



# Evidence

Assessment of MBT input and output quality

Report: SC030144/R4

Better regulation programme  
Evidence Directorate

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Miranda Kavanagh  
**Director of Evidence**

# Executive summary

Mechanical-biological treatment (MBT) refers to systems for the treatment of mixed waste and municipal solid waste feedstocks. MBT is a generic term used for a process stream that includes mechanical sorting and separation of waste into distinct fractions of biodegradable and non-biodegradable materials and subsequent biological processing of the organic-rich fraction. Mechanical Heat Treatment (MHT) in turn refers to similar systems that incorporate heat processes such as autoclaving.

One means by which the biodegradable fraction can be treated is through composting processes to form a compost-like output (CLO); this may either be sent to landfill as a bio-stabilised waste, or alternatively may have a number of uses, including its application to land.

The variety of processes used in MBT/MHT plants and the variability in the input feedstocks leads to a significant variability in the form and characteristics of CLO, both between and within such plants. This variability, in terms of the physical and chemical characteristics of the CLO, makes it especially difficult to assess the potential environmental and human health risks following CLO application to soils.

In 2008, the Environment Agency conducted a screening project which identified a number of chemicals that should be prioritised for closer scrutiny in CLO samples. This work also highlighted key uncertainties in the assessment of risks from application of CLO to agricultural land (Environment Agency, 2009).

The projected reported here builds on the results of that screening project. This latest project aimed to reduce the uncertainty in the risk assessment process. In addition, this report refines the list of priority chemicals, thereby helping to establish a pragmatic and cost-effective approach to their monitoring. For example, chemicals that have not been detected in previous samples of CLO in the UK have been omitted. In addition, chemicals for which detection limits are orders of magnitude greater than effects concentrations have also been removed from the priority list.

Monthly sampling and analysis of CLO from four plants was undertaken over a five-month period. This report evaluates sampling over an extended time period to help develop a framework for monitoring compliance with possible CLO regulation. The monitoring results are also used to estimate exposure concentrations for risk assessment purposes. We also calculate, for several chemicals detected in MBT CLO, the number of samples required to detect differences (of 10%, 20%, 30%, etc.) between the mean recorded levels and “regulatory standards” (or “limit values”). For triclosan, the number of samples required to detect such differences would significantly exceed 12 (i.e. monthly samples).

Through collaboration with representatives of the chemical industry and European Member States we have derived provisional limit values for several priority chemicals that may be found in MBT CLO (and many other materials that are recycled to agricultural land). Previous studies have either been unable to assess the potential environmental risks from these chemicals, or based their metrics on limited ecotoxicity data, so their estimated limit values were extremely precautionary and uncertain.

It has been possible to derive relatively robust limit values for direct toxicity and secondary poisoning for perfluorooctanesulphonate (PFOS), triclosan, butylbenzylphthalate, dibutylphthalate, diethylhexylphthalate and several polycyclic aromatic hydrocarbons (PAHs).

This report also considers the nitrogen and metal release characteristics of CLO after its application to soil through the use of a pot trial. Four CLOs were applied to

agricultural soils at two rates of application before being sown with rye grass. The rye grass was harvested twice over a period of three months and analysed for trace metals and nutrient content. The results of the trial indicate that the availability of N from CLO to grass varied significantly between CLO from different sources. CLOs with an organic C:N ratio similar to that of soil organic matter (9.5–11.5) were immediately effective in supplying plant-available N.

Analyses to monitor the fate of N within CLO amended soils (i.e., mineralisation, immobilisation and leaching) clearly showed that CLO could participate in all these processes. An assessment of metal uptake by the rye grass in the pot trial showed no significant increases as compared to the untreated controls.

To improve our understanding of the variability in the physical and chemical quality of CLO, we carried out a semi-quantitative assessment of the relationship between municipal solid waste inputs and CLO. In collaboration with two of the four plants, samples were taken of input feedstock and material at key stages during the MBT/MHT process (including the final output) over the period of one production cycle. This type of assessment has only been undertaken for a few plants in Europe.

The results of this assessment showed that a wide range of chemicals were present in samples from both sites. The results of most interest were those for bisphenol A and DEHP, which distinctly showed that the concentration of these chemicals increased during the processing (possibly related to the evolution of the plastic content). This trend was also observed for some PAHs and triclosan.

The results of this work provide some interesting insights into the effect of treatment upon the organic chemical content of the material over the course of the MBT process, however there is insufficient data to be able to draw definitive conclusions.

Since conducting this part of the study, both sites have either undertaken or plan to undertake refinements to their processes; these enhancements are likely to significantly affect the chemical quality of the outputs, so further research is recommended.

This report clarifies a number of key uncertainties associated with the assessment of potential risks to environmental and human health from the application of CLO to agricultural land. The findings provide further evidence on which to formulate policy and deliver a robust scientific framework through which CLO can be regulated in a sustainable and transparent way.

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# 1. Introduction

## 1.1 Report structure

This report attempts to address key uncertainties in the assessment of potential risks from the application of waste-derived organic material to land, specifically compost-like output (CLO) produced from mixed waste feedstock via a mechanical biological treatment (MBT) or mechanical heat treatment (MHT) process.

A previous screening assessment of contaminants within CLO (Environment Agency, 2009a), identified four key issues, namely:

- the need for additional physico-chemical data for CLO, collected over an extended time period to account for temporal variability, in order to estimate robust exposure concentrations;
- the inherent precaution associated with metrics by which potential environmental risks are assessed;
- the intrinsic behaviour of macronutrients in CLO when it is recycled to agricultural land;
- the relationship between the chemical characteristics of the input and output material, and the causes of the significant variability in output product.

The introductory chapter of this report briefly describes what CLO is and how these four key issues were identified. It also outlines the aims and objectives of this project.

Chapter 2 explains how the chemical determinands to be monitored in CLO have been reprioritised. The chapter outlines the sampling and analysis scheme which we followed at four MBT/MHT plants in the UK. We then discuss our analysis of samples taken over a five-month period in the context of general compost quality. The methodology to estimate exposure concentrations from these data is described in detail, with examples of how such data may be used to further refine the list of determinands and produce an 'intelligent' sampling strategy for CLO. This chapter also outlines the results of our review of ecotoxicity data in order to derive robust limits for priority chemicals. The full reviews are given in the Annexes to Environment Agency (2009b). These contain the reviews of ecotoxicity data and the numerical details behind our derivation of predicted no effect concentrations (PNECs) for four chemicals that have been identified as priority substances and for which existing limit values were inherently uncertain and precautionary.

Chapter 3 describes the pot trial that was conducted to develop an understanding of the nitrogen release and fate characteristics of CLO applied to agricultural soils. The pot trial does not represent field conditions, but provides an opportunity to assess the behaviour of the CLO with a reduced number of potentially confounding factors. This chapter also presents the results from our analysis of metals concentrations in the second grass harvest from this trial; we contextualise these findings within the assessment of potential environmental risks.

Chapter 4 covers the methodology and results from the assessment of input and output quality. The relevance of this information in relation to the application of CLO to land for both plant operators and regulators is highlighted. The final part of this chapter

describes how plant operators may wish to develop the approach and methodology used in this study to deliver a *more* consistent and homogeneous output.

Finally, in Chapter 5, we draw our conclusions on the assessment of MBT/MHT input and output quality and make recommendations on the use of these additional data and knowledge in the delivery of a transparent, but robust, assessment of potential environmental and human health risks from the recycling of CLO to land.

## 1.2 What is CLO?

Mechanical biological treatment (MBT) is a widely-used term applied to many processes for the treatment of residual mixed waste. MBT approaches use mechanical separation to refine the feedstock by removing non-biodegradable materials, such as ferrous and non ferrous metals, glass and plastic. This separation step can occur before or after some form of biological treatment (e.g. composting or anaerobic digestion) of the organic fraction of the waste material. Mechanical heat treatment (MHT), as the name suggests, includes a heating step such as autoclaving either before or after mechanical separation. The resulting material still requires an effective biological stabilisation stage to reduce the biodegradability to produce a final CLO.

In the last five years MBT/MHT has gone from being a *potential* waste management solution to an *actual* solution in the UK; there are around 10 MBT/MHT plants in operation and more are already being constructed or planned. It is estimated that the total capacity of such plants, including those in operation and under consideration by local authorities, will be in excess of three million tonnes of waste input per year by 2010; this volume of waste will generate some 600,000–700,000 tonnes of part-stabilised biowaste (Chapman *et al.*, 2008).

MBT/MHT processes are predominantly used to increase the bio-stability of the organic fraction of the input material; the bulk of the resulting organic output (referred to within this report as compost-like output or CLO) is sent to landfill as a bio-stabilised waste. Some may be used in landfill engineering as daily cover, or restoration projects such as landfill capping. If the CLO is of suitably high quality and does not pose a significant risk to the environment, it may also be used in certain other non-agricultural applications, although these are fairly limited in scope and closely regulated.

It is theoretically possible for a wide range of contaminants from multiple domestic sources (treated wood, ash from barbecues and fires, food and animal waste, domestic chemicals and general waste for example) to be present in *both* CLO and source-segregated compost. If CLO is to be successfully and sustainably used for land applications, such as soil restoration and remediation over an extended period of time, it is necessary to assess the potential environmental and human health risks of such activities in a proportionate and robust manner. Such an assessment would provide a clear framework through which informed decisions could be made by both environmental regulators and the regulated community alike.

It is clear that within the EU, Member States take different approaches to the assessment, regulation and use of CLO (Partl and Cornander 2006; Environment Agency, 2008). In particular, there is no harmonisation across the EU of the limit values that are used to assess environmental risks from the application of CLO to land. Furthermore, national limit values generally cover only a limited number of chemicals – typically those that have been historically monitored in sewage sludge (i.e. metals).

Recent reviews suggest that organic chemicals such as pharmaceuticals, fragrances, surfactants, and ingredients in household cleaning products may pose potential environmental risks and are very likely to be found in domestic waste streams (Amlinger *et al.*, 2004; Erikson *et al.*, 2008). However, very few Member States have

limit values for many of the chemicals that fall into these categories; few Member States have undertaken any assessment of the potential risks associated with these materials going to agricultural land.

In 2008 the Environment Agency undertook a screening assessment of the potential environmental and human health risks from the application of CLO to agricultural land (Environment Agency, 2009a). This study combined analytical data collected during the course of the project together with previously collected data on the physical and chemical quality of CLO. The study used the data to conduct a screening assessment for environmental and human health risks for a number of exposure scenarios related to the use of CLO for agriculture and regeneration.

The study identified several risks, although such an outcome is not unusual for screening assessments because the assumptions they make in the absence of site specific data are always precautionary.

Yet risk assessment is an iterative process; the risks identified by this earlier screening assessment require more thorough investigation and resolution. The report of the screening assessment identified several data requirements that would reduce uncertainty and provide robust evidence from which policy towards the application of CLO to land could be based.

This project aims to meet these data requirements (see Section 0). The new data will then be used to update the risk assessment. This 'second iteration' forms the basis of a separate report (Environment Agency 2009b).

### 1.3 Project aims and objectives

The aim of this project is to perform additional analyses and assessments on a range of CLOs to provide new data that can feed into a revision of the earlier risk analysis on the application of CLO to land. This project will therefore provide an evidence base for the formulation of policy and regulation regarding the potential application of CLO to land.

There are four specific objectives to the work, which address uncertainties in the Environment Agency's previous risk assessment (Environment Agency, 2009):

- **Estimate exposure concentrations for a prioritised list of chemicals.**  
Through monthly sampling and analysis of CLO from four MBT/MHT plants, this project will derive estimates of exposure concentrations for a prioritised list of chemicals. These estimates will be used in a second iteration of assessment of potential environmental and human health risks resulting from the application of CLO to land. Further, using these estimated exposure concentrations, the project will consider the sampling requirements needed to apply a compliance-based approach, similar to that used to assess water quality.
- **Improve the accuracy of the current limit values.**  
The project aims to improve the accuracy of current limit values so that the potential environmental risks can be assessed for several priority chemicals; at present these limit values are highly precautionary and uncertain.
- **Undertake a controlled pot trial.**  
The pot trial is designed to determine the nitrogen release characteristics of CLO and assess the subsequent uptake of nutrients and metals in rye

grass. The trial will provide an indication of the potential fate and behaviour of metals and nutrients from MBT/MHT CLO if applied to agricultural soils.

- **Assess the relationship between input feedstock quality and output CLO quality.**

The project will take samples of material at key stages in the MBT/MHT process for analysis for organic micropollutants. These laboratory assessments will reveal how an MBT/MHT process affects the chemical composition of mixed waste material and show to what extent, if at all, input quality and output quality may be related to each other. This aspect of the project may also help to establish the component(s) of the feedstock that are the source of the chemicals identified as being of potential concern in the final output material. It may also prove possible to identify which stages of an MBT/MHT process offer the best chemical refinement and to assess the potential to improve the specific MBT/MHT process to optimise output quality and consistency.

## 2. Sampling, analysis and interpretation

The potential environmental and human health risks from the application of CLO to land can be assessed effectively and robustly only if representative samples are taken and analysed for appropriate chemicals. This sampling must be conducted in a manner that facilitates a logical estimation of exposure concentrations in the environment.

It is tempting to specify an extensive list of chemicals in CLO, especially organic micropollutants, that may pose a potential risk to humans and the environment. However, such an exhaustive list of chemical determinands is likely to make any useful estimate of exposure concentrations and calculations of limit values prohibitively expensive and not adequately informative. The practical limitations of commercial laboratories, the complex matrix and the significant heterogeneity of the CLO all add uncertainty to any estimates, so an exhaustive list will provide little in terms of evidence on which to base a risk assessment or develop a framework for assessing compliance for CLO usage.

This chapter describes how the list of chemical determinands produced in previous work (Environment Agency, 2009) has been reprioritised. It also presents the results of a sampling programme undertaken over five months at four plants in England and Wales using the revised determinand list. The use of these data to estimate environmental exposure concentrations is described, as is the possibility of designing a plant specific 'intelligent' monitoring strategy. The chapter concludes with a review of ecotoxicity data for priority chemicals.

### 2.1 Chemical prioritisation and analytical uncertainties

A prioritisation of the chemical determinands under scrutiny is essential so that the analysis of CLO is as cost-effective and informative as possible. A prioritisation process was undertaken in the preceding project (Environment Agency, 2009). However, a further examination of the analytical results obtained from this previous work and a comparison of the specific determinands (in terms of their effect levels, limits of detection and environmental behaviour) make it possible to reduce the list of determinands requiring further assessment.

The determinands can be readily split into two distinct categories. The first is shown in Table 2.1 and includes routine determinands for characterising composts (BSI, 2005), sewage sludges (DoE, 1986) and topsoil (BSI, 2007). Detection of these determinands is generally relatively low cost and readily performed by most analytical laboratories. The collation of the physico-chemical data such as pH, conductivity, carbon and macronutrients also aids the contextualisation and interpretation of many of the other determinands.

**Table 2.1 Routine determinands for the characterisation of composts and other materials recycled to agricultural land (Environment Agency, 2009).**

Total nitrogen (N)	Ammonium (N) (NH <sub>4</sub> -N)	Organic carbon (C) by wet chemistry
Total phosphorus (P), reported as phosphate (P <sub>2</sub> O <sub>5</sub> )	Nitrate – N (NO <sub>3</sub> -N)	Total zinc (Zn)
Total potassium (K), reported as potash (K <sub>2</sub> O)	Conductivity	Total copper (Cu)
Total magnesium (Mg), reported as magnesium oxide (MgO)	pH	Total cadmium (Cd)
Total sulphur (S), reported as the oxide (SO <sub>3</sub> )	Oil content	Total nickel (Ni)
Total calcium (Ca)	Total neutralising value (as CaO)	Total lead (Pb)
Dry matter	Biological oxygen demand (BOD)	Total chromium (Cr)
Total plastic	<i>E. coli</i>	Total mercury (Hg)
Stability as measured by carbon dioxide (CO <sub>2</sub> ) evolution	<i>Salmonella</i> spp.	Total fluoride (F)
Total selenium (Se)	Physical contaminants (glass, plastic, metal)	Total molybdenum (Mo)
Total arsenic (As)		

The second category of determinands cannot be viewed as 'routine'. The list of chemicals analysed in previous work (Environment Agency, 2009) is shown in Table 2.2. This table also shows the half-lives of the chemicals in soils (expressed as degradation rates), the concentration range in CLO (based on an analysis of three and five CLO samples) and the effect concentrations for human and environmental health. The final column in Table 2.2 gives an indication of the limit of detection (LoD) for wastes and soils using current routine methodologies; this column states whether the method used for determination is accredited (e.g. United Kingdom Accreditation Service, UKAS, or the Environment Agency's Monitoring Certification Scheme, MCERTS).

Taking all these factors into account it is possible to reduce the list of determinands in an evidence-based way. For example, there is little point in analysing for a chemical which is never found with current analytical methods, or which has an effect concentration which is significantly lower than the detection limit in CLO, or for which risk characterisation ratios (RCRs) are orders of magnitude below unity.

