General enquiries on this form should be made to:
Defra, Science Directorate, Management Support and Finance Team,
Telephone No. 020 7238 1612
E-mail: research.competitions@defra.gsi.gov.uk

defra

1.1.1SID 5 2.Research Project Final Report

- **Note**
  In line with the Freedom of Information Act 2000, Defra aims to place the results of its completed research projects in the public domain wherever possible. The SID 5 (Research Project Final Report) is designed to capture the information on the results and outputs of Defra-funded research in a format that is easily publishable through the Defra website. A SID 5 must be completed for all projects.
- This form is in Word format and the boxes may be expanded or reduced, as appropriate.
- **ACCESS TO INFORMATION**
  The information collected on this form will be stored electronically and may be sent to any part of Defra, or to individual researchers or organisations outside Defra for the purposes of reviewing the project. Defra may also disclose the information to any outside organisation acting as an agent authorised by Defra to process final research reports on its behalf. Defra intends to publish this form on its website, unless there are strong reasons not to, which fully comply with exemptions under the Environmental Information Regulations or the Freedom of Information Act 2000.
  Defra may be required to release information, including personal data and commercial information, on request under the Environmental Information Regulations or the Freedom of Information Act 2000. However, Defra will not permit any unwarranted breach of confidentiality or act in contravention of its obligations under the Data Protection Act 1998. Defra or its appointed agents may use the name, address or other details on your form to contact you in connection with occasional customer research aimed at improving the processes through which Defra works with its contractors.

Project identification

1. Defra Project code: WQ0206
2. Project title: Agronomic and Environmental Impacts of Organic Materials Applied to Agricultural Land DRAFT REPORT
3. Contractor organisation(s): WRc PLC; AEAT PLC; Reading University
4. Total Defra project costs (agreed fixed price): £ 39964
5. Project: start date .... 05 May 2009
   end date .... 31 August 2009

6. It is Defra's intention to publish this form.
Please confirm your agreement to do so. .... **YES** ☒ **NO** ☐

(a) When preparing SID 5s contractors should bear in mind that Defra intends that they be made public. They should be written in a clear and concise manner and represent a full account of the research project which someone not closely associated with the project can follow.
Defra recognises that in a small minority of cases there may be information, such as intellectual property or commercially confidential data, used in or generated by the research project, which should not be disclosed. In these cases, such information should be detailed in a separate annex (not to be published) so that the SID 5 can be placed in the public domain. Where it is impossible to complete the Final Report without including references to any sensitive or confidential data, the information should be included and section (b) completed. NB: only in exceptional circumstances will Defra expect contractors to give a "No" answer.
In all cases, reasons for withholding information must be fully in line with exemptions under the Environmental Information Regulations or the Freedom of Information Act 2000.

(b) If you have answered NO, please explain why the Final report should not be released into public domain

Executive Summary

7. The executive summary must not exceed 2 sides in total of A4 and should be understandable to the intelligent non-scientist. It should cover the main objectives, methods and findings of the research, together with any other significant events and options for new work.

The characteristics and agronomic benefits of wastes that are traditionally spread to land, such as sewage sludge and farmyard manures, are reasonably well known. However, for other organic materials such as composts and anaerobic digestates, there is little centralised data or research that enables the benefits and impacts of their application to land to be assessed. In most cases there is not sufficient information for their basic characteristics to be directly compared with other materials already being applied to land. In this project we have collated and reviewed available waste characterisation data for a wide range of materials in an attempt to fill some of the gaps in knowledge and make a preliminary assessment of the agronomic benefit and environmental impact these materials could pose if spread on agricultural land. This information is needed to guide future policy decisions in this area.

SUMMARY

Objectives and research methods in outline

Five specific objectives were identified to gain a better understanding of the key issues and pin-point where additional data are needed to provide the science base for future policy:

1. To provide an assessment of the pollution risk, greenhouse gas emissions and agronomic benefits from a range of organic materials recycled to land.
2. To recommend future research needed to develop guidelines and to assess trade-offs between nutrient recycling, losses to water and losses to air.
3. To recommend changes to guidelines for application to land, if applicable.
4. To recommend suitable rates of application of anaerobic digestate to land, in order to optimise greenhouse gas (GHG) mitigation of the process while recovering nutrients.
5. To provide a short executive summary for policy makers *(this section)*

Key Findings

Waste characteristics were found to vary significantly even for wastes with the same List of Waste code.

Although some of the apparent variability can be attributed to differences in analytical techniques and testing laboratories, much is likely to be due to inherent variability within the materials or differences attributable to the large number of data sources used for this study.

More data are required on waste characteristics for parameters that are not routinely monitored to show how these materials behave in the soil. In particular, data are required on biodegradability of the material and availability of nutrients, principally nitrogen and phosphorus, and metals. Total concentrations of these parameters do not provide adequate information in order to compare materials in terms of their benefits and environmental impacts.

Manures and anaerobic digestates of sewage sludge and food waste are generally rich in plant available nitrogen, but may supply excessive phosphorus. Composts contain little available nitrogen but may still be valuable sources of phosphorus and potassium fertiliser, and useful as soil conditioners.

The high rates of carbon added with stabilised composts improve soil physical properties, such as bulk density, porosity and water-holding capacity, which provide agronomic and environmental benefits. High loadings, however, provide excessive phosphorus and metals to soils.

The organisms responsible for biodegradation are well known. No new pathogens were identified in this review to challenge the security of this route as an option for land application of biosolids. However, risks from existing organisms are not constant, and, for reasons that are not clear, their prevalence may increase or they may become of increased concern. For example thorugh acquisition of resistance to certain antibiotics. Therefore, it is important to maintain surveillance of changing patterns in infectious disease epidemiology and use the information to re-evaluate the risks.

Key Recommendations

Data collection should be harmonized across different regulatory regimes for all materials, so that reliable and consistent conclusions can be drawn in terms of their agricultural benefit and environmental impacts. This has been an aim of ‘Project Horizontal’. The current dataset on sewage sludge should be updated for at least total and available basic nutrients (total and available) and metals, to reflect recent changes in legislation (e.g. phosphorus removal requirements under the Water Framework Directive and the Urban Waste Water Treatment Directive).

Further work on the fate of organic wastes in soils in terms of biodegradation and release of nutrients should be carried out to provide correlations with routine laboratory waste characterisation tests. This would allow better prediction of the benefits and disadvantages when such wastes are applied to agricultural land.

Project Report to Defra

8. As a guide this report should be no longer than 20 sides of A4. This report is to provide Defra with details of the outputs of the research project for internal purposes; to meet the terms of the contract; and to allow Defra to publish details of the outputs to meet Environmental Information Regulation or Freedom of Information obligations. This short report to Defra does not preclude contractors from also seeking to publish a full, formal scientific report/paper in an appropriate scientific or other journal/publication. Indeed, Defra actively encourages such publications as part of the contract terms. The report to Defra should include:

- the scientific objectives as set out in the contract;
- the extent to which the objectives set out in the contract have been met;
- details of methods used and the results obtained, including statistical analysis (if appropriate);
- a discussion of the results and their reliability;
- the main implications of the findings;
- possible future work; and
- any action resulting from the research (e.g. IP, Knowledge Transfer).

1. INTRODUCTION

1.1 Background

Waste management is a fast developing field, and new waste treatment technologies are being developed and continually coming on stream. Where residues from these processes are applied to land, it is important to establish an evidence base in order to protect ground and surface water, soils and air, and ensure that these materials are providing agronomic benefit.

