.1 Risk characterisation

Risk was defined as the ratio of an estimated daily dose, mg kg^{-1} d^{-1} to the reference dose to provide a ratio. In this study, this was called a ‘hazard quotient’.

Broadly speaking, where a hazard quotient was calculated to be less than 1, the estimated daily dose was below the published reference daily dose and could be considered to present negligible risk to receptors. Most of the reference daily doses used in this study had an in-built uncertainty factor with a 100-fold margin of safety established from existing practice. Therefore, a hazard quotient of >1 but <100 can be considered to be ‘as low as reasonably practicable’.

4.5.1.2 Data sources

All agricultural scenarios were based on the exposure models described in WRAP (2016c). In this respect, the same application rates, ploughing depths, bulk density (kg L^{1}) of moist compost, grazing densities and grazing animal characteristics as WRAP (2016c) were employed. Where human receptors were included in the QRA scenario, population subgroups were defined according to Hough *et al.* (2004). Further information used in each scenario is detailed in Table 4-1.

Table 4-1 Summary of information and data sources used in each toxicological and physical contaminant QRA scenario

Scenario	Scenario description	Data and Information sources
S2	Incorporation of foreign bodies (glass, metal, plastic) into growing root vegetables	Levels of foreign bodies in PAS100 compost: PAS100 limits; Incidence of contamination of vegetables by foreign bodies: Pallav *et al.* 2009; Graves *et al.* 1998
S3	Exposure of sensitive crops to herbicide residues in source-segregated green waste [SSGW] compost applied to agricultural land	Concentrations of herbicide residues in SSGW compost: Brändli 2006; Bezdicek *et al.* 2001; Miller *et al.* 1992; Recommended application rates/thresholds: Boydston *et al.* 2008; Brändli 2006; Dvorak & Remesova 2001; Renner 2000; Hatfield *et al.* 1978; Collins (unknown date)

Scenario	Scenario description	Data and Information sources
S8	Impact of fungicide residues in SSGW compost on barley grain quality and fermentative power	Fungicide residue levels in SSGW compost: Brändli 2006 Impacts of fungicides on crop/grain quality: Hrivna 2003; Yang *et al.* 2000 Fate and impact of fungicide residues during brewing: Navarro *et al.* 2005; Miyake *et al.* 2003; 2002; 1999; Jones *et al.* 1988
S9	Risks to crop quality from glues and PVA in wood waste incorporated into compost applied to arable land	No QRA attempted: treated wood and wood containing glues/PVA not permitted under PAS100
S10a	Human exposure to PCBs and PCDD/Fs in ready to eat crops grown in soil amended with SSGW compost	Levels of PCBs in SSGW compost: Marb *et al.* 2001; Vergé-Leviel 2001; Zethner *et al.* 2000; Hund *et al.* 1999; Aldag & Bischoff 1995; Bayerisches Landesamt fur Umweltschutz 1995; Berset & Holzer 1995; Krauss 1994 Levels of PCDD/Fs in SSGW compost: Brändli et al 2005; Kuhn & Arnet 2003; Marb *et al.* 2001; Zethner *et al.* 2000; Kummer 1996; Bayerisches Landesamt fur Umweltschutz 1995; Aldag & Bischoff 1995; Krauss 1994; Malloy *et al.* 1993; Harrad *et al.* 1991; Kummer 1990 Bio-concentration factors for PCBs: Mikes *et al.* 2009; Åslund et al 2008; Inui et al 2008 Bio-concentration factors for PCDD/Fs: Inui et al 2008 Consumption of RTE by human receptors: Konz *et al.* 1989 Water content of ready to eat crops: Duckworth 1966
S10b	Human exposure to marine biotoxins from composted shellfish applied to ready to eat crops	Operational aspects of shell fish composting: Bord Iascaigh Mhara 2003 Levels of biotoxins in compost assumed as regulatory limits: EC, 2004 Consumption of RTE by human receptors: Konz *et al.* 1989 Water content of ready to eat crops: Duckworth 1966 Biotoxin reference doses (RFD): FAO 2004; EU/SANCO 2001; Ofuji *et al.* 1999

