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An examination of the limits for potentially toxic elements (PTEs) in anaerobic digestates

PTE limits for digestates in the BSI PAS110 specification are currently set on a dry matter basis. This report examines the suitability of this approach, and proposes new PTE limits for digestates set on a fresh weight basis

Project code: OMK002-013 **Date:** February 2013

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Front cover photography: Anaerobic digestion plant and precision digestate (trailing shoe) application equipment.

Executive summary

The overall objective of this study was to examine current UK industry data on PTE concentrations in digestate, report these in relation to other organic materials that are commonly applied to agricultural land and to use these data to determine whether other limits (either on a dry matter basis or utilising other approaches) could be set that would be equally protective of the environment as the current PAS and/or the JRC suggested limit values from the third working document on End of Waste (EoW) criteria.

The British Standards Institute Publicly Available Specification for Anaerobic Digestate (BSI PAS110) was developed to ensure that the "digested material meets market needs *and protects the environment*". When BSI PAS110 was compiled, the limits for digestate potentially toxic element (PTE) concentrations were drawn directly from the compost specification (BSI PAS100), because there was only an extremely small commercial anaerobic digestion (AD) sector in the UK at the time and data on digestate quality were scarce. Recently, a JRC technical report has suggested PTE limits as part of End-of-Waste (EoW) criteria for composts and digestates. The suggested limits would be the same as those currently specified in BSI PAS110 and PAS100, except for Pb and Cu, which would be lower.

Notably, prior to publication, concerns were expressed by the anaerobic digestion industry that they might not be able to consistently meet the dry-matter-based BSI PAS110 PTE limit values. These concerns were addressed at the time by building-in a secondary mechanism that limits mean annual PTE application rates to soil over a ten year period, which in turn means that AD operators must monitor and control the application of digestate in the field. Similar concerns have subsequently been expressed in relation to the suggested EoW criteria, which contain no such secondary mechanism.

Establishing unduly low limits that do not provide proportionate environmental or health protection places unnecessary constraints on the resource management industry and restricts opportunities for closing nutrient cycles through land application. In the context of soil protection where organic materials are applied to agricultural land, the starting soil PTE concentration and the quantity of PTEs applied to soil are the most important criteria. Notably, typical digestate PTE loading rates to soils are lower than or similar to those from other organic materials that are commonly applied to agricultural land.

Analysis of the database of 90 food-based digestate samples showed that *mean* PTE concentrations in food-based digestates were below the current BSI PAS110 and suggested EoW limit values. However, the data indicated that around 13% of the samples would not meet the current BSI PAS110 limit for Zn, 8% for Cd, 3% for Ni and 7% for Cu (and 17% the lower EoW limit for Cu). Notably, *mean* concentrations of PTEs in biosolids and livestock manures that are widely applied to agricultural land are commonly higher than the current BSI PAS110 and suggested EoW limits for digestate and compost.

The majority of digestates are produced and managed as liquids, and hence are analysed in the laboratory on a sample 'as received' basis. This study concluded that it would be more appropriate for PTE limit concentrations in digestates to be set on a fresh weight basis, rather than on a dry matter basis as is currently the case; this would be consistent with the reporting of nutrient analyses, minimise PTE analytical detection limit problems and reduce the chances of laboratory errors occurring during fresh to dry matter concentration conversions.

Embracing the precautionary principle to ensure that digestate applications are as protective of the soil environment as is reasonably achievable and within the ethos of prevention of pollution, the key recommendation of this report is that (fresh weight) PTE limit concentrations are based on PTE addition rates to soils (in context with other commonly applied organic materials), and that PTE loading rates should not exceed those from compost, which are considered in a JRC technical report (IPTS, 2011) to be protective of the soil.

The following PTE concentration limits are proposed to protect the receiving soil environment.

Proposed fresh weight PTE limit values (g/m^3 or t fresh weight) for digestate products

PTE	Limit values for liquid digestate products (<15% dry matter)	Limit values for digestate fibre (≥15% dry matter)
Zn	30	150
Cu	15	30
Ni	3	5
Cd	0.2	0.2
Pb	5	30
Cr	5	20
Hg	0.1	0.1

Contents

Glossary

AD	Anaerobic digestion
ADQP	Anaerobic Digestate Quality Protocol
ASRS	Additional Scheme Rules for Scotland
BCS	Biofertiliser Certification Scheme
BSI	British Standards Institute
Digestate	For the purpose of this project digestate includes whole digestate, separated liquor and fibre
EoW	End of Waste
Fibre	The separated fibre fraction of digestate which generally contains ≥15% dry matter
JRC	Joint Research Council
LOD	Limit of (analytical) detection
NASM	Non-agricultural source material
NVZ	Nitrate Vulnerable Zone
PAS	Publicly available specification
PTE	Potentially toxic element. Sometimes referred to as heavy metals
RAN	Readily available nitrogen
Separated liquor	The separated liquid fraction of digestate which generally contains <15% dry matter
SGV	Soil guideline value

1.0 Background

The British Standards Institute Publicly Available Specification (BSI PAS) for Anaerobic Digestate (BSI PAS110; BSI, 2010) was developed to ensure that "digested materials are made using suitable inputs and effectively processed by anaerobic digestion (AD) for sufficient time; and to ensure that the process has been well managed and monitored so as to produce digested material that meets market needs *and protects the environment*". However, when BSI PAS110 was compiled, the limits for digestate potentially toxic element (PTE) concentrations were drawn directly from the compost specification (BSI PAS100; BSI, 2011), because there was only an extremely small commercial AD sector in the UK at the time and data on digestate quality were too scarce to consider an alternative approach. The BSI PAS100 limits are set on a dry matter (DM) basis (Table 1). It was recognised at the time that AD operators might find it difficult to consistently meet these limits, because whole and separated liquid digestates have very low dry matter contents; this concern has been reflected in recent industry dialogue.

Table 1. BSI PAS100 PTE limits for compost (and current BSI PAS110 PTE limits for digestate)

PTE	BSI PAS100/PAS110 upper limit (mg/kg dry matter)
Zinc (Zn)	400
Copper (Cu)	200
Nickel (Ni)	50
Cadmium (Cd)	1.5
Lead (Pb)	200
Chromium (Cr)	100
Mercury (Hg)	1.0

To overcome this potential difficulty, an alternative control mechanism was written into BSI PAS110 in the form of annual limits on PTE loading rates to soil (per hectare). These limits are the same as those in the "Sludge Use in Agriculture Regulations" (DoE, 1989), which require operators to monitor PTE loading rates to comply with a 10 year rolling average. This presents a different difficulty, since it requires that digestate be traced from production through to use over at least this time period. This is a challenge for auditors of the BSI PAS110 specification, and does not sit comfortably with the UK's developing end-of-waste approach, which regards some (Quality Protocol or PAS, depending upon the UK nation) compliant materials as products. Products need not be traced through to their end market.

During December 2011 WRAP held a series of workshops to seek industry feedback on all aspects of BSI PAS110 and the AD Quality Protocol (ADQP) / Additional Scheme Rules for Scotland (ASRS[1]). Various comments and suggestions were made on the current approaches to limiting digestate PTEs, including the possibility of setting limits on a fresh weight (mg/l) basis.

In addition, the Joint Research Council (JRC) in Seville has prepared a technical report on behalf of the European commission, containing suggested PTE limits as part of Europe-wide End-of-Waste (EoW) criteria for composts and digestates. The

[1] *http://www.biofertiliser.org.uk/certification/scotland*

second and third working documents on "End-of-Waste Criteria on Biodegradable Waste Subject to Biological Treatment" (IPTS, 2011) suggest that the suggested EoW limits for compost and digestate will be the same, and both set on a mg/kg dry matter basis. These suggested limits are almost identical to those currently in BSI PAS110 and PAS100, except for Pb (120 mg/kg, rather than 200 mg/kg) and Cu (100 mg/kg, rather than 200 mg/kg).

There is a need to understand the potential impact of the suggested EoW approach on the UK AD sector and to assess whether the EoW approach of setting limits on a dry matter basis is appropriate to the UK, given that the majority of digestate products are low in dry matter and are analysed in the laboratory on an 'as received' basis. Furthermore, the actual implications of PTE loading rates to soils can now be considered, since more data on digestate quality is available. This should enable the UK to consider a more evidence-based approach to PTE limit setting for digestates.

2.0 Objectives

The objectives of this study were to:

1. Collate current UK AD industry data on PTE concentrations in digestate and report on these in relation to other organic materials commonly applied to agricultural land.
2. Determine whether other limits (either on a dry matter basis or utilising other approaches) could be set that are equally protective of the environment as the current PAS/suggested EoW approaches, and suggest what those limits might be.
3. Summarise the impact of JRC suggestions to set new PTE limits in EoW criteria for digestates on the UK AD industry.

3.0 PTE concentrations in UK digestates

3.1 Data collation

Data for the project was obtained from the following sources:

a) The Biofertiliser Certification Scheme (BCS) kindly provided access (on the basis of complete anonymity) to data from food-based digestates submitted to NRM laboratories for testing against the BSI PAS110 suite of analyses (i.e. dry matter content and Cd, Cu, Cr, Hg, Ni, Pb and Zn concentrations). There were 84 samples from the BCS.

b) In addition, data already collected on PTE concentrations in manure-based digestates applied at a number of experimental sites as part of the ongoing WRAP/Defra-funded 'DC-*Agri*' project (OMK001-001) were collated. There were 7 samples from this project on the database.

c) Data were also obtained from the WRAP "Compost and Digestate Quality for Welsh Agriculture" project OAV032-004 (Taylor *et al*., 2011). There were 6 food-based digestate samples from this project.

In total data from 97 food- and manure-based digestate samples were collated in the database (Table 2). There were no samples of crop-only derived digestates on the database.

Table 2. Summary of digestate samples on the database

Digestate source	Type	Number of samples
Food-based	Whole	51
	Fibre* (≥15% dry matter*)	22
	Separated liquor (<15% dry matter)	17 Total = 90 samples
Manure-based	Whole	7

*Dry matter distinction between fibre and liquor based on BSI PAS 110 (BSI 2010).

Digestate samples submitted for laboratory analysis as liquids were analysed and the results reported on a fresh weight (sample as received) basis, and dry matter (dm) concentrations back-calculated using the sample dry matter content. Liquid samples were analysed 'as received' because the time and resources involved in pre-drying samples would render the analysis prohibitively expensive. Solid materials (i.e. fibre) were dried prior to analysis and the results reported on a dry matter basis, with the fresh weight concentrations back-calculated using the sample dry matter content. All sample analyses were undertaken using the British Standard – EN13650 "Soluble in aqua regia" method (BSI, 2011).

For samples from WRAP projects OMK001-001 and OAV032-004, data on digestate nitrogen (N) and phosphorus (P) contents were also available, in addition to the BSI PAS110 analysis suite.

3.2 Data analysis

The data were statistically analysed and collated into summary tables showing minimum, maximum, mean, standard deviation and 5, 25, 50 (median) and 95 percentile values. Dry matter PTE concentrations in food-based digestates were compared with the current BSI PAS110 and suggested EoW limit values; they were also compared with PTE concentrations in other organic materials commonly applied to agricultural land and with digestates from other EU countries.

Regression analysis was used to assess if there were any relationships between the following food-based digestate properties, to provide an improved understanding of the influence of digestate characteristics on PTE concentrations:

- Dry matter *vs.* PTE concentrations (dry matter basis)
- Dry matter *vs.* PTE concentrations (fresh weight basis)
- Dry matter *vs.* N and P concentration (fresh weight basis)
- N concentration *vs.* PTE concentration (fresh weight basis)
- P concentration *vs.* PTE concentration (fresh weight basis)

The food-based digestate data were statistically analysed together and were also analysed by type i.e. whole digestate, separated liquor (<15% dry matter) and fibre (≥15% dry matter).

3.3 Results

PTE concentrations (expressed on a fresh weight and dry matter basis), dry matter contents and N and P concentrations (where available) in all the food-based digestate samples are summarised in Tables 3-6. Data from the seven manure-based digestate samples are shown in Table 7 for comparison, but were not included in any subsequent work to determine PTE limit values as manure-based digestates are not considered wastes, and would therefore not benefit from certification to BSI PAS110. The individual analyses for each sample are presented in Appendix 1 (Tables A1-A6).

PTE concentrations (on a dry matter basis) in each of the 90 food-based digestate samples are shown in comparison with the current BSI PAS110 and suggested EoW limit concentrations in Figures 1 to 6.

3.3.1 Dry matter PTE concentrations

For the 90 individual food-based digestate samples, Zn concentrations ranged from <0.1 to 755 mg/kg dry matter (mean 207 mg/kg dm), with twelve samples (13% of total sample numbers) exceeding the current BSI PAS110 limit of 400 mg/kg dm (Table 3, Figure 1).

Cu concentrations ranged from <0.1 to 373 mg/kg dm (mean 66 mg/kg dm), with six samples (7% of total sample numbers) exceeding the current BSI PAS110 limit of 200 mg/kg dm (Table 3, Figure 2). If the Cu limit was reduced to 100 mg/kg as suggested in the EU End-of Waste working document, then fifteen samples (17% of total sample numbers) would exceed this value.

Cd concentrations ranged from <0.1 to 4 mg/kg dm (mean 0.5 mg/kg dm), with seven samples (8% of total sample numbers) exceeding the current BSI PAS110 limit of 1.5 mg/kg dm (Table 3, Figure 3).

Pb concentrations ranged from <0.1 to 98 mg/kg dm (mean 11 mg/kg dm). None of the samples exceeded the current BSI PAS110 limit of 200 mg/kg dm or the lower value of 120 mg/kg suggested in the EU End-of Waste working document (Table 3, Figure 4).

Ni concentrations ranged from 1 to 107 mg/kg dm (mean 13 mg/kg dm), with three samples (3% of total sample numbers) exceeding the current BSI PAS110 limit of 50 mg/kg dm (Table 3, Figure 5). Cr concentrations ranged from <0.1 to 67 mg/kg dm (mean 11 mg/kg dm). None of the samples exceeded the current BSI PAS110 limit of 50 mg/kg dm (Table 3, Figure 6).

Hg concentrations were generally below the limit of analytical detection (<0.01 mg/kg dm). However there was one sample of fibre digestate that exceeded the current BSI PAS110 limit of 1.0 mg/kg dm (Table 3, Figure 7).

The digestate fibre samples generally had higher concentrations of Zn, Cu, Pb and Cr than the whole digestates or separated liquor; this was particularly evident when comparing PTE concentrations on a fresh weight basis (Tables 4 to 6) and reflected the higher dry matter content of the fibre samples.

Based on limited data, manure-based digestates (seven samples) 'typically' contained higher concentrations of Cu, Ni and Cr than the food-based digestate products (Table 7).

Table 3. Food-based digestates – all samples

	Units*	No. of samples	Mini-mum	Maxi-mum	Mean	Standard Deviation	5th Percentile	25th Percentile	50th Percentile (median)	95th Percentile	BSI PAS110 limit	Suggested EoW limit
Dry matter	%dm	90	0.6	34	8.7	8.7	1.6	3.1	4.5	27		
Total N	kg/t fw	9	4.2	8.5	6.3	1.7	4.5	5.0	6.3	8.5		
Total P	kg/t fw	9	0.3	1.0	0.5	0.2	0.3	0.4	0.5	0.9		
Total Zn	mg/kg dm	90	<0.1	755	207	176	52	105	133	593	400	400
Total Cu	mg/kg dm	90	<0.1	373	66	75	10	29	38	244	200	100
Total Cd	mg/kg dm	90	<0.1	4.0	0.5	0.7	<0.1	<0.1	0.3	1.8	1.5	1.5
Total Pb	mg/kg dm	90	<0.1	98	11	16	0.9	3.2	4.9	40	200	120
Total Ni	mg/kg dm	90	1.2	107	13	17	1.9	6.5	9.5	29	50	50
Total Cr	mg/kg dm	90	<0.1	67	11	11	0.9	4.4	6.9	27	100	100
Total Hg	mg/kg dm	90	<0.1	1.5	0.1	0.2	<0.1	<0.1	<0.1	0.1	1.0	1.0
Total Zn	mg/kg fw	90	<0.1	168	24	39	1.2	3.9	5.8	118		
Total Cu	mg/kg fw	90	<0.1	83	6.4	13	0.2	1.3	1.8	24		
Total Cd	mg/kg fw	90	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	0.1		
Total Pb	mg/kg fw	90	<0.1	21.8	1.3	3.1	<0.1	0.1	0.2	6.4		
Total Ni	mg/kg fw	90	0.1	3.5	0.8	0.9	0.1	0.3	0.4	2.6		
Total Cr	mg/kg fw	90	<0.1	11.7	1.3	2.2	<0.1	0.2	0.3	6.2		
Total Hg	mg/kg fw	90	<0.1	0.4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1		

*%dm = percent dry matter; kg/t fw = kilograms per tonne fresh weight; mg/kg dm = milligrams per kilogram dry matter; mg/kg fw = milligrams per kilogram fresh weight

Note: PTE concentrations are not normally distributed

Table 4. Food-based digestates – whole digestate

	Units*	No. of samples	Mini-mum	Maxi-mum	Mean	Standard Deviation	5th Percentile	25th Percentile	50th Percentile (median)	95th Percentile	BSI PAS110 limit	Suggested EoW limit
Dry matter	%dm	51	1.1	6.1	3.8	1.3	1.6	2.8	4.2	5.6		
Total N	kg/t fw	9	4.2	8.5	6.3	1.7	4.5	5.0	6.3	8.5		
Total P	kg/t fw	9	0.3	1.0	0.5	0.2	0.3	0.4	0.5	0.9		
Total Zn	mg/kg dm	51	20	602	167	111	69	109	127	392	400	400
Total Cu	mg/kg dm	51	12	248	62	63	19	29	37	219	200	100
Total Cd	mg/kg dm	51	<0.1	4.0	0.7	0.9	<0.1	<0.1	0.4	2.3	1.5	1.5
Total Pb	mg/kg dm	51	1.0	83	7.5	13	1.2	3.2	4.4	18	200	120
Total Ni	mg/kg dm	51	1.7	107	16	21	4.3	6.5	10	60	50	50
Total Cr	mg/kg dm	51	<0.1	25	8.5	5.7	3.4	4.7	6.8	22	100	100
Total Hg	mg/kg dm	51	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1.0	1.0
Total Zn	mg/l fw	51	1.1	13	5.7	2.7	1.9	4.1	5.4	12		
Total Cu	mg/l fw	51	0.2	9.5	2.0	1.6	0.6	1.2	1.7	4.8		
Total Cd	mg/l fw	51	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	0.1		
Total Pb	mg/l fw	51	<0.1	1.3	0.2	0.3	<0.1	0.1	0.2	0.8		
Total Ni	mg/l fw	51	0.1	1.9	0.5	0.4	0.1	0.3	0.4	1.5		
Total Cr	mg/l fw	51	<0.1	1.1	0.3	0.2	0.1	0.2	0.3	0.7		
Total Hg	mg/l fw	51	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1		

*%dm = percent dry matter; kg/t fw = kilograms per tonne fresh weight; mg/kg dm = milligrams per kilogram dry matter; mg/kg fw = milligrams per kilogram fresh weight