**Table 2.2 Chemical determinand reprioritisation.**

<b>Chemical Name</b>	<b>Cas. No</b>	<b>Persistence in soil/sediment matrices</b>	<b>Concentration range in CLO (n = 3–5)</b>	<b>Current environmental limit value*</b>	<b>Current human health limit value<sup>##</sup></b>	<b>Is the method accredited and if so what is the level of detection (LoD)?</b>
Sum of all polychlorinated dibenzo-dioxins (PCDDs) and polychlorinated dibenzo-furans (PCDFs)	-	Half-life in soil 3650–43800 days	2.5–36 ng kg <sup>-1</sup>	4 ng kg <sup>-1</sup> I-TEQ	360 ng kg <sup>-1</sup>	Yes, 0.3–3 ng kg <sup>-1</sup>
Pentachlorophenol	87-86-5	Half-life in soil >7 months	< 1 mg kg <sup>-1</sup>	0.6 mg kg <sup>-1</sup>		Yes, 1 mg kg <sup>-1</sup>
PCBs	-	Half-life in soil 90–17,239 days	8–67 µg kg <sup>-1</sup>	0.5 mg kg <sup>-1</sup>		Yes, 0.9–2 µg kg <sup>-1</sup>
Hexabromocyclododecane	25637-99-4	Half-life in soil 119 days (aerobic)	ND	5.9 mg kg <sup>-1</sup>		No, 1 mg kg <sup>-1</sup>
Tert-dodecyl mercaptan	75-66-1	Half-life in soils >100 days	< 2.0 mg kg <sup>-1</sup>	0.51 mg kg <sup>-1</sup>		No, 2.0 mg kg <sup>-1</sup>
Nonylphenol	25154-52-3	Half-life in soils 20–300 days	< 0.1 mg kg <sup>-1</sup>	1.7–3.2 mg kg <sup>-1</sup>		No, 0.1 mg kg <sup>-1</sup>
Decabromodiphenyl ether	11163-19-5	Persistent (half-life in freshwater sediments > 120 days)	<0.5 mg kg <sup>-1</sup>	≥ 87 mg kg <sup>-1</sup>		No, 0.1 – 1 mg kg <sup>-1</sup>

Table 2.2 continued overleaf

Table 2.2 continued

Chemical Name	Cas. No	Persistence in soil/sediment matrices	Concentration range in CLO (n = 3–5)	Current environmental limit value*	Current human health limit value**	Is the method accredited and if so what is the level of detection (LoD)?
Octabromodiphenyl ether	32536-52-0	Persistent (half-life in freshwater sediments > 120 days)	ND	$\geq 20.9 \text{ mg kg}^{-1}$		No, 0.1–1 mg kg <sup>-1</sup>
Pentabromodiphenyl ether	32534-81-9	Half-life in soil >29 days	ND	$0.38 \text{ mg kg}^{-1}$		No, 0.1–1 mg kg <sup>-1</sup>
Perfluorooctane sulfonate (PFOS), PFOS derivatives and substances that degrade to PFOS	1763-23-1	Persistent (half-life in freshwater sediments > 120 days)	$0.2 \rightarrow 300 \text{ } \mu\text{g kg}^{-1}$	$10.6 \text{ } \mu\text{g kg}^{-1}$		Yes, $0.1 \text{ } \mu\text{g kg}^{-1}$
Triclosan	3380-34-5	Half-life in soils 17–35 days	$1.8\text{--}18 \text{ mg kg}^{-1}$	$0.096 \text{ } \mu\text{g kg}^{-1*}$		No, $0.2 \text{ mg kg}^{-1}$
Tributyl tin	56-35-9	Half-life in soil 15–20 weeks	$<5 \text{ } \mu\text{g kg}^{-1}$	$0.059 \text{ } \mu\text{g kg}^{-1}$		Yes, $2\text{--}3 \text{ } \mu\text{g kg}^{-1}$
Butylbenzylphthalate	85-68-7	Half-life in soil 7–59.2 days	$<0.1\text{--}6.3 \text{ mg kg}^{-1}$	$1.39 \text{ mg kg}^{-1}$	$294000 \text{ mg kg}^{-1}$	No, 0.1–0.5 mg kg <sup>-1</sup>
Di-n-nonylphthalate	84-76-4	-	ND	-		No, 0.1–0.5 mg kg <sup>-1</sup>
Di-n-octylphthalate	117-84-0	-	$0.15\text{--}2.2 \text{ mg kg}^{-1}$	-		No, 0.1–0.5 mg kg <sup>-1</sup>
Dibutylphthalate	84-74-2	Half-life in soil 1.0–4.8 days (unsterilised)	$<0.1\text{--}6.7 \text{ mg kg}^{-1}$	$2 \text{ mg kg}^{-1}$	$22600 \text{ mg kg}^{-1}$	No, 0.1–0.5 mg kg <sup>-1</sup>

Table 2.2 continued overleaf



Table 2.2 continued

Chemical Name	Cas. No	Persistence in soil/sediment matrices	Concentration range in CLO (n = 3–5)	Current environmental limit value*	Current human health limit value**	Is the method accredited and if so what is the level of detection (LoD)?
Diethylhexylphthalate	117-81-7	Half-life in soil 95 days (suspended 1:1 soil /water)	13–96 mg kg <sup>-1</sup>	> 13 mg kg <sup>-1*</sup>	60 mg kg <sup>-1</sup>	No, 0.1–0.5 mg kg <sup>-1</sup>
Diethylphthalate	84-66-2	-	<0.1–3.9 mg kg <sup>-1</sup>	-	17000 mg kg <sup>-1</sup>	No, 0.1–0.5 mg kg <sup>-1</sup>
Diisobutylphthalate	84-69-5	-	<0.1–9.2 mg kg <sup>-1</sup>	17 mg kg <sup>-1</sup>	83 mg kg <sup>-1</sup>	No, 0.1–0.5 mg kg <sup>-1</sup>
Dimethylphthalate	131-11-3	-	<0.1–0.69 mg kg <sup>-1</sup>	84 mg kg <sup>-1</sup>	82 mg kg <sup>-1</sup>	No, 0.1–0.5 mg kg <sup>-1</sup>
Acenaphthene	208-96-8	Half-life in soil >1000 days	15–62 µg kg <sup>-1</sup>	38 µg kg <sup>-1</sup>		Yes, 0.1 µg kg <sup>-1</sup>
Acenaphthylene	91-20-3	-	6.8–55 µg kg <sup>-1</sup>	290 µg kg <sup>-1</sup>		Yes, 1 µg kg <sup>-1</sup>
Anthanthrene	-	-	<30–98 µg kg <sup>-1</sup>	-		Yes, 30 µg kg <sup>-1</sup>
Anthracene	120-12-7	Half-life in soil > 2000 days	35–78 µg kg <sup>-1</sup>	130 µg kg <sup>-1</sup>		Yes, 20 µg kg <sup>-1</sup>
Benzo(a)anthracene	56-55-3	Half-life in soil > 2900 days	74–160 µg kg <sup>-1</sup>	79 µg kg <sup>-1</sup>		Yes, 20 µg kg <sup>-1</sup>
Benzo(a)pyrene	50-32-8	Half-life in soil > 2900 days	39–160 µg kg <sup>-1</sup>	53 µg kg <sup>-1*</sup>	800 µg kg <sup>-1</sup>	Yes, 20 µg kg <sup>-1</sup>
Benzo(b)fluoranthene	205-99-2	Half-life in soil 3285 days	<200–370 µg kg <sup>-1</sup>	280 µg kg <sup>-1</sup>		Yes, 200 µg kg <sup>-1</sup>

Table 2.2 continued overleaf

Table 2.2 continued

Chemical Name	Cas. No	Persistence in soil/sediment matrices	Concentration range in CLO (n = 3–5)	Current environmental limit value*	Current human health limit value**	Is the method accredited and if so what is the level of detection (LoD)?
Benzo(e)pyrene		-	79–200 µg kg <sup>-1</sup>	-		Yes, 20 µg kg <sup>-1</sup>
Benzo(ghi)perylene	191-24-2	Half-life in soil > 3322 days	51–200 µg kg <sup>-1</sup>	170 µg kg <sup>-1</sup>		Yes, 6 µg kg <sup>-1</sup>
Benzo(k)fluoranthene	207-08-9	-	<100–120 µg kg <sup>-1</sup>	270 µg kg <sup>-1</sup>		Yes, 100 µg kg <sup>-1</sup>
Chrysene	218-01-9	Half-life in soil 2957 days	100–270 µg kg <sup>-1</sup>	550 µg kg <sup>-1</sup>		Yes, 30 µg kg <sup>-1</sup>
Cyclopenta(cd)pyrene		-	11–79 µg kg <sup>-1</sup>	-		Yes, 10 µg kg <sup>-1</sup>
Dibenzo(ah)anthracene	53-70-3	-	8.6–46 µg kg <sup>-1</sup>	54 µg kg <sup>-1</sup>		Yes, 3 µg kg <sup>-1</sup>
Fluoranthene	206-44-0	Half-life in soil 2847 days	160–500 µg kg <sup>-1</sup>	1500 µg kg <sup>-1</sup>		Yes, 20 µg kg <sup>-1</sup>
Fluorene	86-73-7	Half-life in soil >1000 days	18–70 µg kg <sup>-1</sup>	1000 µg kg <sup>-1</sup>		Yes, 10 µg kg <sup>-1</sup>
Indeno(1,2,3cd)pyrene	193-39-5	-	31–130 µg kg <sup>-1</sup>	130 µg kg <sup>-1</sup>		Yes, 30 µg kg <sup>-1</sup>
Naphthalene	91-20-3	Half-life in soil < 28 days	48–160 µg kg <sup>-1</sup>	1000 µg kg <sup>-1</sup>	7–34 mg kg <sup>-1</sup>	Yes, 10 µg kg <sup>-1</sup>
Perylene		-	<30–73 µg kg <sup>-1</sup>	-		Yes, 30 µg kg <sup>-1</sup>
Phenanthrene	85-01-8	Half-life in soil >2000 days	170–490 µg kg <sup>-1</sup>	1800 µg kg <sup>-1</sup>		Yes, 20 µg kg <sup>-1</sup>
TPH Extractable C10–C40		-	527–4260 mg kg <sup>-1</sup>	-		Yes, 300–4000 µg kg <sup>-1</sup>

- Notes:     \$ These are a mix of both aerobic and anaerobic conditions.  
          # These values are a mix of Serious Risk Concentrations (RIVM, 2001 b) and Soil Guideline Values.  
          \* These have the potential to be changed in relation to new data.

Sources of data for Table 2.2:

- Environment Agency, 2005. Environmental Risk Assessment Report: Tert-dodecanethiol.  
([http://www.environment-agency.gov.uk/commondata/acrobat/tdmreport0105\\_955622.pdf](http://www.environment-agency.gov.uk/commondata/acrobat/tdmreport0105_955622.pdf))
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([http://ecb.jrc.it/DOCUMENTS/Existing-Chemicals/RISK\\_ASSESSMENT/REPORT/penta\\_bdperreport015.pdf](http://ecb.jrc.it/DOCUMENTS/Existing-Chemicals/RISK_ASSESSMENT/REPORT/penta_bdperreport015.pdf))
- United Kingdom, 2002. European Union Risk Assessment Report: 4-nonylphenol (branched) and nonylphenol.  
([http://ecb.jrc.it/Documents/Existing-Chemicals/RISK\\_ASSESSMENT/REPORT/4-nonylphenol\\_nonylphenolreport017.pdf](http://ecb.jrc.it/Documents/Existing-Chemicals/RISK_ASSESSMENT/REPORT/4-nonylphenol_nonylphenolreport017.pdf))
- United Kingdom, 2002. European Union Risk Assessment Report: bis (pentabromophenyl) ether.  
([http://ecb.jrc.it/DOCUMENTS/Existing-Chemicals/RISK\\_ASSESSMENT/REPORT/decabromodiphenyletherreport013.pdf](http://ecb.jrc.it/DOCUMENTS/Existing-Chemicals/RISK_ASSESSMENT/REPORT/decabromodiphenyletherreport013.pdf))
- United Kingdom, 2003. European Union Risk Assessment Report: Naphthalene. ([http://ecb.jrc.it/DOCUMENTS/Existing-Chemicals/RISK\\_ASSESSMENT/REPORT/naphthalenereport020.pdf](http://ecb.jrc.it/DOCUMENTS/Existing-Chemicals/RISK_ASSESSMENT/REPORT/naphthalenereport020.pdf))

Chemicals not included in this project are:

- Pentachlorophenol – PCP was not included in the list because the detection limit achievable by the laboratory is above the effect concentration; concentrations in CLOs are routinely below the detection limit.
- Hexabromocyclododecane – HBCD was not included in the list due to analytical difficulties associated with its determination in the CLO matrix in previous samples (see Environment Agency, 2009).
- Tert-dodecyl mercaptan – as with PCP, the environmental effect concentration of tert-dodecyl mercaptan is below the current detection limit and the concentrations in CLO recorded so far from samples taken from numerous sites across the UK for this chemical are all below that limit of detection.
- Nonylphenol – all previous analyses of nonylphenol in CLO from samples taken around the UK have given results below the current limit of detection.
- Decabromodiphenyl ether, octabromodiphenyl ether and pentabromodiphenyl ether – all the flame retardants presented analytical difficulties or gave levels below limits of detection; the methodology for their detection is also not accredited.
- TBT – the concentrations of TBT in CLO are below the levels of detection; the effect concentration is also nearly two orders of magnitude below that level of detection.

The metals, phthalates and PAHs in samples are determined in single suites; generally the cost for detecting additional determinands in these groups is relatively low. Thus the removal of single metals, phthalates or PAHs makes little difference to the overall analysis cost. All these substances were retained in the determinand list on the basis that they did not escalate costs.

It is important to stress that the determinand list described in Table 2.2 is not exhaustive. As new data become available, analytical techniques improve and knowledge develops, chemicals may be added or removed from the list. However, the reasoning for these changes should be clear and auditable.

## 2.2 Sampling and analysis of MBT/MHT CLO

### 2.2.1 MBT/MHT plant selection

The project team contacted a range of MBT/MHT plant operators about participating in the sampling and analysis programme. Having established contact with the plant manager, owner, or another appropriate employee, the team outlined to them the aims and objectives of the project. They were also given a written briefing with details about the project's sampling requirements, the assessment, interpretation and ownership of the data, different roles and responsibilities within the project, the expected project outputs and the likely benefits to them and their organisation.

This approach resulted in four plants participating in the project. As in previous work, plants have co-operated on the basis that the results of the sampling and analysis will not be attributed to individual operations and that anonymity is maintained. The data

will be referred to as being from Site 1, Site 2, Site 3 and Site 4 (S1–S4). Full data sets from the sampling programme are provided in Appendices A–D.

Sampling at the four sites began in December 2008 and continued through to March 2009. Duplicate samples were taken from each site on a monthly basis by Reading Agricultural Consultants Ltd, acting as a subcontractor to WCA Environment Ltd. Sampling of the CLO material was undertaken following the methodology set out in BS EN (2000) and was therefore consistent with sampling undertaken in previous work (Environment Agency, 2009a). On each sampling visit a pro forma data sheet was used for each site, detailing the age and form of the heaps sampled in addition to any local information of relevance, such as plant function, site worker perceptions and weather conditions.

The samples were delivered directly to the respective analytical laboratories following collection. Three separate laboratories were used to obtain data on all of the required determinands listed in Table 2.2, as in the previous project (Environment Agency, 2009a). No single laboratory had the capability to perform all of the analytical requirements.

A summary of the data from each of the four sites is provided in Table 2.3 to Table 2.8, categorised according to:

- physical and chemical properties;

- phthalates and perfluorocarbons;

- dioxins and furans;

- metals and other elements;

- polycyclic aromatic hydrocarbons;

- hydrocarbons;

- polychlorinated biphenyls;

- E. coli* and *Salmonella*.

A brief overview of the results from the sampling programme is given in each case. The significance of the data in relation to the risk assessment is discussed in a separate report (Environment Agency 2009b).

## 2.2.2 Summary of physico-chemical properties

In general the level of physical contaminants in all samples was high. The total quantity of glass, metal and plastic fragments greater than 2 mm in size exceeded the PAS100 (BSI, 2005) upper limit (0.5 per cent) in every case and the subsidiary limit for plastic content (0.25 per cent, or half of the total permissible value of physical contaminants) was exceeded in 19 out of 24 cases. The content of plastic and glass was high in the majority of samples. The highest recorded values for plastic and glass were 22.7 per cent (S1) and 6.6 per cent (S2), respectively. On average CLO from S1 had the highest plastic content and CLO from S2 had the highest average glass content; data were variable in all four sites.

Metal content was variable and less significant; the highest percentage content of metal fragments present in CLO was found at S2 (3.54 per cent). This value greatly exceeds the PAS100 limit, but was an isolated sample; all other samples from site S2 were below the PAS100 limit.

The content of stones in samples was highly variable within and between sites. The highest content of stones never exceeded the PAS100 value for mulch (16 per cent) at any site, although the highest value recorded in CLO from S1 and S2 exceeded the PAS100 limit for uses other than mulch (8 per cent).

pH values were slightly alkaline in CLO from S1 and S2 and slightly acidic in samples from S3 and S4. On average S2 CLO was the most alkaline material and S4 CLO the most acidic; pH values did not vary significantly within the samples at each site.

Total organic carbon content was highest in CLO from S4 (mean 38.4 per cent) and lowest in CLO from S1 (mean 13.8 per cent); mean organic carbon content in CLO from S2 and S3 was approximately 18 per cent.

Nitrogen content in CLO decreased in the order S2 > S1 > S4 > S3; CLO from S2 also had the highest level of ammoniacal nitrogen. The quantity of nitrogen was most consistent in CLO from sites S2 and S3 whereas nitrogen content in CLO from S1 and S4 was much more variable across the samples collected.

### **2.2.3 Summary of results for phthalates, perfluorocarbons (PFCs) and triclosan**

The results of the analyses of phthalates, perfluorocarbons (PFCs) and triclosan are variable; several of these chemicals are not identified above the limit of detection, although every determinand was detected in at least one of the sites on at least one occasion (Table 2.4). At least one determinand was not recorded at each site, although the undetected analyte(s) varied between sites.

There is very little pattern to the data either within any one site or between the four sites. CLO from S4 generally had the highest concentrations of phthalates in its samples across the range of analytes; in the case of individual analytes, diethylhexylphthalate concentrations were the highest or among the highest levels measured in CLO from all four sites. Levels of PFOS were relatively high in CLO from all four sites in comparison to the derived PNEC for soil (see Environment Agency, 2009b). Overall levels of PFCs were highest in CLO from S1, although the data were very inconsistent for all four sites.

