Environment Agency

Evidence

Material comparators for end-of-waste decisions

Materials applied to land: manufactured fertilisers

Report – SC130040/R14

Version 2

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We cannot do this alone. We work closely with a wide range of partners including government, business, local authorities, other agencies, civil society groups and the communities we serve.

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Executive summary

This report details the work undertaken to define non-waste material comparators for end-of-waste decisions for waste-derived materials intended for use as a fertiliser.

The Waste Framework Directive (Article 6) provides criteria for identifying when a waste material has become a product and no longer needs to be regulated as a waste. Through Article 6 the case law requires us to consider the environmental and human health impacts from materials in comparison with their non-waste material alternatives.

> *... "It should be enough that the holder has converted the waste material into a distinct, marketable product, which can be used in exactly the same way as a [non-waste material], and with no worse environmental effects..."*

Data have been collected via a literature review and are presented for:

- Triple superphosphate (TSP)
- Other straight phosphate fertilisers
- Phosphate potassium (PK) fertilisers
- Nitrate phosphate (NP) fertilisers
- Low N (N<19%) fertilisers
- High N (N≥19%) fertilisers

We were not able to find any papers or data identifying organic contaminants in manufactured fertilisers and therefore assume that any such contaminants are below an appropriate level of detection.

Where more than ten data points have been identified, a 90th percentile of the dataset has been calculated.

We recommend comparing the concentrations of analytes in the comparators dataset to the concentrations in the waste-derived material, paying attention to the higher values. This comparison does not constitute a pass/fail test or an end of waste view. It will provide an indication of whether the waste material contains similar levels of analytes to non-waste materials and whether an end-of-waste application may be appropriate or that further analysis or improved treatment processes may be warranted.

The 90th percentile levels (mg/kg) for the main contaminants are given in the table below.

Fertiliser type	**As**	**Cd**	**Co**	**Cr (total)**	**Cu**	**Ni**	**Pb**	**Zn**
Triple superphosphate (TSP)	11.9	30.6	0.5	283.9	49.6	55.7	17.6	637.4
Other straight phosphate	8.6	13.6		114.7	24.7	35.7	34.7	259.5
Nitrate phosphate (NP)	18.6	26.3	1.8	360.3	46.5	46.6	8.7	399.7

Low N (N<19%)	17.4	18	9.4	252.1	55.9	37.3	5.7	339.9
High N (N≥19%)	12.2	5.7	1.2	37.6	11.6	7.7	3.6	51.9

Contents

Tables and figures

Introduction

The Evidence Directorate of the Environment Agency has been tasked with investigating and developing a dataset of different 'non-waste material comparators' to assist with making end-of-waste decisions.

The Waste Framework Directive (Article 6) provides criteria for identifying when a waste material has become a product and no longer needs to be regulated as a waste. Through Article 6 the case law requires us to consider the environmental and human health impacts from materials in comparison with their non-waste alternatives.

> *... "It should be enough that the holder has converted the waste material into a distinct, marketable product, which can be used in exactly the same way as a [non-waste material], and with no worse environmental effects..."*

For example, if we were assessing the impact from a biodiesel derived from waste we would compare it against contaminants within regular diesel.

It is not the purpose of this work to undertake any comparisons between the non-waste materials and the wastes. It is purely to collect and collate the data so that the comparisons can be made by others.

This report presents the results of a literature review designed to collect and collate published data on the chemical analysis of manufactured commercial fertilisers.

Bibliographic search engines and general internet searches were conducted. Contacts within Defra, the Agricultural Industries Confederation (AIC) and ADAS were approached to source grey literature. The literature review search terms are reproduced in Appendix 1.

Six other reports cover ordinary material comparators applied to land:

- non-waste biochar
- non-waste wood
- PAS 100 compost
- peat
- soil improver
- straw

Types of fertiliser

The Defra publication '*Fertiliser Manual* (*RB209*)' states that:

> *Some 13 elements, in addition to carbon (C), hydrogen (H) and oxygen (O) are known to be essential for plant growth and they can be divided into two groups:*
>
> - *Macronutrients: these are nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulphur (S) and are required in relatively large amounts.*
> - *Micronutrients (trace elements): these include iron (Fe), copper (Cu), manganese (Mn), zinc (Zn), boron (B), molybdenum (Mo) and chlorine (Cl), and are required in smaller amounts than the macronutrients.*
>
> *The names macro- and micro- nutrients do not refer to relative importance in plant nutrition; a deficiency of any one of these elements can limit growth and result in decreased yield. It is therefore important to ensure that there is an optimum supply of all nutrients – if a plant is seriously deficient in, for example, potassium it will not be able to utilise fully any added nitrogen and reach its full potential yield and any unutilised nitrogen may be lost from the field.*
>
> *In the UK, two conventions are used as follows:*
>
> - *For fertiliser contents and for recommendations, phosphorus is expressed in the oxide form phosphate (P_2O_5) and potassium as potash (K_2O). Sulphur, magnesium and sodium also are expressed in oxide forms (SO_3, MgO and Na_2O).*
> - *Soil and crop analysis reports usually show elemental forms for example mg P/kg or mg K/l.*
>
> *Other elements found in plants, which may not be essential for their growth include, cobalt (Co), nickel (Ni), selenium (Se), silicon (Si) and sodium (Na). Sodium has a positive effect on the growth of a few crops. Some elements, such as cobalt, iodine (I), nickel and selenium are important in animal nutrition. These are normally supplied to the animal via plants, and must consequently be available in the soil for uptake by plant roots.*

We have followed this naming convention for oxides within this report with respect to N, P and K. However, all other elements, whether plant nutrient or 'contaminant', are expressed in the elemental forms above.

The Defra report *The British Survey of Fertiliser Practice: Fertiliser Use on Farm Crops for Crop Year 2011* places fertilisers into the following categories:

- Ammonium nitrate
- Urea
- Calcium ammonium nitrate (CAN)
- Urea ammonium nitrate (UAN)
- Other straight N
- **Triple superphosphate (TSP)**
- **Other straight P**

- Muriate of potash (MOP)
- Other straight K
- **PK**
- NK
- **Low N (<19% N)**
- **High N (≥19% N)**

We have attempted to follow this characterisation; however, sufficient data were only available for those categories highlighted in **bold** above. In addition data is presented for NP fertilisers, such as monoammonium phosphate and diammonium phosphate (MAP and DAP).

References are presented in two sections:

- One containing references, data from which have been used in Tables 1 to 6 (nine in total).
- The other containing references which, for the reasons explained in Appendices 2 and 3, have not been used to derive non-waste comparators (48 in total).