Note: PTE concentrations are not normally distributed

Table 5. Food-based digestates – separated liquor

	Units*	No. of samples	Mini-mum	Maxi-mum	Mean	Standard Deviation	5th Percentile	25th Percentile	50th Percentile (median)	95th Percentile	BSI PAS110 limit	Suggested EoW limit
Dry matter	%dm	15	0.6	11	3.5	2.3	1.0	2.4	3.3	7.3		
Total N	kg/t fw	0	-	-	-	-	-	-	-	-		
RAN	kg/t fw	0	-	-	-	-	-	-	-	-		
Total P	kg/t fw	0	-	-	-	-	-	-	-	-		
Total Zn	mg/kg dm	15	<0.1	300	112	81	2.6	72	106	236	400	400
Total Cu	mg/kg dm	15	<0.1	117	36	31	<0.1	10	35	83	200	100
Total Cd	mg/kg dm	15	<0.1	0.8	<0.1	0.2	<0.1	<0.1	<0.1	0.6	1.5	1.5
Total Pb	mg/kg dm	15	<0.1	16	7.8	6.0	0.1	2.5	6.6	15	200	120
Total Ni	mg/kg dm	15	1.3	16	9.2	3.7	3.7	7.4	8.9	14	50	50
Total Cr	mg/kg dm	15	<0.1	34	6.2	8.8	<0.1	1.1	3.3	21	100	100
Total Hg	mg/kg dm	15	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	1.0	1.0
Total Zn	mg/l fw	15	<0.1	9.8	3.4	2.7	<0.1	1.1	3.8	7.4		
Total Cu	mg/l fw	15	<0.1	3.6	1.1	1.1	<0.1	0.2	1.0	3.0		
Total Cd	mg/l fw	15	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1		
Total Pb	mg/l fw	15	<0.1	0.5	0.2	0.2	<0.1	0.1	0.2	0.5		
Total Ni	mg/l fw	15	0.1	0.5	0.3	0.1	0.1	0.2	0.3	0.5		
Total Cr	mg/l fw	15	<0.1	1.3	0.2	0.3	<0.1	<0.1	0.1	0.8		
Total Hg	mg/l fw	15	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1		

*%dm = percent dry matter; kg/t fw = kilograms per tonne fresh weight; mg/kg dm = milligrams per kilogram dry matter; mg/kg fw = milligrams per kilogram fresh weight

Note: most PTE concentrations are normally distributed

Table 6. Food-based digestates – separated fibre

	Units*	No. of samples	Min	Max	Mean	Standard deviation	5th Percentile	25th Percentile	50th Percentile (median)	95th Percentile	BSI PAS110 limit	Suggested EoW limit
Dry matter	%dm	24	8.7	34	22	5.3	14	20	22	30		
Total N	kg/t fw	0	-	-	-	-	-	-	-	-		
RAN	kg/t fw	0	-	-	-	-	-	-	-	-		
Total P	kg/t fw	0	-	-	-	-	-	-	-	-		
Total Zn	mg/kg dm	24	56	755	352	239	60	159	286	731	400	400
Total Cu	mg/kg dm	24	8.8	373	93	107	11	29	63	357	200	100
Total Cd	mg/kg dm	24	<0.1	1.3	0.3	0.3	<0.1	0.1	0.2	0.8	1.5	1.5
Total Pb	mg/kg dm	24	0.4	98	19	23.3	0.9	4.6	12	62	200	120
Total Ni	mg/kg dm	24	1.2	27	8.9	5.9	1.8	4.5	9.0	17	50	50
Total Cr	mg/kg dm	24	1.8	67	19	16	2.7	9.0	16	48	100	100
Total Hg	mg/kg dm	24	<0.1	1.5	0.2	0.3	<0.1	<0.1	<0.1	0.5	1.0	1.0
Total Zn	mg/kg fw	24	12	168	75	48	13	28	76	151		
Total Cu	mg/kg fw	24	2.1	83	19	21	2.4	6.7	14	71		
Total Cd	mg/kg fw	24	<0.1	0.2	0.1	<0.1	<0.1	<0.1	<0.1	0.2		
Total Pb	mg/kg fw	24	0.1	22	4.1	5.0	0.2	1.1	2.4	13		
Total Ni	mg/kg fw	24	0.3	3.5	1.9	1.0	0.4	1.1	1.9	3.4		
Total Cr	mg/kg fw	24	0.4	12	3.9	2.8	0.6	2.0	4.0	8.0		
Total Hg	mg/kg fw	24	<0.1	0.4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1		

*%dm = percent dry matter; kg/t fw = kilograms per tonne fresh weight; mg/kg dm = milligrams per kilogram dry matter; mg/kg fw = milligrams per kilogram fresh weight

Note: most PTE concentrations are not normally distributed

Table 7. Manure-based digestate – whole

	Units*	No. of samples	Min	Max	Mean	Standard deviation	5th Percentile	25th Percentile	50th Percentile (median)	95th Percentile	BSI PAS110 limit	Suggested EoW limit
Dry matter	%dm	7	0.7	8.5	4.4	2.5	1.6	3.5	3.9	7.9		
Total N	kg/t fw	4	0.9	4.9	3.2	1.7	1.2	2.5	3.5	4.8		
RAN	kg/t fw	4	0.7	2.8	1.8	0.9	0.8	1.3	1.9	2.8		
Total P	kg/t fw	4	0.1	1.7	0.9	0.7	0.2	0.5	0.8	1.6		
Total Zn	mg/kg dm	7	87	217	153	44	97	127	154	206	400	400
Total Cu	mg/kg dm	7	38	249	105	74	40	53	88	217	200	100
Total Cd	mg/kg dm	7	<0.1	0.6	0.3	0.2	<0.1	0.2	0.4	0.6	1.5	1.5
Total Pb	mg/kg dm	7	2.7	18	6.8	5.4	2.8	3.3	4.7	15	200	120
Total Ni	mg/kg dm	7	5.1	124	35	41	6.5	11	17	99	50	50
Total Cr	mg/kg dm	7	3.7	195	61	69	5.0	10	46	168	100	100
Total Hg	mg/kg dm	7	<0.1	1.4	0.2	0.8	<0.1	0.1	0.1	1.0	1.0	1.0
Total Zn	mg/l fw	7	1.3	18	7.2	6.0	1.8	4.0	5.2	16		
Total Cu	mg/l fw	7	1.3	12	4.3	4.0	1.4	1.7	2.6	11		
Total Cd	mg/l fw	7	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1		
Total Pb	mg/l fw	7	0.1	1.5	0.4	0.5	0.1	0.1	0.1	1.2		
Total Ni	mg/l fw	7	0.1	5.0	1.4	1.7	0.1	0.5	0.9	4.0		
Total Cr	mg/l fw	7	0.1	7.9	2.2	2.8	0.2	0.4	1.1	6.7		
Total Hg	mg/l fw	7	<0.1	0.1	<0.1	<0.1	<0.1	0.1	0.1	0.1		

*%dm = percent dry matter; kg/t fw = kilograms per tonne fresh weight; mg/kg dm = milligrams per kilogram dry matter; mg/kg fw = milligrams per kilogram fresh weight

Note: most PTE concentrations are normally distributed

Figure 1. Dry matter Zn concentrations (mg/kg dm) in all food-based digestates and compliance with BSI PAS110 and suggested EU EoW limits

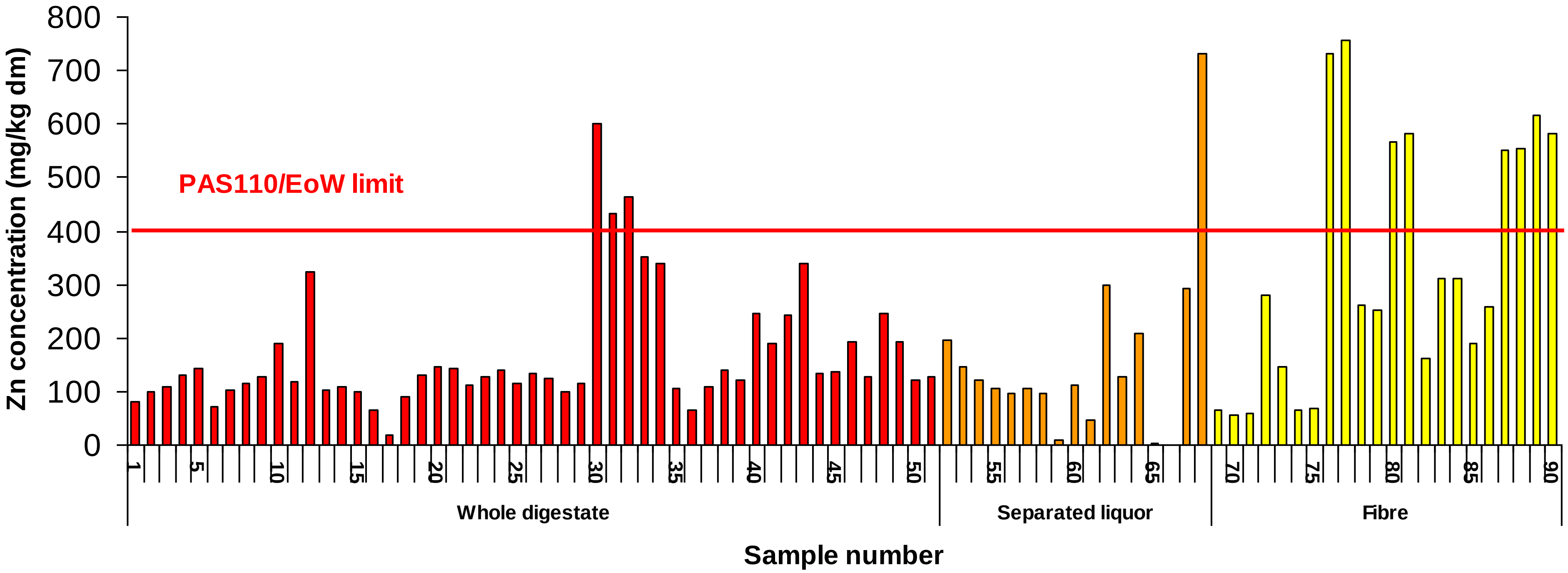


Figure 2. Dry matter Cu concentrations (mg/kg dm) in all food-based digestates and compliance with BSI PAS110 and suggested EU EoW limits

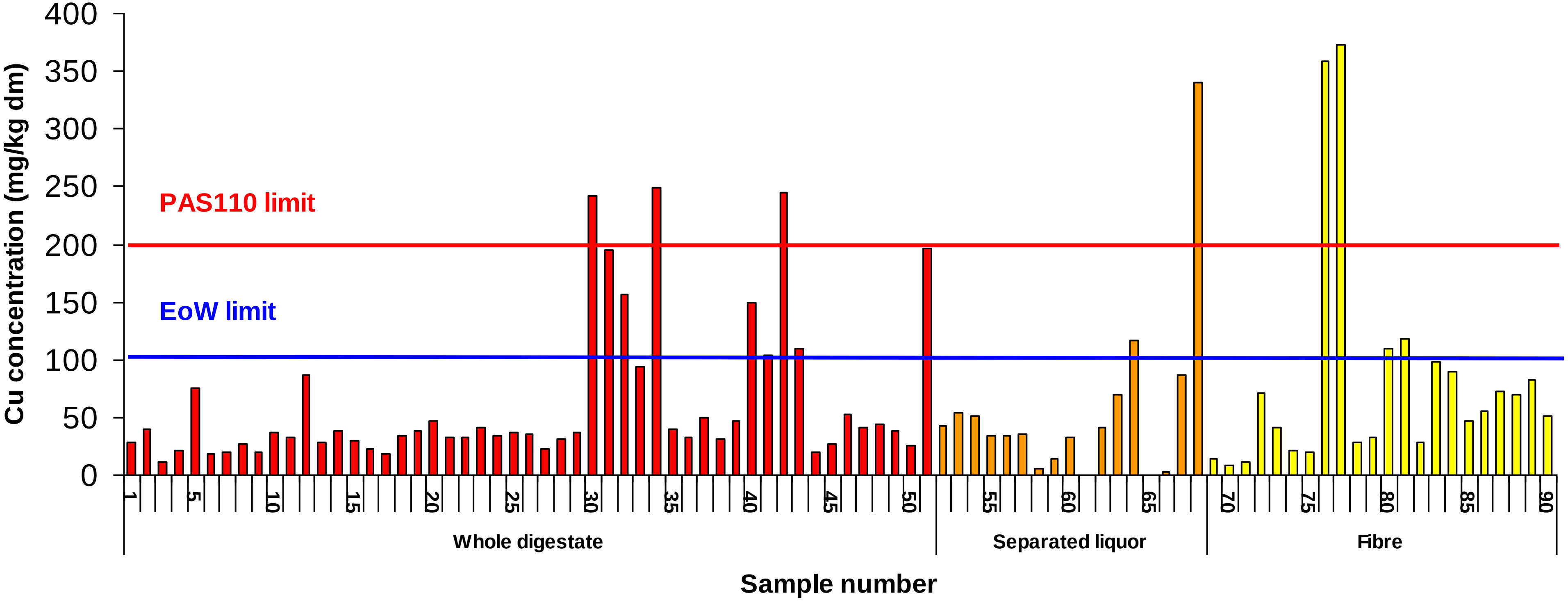


Figure 3. Dry matter Cd concentrations (mg/kg dm) in all food-based digestates and compliance with BSI PAS110 and suggested EU EoW limits

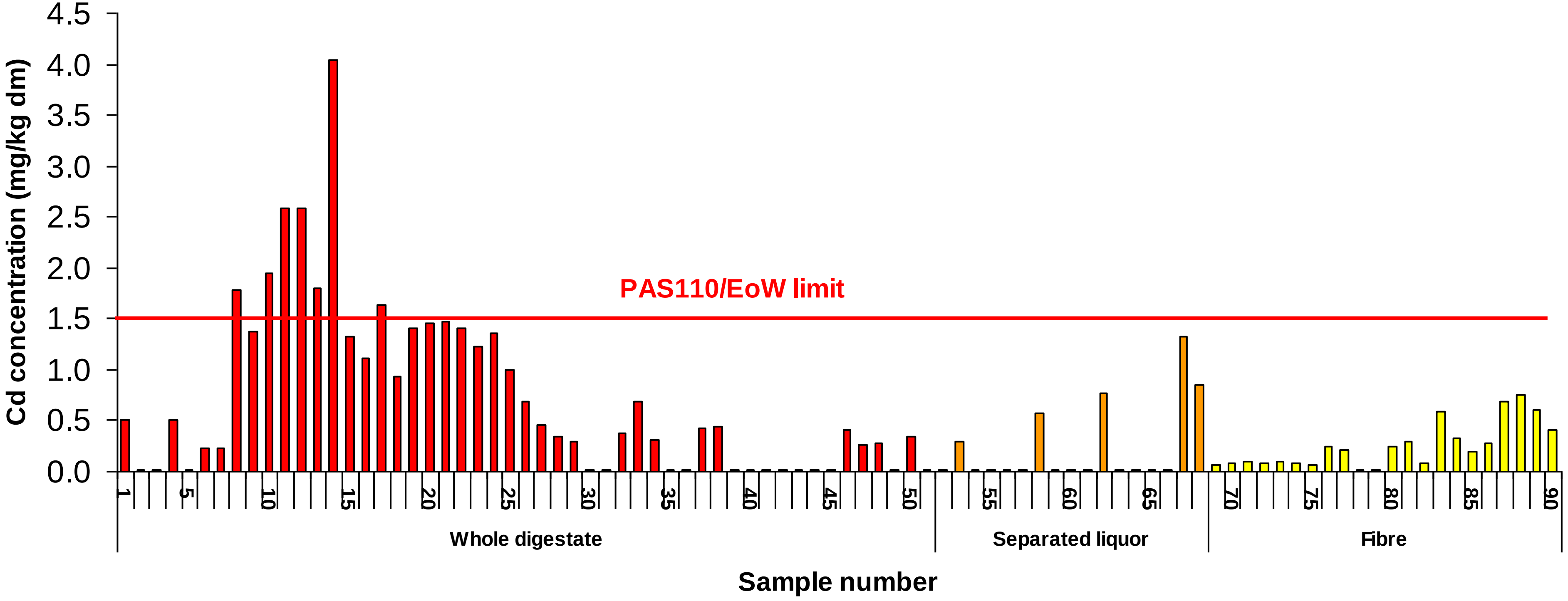


Figure 4. Dry matter Pb concentrations (mg/kg dm) in all food-based digestates and compliance with BSI PAS110 and suggested EU EoW limits

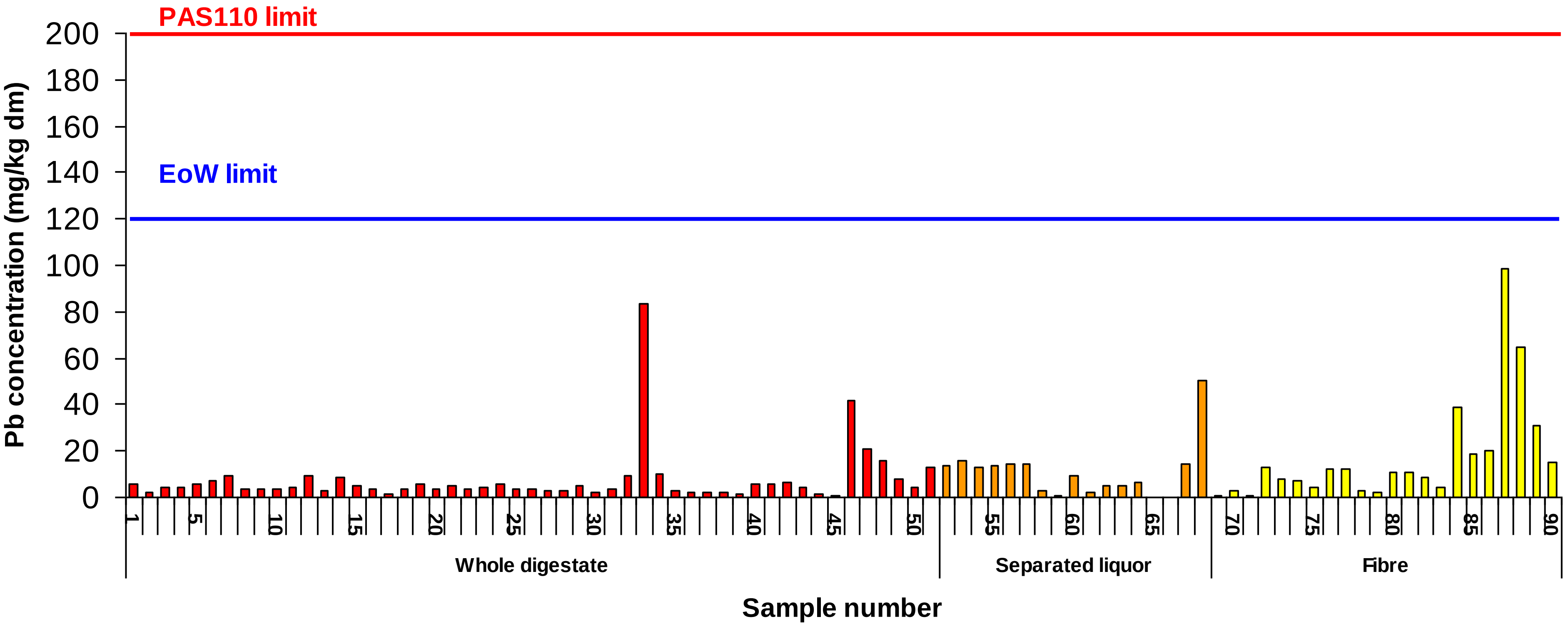


Figure 5. Dry matter Ni concentrations (mg/kg dm) in all food-based digestates and compliance with BSI PAS110 and suggested EU EoW limits

