Summary report

Digestate quality and safety for agriculture

This report summarises the findings of a project commissioned by WRAP to investigate the safety of digestate meeting the PAS 110 quality specification, when used in agriculture and field horticulture. A wide range of hazards were considered – including microbiological, chemical and physical – and risks from digestate use were considered to be acceptably low or negligible in all scenarios examined.

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Front cover photography: Spreading digestate

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Acknowledgements

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- *Risk-based guidance for the use of source-segregated anaerobic digestates in GB agriculture.* Written by: Phil Longhurst*, Sean Tyrrel, Simon Pollard & Ruben Sakrabani - Cranfield University; Brian Chambers & Matt Taylor – ADAS; Audrey Litterick – Earthcare Technical; Paul Gale, Ashley Goddard & Emma Snary, APHA. WRAP project OAV036-008

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Additional thanks are due to the members of the stakeholder steering group who informed the direction of the research summarised here, amply voiced their concerns and questions around digestate safety, and contributed significantly to the overall value of this work.

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

1.0 Context: Digestate and anaerobic digestion in the UK

1.1 What is digestate?

Anaerobic digestion [AD] is a naturally occurring process in which microorganisms break down biodegradable matter in the absence of oxygen. A mixture of carbon dioxide [CO_2] and methane [CH_4] (referred to as biogas), and digestate – a nitrogen-rich biofertiliser – are all products of this process. Biogas is an important source of renewable energy, while the digestate can be used as a renewable fertiliser or soil conditioner.

AD helps deliver a more sustainable farming sector by providing low carbon fertilisers for agriculture, allowing resources to be reused on-farm to reduce greenhouse gases, and provide secure and more sustainable fertiliser inputs (Defra, 2011). Nutrient input, particularly nitrogen, is the biggest determinant of crop yield and has major impacts on crop/sward structure and botanical composition. Currently, inorganic fertilisers are a major source of nutrient input on the majority of agricultural land. Whilst a considerable proportion of agricultural land also receives amendments of livestock manures and slurries, biofertiliser is becoming increasingly available. Using digestate can result in a lower carbon footprint than associated with (conventional) inorganic fertilisers, which it can partially replace (Defra, 2011).

1.2 Digestate production and markets in the UK

Anaerobic digestion can be deployed to treat suitable materials across a range of sectors, including: farming (crops, crop residues, livestock manures and slurries); processing industries (food and drink manufacture); commercial enterprises (food and drink processing and supply). When deployed in the industrial sector, anaerobic digestion is normally incorporated as one stage of a multi-stage effluent treatment system. This means that digestates from industrial AD facilities are normally subjected to further treatment and then discharged to sewer or water course. By contrast, digestates from farm-fed and commercial AD systems are usually available for use on land as a biofertiliser.

Survey data for 2013 report that over a million tonnes of digestate were applied to agricultural land during that year (WRAP, 2014). The agriculture market represented 98% of all markets reported as having accepted digestate in 2013. Continued confidence in the use of digestate in UK agriculture is therefore essential to maintaining the effective use of this resource.

1.3 About this summary report

Whilst the agronomic value of digestate cannot be disputed, its perceived origins from 'waste' materials can prove problematic in the market place. Digestate is produced and used under a range of regulatory constraints, whether it has been made from materials including food waste or not (WRAP, 2016b). However, despite this, and the adoption of the BSI PAS 110 specification for digestate quality (BSI, 2014), key market stakeholders have raised questions around the quality, safety and usability of digestate – 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 Digestate' programme to understand and address stakeholder concerns. The resulting portfolio of projects included a

comprehensive risk assessment devoted to digestate used on land used to grow ready-to-eat and cereal crops for human consumption, and on land used to graze livestock or grow fodder crops for consumption by livestock.

The conclusions from this research underpin WRAP's 'Renewable Fertiliser Matrix', which clearly illustrates cropping and grazing situations where digestate can be safely used. The accompanying good practice guidance available at www.wrap.org.uk/dc-agri provides agronomic advice for digestate use (WRAP, 2016b).

1.4 Overall conclusions

The conclusion of this study is that the risks associated with the use of PAS110 digestates in GB agriculture are assessed to be acceptably low and in many cases, negligible. Whilst it is correct to assert that the risks assessed are negligible, it is also appropriate to recognise that regulatory compliance, strict adherence to the requirements of the PAS110 digestate specification, and a precautionary approach to exposure is prudent. Opportunities to minimise prolonged exposure to any waste-derived material – as well as natural soils and fertilisers – is a sensible precaution. Therefore, normal hygiene practices should be adhered to, such as avoidance of direct handling.

