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Review of evidence on organic material nutrient supply

John Williams[1], Dan Munro[1], Lizzie Sagoo[1] and Fiona Nicholson[2]

[1]ADAS Boxworth, Battlegate Road, Boxworth, Cambridgeshire, UK, CB23 4NN

[2]ADAS Gleadthorpe, Meden Vale, Mansfield, Nottinghamshire, UK, NG20 9PD

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1. Abstract

The Crop Nutrient Management Partnership (CNMP) was set up by AHDB to review and revise the “Fertiliser Manual (RB209)” and produce a new “Nutrient Management Guide (RB209)” for release in May 2017. The main aim of this work package was to review organic material analysis data published since the 8th edition of RB209 to identify whether changes to the guidance on organic material nutrient supply was justified.

For livestock manures, analysis data from 848 manure samples collected since 2008 were collated to provide a database of manure nutrient contents. The data came from Defra, LINK and AHDB funded research projects and from commercial samples collected by Slurrywise/Lancrop. Relationships between dry matter, total N, total P_2O_5, K_2O, MgO and SO_3 were plotted for the slurries and poultry manure data using linear regression (Genstat). The equations were used to derive nutrient content values for contrasting slurry/poultry manure dry matter contents which were compared with those included in the 8th edition of RB209. For farmyard manures, statistical t-tests were used to determine whether there were significant differences between the nutrient contents of the ‘new’ data and the old RB209 database for each manure type.

Information on total N and P_2O_5 contents of biosolids products applied to agricultural land in England and Wales was obtained from the UK Water Industry Biosolids Network. The information was supplemented with data from research projects to identify whether biosolid products and nutrient contents listed in RB209 reflected current industry practice.

A database consisting of analysis data from around 2,000 compost, 1,300 food-based digestate and 800 farm-sourced digestate samples was provided by Renewable Energy Association Limited’s Biofertiliser Certification Scheme and NRM laboratories. The database was used to compare typical dry matter and nutrient content for green and green food compost in the 8th edition of RB209 with more up to date data. The database was used to derive typical dry matter and nutrient contents for whole, separated liquid and separated fibre fractions of food and farm-sourced digestate.

Information from AHDB and Water Industry Funded research (AHDB report RD-2008-3606) was reviewed to provide improved guidance on the crop available sulphur supply from contrasting livestock manures and biosolids types and application timings.

The outputs from the review suggest:

(i) Livestock manures section

- No changes to existing cattle slurry dry matter, total N, readily available N, total P_2O_5, total MgO and total SO_3 figures. Reduce K_2O figures (by *c.*0.7 kg/m^3) to reflect lower concentrations observed in the ‘new’ dataset.

- No change to cattle FYM dry matter, total N, readily available N, total P_2O_5, total MgO and total SO_3 figures. Update total cattle FYM K_2O figures from 8.0 kg/t K_2O to 9.0 kg/t K_2O to reflect the higher values observed in the 'new' dataset.
- No change to pig slurry dry matter, total N, readily available N, total MgO and total SO_3 figures.
- Reduce pig slurry P_2O_5 and K_2O figures to reflect the lower values derived from the RB209 2016 database which reflect changes in diets since the 8th edition of RB209 was published.
- No change to pig FYM dry matter, total N, readily available N, total P_2O_5, K_2O, total MgO and total SO_3 figures.
- Replace layer manure and broiler litter tables with one poultry manure table giving nutrient contents based on the relationships between dry matter and nutrient content.
- Update information on the readily available nitrogen (RAN) composition of poultry manure to reflect increased uric acid N concentrations.
- Reduce poultry manure total P_2O_5 concentrations (by *c.*8 kg/t at 60% dry matter) to reflect reduction caused by increased use of phytase in diets and consequent enhanced feed P use efficiency.
- Increase total K_2O concentrations (by *c.*3 kg/t at 60% DM) to reflect increases caused by changes in feed formulations.
- Replace existing information on the nutrient content of horse FYM with more robust information collected in Defra project WQ1568.
- Small changes to MgO and SO_3 contents of duck and sheep FYM.

(ii) Biosolids products

- Remove the standard values for liquid digested biosolids due to the small volume of material applied to land (less than 1% of total biosolids).
- Change dry matter and total P_2O_5 content of all biosolids products to those reported by the UK Water Industry's Biosolids network (2013).
- Update figures for biosolids sulphur content with data from LINK project 0988.

(iii) Anaerobic digesate and composts

- Update RB209 with values for the dry matter and nutrient content for anaerobic digestate according to feedstock and treatment.
- Provide pie charts describing whole digestate and separated digestate fibre RAN contents.

- Add information on the crop available nitrogen supply from contrasting digestate application timings, by providing more detailed guidance in the text based on the findings of the WRAP funded ‘Digestate and Compost in Agriculture’ (DC-*Agri*) project.
- Update total P_2O_5 and SO_3 values for green/food and K_2O values in green compost to reflect the higher values in the ‘new’ dataset.

(iv) Organic material sulphur supply

- Update RB209 to include information on sulphur supply from contrasting manure types and application timings which is currently available in AHDBCereals & Oilseeds Information sheet 28.

(v) Nutrient content tables

- The readily available nitrogen (RAN) content column should be removed from the nitrogen content tables and replaced with asterisks and footnotes to indicate high RAN manures.
- Emphasise that the nutrient content tables provide good guidance in the absence of manure analysis.

The provision of data from NRM Laboratories, the BioFertiliser Certification Scheme, SlurryWise Contractors, Lancrop Laboratories and the UK Water Industry’s Biosolids Network is gratefully acknowledged.

2. Introduction

Over 100 million tonnes of organic materials (i.e. livestock manure, biosolids, compost, digestate, paper crumble and other ‘industrial’ wastes) are applied to land each year. These applications supply an estimated 460 kt of nitrogen (N), 300 kt of phosphate (P_2O_5) and 428 kt of potash (K_2O), and are estimated to be worth in the region of £500 million (Defra, 2008; Water UK, 2011; WRAP, 2013; WRAP, 2014). Organic materials also supply sulphur, magnesium and micronutrients, thus reducing the need for manufactured fertiliser applications to supply sufficient nutrients to satisfy optimum crop demand.

The data on livestock manure nutrient contents published in the 8th edition of Defra’s “Fertiliser Manual (RB209)” (Anon, 2010) was collated by ADAS in 2003, based on data from the Manure ANalysis DatabasE (MANDE) project (Defra project NT2006). Since then, changes to livestock management practices likely to affect the nutrient concentrations of livestock manures applied to land have included:

- Extended use of phytase in pig and poultry diets to improve feed phosphate utilisation;
- Improvements to pig feed conversion ratios, together with reductions in the crude protein content of pig diets and the use of supplementary synthetic amino acids
- Phasing out of battery cages and the move to on-belt removal or deep litter systems for laying hens which has reduced the amount of deep-pit layer manure produced
- Changes to cattle feeding regimes as a result of longer housing periods and the associated reduction in grazing

Changes in biosolids production technologies, in particular enhanced phosphate removal from waste water and advanced chemical and thermal digestion processes may have impacted on the nutrient content of biosolids products. In addition, the significant increase in the bio-energy sector, which has seen digestate volumes applied to land from less than 0.5 million tonnes in 2010 to over 2 million tonnes in 2014 has led to the need for improved guidance on the nutrient content of anaerobic digestate. The increase in anaerobic digestion has also impacted on the feedstocks available for composting; consequently there was a need to ensure that the figures for the nutrient content of composts were up to date and representative of current practice. In addition, the increasing prevalence of sulphur deficiency in agricultural crops required improved advice on the sulphur supply from contrasting organic material applications.

2.1. Aims and objectives:

To review livestock manure and other organic material analysis data and information on manure nutrient supply published since the 8th edition of RB209 to identify whether changes to the guidance on manure nutrient supply were justified. Specific objectives were:

- To review livestock manure analysis data for cattle and pig slurry, cattle, pig, duck, sheep and goat FYM and poultry manure in RB209 and identify any changes required to reflect recent changes in farm practice
- To review information from the UK water Industry's Biosolids Network and R&D projects on the types of biosolids products applied to land and their nutrient contents to ensure the information reported in the fertiliser manual reflects current practice
- To review analysis data on the nutrient and dry matter contents of food-based and farm-sourced digestate and identify whether the inclusion of information for whole, separated fibre and separated liquid digestate products is justified.
- To review recent research on sulphur availability from organic materials and provide improved guidance on organic material sulphur supply.

3. Methodology

3.1. Livestock manures

Manure analysis data from samples collected since 2008 were collated to provide a new RB209 2016 database of manure nutrient contents (Table 1). The majority of data came from Defra, LINK and AHDB funded research projects where samples were taken by scientific research staff according to standard operating procedures. Additional data were provided by Slurrywise contractors and Lancrop laboratories which came from samples collected by contractors, farmers and agronomists.