Scenario	Scenario description	Data and Information sources
S10c	Human exposure to lead via consumption of eggs from free range hens grazed on compost-amended land	Grazing density: Van Overmeire *et al.*, 2009 Soil ingestion by poultry: Van Overmeire *et al.*, 2009) Chicken physiology: Oomen *et al.*, 2002 Transfer of Pb from diet to eggs: Trampel *et al.*, 2003 Egg laying rhythm: Waegeneers *et al.*, 2009 Assume 100 % of all egg intake is derived from eggs laid by hens exposed to the source term Water content of eggs Moran & Hale 1936) Consumption of eggs: Defra, 2007 Oral reference doses: Mushak *et al.* 1989
S10d	Human exposure to cadmium via consumption of kidney/liver from cattle grazed on compost-amended land	Levels of PTEs in compost: PAS100 standards assumed Assumed surface spread Transfer rate of Cd to the tissues of cattle: Crout *et al.* 2004 1000 days of grazing were assumed Assume 100 % of all offal intake is derived from cattle exposed to the source term for 1000 days Consumption of beef kidney: DEFRA 2007 Consumption of beef liver: DEFRA 2007 Oral reference doses: USEPA 1985
S10e	Human exposure to PCBs and PCDD/Fs in eggs from free-range laying hens grazing land amended with PAS100 green compost	Concentrations of total PCBs in SSGW compost: Krauss 1994; Aldag & Bischoff 1995; Bayerisches Landesamt fur Umweltschutz 1995; Berset & Holzer 1995; Hund et al 1999; Marb et al 2001; Vergé-Leviel 2001; Zethner et al 2000 Concentrations of total PCDD/Fs in SSGW compost: Kummer 1990; Harrad et al 1991; Malloy et al 1993; Krauss 1994; Aldag & Bischoff 1995; Bayerisches Landesamt fur Umweltschutz 1995; Kummer 1996; Zethner et al 2000; Marb et al 2001; Kuhn & Arnet 2003; Brändli et al 2005 All other sources as for Scenario 10c

Scenario	Scenario description	Data and Information sources
S10f	Human exposure to arsenic in carrots grown in soil amended with PAS100 green compost	Concentrations of aqua regia-extractable Arsenic (As) was assumed as the 95th %ile concentration from available data: Petrell *et al.* 2003; SMA 1998; Greenway & Song 2002 Assume 100 % of all RTE intake is derived from crops grown using the source term Water content of carrots: Duckworth 1966 Consumption of carrots: DEFRA 2007 Oral reference doses: Tseng 1977; Tseng et al 1968
S13	Uptake of cadmium and lead from SSGW compost applied to cereal crops	Levels of PTEs in compost: PAS100 standards assumed Uptake of PTEs by wheat and maize: Hough *et al.* 2003 Water content of post-harvest crops: HGCA 2001; Xiccato *et al.* 1994 Maximum permissible concentrations of PTEs for animal feed and human consumption: EC, 2001; EC, 1999
S15	Human exposure to potentially toxic elements (PTEs) from consumption of ready to eat crops to which ABP compost has been applied	Levels of PTEs in compost: PAS100 standards assumed Consumption of RTE by human receptors: Konz *et al.* 1989 Reference doses for PTEs: Hérbert 1993; Mushak et al 1989; Yadrick *et al.* 1989; USEPA 1985; Ambrose *et al.* 1976

4.5.2 Microbiological hazards: risk assessment approach

In the case of pathogens, the concept of infectious dose was used with a classic source-pathway-receptor approach. Outputs from this model for the pathogens *E. coli* O157, *Salmonella* spp., *Campylobacter* spp., *Listeria monocytogenes* and *Cryptosporidium parvum* are presented below.

The dose-response model assumes that pathogens act independently and that the minimum infectious dose is one pathogen (Gale, 2005a). This approach is worst case in that if there were a threshold dose, then low pathogen doses would present much lower risks than assumed in the model here.

The numerical final results, although precise in themselves, are only a guide to the magnitude of the risks. Clearly there is uncertainty associated with the final result, and that uncertainty is not defined in deterministic risk assessments.

4.5.2.1 Assumptions and data sources for microbiological risk assessment

A set of common assumptions and data sources for the microbiological risk assessments is presented in Table 4-2. Data sources and assumptions for individual pathogens are listed in Table 4-3, Table 4-4, Table 4-5, Table 4-6 and Table 4-7.