The mean concentrations of triclosan in the CLOs were relatively constant across all sites with the exception of S1, where the standard deviation was very close to the mean value.

### **2.2.4 Summary of results for dioxins and furans.**

All dioxins and furans analysed were detected in the samples collected on at least one occasion (Table 2.5). Levels were highly variable and there is little pattern to the data either across or within the sites. Octachlorodibenzo-p-dioxin was measured in the highest concentrations at all sites, while the level of 1,2,3,4,6,7,8-heptachlorodibenzo-p-dioxin was also consistently high across all the sites in comparison with the remaining analytes.

**Table 2.3 Selected physical and chemical properties of MBT/MHT CLOs from four sites sampled on five separate occasions (n = 10).**

Property	Units	S1		S2		S3		S4	
		Mean	St dev	Mean	St dev	Mean	St dev	Mean	St dev
Quantity of plastic >2 mm in sample	% dry weight (dw)	9.73	9.99	0.79	0.83	1.76	2.94	1.69	0.87
Quantity of glass >2 mm in sample	% dw	5.36	4.17	6.11	1.87	7.51	3.09	2.79	1.77
Quantity of metal >2 mm in sample	% dw	0.39	0.08	0.91	1.75	0.18	0.30	0.43	0.51
Quantity of stones >2 mm in sample	% dw	3.33	3.63	2	1.29	4.17	4.11	1.45	0.95
Quantity of other physical contaminants >2mm <sup>1</sup>	% dw	0	0	0.57	0.81	BLD	n/a	9.36	18.72
Lime equivalent (as CaCO <sub>3</sub> )	%	10.92	2.13	9.19	1.13	8.0	0.59	5.65	2.21
Neutralising value	as CaCO <sub>3</sub> equiv.	6.12	1.22	5.17	0.62	4.49	0.34	3.17	1.24
Compost stability	mgCO <sub>2</sub> /g OM/d	183.15	481.61	20.86	3.71	26.43	4.57	24.09	4.22
B.O.D.	mg l <sup>-1</sup>	3245.5	2810.1	7396	5207	13555	7127	13983	8104
Dry solids at 30°C	%	68.93	9.54	71.88	6.04	84.12	0.95	60.66	8.52
Dry solids at 105°C	%	70.90	3.14	73.7	3.28	79.84	1.71	62.74	16.81
Loss on ignition at 500°C	%	41.21	18.6	41.28	4.39	53.22	7.01	77.82	7.0
Fluoride, acid extractable	mg kg <sup>-1</sup>	55.43	22.38	86.4	n/a	46.07	20.83	46.1	30.64
Ammoniacal Nitrogen : Dry Wt as N	mg kg <sup>-1</sup>	299.58	634.2	580.7	1146	398.19	685.7	294.49	400.7
Nitrate : dry wt as N	mg kg <sup>-1</sup>	45.8	38	BLD	n/a	BLD	n/a	BLD	n/a
Nitrogen: dry wt as N	mg kg <sup>-1</sup>	17382	5412	21025	639.67	20160	2960	13280	2492
Conductivity (solid)	uS.cm <sup>-1</sup>	3023	3143	7670	2077	7063	1423	6716	960
pH (solid)		8.122	0.14	8.19	0.07	6.42	0.16	6.15	0.77
Total Organic Carbon (TOC)	% dw as C	14.985	4.74	18.45	2.37	19.02	3.4	36.22	5.57

Note: <sup>1</sup> Other physical contaminants besides glass, stone, metal and plastic may include building rubble and composite materials made up of predominantly inorganic material BLD = below limit of detection

**Table 2.4 Summary statistics for phthalates, perfluorocarbons (PFCs) and triclosan from MBT/MHT CLOs from four sites sampled on five separate occasions (n = 10).**

Substance	Units	S1		S2		S3		S4	
		Mean	St dev	Mean	St dev	Mean	St dev	Mean	St dev
PFBS	$\mu\text{g kg}^{-1}$	1.73	1.78	1.09	0.69	1	0.73	0.53	0.25
PFC-10	$\mu\text{g kg}^{-1}$	3.1	1.69	1.13	1.14	0.94	0.74	0.87	0.57
PFC-11	$\mu\text{g kg}^{-1}$	1.18	0.65	6.47	8.08	3.18	1.66	8.64	3.11
PFC-12	$\mu\text{g kg}^{-1}$	3.83	5.25	3.48	3.60	4.2	5.5	1.34	1.55
PFC-6	$\mu\text{g kg}^{-1}$	14.47	21.8	4.05	6.02	6.63	14.9	1.83	1.17
PFC-7	$\mu\text{g kg}^{-1}$	1.71	1.13	1.74	0.60	2.4	n/a	0.5	0.28
PFC-8	$\mu\text{g kg}^{-1}$	7.38	6.82	4.72	8.14	1.01	0.76	2.85	6.56
PFC-9	$\mu\text{g kg}^{-1}$	1.6	0.47	1.3	0.75	1.37	1.0	0.6	n/a
PFHxS	$\mu\text{g kg}^{-1}$	1.28	0.98	1.29	1.16	0.43	0.49	2.27	2.55
PFOS	$\mu\text{g kg}^{-1}$	4.7	2.01	3.13	1.87	2.68	1.61	6.21	6.86
Butylbenzylphthalate	$\text{mg kg}^{-1}$	0.65	0.07	0.55	0.39	2.37	1.77	9.02	3.07
Di-n-nonylphthalate	$\text{mg kg}^{-1}$	1.26	1.18	1.23	0.33	1.25	0.7	5.89	3.26
Di-n-octylphthalate	$\text{mg kg}^{-1}$	1.43	0.64	0.74	0.52	3.59	6.29	6.76	4.36
Dibutylphthalate	$\text{mg kg}^{-1}$	0.65	0.07	0.36	0.29	5.52	1.01	13.31	5.73
Didecylphthalate	$\text{mg kg}^{-1}$	0.5	0.32	0.43	0.37	0.45	0.58	1.67	0.9
Diethylhexylphthalate	$\text{mg kg}^{-1}$	23.06	15.59	15.56	7.37	34.04	12.26	102.89	44.35
Diethylphthalate	$\text{mg kg}^{-1}$	0.25	0.17	0.13	0.05	2.95	1.13	4.94	1.44

Table 2.4 continued overleaf



**Table 2.4 continued**

Substance	Units	S1		S2		S3		S4	
		Mean	St dev	Mean	St dev	Mean	St dev	Mean	St dev
Diisobutylphthalate	mg kg <sup>-1</sup>	0.46	0.46	0.75	0.50	8.79	1.62	35.59	9
Diisononylphthalate	mg kg <sup>-1</sup>	20.9	12.1	11.77	6.00	31.14	17.82	151.7	47.1
Diisooctylphthalate	mg kg <sup>-1</sup>	5.73	5.52	3.75	2.61	6.02	2.17	10.17	5.1
Dimethylphthalate	mg kg <sup>-1</sup>	0.1	n/a	BLD	n/a	0.59	0.46	1.04	0.48
Triclosan	mg kg <sup>-1</sup>	2.03	1.88	3.43	2.43	4.07	3.12	3.81	2.21

Note: BLD = below limit of detection

**Table 2.5 Summary statistics for dioxins and furans from MBT/MHT CLOs from four sites sampled on five separate occasions (n = 9).**

Substance	Units	S1		S2		S3		S4	
		Mean	St dev	Mean	St dev	Mean	St dev	Mean	St dev
1,2,3,4,6,7,8-heptachlorodibenzo-p-dioxin	ng kg <sup>-1</sup>	771.71	475.85	624.75	203.1	114.63	14.07	188.6	74.9
1,2,3,4,6,7,8-heptachlorodibenzo-furan	ng kg <sup>-1</sup>	27.53	9.32	39.3	8.87	18.44	9.57	36.15	16.0
1,2,3,4,7,8,9-heptachlorodibenzo-furan	ng kg <sup>-1</sup>	1.8	0.15	4.38	n/a	2.45	n/a	1.75	n/a
1,2,3,4,7,8-hexachlorodibenzo-p-dioxin	ng kg <sup>-1</sup>	1.75	n/a	2.89	n/a	1.44	n/a	2.1	1.57
1,2,3,4,7,8-hexachlorodibenzo-furan	ng kg <sup>-1</sup>	6.8	4.46	3.82	1.51	3.07	n/a	5.2	2.55
1,2,3,6,7,8-hexachlorodibenzo-p-dioxin	ng kg <sup>-1</sup>	17.35	14.84	11.4	1.11	2.88	2.47	5.15	2.28
1,2,3,6,7,8-hexachlorodibenzo-furan	ng kg <sup>-1</sup>	5.07	3.76	3.67	0.51	2.74	n/a	4.56	2.05
1,2,3,7,8,9-hexachlorodibenzo-p-dioxin	ng kg <sup>-1</sup>	9.99	7.77	9.21	3.15	4.37	n/a	5.25	3.35
1,2,3,7,8,9-hexachlorodibenzo-furan	ng kg <sup>-1</sup>	11.7	n/a	BLD	n/a	1.94	n/a	1.87	1.41
1,2,3,7,8-pentachlorodibenzo-furan	ng kg <sup>-1</sup>	5.1	n/a	1.25	n/a	BLD	n/a	1.74	n/a
1,2,3,7,8-pentachlorodibenzo-p-dioxin	ng kg <sup>-1</sup>	16.45	24.73	2.6	0.74	BLD	n/a	9.4	8.45
2,3,4,6,7,8-hexachlorodibenzo-furan	ng kg <sup>-1</sup>	5.8	3.38	5.33	1.72	3.05	n/a	6.77	3.35
2,3,4,7,8-pentachlorodibenzo-furan	ng kg <sup>-1</sup>	18.61	27.62	4.85	n/a	2.93	n/a	8.96	5.37
2,3,7,8-tetrachloro-dibenzo-p-dioxin	ng kg <sup>-1</sup>	29.48	36.8	BLD	n/a	1.02	n/a	BLD	n/a
2,3,7,8-tetrachlorodibenzo-furan	ng kg <sup>-1</sup>	9.58	9.22	2.95	n/a	BLD	n/a	94.85	156
Octachlorodibenzo-p-dioxin	ng kg <sup>-1</sup>	4061.29	2540.9	4900	1428.9	1011.6	261.22	1580	592
Octachlorodibenzo-furan	ng kg <sup>-1</sup>	58.79	28.73	62.65	12.40	47.4	21.35	59.15	15.9

Table 2.5 continued overleaf

Table 2.5 continued

Substance	Units	S1		S2		S3		S4	
		Mean	St dev	Mean	St dev	Mean	St dev	Mean	St dev
Pentachlorodibenzo-p-dioxins – sum of isomers	ng kg <sup>-1</sup>	5.27	0.74	21.4	19.25	11.1	n/a	5.39	2.76
Pentachlorodibenzo-furan – sum of isomers	ng kg <sup>-1</sup>	15.15	23.15	18.64	11.33	6.25	n/a	21.66	22.7
Tetrachlorodibenzo-p-dioxin – sum of isomers	ng kg <sup>-1</sup>	2.69	1.75	12.04	5.50	2.56	n/a	19.4	16.1
Tetrachlorodibenzo-furan – sum of isomers	ng kg <sup>-1</sup>	245.79	539.01	328.85	359.16	2.175	1.51	160.07	269
Heptachlorodibenzo-p-dioxin – sum of isomers	ng kg <sup>-1</sup>	1235.57	728.31	1186.75	396.47	318.4	152.37	378.2	157
Heptachlorodibenzo-furan – sum of isomers	ng kg <sup>-1</sup>	42.36	21.39	56.15	31.99	28.43	10.14	43	10.7
Hexachlorodibenzo-p-dioxin – sum of isomers	ng kg <sup>-1</sup>	97.7	57.29	76.94	46.61	16.77	13.18	37.13	28.1
Hexachlorodibenzo-furan – sum of isomers	ng kg <sup>-1</sup>	20.13	13.12	45.2	22.20	10.88	12.81	27.13	20.6

Note: BLD = below limit of detection

## 2.2.5 Summary of results for metals and other elements

Levels of the metals and other elements were, as has been shown for other determinands, highly variable within and between sites (Table 2.6). The upper limit value within PAS100 for cadmium ( $1.5 \text{ mg kg}^{-1}$ ), chromium ( $100 \text{ mg kg}^{-1}$ ), copper ( $200 \text{ mg kg}^{-1}$ ) and nickel ( $50 \text{ mg kg}^{-1}$ ) was exceeded by the highest value at site S1; the mean values of cadmium, copper and chromium in S1 CLO also exceeded this limit. In S2 CLO mean values for cadmium, copper and lead ( $200 \text{ mg kg}^{-1}$ ) exceed the PAS100 upper limit, while levels of lead were also notably high in S3 CLO, where even the lowest value exceeded the PAS100 limit; none of the other metals measured in S3 CLO exceeded their respective PAS100 limits. The highest measurements for nickel from S4 CLO were over the PAS100 limit, but no other metals exceeded their PAS100 limit values. Mercury was not detected in any sample at any site, while molybdenum and selenium were only detected in samples from S3 and S4, respectively. The PAS100 limit for zinc ( $400 \text{ mg kg}^{-1}$ ) was never exceeded in any sample. The other elements analysed (i.e. sulphur, calcium, magnesium, potassium and phosphorus) have no limits specified within PAS100.

## 2.2.6 Summary of results for polycyclic aromatic hydrocarbons (PAHs)

Variability in the concentration of PAH values was significant with nearly all sites showing standard deviations for most PAHs equal to or greater than the mean values (Table 2.7). The PAHs displayed the greatest intra-sample variability of any chemical group. No one site had consistently higher values than the others, although levels in CLO from sites S1 and S2 were generally higher than those from sites S3 and S4.

**Table 2.6 Summary statistics for metals and other inorganic elements from MBT/MHT CLOs from four sites sampled on five separate occasions (n = 9).**

Substance	Units	S1		S2		S3		S4	
		Mean	St dev	Mean	St dev	Mean	St dev	Mean	St dev
Arsenic	mg kg <sup>-1</sup>	13.98	2.67	11.42	3.92	10.72	1.07	7.24	2.53
Cadmium	mg kg <sup>-1</sup>	1.83	0.36	4.61	6.6	1.570	1.67	0.67	0.19
Calcium	mg kg <sup>-1</sup>	51600	8171.3	39875	5726	3746	3844	3418	5688.3
Chromium	mg kg <sup>-1</sup>	72.34	33.51	21.58	3.94	29.86	3.51	68.18	17.67
Copper	mg kg <sup>-1</sup>	413.86	186.14	293	40.93	157.8	83.76	56.06	13.28
Lead	mg kg <sup>-1</sup>	623.43	156.76	275.75	52.35	949	1091.7	121.48	80.96
Magnesium	mg kg <sup>-1</sup>	5411.4	1739.4	6607.5	824.60	5538	513.92	3450	298.16
Mercury	mg kg <sup>-1</sup>	BLD	n/a	BLD	n/a	BLD	n/a		
Molybdenum	mg kg <sup>-1</sup>	2.57	0.47	BLD	n/a	2.174	0.12	2.34	0.27
Nickel	mg kg <sup>-1</sup>	46.7	9.78	37.08	7.16	5078	27.66	52.74	5.2
Phosphorus	mg kg <sup>-1</sup>	3698.6	961.07	3715	408.12	3290	313.29	2936	238.18
Potassium	mg kg <sup>-1</sup>	5650	2366.62	8755	1298.4	4908	463.97	4330	772.01
Selenium	mg kg <sup>-1</sup>	BLD	n/a	BLD	n/a	BLD	n/a	1.22	0.05
Sulphur	mg kg <sup>-1</sup>	954.3	621.54	925.5	445.4	691	489.50	228.2	20.13
Zinc	mg kg <sup>-1</sup>	119.32	110.04	43.27	9.16	31	4.81	37.35	0.49

Note: BLD = below limit of detection

**Table 2.7 Summary statistics for PAHs from MBT/MHT CLOs from four sites sampled on five separate occasions (n = 9).**

Substance	Units	S1		S2		S3		S4	
		Mean	St dev	Mean	St dev	Mean	St dev	Mean	St dev
Acenaphthene	µg kg <sup>-1</sup>	37.71	19.19	84.75	45.06	42.5	22.83	464	297.88
Acenaphthylene	µg kg <sup>-1</sup>	20	15.38	42.33	17.62	16	10.39	21	10.89
Anthanthrene	µg kg <sup>-1</sup>	390	296.98	117.67	64.86	116	118.79	37	n/a
Anthracene	µg kg <sup>-1</sup>	188.6	286.95	94.33	35.5	120	113.22	314.6	353.37
Benzo(a)anthracene	µg kg <sup>-1</sup>	428.43	827.99	582.5	507.17	267.5	295.79	350.8	241.54
Benzo(a)pyrene	µg kg <sup>-1</sup>	446.6	924.38	550	574.54	198.67	209.69	195	180.07
Benzo(b)fluoranthene	µg kg <sup>-1</sup>	1615	1958.7	1483.3	1322.5	496.67	302.38	875	120.21
Benzo(e)pyrene	µg kg <sup>-1</sup>	348	644.38	680	630	175.33	126.43	164.4	150.02
Benzo(ghi)perylene	µg kg <sup>-1</sup>	325.4	499.25	540	497.29	185.33	185.97	71.5	26.16
Benzo(k)fluoranthene	µg kg <sup>-1</sup>	785	869.74	733.3	465.01	435.0	304.6	480	113.14
Chrysene	µg kg <sup>-1</sup>	472.71	896.18	785	663.85	302.5	327.86	424.6	291.57
Cyclopenta(cd)pyrene	µg kg <sup>-1</sup>	246.67	350.42	213.33	61.1	101	125.87	131	88.5
Dibenzo(ah)anthracene	µg kg <sup>-1</sup>	120.33	121.6	163.33	137.96	43.5	41.72	18	n/a
Fluoranthene	µg kg <sup>-1</sup>	1190	2047.26	1060	508.33	1143.3	1198.2	1100	941.99
Fluorene	µg kg <sup>-1</sup>	54.5	19.06	112.5	41.12	53.2	38.53	378	213.59

Table 2.7 continued overleaf

**Table 2.7 continued**

Substance	Units	S1		S2		S3		S4	
		Mean	St dev	Mean	St dev	Mean	St dev	Mean	St dev
Indeno(1,2,3cd)pyrene	$\mu\text{g kg}^{-1}$	324	518.35	343.33	166.53	288	328.09	90.33	103.64
Naphthalene	$\mu\text{g kg}^{-1}$	38.5	20.53	76.5	28.05	344	256.67	420.6	284.41
Perylene	$\mu\text{g kg}^{-1}$	307.5	385.37	204.33	16185	182.5	179.74	455	176.78
Phenanthrene	$\mu\text{g kg}^{-1}$	561.43	693.1	1887.5	2736.8	382	154.01	858	554.68

## 2.2.7 Summary of results for hydrocarbons.

Levels of hydrocarbons, especially the longer chain hydrocarbons (C10–C40) are elevated in almost all of the samples in all sites; in some cases the results were as high as 3.12 per cent of the total sample, although there is significant variation within samples from each site (Table 2.8).