All samples were analysed for total nitrogen (N), total phosphate (P_2O_5), total potash (K_2O) and total magnesium (MgO). Samples from Defra/LINK and AHDB research projects were also analysed for total sulphur (as SO_3) and ammonium-N (NH_4-N). Poultry manure (i.e. broiler and turkey litter and layer manure) samples were analysed for uric-acid-N and FYM samples were analysed for nitrate-N (NO_3-N).

Relationships between dry matter, total N, total P_2O_5, K_2O, MgO and SO_3 were plotted for the slurries and poultry manure data included in the RB209 2016 database using linear regression (Genstat). Parallel lines analysis was used to identify differences in the relationships in dry matter and nutrient content between the two databases. The equations were used to derive nutrient content values for contrasting slurry/poultry manure dry matter contents that were compared with those included in the 8th edition of RB209.

Two sample t-tests were used to determine whether there were significant differences between the nutrient contents of cattle, pig, sheep and horse FYM in the RB209 2016 and RB209 8th edition databases.

3.2. Biosolids

A database of total N and P_2O_5 contents of biosolids products applied to agricultural land in England and Wales was obtained from the UK Water Industry Biosolids Network. The database was supplemented with data from Water Industry/AHDB research project RD-2008-3606 and LINK project 0988 to include information on total K_2O, total MgO and total SO_3 content for contrasting biosolids products. The database was interrogated to identify whether there was a need to change the biosolid product types listed in RB209 to reflect current practice and whether the information on dry matter and nutrient products for the different products needed updating.

3.3. Anaerobic digestate and compost

The feedstock used in the bio-energy production process has a significant impact on the nutrient content of anaerobic digestate. Typically, anaerobic digestate from industrial bio-energy plants that use food waste will have higher nutrient contents than 'on-farm' digesters where manure and crops are used as feedstocks. In addition, there is increasing use of separation technologies where whole digestate is separated into liquid and solid fractions to reduce storage, handling and transportation costs. The nutrient concentrations and dry matter contents of the separated liquid and fibre fractions are likely to be significantly different from the whole digestate. Similarly, for composts that include food waste the nutrient content is likely to be different from plant based green compost materials.

A database consisting of analysis data from around 2,000 compost, 1,200 food-based digestate and 800 farm-sourced digestate samples was provided by Renewable Energy Association Limited's Biofertiliser Certification Scheme and NRM laboratories. The database was interrogated to provide typical dry matter, total N, ammonium-N, total P_2O_5, K_2O, SO_3 and MgO contents of whole, separated liquid and separated fibre fractions of food-based and farm-sourced digestate and to identify whether the existing RB209 information on dry matter and nutrient contents for green and green/food composts needed updating.

3.4. Organic material sulphur supply

Information from AHDB and Water Industry Funded research (AHDB report RD-2008-3606) was reviewed to provide improved guidance on the crop available sulphur supply from contrasting livestock manures and biosolids types and application timings.

3.5. Updates to Industrial wastes section

Following discussions with representatives of the Environment Agency it was apparent that there was no suitable information available to update the 'Industrial Wastes' section of RB209. However, a number of minor changes to the text to ensure consistency with current regulations and signposting to relevant information were suggested and these will be included in the RB209 revision document.

Table 1. Number and source of manure analyses used to compile the RB209 2016 livestock manure database.

	Defra projects							LINK	AHDB Cereals & Oilseeds Projects		Slurrywise/ Lancrop	Total
Manure type	**WQ0118**	**SP0530**	**AC0116**	**AC0213**	**WQ0140**	**SCF0202**	**WT1568**	**LK0988**	**216-0007**	**PR522**		
Cattle slurry	30	1	13	2	2	-	33	71	1	3	79	235
Pig Slurry	8	-	1	-	-	16	-	75	-	3	115	218
Poultry manure	4	-	4	-	-	65	-	-	-	6	-	79
Cattle FYM	2	2	7	-	-	-	60	101	2	5	-	179
Pig FYM	3	-	1	-	-	26	-	68	-	6	-	104
Sheep FYM	-	-	-	-	-	-	8	-	-	-	-	8
Duck FYM	-	-	-	-	-	6	-	-	-	-	-	6
Goat FYM	-	-	-	-	-	-	6	-	-	-	-	6
Horse FYM	-	-	-	-	-	-	6	-	-	-	-	6

4. Results

4.1. Livestock manures

4.1.1. Cattle slurry

Analysis of the RB209 2016 database (Table 2) showed that cattle slurry DM content ranged from 0.2% to 17.2% (mean 6.2 %); total N from 0.1 kg/m^3 to 6.5 kg/m^3 (mean 2.6 kg/m^3); total P_2O_5 from <0.1kg/m^3 to 3.8 kg/m^3 (mean 1.0 kg/m^3); total K_2O from 0.10 kg/m^3 to 7.0 kg/m^3 (mean 2.6 kg/m^3); total MgO from <0.1 kg/m^3 to 2.3 kg/m^3 (mean 0.7 kg/m^3); and total SO_3 from 0.1 kg/m^3 to 2.7 kg/m^3 (mean 0.7 kg/m^3). Slurry ammonium-N content ranged between 0.1-3.1 kg/m^3 (mean 1.1 kg/m^3) and accounted for 44% of total N content which was similar to the proportion of readily available N to total N in the RB209 8th edition database.

Table 2. Cattle slurry nutrient composition RB209 2016 database.

	Dry matter* (%)	Total N (kg/m^3)*	Ammonium-N (kg/m^3)**	Total P_2O_5 (kg/m^3)*	Total K_2O (kg/m^3)*	Total MgO (kg/m^3)*	Total SO_3 (kg/m^3)**
Average	6.2	2.6	1.0	1.0	2.6	0.7	0.7
Median	5.5	2.5	1.0	1.0	2.4	0.6	0.6
Maximum	17.2	6.5	3.1	3.8	7.0	2.3	2.7
Minimum	0.2	0.1	0.1	<0.1	0.1	<0.1	0.1

** database comprised of 235 analysis results*

*** database comprised of 158 analysis results*

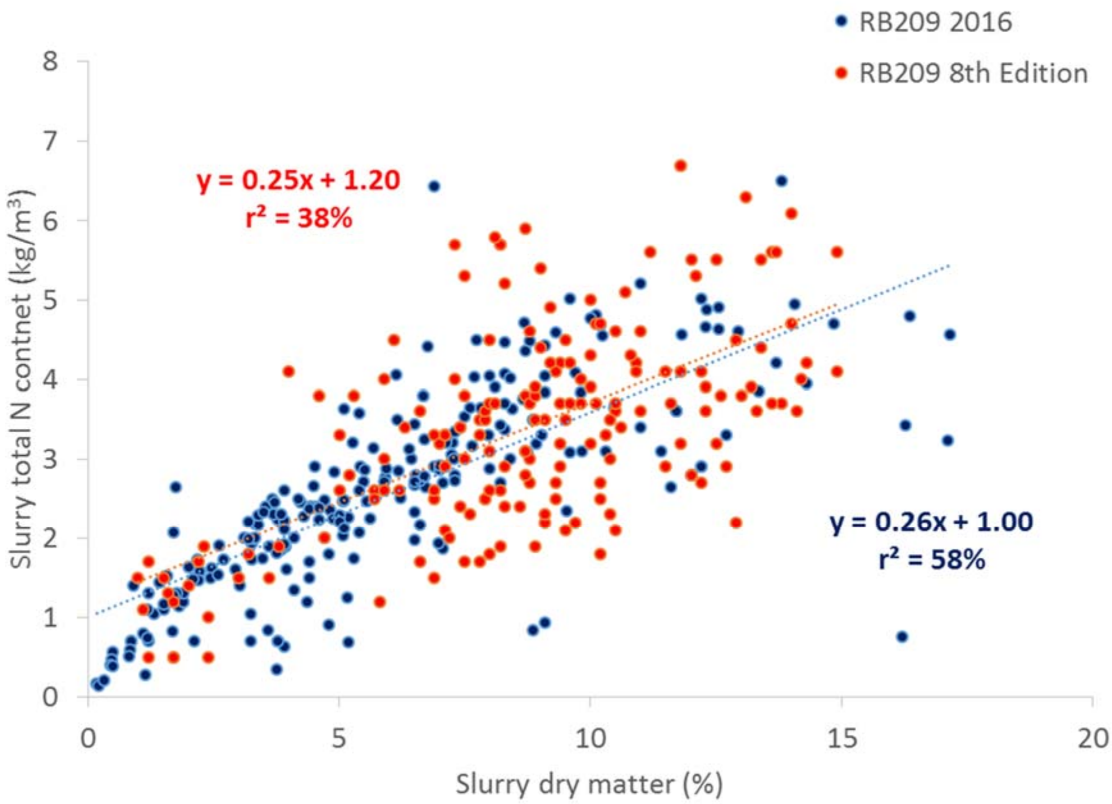

Figure 1. Comparison of relationships between cattle slurry dry matter and total N content for the RB209 8th edition and RB209 2016 livestock manure nutrient content databases.

A comparison of the relationship between slurry dry matter and total N content from the RB209 2016 manure and RB209 8th edition databases (Figure 1), showed no difference between the two datasets (*P* >0.05). The relationship was more robust for the RB209 2016 dataset (60% of the variation accounted for) than for the RB209 8th edition dataset (37% of the variation accounted for).