Recommendations for end-of-waste decision making

Data gaps

We have good data for only a limited number of fertiliser types (see below). Where the composition data do not exist, we recommend that sampling and analysis of fertilisers used in the UK is undertaken. We recommend that this sampling programme covers all fertiliser types (including those for which data do already exist) to ensure a consistent and comprehensive dataset.

For a number of years now, the European Union has discussed setting a maximum cadmium concentration in agricultural fertilisers. Clearly were such a level set for this or other elements, this report would have to be re-visited.

Existing data

Where good data currently exist, we recommend that these are used to screen the materials to be used in the place of manufactured fertilisers. This screening exercise will help compare differences between the waste derived material and the non-waste comparator and in doing so identify where additional risk to the environment and human health may exist.

The screening process is set out below.

Using the data tables

Data are split into six different fertiliser types as follows:

Table 1 Triple superphosphate (TSP)

Table 2 Other straight phosphate fertilisers

Table 3 Nitrate phosphate (NP) fertilisers

Table 4 Phosphate potassium (PK) fertilisers

Table 5 Low N fertilisers (N<19%)

Table 6 High N fertilisers (N≥19%)

Figure 1 in Appendix 3 illustrates the nature of the data distribution and the influence of outliers upon it.

We recommend comparing the concentrations of analytes in the comparators dataset to the concentrations in the waste-derived material, paying attention to the higher values in both datasets.

In making the comparison with the contaminant concentrations it is important to make any necessary adjustments for the application rate.

The levels of N, P and K are specified in the tables. Where a waste-derived material has significantly different levels of N, P and K from the comparator then the effect of application rate must be taken into account. For example, a waste-derived fertiliser with half of the P content of a non-waste comparator will typically require twice the application rate to deliver the same amount of P to an agricultural soil. In order to pass this screening stage, the assessor can take account of this effect by reducing the effective concentration of the comparator (in the example above the level of a contaminant in the comparator would be halved). Other more complex differences in application rates and methods may require more detailed risk assessment.

The data may not cover all the potential contaminants that may be found in waste materials. For example, we were not able to find any papers or data identifying organic contaminants in manufactured fertilisers. Where the data do not exist, we recommend that the level of the contaminant must be below an appropriate limit of detection in order to pass this screening stage.

This comparison does not constitute a pass/fail test or an end of waste view.

It will provide an indication of whether the waste material contains similar levels of analytes to non-waste materials and whether an end-of-waste application may be appropriate or that further analysis or improved treatment processes may be warranted.

Table 1 Triple superphosphate (TSP)

Source	Name	N	P	K	As	Cd	Co	Cr	Cu	Mo	Ni	Pb	Sr	V	Zn	F
		%			mg/kg											
Conceicao 2006	TSP	0	47	0		2		6	10		16	23			25	492
Conceicao 2006	TSP	0	47	0		2		5	9		14	22			20	546
McBride & Spiers 2001	TSP	0	47	0	11	8.1		83	4				538			
Molina 2009	TSP (mean)	0	47	0	17.9	28.8		633	75.1	6.9	10.6	16.5		430	600	
USEPA 1999	TSP	0	47	0	13.9	6.4		90.1	45.1		21.9	13.2		132	87.1	
Marks 1996	TSP (mean n=8)	0	47	0	7.5	30.6		258.1	21.9	18.4	36.5	1.2			485.6	19600
Nziguheba 2008	TSP	0	47	0	7.5	8.4	0.4	167.3	30.6		21	4			281.5	
Nziguheba 2008	TSP	0	47	0	5.9	30.7	0.5	248.3	4.7		12.2	3			223.3	
Nziguheba 2008	TSP	0	47	0	8.6	8.7	0.5	161.3	25.8		21.4	4.6			247	
Nziguheba 2008	TSP	0	47	0	8	23.7	0.5	160.5	50.1		55.4	3.9			603	
Nziguheba 2008	TSP	0	47	0	6.5	31.9	0.4	261.5	4.9		13.6	2.4			247.7	
Nziguheba 2008	GTSP	0	47	0	7.6	24.8	0.4	160.1	39.9		66.4	3.2			636.3	
Nziguheba 2008	GTSP	0	47	0	3.4	13	0.4	65.5	21.2		30.6	2.9			253.4	
Nziguheba 2008	GTSP	0	47	0	6.5	29.6	0.4	150.9	39.1		56.9	2.5			641.7	
Nziguheba 2008	TSP	0	47	0	8.1	22.7	0.4	150	41.6		52.6	2.4			593	
Nziguheba 2008	TSP	0	47	0	7.3	8	0.4	162.1	25.5		20.5	4.7			250.4	
Nziguheba 2008	TSP	0	47	0	5.1	9.4	0.4	177.7	29.7		23.6	4			303	
Nziguheba 2008	TSP	0	47	0	5.2	29.5	0.4	251.6	49.5		12.7	4.7			669.7	
Nziguheba 2008	TSP	0	47	0	7.8	8.6	0.4	154.5	26.6		19.9	4.1			272.4	
Nziguheba 2008	TSP	0	46	0	9.3	24.9	0.4	485.8	44.4		44	3.6			469.4	
Mean					8.2	17.6	0.4	191.6	29.9	12.7	28.9	6.6	538	281	363.6	6879.3
Median					7.5	17.9	0.4	160.9	28.2	12.7	21.4	4	538	281	281.5	546
Minimum					3.4	2	0.4	5	4	6.9	10.6	1.2	538	132	20	492

Source	Name	N	P	K	As	Cd	Co	Cr	Cu	Mo	Ni	Pb	Sr	V	Zn	F
Maximum					17.9	31.9	0.5	633	75.1	18.4	66.4	23	538	430	669.7	19600
Samples					18	20	14	20	20	2	19	19	1	2	19	3
90th percentiles					11.9	30.6	0.5	283.9	49.6	NA	55.7	17.6	NA	NA	637.4	NA