Where growers of very high value, short growth period baby leaf salads wish to use source-segregated digestates, they should satisfy themselves that the materials are 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.

2.0 Introduction

The aim of this work was to develop a full understanding of any residual risks to crops, humans, animals and the environment from the use of source-segregated anaerobic digestate (also referred to as biofertiliser), produced in accordance to the requirements of the baseline PAS110 specification for digestate quality.

Based on the understanding of residual risks developed in this study, a 'Biofertiliser Matrix' was proposed. This built on the PAS110 baseline by suggesting further controls that could be applied to biofertilisers in specific agricultural markets to minimise these risks. When combined with the outputs from three previous risk assessments for the use of composts in agriculture (WRAP, 2016a, 2016c, 2016d) this was subsequently expanded into a 'Renewable Fertiliser Matrix'. This matrix has been incorporated into good practice guidance for the use of composts and digestates in UK agriculture (WRAP, 2016b).

2.1 Project approach

This study was not intended to be all encompassing, as it drew extensively on assessments that had been undertaken elsewhere, including the previous Cranfield University AD-Exposure Assessment (WRAP, 2008). Importantly, input from a stakeholder steering group [SSG] was an integral part of this project – particularly for development and agreement of plausible high hazard scenarios.

More than 140 individuals and organisations, representing food producers, quality assurance organisations, retailers, the anaerobic digestion industry, regulators, and Government departments participated in the SSG across a series of three workshops and direct feedback.

Information gathered during the first workshop was collated into summary tables and allocated into one of the following categories:

- Scenarios for which quantitative risk assessment [QRA] would be conducted;
- Scenarios for which qualitative assessments were undertaken – normally in circumstances in which insufficient information was thought likely to exist in support of a full QRA.

Full lists of completed scenarios are given in Table 1-1 and Table 1-2.

Table 1-1 Summary of completed quantitative risk assessments

Hazards of concern	High hazard pathways considered	Sensitive receptors considered
E. coli O157	Ready to eat crops	Humans
Campylobacter	Ready to eat crops	Humans
Salmonella	Ready to eat crops	Humans
Listeria monocytogenes	Ready to eat crops	Humans
Cryptosporidium parvum	Ready to eat crops	Humans
Scrapie	Grazing land	Sheep and goats
Foot and mouth disease	Grazing land	Livestock
Classical swine fever	Grazing land	Livestock
Toxins naturally present in ragwort (*Senecio jacobaea)*	Grazing land	Livestock

Table 1-2 Summary of completed qualitative risk assessments

Hazards of concern	High hazard pathways considered	Sensitive receptors considered
Tapeworm (*Taenia saginata*)	Ready to eat crops	Humans
Legionella	Ready to eat crops	Humans
Aspergillus	Ready to eat crops	Humans
Mycobacterium paratuberculosis	Grazing land	Sheep and goats
Liver and Rumen flukes	Grazing land	Livestock
Neospora caninum	Grazing land	Livestock
Sarcocystis	Grazing land	Livestock

Hazards of concern	High hazard pathways considered	Sensitive receptors considered
Bovine Cysticercosis	Grazing land	Livestock
Toxoplasma	Grazing land	Livestock
Polychlorinated biphenyl (PCBs) & Plychlorinated dibenzodioxins (PCDD/Fs)	Ready to eat crops	Humans
Polychlorinated biphenyl (PCBs) & Plychlorinated dibenzodioxins (PCDD/Fs)	Grazing land	Livestock
Polycyclic aromatic hydrocarbons (PAHs)	Ready to eat crops	Humans
Polycyclic aromatic hydrocarbons (PAHs)	Grazing land	Livestock
Potentially Toxic Elements (PTEs) (metals)	Ready to eat crops	Humans
Potentially Toxic Elements (PTEs) (metals)	Grazing land	Livestock
Potato cyst nematodes (PCN)	Crop land	Crops e.g. potatoes
Free-living nematodes e.g. stubby root nematodes	Crop land	Crops e.g. potatoes
Powdery and common scab	Application to soil	Potatoes
Ring rot	Application to soil	Potatoes
Brown rot	Application to soil	Potatoes
Phytophthora	Application to soil	Potatoes
Rhizoctonia	Application to soil	Potatoes
Clubroot	Application to soil	Brussels sprouts
Fusarium	Application to soil	Cereals

2.2 Project scope

This study is limited by the following criteria:

- PAS110-compliant processing (with particular reference to the pasteurisation requirements);
- ADQP (Anaerobic Digestate Quality Protocol) permitted source-segregated feedstocks;
- Plausible high hazards. i.e. Circumstances where the concentration of a contaminant is considered to be at a theoretical maximum for PAS110 compliant processes;
- Whole (wet) digestates – as opposed to separated fractions of liquor or fibre – with a dry matter content less than 15%;
- Batch pasteurisation at 70°C for one hour.