Table 4-2 Common assumptions and data sources for microbiological risk assessment

Impact of composting	4.61-log$_{10}$	WRAP, 2016b
Quantity of compost	4,020,000 tonnes of compost produced annually	WRAP, 2012
Dilution in soil	20 tonnes (dry solids) per hectare per year and tilled to a depth of 10 cm	Based on typical compost dry solids content, compost application rates and soil bulk density
Harvest interval	42 days	Based on typical interval for salad crop maturation
Ingestion of soil associated with RTE crops	0.35 grams of soil per day	Assumes 2% of dry matter of ingested crops is soil (Gale, 2005a)

Table 4-3 Key data sources and assumptions for *E. coli* O157

Source	Meat in catering waste: 8,383 tonnes of raw beef and 5,115 tonnes of mutton and lamb	WRAP (2008a)
Loading	44 *E. coli* O157 g^{-1} of minced beef	Cagney *et al.* (2004)
Regrowth before composting	4 log	Based on the results of Berry and Koohmaraie (2001)
Total loading to compost	4.94 x 10^{15} Colony Forming Units (CFU)	Calculated
Loading in compost	3.63 x 10^{4} CFU tonne^{-1}	Calculated
Decay in soil	4.59-log$_{10}$	Nicholson *et al.*, 2005
Loading in soil after harvest interval	0.0123 CFU tonne^{-1} soil	Calculated

Table 4-4 Key data sources and assumptions for *Salmonella* spp.

Source	Meat in catering waste: 58,308 tonnes of raw poultry meat are discarded each year (equating to 25,800,000 carcasses) 19,705t raw pork discarded to catering waste each year	WRAP (2008a)
Loading	278CFU per chicken carcass 2.1Most Probable Number (MPN) g^{-1} raw pork	Jorgensen *et al.* (2002) Prendergast *et al.* (2009)
Regrowth before composting	4 log	Based on Berry and Koohmaraie (2001)
Total loading to compost	8.30 x 10^{13} CFU	Calculated
Loading in compost	5.05 x 10^{2} CFU tonne^{-1}	Calculated

Decay in soil	4.59-$\log_{10}$	Nicholson *et al.*, 2005
Loading in soil after harvest interval	1.72 x 10^{-4} CFU tonne^{-1}	Calculated

Table 4-5 Key data sources and assumptions for *Campylobacter*

Source	Raw chicken in catering waste: 58,308 tonnes of raw poultry meat discarded each year (equating to 25,800,000 carcasses)	WRAP (2008a)
Loading	85,500 MPN carcass^{-1}	Gale (2002)
Regrowth before composting	None	Corry and Atabay, 2001
Total loading to compost	2.21 x 10^{12} CFU	Calculated
Loading in compost	13.5 CFU tonne^{-1}	Calculated
Decay in soil	4.2-$\log_{10}$	Nicholson *et al.*, 2005
Loading in soil after harvest interval	1.13 x 10^{-5} CFU tonne^{-1}	Calculated

Table 4-6 Key data sources and assumptions for *Listeria monocytogenes*

Source	Ready-to-eat meat in catering waste: 9,151 tonnes	Assume 10% of all meat discarded. WRAP (2008a)
Loading	10^8 CFU g^{-1} meat (for 1% of RTE meat, the remainder containing <100 CFU g^{-1})	Patterson *et al.* 2011 Little *et al.* (2009) Meldrum *et al.*, 2010 Elson *et al.*, 2004 Sagoo *et al.*, 2007
Regrowth before composting	None	Corry and Atabay, 2001
Total loading to compost	9.15 x 10^{15} CFU	Calculated
Loading in compost	5.6 x 10^4 CFU tonne^{-1}	Calculated
Decay in soil	4.59-$\log_{10}$	Nicholson *et al.*, 2005
Loading in soil after harvest interval	1.9 x 10^{-2} CFU tonne^{-1}	Calculated

Table 4-7 Key data sources and assumptions for *Cryptosporidium parvum*

Source	33,202 tonnes of raw pork, beef and lamb	WRAP (2008a)
Loading	3.0 x 10^2 g^{-1} meat	Hutchison *et al.* 2004 (assumes that the beef, pork and lamb meat components are contaminated with 0.01% (w/w) faeces (Gale, 2002))

Regrowth before composting	None	Corry and Atabay, 2001
Total loading to compost	1.34×10^{8} oocysts	Calculated
Loading in compost	8.21×10^{-4} oocysts tonne^{-1}	Calculated
Decay in soil	2.0-$\log_{10}$	Hutchison *et al.*, 2002
Loading in soil after harvest interval	1.1×10^{-7} oocysts tonne^{-1}	Calculated

4.6 Quantitative risk assessment results

4.6.1 Toxicological hazards

4.6.1.1 Overview

The results of the QRA exercise indicated that none of the hazards assessed, for the specific scenarios selected, presented an intolerable risk to the receptors identified.

In only a handful of the many exposure/receptor combinations considered were calculated hazard quotients in the order of unity, suggesting that risks lie within the ALARP region. The implications of this are very scenario-specific and are influenced by the margin of safety provided by the 'safe' dose, the vulnerability of the receptor, and the parameter-specific assumptions used within the QRA.