Table 2 Other straight phosphate fertiliser

Source	Name	N	P	K	S	As	Cd	Co	Cr	Cu	Mo	Ni	Pb	Sr	Zn	F
		%				mg/kg										
Conceicao 2006	SSP						2		11	24		36	38		48	510
Conceicao 2006	SSP						3		13	21		31	45		44	420
Marks 1996	SSP (means n=3)					5	11.5		64.4	24.9	17.8	20.7	3.8		221	20000
McBride & Spiers 2001	SSP					8	3.1		33	10				713		
Nziguheba 2008	SSP18+21S	0	18	0	21	3.3	4.7	0.4	93.8	11.9		11.5	1.1		168.4	
Nziguheba 2008	Superphosphate + S					5.5	17.2	0.4	60.5	23.2		41	0.9		263.8	
Nziguheba 2008	SSP					3.5	5.3	0.4	101.3	15.7		15.9	0.4		188.5	
Nziguheba 2008	SSP					5	8.6	0.4	177.2	17.2		14.3	4.1		150.6	
Nziguheba 2008	SSP					5.4	9.2	0.4	71.7	16.5		15	4.1		171.9	
Nziguheba 2008	SSP					3.7	13.9	0.4	109.4	63.6		33.1	3.8		439.2	
Nziguheba 2008	SSP					8.6	10.4	0.4	82.5	19.7		18.7	3.1		189	
Nziguheba 2008	SSP					0.8	10.6	0.4	109.7	6.7		6.4	2.9		83.1	
Nziguheba 2008	SSP					10.4	12.5	1.3	116	10.8		11.7	4.9		106.2	
Mean						5.4	9.7	0.5	92.7	20.0	17.8	18.8	2.9	713.0	198.2	6977
Median						5	9.2	0.4	82.5	17.2	17.8	17.3	3.8	713	170.15	510
Minimum						0.8	2	0.4	11	6.7	17.8	6.4	0.4	713	44	420
Maximum						10.4	17.2	1.3	177.2	63.6	17.8	41	45	713	439.2	20000
Samples						11	13	9	13	13	1	12	12	1	12	3
90th percentiles						**8.6**	**13.6**	**NA**	**114.7**	**24.7**	**NA**	**35.7**	**34.7**	**NA**	**259.5**	**NA**

Table 3 Nitrate phosphate (NP) fertilisers

Source	Name	N	P	K	Ag	As	Cd	Co	Cr	Cu	Mo	Ni	Pb	V	Zn	F
		%			mg/kg											
Conceicao 2006	MAP	12	57	0			2		7	10		15	20		23	330
Conceicao 2006	MAP	12	59	0			2		5	9		13	20		22	372
Molina 2009	MAP (means)					12.1	4.1		82.3	2.4	10.6	4.9	5.6	47	63.5	
USEPA 1999	MAP	11	52	0		18.7	4.9		96.3	24.2		19.4	6.8	132	59.4	
USEPA 1999	MAP	10	50	0		13.2	3.4		72.9	32.3		16.7	4.6	133	40.5	
Lottermoser 2009	DAP (means n=3)	18	20	0	4.44	5.43	1.18			55.9	3.48	23.5	0.33		165	
Molina 2009	DAP (means)					15.3	4.1		89	3.6	8.3	5.7	9.2	35.3	41.3	
USEPA 1999	DAP	18	46	0		16.3	3.4		74.4	25.6		16.7	6.1	95.2	43	
USEPA 1999	DAP	18	48	0		13.8	4.6		77.6	11.3		16.8	4.4	151	0.83	
Marks 1996	MAP (means n=3)	12	52	0		36.9	0.4		4.9	19.1	0.5	3.2	1.4		23	13483
Marks 1996	DAP (means n=2)	18	46	0		10.9	20.1		258.5	40.6	11.5	46.6	3.6		388	12550
Nziguheba 2008	DAP 18/46/0	18	46	0		44.9	<0.4	1.2	5.5	18.9		4	2.5		10.5	
Nziguheba 2008	DAP	18	46	0		12.6	23.4	1.6	303.5	26.2		45.5	4.6		355.3	
Nziguheba 2008	DAP	18	46	0		5.5	0.5	1	12.9	6.9		4.2	<0.4		15.9	
Nziguheba 2008	MAP	12	52	0		14.2	42.1	<0.4	499.3	42.4		65.5	0.8		699.4	
Nziguheba 2008	DAP	18	46	0		4.5	0.4	1.2	14.2	5.7		3.8	<0.4		11.3	
Nziguheba 2008	DAP	18	46	0		14.9	21.3	1.3	340.6	21.3		46.7	2.5		336	
Nziguheba 2008	DAP	18	46	0		16.6		0.9	3.9	12.9		2.2	2		7.9	
Nziguheba 2008	Monoammonium NP	12	52	0		13.5	<0.4	1.2	7.7	25.8		4.6	5.9		7.4	
Nziguheba 2008	Monoammonium NP	12	52	0		8.9	<0.4	1.9	11.7	5.1		7.9	3.2		5.2	
Nziguheba 2008	Diammonium NP	18	46	0		4.4	27.1	0.4	273.1	0		12.1	<0.4		193.5	
Nziguheba 2008	Diammonium NP	18	46	0		4.5	31.9	0.5	277	0.2		12.7	<0.4		229.9	
Nziguheba 2008	Diammonium NP	18	46	0		6.6	1.6	1.1	29.9	12.6		7.4	2		54.4	
Nziguheba 2008	Diammonium NP	18	46	0		6	1.4	1	27.7	14.6		6.8	1.5		48.3	

Source	Name	N	P	K	Ag	As	Cd	Co	Cr	Cu	Mo	Ni	Pb	V	Zn	F
Nziguheba 2008	FertiDAP 18-46-0	18	46	0		18.4	21.3	47.9	403.9	66		47.9	<0.4		435.5	
Nziguheba 2008	Composto 18-46-0	18	46	0		<0.4	4.5	1.7	238.1	15.8		16.3	6.3		130.4	
Nziguheba 2008	DAP 18-46-0	18	46	0		18.3	19.7	0.6	389.9	65.6		44.3	0.9		427	
Nziguheba 2008	MAP					8.5	<0.4	1.6	18.9	3.1		12.1	2.4		8.5	
Mean						13.8	10.7	4.1	134.3	20.6	6.9	18.8	5.1	98.9	137.4	6683.8
Median						13.2	4.1	1.2	74.4	15.2	8.3	12.9	3.6	113.6	45.6	6461
Minimum						4.4	0.4	0.4	3.9	0	0.5	2.2	0.3	35.3	0.8	330
Maximum						44.9	42.1	47.9	499.3	66	11.5	65.5	20	151	699.4	13483
Samples						25	23	16	27	28	5	28	23	6	28	4
90th percentiles						**18.6**	**26.3**	**1.8**	**360.3**	**46.5**	**NA**	**46.6**	**8.7**	**NA**	**399.7**	**NA**