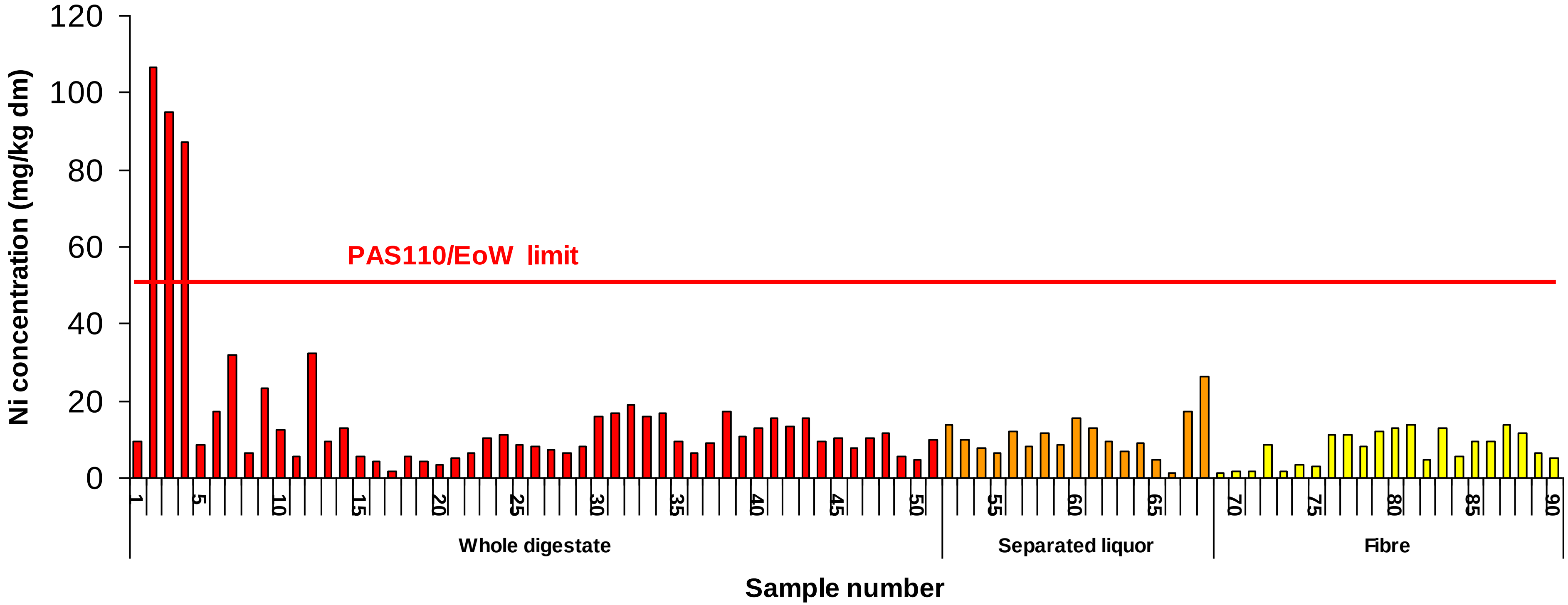


Figure 6. Dry matter Cr concentrations (mg/kg dm) in all food-based digestates and compliance with BSI PAS110 and suggested EU EoW limits

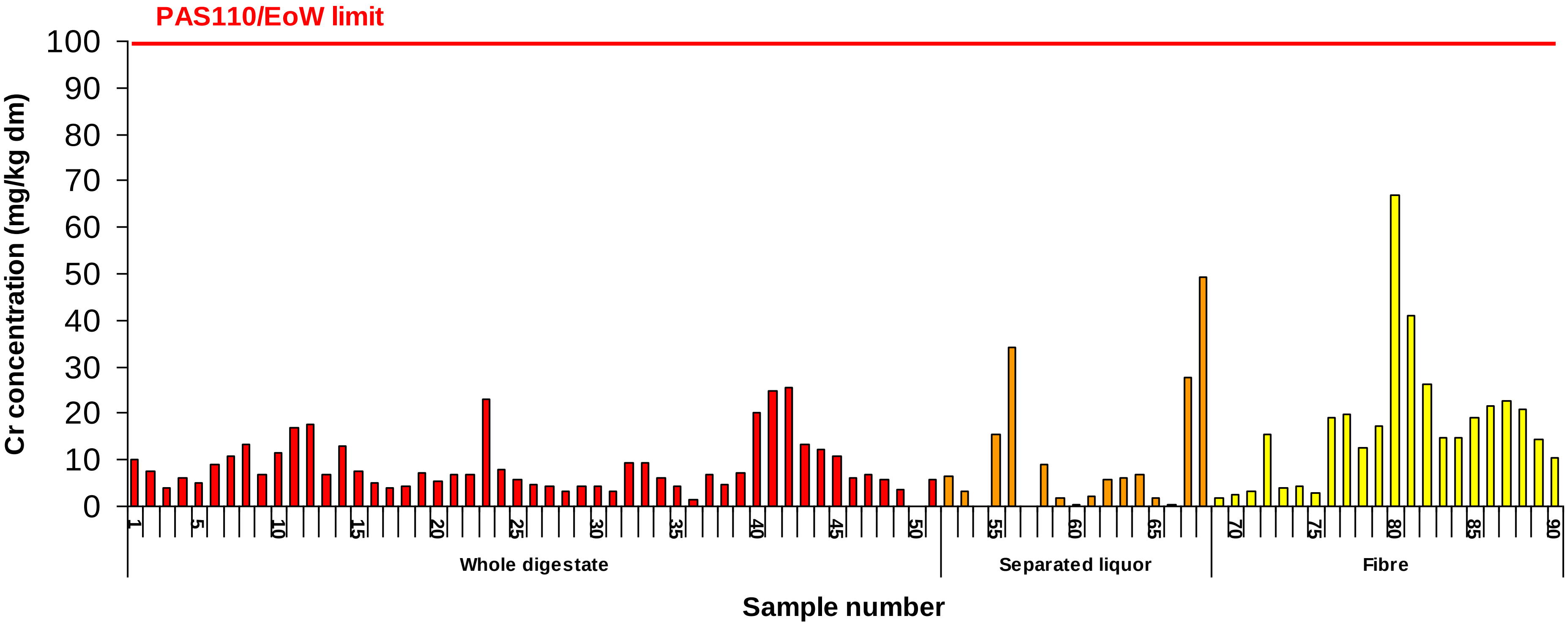
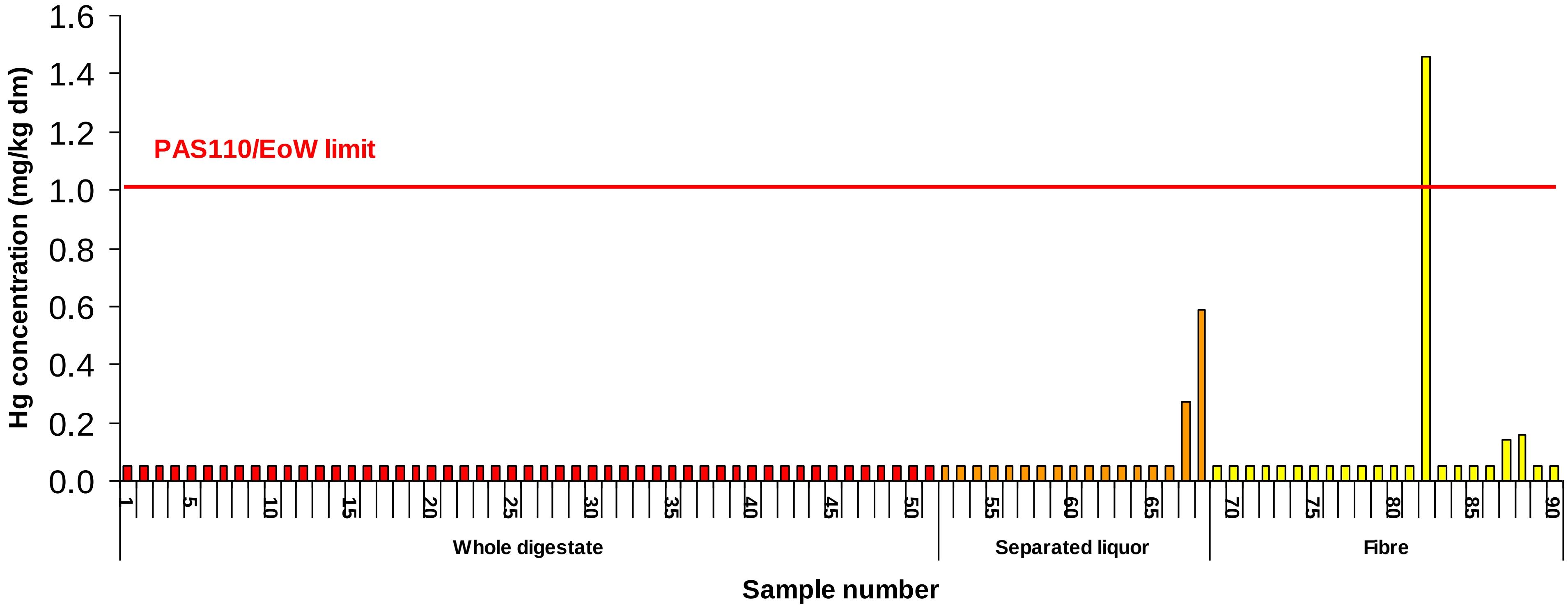


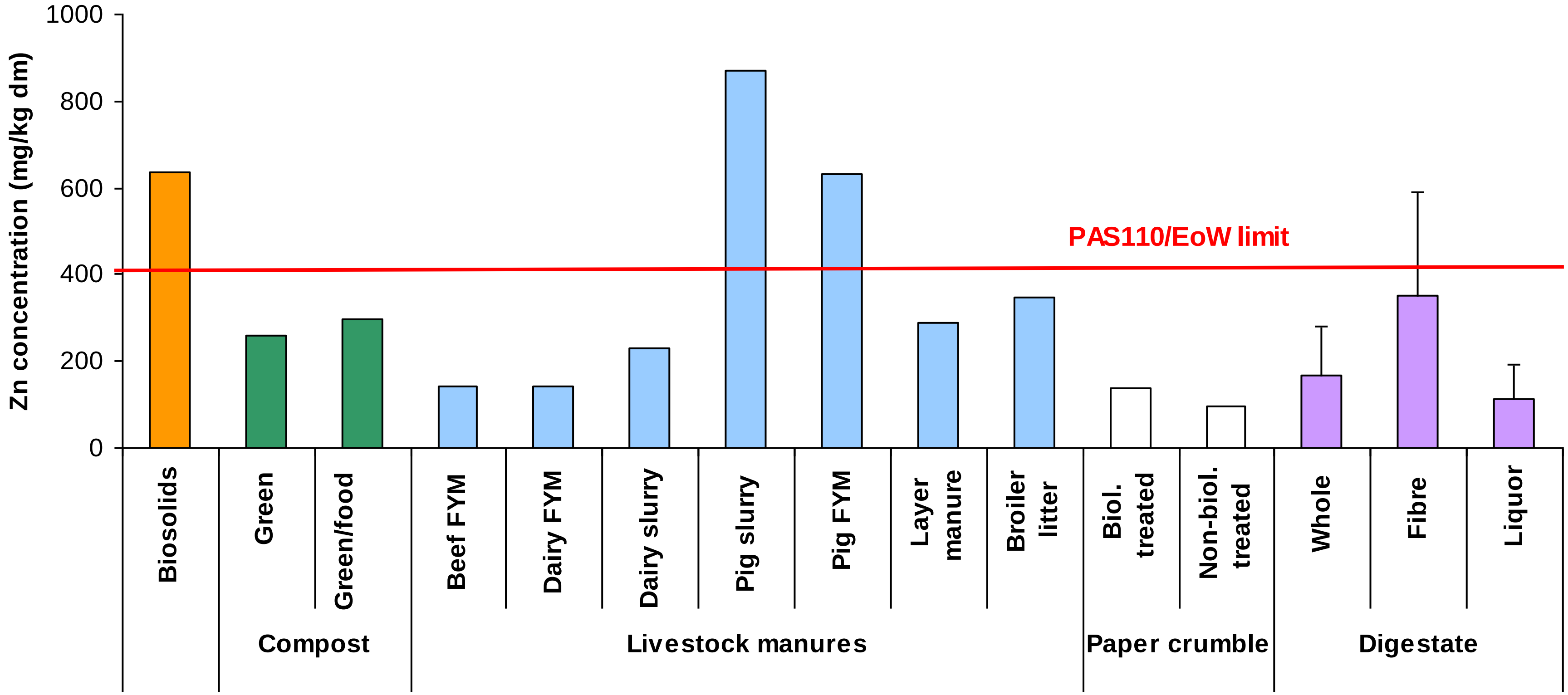
Figure 7. Dry matter Hg concentrations (mg/kg dm) in all food-based digestates and compliance with BSI PAS110 and suggested EU EoW limits



3.3.2 Comparison between mean PTE dry matter concentrations in food-based digestate and other organic materials applied to agricultural land

Mean food-based digestate PTE concentrations (on a dry matter basis) were compared with those in other organic materials commonly applied to agricultural land (i.e. biosolids, livestock manures, compost, paper crumble). Mean Zn concentrations were lower than typical concentrations in biosolids and pig manures (Figure 8), and mean Cu concentrations (Figure 9) were lower than biosolids and some livestock manures and paper crumble. Mean Cd concentrations (Figure 10) were below typical concentrations in biosolids and mean Pb concentrations below typical concentrations in biosolids and compost (Figure 11). Mean Ni and Cr concentrations (Figures 12 and 13) were below typical concentrations in biosolids, and mean Hg concentrations (Figure 14) were below typical concentrations in biosolids.

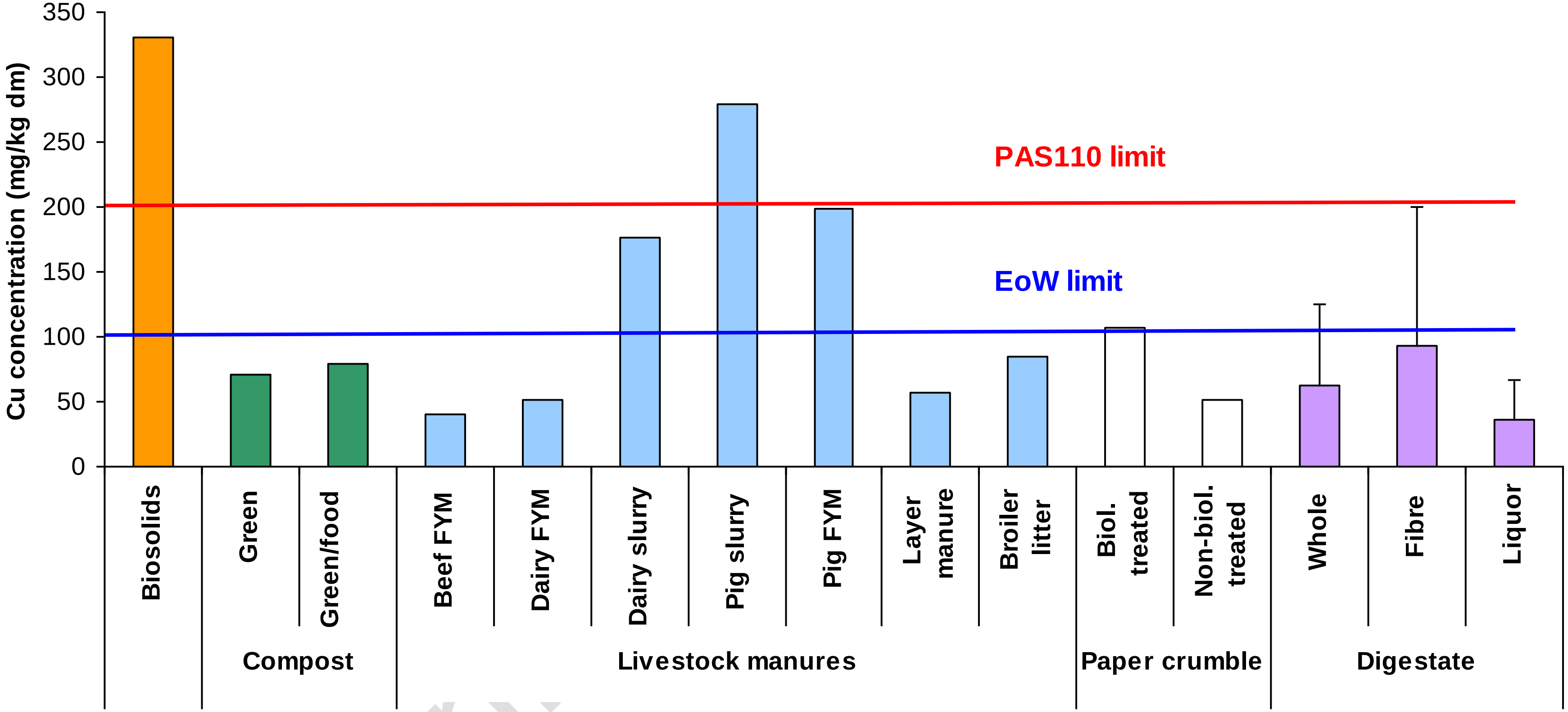
Figure 8. Mean (and standard deviation) Zn concentrations (mg/kg dm) in food-based digestates and other organic materials applied to agricultural land in comparison with the current BSI PAS110 and suggested EU EoW limits



Notes: Standard deviations are only presented for digestates

Data on mean Zn concentrations in biosolids, composts, livestock manures and paper crumble from Nicholson *et al.* (2010).

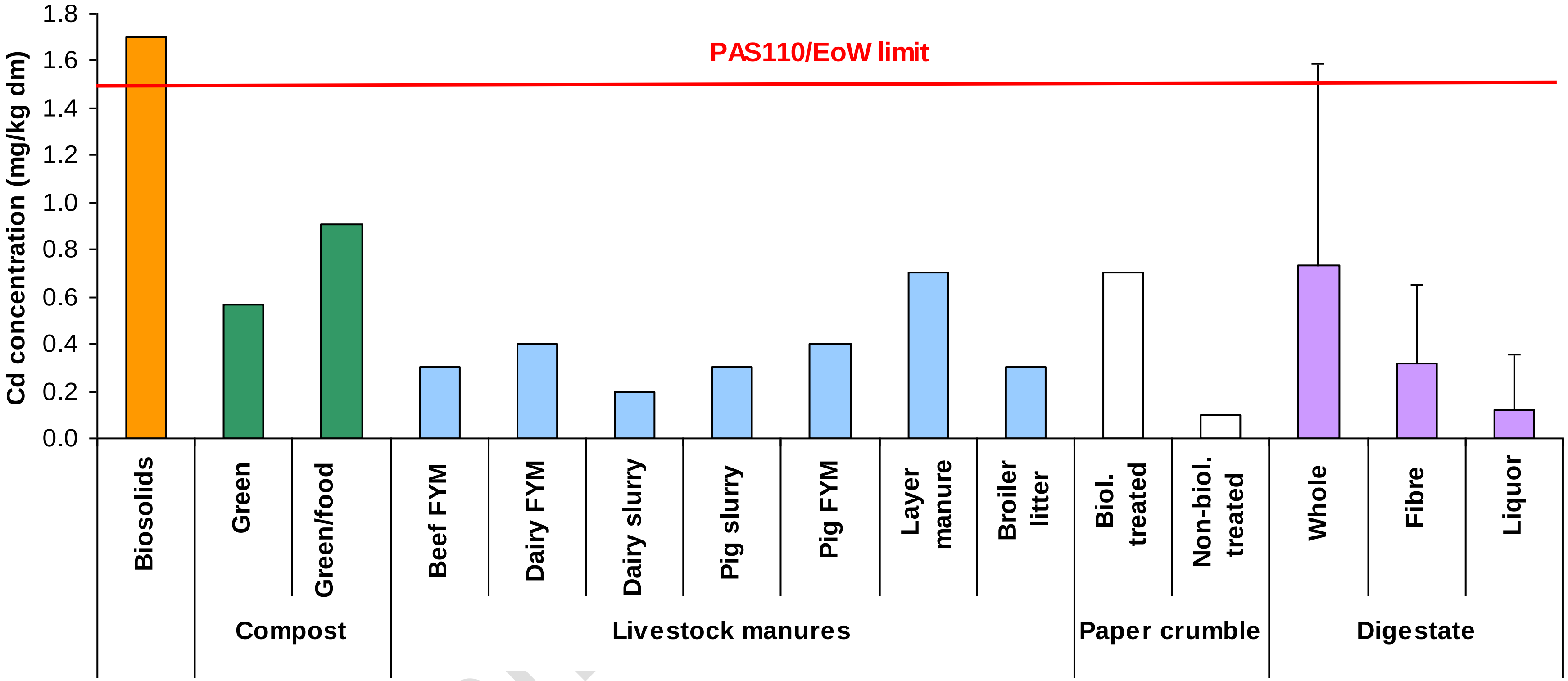
Figure 9. Mean (and standard deviation) Cu concentrations (mg/kg dm) in food-based digestates and other organic materials applied to agricultural land in comparison with the current BSI PAS110 and suggested EU EoW limits



Notes: Standard deviations are only presented for digestates

Data on mean Cu concentrations in biosolids, composts, livestock manures and paper crumble from Nicholson *et al*. (2010).

