

Risk assessment of the use of source-segregated anaerobic digestates in GB agriculture

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Abstract

This paper reports on the completion of a quantitative assessment of residual risks for PAS110 biofertilisers. The work focuses on the practical use of source-segregated biofertilisers as agricultural soil amendments to ensure the protection of crops, humans, animals and the wider environment. Risks from human and animal pathogens, organic compound contaminants and plant pests and diseases are considered. The study details the basis for calculating the potential for exposure to hazards using a source-pathway-receptor method to determine the extent to which controls are needed to ensure protection from harm. Scenarios that consider the highest plausible combination of hazards arising from AD feedstocks, process parameters, land application rates and differing crop categories are used which indicate the extent to which risks could occur. In conclusion, the work provides evidence for process and agricultural management practices to enable the safe use of these high value and low cost soil amendments.

Keywords

Anaerobic digestion (AD), agriculture, biofertilisers, digestates, PAS110, risk assessment

Introduction

Anaerobic digestion offers an opportunity for the generation of renewable energy, and also for the recovery of the nutrients in food waste via the production of quality digestates. To achieve this, long term, sustainable markets for AD digestates are required. Whilst biofertilisers offer numerous benefits to agriculture including replacements for energy-intensive inorganic nitrogenous fertilisers their use must be complemented by guidance based on a robust understanding of safety in use. This is particularly the case on land where crops are grown for human consumption. Therefore a robust approach to risk assessment is necessary to inform the use of these materials and provide evidence-based guidance to ensure good agricultural practice in the use of biofertiliser.

The project built upon previous qualitative risk assessment work using whole wet digestate as the basis for risk assessments, recognising that the publically available specification (BSI: PAS110) includes 'whole digestate, separated liquor and separated fibre derived from the anaerobic digestion of source-segregated biodegradable materials'. Each stage of the assessment builds upon published research as well as datasets and previous projects available from WRAP.

In determining the scope of the assessment, the controls addressed within the PAS110 define the extent of risks to be considered. These include: defined inputs to AD Plant, e.g. source-

segregated feedstocks; the influence of supply agreements with for example local authorities and commercial firm, e.g. on the QA of feedstock supply; plant process control including corrective actions in event of failures; pasteurisation. These include the ABPR specification and requirements where digestates are moved between farms; as well as sampling and analysis including pathogens, potentially toxic elements (PTEs), physical contaminants, biochemical stability, and quality controls at the input stage.

Two toxicological principles, of exposure and potency, underpin the research supporting the development of this risk assessment. 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 enough to cause harm. Living organisms are routinely exposed to hazards which they tolerate and are resistant to. Here, the method and summary findings are set out from determining the highest plausible exposure that a sensitive receptor can be exposed to from the transfer of a hazard from its original source, see Figure 1.

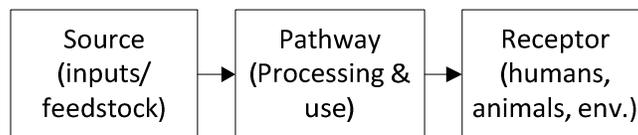


Figure 1: Source – Pathway – Receptor model

The overall method for each QRA uses the source-pathway-receptor approach. Here the source term details the hazard loading on the feedstock materials for anaerobic digestion, the pathway term details the effect of the hazard-reducing barriers during the anaerobic digestion process including pasteurisation and dilution and application to land considers the decay after spreading and incorporation. Where applicable, the receptor term then uses dose-response data to predict the risk of harm after exposure.

Factors that influence the potency include: the state of hazards at source that are of potential concern, typically by their physical/chemical characteristics; their use, control and biogeochemical cycling and processing along the pathway from feedstock to receptor exposure in use; and finally the receptor characteristics. Notably, these include the size, weight, age, vulnerability and sensitivity of the human or animal exposed, or the consequences to these from wider environmental release. A series of controls exist within the PAS110, outlined in Figure 2, which are incorporated within the risk assessment calculation.

The term ‘highest plausible hazard’ is used here to define the basis for calculating the exposure of receptors to key concerns. Quantitative estimates of dose and residual risk to receptors from the highest plausible hazard were used for scenarios where risk is defined using PAS110 compliant feedstocks that account for:

- Feedstock sources with the highest achievable loading for specific hazards that could occur from compliant processes,

- Pathways with the highest and most direct loading that could be transferred to the receptor, in addition to an assessment of the risk of by-pass for engineered processes,
- Definition of the most sensitive receptors that may be routinely exposed to a hazard.