Table 4 Phosphate potassium (PK) fertilisers

Source	N-P-K	N	P	K	As	Cd	Co	Cr	Cu	Ni	Pb	Zn
		%			mg/kg							
Nziguheba 2008	0-7-30	0	7	30	2.1	11.1	<0.4	87.3	1.9	5.2	0.9	83.2
Nziguheba 2008	0-10-20	0	10	20	10.5	<0.4	0.6	5.6	9.5	3.1	4.8	7.3
Nziguheba 2008	PK 20-30	0	20	30	3.3	10.1	<0.4	48.3	17.2	30.2	1.1	266.3
Nziguheba 2008	PK 25-25	0	25	25	5.1	12.5	<0.4	61.3	43.5	36.1	1.4	326.1
Nziguheba 2008	PK 0/10/30+0,2Boron	0	10	30	1.4	2.9	<0.4	42.6	6.1	7.8	1	92.3
Nziguheba 2008	PK 0/15/30	0	15	30	3.9	7.9	<0.4	64.2	4.7	6.2	1.8	87.1
Mean		0	15	28	4	9	0.6	52	14	15	2	144
Median					4	10	0.6	55	8	7	1	90
Minimum					1	3	0.6	6	2	3	1	7
Maximum					10	12	0.6	87	43	36	5	326
Samples					6	5	6	6	6	6	6	6

Table 5 Low N fertilisers (N<19%)

Source	N	P	K	As	Ba	Cd	Co	Cr	Cu	Mo	Ni	Pb	Sb	Se	Sr	Th	U	V	Zn
	%			mg/kg															
McBride & Spiers 2001	10	20	20	4		1.2		21	7	2.6	5	1		1					94
McBride & Spiers 2001	13	13	13	4		1.2		22	1	3.2	6	0.6		1					21
McBride & Spiers 2001	12	16	16	6		1.5		32	1	4.1	7	0.8		1					25
McBride & Spiers 2001	6	24	24	8		2.5		48	1	6.2	10	0.9		1					44
El-Ghawi *et al*. 1999	14	24	11			18		49	26	3.2	17							49	114
El-Ghawi *et al*. 1999	13	9	22			4		3	35	10	4							1	55
El-Ghawi *et al*. 1999	15	18	15			5		3	5	9.7	6							2	15
Lottermoser 2009	13	2	13	1		0.85			50.4	0.89	35.5	0.05	1.09		22.3	1.77	73.1		251
Lottermoser 2009	14	15	13	1		0.54			46.3	2.33	30.2	0.05	1.25		6.67	1.68	63.1		212
Lottermoser 2009	14	15	13	1.9		0.89			45	6.46	29.5	1.03	1.85		442	1.49	64.9		8800
Lottermoser 2009	13	14	12	5.8		0.85			35.4	6.4	25.2	132	18		6.08	2.13	46.4		17700
Lottermoser 2009	13	13	18	5.81		0.6			43.9	2.31	28	0.23	0.66		15.2	0.05	0.05		120
Otero *et al*. 2005	15	5	30	1.3	50	0.3		5	75	21	1	3	0.1	3	2	0.2	0.5	2	2
Otero *et al*. 2005	17	6	18	1.2	50	0.3		5	163	4	1	3	0.1	3	1	0.2	0.5	2	2
Otero *et al*. 2005	15	10	15	1.2	50	0.3		5	101	35	1	3	0.1	3	2	0.2	0.5	2	2.3
Otero *et al*. 2005	12	61	0	1.2	50	0.6		10	1	1	2	3	0.1	3	12	0.2	8.5	3	6
Otero *et al*. 2005	10	10	18	96.2	50	2.3		36	39	1	11	3	0.8	3	1449	1.4	10.3	35	230
Otero *et al*. 2005	5	7	10	60.8	50	2.9		82	73	1	16	133	8.8	3	316	2.3	18.4	40	650
Otero *et al*. 2005	16	8	12	5.3	50	0.3		7	261	108	4	3	0.2	3	137	1.5	0.5	19	77
Otero *et al*. 2005	8	6	20	4.7	50	3.6		40	9	1	8	3	1	3	505	0.9	32.5	39	75
Otero *et al*. 2005	12	12	17	4.6	280	4.5		80	22	2	14	3	0.9	3	183	1	40	62	89
Otero *et al*. 2005	12	12	17	0.5	110	1.2		16	15	1	3	3	0.1	3	4451	4.9	9.5	33	118
Otero *et al*. 2005	15	15	15	1.4	430	0.3		5	10	1	5	3	0.1	3	4535	6.8	0.5	29	12

Source	N	P	K	As	Ba	Cd	Co	Cr	Cu	Mo	Ni	Pb	Sb	Se	Sr	Th	U	V	Zn
Otero *et al*. 2005	7	14	16	6	50	8.1		95	29	1	16	4	2.5	3	463	1.8	60.3	82	175
Nziguheba 2008	16	10	10	7.7		5	0.4	93.5	17.4		11.7	2.5							94.1
Nziguheba 2008	18	46	0	44.9		0.4	1.2	5.5	18.9		4	2.5							10.5
Nziguheba 2008	15	15	15	10.3		6.2	0.4	123.9	18.5		15.9	1.5							129.7
Nziguheba 2008	18	46	0	12.6		23.4	1.6	303.5	26.2		45.5	4.6							355.3
Nziguheba 2008	18	46	0	5.5		0.5	1	12.9	6.9		4.2	0.4							15.9
Nziguheba 2008	12	52	0	14.2		42.1	0.4	499.3	42.4		65.5	0.8							699.4
Nziguheba 2008	18	46	0	4.5		0.4	1.2	14.2	5.7		3.8	0.4							11.3
Nziguheba 2008	18	46	0	14.9		21.3	1.3	340.6	21.3		46.7	2.5							336
Nziguheba 2008	18	46	0	16.6			0.9	3.9	12.9		2.2	2							7.9
Nziguheba 2008	15	15	15	21.9		1.6	0.4	16.4	10.5		3.6	6.2							28
Nziguheba 2008	5	15	30	6.7		6.2	10.3	186.4	9.3		194.9	1.1							124.5
Nziguheba 2008	8	24	24	6.9		9.7	1.1	149.1	6		26.3	0.5							207.2
Nziguheba 2008	17	19	0	14.6		1.8	1.6	26.9	12.4		8.8	5							51.4
Nziguheba 2008	5	9	25	2.8		3.2	5.5	77.4	13		79.9	2.6							57
Nziguheba 2008	17	4	13	7.7		0.4	1.3	6.4	8.9		2.7	2.2							90.6
Nziguheba 2008	12	23	0	6.2		0.4	1.6	4.9	24.7		2.8	1							10.7
Nziguheba 2008	11	5	18	15.8		0.4	1.1	7.5	14		3.3	5.5							275.3
Nziguheba 2008	17	7	14	1.8		0.4	1.4	5.8	2		2	0.5							25.7
Nziguheba 2008	18	6	12	3.4		5.1	0.4	95.8	14.5		15.2	0.5							181.7
Nziguheba 2008	10	10	20	0.4		11.7	0.7	92.9	0.4		4.1	0.4							86
Nziguheba 2008	18	6	12	5.7		5.4	8.8	74.2	13.8		12.6	0.4							102.3
Nziguheba 2008	10	10	20	1.4		14.7	0.4	117.2	0.4		5.1	0.4							108.3
Nziguheba 2008	18	6	12	2.4		7.9	114.4	70.3	2		2.9	1.5							62.3
Nziguheba 2008	10	10	20	5.3		10.1	212.3	168.6	25.6		23.9	1.5							192.8
Nziguheba 2008	18	6	12	0.7		6.2	61.2	54.3	1		3.2	0.4							49.1
Nziguheba 2008	16	7	13	29.7		0.4	1	1.4	20.4		1	7.8							10.4