2.3 Risk assessment approach – microbiological hazards

2.3.1 Overview

The application of two risk principles – exposure and potency (or dose) – underpins this research. Firstly, for there to be a risk of harm there must be exposure 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. Living organisms are routinely exposed to hazards, which they tolerate and are resistant to. Therefore, the study sets out a series of scenarios with which to understand the potential risks from the highest realistic exposures to the most susceptible receptors. 'Worst case realistic scenarios' are used to define conditions where a judgement has been made of the highest plausible hazard that can be assumed for the analysis. This is determined for exposure to, or dose of, a given hazard. These highest plausible hazard scenarios are intended to represent a justifiably cautious approach to risk assessment as opposed to unreasonably precautionary scenarios adopting hypothetical assumptions.

The method used sought evidence from existing research in addition to a comprehensive programme of consultation with sector representatives. All concerns raised by individual stakeholders were recognised, documented and addressed through a screening process that allowed priorities to be determined for each Quantitative Risk Assessment (QRA) scenario.

2.3.2 Approach

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

The dose-response model assumes that pathogens act independently and that the minimum infectious dose is one pathogen (Gale, 2005). 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, should only be considered a guide to the magnitude of the risks.

2.3.3 Assumptions and data sources

A set of common assumptions and data sources for the microbiological risk assessments is presented in Table 2-1. Data sources and assumptions for individual pathogens are listed in Table 2-2, Table 2-, Table 2-, Table 2- and Table 2-.

Table 2-1 Common assumptions and data sources for microbiological risk assessment

Quantity of digestate	2,520,000 tonnes of digestate produced annually	Assumes 2,000,000 tonnes manure / slurry available for digestion and 12% of all meat supplied (based on Defra statistics)
Dilution in soil	30-fold, based on 50t/ha (fresh weight) diluted to 10cm depth in a soil of density 1.5 g/cm^3	Calculated, based on expert opinion
Grazing interval	Zero	Worst case assumption: a

		statutory interval would always apply in practice
Harvest interval	42 days	Assumed, based on expert opinion
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, 2005)

Table 2-2 Key data sources and assumptions for *E. coli* O157

Source	Meat: 174,619 tonnes of beef, veal, mutton and lamb Livestock slurry: 2,000,000 tonnes	Equates to 12% of each type of meat supplied Slurry quantity is an estimate, based on expert opinion
Loading	44 CFU *E. coli* O157 g^{-1} of meat 2.9×10^6 CFU g^{-1} of slurry	Cagney *et al.,* 2004 Hutchison *et al*., 2004
Regrowth before AD	4 log	Based on the results of Berry and Koohmaraie, 2001
Total loading to digestion	8.42×10^{17} CFU per year	Calculated
Impact of pasteurisation	6.0 $\log_{10}$	Modelled from Sahlstrom *et al.*, 2008
Impact of digestion	1.5 $\log_{10}$	Modelled from Horan *et al*., 2004
Loading in digestate	3.63×10^4 CFU $tonne^{-1}$	Calculated
Decay in soil	4.59-$\log_{10}$	Modelled from Nicholson *et al.*, 2005
Loading in soil after harvest interval	9.05×10^{-3} CFU $tonne^{-1}$ soil	Calculated

Table 2-3 Key data sources and assumptions for *Campylobacter* spp.

Source	Meat: 189,747 tonnes of chicken Livestock slurry: 2,000,000 tonnes	Equates to 12% of each type of meat supplied Slurry quantity is an estimate, based on expert opinion
Loading	85,500 CFU per chicken carcass 7.6×10^3 g^{-1} of slurry	WRAP, 2016a Hutchison *et al.*, 2004
Regrowth before digestion	None	Corry and Atabay, 2001
Total loading to digestion	7.18×10^{12} CFU	Calculated
Impact of pasteurisation	6.0 $\log_{10}$	Modelled from Sahlstrom *et al.*, 2008
Impact of digestion	0	
Loading in digestate	7.72×10^2 CFU $tonne^{-1}$	Calculated
Decay in soil	4.2-$\log_{10}$	Modelled from Nicholson *et al.*, 2005
Loading in soil after harvest interval	1.6×10^{-3} CFU $tonne^{-1}$ soil	Calculated

Table 2-4 Key data sources and assumptions for *Salmonella* spp.