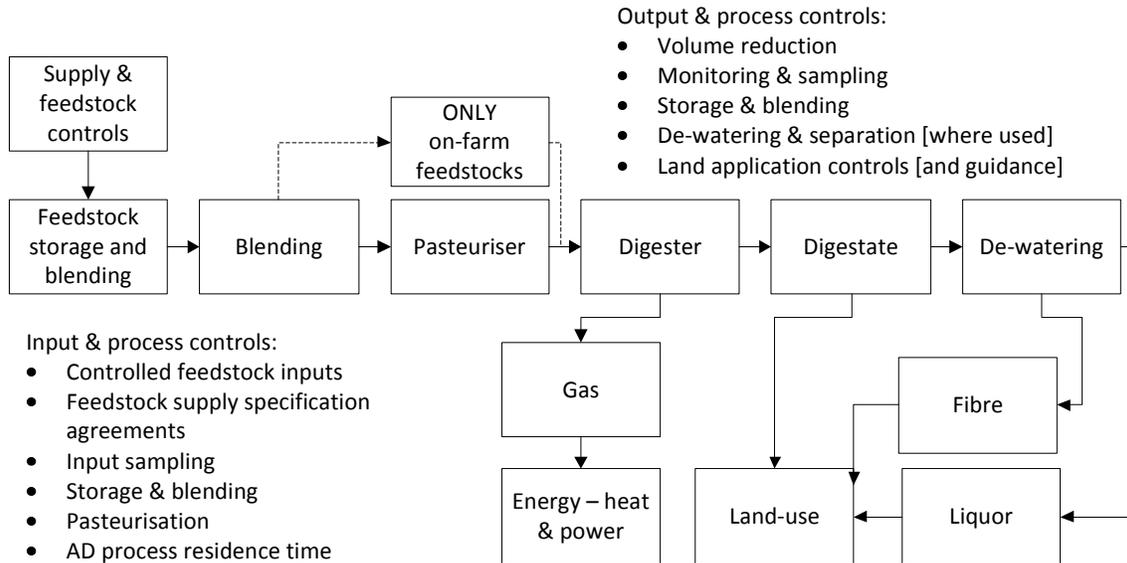


Figure 2: Controls in the PAS110 process

Pasteurisation is the most important barrier both in its magnitude of risk reduction and in the fact that it can be controlled and operated to minimise by-pass. In the case of pathogens, decay on the soil over 42 days is also important in reducing the risks to humans following the land-spreading of anaerobic digestate.

Anaerobic digestion systems vary widely in terms of their design. However, the main types are either continuous wet or dry systems, run at either mesophilic (30-40°C) or thermophilic (50-60°C) temperatures. Most UK operators use mesophilic anaerobic digestion (MAD) systems. Where animal by-product materials (Category 2 and 3) are included in the feedstock, an additional batch pasteurisation phase, i.e. 1 hour at 70°C, with a particle size <12 mm, either before or after digestion is legally required. Pasteurisation, that meets the criteria specified in the most appropriate ABP Regulation (see PAS110:2010 [6], [7], [8] and [9]), is also a key requirement of the PAS110 specification, even where animal by-products are not processed.

There are three main types of biofertiliser (whole, liquid and fibre), with whole biofertiliser being the most commonly available. Some anaerobic digestion plant operators opt to separate the biofertiliser into liquid and fibre fractions for operational reasons. The fibre fraction typically has a dry matter content of between 20 and 40% and the liquid fraction between 1 and 4%, although these proportions will vary depending upon the separation process or processes employed.

Where relevant, biofertiliser applications to agricultural land must also comply with the Animal By-Products Regulations, whereby, pasture land cannot be used for grazing (or cropped for forage) within 3 weeks (or 2 months for pigs) of applying digestate.

Method

Figure 3 shows the development of the risk-assessment and subsequent guidance, reported in a further paper, which was built from a three-stage series of sector steering group (SSG) consultations across three UK venues. Meetings in London, Cardiff and Edinburgh were held initially to understand and record the priority concerns for risk-assessment. Following these first meetings concerns were analysed to determine new risks. Where evidence was available from prior quantitative risk assessments these were reviewed and either incorporated within new assessments or used as the basis to prioritise alternative QRAs.