Table 3. Relationships between nutrient (kg/m^3) and dry matter (DM %) contents of cattle slurry in the RB209 2016 and RB209 8th edition databases.

RB209 8th edition	RB209 2016
N = 1.18 + 0.25 DM (n=179; r^2=37%)	N = 1.00+ 0.26 DM (n=235; r^2=60%)
NH_4-N = 0.80 + 0.08 DM (n=183; r^2=8%)	NH_4-N = 0.75 + 0.05 DM (n=156); r^2=12%)
P_2O_5 = 0.30 + 0.15 DM (n=187; r^2=38%)	P_2O_5 = 0.25+ 0.13 DM (n=235; r^2=50%)
K_2O = 1.84 + 0.25 DM (n=187; r^2=0.12)	K_2O = 1.25 + 0.22 DM (n=235; r^2=36%)
SO_3 = 0.02 + 0.11 DM (n= 92; r^2=0.84)	SO_3 = 0.15 + 0.1 DM (n=156; r^2=65%)
MgO = 0.01 + 0.09 DM (n 48; r^2 = 61)	MgO = 0.15 + 0.09 DM (n=235; r^2=62%)

Parallel line regression analysis also showed that the relationships between slurry dry matter content and total P_2O_5, SO_3 and MgO contents were not different for the two data sets. (Table 3). However, the data analysis suggested the relationship between slurry dry matter and K_2O content was different (P<0.01) for the two datasets with lower slurry K_2O concentrations measured in the 2016 data.

A comparison of nutrient contents calculated using the regression equations derived from the 2016 dataset and the RB209 8th edition dataset are presented in Tables 4 and 5. The data show that there is little or no difference in cattle slurry total N, ammonium-N, total P_2O_5, total MgO and total SO_3 contents calculated from the different datasets. The total K_2O content calculated using the RB209 2016 dataset was 0.7 kg/t (15-30%) lower than the RB209 8th edition for all dry matter contents.

Table 4. Comparison of cattle slurry total N and ammonium N contents derived from RB209 8th edition and RB209 2016 manure databases

Dry matter (%)	Total N (kg/m^3)		Ammonium N (kg/m^3)	
	RB209 8th edition	RB209 2016	RB209 8th edition	RB209 2016
2	1.6	1.5	0.9	0.8
6	2.6	2.6	1.2	1.0
10	3.6	3.6	1.3	1.2

Table 5. Comparison of cattle slurry total P_2O_5, K_2O, MgO and SO_3 contents derived from RB209 8th edition and RB209 2016 manure databases.

Dry matter (%)	Total P_2O_5		Total K_2O		Total MgO		Total SO_3	
	8th edition	2016	8th edition	2016	8th edition	2016	8th edition	2016
2	0.6	0.5	2.4	1.7	0.2	0.3	0.3	0.3
6	1.2	1.1	3.2	2.5	0.6	0.7	0.7	0.7
10	1.8	1.6	4.0	3.4	0.9	1.0	1.0	1.1

4.1.2. Cattle FYM

Two sample t-tests showed that there were no difference in cattle FYM total P_2O_5 and MgO contents between the RB209 8th edition and 2016 manure datasets (Table 6). Two-sample *t*-test results indicated that mean DM, total N and total SO_3 contents in the 2016 dataset were higher (P<0.05) than in the RB209 8th edition database. However, the median values for total dry matter and total N in the 2016 dataset were lower, and for total SO_3 content, similar to the figures derived from the

RB209 8th edition dataset, indicating that overall there was no significant difference in cattle FYM dry matter, total N or sulphur content between the two datasets.

Cattle FYM RAN content of old FYM was the same for both datasets, whilst RAN content of fresh cattle FYM in the 2016 dataset was 0.7 kg/t compared with 1.2 kg/t in the 8th edition RB209 dataset. There was some evidence to suggest that cattle FYM total K_2O content had increased since the RB209 8th edition database was compiled. Two sample *t*-tests showed that the mean total K_2O content of cattle FYM samples in the 2016 dataset (9.4 kg/t) were significantly ($P<0.001$) greater than the RB209 8th edition value (8.0 kg/t). Similarly, the median value of the 2016 dataset was 8.5 kg/t K_2O, which further indicated that there was a difference in cattle FYM K_2O content between the two databases. The increased K_2O content of cattle FYM may reflect increases in the amount of straw used for cattle bedding in response to animal welfare requirements.

Table 6. Comparison of the 2016 and RB209 8th edition datasets: cattle FYM dry matter and nutrient contents (fresh weight basis)

	RB209 8th edition	**RB209 2016 database: n=179 (DM,N), n=36 (Old RAN), n=23 (Fresh RAN) n=174 (P_2O_5,K_2O,SO_3 MgO)**		
		Mean*	**Median**	**Range**
Dry matter (%)	25	26.4 (*P<0.001*)	23.1	14.5-73.4
Total N (kg/t)	6.0	6.7 (*P<0.05)*	5.8	1.5-21.3
RAN (kg/t)[1]	0.6 (old)[2] 1.2 (fresh)[3]	0.6 0.7		
Total P_2O_5 (kg/t)	3.2	3.4 (*NS)*	2.9	0.9-12.7
Total K_2O (kg/t)	8.0	9.4 (*P<0.05*)	8.5	1.1-34.9
Total SO_3 (kg/t)	2.4	2.9 (*P<0.001*)	2.5	0.9-8.3
Total MgO (kg/t)	1.8	2.0 (*NS)*	1.8	0.4-7.4

[1]RAN is the N in the ammonium-N and nitrate-N form.

[2]Old FYM is FYM that has been stored for 3 months or more (36 samples); *t*-test comparison not undertaken.

[3]Fresh FYM is FYM that is spread straight from the building (23 samples); *t*-test comparison not undertaken.

*The *p* value (in brackets) indicates whether the updated mean value is significantly different from the 8th Edition RB209 value; *ns*= not significant.

4.1.3. Pig slurry

Analysis of the RB209 2016 database (Table 7) showed that pig slurry DM content ranged from 0.3% to 11.8% (mean 2.8 %); total N from 0.4 kg/m^3 to 9.2 kg/m^3 (mean 3.3 kg/m^3); total P_2O_5 from <0.1kg/m^3 to 6.5 kg/m^3 (mean 1.1 kg/m^3); total K_2O from <0.1 $kg/m^3$to 6.7 kg/m^3 (mean 2.2 kg/m^3); total MgO from <0.1 kg/m^3 to 2.6 kg/m^3 (mean 0.4 kg/m^3); and total SO_3 from <0.1 kg/m^3 to 3.3 kg/m^3

(mean 0.8 kg/m³). Slurry ammonium-N content ranged between 0.2-4.8 kg/m³ (mean 2.3 kg/m³) and accounted for 70% of total N content which was similar to the proportion of readily available N to total N in the RB209 8th edition database.

Table 7. Pig slurry nutrient composition 2016 RB209 database.

	Dry matter* (%)	Total N (kg/m³)*	Ammonium-N (kg/m³)**	Total P_2O_5 (kg/m³)*	Total K_2O (kg/m³)*	Total MgO (kg/m³)*	Total SO_3 (kg/m³)**
Average	2.8	3.3	2.3	1.1	2.2	0.4	0.8
Median	2.1	3.2	2.3	0.7	2.0	0.3	0.6
Maximum	11.8	9.2	4.8	6.5	6.7	2.6	3.3
Minimum	0.3	0.4	0.2	<0.1	<0.1	<0.1	<0.1

A comparison of the relationship between slurry dry matter and total N content of the RB209 2016 database and the RB209 8th edition database (Figure 2), showed that the intercept and slope of the line were very similar. As was the case for cattle slurry, a comparison of the regression equations derived from each dataset showed that the relationships between slurry dry matter content and all other nutrient contents were very similar (Table 8).