4.6.1.2 Scenario 3: Exposure of sensitive crops to herbicide residues in SSGW compost applied to agricultural land

Hazard quotients did not exceed 1 for either potatoes or peas and beans, indicating that risks can be considered negligible for the following herbicides:

2,4-D	Atrazine	Oryzalin	Terbuthylazine
Alachlor	Clopyralid	Oxadiazon	

4.6.1.3 Scenario 8: Impact of fungicide residues in SSGW compost on barley grain quality with particular reference to fermentative properties

Hazard quotients for the following fungicides were calculated as the ratio of the modelled fungicide concentration in grain to the legally permitted maximum residue level in the grain, based on the assumption that concentrations exceeding the maxima would impact negatively on fermentation characteristics when the grains were used for brewing:

Azaconazole	Epoxiconazole	Myclobutanil
Azoxystrobin	Etaconazole	Oxadixyl
Bitertanol	Fenbuconazole	Propiconazole
Cyproconazole	Fenhexamide	Pyrifenox
Cyprodinil	Fempropimorph	Tebuconazole
Difenoconazole	Flusilazole	Thiabendazole
Dimethomorph	Flutolanil	Thiophanate-methyl
Dodemorph	Imazalil	Triadimenol

The hazard quotients did not exceed 1 for any of the fungicides modelled, indicating that risks can be considered negligible.

4.6.1.4 Scenario 10a: Human exposure to PCBs and PCDD/Fs in ready to eat crops grown in soil amended with SSGW compost

Hazard quotients for the following PCBs and dioxins were considered in this scenario:

PCB 28	PCB 95	PCB 118	PCB 138	PCB 153	PCB 180
PCB 52	PCB 101	PCB 132	PCB 149	PCB 174	Total dioxins

Potential impacts on an 'average person', 'highly exposed infant' and '95th percentile vulnerable person' were modelled. The Hazard Quotient did not exceed 1 for any of the compounds or populations modelled, indicating that risks can be considered negligible.

4.6.1.5 Scenario 10b: Human exposure to marine biotoxins from composted shellfish applied to ready to eat crops

Hazard quotients for the following marine biotoxins were considered in this scenario:

PSP	Paralytic Shellfish Poisoning
ASP	Amnesic Shellfish Poisoning
OA	Okadaic Acids
YTX	Yessotoxins
AZA	Azaspiracids

Potential impacts on an 'average person', 'highly exposed infant' and '95th percentile vulnerable person' were modelled. The Hazard quotient did not exceed 0.1 for any of the compounds or populations modelled, indicating that risks can be considered negligible.

4.6.1.6 Scenario 10c: Human exposure to lead via consumption of eggs from free range hens grazed on compost-amended land

Hazard quotients for lead did not exceed 1 for any of the population groups considered ('average person', 'highly exposed infant' and '95th percentile vulnerable person'), indicating that risks can be considered negligible.

4.6.1.7 Scenario 10d: Human exposure to cadmium via consumption of kidney/liver from cattle grazed on compost-amended land

Hazard quotients for cadmium did not exceed 0.01 for any of the population groups considered ('average person', 'highly exposed infant' and '95th percentile vulnerable person') for either kidney or liver consumption, indicating that risks can be considered negligible.

4.6.1.8 Scenario 10e: Human exposure to PCBs and PCDD/Fs in eggs from free-range laying hens grazing land amended with PAS100 green compost

Hazard quotients for PCBs and PCDD/Fs did not exceed 1 for any of the population groups considered ('average person', 'highly exposed infant' and '95th percentile vulnerable person'), indicating that risks can be considered negligible.

4.6.1.9 Scenario 10f: Human exposure to arsenic in carrots grown in soil amended with PAS100 green compost

Hazard quotients for arsenic did not exceed 0.01 for any of the population groups considered ('average person', 'highly exposed infant' and '95th percentile vulnerable person'), indicating that risks can be considered negligible.

4.6.1.10 Scenario 13: Uptake of cadmium and lead from SSGW compost applied to cereal crops

Hazard quotients for cadmium and lead did not exceed 0.1 whether the crops under consideration was wheat or maize, indicating that risks can be considered negligible.

4.6.1.11 Scenario 15: Human exposure to potentially toxic elements (PTEs) from consumption of ready to eat crops to which PAS100 green compost has been applied

Hazard quotients for the potentially toxic elements (PTEs) considered in this scenario (Cd, Cu, Pb, Ni and Zn) did not exceed 0.1 in any of the populations modelled, indicating that risks can be considered negligible.