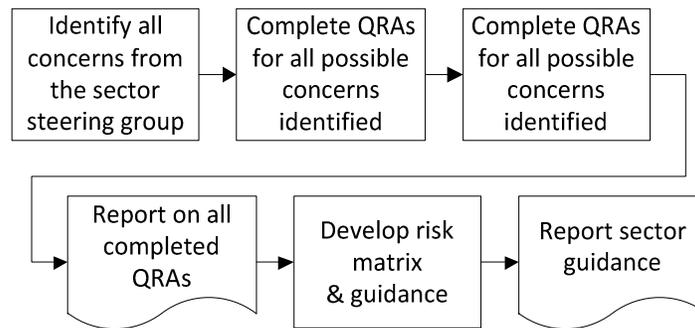


Figure 3: Process of developing QRAs & guidance from consultation with sector groups

Risk assessments were completed for specific scenarios for a wide range of hazards where previous QRAs had not been undertaken, detailed in Table 1. Three receptor and hazard groups were addressed:

- Human & animal pathogens
- Organic compound contaminants and heavy metals
- Nematodes, plant pathogens; fungi and bacteria

Where uncertainty associated with the data available has arisen a number of assumptions are made to fill data gaps and to address the priority for 'high hazard' scenario to be developed. For example, in the case of human and animal pathogens, using data on the total amount of meat eaten in the UK, an estimate of 12% has been made for the proportion of meat supplied that goes to anaerobic digestion. A sensitivity analysis has been performed to test the effect of the assumptions in the baseline models. This analysis showed that, with the exception of scrapie, the proportion of meat going to anaerobic digestion has little effect on the overall risks. In all cases, the highest plausible estimate is used as a precautionary approach alongside a sensitivity analysis of the values applied.

Table 1: Summary of risk assessment scenarios

Hazards of concern	High hazard <u>source(s)</u>	High hazard <u>pathway</u> considerations	High hazard receptor considerations
Human & animal pathogens			
<i>E. coli</i> O157	Faeces; Milk (raw); Meat, e.g. household food waste	Grazing land; Ready to eat crops	Humans & livestock
<i>Campylobacter</i>	Faeces; Milk (raw); Meat, e.g. household food waste	Grazing land; RTE crops	Humans & livestock
<i>Salmonella</i>	Faeces; Milk (raw); Meat, e.g. household food waste	Grazing land; RTE crops	Humans & livestock
<i>Listeria monocytogenes</i>	Faeces; Milk (raw); Meat, e.g. household food waste	Grazing land; RTE crops	Humans & livestock
<i>Cryptosporidium parvum</i>	Faeces	Silage; RTE crops	Livestock; Humans
Scrapie	Abattoir and food processing waste; Meat e.g. household food waste	Grazing land	Sheep & goats
Foot and mouth disease (FMD)	Illegal meat	Grazing land	Livestock
Classical swine fever (CSF)	Illegal meat	Grazing land	Livestock
Organic compound contaminants and heavy metals			
PCBs & PCDD/Fs	Digestate	Application to soil & livestock ingestion	Humans & livestock
PCBs & PCDD/Fs	Digestate produced from green waste	Application to soil & livestock ingestion	Humans & livestock
PAHs	Digestate produced from green waste	Application to soil & livestock ingestion	Humans & livestock
Nematodes, plant pathogens; fungi and bacteria			
Potato cyst nematodes (PCN)	Potato waste, e.g. processing waste	Crop land	Crops e.g. potatoes
Free-living nematodes, e.g. stubby root nematodes	Potato waste	Crop land	Crops e.g. potatoes
Powdery and common scab	Potato waste	Application to soil	Potatoes
Ring rot	Potato waste	Application to soil	Potatoes
Brown rot	Potato waste	Application to soil	Potatoes
Phytophthora	Potato waste	Application to soil	Potatoes
Rhizoctonia	Potato waste	Application to soil	Potatoes
Club root	Vegetable waste	Application to soil	Brussels sprouts
Fusarium	Maize feedstock	Application to soil	Cereals

Human and animal pathogens

Key factors in considering the risk assessment for human and animal pathogens was the source term attributed to each pathogen. Figure 3 illustrates the conceptual model of exposure from source to potential outbreak.