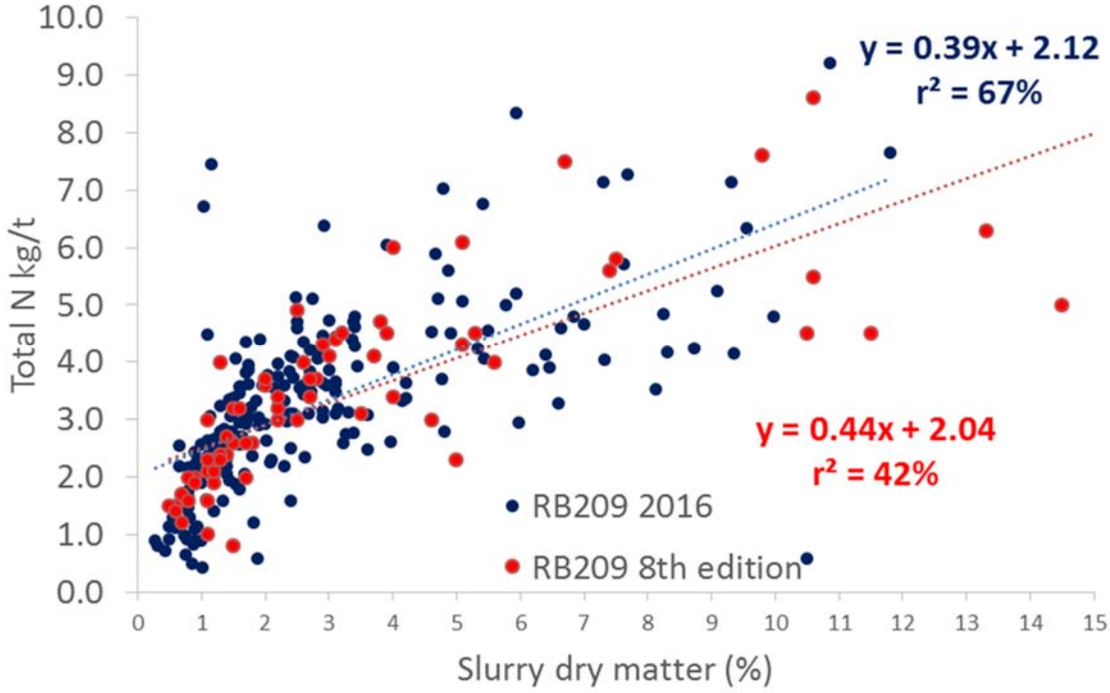

Figure 2. Comparison of relationships between pig slurry dry matter and total N content for the RB209 8th edition and RB209 2016 livestock manure nutrient content databases.

As was the case with cattle slurry, regression analysis also showed that the relationships between slurry dry matter content and all other nutrient contents were similar for both the RB209 2016 and RB209 8th edition datasets (Table 8).

Table 8. Relationships between nutrient (kg/m^3) and dry matter (DM %) contents of pig slurry in the RB209 2016 and RB209 8th edition databases.

RB209 8th Edition	RB209 2016
Linear Regression	**Linear Regression**
N = 2.12 + 0.39 DM (n=71; r^2=67%)	N = 2.04 + 0.44 DM (n=217 r^2 = 42%)
RAN = 1.87 + 0.12 DM (n=74; r^2=20%)	RAN = 1.94 + 0.12 DM (n=103; r^2=15%)
P_2O_5 = 0.20 + 0.40 DM (n=75; r^2=71%)	P_2O_5 = 0.04 + 0.36 DM (n=217, r2 =55%)
K_2O = 1.75 + 0.17 DM (n=75; r^2=29%)	K_2O = 1.44 + 0.20 DM (n=217; r^2=19%)
SO_3 = 0.46 + 0.12 DM (n=17; r^2=65%)	SO_3 = 0.27 + 0.16 DM (n=104; r^2=0.61)
MgO = 0.03 + 0.18 DM (n=15; r^2=81%)	K_2O = 0.05 + 0.15 DM (n=217; r^2=52%)

As was the case for cattle slurry, there was little or no difference in pig slurry total N, ammonium-N, MgO and SO_3 contents between the two datasets (Tables 9 and 10). However, pig slurry total P_2O_5 and total K_2O contents derived from the RB209 2016 database were consistently lower (by *c.*20% for P_2O_5 and *c.*10% for K_2O) than the values in the 8th edition of RB209, which may reflect changes in pig diets with reduced levels of P and K in pig feed since the RB209 8th edition manure analysis data was collected.

Table 9. Comparison of pig slurry total N and ammonium N contents included in the 8th edition of RB209 and calculated from the RB209 2016 database.

Dry matter (%)	**Total N (kg/m^3)**		**Ammonium N (kg/m^3)**	
	8th edition	RB209 2016	8th edition	RB209 2016
2	3.0	2.5	2.2	2.5
4	3.6	3.8	2.5	2.8
6	4.4	4.7	2.8	2.9

Table 10. Comparison of pig slurry total P_2O_5, K_2O, MgO and SO_3 contents included in the 8th edition of RB209 and calculated from the RB209 2016 database.

Dry matter (%)	Total P_2O_5		Total K_2O		Total MgO		Total SO_3	
	8th edition	RB209 2016	8th edition	RB209 2016	8th edition	RB209 2016	8th edition	RB209 2016
2	1.0	0.8	2.0	1.8	0.4	0.4	0.4	0.3
4	1.8	1.5	2.4	2.2	0.7	0.7	0.7	0.6
6	2.6	2.2	2.8	2.6	1.0	1.0	1.0	0.9

Overall recommendation:

- No change to pig slurry dry matter, total N, readily available N, total MgO and total SO_3 figures
- At the Livestock Technical Working Group Meeting on 26th April 2016, it was recommended that the readily available nitrogen content column should be removed from the nitrogen content tables and replaced with asterisks and footnotes to indicate high RAN manures.
- Emphasise that the nutrient content tables provide good guidance in the absence of manure analysis.
- Change pig slurry P_2O_5 and K_2O figures to the lower values derived from the RB209 2016 database, which reflect changes in diets since the 8th edition of RB209 was published.

4.1.4. Pig FYM

A review carried out as part of Defra project SCF0202 compared the nutrient contents of 104 pig FYM samples collected in 2014 with the database used for the RB209 8th edition (Table 11). The review reported that neither the DM content nor the nutrient concentrations of the more recent pig FYM samples were significantly different (p>0.05) from the values published in the 8th edition of RB209. As a result, the SCF0202 review suggested that there was no justification for updating the typical nutrient values for pig FYM.

Table 11. Dry matter and nutrient contents of pig FYM (fresh weight basis).

Manure property	RB209 8th edition	Updated data (n=104)		
		Mean*	Median	Range
Dry matter (%)	25	24 (*ns*)	22	12-51
Total N (kg/t)	7.0	7.7 (*ns*)	7.7	1.0-21
RAN (kg/t)[1]	1.0 (old)[2] 1.8 (fresh)[3]	0.8[2] 1.8[3]	- -	- -
Total P_2O_5 (kg/t)	6.0	5.7 (*ns*)	5.2	0.8-22
Total K_2O (kg/t)	8.0	7.4 (*ns*)	6.5	1.0-26
Total SO_3 (kg/t)	3.4	3.9 (*ns*)	3.3	0.7-12
Total MgO (kg/t)	1.8	2.1 (*ns*)	2.0	0.4-7.9

[1]RAN is N in the ammonium-N and nitrate-N forms.
[2]Old FYM is FYM that has been stored for 3 months or more (11 samples); *t*-test comparison not undertaken.
[3]Fresh FYM is FYM that is spread straight from the building (16 samples); *t*-test comparison not undertaken.
*The *p* value (in brackets) indicates whether the updated mean value is significantly different from the RB209 8th edition value; *ns*= not significant.

Recommendation:

- No change to pig FYM dry matter, total N, readily available N, total P_2O_5, K_2O, total MgO and total SO_3 figures.

4.1.5. Poultry manures

(i) Layer manure

Work carried out as part of Defra project SCF0202 compared the nutrient contents of 31 layer manure samples collected in 2014 with the values in the 8th edition of RB209 (Table 12). The comparison indicated that the mean DM content was significantly (P<0.001) greater in the recent samples (48%, compared with 35% RB209 8th edition). The increase in dry matter content is likely to reflect changes in manure management practices that have occurred since the database for the 8th edition of RB209 was compiled; in particular, the change to on-belt manure removal systems, which produce drier layer manure than deep pit hosing systems.

There was a wide range of layer manure DM contents (22-85%) reflecting the different housing/production systems from which the manures were collected (including cage systems with deep pit or belt-scraped manure removal systems, and free range birds).

Table 12. Dry matter and nutrient contents of layer manure (fresh weight basis).

Manure property	Current RB209	Recent data from Defra project SCF0202 (n=31)		
		Mean*	**Median**	**Range**
Dry matter (%)	35	48 (*P<0.001*)	44	22-85
Total N (kg/t)	19	21 (*ns*)	19	9.1-40
Ammonium-N (kg/t)	6.0	3.5 (*P<0.001*)	3.4	0.9-6.9
Uric acid-N (kg/t)	3.0	4.5 (*P<0.05*)**	3.8	0-15.8
RAN (kg/t)[1]	9.5	8.2 (*ns*)	7.1	3.5-17
Total P_2O_5 (kg/t)	14	15 (*ns*)	14	6.8-27
Total K_2O (kg/t)	9.5	15 (*P<0.001*)	15	6.8-25
Total SO_3 (kg/t)	4.0	5.7 (*P<0.001*)	5.4	2.3-9.9
Total MgO (kg/t)	2.6	4.4 (*P<0.001*)	3.8	1.9-7.5

[1]RAN is the N in the ammonium-N and uric acid-N forms. *Note: the value given in RB209 is not the same as the sum of the ammonium-N and uric acid-N values in the RB 209 8th edition database.*

*The *p* value (in brackets) indicates whether the updated mean value is significantly different from the RB209 8th edition value; *ns*= not significant.