Source	Meat: 189,747 tonnes of chicken; 105,076 tonnes of pork Livestock slurry: 2,000,000 tonnes	Equates to 12% of each type of meat supplied Slurry quantity is an estimate, based on expert opinion
Loading	278 CFU per chicken carcass 1.31×10^{3} CFU g^{-1} pork 3.9×10^{4} g^{-1} of slurry	Jorgensen et al., 2002 Prendergast et al., 2009 Hutchison et al., 2004
Regrowth before composting	4-log	WRAP, 2016a
Total loading to digestion	6.3×10^{15} CFU	Calculated
Impact of pasteurisation	6.0 $\log_{10}$	Modelled from Sahlstrom *et al.*, 2008
Impact of digestion	1.7 $\log_{10}$	Modelled from Horan *et al*., 2004
Loading in digestate	4.99×10^{1} CFU $tonne^{-1}$	Calculated
Decay in soil	4.59-$\log_{10}$	Modelled from Nicholson *et al.*, 2005
Loading in soil after harvest interval	4.24×10^{-5} CFU per tonne of soil	Calculated

Table 2-5 Key data sources and assumptions for *Listeria monocytogenes*

Source	Meat: 52,046 tonnes of ready to eat meat products Livestock slurry: 2,000,000 tonnes	Equates to 12% of each type of meat supplied Slurry quantity is an estimate, based on expert opinion
Loading	3.4×10^{4} CFU g^{-1} ready to eat meat products 1.5×10^{4} g^{-1} of slurry	Elson *et al*., 2004 Hutchison *et al*., 2004
Regrowth before digestion	None	WRAP, 2016a
Total loading to digestion	8.96×10^{15} CFU	Calculated
Impact of pasteurisation	6.0 $\log_{10}$	Modelled from Sahlstrom *et al.*, 2008
Impact of digestion	1.7 $\log_{10}$	Modelled from Horan *et al*., 2004
Loading in digestate	70.9 CFU $tonne^{-1}$	Calculated
Decay in soil	4.59-$\log_{10}$	Modelled from Nicholson *et al.*, 2005
Loading in soil after harvest interval	6.02×10^{-5} CFU $tonne^{-1}$	Calculated

Table 2-6 Key data sources and assumptions for *Cryptosporidium parvum*

Source	Livestock slurry: 2,000,000 tonnes	Estimate, based on expert opinion
Loading	3.0×10^{2} g^{-1} of infected slurry	Hutchison *et al.*, 2004
Regrowth before digestion	None	WRAP, 2016a
Total loading to digestion	8.10×10^{13} oocysts	Calculated
Impact of pasteurisation	6.0 $\log_{10}$	Modelled from Peng *et al.*, 2008
Impact of digestion	1.7 $\log_{10}$	Modelled from Horan *et al.*, 2004
Loading in digestate	6.41×10^{-1} oocysts $tonne^{-1}$	Calculated
Decay in soil	2.0-$\log_{10}$	Modelled from Nicholson *et al.*, 2005
Loading in soil after harvest interval	2.14×10^{-4} oocysts $tonne^{-1}$	Calculated

Table 2-7 Key data sources and assumptions for Foot and Mouth Disease

Source	565kg illegally imported meat	Hartnett *et al.*, 2004
Loading	565,000 oral ID_{50} in total	WRAP, 2016a
Regrowth before digestion	None	WRAP, 2016a
Total loading to digestion	18,080 oral ID_{50}	Calculated
Impact of pasteurisation	5.0 $\log_{10}$	Modelled from Turner *et al.*, 2000
Impact of digestion	1.0 $\log_{10}$	Modelled from Soares *et al.*, 1994
Loading in digestate	0.72×10^{-8} oral ID_{50} $tonne^{-1}$	Calculated
Decay in soil	0.04847 log per day	Haas *et al.*, 1995
Loading in soil	2.4×10^{-10} oral ID_{50} per tonne of soil	Calculated