The source term in the pathway details the total loading of each pathogen going to anaerobic digestion. This involves collecting data on the level or concentration of each pathogen in a particular feedstock and the subsequent volume of the feedstock that is expected to be processed by anaerobic digestion over the course of one year.

Work by Hartnett et al. (2004) of assessments of the import of illegally imported meats into the food chain were used to calculate viruses that are exotic to the UK, i.e. not currently present in any livestock animals in the UK. These estimates were incorporated into the risk assessment model alongside the calculation of the total meat (home produced and imported) potentially being sent to AD if all material were processed in this manner. Office of National Statistics sources were used to provide an age distribution for the UK population which was then used to estimate of the amount of meat and meat products consumed each year in the UK. Comprehensive details of total loading are outside the scope of this paper however, the results presented indicate the quantitative basis used to calculate the source-pathway-receptor loading.

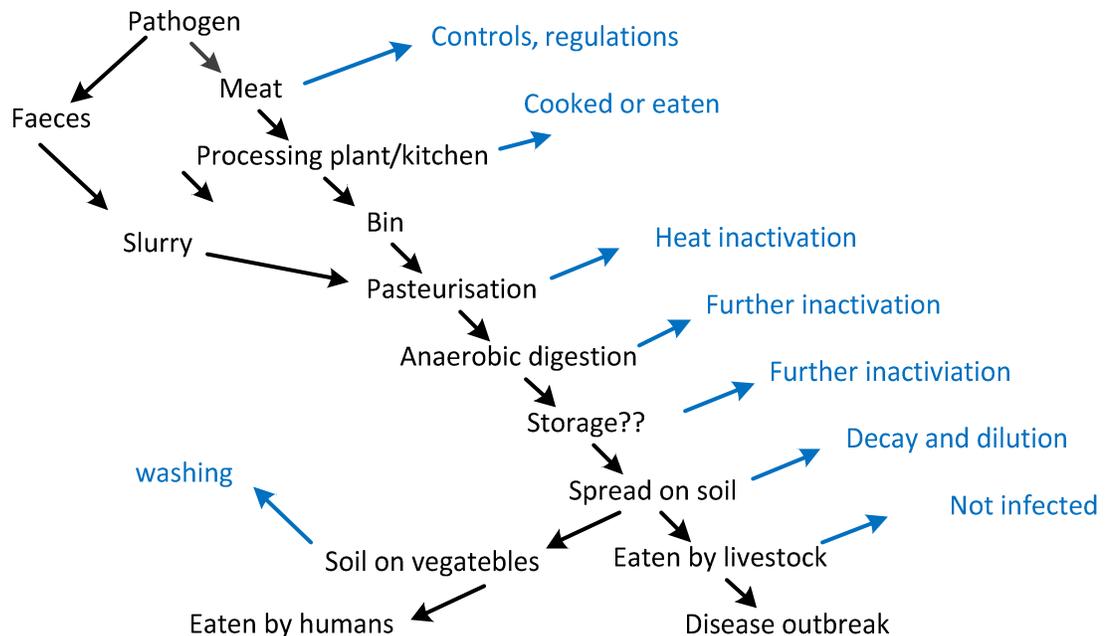


Figure 3: Conceptual model of exposure for pathogens

Figure 3 provides an illustration of the process variables and detail considered in defining the high hazard scenarios to then calculate the status of pathogens in growth or decay stages. Comprehensive details about the pathogen

Organic compound contaminants and heavy metals

The source term used to define an initial input concentration for the source-pathway-receptor approach in this category was defined from maximum concentration limits for PAS110, i.e. compliant digestate. The process of decay or residual concentrations emitted from the process, and the evidence available to consider the toxicity, or potential for harm was then assessed. Each assessment considered the highest plausible hazard concentrations, the most direct route for receptor exposure and the most sensitive receptor categories to evaluate risk. Typically, crops that have high uptake rates or are uniquely vulnerable to harm are considered. This approach to comparing typical loading rates with proposed regulatory limits indicates that very low concentrations are present which are not within proximity of these limits.