***t*-test conducted on log transformed data.

Despite the increase in DM content, layer manure total N, RAN and P_2O_5 concentrations in the recent samples remained similar ($p>0.05$) to the 8th edition RB209 values at 21, 8.2 and 15 kg/t, respectively. However, the composition of the RAN had significantly changed, with the ammonium-N concentration decreasing from 6.0 to 3.5 kg/t and the uric acid-N concentration increasing from 3.0 to 4.5 kg/t. Thus a greater proportion of the RAN was in the form of uric acid-N, probably because less N had been hydrolysed to the ammonium form due to the higher DM content of the manures. The potash, sulphur and magnesium concentrations in the recent samples all increased significantly ($P<0.001$) compared to the RB209 (8th edition) published values, which is in line with the increase in DM content.

(ii) Broiler litter

Information reported in Defra project SCF0202 compared the nutrient contents of 48 broiler/turkey samples taken in 2014 with RB209 (8th edition) values (Table 13). The comparison indicates that there has been no significant change ($P>0.05$) in the DM, total N, RAN or sulphur concentrations.

Table 13. Dry matter and nutrient contents of broiler/turkey litter (fresh weight basis).

Manure property	RB209 8th edition	Recent data from Defra project SCF0202 (n=48)		
		Mean*	Median	Range
Dry matter (%)	60	57 (*ns*)	56	39-80
Total N (kg/t)	30	28 (*ns*)	29	5.5-43
Ammonium-N (kg/t)	5.7	4.0 (*P<0.001*)	4.2	0.3-9.0
Uric acid-N (kg/t)	3.9	5.0 (*P<0.05*)**	5.1	0-10.9
RAN (kg/t)[1]	10.5	9.1 (*ns*)	10.0	0.1-14
Total P_2O_5 (kg/t)	25	15 (*P<0.001*)	16	6.0-25
Total K_2O (kg/t)	18	21 (*P<0.05*)	20	4.9-29
Total SO_3 (kg/t)	8.0	8.2(*ns*)	8.3	2.0-12
Total MgO (kg/t)	4.4	5.8 (*P<0.001*)	5.6	3.6-8.6

[1]RAN is the N in the ammonium-N and uric acid-N forms. *Note: the value given in RB209 is not the same as the sum of the ammonium-N and uric acid-N values in the RB 209 8th edition database.*

*The *P* value (in brackets) indicates whether the updated mean value is significantly different from the RB209 8th edition value; *ns*= not significant.

***t*-test conducted on log transformed data.

As with the layer manures, the composition of the RAN had significantly changed, with the ammonium-N concentration decreasing from 5.7 to 4.0 kg/t and the uric acid-N concentration increasing from 3.9 to 5.0 kg/t.

The range in litter DM contents (39-80%) was narrower than for layer manure and largely driven by the type and quantity of bedding material supplied; of the most widely used bedding materials, straw tends to be less absorbent than woodshavings and hence would produce lower DM litter. Litter P_2O_5 concentrations in the recent samples were significantly (P<0.001) lower at 15 kg/t than the figures in the 8th edition of RB209 (25 kg/t).

The reduction in broiler litter P_2O_5 content in the recent samples, probably reflected the increased use of dietary phytase since the 8th edition RB209 data was collected. Higher feed phytase levels and more efficient phytases enable a greater release of P from plant-based feed and so less mineral P is added to diets in the form of calcium phosphates. In some cases, there may also have been a reduction in P specifications for feeds in response to recent shortages of rock phosphate.

The data comparison indicated that total K_2O concentrations in the recent broiler litter samples at 21 kg/t were greater than the values in the 8th edition of RB209 (18 kg/t). This may reflect the use of higher protein feeds, related to the higher amino acid specifications which are needed for modern poultry genotypes. Typically, this leads to more soya being used in feed than previously, and many companies have reduced or dropped fishmeal from their formulations either for cost reasons or because some retailers want birds fed on vegetable-based feeds. Soya is high in K so both of these changes will have tended to increase K concentrations in the feed and hence in the excreta. It is not clear why magnesium concentrations have also increased (from 4.4 to 5.8 kg/t) as Mg is not routinely added to poultry diets, although it may be related to changes in feed digestibility.

(iii) Relationships between poultry manure dry matter content and nutrient content

Defra project SCF0202 investigated combining the data on layer manure and broiler/turkey litter into a single poultry manure database to determine whether poultry manure nutrient contents are driven by manure DM content, as previously reported by Nicholson *et al.* (1996) and implemented in MANNER-*NPK* and PLANET.

The analysis showed strong and highly significant (P<0.001) linear relationships between poultry manure dry matter contents and the total N (Figure 3), phosphate, potash, sulphur and magnesium contents (Table 14), with no distinction between the relationships for layer manure and broiler litter. The relationship between poultry manure DM and RAN contents was weaker (r^2= 0.14; P<0.01), although when RAN was expressed as a percentage of the total N content, there was a significant (r^2= 0.28; P<0.001) inverse relationship with DM content (Figure 4; Table 2.8).

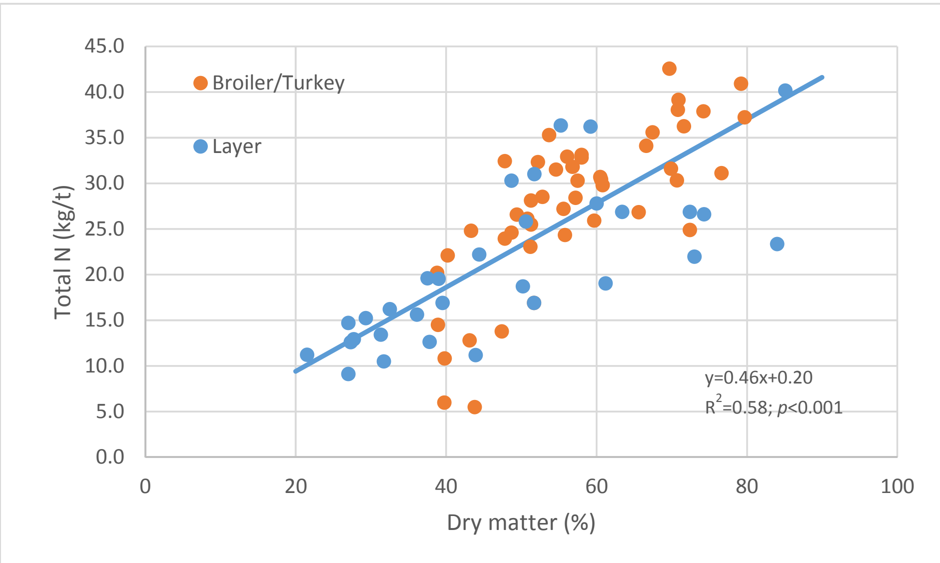

Figure 3. Relationship between poultry manure dry matter (%) and total N (kg/t) contents.

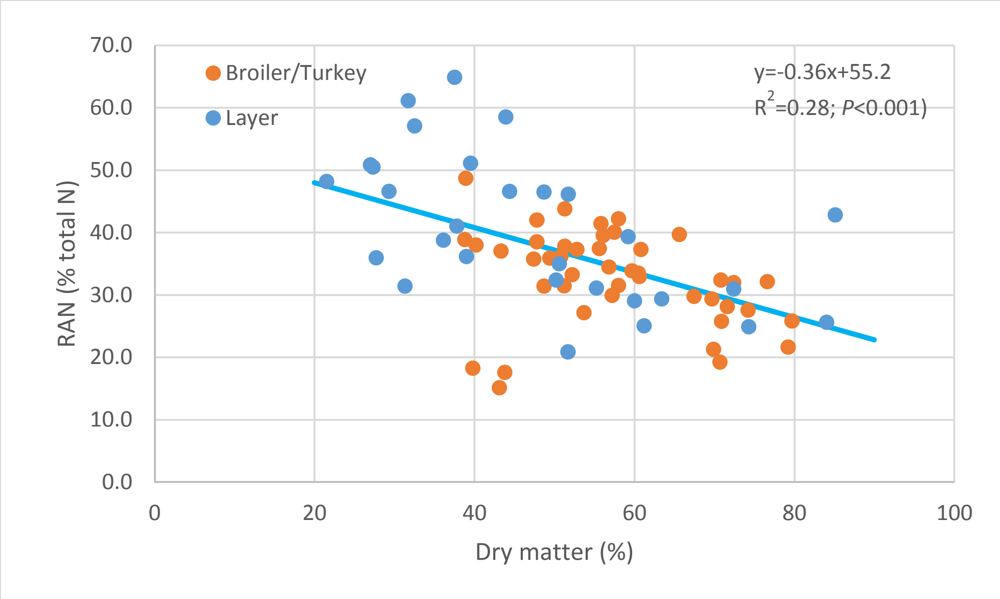

Figure 4. Relationship between poultry manure dry matter (%) and RAN (% total N) contents.

This would indicate that the nutrient content figures for poultry manure (layer manure, and broiler and turkey litter) could be combined and given for a typical range of dry matter contents as is currently the case for slurries. Suggested values, calculated using the regression equations in Table 14, are presented in Tables 15 and 16.

Table 14. Relationships between dry matter (%) and nutrient contents of poultry manures (Defra project SCF0202).