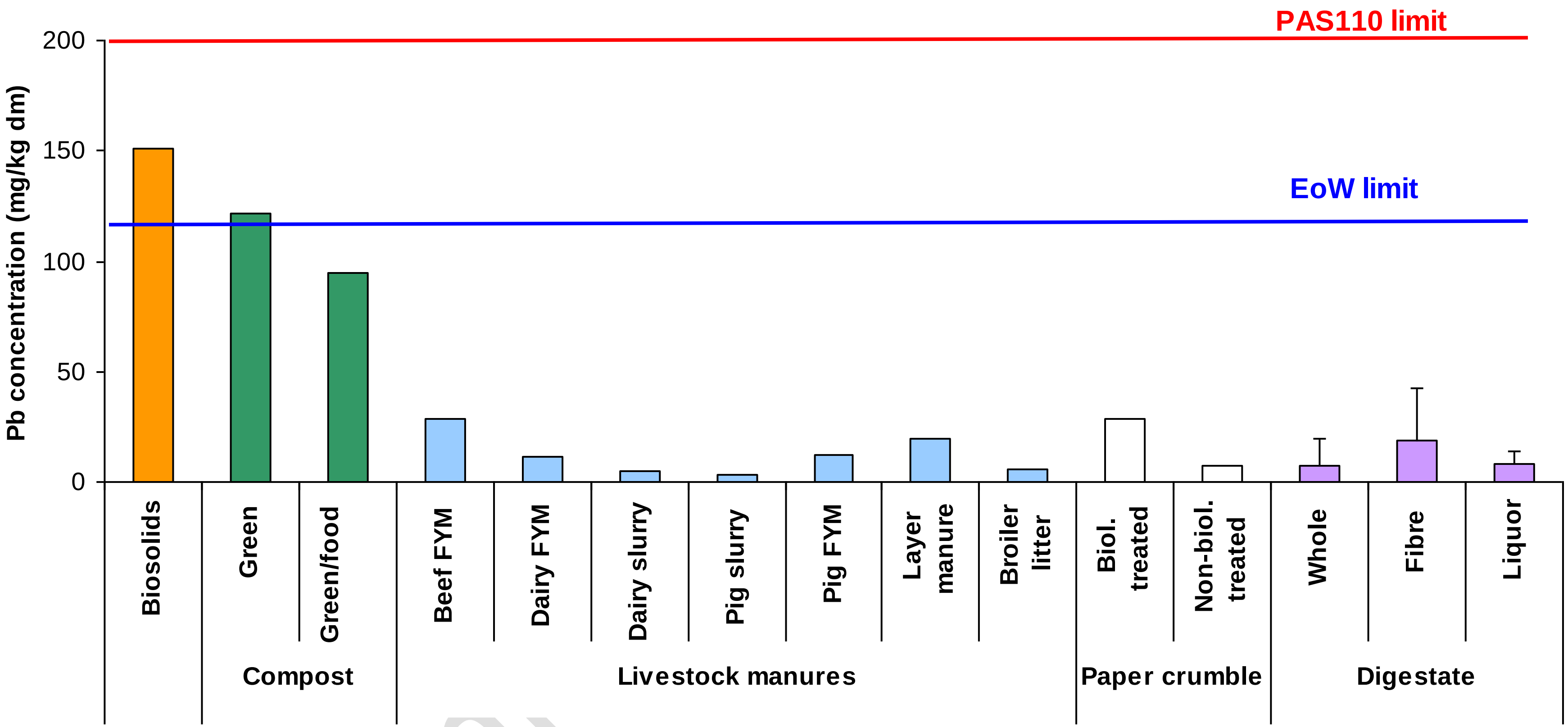
Figure 10. Mean (and standard deviation) Cd concentrations (mg/kg dm) in food-based digestates and other organic materials applied to agricultural land in comparison with the current BSI PAS110 and suggested EU EoW limits



Notes: Standard deviations are only presented for digestates

Data on mean Cd concentrations in biosolids, composts, livestock manures and paper crumble from Nicholson *et al*. (2010).

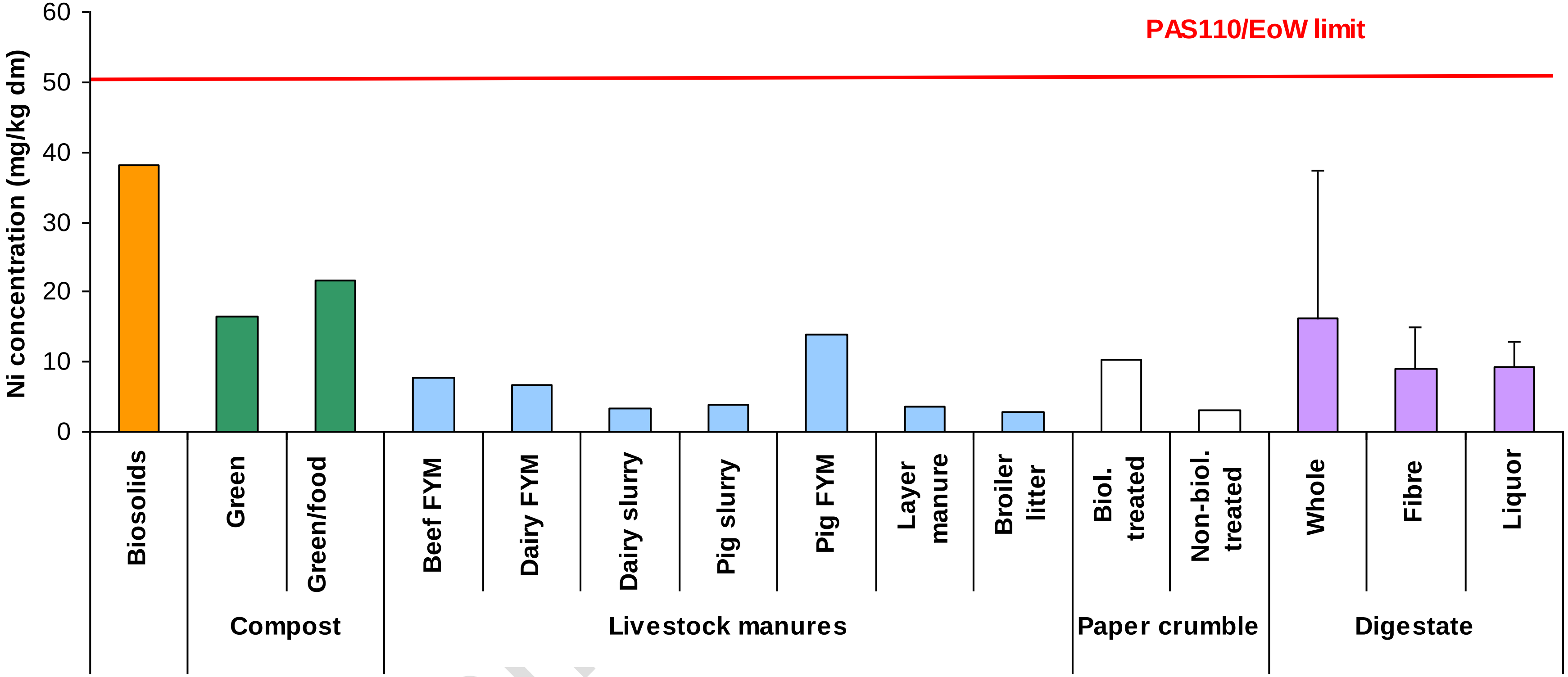
Figure 11. Mean (and standard deviation) Pb concentrations (mg/kg dm) in food-based digestates and other organic materials applied to agricultural land in comparison with the current BSI PAS110 and suggested EU EoW limits



Notes: Standard deviations are only presented for digestates

Data on mean Pb concentrations in biosolids, composts, livestock manures and paper crumble from Nicholson *et al.* (2010).

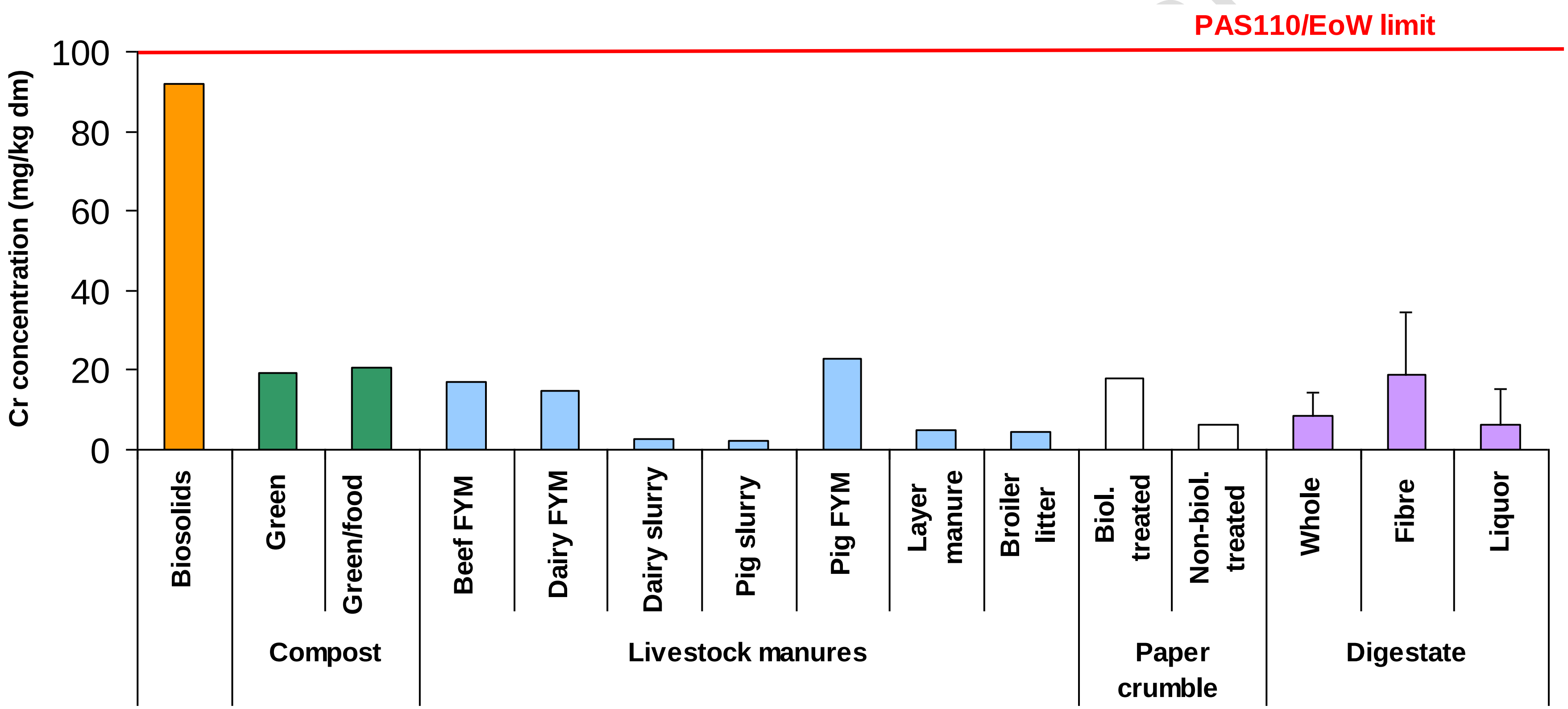
Figure 12. Mean (and standard deviation) Ni concentrations (mg/kg dm) in food-based digestates and other organic materials applied to agricultural land in comparison with the current BSI PAS110 and suggested EU EoW limits



Notes: Standard deviations are only presented for digestates

Data on mean Ni concentrations in biosolids, composts, livestock manures and paper crumble from Nicholson *et al*. (2010).

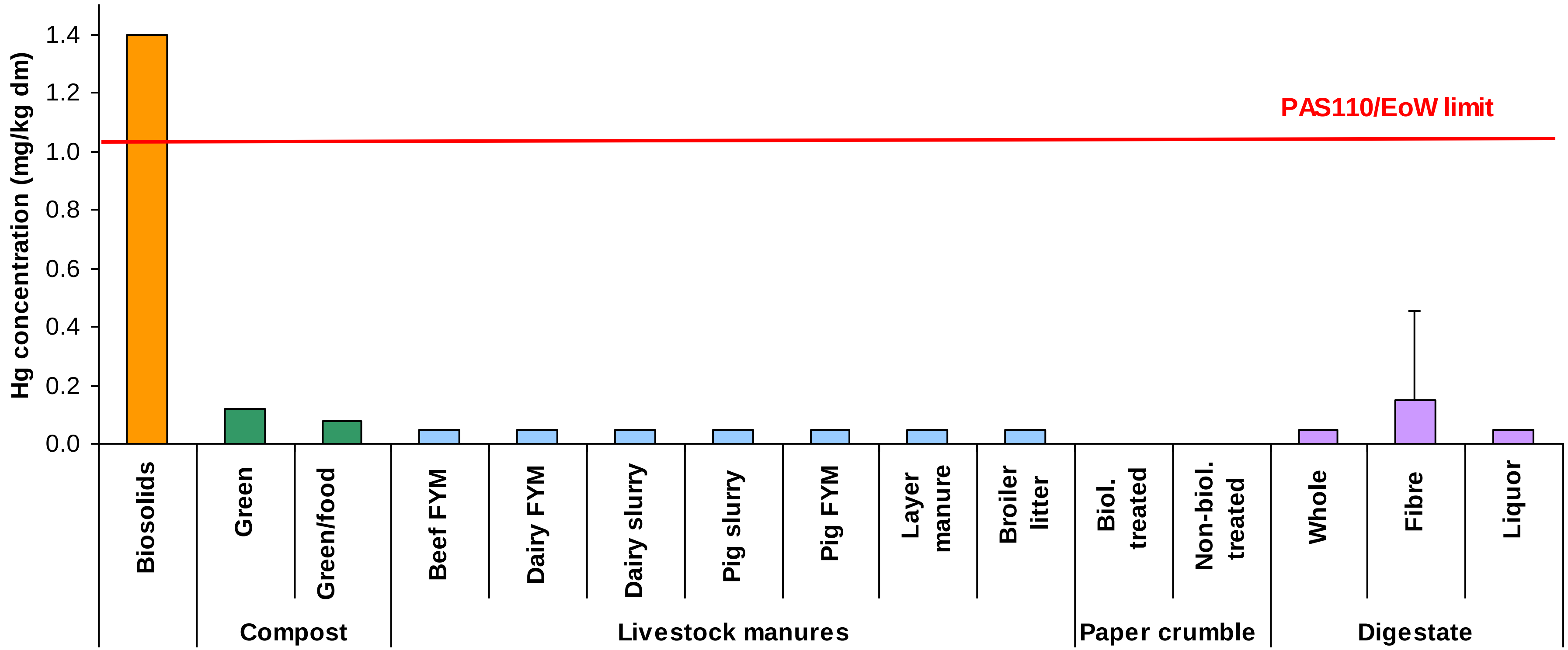
Figure 13. Mean (and standard deviation) Cr concentrations (mg/kg dm) in digestates and other organic materials applied to agricultural land in comparison with the current BSI PAS110 and suggested EU EoW limits



Notes: Standard deviations are only presented for digestates

Data on mean Cr concentrations in biosolids, composts, livestock manures and paper crumble from Nicholson *et al*. (2010).

Figure 13. Mean (and standard deviation) Hg concentrations (mg/kg dm) in digestates and other organic materials applied to agricultural land in comparison with the current BSI PAS110 and suggested EU EoW limits



Notes: Standard deviations are only presented for digestates

Data on mean Hg concentrations in biosolids from Nicholson *et al*. (2010). Data on mean Hg concentrations in compost and livestock manures from WRAP project-OAV032-004

3.3.3 Digestate PTE concentrations in other countries

Based on a web-based literature search, only a limited amount of information on digestate PTE concentrations from other EU countries could be identified (Table 8), which indicated that food-based digestate PTE concentrations collated in this study were generally comparable to those in other EU countries.

Table 8. Examples of PTE concentrations (mg/kg dm) in digestates from other EU countries

PTE	BSI PAS110/ suggested EoW limit	Mean of food-based digestates (this study)	Austria[1]			Norway[2]	
			Agric-ultural residues (50 samples)	Food industry waste (20 samples)	House-hold catering waste (20 samples)	Fibre digestate (12 month average from 1 plant treating household waste)	Liquid digestate
Zn	400	207	-	-	-	217	263
Cu	200/100	66	-	-	-	53	44
Cd	1.5	0.6	0.4	0.5	0.3	0.3	0.4
Pb	200/120	11	2	5	4	10	5
Ni	50	13	6	12	10	11	6
Cr	100	11	5	12	9	24	9
Hg	1.0	<0.1	<0.1	<0.1	<0.1	0.07	0.09

[1]Pfundtner (2009)
[2]Holen *et al*. (2011)

3.3.4 Results of regression analysis

As expected, there were no relationships ($P>0.05$) between digestate dry matter content and PTE concentrations expressed on a dry matter basis. However, there were positive ($P<0.05$) relationships between digestate dry matter content and PTE concentrations expressed on a fresh weight basis for Zn (Figure 14), Cu, Cd, Pb, Ni and Cr (Table 9). These data support the assertion that the digestate separation will redistribute PTEs between the liquid and fibre fractions. Some work on this subject has been undertaken with livestock manures. For example, Burton (2006) reported that >90% of the Zn and Cu in pig slurry was in an insoluble form and would therefore be present in the solid fraction after separation. Similarly, Chambers *et al*. (1999) showed there was a strong positive relationship between the dry matter content of cattle and pig slurry and PTE concentrations (expressed on a fresh weight basis).

When the liquid (<15% dry matter) and fibre (≥15% dry matter) digestates were examined separately, relationships between digestate dry matter content and PTE concentrations expressed on a fresh weight basis were only evident ($P>0.05$) for liquid digestates (Figure 15 and Table 10), with the relationships largely driven by three samples with dry matter content >8%.