Table 2-3 Key data sources and assumptions for Classical Swine Fever

Source	794 tonnes of illegally imported meat	Hartnett *et al.*, 2004
Loading	4.61×10^{9} porcine ID_{50} in total	WRAP, 2016a
Regrowth before digestion	None	WRAP, 2016a
Total loading to digestion	9.68×10^{7} porcine ID_{50}	Calculated
Impact of pasteurisation	5.0 $\log_{10}$	Modelled from Turner *et al.*, 2000
Impact of digestion	1.0 $\log_{10}$	Modelled from Soares *et al.*, 1994
Loading in digestate	3.84×10^{-5} porcine oral ID_{50} $tonne^{-1}$	Calculated
Decay in soil	0.05459 log per day	Haas *et al.*, 1995
Loading in soil	1.28×10^{-6} porcine oral ID_{50} $tonne^{-1}$	Calculated

	of soil	

Table 2-4 Key data sources and assumptions for Scrapie

Source	47,026 tonnes lamb	Equates to 12% of all lamb supplied
Total loading to digestion	29,235 ovine oral ID_{50} (classical) 1,915 ovine oral ID_{50} (atypical)	Calculated
Impact of pasteurisation	None	
Impact of digestion	1.7 log_{10}	Miles *et al*. 2011
Loading in digestate	2.3×10^{-4} ovine oral ID_{50} $tonne^{-1}$ (classical) 1.2×10^{-5} ovine oral ID_{50} $tonne^{-1}$ (atypical)	Calculated
Decay in soil	None	
Loading in soil	7.7×10^{-6} ovine oral ID_{50} $tonne^{-1}$ (classical) 5.1×10^{-7} ovine oral ID_{50} $tonne^{-1}$ (atypical)	Calculated

2.4 Quantitative risk assessment results

2.4.1 Microbiological hazards

Overall, with the exception of scrapie, the results of the QRAs suggest that the risks of infection in humans and livestock caused by the land-spreading of digestate are very low to negligible, with many years predicted between infections in the UK for most of the pathogens studied (Table 2-). In some instances, these estimates are considered excessively high when applying the highest plausible hazard scenarios, for example, the model assumes no grazing interval following the application of digestate to pasture. In practice, a regulatory interval would be applied, bringing down the estimated risks from Classical Swine Fever Virus (CSFV) to one case in 5 million years for pigs.

Table 2-10 Summary of the baseline results of the QRAs in context with the number of background infections

Hazard	Predicted number of infections per year from AD	Predicted number of years between infections from AD	Context: reported number of GB infections in 2010	Predicted percentage increase in infections per year through AD
Human Pathogens				
E. coli O157	0.007	145	1,064[a]	0.0007%
Campylobacter	0.0022	452	69,008[a]	0.000003%
Salmonella	0.0018	555	8,998[a]	0.00002%
L. monocytogenes	2.3×10^{-8}	43,926,600	156[b]	0.00000001%
Cryptosporidium parvum	6.43×10^{-5}	15,555	4,470[a]	0.0000004%

[a](HPA 2011; HPS, 2011)

[b] England and Wales in 2010

Hazard	Predicted number of infections per year from AD	Predicted number of years between infections from AD	Context: reported number of GB infections in 2010	Predicted percentage increase in infections per year through AD
Animal Pathogens				
Classical scrapie[c]	0.038	26.5	21,616[e]	0.0002%
Atypical scrapie[c]	0.013	77.1	46,003[e]	0.00003%
Total scrapie	0.051	19.6	67,619[e]	0.00007%
Foot and Mouth Disease[d] (cattle) (sheep) (pigs)	 0.8×10^{-7} 1.6×10^{-7} 0.5×10^{-7}	 12,191,000 6,196,800 19,867,600	0	N/A
Classical Swine Fever[d]	2.4×10^{-4}	4,150	0	N/A

[c]Assumes 15 day retention time for mesophilic anaerobic digestion

[d]Assumes no grazing ban between application of digestate and livestock grazing. In practice a 3 week time interval (EU Control Regulation (EC, 2009) would be observed, allowing further decay of the pathogen in the soil and greatly reduced risks.

[e]Number of scrapie infections entering GB food chain per year based on 2009 prevalence data

2.4.1.1 Impact of reducing the harvest interval

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* (Table 2-51).

Table 2-5 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 anaerobic digestate injected to 10 cm depth: Sensitivity to duration of harvest interval between applying digestate and harvesting crop.

Harvest interval/decay time on soil	14 days	28 days	42 days
E. coli O157 (illness)	8 per year (0.13 years)	0.235 per year (4.3 years)	0.007 per year (144.7 years)
Salmonella	2.1 per year (0.5 years)	0.06 per year (16.3 years)	0.0018 (555.3 years)
Campylobacter	1.4 per year (0.7 year)	0.056 per year (18 years)	0.0022 per year (452 years)
Listeria monocytogenes	2.3×10^{-5} per year (42,647 years)	6.8×10^{-7} per year (1.5×10^{6} years)	2.3×10^{-8} per year (4.39×10^{7} years)
Cryptosporidium parvum	1.4×10^{-3} per year (722 years)	3.0×10^{-4} per year (3,351 years)	6.4×10^{-5} per year (15,555 years)

[Assumes 561,784 persons ingesting 35 g/person/day of uncooked vegetable crops over period of one year]

These risks are estimated using an extremely precautionary approach, and in practice can be expected to be significantly lower. However, where growers of very high value, short growth period baby leaf salads wish to use source-segregated digestates, they

should satisfy themselves that the materials are 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.