Nutrient	Linear regression
Total N (kg/t)	N = 0.20 + 0.46 DM (n=79; r^2=0.58; *P*<0.001)
RAN (kg/t)	RAN = 4.54 + 0.08 DM (n=74; r^2=0.14; *P*<0.01)
RAN (% total N)	RAN = 55.2 - 0.36 DM (n=74; r^2=0.28; *P*<0.001)
Phosphate (kg/t)	P_2O_5 = 3.62 + 0.22 DM (n=79; r^2=0.43; *P*<0.001)
Potash (kg/t)	K_2O = 2.48 + 0.30 DM (n=79; r^2=0.59; *P*<0.001)
Sulphur (kg/t)	SO_3 = 0.39 + 0.13 DM (n=79; r^2=0.58; *P*<0.001)
Magnesium (kg/t)	MgO = 1.10 + 0.08 DM (n=79; r^2=0.48; *P*<0.001)

Table 15. RB209 8th edition and suggested revised total and readily available N (RAN) contents for poultry manures (Defra project SCF0202).

Dry matter (%)	Total N (kg/t fw)		RAN (kg/t fw)	
	Current	Revised	Current	Revised
20	-	9.4	-	4.5
35 (layer)[1]	19	-	9.5	-
40	-	19	-	7.8
60 (broiler)[2]	30	28	10.5	9.4
80	-	37	-	9.8

[1]RB209 8th edition gives a typical dry matter content of 35% for layer manure.

[2]RB209 8th edition gives a typical dry matter content of 60% for broiler/turkey litter.

Table 16. RB209 8th edition and suggested revised nutrient contents for poultry manures (Defra project SCF0202).

Dry matter (%)	P_2O_5 (kg/t fw)		K_2O (kg/t fw)		SO_3 (kg/t fw)		MgO (kg/t fw)	
	Current	Revised	Current	Revised	Current	Revised	Current	Revised
20	-	8.0	-	8.5	-	3.0	-	2.7
35 (layer)[1]	14	-	9.5	-	4.0	-	2.6	-
40	-	12	-	15	-	5.6	-	4.3
60 (broiler)[2]	25	17	18	21	8.0	8.2	4.4	5.9
80	-	21	-	27	-	11	-	7.5

[1]RB209 currently gives a typical dry matter content of 35% for layer manure.

[2]RB209 currently gives a typical dry matter content of 60% for broiler/turkey litter.

Overall recommendations:

- Replace layer manure and broiler litter tables with one poultry manure table giving nutrient contents based on the relationships between dry matter and nutrient content.
- Update information on the RAN composition to reflect increased uric acid N concentrations.
- Update total P_2O_5 concentrations to reflect reduction caused by increased use of phytase in diets and consequent enhanced feed P use efficiency.
- Update total K_2O concentrations to reflect increases caused by changes in feed formulations.

4.1.6. Other FYM

(i) Duck FYM

Information from Defra project SCF0202 compared the nutrient contents of the 6 duck manure samples taken in 2014 with current RB209 values. The review reported that there had been no significant change (P>0.05) in the DM or nutrient concentrations of duck manures, except for magnesium increased from 1.2 to 2.4 kg/t. It was suggested that the increased MgO content of duck FYM reflected improved feed digestibility (in line with genetic progress which has been improving at a faster rate than for other poultry).

Table 17. Dry matter and nutrient contents of duck manure (fresh weight basis) from Defra project SCF0202.

Manure property	RB209 8th edition value	Updated data(n=6)		
		Mean*	Median	Range
Dry matter (%)	25	24 (*ns*)	25	20-29
Total N (kg/t)	6.5	7.8 (*ns*)	7.7	4.1-13
RAN (kg/t)[1]	1.0 (old) 1.6 (fresh)	1.9 (*ns*)	1.2	0.1-6.9
Total P_2O_5 (kg/t)	5.5	6.5 (*ns*)	6.2	2.8-13
Total K_2O (kg/t)	7.5	8.5 (*ns*)	7.4	2.7-16
Total SO_3 (kg/t)	2.6	3.2 (*ns*)	3.3	1.6-4.6
Total MgO (kg/t)	1.2	2.4 (P<0.01)	2.3	1.2-4.4

(ii) Sheep FYM

Two-sample *t*-test results indicated that sheep FYM DM, total N, RAN, total P_2O_5 and total K_2O content in the 2016 database were not different from those in the RB209 8th edition database (Table 13). However, sheep FYM total SO_3 and MgO concentrations in the RB209 2016 manure database at 4.0 and 2.8 kg/t respectively, were significantly greater (P<0.05) than in the RB209 8th edition database. The elevated SO_3 and MgO concentrations in the recent samples may reflect changes to sheep feed formulations that have occurred since the RB209 8th edition database was collated.

Table 13. Dry matter and nutrient contents of sheep FYM (fresh weight basis).

Manure property	RB209 8th edition value	2016 database (n=8)		
		Mean*	Median	Range
Dry matter (%)	25	28.3 (*ns*)	25.8	24.7-36.3
Total N (kg/t)	7.0	6.5 (*ns*)	5.9	4.0-10.7
RAN (kg/t)[1]	0.7 (old)[2] 1.4 (fresh)[3]	0.5 0.7		
Total P_2O_5 (kg/t)	3.2	4.7 (*ns*)	4.1	2.5-9.4
Total K_2O (kg/t)	8.0	14.1 (*ns*)	12.0	9.8-22.6
Total SO_3 (kg/t)	3.0	4.0 ($P<0.05$)	4.0	2.4-6.0
Total MgO (kg/t)	1.6	2.8 ($P<0.05$)	2.9	2.0-3.7

[1]RAN is the N in the ammonium-N and nitrate-N forms.
[2]Old FYM is FYM that has been stored for 3 months or more (5 samples); *t*-test comparison not undertaken.
[3]Fresh FYM is FYM that is spread straight from the building (3 samples); *t*-test comparison not undertaken.
*The *p* value (in brackets) indicates whether the updated mean value is significantly different from the current RB209 8th edition value; *ns*= not significant.

(iii) Horse FYM

Dry matter and nutrient content data from 6 horse FYM samples taken in this study were compared with values in the RB209 8th edition database (Table 14). It was not appropriate to carry out statistical analysis of datasets because of the small number of samples. However, a simple comparison suggests that there was difference in total N and P_2O_5 content of horse manure. However, the dry matter content was lower and K_2O content was higher than the values included in the RB209 8th edition database. The elevated K_2O content may reflect increased use of straw for bedding.

Table 14. Dry matter and nutrient contents of horse FYM (fresh weight basis).

Manure property	RB209 8th edition	2016 database (n=6)		
		Mean	Median	Range
Dry matter (%)	30	22.5	21.3	19.3-26.6
Total N (kg/t)	5.0	4.6	4.6	3.5-5.8
RAN (kg/t)	ND	0.5	0.4	0.1-1.0
Total P_2O_5 (kg/t)	5.0	4.9	4.4	2.8-8.1
Total K_2O (kg/t)	3.0	5.5	5.7	2.4-8.8
Total SO_3 (kg/t)	ND	1.6	1.5	1.0-2.9
Total MgO (kg/t)	ND	1.5	1.3	0.7-2.6

The mean readily available N content of horse manure was only 0.5 kg/t (equivalent to 10% of total N) and similar to sheep and old cattle FYM. Horse FYM. SO_3 and MgO contents at 1.6.and 1.5 kg/t, respectively were lower than other straw based manures and probably reflected the feed consumed by the different livestock types.

(iv) Goat FYM

There was no information in the RB209 8th edition database on the nutrient content of goat FYM. Information from the 6 goat FYM samples taken as part of this project are reported in Table 15. Mean dry matter content was 43.1% which was higher than all other straw based FYM and probably reflected a greater amount of bedding use. Total N, P_2O_5 and K_2O contents at 9.5 kg/t, 4.5 kg/t and 12.2 kg/t, respectively were also higher than for other FYMs which reflected the high dry matter content. Mean total SO_3 and MgO contents were 2.8 kg/t and 1.9 kg/t respectively. Mean RAN content was particularly low at *c*.5% of total N (0.5 kg/t), which probably reflected the low N content of the goat's diet and high bedding use.

Table 15. Dry matter and nutrient contents of goat FYM (fresh weight basis).

Manure property	RB209 8th edition	2016 manure database (n=6)		
		Mean*	Median	Range
Dry matter (%)	ND	43.1	40.9	22.5-73.6
Total N (kg/t)	ND	9.5	8.4	4.7-15.9
RAN (kg/t)[1]	ND	0.5	0.4	0.1-0.9
Total P_2O_5 (kg/t)	ND	4.5	4.9	0.1-3.9
Total K_2O (kg/t)	ND	12.2	11.9	0.5-26.7
Total SO_3 (kg/t)	ND	2.8	2.3	0.1-6.6
Total MgO (kg/t)	ND	1.9	1.8	0.1-4.0

Overall recommendations

- Update total MgO contents for Duck FYM.
- Update total SO_3 and MgO contents for sheep FYM.
- Replace existing information on the nutrient content of horse FYM with more robust information collected in Defra project WT1568.
- Include new information on the nutrient content of goat FYM from Defra project WT1568.