This project has been commissioned in order to gather available evidence on materials applied to land. In particular:

- To provide an assessment of the pollution risk, greenhouse gas emissions and agronomic benefits from a range of organic materials recycled to land.
- To recommend future research needed to develop guidelines and to assess trade-offs between nutrient recycling, losses to water and losses to air.
- To recommend changes to guidelines for application to land of the above materials, if applicable.
- To recommend suitable rates of application of anaerobic digestate to land, in order to optimise greenhouse gas (GHG) mitigation of the process while recovering nutrients.
- To provide a short executive summary for policy makers.

The following provides an overview of the assessment carried out for this research project. Detailed discussion on all sections can be found in Appendix A to this report.

1.3 Approach

A large amount of data were collected for organic materials currently applied to land for agronomic benefit. The data have been collated from field trials and published reports, as well as data submitted to fulfil regulatory requirements. This information has been reviewed, and used to assess and rank organic materials applied to land in terms of their agronomic and environmental impacts. Where the data were sparse, as was the case for a number of waste types and waste characteristics, the information has been supplemented through review of the literature for qualitative information.

1.4 Report structure

The results of the data assessment are summarised here, full details on the assessment of impacts and benefits is given in Appendix A with data summaries provided in Appendix B.

1.5 Glossary

Acronyms have been used throughout this report although they have been stated in full on first occurrence. A glossary of less frequently used terms is provided in Appendix A.

2. DATA COLLECTION AND INITIAL ANALYSIS BY WASTE TYPE

2.1 Waste categories

In order to carry out a risk assessment of the benefits and impacts of organic materials applied to land, a large and robust dataset is necessary. Data were collated from a number of sources on waste materials currently being spread to land. The majority of this data were from Environmental Permitting Regulations 2007 Schedule 3 paragraph 7 notifications for spreading of waste to land for agricultural benefit. Data were also collected from published literature on field trials and review articles, data submitted as part of the quality protocol PAS100 compliance and the most recent Environment Agency survey of sewage sludge quality.

Data were available for a diverse number of waste types and treatment processes. A system of waste categories has been devised in order to allow an informative comparison of waste types as detailed in Appendix A.

2.1 Data collation

Data were collated (where available) for the following parameters:

- pH
- % DM (dry matter)
- % moisture content
- Total nitrogen
- Mineral nitrogen
- Extractable (available) nitrogen
- Total NH_3 (ammonium)
- Total NO_3 (nitrate) (water soluble)
- Total P (phosphorous)
- Extractable (available) P or phosphorous
- Total K (potassium)
- Extractable (available) K (potassium)
- Total S (sulphur)
- Extractable (available) S (sulphur)
- Total Mg (magnesium)
- Extractable (available) Mg (magnesium)
- Organic matter (or loss on ignition (LOI))
- Organic carbon
- Zn (zinc)
- Cu (copper)
- Ni (nickel)
- Pb (lead)
- Cd (cadmium)
- Cr (chromium)
- Hg (mercury)

Data on pathogens, organic parameters and leachability were assessed separately. Full details are given in Appendix A of this report. In addition, data on biodegradability of wastes was extracted from the literature, as no information could be found on this from monitoring data.

2.3 Data availability

The extent of available organic waste characterisation data typically depended on the initial testing objective. Data were collected from over 4500 sets of analysis, and these were then sorted into generic categories. However, the available dataset for some of these categories was limited. This is discussed in Appendix B.

Much of the testing has been undertaken to meet the analysis requirements for notification of paragraph 7 exemptions from Environmental Permitting. The parameters measured and the methods used are commonly not consistent and gaps are apparent for certain waste types and parameters. These gaps are most common for the more complex characteristics, which are expensive to analyse, such as: biodegradability, bioavailability, leachability, toxicity, nitrogen mineralisation rate, organic pollutants and microbial pathogen content.

Data were reported in a diverse range of units, making comparison between different waste streams a difficult process.

2.4 Characteristics by waste type

The data collected shows a significant variability in waste characteristics within specific categories of input waste types and treatment types. Statistical information e.g. highest and lowest concentrations, median value, central 50% of data have been plotted systematically in box and whisker plots in Appendix B to illustrate this point.

The study found that although there were differences in the average concentrations of individual materials, there was significant overlap when the dataset was examined as a whole. There was large variability even where the input material and treatment type was the same.

Composts showed similar characteristics regardless of the input waste stream, as did anaerobic digestates. However, there was still very large variability within each treated waste type after treatment, making it difficult to predict characteristics on the basis of material type and treatment. This may be due to the large number of sources that data were drawn from.

The category of input material was found to have a substantial influence on total metal concentrations when the analytical data are normalised on a dry matter basis, the higher moisture content of some wastes masks these between-waste differences if the data are assessed on an ‘as applied’ (i.e. wet weight) basis.

Key findings from the data examination include:

- Total metal concentrations were extremely variable in most waste streams.
- Nitrogen concentrations were higher for manures and sewage sludges than composts. Anaerobic digestates also had higher concentrations of nitrogen and phosphorus.
- Data on the variability of nutrients was sparse and therefore it was difficult to undertake a comparison between material types for these parameters.
- There was no significant difference in mesophillic and thermophillic digestate properties in the materials studied.
- Total nitrogen and potassium concentrations in composts were low (<20 g/kg) but showed a high degree of variability.

3. EXAMINATION OF ISSUES BY ENVIRONMENTAL COMPARTMENT

3.1 Overview

The potential risks posed by each generic waste category were reviewed for a number of specific environmental compartments as listed below:

- Surface and groundwater qualityr;
- Soil quality;
- Greenhouse gas emissions and pollution to air; and
- Human and animal health by pathogens.

To make comparisons of the quality characteristics and potential risks from waste spread to land it was necessary to define assessment criteria for each of these compartments. These were then used in conjunction with the collated dataset to make comparisons of impacts by waste category. These are elaborated in the following section.

3.2 Assessment criteria

3.2.1 Surface and ground water

Risk to surface and ground water was assessed using the software package Consim®. As very limited leachability data were available, it was only possible to conduct a Level 1 (top level conservative tier) assessment of the impacts of waste materials (Full details given in Section 8, Appendix A). The assessment offers an overview of the potential impacts of organic materials when applied to land, but should be considered a conservative estimate for potential impact.

For this risk assessment, major nutrients and heavy metals were assessed for their potential impact. The calculated leachate values were then compared with either surface water Environmental Quality Standards, background groundwater quality in the United Kingdom or drinking water quality standards.

3.2.2 Soil quality and agronomic benefit

An assessment of benefit and impact by waste category has been undertaken by looking at the normalised application rate. The application rates based on potentially available nitrogen (PAN) and soil organic carbon (SOC). The different approach to calculation of loadings is given in Table 3.1.

Table 3.1 Comparing potentially available nitrogen (PAN) with soil organic carbon (SOC)

Loading to potentially available nitrogen (PAN)	Loading to soil organic carbon (SOC)
Loading of 100 kg/ha of potentially available nitrogen.	Loading to achieve increase in soil organic carbon of 1% of stabilised carbon in the top 25 cm of the soil (plough depth).
Corresponds to nitrogen requirement for a light	Accounts for expected loss of organic through

Loading to potentially available nitrogen (PAN)	Loading to soil organic carbon (SOC)
sand soil with a soil nitrogen supply (SNS) index of 1 for the growth of autumn and early sown wheat (RB209).	decomposition, i.e. the biodegradability of the waste.