4.6.2 Microbiological hazards

4.6.2.1 Overview

It is concluded that the risks to humans from *Listeria monocytogenes*, *Cryptosporidium parvum* and *Campylobacter* through consumption of ready-to-eat crops are remote. The predicted risks from *E. coli* O157 and *Salmonella* are higher – although still low – reflecting the worst-case assumptions adopted regarding loading on meat, regrowth on meat and dose-response. Decay on the soil and dilution of the compost in the soil (e.g. by tilling-in) are important in reducing the risks from *E. coli* O157 and *Salmonella* to acceptable levels.

Table 4-8 Summary of baseline risks of infection (42 days decay on soil and 10 cm depth of incorporation) to humans through consumption of ready-to-eat crops grown on soil treated with compost

	Individual risk (per person per year)	Number of years between infections in UK	Number of underlying infections
E. coli O157 (illness)	1.70×10^{-8}	26	1,182 cases in 2011 and an annual average of 786 cases in the 21 years between 1991 and 2011
Campylobacter	2.75×10^{-11}	16,230	64,608 cases reported to the UK-HPA in 2011
Salmonella	1.30×10^{-8}	34	8,998 cases reported for 2010
L. monocytogenes	1.13×10^{-11}	39,497	4,480 cases recorded by the HPA between 1983 and 2011, or the 147 cases in 2011 alone
C. parvum	5.86×10^{-14}	7,616,396	Between 3,000 and 6,000 cases reported to the HPA in the UK annually.

4.6.2.2 Changing the harvest interval

Decay over the 42 day time period is significant in reducing the risks from *Salmonella* and *E. coli* O157 to the acceptably-low levels reported in Section 4.6.2.1. This is not surprising since decay in soil contributes 4 to 5-log decay for the bacterial pathogens over the 42 days, representing a 10,000 to 100,000-fold reduction in risk. The 75-fold reduction in risk through dilution of the compost in the soil is also important for minimising the risks of *Salmonella* and *E. coli* O157.

Further analysis is shown here to take account of field practices where, in contrast to the guidance provided, some growers use harvest intervals of 14 days and 28 days for ready-to-eat crops. For the bacterial pathogens, the decay data of Nicholson *et al*. (2005) were used, while the data of Hutchison *et al.* (2002) were used for *C. parvum*. The predicted numbers of infections per year for source-segregated composts are set out in Table 4-9.

Table 4-9 Predicted mean number of human infections in GB (average time between infections) from consumption of ready to eat vegetable crops grown on soil treated with source-segregated compost tilled to 10 cm depth: Sensitivity to duration of harvest interval between applying compost and harvesting crop.

Harvest interval/decay time on soil	**14 days**	**28 days**	**42 days**
E. coli O157 (illness)	43.3 per year (0.023 years)	1.27 per year (0.78 years)	0.04 per year (26.7 years)
Salmonella	33.6 per year (0.03 year)	1.0 per year (1.0 years)	0.029 per year (34.4 years)
Campylobacter	0.04 per year (26 years)	1.6×10^{-3} per year (647 years)	6.2×10^{-5} per year (16,245 years)
Listeria monocytogenes	0.03 per year (34 years)	8.7×10^{-4} per year (1,154 years)	2.5×10^{-5} per year (39,337 years)
Cryptosporidium parvum	2.8×10^{-6} per year (354,000 years)	6.1×10^{-7} per year (1.6 million years)	1.3×10^{-7} per year (7.6 million years)

While short harvest intervals predict high numbers of infections/illness for *E. coli* O157 and salmonellas, it should be noted that an unrealistic 4-$\log_{10}$ regrowth was allowed for on the meat for both these pathogens. Where growers of very high value, short growth period baby leaf salads wish to use source-segregated composts, they should satisfy themselves that the substrate is of appropriate sanitary quality. This may require a degree of processing and testing that would be over and above the baseline norms considered in this risk assessment.

4.6.2.3 Scenario 7b: Human exposure to pathogens from minimally-processed grains (oats) grown in soil amended with green/food compost

Two heat treatments are commonly used in the processing of combinable crops such as oats (Gates, 2007). The first, kilning, is to stabilise the oat. The second is steam-tempering to soften the oat during flaking. Kilning and tempering typically involves temperatures of >80°C for at least 30 min (Gates *et al.*, 2008). After steaming, the oats are tempered in an oven at 80 – 110°C for 30 – 90 minutes (Gates, 2007). Avery *et al.* (2009) report that treatment at 60°C for 10 min effectively eradicated *E. coli* O157 in abattoir wastes, and 50°C for 10 min gave 2 – 4 log reductions. Based on this, it is concluded that heat treatment used in the processing of oats will eliminate any *E. coli* O157 such that the risks to humans are negligible.

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