Hydrocarbons were measured using GCMS<sup>1</sup> following a solvent extraction in hexane/acetone with a solid phase separation on a silica column, which also acts to remove interferences such as fatty acids. However, at the levels observed in these cases, the fatty acids will break through the clean up column due to overloading; other phthalates and carboxylic acids that were not removed by the clean up may also be present. Nevertheless, the majority of the reading is due to hydrocarbons, which appear to be an oil, often found in composted materials. However, although they may appear high, the values fall below the PNEC concentrations derived in published data (RIVM, 2001).

We acknowledge that these PNEC values are of low reliability, however, and therefore the values obtained in the CLO may still be of concern.

## 2.2.8 Summary of results for polychlorinated biphenyls (PCB).

A suite of 18 PCBs have been analysed within the project. On no occasion in any of the samples from any site were PCBs present above the limit of detection.

## 2.2.9 Summary of results for *E. coli* and *Salmonella*.

Results for *Salmonella* were negative for all samples from sites S1, S2 and S4; site S3 had a positive result for *Salmonella* in five out of six samples. *Salmonella* must be absent in order to comply with PAS100 criteria.

*E. coli* results were more variable, both within and between sites. Half of the samples from S1 did not register *E. coli* at a concentration above 10 colony forming units (cfu) per gram, while the maximum value was 3800 cfu g<sup>-1</sup>. At S2, five of the six samples registered above the limit of detection, although the numbers of cfu were lower (10–1000 cfu g<sup>-1</sup>). Contamination from *E. coli* was much more severe at S3; all samples registered *E. coli* and the numbers of cfu per gram were far higher than other locations (21,000–1,750,000 cfu g<sup>-1</sup>). Although only one sample from S4 was below 10 cfu per gram, the values registered were the lowest of the four sites (10–130 cfu g<sup>-1</sup>). The pass level for *E. coli* in PAS100 is 1000 cfu g<sup>-1</sup>. This level was exceeded a total of nine times at three different sites, although six of the failures were at S3.

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<sup>1</sup> Gas chromatography-mass spectrometry



**Table 2.8. Summary statistics for hydrocarbons from MBT/MHT CLOs from four sites sampled on five separate occasions (n = 9).**

Substance	Units	S1		S2		S3		S4	
		Mean	St dev	Mean	St dev	Mean	St dev	Mean	St dev
Equiv. Carbon No. >10–12 aliphatic fraction	mg kg <sup>-1</sup>	1.12	n/a	0.62	1.07	2.8	3.82	13.9	14.22
Equiv. Carbon No. >10–12 aromatic fraction	mg kg <sup>-1</sup>	4.4	2.7	0.32	0.5	9.06	13.02	16.8	17.24
Equiv. Carbon No. >12–16 aliphatic fraction	mg kg <sup>-1</sup>	12.6	15.0	2.57	3.79	11.77	16.32	21.2	21.71
Equiv. Carbon No. >12–16 aromatic fraction	mg kg <sup>-1</sup>	15.6	19	4.41	5.63	12.85	20.26	25.6	26.58
Equiv. Carbon No. >16–21 aliphatic fraction	mg kg <sup>-1</sup>	360	789	28.52	29.82	61.09	69.86	107.8	106.3
Equiv. Carbon No. >16–21 aromatic fraction	mg kg <sup>-1</sup>	279	455	154.9	191.2	146.0	203.6	203.3	199.6
Equiv. Carbon No. >21–35 aliphatic fraction	mg kg <sup>-1</sup>	2622	4412	700	891.06	607.5	724.4	1364	1384
Equiv. Carbon No. >21–35 aromatic fraction	mg kg <sup>-1</sup>	2705	4199	999.6	1102.6	958.1	1264	1592	1544
Equiv. Carbon No. >35–40 aliphatic fraction	mg kg <sup>-1</sup>	583	1001	90.14	115.08	69.66	1260	101.1	136.4
Equiv. Carbon No. >35–40 aromatic fraction	mg kg <sup>-1</sup>	288	341	97.1	107.43	70.97	80.21	157.7	169.3
Hydrocarbons, aliphatic extractable C10–C40	mg kg <sup>-1</sup>	3573	6192	820.9	1005	751.9	916.1	1608	1639
Hydrocarbons, aromatic extractable C10–C40	mg kg <sup>-1</sup>	3291	4981	1256	1346	1197	1559	1995	1929
Hydrocarbons, total extractable C10–C40: Dry Wt	mg kg <sup>-1</sup>	6865	11168	2077	2316	1949	2292	3603	3514

## 2.3 Calculating exposure concentrations

The temporal variability of CLO chemical characteristics both within and between plants has been well highlighted (Amlinger *et al.*, 2004; Lasaridi *et al.*, 2006; Zmora-Nahum *et al.*, 2007). Therefore, just using maximum measured values to represent concentrations of chemicals in CLO could potentially overestimate or underestimate the true concentration. It is therefore common risk assessment practice to use a parameter such as a 'reasonable worst case percentile' (e.g. 90th percentile) to represent the temporal distribution of exposure values (EC, 2003). This is appropriate if the frequency distribution can reasonably be inferred from measurement or theory.

However, we may not know or be able to predict the distributions of some chemicals in CLO and therefore estimates of 90th percentiles may not be a valid method on which to base exposure concentrations. We therefore took the results from our monthly analyses of outputs to determine whether a defensible statistical distribution could be fitted to the data.

We were unable to justifiably fit a distribution due to the significant variability in the concentration of some determinands and the relatively limited number of samples (fewer than 15), especially as many values were below the levels of detection. Instead, data was logged and the percentile function in Excel was used, which ranks the logged data. This simplistic approach was deemed to be fit for purpose because the data set was limited, the approach is relatively insensitive to samples with values at the limits of detection and because this is a non-distributional method (i.e. does not rely upon the fit of a curve).

### 2.3.1 Calculation of exposure concentrations for the sites sampled.

The calculated 10th and 90th percentile concentrations of priority physical and chemical determinands from the CLO are shown in Table 2.9 to Table 2.11. These data will be used to assess the potential chemical risks from the use of CLO.

**Table 2.9 The 10th and 90th percentiles of metals, pH and organic carbon in MBT/MHT CLOs from four sites sampled on five separate occasions (n < 10).**

Substance	Units	S1		S2		S3		S4	
		10th%	90th%	10th%	90th%	10th%	90th%	10th%	90th%
pH		8.00	8.25	7.51	8.67	6.16	7.26	5.40	7.60
OC	%	9.15	18.51	17.37	21.74	14.42	23.54	24.61	41.03
Cd	mg kg <sup>-1</sup>	1.48	2.22	1.10	5.24	0.43	1.47	0.48	0.79
Cr	mg kg <sup>-1</sup>	38.15	107.27	18.52	28.64	26.90	34.46	48.16	87.54
Cu	mg kg <sup>-1</sup>	257.72	643.45	262.27	423.52	94.53	323.16	42.56	80.39
Ni	mg kg <sup>-1</sup>	36.72	52.72	34.34	53.56	30.46	59.47	38.35	58.55
Pb	mg kg <sup>-1</sup>	437.17	776.23	229.63	390.29	199.13	842.42	68.84	139.24
Zn	mg kg <sup>-1</sup>	531.97	1700.60	580.17	947.06	390.89	691.26	188.90	250.77

**Table 2.10 The 10th and 90th percentiles of selected organic chemicals in MBT/MHT CLOs from four sites sampled on five separate occasions (n < 10).**

Substance	Units	S1		S2		S3		S4	
		10th%	90th%	10th%	90th%	10th%	90th%	10th%	90th%
Sum of all PCDD/Fs	ITEQ in ng kg <sup>-1</sup>	7.04	25.84	-	-	-	-	-	-
Hydrocarbons - Total extractable	mg kg <sup>-1</sup>	1881	8897	3.49	4804.91	9.30	4764.87	5.97	7552
PFOS (µg/kg)	mg kg <sup>-1</sup>	0.13	7.02	0.0001	4.67	0.0001	3.89	0.0001	15.12
BaP (µg/kg)	mg kg <sup>-1</sup>	0.0001	238.67	0.0001	437.54	0.0001	234.16	0.0001	191.21
Fluoranthene	mg kg <sup>-1</sup>	228.65	1780.2	597.6	1500.0	0.0001	1128.50	254.27	1364.05
Butylbenzylphthalate	mg kg <sup>-1</sup>	-	-	-	-	0.21	5.04	6.26	12.00
Dibutylphthalate	mg kg <sup>-1</sup>	-	-	0.0001	0.72	1.48	6.73	8.12	18.67
DEHP	mg kg <sup>-1</sup>	0.78	37.43	9.17	26.00	19.98	47.08	56.52	170.30
Triclosan	mg kg <sup>-1</sup>	0.0001	3.86	0.0001	5.87	0.43	7.55	0.0001	6.18

**Table 2.11 The 10th and 90th percentiles of physical contaminants in MBT/MHT CLOs from four sites sampled on five separate occasions (n < 10).**

Substance	Units	S1		S2		S3		S4	
		10th%	90th%	10th%	90th%	10th%	90th%	10th%	90th%
Plastic >2 mm	% of total sample (W/W)	0.25	21.94	0.54	2.81	0.40	4.63	0.42	3.64
Glass >2 mm	% of total sample (W/W)	0.54	14.00	3.99	7.94	4.59	12.69	0.78	4.59
Metal >2 mm	% of total sample (W/W)	0.0001	0.63	0.0001	0.59	0.0001	0.16	0.004	1.13

### 2.3.2 Estimation of required sample numbers to assess compliance

Whenever the quality of a material is assessed against a limit value or standard it is clearly important that samples of the material are representative of the entire batch. We have followed existing guidelines for CLO sampling (Section 0). However, a recent study involving non-source-segregated materials demonstrated that the heterogeneity of some chemicals in MBT CLO was so great that even with relatively large numbers of point samples ( $n = 25$ ), it could not be stated with confidence that composite samples represented the entire batch (MacLeod *et al.*, 2007).

This heterogeneity was only observed for some chemicals, however. Hence for many chemicals it is possible to use existing analytical data from the previous project (Environment Agency, 2009) and apply simple power analyses to determine the sample sizes required to detect a difference from a limit value (i.e. regulatory standard), specifically 10–70 per cent different from the mean value determined from up to 12 samples of CLO taken over one year. Table 2.12 gives the results of the power analysis for two example chemicals, cadmium and triclosan.<sup>2</sup>

**Table 2.12 Results of power analysis to assess the number of samples needed to detect a difference from a limit value (a set percentage different from the mean measured concentration from up to 12 CLO samples).**

	Triclosan	Cadmium
To detect a significant difference if the “standard” is 10% different from the sample mean you would need the following number of samples:	498	77
To detect a significant difference if the “standard” is 20% different from the sample mean you would need the following number of samples:	124	19
To detect a significant difference if the “standard” is 30% different from the sample mean you would need the following number of samples:	55	9
To detect a significant difference if the “standard” is 40% different from the sample mean you would need the following number of samples:	31	5
To detect a significant difference if the “standard” is 50% different from the sample mean you would need the following number of samples:	20	5
To detect a significant difference if the “standard” is 60% different from the sample mean you would need the following number of samples:	14	5
To detect a significant difference if the “standard” is 70% different from the sample mean you would need the following number of samples:	10	5

Note: These values assume a limit value for Cd of  $3 \text{ mg kg}^{-1}$  (DoE, 1986) and  $1 \text{ mg kg}^{-1}$  for triclosan (Environment Agency, 2009).

<sup>2</sup> The data have been ‘logged’ first of all because the power analysis assumes normality. The significance level (alpha) is set at 5 per cent and beta at 50 per cent.

The data in Table 2.12 show that if 10 to 12 samples of CLO were taken each year, assuming that their mean and standard deviation were similar to those reported in the previous study (Environment Agency, 2009a), it would be possible to detect with confidence a change in cadmium levels when this chemical exceeded or fell below about 30 per cent of its standard mean; for triclosan the level of the chemical would have to be 70 per cent above or below its standard mean.

These percentage differences from the standard mean are reasonable if the mean sample values are substantially above or substantially below the regulatory standard (i.e. 3 and 1 mg kg<sup>-1</sup> for Cd and triclosan respectively), but if their standard means are close to the regulatory values, one would have to accept that a “true” triclosan concentration could be as much as 1.7-fold higher than the standard of 1 mg kg<sup>-1</sup>, but not appear to differ significantly from it.

## 2.4 Review of terrestrial ecotoxicity data for priority chemicals.

The previous screening risk assessment (Environment Agency, 2009a) identified what additional data was required to reduce uncertainty and provide evidence on which policy could be based. One of these requirements focused on establishing robust estimates of soil-based predicted no effect concentrations (PNECs). These limit values are used to characterise the final risks associated with a particular exposure scenario.

The ‘high priority’ chemicals in this study were those for which existing limits were highly uncertain and for which relatively high concentrations were present in the CLO. The use of these unreliable PNECs to characterise risk from recycling CLO on agricultural land led to high risk quotients.

Four chemicals or groups of chemicals were given top priority because no soil related limit value currently exists. The chemicals were:

- i. **Triclosan**  
Section 0 reports that concentrations of this chemical in CLO are highly variable. The previous limit value was derived using aquatic ecotoxicity data; it is therefore highly precautionary and unreliable in this context (Danish EPA 2003).
- ii. **Phthalates**  
This family of chemicals includes especially butylbenzylphthalate, dibutylphthalate and diethylhexylphthalate. These three phthalates are regularly detected in all samples of CLO.
- iii. **PAHs**  
PAHs are detected in a range of concentrations in all CLOs; aside from benzo-a-pyrene few limit values currently exist to assess the potential risks from PAHs.
- iv. **Perfluorooctanesulphonate**  
Perfluorooctanesulphonate (PFOS) was detected in a number of samples and has significant potential to accumulate through food chains, but there is currently no metric by which this potential risk can be assessed.

PNECs were calculated for these chemicals to assess the potential risks to the environment (Table 2.13) from CLO. No human health limit values were derived. We followed the methodology described in the Environment Agency’s own guidance (Environment Agency, 2008). It should be noted that a number of the limit values reported by the Environment Agency (2009a) are still likely to be considered too

uncertain (i.e. they have an assessment factor of greater than 50 or they are not derived using terrestrial ecotoxicity data). Only the ecotoxicity data was reviewed; we assumed that any previous reviews undertaken by another regulatory agency or under the auspices of other European regulation (such as the Existing Substance Regulations, 793/93/EEC) would be robust.

Where inadequacies of data in the open literature were known, we made contact with environmental managers from industry who were responsible for the production of those chemicals. This contact enabled us to access a number of key data sets.

**Table 2.13 Summary of predicted no effect concentrations as given in Environment Agency (2009a).**

<b>Chemical</b>	<b>PNEC<sub>soil</sub></b>	<b>PNEC<sub>oral</sub> (secondary poisoning)</b>
Perfluorooctanesulphonate (PFOS)	0.029 mg kg <sup>-1</sup>	0.087 mg kg <sup>-1</sup> dry soil
Polycyclic aromatic hydrocarbons (PAHs)	0.038–1.8 mg kg <sup>-1</sup>	None derived due to lack of data
Butylbenzyl phthalate	1.39 mg kg <sup>-1</sup> *	33 mg kg <sup>-1</sup> (prey concentration)
Di-butyl phthalate	0.28 mg kg <sup>-1</sup>	104 mg kg <sup>-1</sup> (prey concentration)
Di-ethylhexyl phthalate	>13 mg kg <sup>-1</sup>	3.3 mg kg <sup>-1</sup> (prey concentration)
Triclosan	1.43 mg kg <sup>-1</sup>	188 mg kg <sup>-1</sup> dry soil*

Note: \* Likely to be considered too uncertain according to Environment Agency guidance (2008).



### 3. Pot trial to assess nitrogen uptake, leaching loss and availability of metals to grass in soils treated with CLO

The total nitrogen content of organic materials derived from MBT processes in the UK are reported to range from 4 to 13 kg t<sup>-1</sup> fresh weight (Environment Agency, 2007). A number of trials of crop performance carried out on soils amended with CLO suggest that this nitrogen is mostly found in relatively unavailable forms.

Conversely, there is also some evidence that CLO-type materials are capable of immobilising nitrogen, resulting in deficiency symptoms in test plants and crops (Hargreaves *et al.*, 2008). However, little is known about nitrogen release and plant uptake in soils amended with MBT/MHT CLO.