The assessment of risk or benefit to each environmental compartment was undertaken using sewage sludge application rates as the benchmark for applying organic wastes to agricultural soils. Other key parameters are benchmarked as a proportion of the loadings from sewage sludge.

3.2.3 Greenhouse gas emissions and pollution to air

Potential emission to air, including greenhouse gas emissions were compared for each waste type with sewage sludge, for loadings based on potentially available nitrogen and soil organic carbon. This allows a relative risk ranking to be carried out to assess which wastes enhance the risk of specific emissions when applied at rates to give the same agricultural benefit. Table 3.2 summarises the parameters used for the emissions to air risk assessment.

Table 3.2 Parameters for assessment of emissions to air

Parameter	Assessment
Ammonia emissions	Comparison of estimated ammonia emission during application to land. Emission factors generated for different wastes dependent on dry matter content.
N_2O emissions	Comparison of estimated N_2O emission from total nitrogen application based on assumption 1% of applied nitrogen is released as N_2O (IPCC method).
CO_2 emissions	Comparison of biostabilisation of the waste achieved by pre-treatment equating to the extent of decomposition expected when applied to the soil to reach a stabilised state and C-sequestration in soil.
Odours	Qualitative comparison with sewage sludge odour issues based on the relative loadings required to achieve the same benefit and the potential of the waste to be odorous.

3.3 <u>Impact to soil quality and agronomic benefit</u>

3.3.1 Introduction

The mean data for the different waste input types and waste treatments have been compared with sewage sludge applications when applied as a nitrogen fertiliser (to increase potentially available nitrogen) or to increase soil organic carbon (SOC). For many wastes, there was limited analytical data and key data points were often missing to prevent any comparison. Key parameters for the assessment were dry matter (DM) and the organic matter (as LOI or TOC) content of the wastes. Where these data were missing, values have been assumed based on technical experience, in order to provide a partial comparison.

The comparison methodology also requires information on how the wastes would decompose in the soil, particularly with respect to carbon decomposition, nitrogen-mineralisation and phosphorus availability. In virtually all cases, these parameters have not been measured as part of routine waste compliance monitoring. For this study, assumed values have therefore been needed to further the initial assessment. This work should be revisited as new analytical test data becomes available.

Full details on the assumptions made for this assessment are provided in Appendix A of this report. Given that a number of assumptions have been made to compensate for the lack of data it should be recognised that the assessment provides a first pass comparison. It is believed that the approach demonstrates the value of the methodology which could then be refined when additional real data are made available.

3.3.2 Calculation of loadings by potentially available nitrogen (PAN)

In this review, two types of assessment were made of loadings on the basis of:
- potentially available nitrogen (PAN) and
- loadings on the basis of soil organic carbon (SOC).

Application rates on the basis of potentially available nitrogen are discussed in this section, with soil organic carbon loadings discussed in Section 3.3.3. The data are compared with sewage sludge as this is one of the best understood and most researched wastes currently spread to land. Estimated total loadings (t/ha) and the loadings of the waste materials, and the loadings of other nutrients and metals this would subsequently produce, have been calculated on this basis. The results of this exercise are shown in series of plots in Section 4 of Appendix A. The findings of the assessment are summarised here.

a) Nitrogen loading

The estimation of the total loading (total t/ha wet weight of the waste) required to achieve an effective potentially available nitrogen of 100 kg/ha is very dependent on the waste characteristics with respect to its total mineral nitrogen content, and the decomposition of the organic matter in soil which may either mineralise organic nitrogen (to convert it to an available form) or consume mineral nitrogen (subtract from potentially available nitrogen).

The assessment indicates that for many wastes the loadings required to give comparable available nitrogen concentration may be similar to the loadings of sewage sludge. There are some waste input types (notably de-inking sludges from paper recycling and dredgings) that would not normally be considered as sources of nitrogen fertiliser and these are shown here to require the highest loadings. The mechanical biological treatment (MBT) residues (most of which are composted) would require very large loadings of the waste material to achieve an equivalent available nitrogen, and therefore are not considered to be as good a nitrogen fertilizer. Wastes that require significantly higher loadings than sewage sludge to give the same potentially available nitrogen benefit may not be suitable for land application as nitrogen fertilisers, as they may carry excessive quantities of other materials as contaminants. In addition, nitrogen limits imposed by the Nitrates Directive are set on the basis of total nitrogen per hectare rather than potentially available nitrogen. Therefore wastes with a high total nitrogen: potentially available nitrogen ratio (i.e. only a small proportion of the total nitrogen is available for crop uptake) would be limited in their usefulness as nitrogen fertilizers.

Using the approach of assessing the quantity of waste required to provide a specific amount of available nitrogen would allow focus on those wastes that may not provide a good nitrogen source, and allow consideration of whether they contribute other benefits or harm.

Loadings to potentially available nitrogen by treatment type indicate that application rates are much higher for the composts, as only a small amount of their total nitrogen is available for crop uptake within the first year.

b) Phosphorous loadings

Sewage sludge is usually recognised as being phosphorous rich in comparison with nitrogen concentrations. Sewage applications as an nitrogen fertilizer value can therefore potentially provide excessive total phosphurous. When applied at the potentially available nitrogen application rate of 100 kg nitrogen/ha, sewage sludge gives an average total P loading of 112 kg/ha. If it is assumed that the phosphorus availability is about 50% (as given in Defra's Fertiliser Handbook RB209) then this represents approximately double the plant nutrient phosphorous requirement. However, phosphorous availability can vary considerably depending on the treatment type the sewage sludge has originated from. A comparison of the total phosphorous loadings relative to sewage sludge for the other waste types indicates that phosphorous loadings would be lower for many of the wastes (for plots see Appendix A). Wastes with lower phosphorous loadings may be of value as nitrogen and phosphorous fertilizers even if their total application exceed that of sewage sludge if there are no excessive contaminants carried within the wastes. It may be possible to select appropriate wastes in combination to optimise the nitrogen and phosphorous fertilizer requirements of any soil.

c) Loadings of major nutrients K, Mg and S

Organic wastes would provide other major plant nutrients (K, Mg and S) as well as nitrogen and phosphorous. Whilst these present lower potential for environmental harm than nitrogen and phosphorus it would be important to understand how much is added to soil in order to optimise organic waste applications to land.

In general, for most of the waste types, the nutrient loadings of the major elements K, Mg and S are similar to or exceed the loading from sewage sludge when applied at the normalised potentially available nitrogen loading of 100 kg nitrogen/ha. This indicates that most organic wastes would be good sources of these major plant nutrients.

A simple comparison of the P, K, Mg and S contents of sewage sludge and composts demonstrates these differences in concentrations of plant nutrients (Table 3.3). One of the reasons that sewage sludge is low in K is that this element is very soluble and would be partitioned mainly in the waste water treatment plant effluent rather than the solid waste. Where there is little leachate formation in the maturation of composts, levels of K would be higher.

Table 3.3 Comparison content of plant nutrients in sewage sludge and composts (units g/kg DM)

Waste	Total nitrogen	Total P	Total K	Total Mg	Total S
Sewage sludge	38.7	21.7	5.4	2.8	8.5
Compost	20.2	3.6	8.5	2.8	7.8

Digestates from wet AD processes treating food wastes and similar materials have been shown to have similar nutrient levels to sewage sludge if there is mechanical dewatering. Digestates from dry AD processes where there is less leachate generated may retain more plant nutrients.

d) Metals

Virtually all organic wastes will contain potentially toxic elements (PTEs) at some level, and the most commonly monitored of these are the metals required by the 1996 DoE Code of Practice for the Agricultural Use of Sewage Sludge – cadmium , chromium, copper, lead, mercury, nickel and zinc. Whilst some of these are trace elements (copper, nickel, zinc) required for growth, it is rare for these to be limiting and most concerns would be for their excessive application to soils.