Within the category of PCBs the sum of 7 congeners with a maximum from 18 crop/manure & food-based digestates = 4.42 µg/kg dm (mean 2.83 µg/kg dm) were assessed. Rural soils typically contain 1.25 µg/kg dm (EA, 2007), herbage typically contains 0.54 µg/kg dm (EA, 2007), and the Draft Biowaste Directive defines a limit of 400 µg/kg dm (EU, 2001). The Draft Sewage Sludge Directive Working Document defines a limit of 800 µg/kg dm (EU, 2000).

For PCDD/Fs the sum of 17 congeners with a maximum of 18 crop/manure & food-based digestates = 3.81 ng TEQ/kg dm (mean 1.8 ng TEQ/kg dm) were assessed. Rural soils typically contain 4.70 ng TEQ/kg dm (EA, 2007), herbage typically contains 2.73 ng TEQ/kg dm (EA, 2007), and the Draft Sewage Sludge Directive Working Document defines a limit of 100 ng TEQ/kg dm (EU, 2000).

In the sub-category of PAHs the sum of 9 congeners with a maximum from 18 crop/manure & food-based digestates = 2,025 µg/kg dm (mean 1,292 µg/kg dm) were assessed. Rural soils typically contain 1,693 µg/kg dm (EA, 2007), herbage typically contains 166 µg/kg dm (EA, 2007), and the proposed Biowaste Directive defines a limit of 3,000 µg/kg dm (EU, 2001). The Draft Sewage Sludge Directive Working Document defines a limit of 6,000 µg/kg dm (EU, 2000).

Further data for the UK on PCB or PCDD/F concentrations specifically in digestate and digestate produced from green waste is required and the authors recognise the need to extend this work for application to a quantitative risk assessment.

PAS110 limits	Crop and livestock exposure	Human exposure
Zn = 400 mg/kg dm	✓	✘
Cu = 200 mg/kg dm	✓	✘
Cd = 1.50 mg/kg dm	✓	✓
Ni = 50 mg/kg dm	✓	✘
Pb = 200 mg/kg dm	✓	✓
Cr = 100 mg/kg dm	✓	✘
Hg = 1.00 mg/kg dm	✓	✘
As = 2.43 mg/kg dm	(max. value, Taylor et al., 2010)	✓

Table 2: Exposure limits with those used to assess potential heavy metals exposure

Nematodes, plant pathogens; fungi and bacteria

The source definition for this group considered source segregated 'waste' materials where the contaminants with hazards of concern were in the maximum permissible or likely to be achieved concentrations for PAS110 compliant digestate. The pathway of exposure considered an application rate of digestate applied to land at 50m³/ha (incorporated to 10cm within the soil). The sensitive receptor assessed for exposure in these cases was sensitive crops, i.e. potatoes for PCN, b-sprouts for clubroot. Each batch of digestate was defined as being treated using ABP compliant pasteurisation + mesophilic AD (MAD), where MAD is only permitted for recycle on producers own land.

Source term assessments for this category were defined from feedstock containing potato processing 'wastes'. The scenario was specified as including cyst nematodes - Potato cyst nematode (PCN); free living nematodes - Stubby root; Needle, Stunt, Spiral, Root lesion; as well as Clubroot exposure from digestate contain vegetable processing 'wastes'.

The source term for fungi and bacteria were defined as feedstock containing: Fusarium as a result of exposure from digestate containing maize; and, Mycotoxin exposure through contaminated digestate applications to cereal crops.

Results & discussion

In the categories of human and animal pathogens, results calculated from the quantitative risk assessments for each of these categories were then compared to the current context in terms of numbers of infections per year, years between infections, and the context of current infections from using AD biofertiliser. Reports of current GB infections could then be compared to present the resulting percentage increase predicted to occur, as shown in Table 2, below.

Table 2: Summary of results of the human & animal pathogen QRAs in context with number of background infections

Hazard	Predicted no. of infections per year from AD	Predicted no. of years between infections from AD	Context: reported no. of GB infections in 2010	Predicted percentage increase in infections per year through AD
<u>Human Pathogens</u>				
<i>E. coli</i> O157 (illness)	0.007	145	1,064 ^c	0.0007%
<i>Campylobacter</i>	0.0022	452	69,008 ^c	0.000003%
<i>Salmonella</i>	0.0018	555	8,998 ^c	0.00002%
<i>L. monocytogenes</i>	2.3 x 10 ⁻⁸	43,926,600	156 ^d	0.00000001%
<i>C. parvum</i>	6.43 x 10 ⁻⁵	15,555	4,470 ^c	0.0000004%