Source	N	P	K	As	Ba	Cd	Co	Cr	Cu	Mo	Ni	Pb	Sb	Se	Sr	Th	U	V	Zn
Nziguheba 2008	10	10	20	3.9		14.4	141.3	139	1.9		7.1	1.2							115.3
Nziguheba 2008	18	6	12	1.9		0.5	0.8	8.8	3.5		2.7	14.3							40.7
Nziguheba 2008	18	6	12	24.6		0.4	1	5.7	21.1		3.7	8.4							10.7
Nziguheba 2008	10	10	20	3.2		9.5	0.4	117.2	2.8		3.8	1.5							74.5
Nziguheba 2008	18	6	12	1		3.2	0.4	58.1	0.5		2.8	0.3							25.9
Nziguheba 2008	12	52	0	13.5		0.4	1.2	7.7	25.8		4.6	5.9							7.4
Nziguheba 2008	12	52	0	8.9		0.4	1.9	11.7	5.1		7.9	3.2							5.2
Nziguheba 2008	18	46	0	4.4		27.1	0.4	273.1	0		12.1	0.4							193.5
Nziguheba 2008	18	46	0	4.5		31.9	0.5	277	0.2		12.7	0.4							229.9
Nziguheba 2008	18	46	0	6.6		1.6	1.1	29.9	12.6		7.4	2							54.4
Nziguheba 2008	18	46	0	6		1.4	1	27.7	14.6		6.8	1.5							48.3
Nziguheba 2008	12	24	12	7.1		13.6	0.5	159.4	16.4		22.9	1.5							198.6
Nziguheba 2008	12	24	12	12.8		10.1	1.9	204.6	35.2		29.4	3							230.8
Nziguheba 2008	12	18	12	9.1		14.6	0.7	186.7	23.2		30.7	1.6							227.1
Nziguheba 2008	18	46	0	18.4		21.3	47.9	403.9	66		47.9	0.4							435.5
Nziguheba 2008	18	46	0	0.4		4.5	1.7	238.1	15.8		16.3	6.3							130.4
Nziguheba 2008	10	10	10	2.7		7.1	0.4	25.7	12.2		14.7	2.4							146.5
Nziguheba 2008	7	14	14	1.1		7.7	0.4	30.2	14		15.5	1.7							163.8
Nziguheba 2008	15	15	15	1.7		10	0.4	96.7	7.7		11.7	1.3							115.1
Nziguheba 2008	7	21	0	4.4		11.9	0.4	137.2	21.3		19.9	2							203.6
Nziguheba 2008	7	21	0	0.4		13.6	0.4	39.7	19.4		31.1	1.1							249.5
Nziguheba 2008	15	15	15	6.5		6.2	0.8	118.3	19.1		16.8	0.5							143.1
Nziguheba 2008	18	46	0	18.3		19.7	0.6	389.9	65.6		44.3	0.9							427
Nziguheba 2008	15	15	15	4.2		5.4	0.5	117.7	20.6		18	0.4							151.3
Nziguheba 2008	8	24	8	6.6		7.7	2.1	180.9	28.3		28.3	1.2							213.2
Nziguheba 2008	9	18	27	6.5		7.1	0.8	165.4	31.7		27.6	0.4							185.1
Nziguheba 2008	12	61	0	6.9		4.4	0.4	114.1	13.9		11.6	0.4							123.8

Source	N	P	K	As	Ba	Cd	Co	Cr	Cu	Mo	Ni	Pb	Sb	Se	Sr	Th	U	V	Zn
Nziguheba 2008	18	46	0	13.7		18.1	0.4	389.9	59.3		49	0.4							389.9
Nziguheba 2008	8	15	15	3.4		7.3	3.5	113.4	34.6		18.5	4.8							236.7
Nziguheba 2008	8	24	8	6.2		10.7	4	160.1	55		27.2	5							284.7
Nziguheba 2008	12	52	0	8.5		0.4	1.6	18.9	3.1		12.1	2.4							8.5
Mean	13.2	21.9	11	9.2	105.8	6.9	11.4	96	26.4	9.5	18.1	5.7	2.2	2.7	738.1	1.7	25.3	26.7	470.5
Median	13	15	12	5.8	50	4.5	1	54.3	16.4	3.2	11.7	1.6	0.8	3	137	1.5	10.3	29	115.1
Minimum	5	2	0	0.4	50	0.3	0.4	1.4	0	0.9	1	0.1	0.1	1	1	0.1	0.1	1	2
Maximum	18	61	30	96.2	430	42.1	212.3	499.3	261	108	194.9	133	18	3	4535	6.8	73.1	82	17700
Samples	82	82	82	79	12	81	57	77	82	25	82	79	17	17	17	17	17	15	82
90th percentiles	**18**	**46**	**20**	**17.4**	**263**	**18**	**9.4**	**252.1**	**55.9**	**16.6**	**37.3**	**5.7**	**5**	**3**	**2649.8**	**3.3**	**63.8**	**56.8**	**339.9**

Table 6 High N fertilisers (N≥19%)