The metal addition to soils from the different waste input types were compared with those expected from sewage sludge when applied to give a potentially available nitrogen of 100 kg nitrogen/ha. The comparison was carried out on the basis of estimating the number of applications that would be needed to exceed the soil metal limits for a typical soil.

For most wastes, the number of applications required to exceed the soil limits were similar or greater than sewage sludge indicating there was little enhanced concern. The metal which tended to require the least number of applications to reach its soil limit was zinc (see Appendix A) where 90 applications were required for sewage sludge before reaching the limits. For some wastes, the numbers of applications was lower and most notable amongst these were MBT residues (code 54) which would require very few applications before limits were breached, as MBT residues used in this study were high in metals. Other low application numbers to exceed zinc soil limits when applied as nitrogen fertilisers were from de-inking sludges from paper recycling and dredgings. These would not be considered as materials applied for nitrogen fertiliser value however, although dredgings (code 73) are typically applied to soils at high loadings and are a very variable material depending on their source.

A similar analysis for the waste treatments indicated composts showed fewer applications compared with sewage sludge with only 30 – 40 applications needed. This is a consequence of the higher application rates required to achieve the same potentially available nitrogen as sewage sludge even though zinc contents of the composts (164 – 221 mg/kg DM) were lower than that of sewage sludge (675 mg/kg DM).

3.3.3 Calculation based on soil organic carbon

The alternative assessment for agricultural benefit considers loading the organic wastes to land in order to significantly increase the soil organic carbon rather than to add nutrients. The analysis is simplified as a one-off application to increase the top 25 cm of the soil organic carbon by 10,000 mg C/kg soil.

The key consideration affecting the loading is the amount of organic carbon in the waste and the extent to which it is degraded in the first year following application. For example, we can compare a readily decomposable organic waste, such as manure, with a stabilised waste such as a mature compost. To achieve a target increase in soil organic carbon by compensating for the loss of carbon during its decomposition in the soil, a greater quantity of manure needs to applied compared to a mature compost. Most waste characterisation exercises do not include biodegradability testing, and where these have been undertaken they are generally rapid laboratory tests which may not reflect decomposition in the soil.

The loadings have again been compared with sewage sludge. However, this is not a material that would typically be applied to significantly increase soil organic carbon as it is much more biodegradable than a mature compost.

The estimated loadings required to achieve the increase in soil organic carbon for different waste input types indicates that for most wastes types, loadings are similar or lower than sewage sludge. The notable exceptions would be fish farm wastes and dredgings which are due to the low organic carbon of these wastes. Note also that the sewage sludge loading to achieve the target soil organic carbon increase is much greater at 225 t DM/ha compared with the loading to achieve the nitrogen fertilizer potentially available nitrogen target (5.2 t DM/ha). This means that the carbon decomposition/soil respiration load from the sewage sludge application would be increased by a factor of 40 compared with application of a nitrogen fertilizer. Whilst the impact of this is not known it may be considered that although it represents an increase in the energy supplied to the soil it may be excessive and cause anoxic conditions with potential short term impacts on soil microbial processes and emissions.

When the loadings to achieve the same soil organic carbon increase are compared for the treatment types, it would seem that similar loadings of composts would be required for sewage sludge (see Appendix A) despite the increased stability of the organic matter in composts. This is because although the organic carbon in compost is much more stable, there is less present in the waste as a percentage of the dry matter content. The carbon emitted as CO_2 during decomposition would be 45 t/ha for the sewage sludge and 3.3 t/ha for the composts which would reflect the marked decrease in decomposition/soil respiration that results from the compost addition.

a) Nitrogen loadings for applications to increase soil organic carbon

The application of large amounts of organic wastes would significantly increase the nitrogen loadings to the soil (see Appendix A) greatly exceeding nitrogen vulnerable zones (NVZ) limits of 170 kg nitrogen/ha, even if the waste were applied over 10 years rather than as a single application.

It may be argued that for stabilised materials, the nitrogen is much less available and potentially of less concern. On this basis, the applications of sewage sludge would give significant loadings of potentially available nitrogen which would be in excess of plant requirements and a risk of environmental emissions. The potentially available nitrogen from the composts would be much smaller and of lower risk, although the overall nitrogen loadings for the compost would be half that of sewage sludge.

b) Phosphorous loadings for applications to increase soil organic carbon

Increasing the loadings to adjust the soil organic carbon content would also increase phosphorous loadings. Comparing the waste types with sewage sludge indicates that most wastes would load a similar or lower amount of phosphorous to soils. The total phosphorous loading from sewage sludge would be very excessive even if added over a 10 year period. Sludge from treatment of drinking water would also provide very high P, as it is composed mainly of inorganic sludge and therefore very large loadings would be required to achieve an increase in soil organic carbon. Composted materials applied to increase soil organic carbon levels would apply significantly lower loads of total phosphorous relative to sewage sludge. The total phosphorous loading for compost (code C) in this case is 943 kg P/ha which if applied over a 10 year period may be acceptable on low phosphorous containing soils. It would, however, be about twice the required application for a soil with P index 2 assuming a 60% availability of the P. Therefore P loadings from high applications of compost may not be an issue of great concern for some soils.

c) Nutrients K, Mg and S

The greater loadings associated with increasing the soil organic carbon contents would similarly increase the loadings of the nutrients K, Mg and S. The analysis indicates that this would be similar for most wastes although the amounts would greatly exceed plant growth requirements by more than 3 to 8 times even if applied over a 10 year period. It is not expected that this would not be problematical for K and Mg. Of potential concern may be the high loadings of S which, if in the form of reduced S, may enhance odour and soil acidification risks. Alternatively, if combined with a readily biodegradable waste there may be significant sulphate reduction causing odours and a potential adverse impact on soil quality from the toxic sulphides produced. The impacts of excessive K, Mg and S loadings may need to be considered in more detail.

d) Metals

The larger loadings required to increase the soil organic carbon would reduce the number of applications that may be possible before exceeding the soil metal limits. This again appears to be most sensitive for zinc where for many wastes only 2-4 applications would be possible before soil guideline values are breached. This would not be a sustainable practice even if the applications were spread over a longer period.

A similar picture is presented for zinc with the different waste treatments and although composts may apply less zinc than sewage sludge there may be very few applications (between 5 -10) before soil zinc limits are exceeded.

These results indicate that repeated large applications of most organic wastes to significantly increase soil organic carbon contents may not be a sustainable practice as it may significantly increase soil metal contents (particularly zinc). A significant increase in soil metal concentrations would limit the future potential of the soil to receive more organic wastes.

3.4 Surface and ground water

3.4.1 Key issues

Due to the different issues involved in assessing impact to ground and surface water, a separate methodology has been followed from that used to assess the impact of waste application to land. A more comprehensive account of the assessment process for surface and ground water is provided in Appendix A.

In the absence of laboratory leaching test data, theoretical leachate concentrations for selected parameters were calculated by Consim© from total composition data on a dry weight basis. In the Tier 1 risk assessment the calculated leachate concentrations were then compared with relevant water quality standards and in the case of groundwater published background water quality in the UK (Shand *et al.* 2007). To provide a worst case assessment, the 95th percentile leachate concentration obtained for each waste category was used to assess compliance or breach of water quality benchmarks. It should be noted that the Tier 1 approach and use of essentially predicted maximum concentrations provides a worst case assessment of risk. The assessment has been carried out for priority hazardous substances (formally List I substances) which must not be discharged to groundwater under Directive 2008/105/EC, and priority substances (formally List II substances) for which discharge to groundwater should be limited.