In the UK, restrictions on the use of CLO on land limit the number of opportunities for field trials. Some plot-scale trials have been undertaken by Cameron *et al.* (2008) along with some pot trials to assess the performance of willow, poplar and eucalyptus in a range of CLO-coal spoil media. These researchers have also tested nitrate leaching from CLO and a CLO-substrate mix.

In this present study we performed a pot trial using CLO materials collected from the four sites participating in the project. The aims of the pot trial were to:

- compare the effects of different CLO materials on nitrogen (N) uptake by plants;
- assess the fate of nitrogen within CLO amended soils (i.e. mineralisation, immobilisation and leaching);
- assess the availability of potentially toxic metals to grass in the soils treated with CLO in comparison with untreated soils.

Due to the general lack of information on the effects of CLO in soils, a commercial compost made from green waste (GWC) was included in the trial. The GWC provided a benchmark for the CLO treatments.

Samples of the four CLO materials and GWC were incorporated into the soil at two ratios. One ratio was at a concentration equivalent to the maximum N application to agricultural land allowed by the Defra's Soil Code (250 kg N ha<sup>-1</sup>; see Defra, 2007) and the second was four times this concentration. These concentrations were selected to represent first a high rate that might be used for brownfield remediation or capping landfill, and second what might happen in the case of localised accidental excessive application.

It is known that the C:N ratio of CLO can be high, giving the possibility that mineral N might be immobilised in soil organic matter, at least in the initial stages of CLO decomposition in soil. Therefore, we included a subsidiary experiment in which mineral (inorganic) N fertilizer was added to the mix. If the capacity for N immobilisation were to exceed the mineral N supply, then a high immobilisation potential might be observed.

We tested the mineralisation of N from CLO in the soil-CLO mixtures by:

- assessing grass growth and N uptake;
- measuring mineral N (ammonium plus nitrate) in soil, both with grass and in a parallel incubation experiment without grass;
- leaching the soil (in both grass and “fallow” treatments) with water to simulate a heavy rainfall event at the end of the experiment.

The potential for both N uptake by crops and N losses through leaching are major concerns in the use of nitrogenous fertilizers; this subsidiary experiment within the project aimed to assess the potential for both phenomena.

Ryegrass is an efficient extractor of available N, while fallow soil with no crop provides a model for the opposite situation i.e. potentially high N losses. Therefore, in this experiment we assessed the extremes of potential uptake and loss by two main treatments, namely:

- ryegrass grown on the soil-CLO mixtures;
- companion pots with the same CLO materials and application concentrations, but without grass, maintained at approximately the same water content and then leached with water at the end of the experiment.

To ensure that the experiment assess realistic extremes, we used two soil types. The first was a sandy soil, providing a “worst case scenario” for N leaching (Sonning series soil from the University of Reading Sonning Farm near Reading, located in a Nitrate Vulnerable Zone). The second soil was of the Wickham series, used to indicate effects of CLO in a heavier textured soil. Other crop and soil combinations are expected to fall somewhere between the ‘extreme’ combinations assessed in this experiment; therefore the trial identifies the range of anticipated conditions for N release and uptake.

## 3.1 Materials and methods

### 3.1.1 Main experimental design

It was necessary to test the effects of four different aspects of treatment characteristics (factors), specifically:

- compost type (CLO amendment with four CLOs or GWC i.e. five different treatments);
- application rate (‘Low’ or ‘High’ i.e. two treatment types);
- soil type (either sandy loam or silt loam i.e. two treatment types);
- crop treatment (either ryegrass or fallow i.e. two treatments).

The experimental design included all possible combinations of these four different factors (i.e. compost type, application rate, soil type and crop treatment). The treatments were therefore applied following a factorial design for statistical analysis of the data. Additional control treatments were required without CLO or compost addition, both cropped and fallow, in order to assess the benefit or otherwise of CLO (e.g. the effect on N uptake) against the controls. There were three replicates of all treatment combinations. This resulted in a total trial of 132 pots; 40 different combinations of CLO and treatments, four controls and three replicates.

### 3.1.2 Immobilisation sub-experiment design

A second experiment was run concurrently to assess and compare the ability of the CLOs to immobilise N in the soil. The CLOs with the highest and lowest total N concentrations (as measured on receipt) were selected for the trial. Mineral (fertilizer) N was added at the start of the experiment. The two soils had low mineral N concentrations ( $1\text{--}3\text{ mg kg}^{-1}$ ). This was increased by adding  $50\text{ mg N per pot}$  as ammonium nitrate, equivalent to approximately  $130\text{ kg N ha}^{-1}$  and similar to the anticipated N uptake by the grass. Immobilisation would be detected if the residual mineral N was less than the initial N minus leaching and plant uptake. Five factors were tested in this trial, specifically:

- Compost type (two types, from sites S1 and S2);
- Application rate (either 'Low' or 'High' i.e. two treatment types);
- Fertilizer N rate (either 'No N' (N0) or 'Plus N' (N50) i.e. two treatment types);
- Crop treatment (either grass or fallow i.e. two treatments);
- Soil type (sandy loam or silt loam i.e. two treatment types).

Again, there were additional control treatments without CLO and without the grass crop (i.e. fallow). The experiment was designed to include all possible combinations of the five factors. There were three replicates of all treatment combinations. This resulted in a total trial of 96 pots. However some of the combinations (i.e. the 'No N' treatments) had already been produced for the main trial and were not reproduced, reducing the trial to 48 extra pots, plus 12 no-compost controls (these no-compost posts included controls with fertilizer N, with both soils and with and without grass).

A total of 192 pots were used for the two trials.

### 3.1.3 Materials

#### *Soil*

Two soils were taken from the University Farm, Sonning, Berks on 18 November 2008. The upper horizon (0–5 cm) was sampled at one location on each series. They were as follows:

- Sonning series**  
Sonning series stony phase soil, taken at grid reference SU768761. Information on a typical profile of this series is given by Jarvis (1968), where it is mapped as unit SL2. It is a sandy loam: sand/silt/clay are reported as 65/30/15 per cent, respectively. As sampled, it contained approximately 35 per cent stones ( $>15\text{ mm}$ ).
- Wickham series**  
Wickham series soil, taken at grid reference SU762756. Information on a typical profile of this series is given by Jarvis (1968), where it is mapped as unit Wh. It is a silt loam: sand/silt/clay are reported as 29/52/19 per cent, respectively. As sampled, it contained approximately 7 per cent stones ( $>15\text{ mm}$ ).

The soils were sieved through screens of aperture  $15\text{ mm}$  to remove large stones, mixed thoroughly and stored under cover in an unheated greenhouse until used. A

sample of each soil was taken, air-dried and ground to pass a 2 mm sieve for total N analysis.

### *CLO materials*

A sample of the four CLO materials (> 20 kg each) and one sample of green waste compost (> 20 kg) were supplied by WCA Environment from one sampling period (see Section 0). The samples were mixed thoroughly and a portion of each was sampled and dried at 70° C. It was initially crushed by hand in a pestle and mortar, and then ground in a 'Tema' puck mill. The resulting crushed CLO was sieved through a 2 mm sieve; the fine fraction was then analysed for total N.

#### **3.1.4 Pot experiment method**

The mass of moist soil (as prepared above) that occupied a 1 litre ('five-inch') plant pot differed between the two soils; the amounts used are given in Table 3.1. Field-moist soil was weighed and 10 ml of K<sub>2</sub>HPO<sub>4</sub> nutrient solution was added (providing 50 mg K and 19.8 mg P per pot, to ensure that growth was not inhibited by a lack of other key nutrients). The CLO amendments were weighed and mixed in by hand.

The method to translate field scale application into a concentration for the pot trial was based on bulk density.

The total N concentration of each dry CLO was measured and the mass of dry CLO containing 250 kg N calculated. It was assumed that this amount would be fully mixed with the surface 15 cm soil horizon, and that the field bulk density of the soils was 1.3 (i.e. 1950 tonnes dry soil ha<sup>-1</sup> to 15 cm), to find a dry CLO concentration in the field kg CLO tonne<sup>-1</sup> soil). This concentration in g CLO kg<sup>-1</sup> soil was used for the pots, based on the air-dry soil mass per pot. The measured water content of the CLO was then used to calculate the amount required for each pot.

**Table 3.1 Amounts of soil used per pot.**

<b>Soil</b>	<b>Field moist mass (g)</b>	<b>Oven-dry &lt;2 mm soil (g)</b>	<b>Gravel (2-15 mm) (g)</b>
Sonning	850	551	165
Wickham	800	581	64

The CLO treatments were applied as specified in Table 3.2. The 'Low' application rate was to provide 93 and 84 mg total N per pot in Sonning and Wickham soils, respectively, based on the preliminary analyses of the CLO, while the 'High' concentration treatments aimed to provide 370 and 334 mg total N per pot in Sonning and Wickham soils, respectively.

There was one additional treatment: soil without CLO provided the control treatment. The fallow pots were prepared in exactly the same way as for the pots containing grass. All treatments were repeated for both soils, with grass and fallow treatments and with three replicates.

The fertilizer sub-experiment used a control containing no CLO; other pots contained CLO materials at both low and high application rates, but with CLO from sites S1 and S2 only. The pots in this experiment contained 50 mg fertilizer N, as NH<sub>4</sub>NO<sub>3</sub> solution which was added in 10 ml water at the same time as the K<sub>2</sub>HPO<sub>4</sub> fertilizer. The sub-experiment was

repeated for both soils, in pots with and without grass and with three replicates. All other details of management were the same as for the main experiment.

**Table 3.2 Amounts of CLO used, g moist CLO per pot.**

CLO	Sonning		Wickham	
	Low conc.	High conc.	Low conc.	High conc.
GWC	7.4	29.7	6.7	26.8
S1	14.3	57.3	12.9	51.8
S2	6.4	25.7	5.8	23.2
S3	8.1	32.2	7.3	29.1
S4	12.6	50.4	11.4	45.5

The soils were placed in five-inch (13 cm) plastic plant pots standing on six-inch (15 cm) saucers. For the pots with grass, seeds (0.5 g) of perennial ryegrass (*Lolium perenne*, supplied by Herbiseed Ltd, Twyford, Berks) were mixed with the top 1 cm of the soil. No additional water was required for a reasonable texture for plant growth. The fallow treatment pots were covered with a smaller saucer. All pots were placed in the greenhouse maintained at between 15 and 18° C. Natural light was supplemented with artificial light for 16 hours per day, provided by Thorn 400w lamps.

Two weeks after sowing, the pots planted with grass were watered *ad libitum* (in the saucer) twice per week; the fallow pots were not watered, except in the specific watering protocols describe as follows.

Eleven days after sowing, all pots were watered to saturation. Water was added slowly to the soil surface until drainage to the saucer started. The pots were allowed to stand overnight and then weighed. This weight of soil was taken to represent the soil at field capacity.

At 29 days from sowing, all pots were watered to the surface until at field capacity, and no more water supplied until 33 days from sowing. At that time, the pots were weighed, and the weight loss, assumed equal to evapotranspiration, used as an indicator of grass growth. At 64 days from sowing, all pots were again watered to the surface until they reached their field capacity.

The pots with grass and those without grass (fallow pots) were watered at 65 and 66 days, respectively. Water (150 ml) was added to the soil surface and allowed to drain for 30 to 60 minutes. Leachate was tipped from the saucer to a measuring cylinder, the volume recorded and transferred to a bottle. This leachate was filtered (Fisherbrand QL100 paper filter) on the same day and stored in a refrigerator and analysed within two days.

The first harvest took place 37 days after sowing; the second harvest occurred 68 days after sowing. Plant matter over 1 cm from the soil surface was cut, dried at 70° C in a forced-draught oven and weighed. The harvests were combined and ground to pass through a 0.25 mm sieve. The soil was removed from each pot, mixed and a portion was oven-dried (105° C) to find the water content at harvesting.

### 3.1.5 Methods of analysis

#### *Total N analysis*

Soil and CLO were analysed with a Europa Scientific Roboprep CN machine, which uses the Dumas principle (combustion to N<sub>2</sub>).

#### *Leachate N and P*

Analysis of the leachates was made on a Chemlab 40 system autoanalyser that measures NO<sub>3</sub>-N, NH<sub>4</sub>-N and PO<sub>4</sub>-P. Concentrations were multiplied by the volume of leachate collected to calculate the amounts of N and P leached per pot. Leachate N was the sum of ammonium-N and nitrate-N.

#### *Extractable N and P*

Moist soil or CLO (containing approximately 40 g oven-dry matter) was weighed into a 200 ml bottle, 1 M KCl solution (200 ml) added, shaken end-over-end for 30 minutes and the extract filtered (Fisherbrand QL100 paper filter). The CLO extracts were further filtered through a 'Millipore' 0.45 µm filter. Extracts were analysed on the Chemlab 40 autoanalyser system that measures NO<sub>3</sub>-N, NH<sub>4</sub>-N and PO<sub>4</sub>-P. The water content at harvest (Table 3.1) was used to calculate the amounts of mineral N and P on an oven-dry soil basis, and then the mean oven dry soil mass per pot (Table 3.1) used to calculate the amounts of N and P extracted by KCl per pot.

The values for 'extractable N' and 'extractable P' at the end of the experiment are calculated as the sums of the amounts per pot extracted by the water leaching just before the end of the experiment and the amounts per pot extracted by KCl immediately after harvest.

The value for extractable N at the start of the experiment is calculated as the sum of the mineral N extracted by KCl from:

- soil;
- directly from CLO;
- added in fertilizer, when appropriate.

Net mineralisation in the fallow pots during the experiment was measured by the difference in extractable N between the start and finish of the experiment. Net mineralisation in the pots with grass was measured by the difference in extractable N between the start and finish of the project, plus N uptake by the grass.

#### *Carbon analyses*

Total C was measured by the dry combustion method (LECO SC444 analyser). Organic C was measured by heating finely ground soil and CLO for two hours at 130–135° C with H<sub>2</sub>SO<sub>4</sub> / H<sub>3</sub>PO<sub>4</sub> / K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub> mixture followed by back-titration with (NH<sub>4</sub>)<sub>2</sub>.Fe(SO<sub>4</sub>)<sub>2</sub> (Anderson and Ingram, 1993).

## *Analysis for metals*

Plant material (0.5 g) was weighed into a 100 ml block digestion tube; concentrated HNO<sub>3</sub> (10 ml) was added and allowed to stand overnight. The digest was then heated for three hours at 60° C followed by six hours at 110° C. After cooling, the digest was filtered (Whatman No. 540, pre-washed) and made up to volume (100 ml). The concentrations of Ca, Cd, Cu, K, Mg, Mn, Mo, Na, Ni, P, Pb, Se, V and Zn were measured by ICP-OES spectrometry (Perkin-Elmer Optima 3000) using a certified multi-element standard (Merck, Darmstadt).

## *Statistical analysis*

Data for each experiment and soil were analysed by one-way ANOVA over all 11 treatments. In some cases, two factor ANOVAs were used to compare N fertilizer and CLO types

## 3.2 Results

### 3.2.1 Soil and CLO analyses

Two of the CLOs contained a noticeable component of material that did not pass a 2 mm mesh sieve, even after vigorous grinding in the Tema mill. This mill normally reduces plant or mineral material to powder <0.25 mm quickly and effectively (Table 3.3). However, some fibrous material and plastic pieces of a resilient nature could not be crushed. It is presumed that this portion of the CLO is inert so far as N dynamics are concerned, at least on the timescale of this experiment.

For green compost (GWC) and CLO from S2, the organic carbon comprised the majority of the C content, since total C was little more than organic C. For the other three CLOs, there was a substantial inorganic component of the C, particularly for S4.

**Table 3.3 Properties of the CLO materials and soils.**

	<b>GWC</b>	<b>S1</b>	<b>S2</b>	<b>S3</b>	<b>S4</b>	<b>Sonning</b>	<b>Wickham</b>
% >2 mm	1.2	4.2	0.1	0.6	8.9	n/a	n/a
Water, % wet weight	37.4	43.3	16.3	16.1	48.9		
Total N (%)	2.06	1.19	1.68	1.51	1.43	0.237	0.193
NH <sub>4</sub> -N (mg kg <sup>-1</sup> )	8.9	5.5	1799	407	21.9	0.4	0.4
NO <sub>3</sub> -N (mg kg <sup>-1</sup> )	0.0	182	0.0	0.0	0.0	2.7	1.2
PO <sub>4</sub> -P (mg kg <sup>-1</sup> )	24.3	7.0	11.7	25.3	32.1	13.1	3.5
Total C (%)	32.7	18.5	21.7	23.2	41.2	2.65	2.45
Organic C (%)	31.8	11.3	19.4	17.2	29.9	2.17	1.84
Organic C/N	15.5	9.51	11.5	11.4	20.9	9.16	9.53

The total N content of the CLOs varied in the range 1.1 to 2.1 per cent. The organic C/N ratio was in the range 9.5 to 11.5 per cent for S1, S2 and S3, but much higher for GWC and material from S4.