Source	N	P	K	S	As	Cd	Co	Cr	Cu	Ni	Pb	Zn
	%				mg/kg							
Nziguheba 2008	24	14	0	4	11.3	6.7	0.4	114.1	835.1	14.5	2.6	1374
Nziguheba 2008	20	8	8		5.5	4.3	<0.4	66.6	11	8.6	2.2	65.6
Nziguheba 2008	21	6	12		1	0.7	1.2	9.6	2.7	7.7	<0.4	26
Nziguheba 2008	21	6	12		6.3	<0.4	0.9	4.4	7.3	3.1	2.6	15.1
Nziguheba 2008	21	6	12		12.2	<0.4	0.5	3.9	9.5	2.7	3.1	9.1
Nziguheba 2008	20	20	0		4.1	8.8	<0.4	135.8	3	14.9	1	130.8
Nziguheba 2008	22	5	5		9.9	<0.4	2.8	5.5	10.1	2.2	2.8	23.9
Nziguheba 2008	20	3	8		8.4	<0.4	1.2	4.6	9.7	3.3	3.5	1124
Nziguheba 2008	20	4	8		7.3	<0.4	1.4	16.1	4.5	2.8	2.1	7.1
Nziguheba 2008	21	4	8		21.1	<0.4	0.5	3.1	12.8	2	5.3	7.7
Nziguheba 2008	26	4		4	1.4	<0.4	0.6	3.9	2	1.7	0.4	10.8
Nziguheba 2008	21	3	10		1.1	<0.4	0.7	3	0.7	1.5	<0.4	13.3
Nziguheba 2008	27	2	5	5	11.9	<0.4	<0.4	4.8	9.9	2.4	3.1	3
Nziguheba 2008	24	2	5	10	2.2	2.1	<0.4	36.8	7.8	5.2	0.6	39.1
Nziguheba 2008	27	2	5	5	11.3	<0.4	<0.4	4.6	10.6	2.2	3.1	3.1
Nziguheba 2008	24	2	5	10	2	<0.4	0.9	5.2	6.1	2.4	1.6	15.5
Nziguheba 2008	27	2	5	5	9.7	<0.4	0.4	5.6	9.8	2.7	2.7	2.2
Nziguheba 2008	27	3	5	5	2.1	2.2	<0.4	40.8	7.6	6.1	0.5	44.9
Nziguheba 2008	24	2	5	10	1.4	0.8	<0.4	14.3	4.2	2.6	0.7	16.4
Nziguheba 2008	24	2	5	5	2	<0.4	0.8	5.5	5.7	2.4	1.3	14.3
Nziguheba 2008	24	2	5	10	11.6	<0.4	<0.4	2.9	11.5	0.8	3.8	8.3
Nziguheba 2008	27	2	5	5	7	1.3	<0.4	23.7	10.6	4	1.6	30.2
Nziguheba 2008	24	2	5	10	9	<0.4	0.6	5.1	10.1	2.9	3.2	3.7
Nziguheba 2008	27	2	5	5	9.8	<0.4	0.4	5.6	9.7	2.5	2.7	2.3

Source	N	P	K	S	As	Cd	Co	Cr	Cu	Ni	Pb	Zn
Nziguheba 2008	27	2	5	5	14.3	<0.4	<0.4	0.9	10.1	0.4	3.5	4.2
Nziguheba 2008	27	2	5	5	1	<0.4	<0.4	1.2	0.3	0.6	<0.4	0.4
Nziguheba 2008	24	2	5	10	10	<0.4	0.4	0.7	8	0.6	3.4	4.6
Nziguheba 2008	24	2	5	10	8.2	1	<0.4	19.5	11.6	3.2	1.9	26
Nziguheba 2008	27	2	5	5	11.4	<0.4	<0.4	4.3	8.9	2.9	2.9	3.1
Nziguheba 2008	27	2	5	5	10.2	<0.4	<0.4	0.6	6.5	0.3	2.5	2.7
Nziguheba 2008	24	2	5	10	13.7	<0.4	<0.4	0.8	11	0.6	4	5.1
Nziguheba 2008	27	2	5	5	2.9	2.1	<0.4	25.7	5.9	6	0.6	51.9
Nziguheba 2008	24	2	5	10	12.7	<0.4	0.6	5.2	12.6	4	3.7	4.3
Nziguheba 2008	24	2	5	10	9.5	<0.4	0.4	4.2	10.5	3	2.8	7.3
Nziguheba 2008	24	2	5	10	9.5	<0.4	0.6	5.3	12.2	2.8	3.4	5
Nziguheba 2008	27	2	5	5	9.4	0.8	<0.4	14.1	11	3	2.7	21.7
Nziguheba 2008	27	2	5	5	3.1	2.7	<0.4	33	7.4	7.8	0.9	51.9
Nziguheba 2008	27	2	5	5	11.6	<0.4	0.4	1	8.5	0.5	3.4	4.3
Nziguheba 2008	27	2	5	5	8.6	0.9	<0.4	15.2	9.6	3	2.4	22.1
Lottermoser 2009	30	3	14		1	0.11			6.21	2.78	0.53	27.8
Lottermoser 2009	29	0	18		1	0.05			1.22	2.07	2.78	5.5
Mean	24.6	3.4	6.3	6.8	7.5	2.3	0.8	16.8	28.1	3.5	2.4	79
Median	24	2	5	5	8.6	1.3	0.6	5.2	9.5	2.8	2.7	10.8
Minimum	20	0	0	4	1	0.1	0.4	0.6	0.3	0.3	0.4	0.4
Maximum	30	20	18	10	21.1	8.8	2.8	135.8	835.1	14.9	5.3	1374.2
Samples	41	41	40	29	41	15	20	39	41	41	38	41
90th percentiles	27	6	12	10	12.2	5.7	1.2	37.6	11.6	7.7	3.6	51.9

Table 7 90th percentiles

Fertiliser type	N	P	K	S	As	Ba	Cd	Co	Cr	Cu	Mo	Ni	Pb	Sb	Se	Sr	Th	U	V	Zn
			%										mg/kg							
Triple superphosphate (TSP)					11.9		30.6	0.5	283.9	49.6		55.7	17.6							637.4
Other straight phosphate					8.6		13.6		114.7	24.7		35.7	34.7							259.5
Nitrate phosphate (NP)					18.6		26.3	1.8	360.3	46.5		46.6	8.7							399.7
Low N (N<19%)	18	46	20		17.4	263	18	9.4	252	55.9	16.6	37.3	5.7	5	3	2650	3.3	63.8	56.8	340
High N (N≥19%)	27	6	12	10	12.2		5.7	1.2	37.6	11.6		7.7	3.6							51.9

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Abbreviations and acronyms

Ag	silver
AIC	Agricultural Industries Confederation
As	arsenic
Ba	barium
CAN	calcium ammonium nitrate
Cd	cadmium
Co	cobalt
Cr	chromium
Cu	copper
DAP	diammonium phosphate
Defra	Department for Environment, Food and Rural Affairs
F	fluorine
FYM	farmyard manure
GTSP	granular triple superphosphate
Hg	mercury
K	potassium
MAP	monoammonium phosphate
Mo	molybdenum
MOP	muriate of potash
N	nitrogen
Ni	nickel
NiPERA	Nickel Producers Environmental Research Association
NP	nitrate phosphate
P	phosphorus
Pb	lead
PK	phosphate potassium
S	sulphur
Sb	antimony
Se	selenium
Sr	strontium
SSP	single superphosphate
Th	thorium
TSP	triple superphosphate
U	uranium
USEPA	United States Environmental Protection Agency
V	vanadium
Zn	zinc