Priority hazardous substances cadmium and mercury (formerly List I substances) are present in almost all of the wastes reviewed for this project. However, for the most part these are generally present at concentrations that would require little or no dilution to be below background water quality benchmarks. The presence of these substances is therefore not considered to present a significant risk to the environment (surface and ground waters). The exceptions, where calculated leachate concentrations were much higher than background concentrations or environmental quality standards for surface or groundwater, were some datasets for sewage sludge (waste type 20) and the organic fraction of municipal solid waste (waste type 60).

From the assessment of priority substances, only lead and nickel are higher than background concentrations (10 to 20 times higher) for sewage sludge and organic fraction of municipal solid waste (MSW). Leachate produced by application of these wastes to land, may pose problems for the environment. Calculated chromium and copper leachate concentrations for almost all wastes reviewed exceed background concentrations by 2500 and 5 times and may therefore pose a possible significant risk to surface and groundwater quality. The exceptions are waste from processing of food and 'other' categories. Calculated leachate concentrations for zinc are not deemed to present a risk to surface and groundwater. Possible mitigation could include control of the input waste streams to the treatment processes, blending of the outputs, a reduction in the quantity of waste applied to land and good agricultural practice related to applications in the proximity of surface water. This requires routine monitoring of the treatment residues for total and leachable lead, nickel, chromium, cadmium, copper and zinc which are not being undertaken at present.

In many areas of England and Wales, phosphorous and nitrogen levels are high, and many water bodies are failing to achieve good status. Using the 95th percentile concentrations, most of the wastes studied for this project have the potential to cause harm to surface and ground waters due to high concentrations of nitrogen and phosphorous. The exception to this statement relate to phosphorous levels in the 'other' waste category. The application of wastes that contain high levels of phosphorous and nitrogen to land should be undertaken with care to avoid compromising ability to achieve good status for water bodies in England and Wales.

In the absence of other relevant benchmarks, potassium concentrations were compared to groundwater background concentrations for the UK and indicate that predicted concentrations are close to background levels, and therefore not deemed to present a risk to surface or groundwater.

It should be noted that for this study only a Level 1 risk assessment was undertaken due to paucity of data, and variability in environmental conditions across England and Wales. Leaching concentrations were calculated from total concentrations obtained in the data collation. As such, the conclusions represent a worst case scenario, but indicate where extra care may be needed. It is recommended that a robust leachability dataset is compiled in future research on these materials to allow a comprehensive risk assessment to be undertaken in the future. Mitigation factors as outlined in Defra's Code of Good Agricultural Practice are very important for the protection of surface water and groundwater and should be followed.

3.5 Greenhouse gas emissions and pollution to air

3.5.1 Introduction

Greenhouse gas emissions have been estimated for waste types on the basis of applying the waste for its nitrogen content and organic carbon using the same methodology as the assessment of impact to soil quality. In addition, a review of the available literature has been conducted on the potential for carbon sequestration in soil.

3.5.2 Calculations on the basis of potentially available nitrogen

a) Emissions of ammonia to air

Ammonia losses to air during the spreading of organic wastes to land are often significant and measures are advised to minimise the losses so that fertilizer value is not lost and air pollution is minimised. Wastes with high ammonium contents, low moisture and high pH are typically at higher risk of losing ammonia to air than other wastes. Losses of ammonia also depend on soil properties (pH, calcium content, water content and porosity); meteorological conditions; crop and method and rate of application.

Insufficient data were available for a comparison of emissions to air by waste treatment although as composts typically contain comparatively little free ammonium compared to sewage sludge and manures then emissions would be expected to be lower than sewage sludge. By assuming all the mineral nitrogen in compost is ammonium, then the emissions are estimated as about 5 times lower for composts compared with sewage sludge loaded to the same potentially available nitrogen. Wastes that may emit high levels of ammonia include manures, sludge from treatment of industrial effluents, ABOR wastes; de-inking sludges from paper recycling and anaerobic digestates.

b) Emissions of nitrous oxide to air

Emissions of N_2O from applications of organic wastes will be very difficult to predict as they are dependent on a multitude of factors such as the waste characteristics and its decomposition, the microbial processes of nitrification and denitrification in the soil and the factors such as moisture, oxygen, and temperature that affect these process. For a first pass comparison a simple 1% of the applied nitrogen is assumed to be released as N_2O.

The comparison of N_2O emissions is made on the basis that 1% of the total nitrogen applied is released as N_2O. This assumption may be quite erroneous for some wastes. However, the analysis indicated that N_2O emissions for most wastes may be similar to sewage sludge with only a few wastes that may give greater emissions. However as the highest emission would appear to be from wood (code 37) and dredgings (code 73) the analysis is clearly suspicious. There is a need to obtain more detailed information on emissions from different wastes.

The analysis of N_2O emissions by waste treatment indicates that composted materials may give about 5 times more emissions relative to sewage sludge. These high estimations result from the high loadings of compost to give the same potentially available nitrogen as sewage sludge. Further work may be required to establish whether the same 1% of total nitrogen proportion is released as N_2O for composts in soil especially as the turnover of nitrogen and carbon in soil are related.

3.5.3 Calculations on the basis of soil organic carbon

The emissions to air of ammonia and N_2O would be expected to increase as the amount of organic matter is increased. It is difficult to predict the outcome as there are probably additional dose-response factors to consider associated with the management and spreading of greater loads. Based on total nitrogen loadings, however, N_2O emissions would be similar for the different waste input types assuming that 1% of the total nitrogen was released. However, as the nitrogen loadings would be significantly higher than when loadings were made to potentially available nitrogen (as nitrogen fertilizer) then the assumptions made may need to be reconsidered. If the percentage nitrogen released as N_2O was significantly greater than 1% at high loadings then N_2O emissions may be much greater than predicted here.

3.5.4 Carbon sequestration

Soils are an important store of fixed carbon. Smith *et al*. (2005), discussing the potential of carbon sequestration in Europe, pointed out the lack of data on compost management as a means of carbon sequestration. Barral *et al*. (2009) showed that after 150 days of compost application, the labile fraction was completely degraded and the recalcitrant fraction had not been degraded. The non-hydrolyzable OM (biochemically protected OM), i.e., the recalcitrant fraction was previously shown to be the fraction that contributes to the stable OM of soil (Rovira and Vallejo, 2002; Mikutta *et al.,* 2006). These data point to a slight increase in the fraction of carbon retained with increasing compost application. This is in contrast with literature data that showed constant or decreasing percentage of carbon accumulation with increasing amount of organic matter (OM) application (Körschens and Müller, 1996; Smith *et al.,* 2000). One possible explanation is that the compost used in this experiment was highly stable with a recalcitrant fraction over 50%, and other experiments may have used more degradable compost.

The authors concluded that compost use represents an interesting opportunity to sequester carbon in the soil, especially in the light of increasing interest on agricultural compost use. As compost represents 'predigested' OM, the large content of recalcitrant-OM allows for substantial soil-carbon accumulation levels after a short time. In this study, both the amount of carbon retained and degraded increased with the amount of compost applied. The fraction of the carbon added that was retained appeared to increase slightly with the increased compost dose. Further investigations are needed to better elucidate on how compost characterization in labile and recalcitrant carbon fractions can predict the carbon sequestered in the soil in short- and long-term experiments.