Figure 14. Relationship between digestate dry matter content and Zn concentration (fresh weight basis) for all food-based digestates

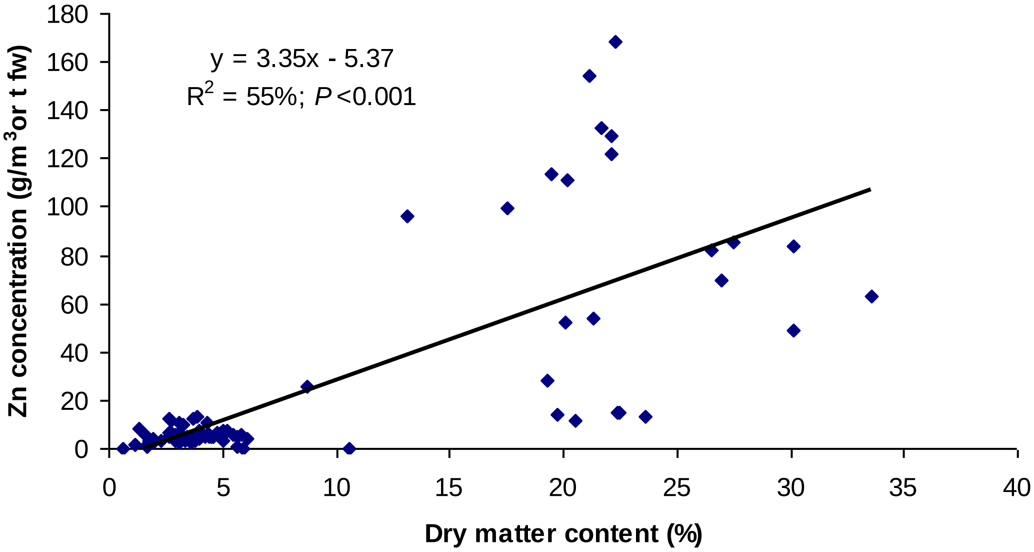
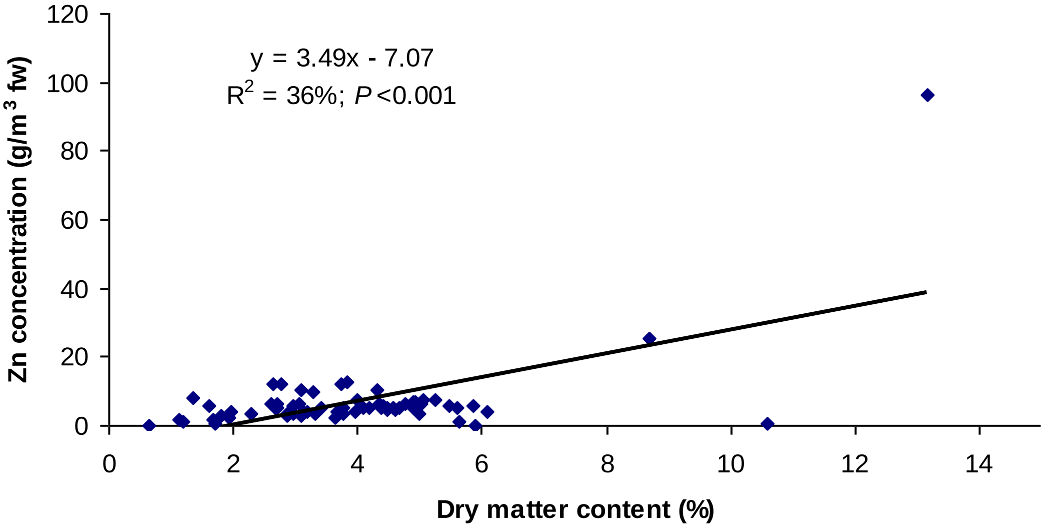


Figure 15. Relationship between digestate dry matter content and Zn concentration (fresh weight basis) for liquid digestates (<15% dry matter)



Note: If the 13.3% dry matter sample is removed from the data set, there is no relationship (P>0.05) between dry matter and Zn concentrations (i.e. the relationship is dependent upon inclusion of the high dry matter sample).

Table 9. Relationships between digestate dry matter content and PTE concentration (fresh weight basis) for all food-based digestates

PTE	Regression equation	R^2	Significance (P)
Zn	Zn (mg/kg fw) = 3.35 x dry matter – 5.4	55%	<0.001
Cu	Cu (mg/kg fw) = 0.82 x dry matter – 0.65	29%	<0.001
Cd	Cd (mg/kg fw) = 0.002 x dry matter + 0.026	11%	<0.05
Pb	Pb (mg/kg fw) = 0.19 x dry matter – 0.43	30%	<0.001
Ni	Ni (mg/kg fw) = 0.07 x dry matter + 0.22	48%	<0.001
Cr	Cr (mg/kg fw) = 0.18 x dry matter – 0.31	53%	<0.001

Note: regression analysis not undertaken for Hg as most samples were below the limit of analytical detection.

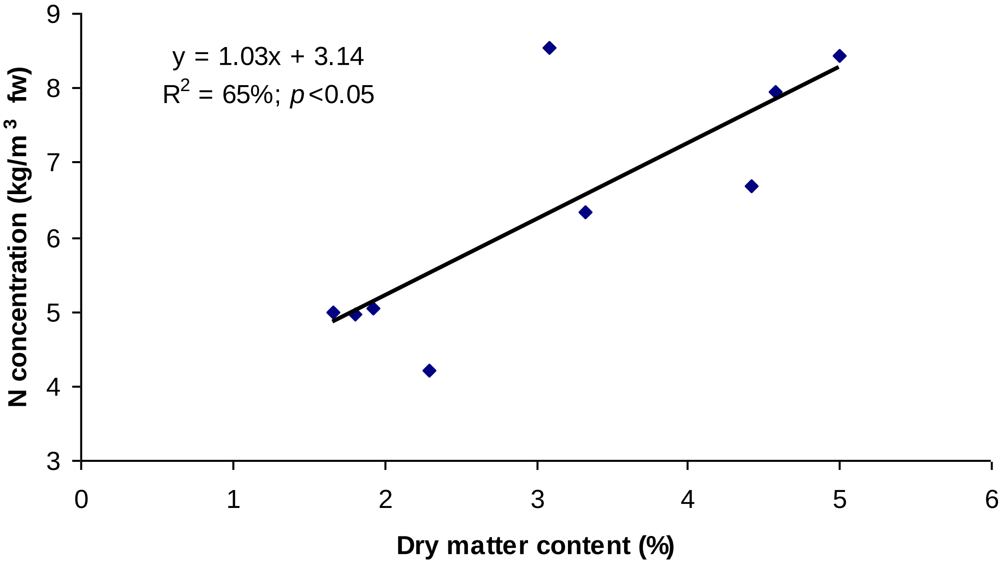
Table 10. Relationships between digestate dry matter content and PTE concentration (fresh weight basis) for liquid digestates (<15% dry matter)

PTE	Regression equation	R^2	Significance (P)
Zn	Zn (mg/kg fw) = 3.5 x dry matter – 7.1	36%	<0.001
Cu	Cu (mg/kg fw) = 1.5 x dry matter – 3.5	31%	<0.001
Cd	Cd (mg/kg fw) = 0.01 x dry matter + 0.004	27%	<0.001
Pb	Pb (mg/kg fw) = 0.23 x dry matter – 0.56	31%	<0.001
Ni	Ni (mg/kg fw) = 0.11 x dry matter + 0.08	16%	<0.001
Cr	Cr (mg/kg fw) = 0.27 x dry matter – 0.66	43%	<0.001

Note: regression analysis not undertaken for Hg as most samples were below the limit of analytical detection.

Nine food-based digestate samples had been analysed for N and P concentrations. To explore if PTE limit concentrations could be expressed on the basis of digestate nutrient (i.e. nitrogen and phosphorus) contents, a number of regression analyses were undertaken. These showed no relationship (P>0.05) between digestate dry matter and fresh weight P concentrations, although there was a weak positive relationship (P<0.05) between dry matter and fresh weight N concentration (Figure 16).

Figure 16. Relationship between food-based digestate dry matter content and fresh weight total N concentration



Notably, there were no relationships (*P*>0.05) between digestate fresh weight N or P concentrations and PTE concentrations expressed on either a fresh weight or dry matter basis, except for Cr were there was a weak (*P*<0.05) positive relationship with fresh weight total N concentration.

4.0 Setting new limits for PTEs in digestates

The merits of setting PTE limit values on a fresh weight basis, rather than using the current dry matter basis, are discussed in this section in the wider context of PTE addition rates to soil. A set of 'theoretical' PTE limits for digestate were derived that would provide *at least the same level of environmental (i.e. soil) protection* as <u>compost</u> at suggested EoW limit values.

As discussed below, these limits are based on addition rates of PTEs to soils, which – given that PTEs are largely associated with dry matter in digestates, and that digestates contain much lower dry matter contents than composts – means that digestates can in theory be applied to land at much higher rates than composts before similar applications of PTEs are achieved. However, application rates for all materials tend to be limited by other (agronomic) factors such as total nitrogen loading rates, and digestate is normally applied at nitrogen application rates very similar to composts and livestock slurries. It is possible that the current approach to common dry-matter PTE limit setting for composts and digestates (adopted by BSI PAS100 and PAS110, together with the JRC suggestions), is unnecessarily restrictive for digestates. It is proposed that new limits are set on a fresh weight basis that will still allow digestates (whole, separated liquor and separated fibre) to be applied to soils as safely as composts.

The proposed 'precautionary' limit values for PTEs in digestate are intended to prevent pollution and protect the receiving soil environment, whilst increasing the auditability and flexibility that BSI PAS110 offers to the UK AD industry. This approach builds upon existing legislation in NVZs (Nitrate Vulnerable Zones) and as recommended in Codes of Good Agricultural Practice that organic material application rates should supply no more than (an average) of 250kg/ha total N per annum.

4.1 PTE limit concentrations

In developing this approach, this report recommends that PTE additions to soil from digestate should not exceed those from compost at suggested EoW limit concentrations, which EU guidelines consider are protective of the soil (IPTS, 2011).

PTE limit concentrations for compost were set in BSI PAS100 on a dry matter basis as composts are solid, stackable materials with a dry matter content of around 60% (Defra, 2010). In contrast, most digestates are liquid materials (i.e. whole digestate and separated liquid fractions) with a dry matter content of around 5% (prior to any separation that may occur post digestion). These digestate materials are analysed as liquids in the laboratory (i.e. the samples are analysed 'as received' and not dried or ground prior to analysis) with the analysis results recorded on a fresh weight basis and then calculated to a dry matter basis for reporting, which can result in calculation errors. It would therefore seem logical that digestate PTE limit concentrations should also be set on a fresh weight basis. This would have the following advantages for users:

1. The approach would be consistent with nutrient analyses (N, P, K, S, Mg), which are reported on a fresh weight basis (Defra, 2010).
2. Occurrences of apparently poor detection limits would be minimised. This can cause problems during the conversion from fresh to dry weight concentrations, particularly for determinands in samples which are at or near detection limits (e.g. Hg).

Such an approach is not without precedent. For example, in Ontario (Canada) Non-Agricultural Source Material (NASM) applications to agricultural land are controlled under Ontario Regulation 267/03[2]. NASMs comprise treated and recycled materials from non-

[2] http://www.omafra.gov.on.ca/english/nm/nasm/labs.htm

agricultural sources such as food processing waste, paper sludge and biosolids. A material cannot be categorized as a NASM unless it can be shown to have a benefit for the soil and to crops grown on that land. Liquid products (defined as having a dry matter content <18%) must be analysed on a fresh weight basis (mg/litre) for nutrients and PTEs, with PTE limit values for liquid NASMs specified in the regulations on a fresh weight basis.

The separated fibre fraction of digestate typically has a dry matter content of *c.*25% and is analysed on a dry matter basis in the laboratory. However, fibre digestate has a lower dry matter content than compost (60% dry matter) and typically contains around 30% of total N as readily available N - RAN (based on the limited industry data) compared with green and green/food compost which contains <5% RAN (Defra, 2010). In this context, fibre digestate is likely to be more akin to 'fresh' farmyard manure/poultry manure in its management and nutrient supply properties.

In order to be consistent with the reporting format for liquid digestate products, it is recommended that PTE concentrations (and limits) in the small number of fibre digestate samples analysed from operational AD units should also be reported on a fresh weight basis, whilst recognising the differences in dry matter content of the different digestate fractions which influence PTE loading rates.

4.2 Ensuring soil protection

4.2.1 Maximum permitted PTE addition rates to soils

When organic materials are applied to agricultural land the starting soil PTE concentration and the quantity of PTEs applied to the soil with each application are the most important criteria in terms of soil protection. The only UK legislative limits for PTE additions to soil are those specified in the Sludge (Use in Agriculture) Regulations (SI, 1989) and the Code of Practice for Agricultural Use of Sewage Sludge (DoE, 1996), Table 11. Notably, compost with 'typical' dry matter and total N contents, and with PTE concentrations at the maximum BSI PAS100 limit values, will add PTEs to the soil at a considerably lower rate than those specified in the Code of Practice for Agricultural Use of Sewage Sludge (Table 11).

Table 11. PTE addition rates from compost at BSI PAS100 and suggested EoW concentrations applied at the maximum permitted rate (250 kg total N/ha), and maximum permitted PTE addition rates from biosolids

PTE	Maximum addition rate from BSI PAS100 green compost* (kg/ha/yr)	Maximum addition rate from compost at the suggested EoW PTE limits* (kg/ha/yr)	Maximum permitted addition rate (DoE, 1996) (kg/ha/yr) based on a 10 year average
Zn	8.0	8.0	15
Cu	4.0	2.0	7.5
Ni	1.0	1.0	3
Cd	0.03	0.03	0.15
Pb	4.0	2.4	15
Cr	2.0	2.0	15
Hg	0.02	0.02	0.1

*Assumes green compost with 60% dry matter and 7.5 kg N/t applied at 250 kg total N/ha (33 t/ha) – see Section 4.2.3 below.

4.2.2 Typical PTE addition rates to soils

PTE addition rates to soils from food-based digestate with average PTE concentrations (derived from the project database) applied at a rate of 250 kg total N/ha, which is the maximum field N rate permitted in NVZs (SI, 2008; SSI, 2008; WSI, 2008) and recommended in the Codes of Good Agricultural Practice in England, Scotland and Wales (Defra, 2009; SG, 2005; WG, 2011), were comparable to loading rates from other organic materials based on 'typical' PTE concentrations and an application rate of 250 kg total N/ha (Figures 17-22). Notably, PTE addition rates from whole and liquid digestates were much lower than from most other organic materials. The fibre digestate had higher PTE addition rates than the liquid products, but lower or similar PTE loading rates to compost, biosolids and livestock manures. 'Worst-case' PTE addition rates – where digestates have low nitrogen contents – are examined in Section 4.3.3.

Figure 17. Zn addition rates from 'typical' organic material applications to soils (biosolids, compost, livestock manures and food-based digestates applied at a rate equivalent to 250 kg/ha total N)

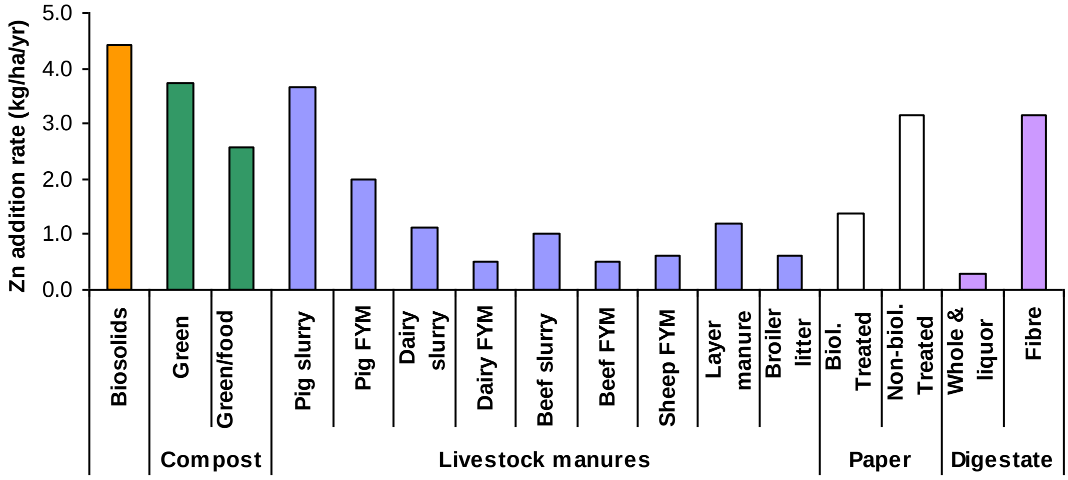


Figure 18. Cu addition rates from 'typical' organic material applications to soils (biosolids, compost, livestock manures and food-based digestates applied at a rate equivalent to 250 kg/ha total N)

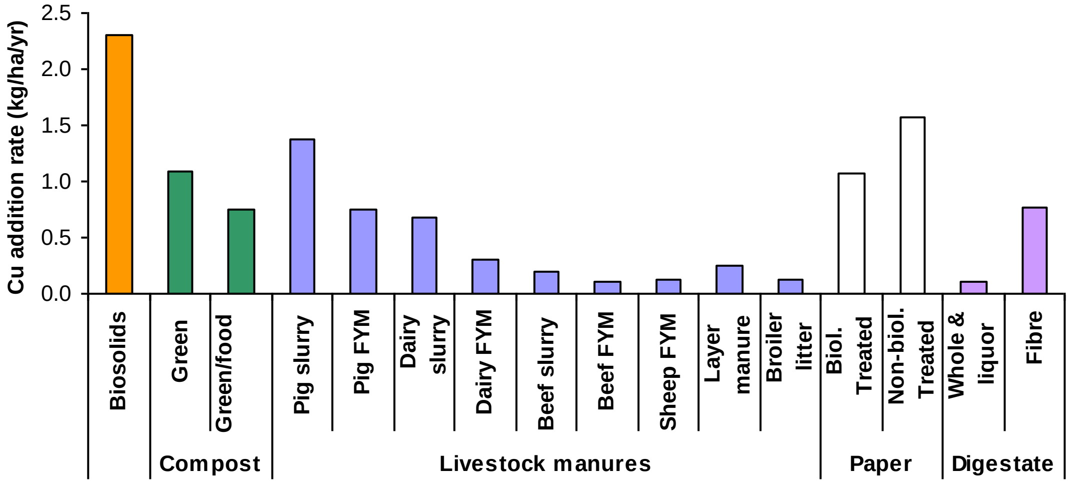


Figure 19. Ni addition rates from 'typical' organic material applications to soils (biosolids, compost, livestock manures and food-based digestates applied at a rate equivalent to 250 kg/ha total N)

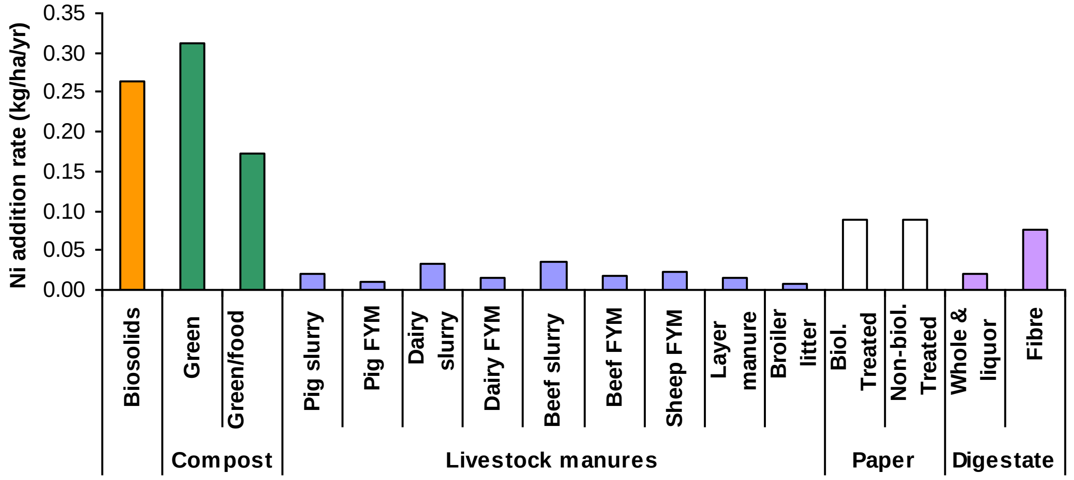


Figure 20. Cd addition rates from 'typical' organic material applications to soils (biosolids, compost, livestock manures and food-based digestates applied at a rate equivalent to 250 kg/ha total N)