Appendix 1 Literature search terms

Waste type	Proposed non-waste comparator	Definition of comparator and nutrient composition	Specific key words, synonyms, definitions
Fertiliser derived from organic waste	Organic manures		farmyard manures (FYM), slurry, poultry manures, treated sewage sludge, biosolids
For the application of N. Readily available nitrogen, organic-N, crop available nitrogen	Nitrogen fertilisers	Ammonium nitrate (33.5–34.5% N)	ammonium nitrate,
		Ammonium sulphate (21% N, 60% SO_3)	ammonium sulphate, ammonium sulfate
		Calcium ammonium nitrate or CAN (26–28% N)	calcium ammonium nitrate, CAN
		Urea (46% N)	urea, carbamide, carbonyl diamide, carbonyldiamine, diaminomethanal, diaminomethanone
		Liquid nitrogen solutions (18–30% N)	liquid nitrogen
For the application of P	Phosphate fertilisers	Diammonium phosphate (DAP), $(NH_4)_2HPO_4$ (18% N, 46% P_2O_5)	diammonium phosphate, DAP, diammonium hydrogen phosphate
		Monoammonium phosphate (MAP) (12% N, 52% P_2O_5)	monoammonium phosphate, MAP, ammonium dihydrogen phosphate, ADP
		Triple superphosphate (TSP) (45–46% P_2O_5)	triple superphosphate, TSP
		Superphosphate (SSP), $CaH_4P_2O_8$ (16–20% P_2O_5)	superphosphate, single superphosphate, SSP, calcium dihydrogenphosphate,
		Concentrated superphosphate (CSP) (>25% P_2O_5)	
		Soft ground rock phosphate (27–33% P_2O_5) (>25% P_2O_5)	e.g. Gafsa, Peru,

Waste type	Proposed non-waste comparator	Definition of comparator and nutrient composition	Specific key words, synonyms, definitions
		Partially solubilised rock phosphate (>20% P_2O_5)	
		Rock phosphate (more than 5%)	
		Basic slag (>12% P_2O_5)	Thomas phosphates, Thomas slag
For the application of K and Mg	Potash and magnesium fertilisers	Muriate of potash (MOP) (60% K_2O)	muriate of potash, MOP
		Potassium sulphate (SOP) (50% K_2O, 45% SO_3)	potassium sulphate, potassium sulfate, sulphate of potash
		Potassium nitrate (13% N, 45% K_2O)	
		Kieserite (typically 25% MgO, 50% SO_3)	kieserite, magnesium sulphate
		Epsom salts (16% MgO)	epsom salts, magnesium sulfate, magnesium sulphate
		Kainite (11% K_2O, 5% MgO, 26% Na_2O, 10% SO_3)	kainit
		Calcined magnesite (typically 80% MgO)	
For the application of S	Sulphur fertilisers	Ammonium sulphate (21% N, 60% SO_3)	ammonium sulphate, ammonium sulfate
		Kieserite (typically 52–55% SO_3)	kieserite
		Gypsum (calcium sulphate)	gypsum, calcium sulphate, calcium sulfate, drierite
For the application of micronutrients	Micronutrient fertilisers		
For the application of Na	Sodium fertilisers	In the form of Na_2O	

Taken from RB209 Fertiliser Manual 8th edition, Defra
http://www.defra.gov.uk/publications/files/rb209-fertiliser-manual-110412.pdf
and EU Regulation 2003/2003 (2009)
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CONSLEG:2003R2003:20090420:en:PDF
When a concentration is expressed as >X%, that value is taken from Annex 1 of EU Regulation 2003/2003.

Appendix 2 Results of the literature review

Anecdotally, the fertiliser market is a world one. However, we needed to ascertain the sources of fertiliser used in the UK. Therefore at an early stage we contacted the Agricultural Industries Confederation (Jane Salter), who stated that the main sources of phosphate fertilisers into the UK are Egypt, Israel, Jordan, Morocco & Western Sahara and South Africa (pers. comm.). The properties and contaminant levels within fertilisers vary depending upon the source. We therefore needed to be able to take a view on any weighting to be applied to data we collect based upon their relevance to the UK.

Quality assurance

On reviewing the papers and the data they contained it soon became clear that detailed quality assurance and review was going to be necessary. For instance a consultancy working for the Environment Agency on a different project provided us 36 papers from a literature review they had undertaken purportedly containing chemical analysis data on phosphate rock. Following our review we discarded all but four of them.

Most papers do not contain original data but re-hash those from existing papers. In accordance with the statistical principles detailed in Appendix 3, all duplicate datasets have been discarded.

We have identified some problems with the correct identification of data sources within published papers. Aydin *et al*. (2010) for instance, reference a paper by Baysal *et al*. (2002) to present 'Global pattern of toxic, major, minor elements in phosphate rocks (mg kg^{-1})'. The Baysal *et al*. (2002) paper is actually entitled 'Comparison of microwave digestion procedures for the determination of some elements in asphaltite ash using ICP-AES'. That is the analysis of ash from burning tar sands, and has no relevance to phosphate rock.

One error we identified has often been copied and has found its way into Defra, Environment Agency and USEPA publications. This is that UK phosphate fertilisers contain an average of 654 mg/kg zinc, which is cited to Marks (1996). The Marks paper was never published but we obtained a copy from ADAS. It transpires that 654 is actually the median zinc concentration expressed as mg/kg P_2O_5, i.e. for every kg of phosphate in the fertiliser there are 654 mg of zinc (median (most likely) value), and Marks' mean concentration (of 98 phosphate fertilisers) was actually 150.8 mg/kg. The need for this level of quality assurance not only greatly lengthened the exercise, but also resulted in a smaller dataset than reported elsewhere.

Discussion of the data themselves

Many papers presented summaries of data. Nziguheba (2008) for instance analysed 196 European phosphate fertilisers. Table 8 below is reproduced from Marks (1996) and Table 9 from Nziguheba (2008).