Hazard	Predicted no. of infections per year from AD	Predicted no. of years between infections from AD	Context: reported no. of GB infections in 2010	Predicted percentage increase in infections per year through AD
<u>Animal Pathogens</u>				
Classical scrapie ^a	0.038	26.5	21,616 ^e	0.0002%
Atypical scrapie ^a	0.013	77.1	46,003 ^e	0.00003%
Total scrapie	0.051	19.6	67,619 ^e	0.00007%
FMDV ^b (cattle)	0.8×10^{-7}	12,191,000	0	N/A
(sheep)	1.6×10^{-7}	6,196,800		
(pigs)	0.5×10^{-7}	19,867,600		
CSFV ^b	2.4×10^{-4}	4,150	0	N/A

^a Assumes 15 day retention time for MAD

^b Assumes no grazing ban between application of digestate and livestock grazing. In practice a 3 week time interval (EC Control Regulation (1069/2009)) would be observed allowing further decay of the pathogen in the soil and greatly reduced risks

^c (HPA 2011a; HPS, 2011)

^d England and Wales in 2010

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

Overall, the results of the quantitative risk assessments suggest that the risks of infection caused by the land-spreading of digestate are low, with many years predicted between infections for the majority of the pathogens considered. This is illustrated by, for example, comparison of predicted risks of E. coli O157 resulting from digestate use, with existing rates of gastrointestinal infection in the UK. The prediction is for one infection in 145 years as against existing rates of more than one thousand cases a year.

For human and animals pathogens we posed the following question: “What is the risk of a pathogen infection in humans and/or livestock animals occurring due to the spreading of PAS110 compliant digestate onto arable or grazing land?” Overall, the results of the QRAs suggest that the risks of infection caused by the land-spreading of digestate are low, with many years predicted between infections for the majority of the pathogens considered. By comparison to existing rates of gastrointestinal infection in the UK, the chances of additional infection due to the use of PAS110 are extremely low. Batch pasteurisation using a ‘closed reactor’ plays a key role both in terms of the magnitude of risk reduction, and the fact that it can be controlled and operated to eliminate short-circuiting.

Batch pasteurisation plays a key role both in terms of the magnitude of risk reduction and the fact that it can be controlled and operated to minimise short-circuiting. The highest risk predicted by the QRA is for scrapie, where 0.38 and 0.13 infections of classical and atypical scrapie, respectively, are predicted per year. Scrapie is an endemic disease in the UK with a predicted >67,000 infections per year in the UK flock; the additional infections predicted through application of anaerobic digestate would be <0.00007% of the total in the UK. The

higher risk for scrapie is attributable in part to the fact that we have assumed no significant reduction from batch pasteurisation but a partial reduction from MAD.

An assessment was made of the risk of harm to crops, livestock and humans from exposure to a range of hazardous chemicals that have the potential to be present as contaminants in feedstocks for the digestion process such as PCBs & PCDD/Fs, PAHs and heavy metals. Feedstocks arising from food wastes which originated for the human food chain are expected to retain minimal chemical contamination. Concentrations of heavy metals may be higher in digestates where pig slurries are used as a feedstock. However, existing monitoring data suggests that chemical contaminants are present in digestate in very low concentrations. Indeed, the measured concentrations are well below the acceptable levels proposed in the draft Sewage Sludge Working Document (EU, 2000) and Draft Biowaste Directive (EU, 2001). Moreover, values were similar to those measured in soil and herbage samples taken from throughout the United Kingdom. As a result, we conclude that the risk of harm from chemical contaminants is low.

It is clear that heavy metal loading rates are very low with the result that they will have little effect on the soil heavy metal concentrations. Many years of annual application would be required to reach the soil heavy metal limit values when assessed at with a precautionary approach of using 10cm incorporation with no rotational ploughing to 25/30cm, see Table 3.

Table 3: Years of application to reach soil limits

Metal / yrs of application	Metal / yrs of application
Zn = 206 years	Pb = 672 years
Cu = 309 years	Cr = 1,907 years
Cd = 703 years	Hg = 334 years
Ni = 533 years	

As with the human and animal pathogens, the literature suggests that batch pasteurisation would be expected to be effective at reducing plant pests and pathogens present in feedstocks (including nematodes, fungi and bacteria) to very low levels.