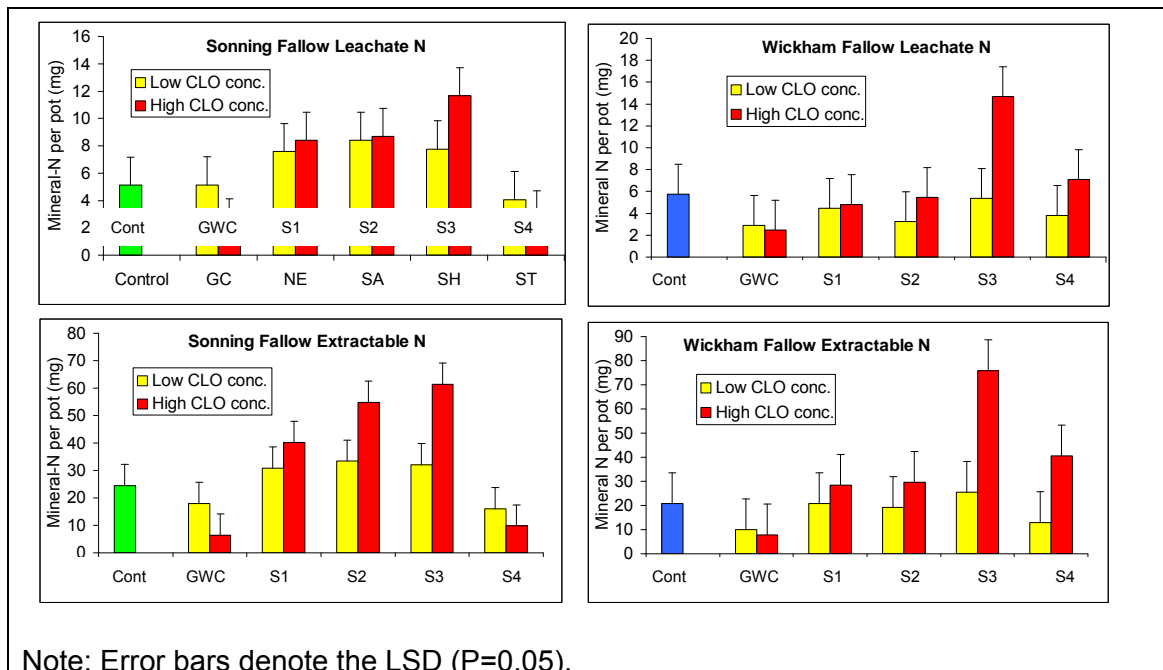
The mineral N component of CLO varied very widely, reaching a remarkable 1799 mg kg<sup>-1</sup> of ammonium-N for material from S2. CLO from S1 was different from the others because it contained a high concentration of nitrate. We also observed that Millipore filtration was difficult for material from site S1; the filter blocked after a small (<5 ml) volume, indicating a high content of colloidal material. It is possible that the N in these fine particles could be quickly decomposed to inorganic form in soil, adding to the available N pool.

These analyses show that although the experiment had been designed to provide approximately the same amount of total N from each CLO, the amounts of mineral N were high for CLO from S2 and S3.

### 3.2.2 Main experiment: fallow treatment

Ammonium and nitrate were measured separately, but for the great majority of the 96 fallow pots, ammonium-N comprised less than one per cent of the extractable N. This is as expected in aerobic soils. Therefore, separate results for ammonium and nitrate are not presented in these results. However, it may be noted that of the seven pots where ammonium did contribute more than 10 per cent of the mineral N extracted by KCl, five had received GWC.

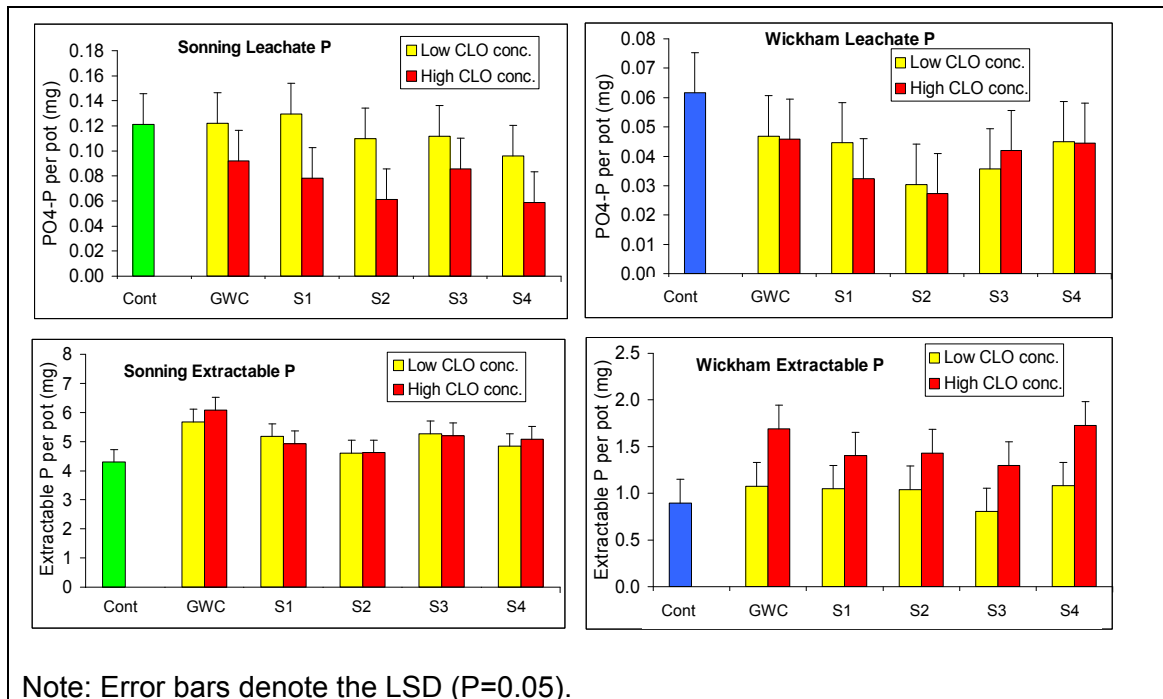
Compared with the control soil, GWC lowered the amounts of mineral N that could be leached by water or that could be extracted by water plus KCl (Figure 3.1). This effect was always significant at the high concentration of N addition and for leachate from the low concentration in Wickham soil. The CLO from S4 lowered leachate N (high concentration only) and extractable N in Sonning soil, but its effects were not significant in Wickham soil. In Sonning soil, the other three CLO materials (S1, S2 and S3) always significantly increased leachate N, and the extractable N when applied at the high concentration. In Wickham soil, their effects were small except for the significant increases caused by S3 at the high concentration.



**Figure 3.1 Leachate N and extractable N in the fallow treatments of the main experiment.**



The phosphate-P removable by leaching was always lowered significantly by all CLO treatments in Wickham soil and by all the high CLO concentration treatments in Sonning soil (Figure 3.2). On the other hand, the extractable P was normally increased by the CLO additions: increases were measured for all the high concentration additions in Wickham soil and by GWC, S1, S3 and S4 at both CLO concentrations in Sonning soil.



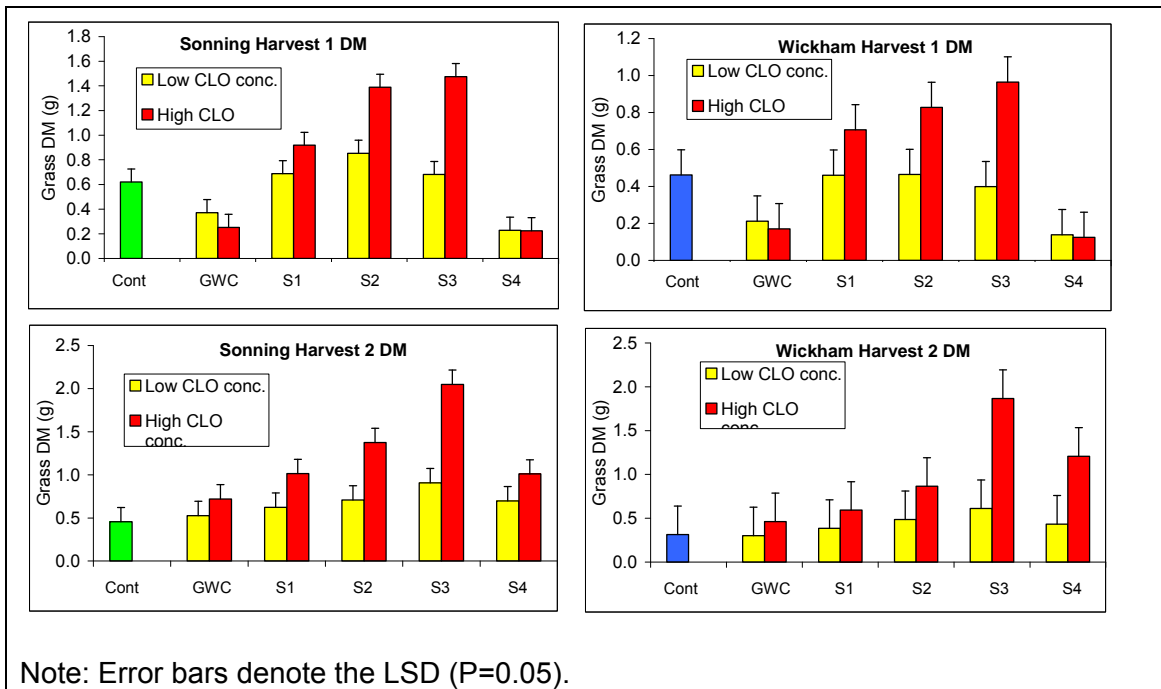
**Figure 3.2 Leachate P and extractable P in the fallow treatments of the main experiment.**

### 3.2.3 Main experiment: grass treatment

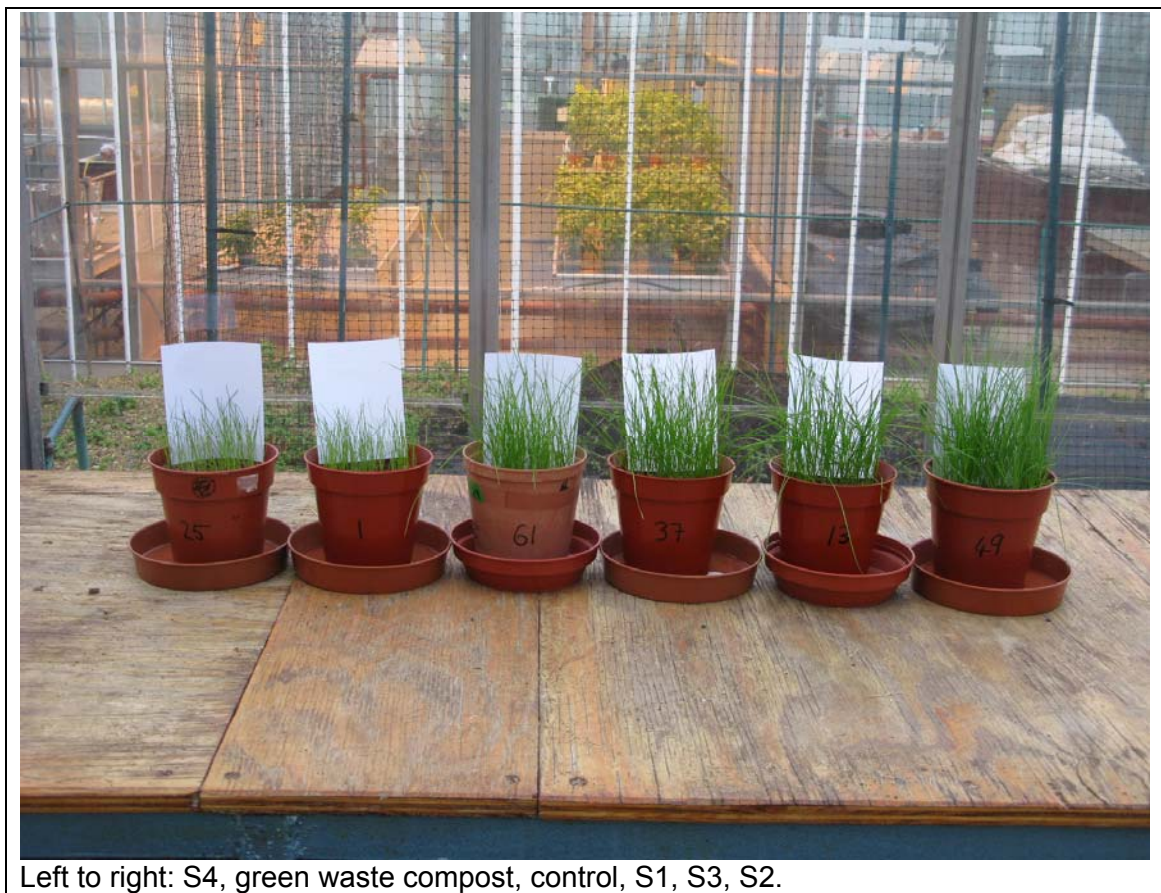
#### *Dry matter yield.*

At the first harvest (Harvest 1) in both soils, GWC and S4 depressed grass yield compared to the control (Figure 3.3 and Figure 3.4). At low concentrations of S2, S3 and S4 the yield was not affected, except for a small increase caused by S2 in Sonning soil only. At high concentrations, S2, S3 and S4 all gave significant increases in yield.

At Harvest 2, there were no longer any depressions of yield. At low concentrations in Sonning soil, the increase was not significant for GWC, but was significant for all the CLOs. At high concentrations in Sonning soil, all compost treatments gave significant increases. In Wickham soil, only the high concentrations of S2, S3 and S4 increased yield.



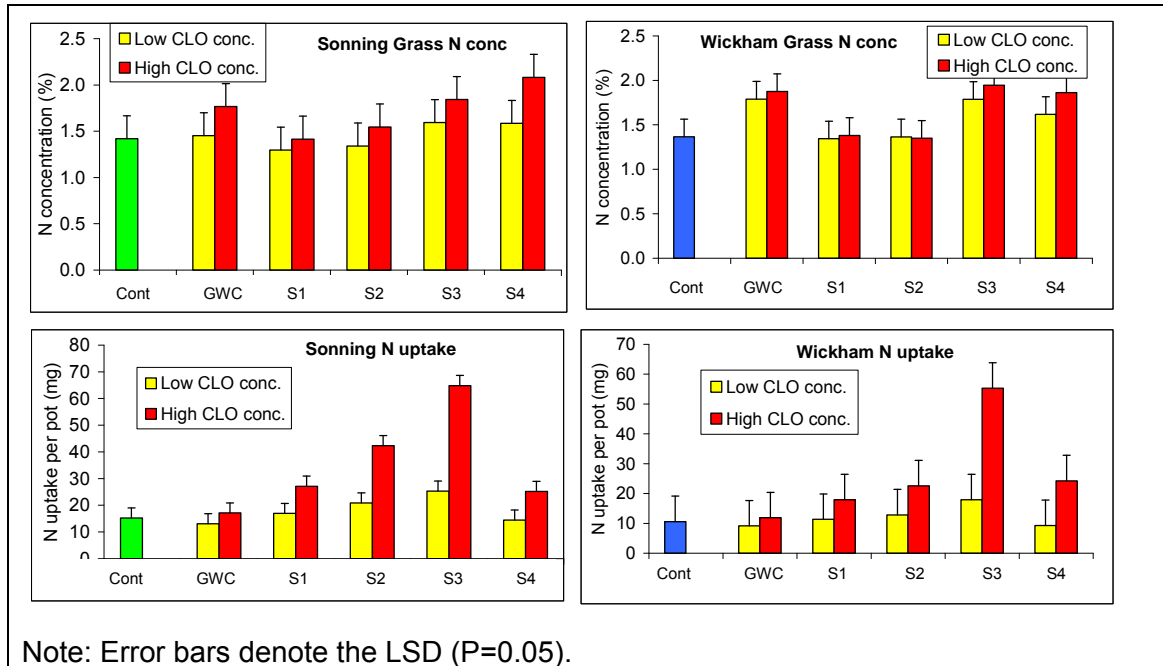
**Figure 3.3** Grass dry matter yield (g per pot) in the main experiment.



**Figure 3.4** Pots from replicate 1 of the grass treatment on Sonning soil with high rates of CLO application 25 days after sowing.

## N concentrations and uptake

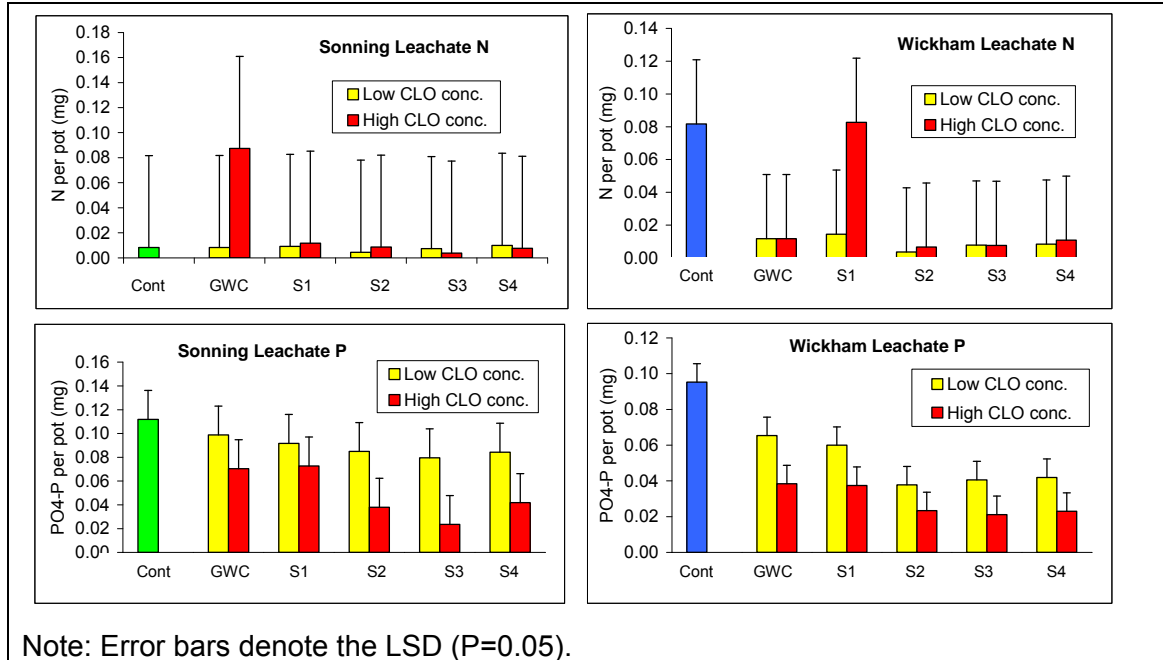
It was clear that the CLOs had different effects on N nutrition of the grass. In Sonning soil, for S1, S2 and S3, the grass N concentration was not increased significantly by CLO (except for S3 and high CLO concentrations); the N uptake increased with increasing CLO concentration (Figure 3.5). The effectiveness of the CLOs increased in the order S1 < S2 < S3. GWC did not increase N uptake, although it did increase N concentration if applied at the high concentration. S4 appeared to raise grass N concentration, but had limited effect on the N uptake. The pattern was similar in Wickham soil, but less distinct for N uptake because of higher variability leading to a larger standard error and least significant difference.