Table 8 Elemental composition of fertilisers (mg/kg) (Marks 1996)

Phosphatic fertilisers					
Element	**Number**	**Range**	**Mean**	**Median**	**St. Dev.**
Arsenic	98	0.5–76.8	6.2	3.5	10.9
Cadmium	98	0.1–41.6	8.1	2.4	10.4
Chromium	98	1.4–637.0	70.3	33.9	102.1
Copper	98	1.4–477.0	28.1	12.4	72.5
Fluorine	98	165–35400	8070	5175	7770
Lead	98	1.0–29.5	2.6	1.0	3.8
Mercury	98	0.01–0.2	0.02	0.01	3.8
Molybdenum	98	0.01–32.5	5.4	2.8	6.7
Nickel	98	0.1–60.4	11.9	8.0	12.2
Selenium	98	0.01–13.1	1.6	0.6	2.6
Zinc	98	2.3–1540	150.8	67.1	223.2

Table 9 Fertiliser weight based (n=196) (Nziguheba 2008)

	Units	**Mean**	**Median**	**P90**	**P95**
Arsenic	mg kg^{-1}	7.6	5.7	14.4	20.9
Cadmium	mg kg^{-1}	7.4	5	21	25.3
Chromium	mg kg^{-1}	89.5	56.2	214	281
Lead	mg kg^{-1}	2.9	2.1	5.4	7.5
Nickel	mg kg^{-1}	14.8	11.3	33.1	47.5
Phosphate	g kg^{-1}	194	156	401	420
Zinc	mg kg^{-1}	166	115	353	516

The two sets of data in Tables 8 and 9 are of the same order, but the statistical descriptors are different. Nziguheba obtained fertiliser samples from 12 different European countries; unfortunately the UK was not one of them. However, the similarity between the two datasets gave us sufficient assurance to use the Nziguheba data for this report.

We contacted NiPERA (the Nickel Producers Environmental Research Association), who funded the Nziguheba work, and they very kindly supplied the raw data for our use in this study. These data were originally published in summary form only by Generose Nziguheba and Eric Smolders in 2008.

Appendix 3 Statistical analysis of data

While extracting the data from published material, care was taken to:

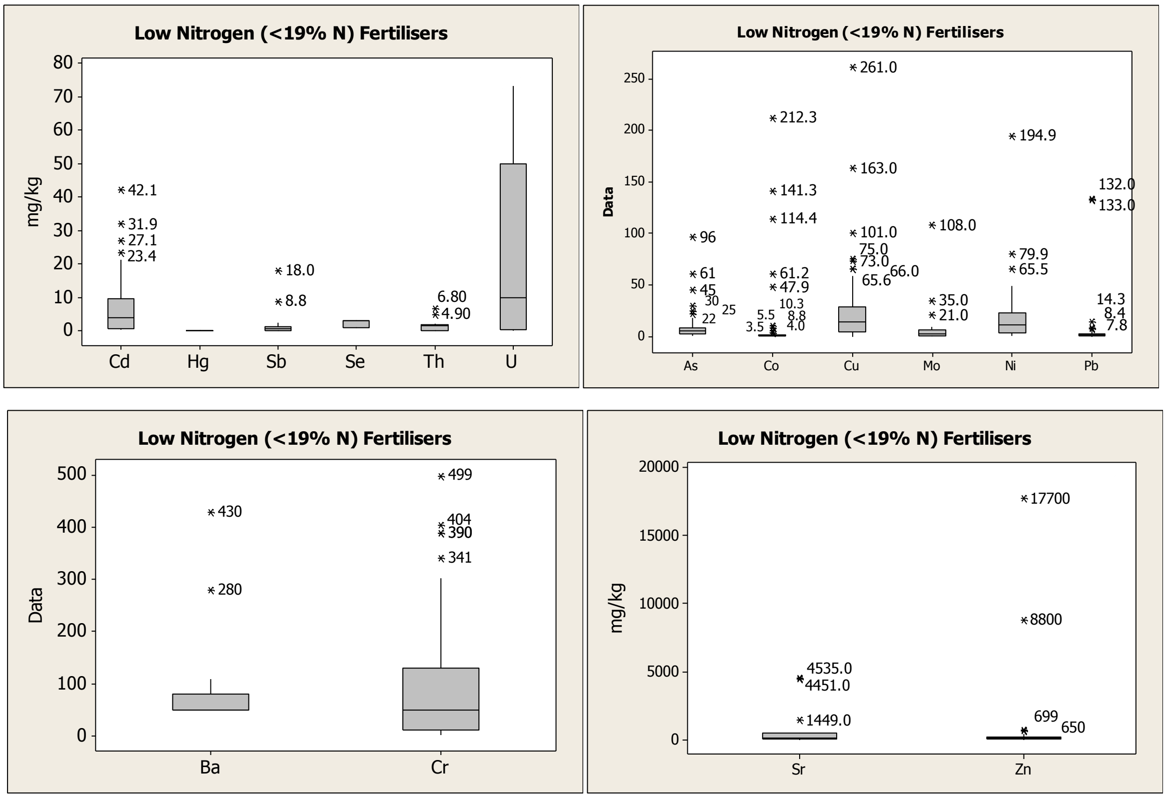
- assess whether the data are applicable to the UK market;
- deal with ‘<’ values and consider using statistical techniques to deal with them;
- make sure each sample is independent of the others, i.e. a sample’s data was not simply a duplicate of another sample’s data separately reported;
- compare data between studies.

Data were assessed using both Excel and Minitab.

All < values were taken as the value themselves. While there were other data with analyses for that particular determinand lower than some of the < values, they were only by an order of magnitude or two. All < values were at least an order of magnitude below the median value.

Box and whiskers plots of the low nitrogen fertilisers data are presented in Figure 1. These diagrams demonstrate the issue of outliers in the datasets, outliers being identified with an asterisk.

Figure 1 Low nitrogen fertilisers (N<19%)



Outliers can adversely affect the statistical analysis by:

- giving serious bias or influence to estimates that may be of less interest;
- increasing the error variance and reducing the power of statistical tests;
- decreasing normality (if non-random) and altering the odds of Type I and II errors.

In addition we are interested in providing a reasonable dataset for comparison purposes. As the data are taken from a variety of papers with different analytical suites, the number of samples for each determinand varies.

Where we consider there is sufficient sample size (n ≥10) to calculate a 90th percentile of the data we have done so.

We were unable to discover any data on organic contaminants in primary manufactured fertilisers in the searches conducted. While some dioxin data have been identified (Rogowski 1999, USEPA 1999) they are from the analysis of waste-derived fertilisers or soil improvers. For the purposes of non-waste comparators it is recommended we assume that primary manufactured fertilisers contain organic contaminants at a level below an appropriate limit of detection.

Full and trimmed data are presented in Tables 1 to 6.

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