Barral *et al.* (2009) calculated the amounts of compost to be added to three soils every year to meet the needs of soil organic carbon under two scenarios. The first was the conservation of the current soil organic carbon concentrations, and the second was to reach a soil organic carbon concentration of 3.5%, that had been considered as a threshold value for the productive and structural functions of soils of temperate regions. The amounts of compost to be added were estimated to range between 4 and 10 t/ha (dry weight), depending on the targeted soil organic carbon values and the temperature. It was noted that an increment of 2°C in the mean temperature would increase by 10% the requirements for composts to maintain adequate soil organic carbon. Mineralization rates were obtained after incubation of the samples at 25°C for 10 weeks. Previously to the incubation, soil moisture was adjusted to c. 70% of field capacity. 25-gram samples of each soil, compost, or soil/compost mixture were placed in 100 ml incubation vessels, three replicates per soil/compost, and introduced in 1-L jars, each jar containing 25 ml of water, and 20 ml of 1M NaOH in a 50 ml vial. The jars were hermetically sealed and incubated at 25°C for 10 weeks. The CO_2 evolved by microbial respiration was measured twice a week by titration of the residual NaOH with 0.1N HCl for the soils and 0.5N HCl for the composts. These data were transformed to percentage of total carbon evolved as CO_2-C, and the cumulative mineralization data were fitted to first-order kinetic models. The authors concluded that the mineralization rate of soil organic carbon in field conditions can be adequately predicted from laboratory incubation experiments; the doses of organic amendments needed to counteract the losses due to mineralization or to reach fixed soil organic carbon objectives in agricultural soils can therefore be estimated.

3.6 Food safety and livestock health

3.6.1 Introduction

Pathogens in organic wastes recycled to land present no agricultural benefit. Waste organic materials have the potential to contain a variety of pathogens, depending on the source of material. Pathogens pose an environmental risk for several reasons, including the transmission of human disease through the food chain, the transmission of diseases through farm animals and wildlife and the transmission of plant pathogens into the environment. There is also an issue of public perception which may override actual risks and require addressing. A risk assessment from basic principles was outside of the scope of this study. Relevant literature was reviewed for any gaps that would require further study.

Pathogens are clearly a risk from materials of human and animal and faecal origin. Plant pathogens may also be a concern in infected material being composted and insufficiently sanitized and then used for land applications. For example, there are concerns regarding the potential spread of plant pathogens such as sudden oak death through composted materials that have not been sufficiently studied.

3.6.2 Key issues

There are many plant pathogens species, some of which are of greater concern than others. In this context *Phytopthora ramorum* is notable as a plant pathogen which is attracting interest at national and international level. This plant pathogen is known to be infectious to several plant species and is a notifiable disease in the UK [UKSI n°2155 and Commission Decision (2002/757/EC)].

Composting of green waste by windrows may not be adequate for control of some pathogens. Composting by processes that match the requirements of the animal by-products order would pose less of a risk. The environmental risk from the spread of plant pathogens may be significant and not readily prevented or observed and therefore a precautionary approach is warranted.

A study by WRAP found that whilst composting at a temperature of 55^oC for at least 3 days was sufficient to eradicate most pathogens, some resistant organisms such as *C. perfringens, C. botulinum* and the cysts and eggs of protozoan and *helminth* parasites may survive. There is also a risk that *E. coli* and *Salmonella* may grow in the final compost product where the organic material has been poorly stabilised. The report concluded that more research was required to determine the risk of *E. coli* and *Salmonella* developing in finished compost, and also on the survival of temperature resistant bacteria such as *C. perfringens. E. coli* and *Salmonella* are the two surrogate pathogen paramters used to determine pathogen content in composts for the PAS100 quality compost standard.

An investigation in 2004 also commissioned by WRAP found that Enterohaemorrhagic *E. coli*, *Salmonella typhimurium* and *S. enteriditis* were not detectable after 1 hour at 50^oC, and therefore concluded that green waste would not be a significant risk for the spread of most bacterial diseases. However, this study did not investigate the growth of these bacteria in the final compost product. The investigation also found that all but the most temperature resistant plant pathogens (*Microdochiumnivale, Plasmodiophora brassicae* and Tobacco Mosaic Virus, *Microdochium nivale, Phytophthora nicotianae*) were eradicated by temperatures of 52^oC held for 7 days.

When considering the management of waste and the potential for dispersal of plant pathogens, it is clear that there are many pathways whereby plant pathogens may be transported to the receptor before the waste is treated in any composting plant. For example, routes of dispersal may occur if the infected waste material is home composted, transported in open trailers by householders to recycling centres, transported to transfer stations, and/or bulked up at transfer stations before being sent for treatment. Additionally there may be risks from the use of compost derived from infected waste that has not been adequately treated

A literature review commissioned by WRAP in 2005 found that of the 60 pathogen and nematode species investigated, compost temperature of 55^oC is sufficient to eradicate all bacterial species. The fungal plant pathogens, *Plasmodiophora brassicae*, the causal agent of clubroot of brassicas, and *Fusarium oxysporum f. sp. lycopersici*, the causal agent of tomato wilt, were more temperature tolerant. A compost temperature of at least 65°C for up to 21 days was required for eradication. Several plant viruses, particularly Tobacco Mosaic Virus (TMV) were temperature tolerant. However, there is evidence that Tobacco Mosiac Virus and Tomato Mosaic Virus are degraded over time in compost, even at temperatures below 50°C. The review singled out in-vessel composting systems as not being sufficient to degrade plant pathogens, as where the composting material is not turned, this increases the risk of cool-spots in the mix.

The risk assessment covered treated industrial wastes but did not include untreated waste that is currently spread to land, such as animal manures.

<u>Sewage sludge</u>

The principal method employed in the UK for pathogen inactivation is mesophilic anaerobic digestion. Mechanisms for pathogen inactivation in this process is still poorly understood. Smith *et al.* (2008) also found that further research is necessary into enteric microbes, and to quantify the decay of enteric viruses in sludge-treated agricultural soil. However, a report commissioned by UKWIR in 2003 found that the risk to the UK population is negligible where the Safe Sludge Matrix is adhered to. The Safe Sludge Matrix stipulates that a minimum of 10 month interval must be observed between spreading of the sludge and harvest, and this is sufficient to compensate for any inefficiencies in the sludge treatment process. Lang *et al.* (2003) found that thermally dried or composted sewage sludge did not contribute to background soil level of *E. Coli,* but anaerobically digested sludges did increase *E coli* levels. However, the survival of the bacteria was limited to 3 months. A field trial carried out by ADAS also showed that *E. Coli O157*, *Salmonella* and Campylobacter survived for up to 3 months in stored slurries, and *Listeria* for up to 6 months. They also found that the bacteria *E. Coli* survived in the soil for up to 1 month after application.

Avery *et al. (2006)* found that sub-surface injection may reduce the risk of pathogen survival.

<u>Manure</u>

Defra's review of agriculture reviewed all Defra research in to agriculture between 1990 and 2005. This review found that there is significant pathogenic risk to contaminate food crops (particularly ready to eat crops e.g. salads) where untreated animal manure is applied to the land. Pathogens of particular concern were bacteria *Salmonella, campylobacter* and entero-hemorrhagic *E. Coli*, viruses and parasitic protazoa such as *Cryptosporidium* and *Giardia.* These pathogens can also pose a risk in run-off to surface waters, resulting in illness in humans from bathing waters. The review also found that some pathogens could be transported up 1500m from the site of spreading via aerosol dispersion in small amounts, particularly from slurry spreading. The most cost effective barrier for transmission of these pathogens was longer storage periods prior to application, although this would increase ammonia, nitrous oxide and methane emissions during storage.