2.5 Qualitative risk assessment results

2.5.1 PCBs and dioxin-like PCBs

Based on a UK digestate dataset (WRAP, 2011), the sum of the 7 indicator PCBs of concern (28, 52, 101, 118, 138, 153 and 180) in UK digestate samples was only 2.89 µg/kg dm – slightly higher than the mean concentration in urban soils (EA, 2007). However, when maximum datapoints were considered, the sum of the 7 indicator PCBs of concern (28, 52, 101, 118, 138, 153 and 180) was 7.90 µg/kg dm, which is well below the environmental backgrounds for rural soils and herbage.

In addition to the PCBs of concern, there are considered to be 12 dioxin-like PCBs. These had a mean concentration of 636 ng/kg dm, and a maximum concentration of 1485 ng/kg dm in UK digestate samples (WRAP, 2011). Concentrations of dioxin-like PCBs in digestate are well below those found in environmental samples, whether from rural or urban environments (EA, 2007).

2.5.2 PCDD/Fs

The maximum concentration for the 17 dioxin/furan WHO congeners in UK digestate samples was 12.7ng TEQ/kg dm, while the mean was 2.89 ng TEQ/kg dm (converted from WRAP (2011) using the toxic-equivalency factors of Van den Berg et al., 2006).

Concentrations of dioxins and furans in UK digestate samples were equivalent to those found in the background environment (EA, 2007). It should be noted that, since the risk assessment is focussed principally on whole digestates, which have a low dry matter concentration (typically 5%), the application of dry matter to the soil when digestate is used will be extremely low per hectare. For example, digestate with 5% dry matter applied at a rate of 50m^3 per hectare will apply an equivalent of only 2.5t of dry matter. This means that any PCBs, dioxins or furans will be applied at rates that are much lower than the environmental background.

2.5.3 PAHs

The EFSA CONTAM panel (EFSA, 2008) concluded that suites of either four or eight PAHs were suitable indicators of PAHs in food. The eight carcinogenic PAHs of interest were Benzo(a)anthracene, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(ghi)perylene, Benzo(k)fluoranthene, Chrysene, Dibenzo(ah)anthracene and Indeno(1,2,3-cd)pyrene. Selecting this suite of eight compounds from a UK digestate dataset (WRAP, 2011) the maximum value in digestates was 3,050µg/kg, while the mean value in digestates was 1,286µg/kg.

The maximum concentration of the sum of eight PAHs of relevance to food safety is lower in digestates (3,050µg/kg) than maxima in the environmental background. The mean concentration of the sum of eight PAHs of relevance to food safety is much lower in digestates (1,286µg/kg) than in urban soils, and similar to that of rural soils (EA, 2007). It is higher than herbage concentrations. Based on the low dry matter content of

digestates, the PAH loadings to the receiving environment (soils) would be expected to be considerably lower than background concentrations.

2.5.4 Potentially toxic elements (PTEs)

Potentially toxic element (PTE) loadings to soil were calculated for digestates complying with the maximum PTE limits in PAS110, and compared with loadings from actual UK digestates (based on data from WRAP (2011)). These are listed in Table 2-6.

Table 2-6 Maximum PTE loading from a single application of digestate at maximum permissible PAS110 concentrations, compared with maximum loadings from actual digestates (calculated from WRAP, 2011)

Heavy metal	Maximum permitted in PAS110 (kg/ha)	Maximum from actual samples (kg/ha)
Zn	9.6	0.148
Cu	4.8	0.041
Cd	0.036	0.003
Ni	1.2	0.063
Pb	4.8	0.018
Cr	2.4	0.021
Hg	0.024	0.002

By way of context, 'typical' PTE loading rates from cattle and pig slurry applied at a rate of 50m^3/ha are shown in Table 2-7. For comparison, the average annual loading rate limits in the 'Code of Practice for Agricultural Use of Sewage Sludge (DoE, 1996)' are also shown. The digestate loadings are well below the sludge values and in the same order of magnitude as the livestock slurries.