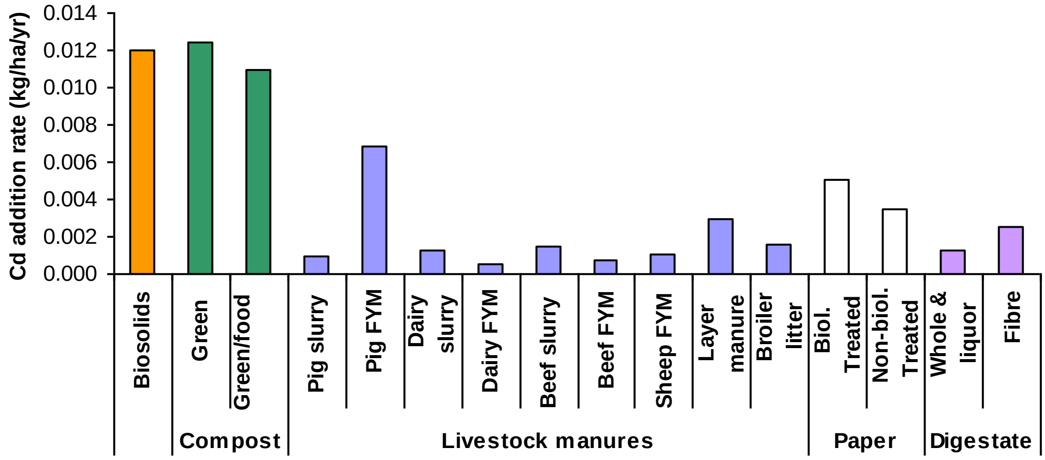


Figure 21. Pb addition rates from 'typical' organic material applications to soils (biosolids, compost, livestock manures and food-based digestates applied at a rate equivalent to 250 kg/ha total N)

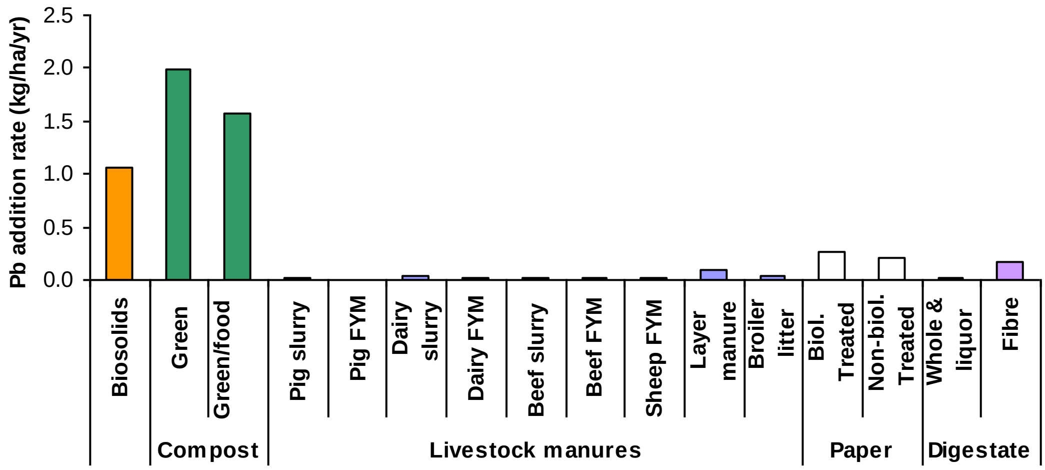
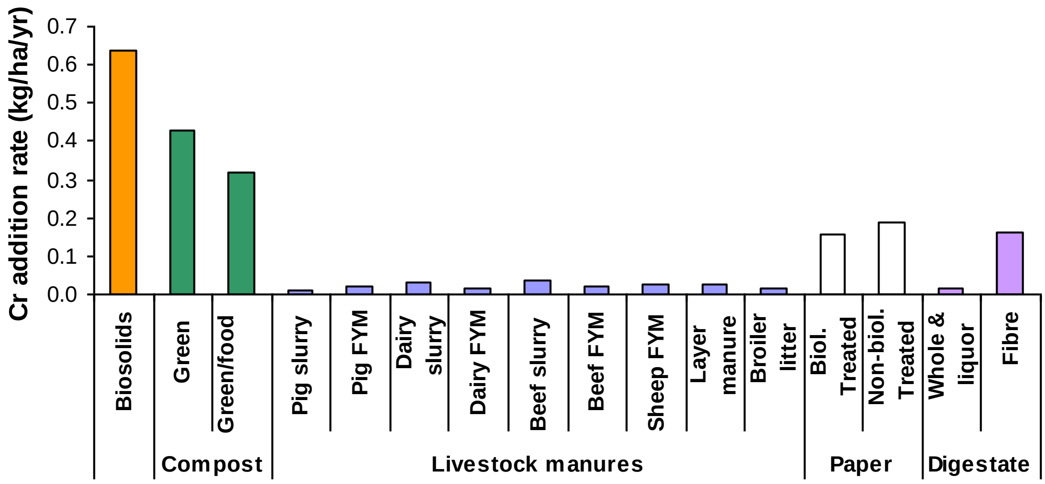


Figure 22. Cr addition rates from 'typical' organic material applications to soils (biosolids, compost, livestock manures and food-based digestates applied at a rate equivalent to 250 kg/ha total N)



4.2.3 Setting new limits based on PTE addition rates

In developing an approach to setting PTE concentration limits for digestate (to set a ceiling on loading rates) it was considered that PTE additions from digestate should not exceed those from compost at suggested EoW limit concentrations, which the JRC technical report considers are 'protective' of the soil (IPTS, 2011). Reservations around the suitability of the suggested EoW limits for digestate have been set out in Section 4.0, and it was therefore decided to examine PTE limits for digestate that provide *at least the same level of environmental (i.e. soil) protection* as compost at suggested EoW limit values. To do this, the maximum rate at which digestate (and compost) could be applied to agricultural soils needed to be established. The maximum permitted field N limit for organic manure applications in NVZs is 250 kg/ha of total N in any 12 month period (SI, 2008; SSI, 2008; WSI, 2008). Moreover, outside NVZs the Codes of Good Agricultural Practice (Defra, 2009; SG, 2005; WG, 2011) also recommend that farmers should not apply more than 250 kg/ha total N per annum.

The next step was to determine theoretical fresh weight PTE concentrations in digestate products that would deliver the same PTE addition rates as compost at suggested EoW limit values i.e. which are as protective of the soil environment as the suggested EoW limits for compost applications. To calculate fresh weight concentrations, information on the N content of the digestates was required. Using data for food-based digestate samples from the DC-*Agri* (WRAP project OAV037-001/ Defra project AC0116) and the Compost and Anaerobic Digestate Quality for Welsh Agriculture (WRAP project OAV032-004; Taylor *et al*., 2011) projects, a mean liquid digestate total N concentration of 5 kg/m^3 was used (DC-*Agri* Bulletin 2; WRAP, 2011).

A range of fresh weight PTE limit concentrations were calculated that would apply the same quantity of PTEs to soil as a compost at suggested EoW limit values, based on a range of liquid digestate N contents (3, 5 and 7 kg/m^3, Table 12), and fibre digestate N contents (4, 6 and 8 kg/t, Table 13). As the N content of the liquid and fibre digestate increased, the PTE limit value also increased, which was a result of lower digestate application rates to comply with the 250 kg total N/ha field limit.

Table 12. Fresh weight PTE concentrations (g/m^3 fresh weight) for liquid digestates that would apply the same amount of PTEs as compost at suggested EoW limit values (applied at 250 kg/ha total N)

PTE	Addition rate from EoW compost (kg/ha/yr)	N content 3 kg/m^3 (application rate = 83 m^3/ha)	N content 5 kg/m^3 (application rate = 50 m^3/ha)	N content 7 kg/m^3 (application rate = 36 m^3/ha)
Zn	8.0	96	160	222
Cu	2.0	24	40	56
Ni	1.0	12	20	28
Cd	0.03	0.4	0.6	0.8
Pb	2.4	29	48	67
Cr	2.0	24	40	56
Hg	0.02	0.2	0.4	0.6

Table 13. Fresh weight PTE concentrations (g/t fresh weight) for fibre digestates that would apply the same amount of PTEs as compost at suggested EoW limit values (applied at 250 kg/ha total N)

PTE	Addition rate from EoW green compost (kg/ha/yr)	N content 4 kg/t (application rate = 63 t/ha)	N content 6 kg/t (application rate = 42 t/ha)	N content 8 kg/t (application rate = 31 t/ha)
Zn	8.0	127	190	258
Cu	2.0	32	48	65
Ni	1.0	16	24	32
Cd	0.03	0.5	0.7	1.0
Pb	2.4	38	57	77
Cr	2.0	32	48	65
Hg	0.02	0.3	0.5	0.6

4.3 Setting new limit values for liquid digestates

4.3.1 Implications of theoretical fresh weight PTE limit values

The theoretical fresh weight PTE limit values for liquid digestate with a 'typical' total N content of 5 kg/m^3 were assessed against the 68 values on the database for whole and separated liquid fraction food-based digestates (Figures 23 to 28). For all PTEs, fresh weight concentrations were below the theoretical limit value that would provide the same level of soil protection as compost at the suggested EoW limit values, and applied at the maximum permitted field N application rates in NVZs. If the theoretical limit values were implemented then all liquid food-based digestates on the database would 'pass' the criteria and be deemed acceptable for application to agricultural land, because they meet the condition that PTE additions must not exceed those from compost at suggested EoW PTE limit values.

4.3.2 Precautionary limit values

Minimising PTE loading rates to soils (and more generally the wider environment) in digestate and compost applications is a key objective of the suggested EoW criteria. However, establishing unduly low limits that do not provide proportionate environmental or health benefits would place unnecessary constraints on the resource management industry and restrict opportunities for closing nutrient cycles through the land application of these organic materials.

The suggested rationale underpinning the setting of PTE limit concentrations below the theoretical maxima established above aimed to establish PTE concentration values that were within an ethos of 'prevention of pollution' (EU, 2000).

This report has therefore adopted a 'precautionary principle' approach by proposing limit values that are 'as low as reasonably achievable'. In this way, a significantly greater level of protection will be achieved for digestates than for EoW compost, but without unduly restricting or penalising the resource management industry. 95th percentile values could not be used to set limit values as PTE data were not always normally distributed, so the decision making process used to arrive at proposed PTE limit values is summarised below:

1. Collation of data on digestate PTE concentrations and N contents.
2. Calculation of compost and digestate application rates to soils that are compliant with NVZ legislation and Codes of Good Agricultural Practice for nitrogen loading rates (i.e. an average of 250 kg/ha total N per annum).
3. Calculation of maximum PTE loading rates to soils from compost applications at the suggested EoW limit values (and BSI PAS 100 limit values for Zn, Ni, Cd, Cr and Hg), based on 250 kg/ha total N field loading rate i.e. the theoretical maximum PTE loading rate for compost.
4. Calculation of the PTE concentrations in digestate that would give the same PTE loading rate as compost applications at the suggested EoW limit values, when digestate of a 'typical' N content is applied at 250 kg/ha total N field loading rate.
5. Compare the calculated PTE concentrations in digestate with actual PTE concentrations in digestate.
6. Application of 'precautionary principle' approach (i.e. the exclusion of 'elevated' concentration samples) to set PTE limit.

Figures 23 to 28 and Table 14 summarise the proposed precautionary limit values for digestates in comparison with the theoretical limit that would provide the same protection as compost at EoW PTE concentrations.

Table 14. Theoretical and precautionary fresh weight PTE limit values (g/m^3 fw) for liquid digestates (<15% dry matter)

PTE	Theoretical limit value (based on 5 kg N/t)	Precautionary limit value	Maximum value in database
Zn	160	**30**	96
Cu	40	**15**	45
Ni	20	**3**	3.5
Cd	0.6	**0.2**	0.19
Pb	48	**5**	6.6
Cr	40	**5**	6.5
Hg*	0.4	**0.1**	0.05

*All database samples were at or below the limit of detection (LOD i.e. 0.05 g/m^3 fw). The precautionary limit value has therefore been set to twice the LOD.

Figure 23. Fresh weight Zn concentrations in samples of whole and separated liquid food-based digestates showing the theoretical limit and proposed precautionary limit concentrations

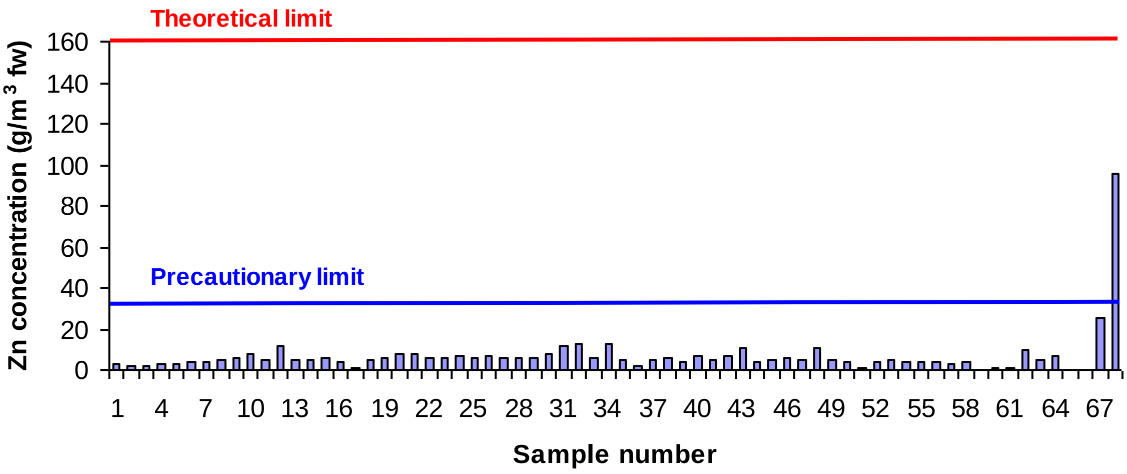


Figure 24. Fresh weight Cu concentrations in samples of whole and separated liquid food-based digestates showing the theoretical limit and proposed precautionary limit concentrations

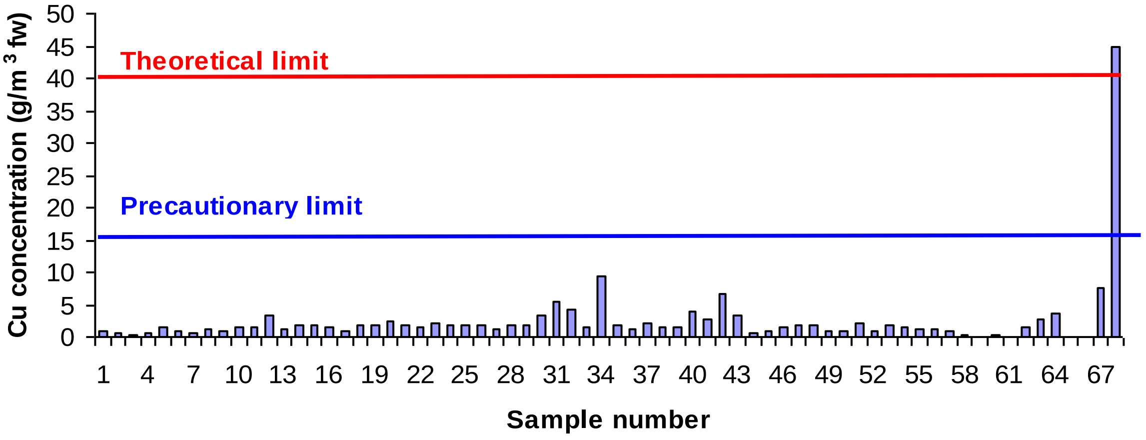


Figure 25. Fresh weight Ni concentrations in samples of whole and separated liquid food-based digestates showing the theoretical limit and proposed precautionary limit concentrations

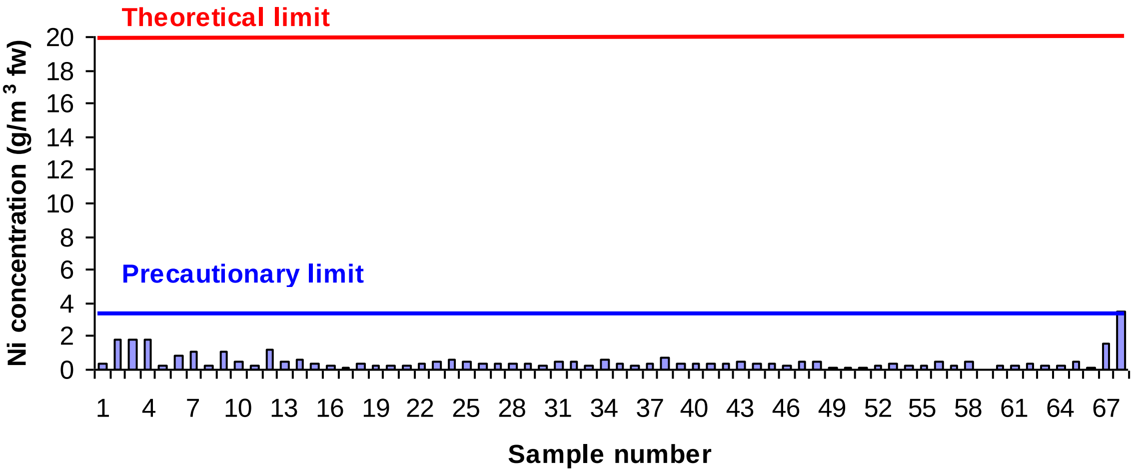


Figure 26. Fresh weight Cd concentrations in samples of whole and separated liquid food-based digestates showing the theoretical limit and proposed precautionary limit concentrations

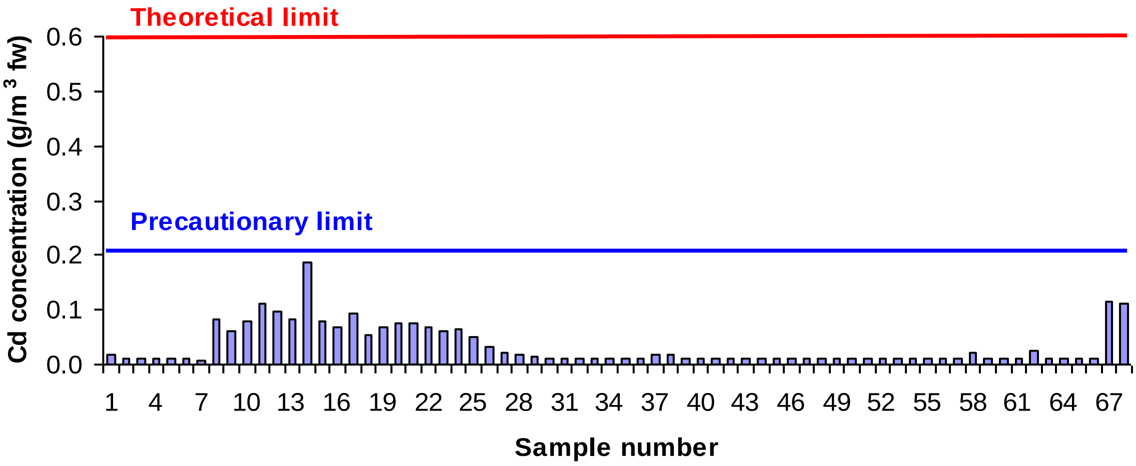


Figure 27. Fresh weight Pb concentrations in samples of whole and separated liquid food-based digestates showing the theoretical limit and proposed precautionary limit concentrations