4.2. Biosolids products

The 8th edition of RB209 gives guidance on the dry matter and nutrient concentrations for a range of biosolids products (Table 21).

Table 21. Guidance on dry matter and nutrient contents of biosolids products in the 8th edition of RB209.

Product	Dry matter (%)	Total N	Readily available N	Total P_2O_5	Total K_2O	Total MgO	Total SO_3
		(kg/m^3 or kg/t)					
Digested liquid	4	2.0	0.8	3	0.1	0.3	1.0
Digested Cake	25	11	1.6	18	0.6	1.6	6.0
Thermally dried	95	40	2.0	70	2.0	6.0	23
Lime stabilised	40	8.5	0.9	26	0.8	2.4	8.5
Composted	60	11	0.6	6.0	3.0	2.0	2.6

Data from the UK Water industry's Biosolids Network (2013) suggests that biosolids applications of 786,000 tonnes dry solids (3.3 million tonnes fresh weight) are applied to agricultural land each year. Around 85% are conventionally treated and 15% enhanced treated to reduce the risks of microbial pathogen contamination (Table 22). Liquid biosolids products account for less than 1% and thermally dried products account for c.2% of total dry solids applications.

Table 22. Biosolids products applied to agricultural land in England and Wales (Water UK).

	Product type (tonnes dry solids)						
Treatment	Advanced AD	Mesophilic AD	Liquid digested	Lime stabilised	Thermal drying	Composting	Total
Conventional	70,000	404,000	1,000	114,000	8,000	71,000	668,000
Enhanced	53,000	0	3,000	56,000	6,000	0	118,000
Total	123,000	404,000	4,000	170,000	14,000	71,000	786,000

(i) Dry matter, total N and total P_2O_5

UK Water Industry data summarising the dry matter total N, and total P_2O_5 content of the contrasting biosolids products is shown in Table 23. The values are based on the analysis of a large number of samples form water companies across England and Wales and the nutrient content varies depending on the individual source and treatment process. There are no nutrient content data for liquid digested sludge because of the small quantities applied to land. Also, the UK water Industry's Biosolids network does not routinely collect information on biosolid RAN, total K_2O, total MgO and total SO_3 contents.

Table 23. Dry matter, total N and total P_2O_5 content of biosolids products applied to agricultural land in England and Wales (Water UK, 2013).

	Biosolids product				
	Advanced digested cake	**Conventional digested cake**	**Lime stabilised**	**Thermally dried**	**Composted**
Dry matter (%)	24	22	25	98	40
Total N (kg/t)	11	10	7.8	41	10
Total P_2O_5 (kg/t)	15	11	7.3	55	10

The data indicate that total N content of all the biosolids products in the 8th edition of RB209 are similar to the more recent data supplied by the Water Industry. However, the dry matter content of composted (60%) and lime stabilised (40%) is greater than the latest data reported by the industry i.e. 40% for composted and 25% for lime stabilised (Table 23).

A comparison of the total P_2O_5 contents of the biosolids products showed large differences between the 8th edition of RB209 and the recent Water Industry data. RB209 (8th edition) figures for digested cake, thermally dried and lime stabilised products were c. 30%, 20% and 70% higher than the Water Industry data, respectively. Total P_2O_5 concentrations in composted biosolids were 60% higher in the Water Industry data compared with the 8th edition of RB209. The changes in biosolids total P_2O_5 contents probably reflect changes in production technologies implemented since the 8th edition of RB209 was published.

(ii) Other nutrients

Additional data on biosolids dry matter and nutrient contents from LINK project 0988 (Table 24), and the current Water Industry/AHDB funded OPTI-S project were reviewed to assess whether there was sufficient information available to include data on the nutrient contents of all the products currently supplied to land and to identify changes in biosolids nutrient and dry matter contents that may have occurred since the 8th edition of RB209 was published.

Table 24. Biosolids dry matter nutrient and concentrations in samples collected as part of LINK project 0988.

Biosolids product		Dry matter (%)	Total N (kg/t)	Total P_2O_5 (kg/t)	Total SO_3 (kg/t)	Total K_2O (kg/t)	Total MgO (kg/t)	NH_4-N (kg/t)	pH
Composted N=31	Mean	34.1	9.4	9.0	6.1	1.1	2.0	0.7	6.9
	Median	30.9	9.7	8.8	6.2	0.7	1.6	0.3	6.9
	Min	23.7	3.1	1.7	1.4	0.3	0.9	0.0	5.3
	Max	62.7	15.0	18.9	11.3	2.8	12.4	3.7	8.7
Digested cake N=40	Mean	23.8	12.4	14.2	8.2	0.6	1.7	2.9	8.2
	Median	21.6	12.1	13.5	7.5	0.5	1.5	2.9	8.3
	Min	16.9	8.8	7.3	5.9	0.3	0.6	1.5	7.6
	Max	57.3	29.9	50.3	19.0	1.9	8.6	4.4	8.6
Digested liquid N = 3	Mean	2.9	1.9	1.7	0.8	0.1	0.2	0.9	7.3
	Median	3.4	1.9	1.8	0.9	0.1	0.2	1.0	7.3
	Min	2.0	1.2	0.9	0.5	0.1	0.2	0.6	7.2
	Max	3.4	2.8	2.3	1.0	0.2	0.2	1.1	7.4
Lime stabilised N = 4	Mean	32.3	8.0	12.1	7.4	0.7	1.5	1.1	11.3
	Median	34.1	7.9	11.8	7.3	0.7	1.5	0.7	12.2
	Min	18.7	5.1	11.0	6.4	0.4	1.2	0.1	8.2
	Max	42.4	11.0	14.0	8.7	1.0	2.0	2.8	12.8
Thermally dried N = 4	Mean	88.0	45.7	56.1	23.6	2.9	8.0	2.7	7.6
	Median	87.7	46.2	56.2	22.9	2.9	7.5	2.7	7.6
	Min	87.6	44.1	55.5	22.0	2.7	7.4	2.6	7.5
	Max	89.0	46.5	56.3	26.3	3.0	9.8	2.9	7.7

The RAN content of the biosolids products at 23% of total N for digested cake, 6% for thermally dried, 3% for lime stabilised and 7% for composted biosolids were similar to those reported in RB209 (8^{th} edition, i.e.14% for cake, 5% for thermally dried, 10% for lime stabilised and 5% for composted biosolids). Similarly, there was generally good agreement between MgO and K_2O values in the 8^{th} edition of RB209 and the more recent data for all biosolids products. However, total SO_3 contents of digested cake (6.0 kg/t) and composted biosolids (2.6 kg/t) were lower (8.2 kg/t for cake, and 6.1

kg/t for composted) than in the more recent data. There was generally good agreement between the 8th edition RB209 and recent data for total SO_3 values in thermally dried and lime stabilised biosolids.

Table 25. Biosolids dry matter nutrient and concentrations of conventionally and enhanced treated sludge cake (Water Industry/AHDB funded OPTI- S project).

Treatment		Dry matter (%)	Total N	Total P_2O_5	Total K_2O	Total MgO	Total SO_3	NH_4-N
			Kg/m^3 or kg/t					
Conventional cake N = 6	Mean	24	10	18	0.4	2.1	6.5	2.1
	Max	28	12	36	0.5	3.5	10	3.4
	Min	21	9	12	0.3	1.4	4.2	0.6
Enhanced treated cake N= 2	Mean	26	13	15	0.3	1.6	8.1	3.0
	Max	30	15	16	0.4	2.0	10	3.9
	Min	22	11	14	0.3	1.2	6.9	2.2

Comparison of a limited amount of data from enhanced and conventionally treated biosolids products suggests that there is insufficient evidence to report the nutrient and dry matter contents of the products separately (Table 25).

Recommendations

- Remove the standard values for liquid digested biosolids due to the small volume of material applied to land (less than 1% of total biosolids).
- Change dry matter and total P_2O_5 content of all biosolids products to those reported by the UK Water Industry's Biosolids network (2013).
- Update figures for biosolids sulphur content with data from LINK project 0988.

4.3. Anaerobic digestate and composts

(i) Anaerobic digestate

Data supplied by the Biofertiliser Certification Scheme and NRM laboratories were reviewed to provide indicative values for whole, separated liquor and separated fibre food-based digestate (Table 26) and whole, separated liquor and separated fibre farm-sourced digestate (Table 27). The values in the tables are the mean of the values from the dataset. The data for food -based and farm-sourced digestate were reported separately to reflect differences in the types (and nutrient contents) of the feedstocks. Separate data for whole, separated liquor and separated fibre reflected differences in the dry matter and distribution of nutrients between solid and liquid digestate fractions.

Table 26. Indicative dry matter and nutrient contents for whole, separated liquid and separated fibre food-based digestate.