Table 2-7 Average annual loading rate limits in the 'Code of Practice for Agricultural Use of Sewage Sludge' (DoE, 1996) and typical PTE loading rates from cattle and pig slurry (Nicholson *et al.*, 2010)

PTE	Average annual loading rates for sewage sludge (kg/ha)	Cattle Slurry (kg/ha)	Pig Slurry (kg/ha)
Zn	15.0	0.58	2.17
Cu	7.50	0.44	0.70
Cd	0.15	0.0004	0.001
Ni	3.00	0.01	0.01
Pb	15.0	0.01	0.01
Cr	15.0	0.01	0.01
Hg	0.10	n.d.	n.d.

In summary, the quantities of potentially toxic elements applied in digestate are very low and will therefore have little effect on soil PTE concentrations.

2.5.5 Plant pests and diseases

The results of the qualitative assessment of risks from a range of plant pests and diseases are presented in Table 2-8. Overall, the literature suggests that pasteurisation would be expected to be effective at reducing plant pests and pathogens (including nematodes, fungi and bacteria) to very low levels.

Whilst mesophilic anaerobic digestion without pasteurisation may reduce plant pathogen numbers, there is less evidence that this provides effective protection when compared with a thermal treatment step such as pasteurisation. It is therefore advised that where digestate processes do not include a pasteurisation step, growers wishing to use digestate on land growing high value crops should have digestate tested for the presence of relevant pathogens, particularly where vegetable processing wastes represent a significant percentage of the feedstock. This is a precautionary recommendation, in contrast to existing practices where crop residues not processed through AD may be spread widely with no monitoring measures in place to prevent the spread of plant pathogens.

It is recommended that all digestates derived from potato waste MUST originate from a system that includes a pasteurisation step if they are to be applied to potato land.

Table 2-8 Summary of plant pest and disease scenarios considered, and risk outcomes

Potato cyst nematodes (PCN)
Source: Potato waste, e.g. processing waste
Pathway: Cropped land
Key data sources: Van Loenen *et al*., 2003; Spaull *et al*., 1989; Heinicke, 1989; Turner *et al*., 1983; Bollen, 1985; Noble and Roberts, 2004; Stone and Webley, 1975
Risk assessment outcome: Pasteurisation at 70°C for one hour would kill all eggs within PCN cysts, although the cysts themselves are likely to remain intact. However, it was unclear whether continuous-process Mesophilic Anaerobic Digestion (MAD) would result in all PCN cysts being non-viable. It is recommended that growers concerned about the transfer of PCN have the digestate tested for PCN presence.
Context: PCN is widespread in ware potato fields; just under 70% of land in England and Wales is estimated to be infected.

Free-living nematodes e.g. stubby root nematodes
Source: Potato waste, e.g. processing waste
Pathway: Cropped land
Key data sources: Bohm *et al*., 1999; Lukehurst *et al*., 2010; Ploeg and Stapleton, 2001; Porter & Merriman, 1983; Boag *et al*., 1991; Van Loenen *et al.,* 2003
Risk assessment outcome: As PCN would be killed by pasteurisation at 70°C for one hour, this treatment will also be effective for free-living nematodes. However, it was unclear whether continuous process MAD would result in all free-living nematodes being killed. It is recommended that growers concerned about the transfer of PCN have the digestate tested for PCN presence.

Context: Free-living nematodes are present in all soil types and are particularly common in light sands. Stubby root nematodes transmit the virus (tobacco rattle virus) that causes spraing. Also, direct feeding damage to potatoes can occur if free-living nematodes are sufficiently numerous.

Powdery and common scab; Ring rot; Brown rot; Phytophthora
Source: Potato waste, e.g. processing waste
Pathway: Cropped land
Key data sources: Lee *et al*., 1998; Ryckeboer, 2002; Ryckeboer *et al*., 2002; Ryckeboer, 2003; Termorshuizen *et al*., 2003; Secor *et al*., 1987; Noble *et al.*, 2009
Risk assessment outcome: Pasteurisation at 70°C for one hour would (be expected to) kill the range of plant pathogens considered in this scenario. However, continuous process MAD is only likely to reduce plant pathogen numbers; it is unlikely to kill all plant pathogens. It is recommended that growers concerned about the transfer of pathogens (and in particular powdery scab) have the digestate tested for their presence.
Context: The pathogens causing common scab, powdery scab, late blight and black scurf are common in potato production. The main risk from brown rot and ring rot would be from digestates which included imported seed potato 'waste' as a feedstock. If brown rot and ring rot are found in potato crops, the crops have to be destroyed and potato production may be halted on affected farms.