**Figure 3.5 N concentration in grass and N uptake (g per pot) in the main experiment.**

## Leachates.

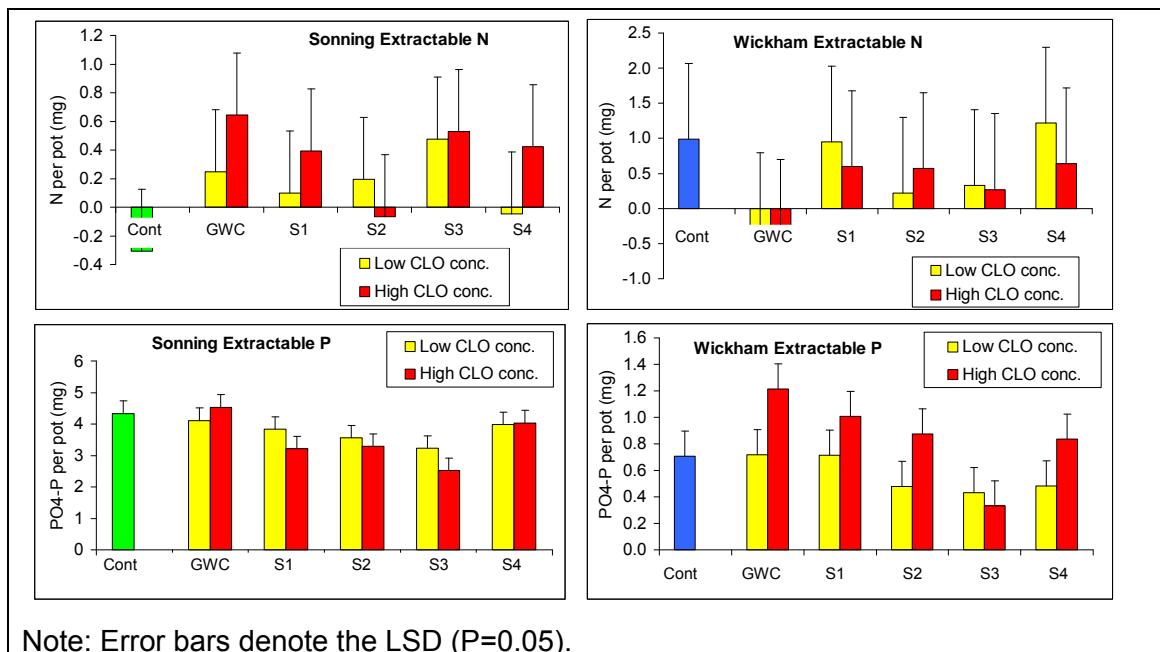
Leaching through the grass pots gave very low losses of N (less than 0.1 mg N per pot in all treatments, see Figure 3.6). Almost all compost treatments reduced the loss of P in leachate under grass, the only exceptions being for GWC and S1 in Sonning soil.



**Figure 3.6** Leachate mineral N and leachate P in the grass treatments of the main experiment.

## Extractable N and P.

The amounts of extractable N remaining in the pots planted with grass at the end of the experiment were very small (Figure 3.7). In the case of Sonning soil, there was a little more extractable N in some CLO treatments, but this was not the case in Wickham soil. In Sonning soil, the extractable P was progressively lowered for the higher CLO concentration, for S1, S2, and S3. On the other hand, in Wickham soil, the high CLO concentration resulted in an increase in extractable P for GWC and S1, but depletion of extractable P for some treatments with S2, S3 and S4.



**Figure 3.7 Extractable N and extractable P in the grass treatments of the main experiment.**

### 3.2.4 Net mineralisation in the main experiment

Net mineralisation is the change in extractable N between the start and finish of the experiment, plus grass N uptake when appropriate (see Section 3.1.5). Results for net mineralisation showed marked differences between CLOs (Figure 3.8). It appeared that GWC, S2 and S4 could depress net mineralisation, while S1, S3 and S4 could increase it.

For S2, net mineralisation was always lower than in the control, although it must be noted that this CLO supplied very high amounts of ammonium-N (Table 3.3). In fallow pots GWC lowered net mineralisation in comparison with the control for both soils; this may of course be caused by either immobilisation of N by the CLO or promotion of gaseous loss. In grass pots, GWC had little effect on net mineralisation. The direction of the effect of S4 varied. It lowered net mineralisation in fallow treatment in Sonning soil and in Wickham soil at low concentration (as with GWC). However, with grass at a high rate of application, S4 increased net mineralisation.

S3 was clearly effective at increasing net mineralisation, in fallow and grass conditions. The effects of S1 were small, but show the same pattern as S3, suggesting that net mineralisation could take place.

The apparent net mineralisation always appears lower for grass compared to fallow pots. This difference arises because the estimate of net mineralisation is too low for grass (only above-ground (i.e. leaf) N was measured, but a further component of mineralised N would have been taken up by the grass roots).

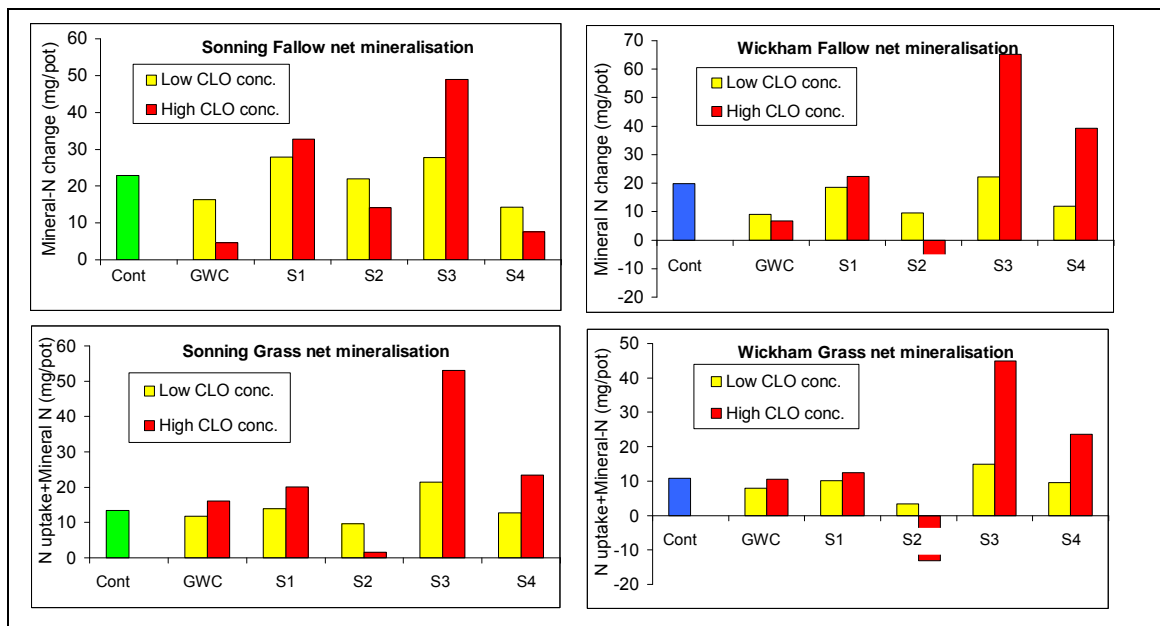


Figure 3.8 Net mineralisation of N in the main experiment.

### 3.2.5 Immobilisation experiment

#### Grass yield and N uptake

Fertilizer N always increased grass yield significantly (Figure 3.9). In Sonning soil, fertilizer N caused yield increases that were lower at the high CLO concentration compared with the low CLO concentration and the control. The suppression of yield by the high concentration of S2 may be an outlier. In Wickham soil, there was no interaction between fertilizer N and CLO, showing that the effect of fertilizer N was the same whether or not CLO was used and its concentration.

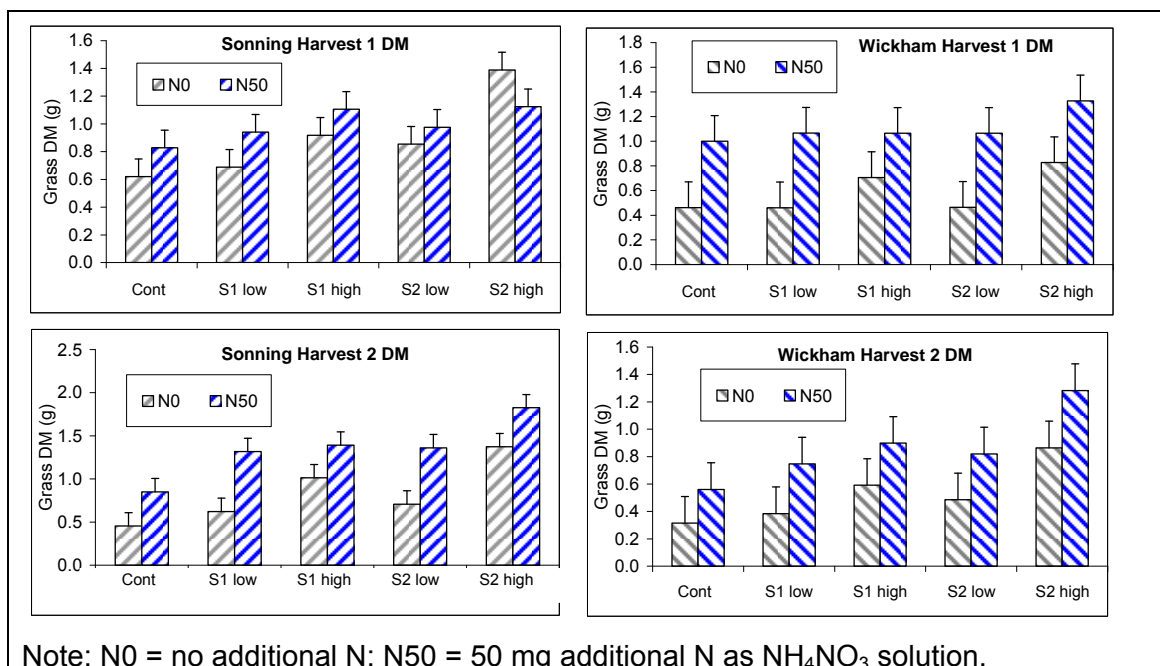
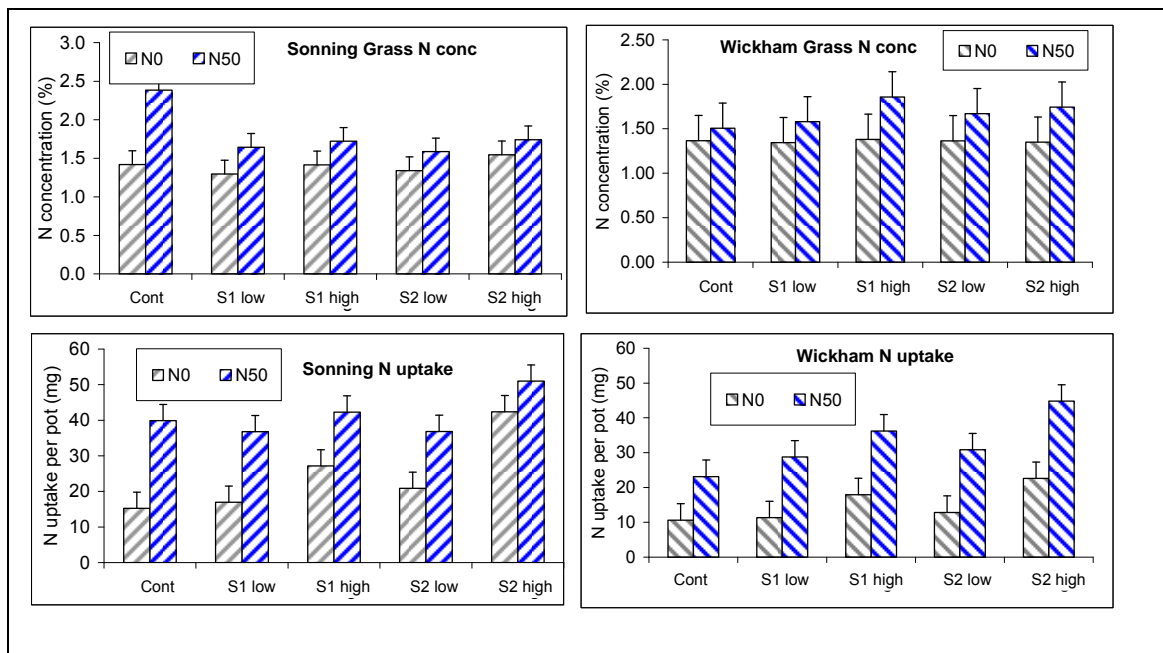


Figure 3.9 Grass dry matter yields (g per pot) in the immobilisation experiment.

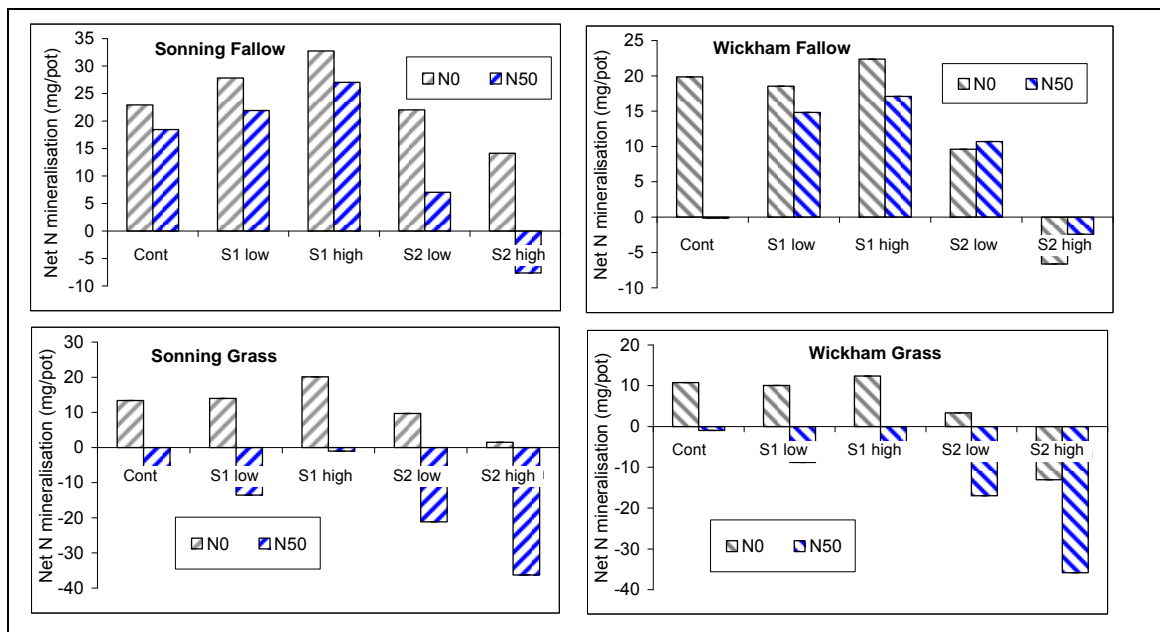
In Sonning soil, fertilizer N always increased the N concentration in grass; the increase was significantly larger in the control soil than in soils with CLO (Figure 3.10). Similarly, the total N uptake by grass in Sonning soil was always increased by fertilizer N and the increase was larger without CLO.

In Wickham soil, increases in N concentration caused by fertilizer were not so consistent; although the increases were of a similar magnitude to the increases observed in Sonning soil, they were not consistently significant. The increase in N uptake caused by fertilizer N was the same in all soil CLO treatments.



**Figure 3.10 Grass N concentrations and N uptakes (g per pot) in the immobilisation experiment.**

As in the main experiment, the calculated net mineralisation is low for the grass treatment because N taken up by the roots was not measured. The addition of fertilizer N always lowered net mineralisation (Figure 3.11). S2 provided a large input of mineral N at the start (Table 3.3) which appeared to lead to lower net mineralisation compared with S1.



**Figure 3.11 Net mineralisation of N in the Immobilisation Experiment.**

### 3.2.6 Metal uptake by grass

#### *Minor/trace elements*

There was no evidence that the application of CLO to soil caused increases in the concentrations of the potentially hazardous metals Cd, Cu, Ni, Pb, Se, V and Zn in the grass (Table 3.4). There were a few isolated cases of apparently significant increases with individual combinations of CLO and soil (e.g. increases in Zn concentration caused with the high application rate of CLO from S1 in Wickham soil). However, these one-off observations are not supported by any similar results, so it is assumed that they are random fluctuations in results and not caused by any general effect of CLO.

Grass Mn concentration showed some increases in Sonning soil, although only significant for GWC and S4. On the other hand, in Wickham soil, S1, S2 and S3 caused significant decreases in grass Mn concentration. This decrease may simply be due to dilution caused by the increased grass DM yield.

Grass Mo concentration was increased by GWC in both soils, but decreased significantly by S1, S2 and S3 in Sonning soil.

It is interesting to remark that grass Cd concentration appeared to be reduced in some cases for Wickham soil. However, examination of the results revealed that minor contamination of the zero calibration standard created a calibration error for that particular batch of results. Since there was no sign of Cd increases caused by CLO, the matter was not pursued further.