Eggs within Potato cyst nematodes will be killed by pasteurisation at 70°C for one hour, whereas it is unclear whether MAD alone for (>20 days at 35-40°C) would result in all PCN cysts being killed. As for PCN, pasteurisation at 70°C for one hour will also be effective for free-living nematodes with the same caveat for MAD.

In general, pasteurisation at 70°C for one hour would be expected to kill plant pathogens, whereas uncertainty remains on the effectiveness of MAD in destroying pathogens. Growers concerned about the transfer of pathogens (particularly powdery scab) could have the digestate tested for their presence. Where potato waste is being applied to land growing potatoes (even later in the rotation), digestate must be pasteurised

In view of the potential for some survival, albeit low, of some plant pathogens, e.g. clubroot, where vegetable processing wastes may represent a significant percentage of the feedstock, growers wishing to use digestate on land growing high value crops are advised to have unpasteurised digestate tested for presence of relevant pathogens. This is a precautionary recommendation in contrast to existing practices where crop residues not processed through AD may be spread widely with no control monitoring measures in place to prevent the spread of plant pathogens. Whilst mesophilic anaerobic digestion without batch pasteurisation may reduce plant pathogen numbers, there is less evidence that this provides effective protection than a thermal treatment step such as pasteurisation. In the assessment of *Fusarium* pasteurisation at 70°C for one hour will kill *Fusarium* spp therefore there is no mycotoxin risk to cereal crops. It is unlikely that MAD will kill resistant chlamydospores, however ploughing down digestate applications will reduce risk.

The risks associated with the transmission of plant toxins (that may potentially be in some feedstocks) to humans and animals consuming crops grown on land where digestate was been applied was assessed to be low. For example, the Mycotoxin DON and ZEA will be strongly bound to soil clay minerals and organic matter, and the potential for foliar uptake can be mitigated by the use of a band-spreader/shallow injector equipment or soil incorporation. Whilst ragwort is one of the most frequent causes of plant poisoning of livestock in the UK, the risk assessment indicated that it was improbable that harm would come to animals grazing land to which digestate has been applied. Nevertheless, plant operators should aim to eliminate ragwort in feedstocks for AD.

Although ragwort is often rejected by grazing animals where it is growing amongst grass, it becomes more palatable to stock if dried, for example in hay and haylage. For this reason ragwort is one of the most frequent causes of plant poisoning of livestock in the UK. There are reported cases of cows being poisoned by ensiled grass that had been heavily infested with ragwort, where the presence of pyrrolizidine alkaloids (the toxic compounds in ragwort) had not been tested. Use of ragwort in AD systems would be highly unusual. Nevertheless, 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 pre-digested weight of the feedstock.

Conclusions

In summary, we conclude that the risks associated with the use of PAS110 compliant digestate in agriculture are acceptably low. These can be summarised as follows:

Human and animal pathogens:

- The risk of pathogens from AD digestate for humans and animals is very low and at an acceptable level

Organic compound contaminants:

- these are likely to be present in very low concentrations in digestate, around the levels found in soil and herbage

- Levels are well below limit values proposed in the draft Sewage Sludge Working Document and draft Biowaste Directive

Heavy metals:

- The quantities of Cd, Pb and As applied in digestate are very low and will not present a risk to human health

Nematodes, plant pathogens; fungi and bacteria: Potato cyst; nematodes (PCN); Free-living nematodes, e.g. stubby root nematodes; Powdery and common scab; Ring rot; Brown rot; Phytophthora; Rhizoctonia; Club root; Fusarium.

- Pasteurisation at 70°C for one hour is likely to be effective, whereas it is unclear whether MAD alone for (>20 days at 35-40°C) would result in destruction of plant pathogens.
- Mycotoxins are thermally tolerant, however, they strongly bind to soil clay minerals and organic matter, meaning they will be unavailable for plant uptake
- Control of weeds and plant toxins is practical using guidance and good agricultural practice.
- Education of all suppliers of AD feedstock can ensure that the presence of seeds of injurious and invasive weeds is minimised / eliminated
- Include a pasteurisation step in MAD wherever possible.
- Where MAD is proposed (with and without pasteurisation) further work is needed to determine the impact of on propagules of invasive and exotic weed species in feedstocks.
- Sector guidance should be used to increase the opportunities for risk management

Acknowledgement

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