Club root
Source: Vegetable wastes, e.g. processing waste
Pathway: Cropped land
Key data sources: Ryckeboer *et al*., 2002; Noble *et al*., 2009
Risk assessment outcome: Pasteurisation at 70°C for one hour would (be expected to) kill clubroot. However, continuous process MAD is only likely to reduce clubroot presence; it is unlikely to kill clubroot. It is recommended that growers wishing to use digestate on land growing brassica crops (and in particular high value crops) have the digestate tested for presence of the clubroot pathogen.
Context: The pathogen is already common in soils, and in England about 1% of oilseed rape crops show significant infection. Management with liming and use of resistant varieties is possible, but eradication would require very costly soil sterilisation. Molecular diagnostic and plant bait tests are available for clubroot.

Fusarium
Source: Maize feedstock
Pathway: Cropped land
Key data sources: Termorshuizen *et al.*, 2003; Bollen, 1993; Bollen and Volker, 1996; Haraldsson, 2008; Zetterström, 2008; Noble *et al*., 2009; HGCA, 2007
Risk assessment outcome: Pasteurisation at 70°C for one hour would kill *Fusarium* spp. and should pose no mycotoxin risk to cereal crops. However, it was unclear whether continuous process MAD would result in all *Fusarium* spp. being killed. Where continuous process MAD has been used, digestate applications should only be made where the digestate can be ploughed down (*i.e*. inverted) into the soil following application in order to reduce risks (rather than applied directly to growing cereal crops).
Context: Fusarium species are common plant pathogens and occur widely in soils.

2.5.6 Mycotoxins and plant toxins

The results of the qualitative assessment of risks from mycotoxins and plant toxins are presented in Table 2-9. The risks associated with the transmission of plant toxins to humans and animals consuming crops grown on land to which digestate has been applied are assessed to be low. For example, the mycotoxins DON and ZEA will be strongly bound to soil clay minerals and organic matter, and the potential for foliar uptake is easily mitigated by the use of a bandspreader/shallow injector to apply digestate, or through soil incorporation after digestate application.

The modelling suggests a small risk of harm to livestock following application of digestate based on a feedstock containing 5% ragwort. AD plant operators should therefore aim to eliminate ragwort in feedstock, or where it is present, ensure that it constitutes less than 1% by weight of the feedstock. Practical options include:

- Controlling ragwort with the aim of eliminating it in energy crops grown for digestion, paying particular attention to grass crops, in which ragwort can be common;
- Rejecting feedstocks if ragwort can be seen in them;
- Taking measures to educate suppliers of feedstock for all types of AD systems and ensure that the presence of ragwort in feedstocks is minimised, with the aim of eliminating it altogether.

Table 2-9 Summary of mycotoxin and plant toxin scenarios considered, and risk outcomes

Mycotoxins
Source: Maize feedstock
Pathway: application to soil
Key data sources: Lauren and Ringrose, 1997; Huwig *et al.*, 2001; Mantle, 2000; EMAN, 2011
Risk assessment outcome: The mycotoxins DON and ZEA will be strongly bound to soil clay minerals and organic matter. The potential for foliar uptake is easily mitigated by the use of a bandspreader/shallow injector or soil incorporation. Overall, the risks of mycotoxin contamination of crop and livestock products (and human health exposure) are considered to be negligible.
Context: Fusarium species are common plant pathogens and occur widely in soils. The potential for mycotoxin formation is a constant and is managed through good crop hygiene management – particularly after harvest.

Plant toxins (Pyrrolizidine Alkaloids in ragwort)
Source: Green waste feedstock
Pathway: Application to grazing land
Key data sources: Candrian *et al*., 1984; Hough *et al*., 2010; Crews *et al*., 2009
Risk assessment outcome: There is a small theoretical risk of harm to livestock following application of digestate based on a feedstock containing 5% ragwort, AD plant operators should aim to eliminate ragwort in feedstock for AD. If it is present at all, they should ensure that it constitutes less than 1% by weight of the feedstock. A short grazing interval of 1 to 2 weeks would also allow time for any alkaloids present to dissolve in soil water and leach from the soil surface or degrade to non-toxic compounds.
Context: Ragwort is often rejected by grazing animals where it is growing amongst grass, but it becomes more palatable to stock if dried, for example in hay and haylage (Defra, 2007). There is considerable anecdotal evidence of the contribution of alkaloids to toxicity in hay (Giles, 1983; Leyland, 1985; McDowell, 1999), but only recently has it been proved that hay can be toxic owing to high alkaloid concentrations within it (Crews & Anderson, 2009). Several cases have been reported of cows being poisoned by ensiled grass that had been heavily infested with ragwort, but in none of these cases had the silage actually been tested for the presence of pyrrolizidine alkaloids.

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