4. KEY FINDINGS AND CONCLUSIONS

Data from over 4500 sources have been collated and used to assess the impact and benefits of the application of a range of wastes from different treatment processes to land. A review of the available literature has also been undertaken.

4.1 Impact to soil quality and agronomic benefit

The analysis methodology allows a comparison of the differences between waste input types and waste treatments based on their use as a fertiliser or soil amendment to increase soil organic carbon or potentially available nitrogen.

The study highlights that specific waste characteristics relevant to this assessment are not routinely measured during waste characterisation. The application of assumed values limits the reliability of any interpretation of the results, although this approach demonstrates a useful way of comparing waste types. In addition, only one soil type was considered for this assessment, and application rates will vary on different soil types.

The characteristics where data are not available are:

- the extent of organic carbon mineralization in soil;
- the extent of organic nitrogen mineralization in soil;
- the mineral nitrogen content of wastes;
- the available P content of organic wastes in the soil environment;
- the amount of nitrogen released as N_2O in the soil environment and its dependency, if any, on nitrogen load and nitrogen species; and
- the amount of ammonia lost to atmosphere from different wastes.

Assessment of this data every time a waste is applied to land may be considered excessive. However, it is important to establish basic characterisation data for these materials in order to predict their impacts and benefits, particularly for new or novel wastes. Current routine organic waste characterisation data are insufficient to make realistic predictions on the impact of the organic waste in the soil environment, and it was therefore necessary to make a number of assumptions for the assessment. The large variability within different waste streams for many parameters also highlights the need to consider materials on a case-by-case basis.

The study highlights that there are differences between waste treatments (principally composted and un-composted wastes) as well as differences between waste input types to consider. Materials such as sewage sludge are more useful as fertilisers, and composts are potentially more useful as soil amendments. Future anaerobic digestates are more likely to be considered as similar to sewage sludge and used as fertilisers unless they have been composted.

The approach used in this report would allow comparisons between sewage sludge with any other waste spread to land in the future. It could be used to evaluate the efficacy of land application and waste specific application rates and whether certain of the waste characteristics need to be more closely monitored than others. For example, this study indicates that zinc accumulation in soils to which large amounts of organic wastes are added may be a significant risk.

Further work is recommended to characterise waste for parameters relevant to soil. Establishing links and correlations between the response in soil and appropriate routine laboratory tests would enable extrapolation of laboratory waste characterisation tests to predict soil fate and effect.

4.2 Surface and groundwater

The assessment procedure used in this project represents a worst case screening approach and it is possible that use of site specific conditions on a waste specific basis will show that there are few risks to surface and groundwaters from the list of organic wastes reviewed. However, the current review does serve to highlight those wastes where further, more detailed review is required.

Although priority hazardous substances are present in the list of wastes reviewed for this study, they are generally present at concentrations that would require little or no dilution to reach background concentrations in UK surface and ground waters based on calculated 95%ile leachate concentrations. The exception is a number of sewage sludge wastes and organic fractions from treated MSW. The circumstances under which sampling and testing has been undertaken is unknown and these data may relate to specific industrial catchments in the case of sewage sludge or episodic contamination in the municipal waste stream. Further data, with an auditable sampling history is required before the cause of data variability for these waste streams can be identified. This can then be used to make a more sensitive evaluation of risk.

The predicted leachability of lead, chromium, nickel and copper indicates there are potential water quality issues from many wastes, in particular sewage sludges and composts. Laboratory leaching data must be generated before these initial conclusions can be verified, again with clear traceability to waste origin and the treatment process generating the material. The initial screen indicates that zinc is not a problem parameter with respect to surface and groundwater.

In many areas of England and Wales, phosphorous and nitrogen levels are high and many water bodies are failing to achieve good status. Using the 95^{th} percentile concentrations, most of the wastes studied for this project have the potential to cause harm to surface and ground waters due to high concentrations of nitrogen and phosphorous. The exception to this statement relate to phosphorous levels in the 'other' waste category. The application of wastes that contain high levels of phosphorous and nitrogen to land should be undertaken with care to avoid compromising the ability to achieve good status for water bodies in England and Wales.

For this type of assessment, leachability data are the most suitable. However, in the absence of suitable leachability data, total values were used, which limits the confidence that can be placed in the results. In addition, concentrations were assessed at the 95^{th} percentile level, and therefore this represents a worst case scenario. The assessment does however highlight the need to follow good practice when applying wastes with high nutrient content, and that more work is needed in this area.

4.3 Greenhouse gas emissions

The review undertaken in this project confirms that emissions of N_2O and ammonia are influenced by the same factors as those that determine emissions from other organic manures: potentially available nitrogen content, moisture content, pH, soil type and time of application in relation to the period of excess winter rainfall. Analysis of digestates should provide a basis for reasonably accurate estimates of emissions and crop nitrogen uptake. Predictions of greenhouse gas emissions have been based on a simplistic model, but this form of assessment could be used in the future when more sophisticated models are developed.

Emissions of ammonia, N_2O, leaching and crop nitrogen uptake may be made on the basis of the total available nitrogen content of the digested slurries. Where necessary, the estimates of ammonia emission may be modified using the dry matter relationship reported in the IAEUKA.

4.4 Agronomic benefits

Organic waste application to agricultural land is often justified on the basis of provision of plant nutrients, in particular nitrogen, P and K. Sewage sludge is rich in available nitrogen and compared with most other organic materials would be applied at modest loads in order to provide crop nitrogen fertilizer requirements. Sewage sludge is, however, rich in P and poor in K so on its own does not provide a complete fertilizer balance. Excessive P application from sewage sludge is an environmental concern.

Compost can provide crop nitrogen requirements, but very large compost loadings are required to supply the small portion of mineralisable nitrogen from such a stable nitrogen fertility source. While compost has been demonstrated to improve soil chemical and physical properties, it is not a good source of potentially available nitrogen. However, composts are rich in P and K and modest application of compost would be sufficient to supply these crop nutrients. If sewage sludge and composts were applied together, the difference in nitrogen availability between sewage sludge and composts would compliment each other and provide balanced applications of nitrogen, K, and P and thus minimise inputs of inorganic fertilisers. However, although this combined application of different organic wastes with different plant nutrient properties is seen as a sensible approach it would still be difficult to prevent excessive P applications unless only modest applications were made which were supplemented with inorganic nitrogen fertiliser. Digestates produced, for example, from food wastes would be expected to have similar properties to sewage sludge and be a substitute for sewage sludge.

Large annual application rates of compost greatly increase soil carbon, nitrogen, P and metal concentrations compared with the standard fertility. The high rates of carbon added would be expected to improve soil physical properties, such as bulk density, porosity, and water-holding capacity, which provide agronomic and environmental benefits. However, the environmental impacts and lack of sustainability of repeated large applications would require careful controls on this practice. Soil physical properties were improved with the application of compost, but the positive effects occurred more quickly with the greater rates. After three years, improvements in some soil physical properties demonstrated that benefits from long-term, small compost rate additions may accrue with time. Understanding the carbon replacement rate is necessary to calculate the rate of organic amendment required to increase or maintain soil quality-enhancing organic matter concentration. The input of biodegradable organic matter would enhance microbial growth which also aids soil structure. However applying as a single application rather than many smaller applications may cause temporary soil overloads which may be considerable for unstabilised wastes including digestates. This would be an area to study as part of an assessment of the impact of wastes with different extents of biostabilisation.