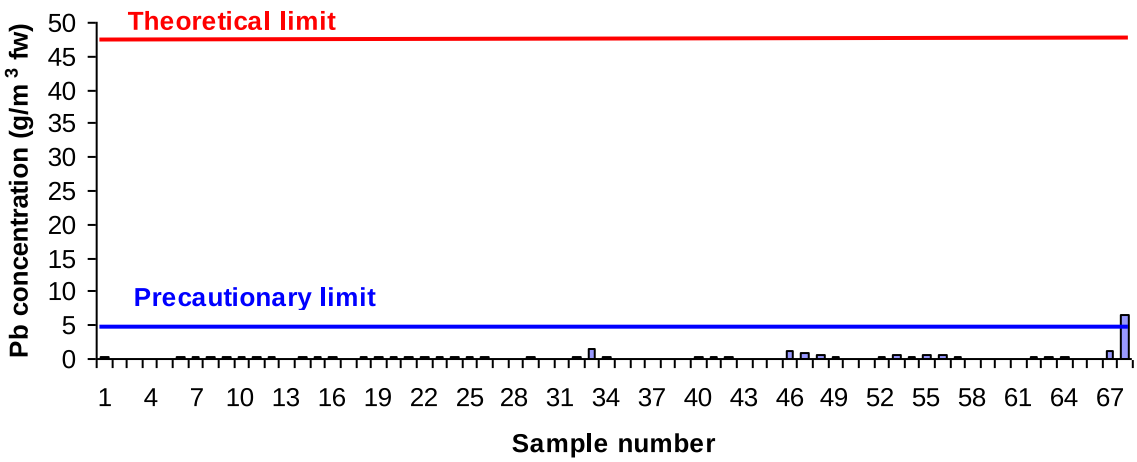
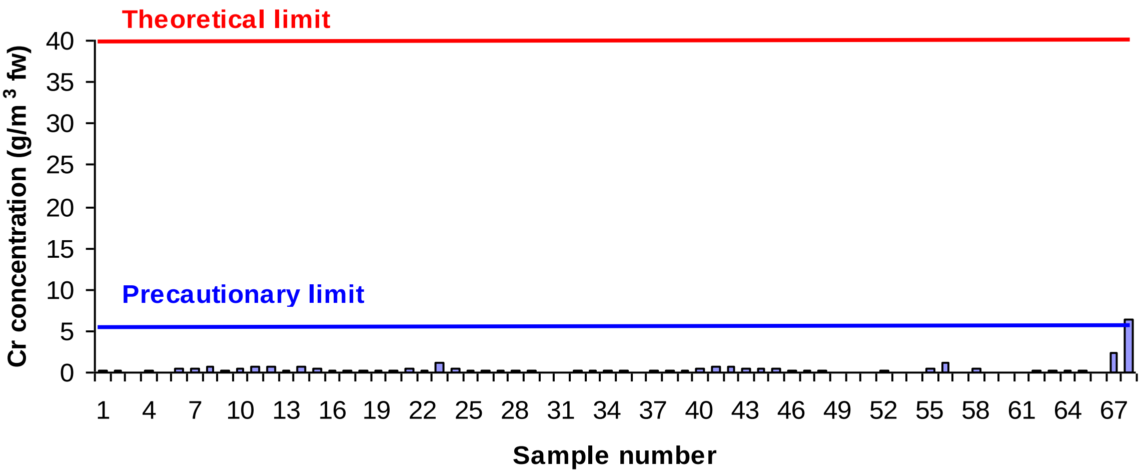


Figure 28. Fresh weight Cr concentrations in samples of whole and separated liquid food-based digestates showing the theoretical limit and proposed precautionary limit concentrations



4.3.3 Scenario testing

The implications for soil metal addition rates were assessed for a 'worst-case' scenario situation i.e. where a liquid digestate with a 'low' N content (3 kg N/m^3) but with PTE concentrations at the proposed limit values was applied to land at 250 kg/ha total N. In this scenario, PTE addition rates were all still substantially lower than those from composts at the suggested EoW limit values (Table 15).

Table 15. PTE addition rates under a 'worst-case' scenario

PTE	Addition rate from compost at suggested EoW limit values (kg/ha/yr)	Addition rate from digestate under 'worst case' scenario (kg/ha/yr)
Zn	8.0	2.5
Cu	2.0	1.2
Ni	1.0	0.25
Cd	0.03	0.02
Pb	2.4	0.4
Cr	2.0	0.4
Hg	0.02	0.01

4.4 Setting new limit values for digestate fibre

4.4.1 Implications of theoretical limit values

The theoretical fresh weight PTE limit values for digestate fibre with a 'typical' total N content of 6 kg/t were compared against the 22 values on the database (Figures 29 to 34). For all PTEs except Cu, fresh weight concentrations were below the theoretical limit value that would provide the same level of soil protection as compost at suggested EoW limit values and applied at the maximum permitted field N rate in NVZs. In summary, if the theoretical limit values were implemented then all of the food-based digestate fibre samples (with the exception of two samples for Cu from the same AD plant) on the database would 'pass' the criteria and be deemed acceptable for application to agricultural land, because they meet the condition that PTE additions must not exceed those from compost at suggested EoW PTE limit values.

4.4.2 *Precautionary limit values*

The separated fibre fraction from digestate generally has higher PTE concentrations than whole digestate or the separated liquid fraction, because most PTEs are associated with the dry matter fraction of the material. The aim was to set precautionary limit values (as previously described in Section 4.2) for digestate fibre such that PTE addition rates were lower than those from compost (and many other organic materials applied to agricultural land) at suggested EoW limit values and maximum permitted application rates in NVZs.

Precautionary limits are proposed, as described previously for liquids, that would provide the same level of soil protection as compost at the suggested EoW PTE concentrations (Table 16).

Table 16. Theoretical and precautionary fresh weight PTE limit values (g/t fresh weight) for digestate fibre (≥15% dry matter).

PTE	Theoretical limit value (based on 6 kg N/t)	Precautionary limit value	Maximum value in database
Zn	190	**150**	168
Cu	48	**30**	83
Ni	24	**5**	3.4
Cd	0.7	**0.2**	0.16
Pb	57	**30**	22
Cr	48	**20**	12
Hg*	0.5	**0.1**	0.05

*All database samples were at or below the limit of detection (LOD i.e. 0.05 g/m^3 fw). The precautionary limit value has therefore been set to twice the LOD.

Figure 29. Fresh weight Zn concentrations in samples of digestate fibre showing the theoretical limit and the proposed precautionary limit concentrations

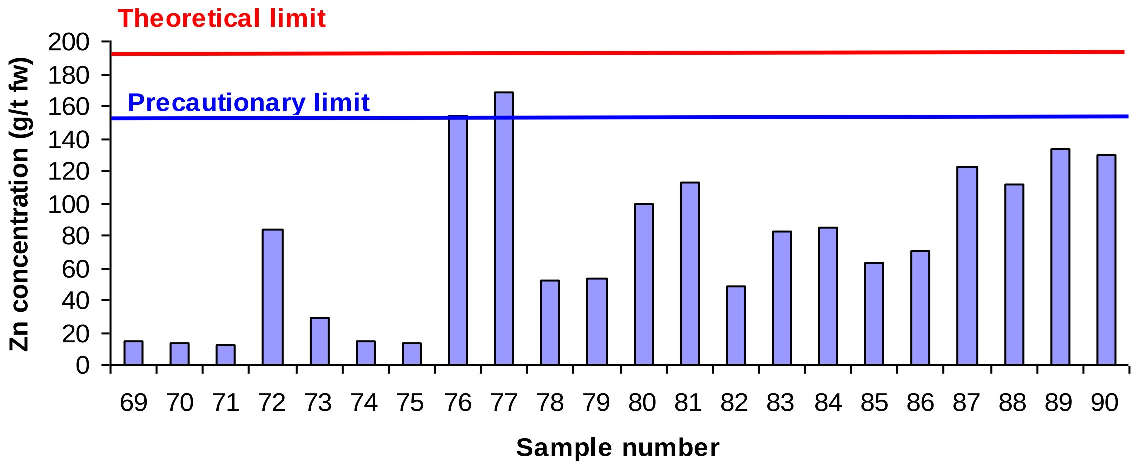


Figure 30. Fresh weight Cu concentrations in samples of digestate fibre showing the theoretical limit and the proposed precautionary limit concentrations

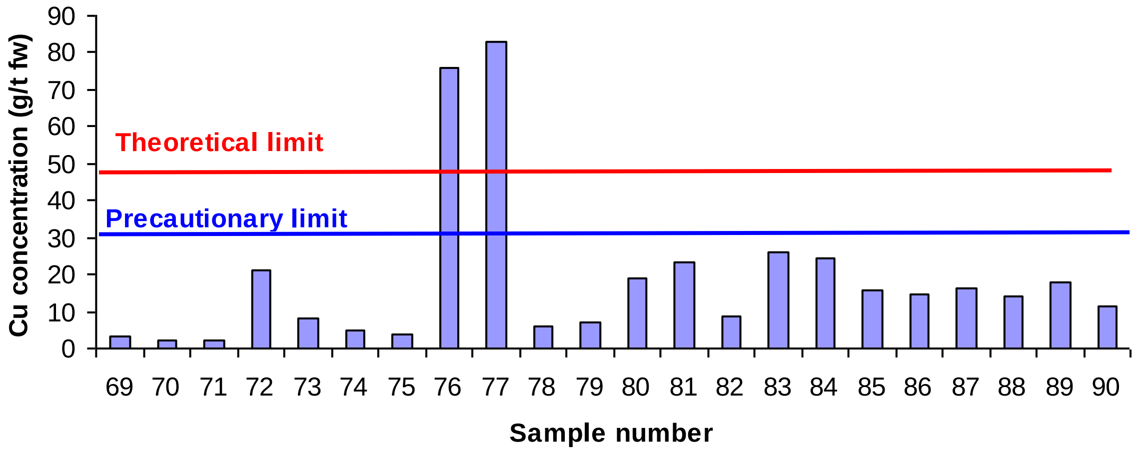


Figure 31. Fresh weight Ni concentrations in samples of digestate fibre showing the theoretical limit and the proposed precautionary limit concentrations

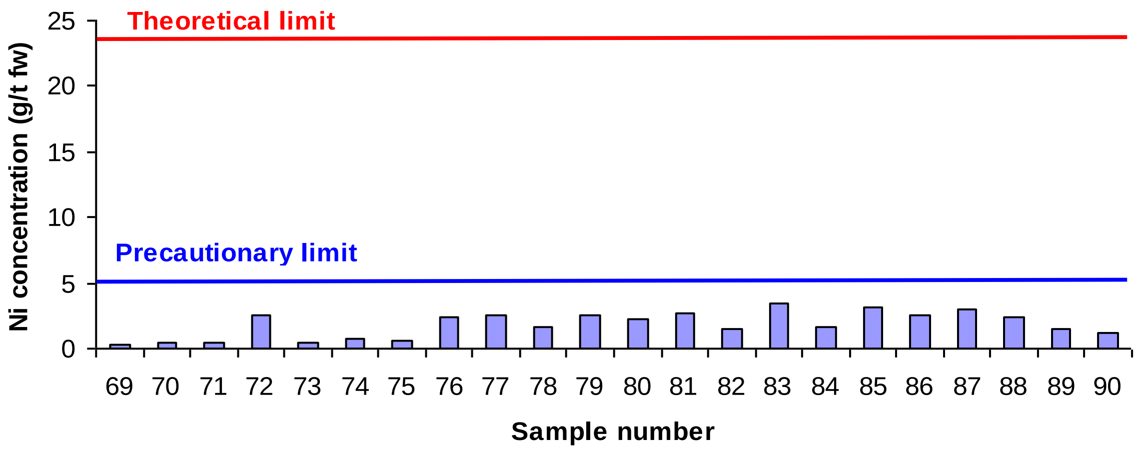


Figure 32. Fresh weight Cd concentrations in samples of digestate fibre showing the theoretical limit and the proposed precautionary limit concentrations

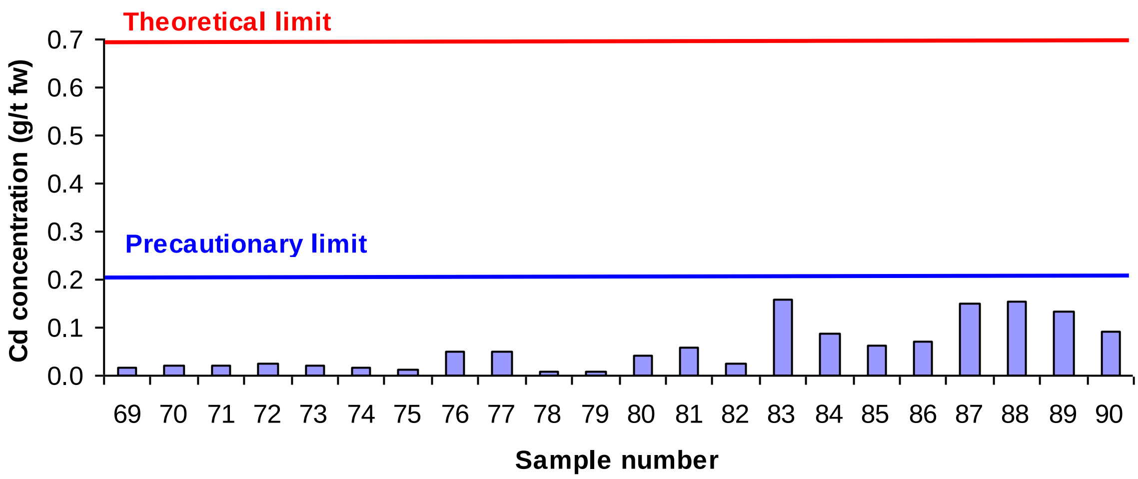


Figure 33. Fresh weight Pb concentrations in samples of digestate fibre showing the theoretical limit and the proposed precautionary limit concentrations

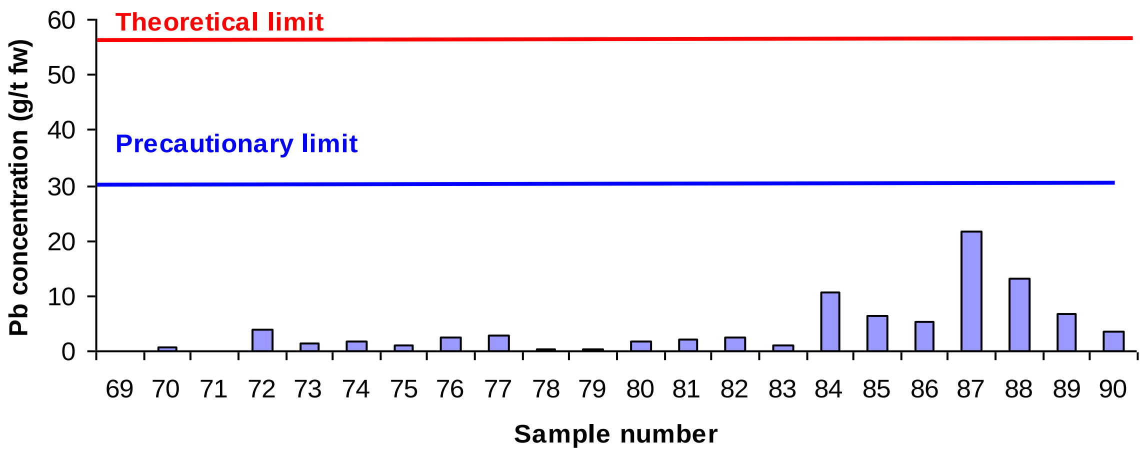
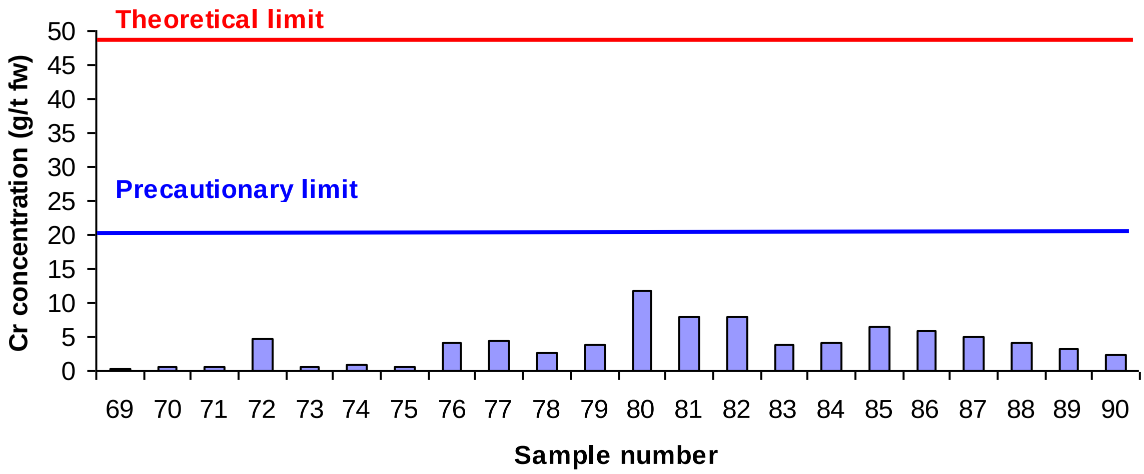


Figure 34. Fresh weight Cr concentrations in samples of digestate fibre showing the theoretical limit and the proposed precautionary limit concentrations



4.4.3 Scenario testing

The implications for soil PTE addition rates were assessed for a 'worst-case' scenario situation i.e. where a digestate fibre with a 'low' N content (4 kg N/t) but with PTE concentrations at the proposed limit values was applied to land at 250 kg/ha total N. In this scenario, addition rates from all PTEs were generally similar to or below those from compost at suggested EoW limit values (Table 17).

Table 17. PTE addition rates under a 'worst-case' scenario

PTE	Addition rate from compost at suggested EoW limit values (kg/ha/yr)	Addition rate from fibre under 'worst-case' scenario (kg/ha/yr)
Zn	8.0	9.5
Cu	2.0	1.9
Ni	1.0	0.3
Cd	0.03	0.01
Pb	2.4	1.9
Cr	2.0	1.3
Hg	0.02	0.01

5.0 Potential impact of EoW proposals in the UK

Examination of the digestate PTE concentration database showed that, if the EU EoW limits were introduced at the levels currently suggested, 17% of digestate samples would not meet the proposed criteria for Cu (7% at the current BSI PAS110 value), 13% for Zn, 8% for Cd and 3% for Ni (see Section 3.3.1).

The introduction of pan European EoW standards would aim to reduce soil pollution and potential ecotoxicological impacts associated with the longer-term build of soil PTEs. In this report it has been shown that typical digestate PTE concentrations and loading rates to land are already lower than or similar to those from other organic materials applied to agricultural land (e.g. biosolids, compost, livestock manures – see Sections 3.2.3 and 4.2.2). It would be questionable from environmental and health viewpoints if digestate PTE addition rates to soils were set at a much lower level than other 'regulated' organic materials (e.g. biosolids, composts) or for livestock manures (where PTE additions to soils are not directly controlled and which are applied to land in much larger quantities). There is clearly a need to ensure *proportionate* risk regulation for digestate recycling to land.

Unnecessarily strict PTE limits will reduce the amounts of digestate that can attain EoW status and slow down market development, and may compromise the ability of the UK government to achieve recycling rate targets – without producing significant environmental benefit. There will also be knock-on effects in terms of not being able to use digestate to replace the use of manufactured fertiliser N (which is energy intensive to produce) and phosphate (which is a non-renewable natural resource). Ultimately, the most likely outlets for non-compliant digestate would be agriculture under an environmental permit and restoration/reclamation sites (where these are in close proximity to AD plants), delivery to sewage treatment works, direct sewer discharge or into landfill (for fibre digestates).

6.0 Conclusions and recommendations

- Analysis of the database of 90 food-based digestate samples showed that *mean* PTE concentrations in food-based digestates were below the current BSI PAS110 and suggested EoW limit values. However, the data indicated that around 13% of the samples would not meet the current BSI PAS110 limit for Zn, 8% for Cd, 3% for Ni and 7% for Cu (and 17% the lower EoW limit for Cu).