Type	Dry matter (%)	Total N	RAN	Total P_2O_5	Total K_2O	Total MgO	Total SO_3
		kg/m³ or kg/t					
Whole (n= 853)	4.1	4.8	4.3	1.1	2.4	0.2	0.7
Separated Liquor (n = 146)	3.8	4.5	3.8	1.0	2.8	0.2	1.0
Separated Fibre (n=268)	27	8.9	2.6	10.2	3.0	2.2	4.1

n = Number of data points used to derive the mean value

Table 27. Indicative dry matter and nutrient contents for whole, separated liquid and separated fibre farm-sourced digestate

Type	Dry matter (%)	Total N	RAN	Total P_2O_5	Total K_2O	Total MgO	Total SO_3
		kg/m³ or kg/t					
Whole (n= 464)	5.6	3.6	2.3	1.7	4.4	0.6	0.8
Separated Liquor (n = 17)	3.0	1.9	1.3	0.6	2.5	0.4	<0.1
Separated Fibre (n=275)	24.0	5.6	1.2	4.7	6.0	1.8	2.1

n = number of data points used to derive mean value

The data demonstrate the importance of liquid digestate as a source of plant available nitrogen with the RAN contents of whole and separated liquor food-based digestate equivalent to c.90% and 85% total N, respectively. The RAN content of whole and separated liquor farm-sourced digestate expressed as a percentage of total N was c.65% and 70% of total N, respectively.

The dry matter content of the separated fibre fraction from both farm-sourced and food-based digestate was equivalent to *c.* 25% which was reflected in elevated total N and total P_2O_5 contents and reduced RAN contents compared with the whole and separated liquor fractions. Notably, the average RAN content of separated fibre from farm-sourced digestate was equivalent to *c.*20% of total N, indicating that the material would not be subject to the closed spreading periods for high readily available N materials stipulated in the Nitrate Vulnerable Zone Action programme rules.

Information from the recently published DC-*Agri* project (Nicholson *et al.,* 2016) reported nitrogen use efficiency data for food-based digestate applications of *c.*10% of total N applied for autumn applications and *c.*55% of total N applied for spring application timings. Ammonia emissions were greater from applications of food-based digestates (*c*.40% of total N applied) than from livestock slurry (*c*.30% of total N applied); this is partly due to the higher ammonium content of the food-based digestate and partly to its elevated pH (mean 8.3).

The current version of MANNER-*NPK* uses ammonia emission and nitrate leaching loss algorithms derived from pig slurry to provide estimates of the crop available nitrogen supply from digestate applications. There is a need to update MANNER-*NPK* with ammonia volatilisation data from DC-*Agri* to provide more robust estimates of crop available N supply from digestate applications. There is insufficient experimental data to provide crop available nitrogen supply information for the separated digestate fibre.

(ii) Composts

Analysis data provided by the BioFertiliser Certification Scheme and NRM laboratories (Table 28) confirm that the standard values for the dry matter and most of the nutrients in green and green/food composts reflects the current products. Total P_2O_5 and SO_3 content of green food compost in the 2016 dataset were 1.1. kg/t and 1.7 kg/t greater, respectively than the figures in the 8th edition of RB209. For green compost, the 2016 data suggest that increasing total K_2O content from 5.5 to 6.8 kg/t may be justified in the new version of RB209.

Table 28. Comparison of standard values from 8th edition of RB209 and recent Biofertiliser Certification Scheme data for dry matter and nutrient contents of green.

Type	Dry matter (%)	Total N	RAN	Total P_2O_5	Total K_2O	Total MgO	Total SO_3
		Kg/m^3 or kg/t					
Green compost							
2016 data	60	8.3	0.2	3.4	6.8	2.6	3.4
8th edition RB209	60	7.5	<0.2	3.0	5.5	2.6	3.4
Green/food compost							
2016 data	60	11	0.6	4.9	8.0	3.8	5.1
8th edition RB209	60	11	0.6	3.8	8.0	3.4	3.4

Recommendation:

- Update RB209 with values for the dry matter and nutrient content for anaerobic digestate according to feedstock and treatment.
- Provide clear explanations of what is meant by food-based and farm-sourced digestates.
- Stress the importance of digestate (and other organic material) analysis and good sampling practice.
- Provide information on the crop available nitrogen supply from contrasting digestate application timings, either by providing tables based on current MANNER-*NPK* estimates, which use pig slurry ammonia emission algorithms to estimate digestate crop available N supply, or by providing more detailed guidance in the text based on DC-*Agri* project findings.
- Update total P_2O_5 and SO_3 values for green/food and K_2O values in green compost to reflect the higher values reported by the 2016 dataset.

4.4. Organic material sulphur supply

A comprehensive review and field experiments carried out in AHDB and water Industry project RD-2008-3606 quantified factors controlling plant available sulphur supply from applications of a range of organic materials, including livestock manures and biosolids products. The work identified that organic material sulphur supply was influenced by the extractable sulphur content of the applied manures and application timing.

The project quantified differences in the amount of extractable sulphur between manure types with broiler litter and livestock slurry containing more extractable sulphur expressed as a percentage of total sulphur content (Table 29). Generally, sulphur use efficiency from autumn applied manures is less than from spring application timings, because a proportion of the sulphur applied in autumn is lost by overwinter leaching.

Table 29. A comparison of extractable sulphur contents and sulphur supply from spring application timings for contrasting organic materials.

Organic material	% total SO_3 available
Autumn applied	
Livestock manures	5-10%
Biosolids	10-20%
Spring applied	
Cattle FYM	15%
Pig FYM	25%
Broiler litter	60%
Cattle/pig slurry	35%
Biosolids	20%

Recommendation

- Update RB209 to include information on sulphur supply from contrasting manure types and application timings that is currently available in AHDB Cereals & Oilseeds Information sheet 28.

5. Gaps in knowledge and future research required

- There is a need to update MANNER-*NPK* to include material specific nitrate leaching and ammonia volatilisation algorithms based on the data from the DC-*Agri* project to improve the guidance on crop available N supply from digestate applications.
- MANNER-*NPK* will also need updating to reflect changes in the typical nutrient content of manures.
- Further experimentation is required to establish crop available nutrient supply from separated digestate fibre and liquid fractions.
- There is a need to carry out further research to provide up-to-date information on nutrient use efficiency that reflect changes in poultry manure management systems. In particular changes to poultry manure composition (i.e. increased dry matter and uric acid-N content and reduced phosphorous content) from recent changes in housing configuration and diets.

6. References

Anon (2010). The Fertiliser manual (RB209) www.defra.gov.uk

Defra (2008). The national inventory and map of livestock manure loadings to agricultural land (Manures-GIS)

Nicholson, F.A. Taylor, M.J., Bhogal, A., Rollett, A.J., Williams, J.R., Newell-Price, J.P., Chambers, B.J., Becvar, A., Wood, M., Llitterick, A., Crooks, B., Knox, O., Misselbrook, T., Cardenas, L., Chadwick, D., Lewis, P. and Else, M. (2016). *DC-Agri;* field experiments for quality digestate and compost in agriculture. Work Package 1 report: Effect of repeated digestate and compost applications on soil and crop quality. WRAP OMK001-001/WR1212

UKWIR (2011) 'Integrated Waste Management' report (Report Ref: No. 11/SL/12/2)

WRAP (2013) *A Survey of the UK organics recycling industry in 2012*. WRAP RAK005-002

WRAP (2014). *A survey of the UK Anaerobic Digestion industry in 2013*. WRAP.

Data sources:

(i) Defra projects:

AC0116 GHG Platforms. Measurements of greenhouse gas emissions from soils

AC0213. Potential for nitrification inhibitors and fertiliser nitrogen application timing strategies to reduce direct and indirect nitrous oxide emissions from UK agriculture.

SCF0202 Analysing the characteristics of UK pig and poultry manures and slurries

SP0530 Organic Manure and Crop Organic Carbon Returns - Effects on Soil Quality (Soil-QC)

WQ0118 Understanding the behaviour of livestock manure multiple pollutants through contrasting cracking clay soils

WQ0140 Minimising the environmental impacts of maize cultivation

WT1568 Pollutant Losses from Solid Manure Applications and From Solid Manures Stored in Temporary Field Heaps

(ii) Industry projects

Link project LK0988 Reducing the risk of diffuse pollution by improved assessment of the nutrient content in farm manures and biosolids via Near Infrared Reflectance Spectroscopy (NIRS)

AHDB Cereals & Oilseeds Project Report 522 Quantifying the sulphur supply of organic manures to winter wheat crops

AHDB Cereals & Oilseeeds Project 216-0007 Optimising sulphur management to maximise oilseed rape yields and farm profitability

7. Acknowledgements

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8. Appendix I: companies invited to submit data to inform the review

ADAS

Agrii

AHDB (RB209 Review Arable TWG and Crop Nutrient Management Partnership Steering Group)

Association of Independent Crop Consultants (AICC; various individual contacts)

Ecopt Consultancy

Frontier Agriculture Ltd

Harper Adams University

Hutchinsons

Institute of Biological, Environmental and Rural Sciences (IBERS), Aberystwyth University

International Fertilizer Society

The James Hutton Institute

NIAB

NPK Club

NRM Laboratories

Potash Development Association (PDA)

Rothamsted Research

Scotland’s Rural College (SRUC)

Teagasc