4.5 Animal and human health

A considerable amount of research has been undertaken to assess the risks from human pathogens likely to be present in biosolids derived from sewage. The organisms responsible are well known and no new pathogens, as such, were identified in this review to challenge the security of this route as an option for land application of biosolids. However, risks from existing organisms are not constant, and, for whatever the reason, their prevalence may increase or they may become of more concern through, for example, acquisition of resistance to certain antibiotics. Therefore, it is important to maintain surveillance of changing patterns in infectious disease epidemiology and use the information to re-evaluate the risks.

4.6 Guidelines for application of materials to land

Waste characteristics were found to vary significantly even where input material and treatment type are identical. It is not clear whether this is due to inherent variability within the materials or differences in the large number of data sources used for this study. Comparison between materials was difficult due to this variability.

Data collected for regulatory compliance (principally for paragraph 7 exemptions) should be standardised as far as possible. Data on similar waste types should be collated regularly to assess against data already collated to determine potential impact. More detail should be required from operators on waste types and quantities, so cumulative impact can be quantified using the methods outlined here.

Robust data needs to be collated for the following parameters that limited the assessment possible in this study.

- the extent of organic carbon mineralization in soil;
- the extent of organic nitrogen mineralization in soil;
- the mineral nitrogen content of wastes;
- the available P content of organic wastes in the soil environment;
- the amount of nitrogen released as N_2O in the soil environment and its dependency, if any, on nitrogen load and nitrogen species; and
- the amount of ammonia lost to atmosphere from different wastes.

4.7 Suggested minimum waste characterisation suite

The suggested waste characteristics and testing that would be required in order to provide a greater understanding of the agronomic benefit and environmental impact are given in Table 4.1.

Table 4.1 Suggested waste characterisation testing required to improve prediction of agronomic benefit and environmental impact of organic wastes spread to land

Waste Parameter	Benefit or adverse impact	Relevant waste tests	Correlating soil test
ammonia	Air emission	Extractable ammonium pH Dry matter	Testing to confirm correlations used for manure applications can be applied to all wastes
potentially available nitrogen	Plant nutrient content	Laboratory soil nitrogen mineralization test	Confirm reflects soil conditions.
Available P	Plant nutrient content. P mobility as pollutant	Laboratory P availability testing.	Confirm reflects P availability in soil.
Biodegradability	Soil quality, nutrient releases, air emissions	Short and long term aerobic biodegradability tests to determine initial rate of degradation and the full extent of degradation	Confirm and correlate with waste decomposition in soil
Organic pollutants	Soil contamination, crop contamination and diffuse pollution	Possible ecotoxicological screening tests	Correlation with soil fate and effect studies

Table 4.2 Summary of application rates to achieve for anaerobic digestates by input waste type

Waste type	Maximum application rate (kg/ha DM)	Limiting factors
BMW; Blood and BMW	6.5 - 3.4	Nitrogen
BMW and Blood	3.1 - 2.5	Nitrogen
BMW; Gut content and BMW	11 - 4.7	Nitrogen
BMW and Gut content	3.7 - 3.4	Nitrogen
Bio waste municipal and Foodwaste (general)	6.4 - 2.1	Nitrogen
Foodwaste (general); Cardboard and Catering Waste	8.4 - 5.5	Nitrogen
Foodwaste (general) and Cardboard	4.8 - 4.1	Nitrogen
Foodwaste (general); Cattle Slurry and Catering Waste	7.7 - 4.0	Nitrogen
Foodwaste (general) and Cattle Slurry	3.7 - 3.4	Nitrogen
Not specified	8.1 - 3.0	Nitrogen
Manure and biobin material	5.8 - 3.9	Nitrogen
MBT residues	17 - 17	Nitrogen
BMW	15 - 7.9	Nitrogen
Bio waste municipal	15 - 15	Nitrogen
MSW and manure	4.2 - 3.4	Nitrogen
Fish farm (faeces & uneaten food)	27 - 26	Nitrogen
Sludges from cleaning for food prepn	0.4 - 0.4	Nitrogen
Foodwaste (general)	10.0 - 2.5	Nitrogen
Sewage sludge (general)	6.4 - 4.2	Nitrogen
Livestock slurry	7.6 - 7.6	Nitrogen
Poultry manure	17 - 17	Nitrogen
Cattle manure	11 - 11	Nitrogen

4.8 Recommendations for future work

The lack of waste characterisation data relevant to the fate in and impact on the soil environment means it is not possible at this stage to make strong recommendations for potential guidance change. We consider that the current guidelines for nutrients as presented in RB209 are applicable and can be amended as more data becomes available on other organic wastes. For example, the assumption for available P as given in RB209 is still recommended as a precautionary approach until robust P availability data are available. Measures limiting nitrogen applications such as in NVZs are based on total nitrogen and again are precautionary as it could be argued that actual available nitrogen is the relevant nitrogen component. Therefore nitrogen guidance may be amended in terms of available nitrogen when further relevant data for specific wastes becomes available. The metal limits applied for sewage sludge regulations seem to provide a benchmark for limiting organic waste applications to minimise risks from metal accumulation in soil. These metal limits would put a constraint on high loadings of composts as soil improvers for example.

The dataset for sewage sludge spread to land should be updated to take account of changing sludge characteristics brought about by legislative changes and new technology.

Further study is required to determine waste specific testing for routine compliance. Future data collection should focus on biodegradation of wastes and leachability properties (e.g. the BS EN 12457-3 batch leaching test and appropriate leaching behaviour tests). Most waste characterisation does not include biodegradability tests and where these have been undertaken, they are generally rapid laboratory tests which may not reflect decomposition in the soil. A comprehensive dataset of biodegradation data are required in order for a full assessment to be undertaken.

References to published material

9. This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project.

Consim 1.06. Contamination Impact on Groundwater: Simulation by Monte Carlo Method. EA and Golder Associates 2002 (Environment Agency R&D project P2-007). Available on http://www.consim.co.uk/.

DEFRA Research In Agriculture And Environmental Protection Between 1990 And 2005: Summary And Analysis (ES0127).

Directive 2008/105/EC of the European Parliament and of the Council of 16 December 2008 on environmental quality standards in the field of water policy, amending and subsequently repealing Council Directives 82/176/EEC, 83/513/EEC, 84/156/EEC, 84/491/EEC, 86/280/EEC and amending Directive 2000/60/EC of the European Parliament and of the Council.

Gendebien, A., C. Carlton-Smith, M. Izzo, and J.E. Hall. 1999. UK sewage sludge survey, national presentation. R&D Tech. Rep. P165. Environ. Agency, Bristol, UK.

Noble and S.J. Roberts (2005) A Review Of The Literature On Eradication Of Plant Pathogens And Nematodes During Composting, Disease Suppression And Detection Of Plant Pathogens In Compost, Horticulture Research International.

Olsen, S.R., C.V. Cole, F.S. Watanabe, and L.A. Dean. 1954. Estimation of available phosphorous in soils by extraction with sodium bicarbonate. U.S. Dep. of Agric. Circ. 939.

Pain BF, Misselbrook TH, Clarkson CR, Rees YJ. 1990. Odour and ammonia emissions following the spreading of anaerobically-digested pig slurry on grassland. Biological Waste 34, 259–267.

Smith (2008)The Implications for Human Health and the Environment of Recycling Biosolids on Agricultural Land.

WRc (2003) Pathogens in biosolids – Microbiological Risk Assessment.