- The majority of digestates are produced and managed as liquids, and hence are analysed in the laboratory on a fresh weight (sample 'as received') basis. The analysis in this report suggests that PTE limit concentrations in digestates should be set on a fresh weight basis, rather than on a dry matter basis as is currently the case; this would be consistent with the reporting of nutrient analyses, minimise PTE analytical detection limit problems and reduce the chances of laboratory errors occurring during fresh to dry matter concentration conversions.

- Embracing the precautionary principle to ensure that digestate applications are as protective of the soil environment as is reasonably achievable, it is recommended that (fresh weight) PTE limit concentrations are based on PTE addition rates to soils (in context with other commonly applied organic materials) and that PTE loading rates should not exceed those from compost that are considered in EU guidance (IPTS, 2011) to be protective of the soil.

- New sets of PTE concentration limit values are proposed that protect the receiving soil environment (see Table 18).

Table 18. Proposed precautionary fresh weight PTE limit values (g/m^3 or t fw) for digestate products

PTE	Proposed limit values for liquid digestate products (generally with <15% dry matter)	Proposed limit values for digestate fibre (generally with ≥15% dry matter)
Zn	30	150
Cu	15	30
Ni	3	5
Cd	0.2	0.2
Pb	5	30
Cr	5	20
Hg	0.1	0.1

7.0 Acknowledgements

We are grateful to the Renewable Energy Association for kindly providing access to data from the Biofertiliser Certification Scheme (BCS).

8.0 References

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Appendix 1

Table A1. Dry matter and PTE concentrations (dry matter basis) of whole food-based digestates

Sample number	Dry matter (%)	PTE concentration (mg/kg dry matter)						
		Zn	Cu	Cd	Pb	Ni	Cr	Hg
1	3.1	82	29	0.51	5.5	9.6	10.1	<LOD
2	1.7	99	39	<LOD	2.0	106.6	7.5	<LOD
3	1.9	110	12	<LOD	4.4	94.9	4.1	<LOD
4	1.8	132	22	0.50	4.4	87.3	6.3	<LOD
5	2.3	142	75	<LOD	5.8	8.6	5.1	<LOD
6	5.0	71	19	0.23	7.5	17.1	8.9	<LOD
7	3.3	104	20	0.23	9.5	31.9	10.8	<LOD
8	4.6	115	27	1.78	3.6	6.5	13.2	<LOD
9	4.4	127	20	1.37	3.7	23.2	7.0	<LOD
10	4.0	189	37	1.95	3.9	12.3	11.6	<LOD
11	4.4	119	33	2.58	4.5	5.7	17.0	<LOD
12	3.7	324	87	2.58	9.7	32.5	17.5	<LOD
13	4.6	102	29	1.80	3.2	9.3	7.0	<LOD
14	4.6	109	38	4.04	8.9	13.0	13.1	<LOD
15	5.9	100	30	1.33	4.7	5.6	7.6	<LOD
16	6.1	65	23	1.12	3.6	4.1	5.0	<LOD
17	5.6	20	18	1.63	1.2	1.7	4.0	<LOD
18	5.6	91	35	0.93	3.9	5.8	4.4	<LOD
19	4.8	131	39	1.41	5.5	4.5	7.3	<LOD
20	5.1	147	47	1.46	3.9	3.6	5.3	<LOD
21	5.2	142	32	1.47	4.8	5.4	6.8	<LOD
22	4.9	112	33	1.41	3.6	6.5	6.8	<LOD
23	5.0	127	41	1.23	4.0	10.5	23.1	<LOD
24	4.9	139	34	1.35	5.4	11.2	8.0	<LOD
25	5.0	114	38	1.00	3.6	8.6	5.6	<LOD
26	4.9	135	36	0.69	3.7	8.4	4.9	<LOD
27	5.0	125	22	0.46	2.7	7.3	4.2	<LOD
28	5.5	101	32	0.35	2.7	6.6	3.4	<LOD
29	4.7	116	37	0.30	4.9	8.4	4.5	<LOD
30	1.4	602	242	<LOD	1.9	16.1	4.4	<LOD
31	2.8	432	194	<LOD	3.3	16.9	3.3	<LOD
32	2.6	464	156	0.38	9.6	19.2	9.4	<LOD
33	1.6	352	95	0.68	83.1	15.9	9.5	<LOD
34	3.8	338	248	0.31	10.1	16.8	6.3	<LOD
35	4.5	105	40	<LOD	2.9	9.3	4.3	<LOD
36	3.7	66	32	<LOD	2.1	6.5	1.6	<LOD
37	4.5	110	49	0.42	2.1	9.2	6.9	<LOD
38	4.4	139	32	0.44	2.5	17.4	4.5	<LOD
39	2.9	122	47	<LOD	1.2	10.9	7.2	<LOD
40	2.6	247	149	<LOD	5.8	13.0	20.3	<LOD
41	2.7	191	104	<LOD	5.7	15.5	24.9	<LOD
42	2.7	243	245	<LOD	6.7	13.5	25.4	<LOD
43	3.1	340	109	<LOD	4.7	15.6	13.2	<LOD

Table A1 (cont.). Dry matter and PTE concentrations (dry matter basis) of whole food-based digestates

Sample number	Dry matter (%)	PTE concentration (mg/kg dry matter)						
		Zn	Cu	Cd	Pb	Ni	Cr	Hg
44	3.1	133	20	<LOD	1.2	9.7	12.2	<LOD
45	3.78	137	26	<LOD	1.0	10.2	11.0	<LOD
46	2.95	194	52	0.41	41.6	7.7	6.0	<LOD
47	4.19	126	41	0.26	20.7	10.2	6.7	<LOD
48	4.31	246	44	0.28	15.5	11.5	5.8	<LOD
49	2.69	193	39	<LOD	8.0	5.7	3.6	<LOD
50	2.97	120	26	0.34	4.1	4.6	0.0	<LOD
51	1.14	127	197	<LOD	12.6	10.1	5.9	<LOD

<LOD = Below limit of (analytical) detection

Table A2. Dry matter, nutrient and PTE concentrations (fresh weight basis) of whole food-based digestates

Sample number	Dry matter (%)	Nutrient content (kg/t)		PTE concentration (mg/l fresh weight)						
		N	P	Zn	Cu	Cd	Pb	Ni	Cr	Hg
1	3.1	8.5	1.0	2.7	0.9	0.02	0.2	0.3	0.3	<LOD
2	1.7	5.0	0.4	1.7	0.7	<LOD	<0.1	1.8	0.1	<LOD
3	1.9	5.0	0.5	2.1	0.2	<LOD	0.1	1.8	0.1	<LOD
4	1.8	5.0	0.5	3.1	0.6	0.01	0.1	1.9	0.1	<LOD
5	2.3	4.2	0.4	3.2	1.6	<LOD	0.1	0.2	0.1	<LOD
6	5.0	8.4	0.3	3.6	0.9	0.01	0.4	0.9	0.4	<LOD
7	3.3	6.3	0.3	3.4	0.7	0.01	0.3	1.1	0.4	<LOD
8	4.6	8.0	0.5	5.3	1.3	0.08	0.2	0.3	0.6	<LOD
9	4.4	6.7	0.7	5.6	0.9	0.06	0.2	1.0	0.3	<LOD
10	4.0	-	-	7.6	1.5	0.08	0.2	0.5	0.5	<LOD
11	4.4	-	-	5.2	1.4	0.11	0.2	0.3	0.7	<LOD
12	3.7	-	-	12.1	3.2	0.10	0.4	1.2	0.7	<LOD
13	4.6	-	-	4.7	1.3	0.08	0.1	0.4	0.3	<LOD
14	4.6	-	-	5.0	1.7	0.19	0.4	0.6	0.6	<LOD
15	5.9	-	-	5.9	1.8	0.08	0.3	0.3	0.4	<LOD
16	6.1	-	-	4.0	1.4	0.07	0.2	0.2	0.3	<LOD
17	5.6	-	-	1.1	1.0	0.09	0.1	0.1	0.2	<LOD
18	5.6	-	-	5.1	1.9	0.05	0.2	0.3	0.2	<LOD
19	4.8	-	-	6.3	1.9	0.07	0.3	0.2	0.3	<LOD
20	5.1	-	-	7.4	2.4	0.07	0.2	0.2	0.3	<LOD
21	5.2	-	-	7.4	1.7	0.08	0.2	0.3	0.4	<LOD
22	4.9	-	-	5.5	1.6	0.07	0.2	0.3	0.3	<LOD
23	5.0	-	-	6.3	2.0	0.06	0.2	0.5	1.1	<LOD
24	4.9	-	-	6.8	1.7	0.07	0.3	0.5	0.4	<LOD
25	5.0	-	-	5.7	1.9	0.05	0.2	0.4	0.3	<LOD
26	4.9	-	-	6.7	1.8	0.03	0.2	0.4	0.2	<LOD
27	5.0	-	-	6.3	1.1	0.02	0.1	0.4	0.2	<LOD
28	5.5	-	-	5.5	1.7	0.02	0.1	0.4	0.2	<LOD
29	4.7	-	-	5.4	1.7	0.01	0.2	0.4	0.2	<LOD
30	1.4	-	-	8.1	3.3	<LOD	<0.1	0.2	0.1	<LOD
31	2.8	-	-	12.0	5.4	<LOD	0.1	0.5	0.1	<LOD
32	2.6	-	-	12.2	4.1	0.01	0.3	0.5	0.2	<LOD
33	1.6	-	-	5.7	1.5	0.01	1.3	0.3	0.2	<LOD
34	3.8	-	-	13.0	9.5	0.01	0.4	0.6	0.2	<LOD
35	4.5	-	-	4.7	1.8	<LOD	0.1	0.4	0.2	<LOD
36	3.7	-	-	2.4	1.2	<LOD	0.1	0.2	0.1	<LOD
37	4.5	-	-	4.9	2.2	0.02	0.1	0.4	0.3	<LOD
38	4.4	-	-	6.1	1.4	0.02	0.1	0.8	0.2	<LOD
39	2.9	-	-	3.5	1.4	<LOD	<0.1	0.3	0.2	<LOD
40	2.6	-	-	6.4	3.9	<LOD	0.2	0.3	0.5	<LOD
41	2.7	-	-	5.1	2.8	<LOD	0.2	0.4	0.7	<LOD
42	2.7	-	-	6.5	6.6	<LOD	0.2	0.4	0.7	<LOD
43	3.1	-	-	10.5	3.4	<LOD	0.1	0.5	0.4	<LOD

Table A2 (cont.). Dry matter, nutrient and PTE concentrations (fresh weight basis) of whole food-based digestates

Sample number	Dry matter (%)	Nutrient content (kg/t)		PTE concentration (mg/l fresh weight)						
		N	P	Zn	Cu	Cd	Pb	Ni	Cr	Hg
44	3.1	-	-	4.2	0.6	<LOD	<0.1	0.3	0.4	<LOD
45	3.78	-	-	5.2	1.0	<LOD	<0.1	0.4	0.4	<LOD
46	2.95	-	-	5.7	1.5	0.01	1.2	0.2	0.2	<LOD
47	4.19	-	-	5.3	1.7	0.01	0.9	0.4	0.3	<LOD
48	4.31	-	-	10.6	1.9	0.01	0.7	0.5	0.2	<LOD
49	2.69	-	-	5.2	1.0	<LOD	0.2	0.2	0.1	<LOD
50	2.97	-	-	3.6	0.8	0.01	0.1	0.1	<0.1	<LOD
51	1.14	-	-	1.4	2.2	<LOD	0.1	0.1	0.1	<LOD

<LOD = Below limit of (analytical) detection

Table A3. Dry matter and PTE concentrations (dry matter basis) of food-based digestates (separated liquids)

Sample number	Dry matter (%)	PTE concentration (mg/kg dry matter)						
		Zn	Cu	Cd	Pb	Ni	Cr	Hg
52	2.0	196	43	<LOD	13.9	13.7	6.4	<LOD
53	3.4	147	55	0.29	16.0	9.9	3.3	<LOD
54	3.2	120	52	<LOD	12.7	7.9	0.0	<LOD
55	3.7	105	35	<LOD	13.9	6.6	15.3	<LOD
56	3.8	97	34	<LOD	14.5	12.1	34.4	<LOD
57	2.9	106	35	<LOD	14.6	8.1	<0.1	<LOD
58	4.0	97	5	0.58	3.1	11.7	9.1	<LOD
59	0.6	10	14	<LOD	0.8	8.6	1.8	<LOD
60	1.2	111	32	<LOD	9.2	15.6	0.4	<LOD
61	1.7	48	<1	<LOD	1.9	12.8	2.3	<LOD
62	3.3	300	42	0.77	4.9	9.6	5.8	<LOD
63	4.1	128	69	<LOD	4.8	6.8	6.1	<LOD
64	3.1	208	117	<LOD	6.6	8.9	6.9	<LOD
65	10.6	4	0	<LOD	<0.1	4.7	1.7	<LOD
66	5.9	<1	2	<LOD	0.2	1.3	0.4	<LOD
67*	8.7	293	86	1.33	14.6	17.4	27.7	0.27
68*	13.2	731	341	0.85	50.3	26.5	49.4	0.59

<LOD = Below limit of (analytical) detection
*Samples submitted for analysis as fibres although dry matter was <15%

Table A4. Dry matter, nutrient and PTE concentrations (fresh weight basis) of food-based digestates (separated liquids)

Sample number	Dry matter (%)	Nutrient content (kg/t)		PTE concentration (mg/l fresh weight)						
		N	P	Zn	Cu	Cd	Pb	Ni	Cr	Hg
52	2.0	-	-	3.8	0.8	<LOD	0.3	0.3	0.1	<LOD
53	3.4	-	-	5.0	1.9	0.01	0.5	0.3	0.1	<LOD
54	3.2	-	-	3.8	1.7	<LOD	0.4	0.3	<0.1	<LOD
55	3.7	-	-	3.9	1.3	<LOD	0.5	0.2	0.6	<LOD
56	3.8	-	-	3.7	1.3	<LOD	0.5	0.5	1.3	<LOD
57	2.9	-	-	3.1	1.0	<LOD	0.4	0.2	<0.1	<LOD
58	4.0	-	-	3.8	0.2	0.02	0.1	0.5	0.4	<LOD
59	0.6	-	-	0.1	0.1	<LOD	<0.1	0.1	<0.1	<LOD
60	1.2	-	-	1.3	0.4	<LOD	0.1	0.2	<0.1	<LOD
61	1.7	-	-	0.8	0.0	<LOD	<0.1	0.2	<0.1	<LOD
62	3.3	-	-	9.8	1.4	0.03	0.2	0.3	0.2	<LOD
63	4.1	-	-	5.2	2.8	<LOD	0.2	0.3	0.3	<LOD
64	3.1	-	-	6.4	3.6	<LOD	0.2	0.3	0.2	<LOD
65	10.6	-	-	0.4	0.0	<LOD	<0.1	0.5	0.2	<LOD
66	5.9	-	-	0.0	0.1	<LOD	<0.1	0.1	<0.1	<LOD
67*	8.7	-	-	25.5	7.5	0.12	1.3	1.5	2.4	<LOD
68*	13.2	-	-	96.1	44.8	0.11	6.6	3.5	6.5	0.08

<LOD = Below limit of (analytical) detection
*Samples submitted for analysis as fibre, although dry matter was <15%

Table A5. Dry matter and PTE concentrations (dry matter basis) of food-based digestates (fibre digestates)

Sample number	Dry matter (%)	PTE concentration (mg/kg dry matter)						
		Zn	Cu	Cd	Pb	Ni	Cr	Hg
69	22.4	66	14	0.07	0.4	1.2	1.8	<LOD
70	23.6	56	9	0.09	2.5	1.8	2.6	<LOD
71	20.5	58	11	0.10	0.7	1.9	3.4	<LOD
72	30.2	279	71	0.08	12.8	8.6	15.4	<LOD
73	19.3	148	42	0.10	7.7	1.9	3.8	<LOD
74	22.5	67	21	0.08	7.4	3.5	4.5	<LOD
75	19.7	70	20	0.07	4.7	2.9	2.8	<LOD
76	21.1	731	359	0.24	12.4	11.1	19.1	<LOD
77	22.3	755	373	0.22	12.3	11.2	19.7	<LOD
78	20.1	260	29	<LOD	2.5	8.0	12.5	<LOD
79	21.3	252	33	<LOD	2.3	12.1	17.4	<LOD
80	17.5	568	109	0.25	11.1	13.0	66.9	<LOD
81	19.5	581	119	0.29	10.9	13.7	41.0	<LOD
82	30.1	163	29	0.08	8.6	4.9	26.4	1.46
83	26.5	310	98	0.59	4.3	12.8	14.6	<LOD
84	27.5	310	89	0.32	39.1	5.8	14.8	<LOD
85	33.5	189	47	0.19	18.6	9.4	19.2	<LOD
86	27.0	260	55	0.27	19.9	9.4	21.5	0.14
87	22.1	551	73	0.68	98.4	13.8	22.5	0.16
88	20.2	554	70	0.76	64.6	11.5	20.9	<LOD
89	21.6	615	82	0.61	30.8	6.6	14.3	<LOD
90	22.1	583	51	0.41	15.3	5.4	10.5	<LOD

<LOD = Below limit of (analytical) detection

Table A6. Dry matter, nutrient and PTE concentrations (fresh weight basis) of food-based digestates (fibre digestates)

Sample number	Dry matter (%)	Nutrient content (kg/t)		PTE concentration (mg/kg fresh weight)						
		N	P	Zn	Cu	Cd	Pb	Ni	Cr	Hg
69	22.4	-	-	14.8	3.1	0.02	0.1	0.3	0.4	<LOD
70	23.6	-	-	13.3	2.1	0.02	0.6	0.4	0.6	<LOD
71	20.5	-	-	12.0	2.2	0.02	0.1	0.4	0.7	<LOD
72	30.2	-	-	84.1	21.3	0.02	3.9	2.6	4.6	<LOD
73	19.3	-	-	28.5	8.1	0.02	1.5	0.4	0.7	<LOD
74	22.5	-	-	15.0	4.8	0.02	1.7	0.8	1.0	<LOD
75	19.7	-	-	13.8	4.0	0.01	0.9	0.6	0.6	<LOD
76	21.1	-	-	154.4	75.9	0.05	2.6	2.3	4.0	<LOD
77	22.3	-	-	168.1	83.0	0.05	2.7	2.5	4.4	<LOD
78	20.1	-	-	52.4	5.8	<LOD	0.5	1.6	2.5	<LOD
79	21.3	-	-	53.6	7.0	<LOD	0.5	2.6	3.7	<LOD
80	17.5	-	-	99.3	19.1	0.04	1.9	2.3	11.7	<LOD
81	19.5	-	-	113.2	23.1	0.06	2.1	2.7	8.0	0.44
82	30.1	-	-	49.0	8.6	0.02	2.6	1.5	7.9	<LOD
83	26.5	-	-	82.3	25.9	0.16	1.1	3.4	3.9	<LOD
84	27.5	-	-	85.1	24.5	0.09	10.7	1.6	4.1	<LOD
85	33.5	-	-	63.3	15.6	0.06	6.3	3.2	6.4	<LOD
86	27.0	-	-	70.1	14.8	0.07	5.4	2.5	5.8	<LOD
87	22.1	-	-	122.0	16.2	0.15	21.8	3.1	5.0	<LOD
88	20.2	-	-	111.5	14.1	0.15	13.0	2.3	4.2	<LOD
89	21.6	-	-	133.0	17.8	0.13	6.7	1.4	3.1	<LOD
90	22.1	-	-	129.2	11.3	0.09	3.4	1.2	2.3	<LOD

<LOD = Below limit of (analytical) detection

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