A likely outlier is seen in the grass Cu concentration for Sonning soil with S4 CLO applied at a low rate ( $105 \text{ mg kg}^{-1}$ ; see Table 3.4). This figure arises from the result of a single value of  $300.3 \text{ mg kg}^{-1}$  in one grass sample. Statistically, and for this experiment, it is an outlier. However, CLO is a material which potentially has high variability, so this apparent outlier could have been generated by an isolated particle of some contamination.



## *Major elements*

There was a very large effect by all CLOs and GWC on the concentration of Na in grass. This concentration was increased by between 3.4 (S1, Sonning soil) and 14.8 (S3, Sonning soil) times. Even at the low CLO application rates, the increases were always highly significant. This input of Na could have some adverse effects if allowed to continue, for example:

- a dilution effect on other nutrients within crops;
- effects on soil structure.

Grass Ca could be reduced significantly by CLO from S1, S3 and S4 in Sonning soil. This soil is sandy and thus expected to have low CEC<sup>3</sup> and reserves of Ca. This Ca reduction by CLO may be caused in part by a dilution of a fixed supply within the grass, caused by the increased DM yields (Figure 3.3). On the other hand, in Wickham soil, grass Ca concentrations were often increased; a notably significant increase was related to CLO from S2, for instance.

Grass K concentrations were little affected by CLO application, although it should be remembered that some fertilizer K was supplied to all pots. GWC increased grass K.

Grass Mg concentrations were often increased by CLO, with many significant effects, suggesting that CLOs could be useful sources of fertilizer Mg.

Even though P was also supplied as a soluble fertilizer, grass P concentrations were often reduced significantly by CLO, notably by material from S2, S3 and S4. At the same time, P concentrations in the leachates were also lowered (Figure 3.6). These results indicate that if CLOs are used as fertilizers, there may be cases where additional fertilizer P is required. In this particular experiment, P was not limiting to grass growth – there were very high grass P concentrations (~0.5 per cent) and high concentrations of extractable and leachable P (Figures 3.6 and 3.7).

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<sup>3</sup> Cation exchange capacity

**Table 3.4 Metal concentrations in grass (mg/kg).**

Yellow denotes a significant decrease relative to Control (P=0.05)  
 Blue denotes a significant increase relative to Control (P=0.05)

**1. Major elements**

Ca (mg/kg)	Sonning soil		Wickham soil	
	Low CLO conc.	High CLO conc.	Low CLO conc.	High CLO conc.
Control	7425		6094	
GWC	6978	6339	6823	6435
S1	6657	6014	6948	5772
S2	7004	7093	7094	6746
S3	6769	6396	6595	5531
S4	6589	6697	6111	5375
LSD (P=0.05)	635.2		642.7	
F pr.=	0.01		<0.001	

K (mg/kg)	Sonning soil		Wickham soil	
	Low CLO conc.	High CLO conc.	Low CLO conc.	High CLO conc.
Control	30662		32032	
GWC	34350	39528	35618	38497
S1	28806	28953	28652	28693
S2	29055	31583	33289	32828
S3	32264	32725	31851	34297
S4	32485	36452	33004	34566
LSD (P=0.05)	2589		2698	
F pr.=	<0.001		<0.001	

Mg (mg/kg)	Sonning soil		Wickham soil	
	Low CLO conc.	High CLO conc.	Low CLO conc.	High CLO conc.
Control	1617		1481	
GWC	1942	1750	1979	1994
S1	1650	1746	1612	1564
S2	1667	1719	1848	1731
S3	1881	2041	1830	1781
S4	2044	2096	1993	1598
LSD (P=0.05)	175.4		169.9	
F pr.=	<0.001		<0.001	

Na (mg/kg)	Sonning soil		Wickham soil	
	Low CLO conc.	High CLO conc.	Low CLO conc.	High CLO conc.
Control	427		429	
GWC	1927	4551	1685	3408
S1	1448	3983	1908	2975
S2	2011	5576	1897	3908
S3	2512	6319	2265	4233
S4	2271	5898	2299	3819
LSD (P=0.05)	810		629	
F pr.=	<0.001		<0.001	

P (mg/kg)	Sonning soil		Wickham soil	
	Low CLO conc.	High CLO conc.	Low CLO conc.	High CLO conc.
Control	5979		4977	
GWC	5462	5525	5773	5613
S1	5092	5315	4893	4681
S2	4686	5032	5122	4260
S3	5081	5679	5260	4402
S4	4965	5415	5359	4250
LSD (P=0.05)	465		524	
F pr.=	<0.001		<0.001	

## 2. Minor/trace elements

Cd (mg/kg)		Sonning soil		Wickham soil	
		Low CLO conc.	High CLO conc.	Low CLO conc.	High CLO conc.
		Control	-0.219		0.367
GWC	0.202	-0.23	-0.251	-0.152	
S1	-0.331	0.031	0.448	-0.624	
S2	-0.255	0.359	0.712	0.451	
S3	-0.11	-0.028	-0.375	-0.061	
S4	-0.049	-0.155	-1.308	-0.621	
LSD (P=0.05)	0.665		0.441		
F pr.=	NS		<0.001		

Cu (mg/kg)		Sonning soil		Wickham soil	
		Low CLO conc.	High CLO conc.	Low CLO conc.	High CLO conc.
		Control	6.5		7.4
GWC	10.4	9.6	7.54	8.26	
S1	5.9	6.5	9.03	7.66	
S2	5.7	7.6	6.53	6.34	
S3	9	9.1	7.00	6.31	
S4	105.6	7.4	7.58	7.97	
LSD (P=0.05)	86.7		1.8		
F pr.=	NS		NS		

Mn (mg/kg)		Sonning soil		Wickham soil	
		Low CLO conc.	High CLO conc.	Low CLO conc.	High CLO conc.
		Control	28.4		49.3
GWC	61.7	139.2	38.0	49.9	
S1	32.8	36.0	33.2	26.1	
S2	34.9	47.6	33.3	27.7	
S3	56.4	57.1	38.2	28.9	
S4	57.8	156.1	46.3	51.5	
LSD (P=0.05)	31.9		7.4		
F pr.=	<0.001		<0.001		

Mo (mg/kg)		Sonning soil		Wickham soil	
		Low CLO conc.	High CLO conc.	Low CLO conc.	High CLO conc.
		Control	9.76		5.40
GWC	12.25	15.01	11.55	12.92	
S1	7.15	4.54	6.09	4.57	
S2	6.33	4.48	6.92	5.70	
S3	7.49	5.12	7.23	3.34	
S4	9.65	9.81	10.11	5.08	
LSD (P=0.05)	1.68		2.09		
F pr.=	<0.001		<0.001		

Ni (mg/kg)		Sonning soil		Wickham soil	
		Low CLO conc.	High CLO conc.	Low CLO conc.	High CLO conc.
		Control	4.12		8.34
GWC	5.65	9.81	6.19	6.37	
S1	5.57	4.75	6.99	18.47	
S2	4.26	3.32	6.46	5.76	
S3	4.04	4.86	8.8	3.89	
S4	4.99	4.29	6.66	9.96	
LSD (P=0.05)	2.7		8.7		
F pr.=	0.008		NS		

Pb (mg/kg)		Sonning soil		Wickham soil	
		Low CLO conc.	High CLO conc.	Low CLO conc.	High CLO conc.
		Control	1.29		0.88
GWC	3.55	3.05	2.56	3.78	
S1	2.48	2.10	5.33	0.63	
S2	1.43	7.13	2.89	2.57	
S3	4.29	4.59	1.05	1.65	
S4	6.90	3.80	1.31	0.77	
LSD (P=0.05)	5.56		3.58		
F pr.=	NS		NS		

Se (mg/kg)		Sonning soil		Wickham soil	
		Low CLO conc.	High CLO conc.	Low CLO conc.	High CLO conc.
		Control	39.4		51.2
GWC	46.1	95.7	34.5	61.0	
S1	27.3	19.6	45.7	8.4	
S2	7.2	13.0	2.7	10.7	
S3	31.4	6.2	34.3	11.6	
S4	-7.6	5.0	19.0	28.6	
LSD (P=0.05)	46.6		44.1		
F pr.=	0.013		NS		

V (mg/kg)		Sonning soil		Wickham soil	
		Low CLO conc.	High CLO conc.	Low CLO conc.	High CLO conc.
		Control	0.179		0.000
GWC	0.053	0.040	-0.007	0.210	
S1	0.228	0.028	0.066	0.040	
S2	0.146	0.109	0.163	0.082	
S3	0.021	0.016	0.135	0.124	
S4	0.008	0.023	0.140	0.155	
LSD (P=0.05)	0.167		0.328		
F pr.=	NS		NS		

Zn (mg/kg)		Sonning soil		Wickham soil	
		Low CLO conc.	High CLO conc.	Low CLO conc.	High CLO conc.
		Control	26.2		29.1
GWC	33.5	46.1	23.0	29.5	
S1	27.1	31.7	36.2	49.8	
S2	23.0	32.3	25.5	18.1	
S3	33.3	44.8	29.8	25.6	
S4	95.0	37.0	56.5	38.4	
LSD (P=0.05)	58.4		18.6		
F pr.=	NS		0.010		

### 3.3 Discussion of results

#### 3.3.1 CLO composition

It had been anticipated that CLOs might vary widely in their composition. With respect to N availability, two features stand out. First, it was notable that for three materials (sites S1, S2 and S3), the organic C:N ratio ranged between 9.5 and 11.5, which is typical of natural soil organic matter. For the other two materials (i.e. GWC and S4), the C:N ratio was much higher, indicating the possibility of N immobilisation.

The experiments also revealed a high content of mineral N in two cases. S2 contained a high concentration of ammonium. The addition of available N that came with the high

concentration of CLO (39 and 35 mg in Sonning and Wickham soils, respectively) was sufficient to supply the entire N uptake requirement for two harvests of grass.

### 3.3.2 Grass growth

The experiment was designed so that grass growth would be N-limited to test the ability of CLOs to supply N. This objective appeared to be achieved. N concentrations in the main experiment did not vary very widely; increased N supply generally produced more growth and N uptake (rather than “luxury uptake” or a high N concentration without an increase in yield). However, there were a few exceptions that we have not been able to explain, such as the increased N concentration caused by GWC in Wickham soil. At the end of the experiment the amounts of leachable and extractable N were always low in all grass treatments. However, in the fallow treatments these amounts normally increased.

It was clear that CLOs S1, S2 and S3 acted as effective N fertilizers. Yields of grass dry matter (Figure 3.3) and N uptake (Figure 3.5) were increased significantly at the high application concentration, and in many cases at the low concentration as well. This increase occurs within a short period of application – up to 68 days from incorporation in the soil. S1, S2 and S3 were the three CLOs with low C:N ratios.

During the first month of the experiment growth on GWC and S4 was suppressed compared to the control (see Figure 3.4). We suggest that this may be due to short-term immobilisation of available N caused by these materials. Several results support this hypothesis, for example:

- overall N uptake was not increased by these CLOs (Figure 3.5);
- for GWC in fallow Sonning soil, the final extractable N was depressed by GWC compared with the control, although the result was not so clear for Wickham soil;
- GWC and S4 had high C:N ratios (15.5 and 20.9, respectively).

The lower yield may also be caused by the presence of toxic components in the CLO, or other unfavourable conditions such as high salinity. These causes cannot be ruled out, and further analysis of the CLOs is required, for example a study of their effects on soil solution conductivity and soluble metals when applied to soil.

### 3.3.3 Potential for N and P leaching from CLO

The leaching experiment used 150 ml water per pot, representing a rainfall event of approximately 2 mm. The soil was at field capacity, and on average 99 ml leachate (66 per cent of water applied) was collected. Leachate N concentrations were always very low for pots with grass (Figure 3.6), because the dense network of roots in every pot effectively captured mineralised N. Under fallow conditions in the main experiment, net mineralisation was increased by the application of CLO from S1 and S3 (Figure 3.8). The CLO from S2 started with a high initial mineral N input and therefore increased the amount of N leached in both soils, while CLO from S1 increased N leached in Sonning soil (Figure 3.1). Therefore, there is increased leaching loss of N for these CLOs with a high potential for N mineralisation, particularly in Sonning soil. In the heavier textured Wickham soil, N leaching was increased only when S3 was applied at the high concentration.

The actual concentrations of nitrate in leachate exceeded the permissible concentration for drinking water ( $11.3 \text{ mg N l}^{-1}$ ) in several cases. The largest leachate N concentration

from pots without grass was for S3 applied at the high concentration, giving 16.3 and 22.8 mg N l<sup>-1</sup> in leachate from Sonning and Wickham soils, respectively. In the other cases, with CLO from S1 and S2, the limit was exceeded by small amounts (the highest leachate concentration was 12.1 mg N l<sup>-1</sup>). In the immobilisation experiment, the 11.3 mg l<sup>-1</sup> limit was always exceeded where N fertilizer was used, including for the control soils.

We conclude from these observations that the CLOs with a high N content do increase the risk of higher N leaching. At the low CLO application rate (equivalent to 250 kg N ha<sup>-1</sup>), the leachate N concentrations under fallow conditions did not exceed the limit for drinking water. Therefore, the results indicate that CLO may be used as an organic N fertilizer if applied in accordance with the existing regulations. However, materials with a high C:N ratio could be applied at elevated concentrations without increasing the risk of N leaching, although this increased application rate would need to be shown to be beneficial.

Recently, the potential for diffuse pollution by P from agricultural sources has come under some attention. We found that CLO adds soluble P to the soil in the form of extractable P (Figure 3.2 and Figure 3.7). The P extracted by KCl is not a quantity normally used to assess available P in soils, but may approximate to water-extractable P (although salt solutions usually extract less P than water). The amount of phosphate-P extracted directly from CLO fell in a slightly higher range (7–32 mg P kg<sup>-1</sup>) than the soils used (3–13 mg P kg<sup>-1</sup>) (Table 3.3).

When applied to soil, CLO normally increased the extractable P (Figures 3.2 and 3.7), but CLO never increased leached P and in many cases caused highly significant depression of the leached phosphate-P (Figure 3.2 and Figure 3.6). These findings suggest that CLO application does not increase the risk of P leaching.

### 3.3.4 Mineralisation and immobilisation of N

Evidence for mineralisation of N from CLO was clear. The strongest evidence was the significant increase in N uptake by grass (Figure 3.5) caused by three CLOs (S1, S2 and S3), compared with control soil. The elevated amounts of extractable mineral N in fallow Sonning soil with the same CLOs also support this finding (Figure 3.1).

Regarding net mineralisation in fallow soil, net immobilisation might have occurred in pots containing GWC and S2. However, this experiment would be unable to distinguish between immobilisation and gaseous loss of N. In the case of S2, this CLO added a large amount of ammonium N, potentially a good substrate for immobilisation or ammonia loss. In the case of GWC, initial mineral N was at a low concentration (Table 3.3), so the decline in extractable N is most likely to be via immobilisation.

The subsidiary immobilisation experiment aimed to test for a possible decline in extractable N from an extra N source. Unfortunately, the most appropriate CLOs for this experiment were not selected. CLO from both S1 and S2 had substantial amounts of initial mineral N; in hindsight GWC and material from S4 would have been better choices.

We observed that fertilizer N significantly increased grass yield and N uptake (Figures 3.9 and 3.10). But in fallow soil, fertilizer N lowered the degree of net mineralisation. This finding supports a hypothesis that the presence of fertilizer, which creates a larger mineral N pool, encouraged a higher immobilisation rate. However, the effect of fertilizer N was the same in both CLO treatments and control. This suggests that material from S1 and S2 did not directly immobilise N.

### 3.3.5 Metal uptake by grass

In terms of the minor elements analysed, CLO applications did not cause any significant increases in the potentially toxic metals Cd, Cu, Ni, Pb, Se, V and Zn. Mn and Mo were the elements whose concentrations in crops are most likely to be affected by CLO application to soil, but even with these metals, the changes were not large and decreases could be possible as well as increases.

In the case of the major elements analysed, no large adverse effects were found for the major nutrients Ca, K and Mg; the results suggest that CLO may be useful as a source of Mg. The results for grass P concentration appeared to confirm results found by the leaching experiment (i.e. the availability of P is lowered slightly by CLO).

### 3.3.6 General conclusions

The pots trials aimed to:

- compare the effects of CLO materials on N uptake by plants;
- assess the fate of N within CLO amended soils (i.e. mineralisation, immobilisation and leaching).

It was clear from the experiments that the availability of N from CLO to grass varied significantly between CLO from different sources (Figure 3.4 and Figure 3.5). CLOs with an organic C:N ratio similar to that of soil organic matter (9.5–11.5) were immediately effective in supplying plant-available N.

It was also clear that CLO could participate in all these processes. Comparisons between the control soil and CLO-amended soils in the fallow pots showed that CLO could mineralise N to the extractable and available pool; CLO could also immobilise N from the leachable and extractable pool, and provide N for leaching (Figure 3.1).

## 4. Relating MBT/MHT input and output quality

A recurring issue of concern over the organic fraction produced through MBT/MHT processes is that the quality of the material is overly affected by the quality of the input material to the process, i.e. mixed Municipal Solid Waste (MSW). The overall objective of this Task was to assess how an MBT/MHT process affects the chemical composition of mixed waste material and to what extent, if at all, input quality and output quality could be related to each other. Specifically, the aims of this section are to:

- Provide a qualitative analysis of the input waste material in terms of its organic and inorganic content/natural and anthropogenic content,
- establish the component(s) of the feedstock that might be a source of chemicals identified as being of potential concern in the final CLO product;
- examine the material at key stages during the plant-specific production process to understand how the MBT/MHT process refines the feedstock, especially in relation to several organic chemicals;
- establish the influence of material size on chemical concentrations;
- identify which stages of the process result in the greatest refinement of the material and identify any potential to improve the process to optimise output quality and consistency.

The nature of material that is supplied to an MBT/MHT plant for processing is highly variable, depending on the time of year, the location of the plant (urban or rural) and the recycling regime in the area (high levels of kerbside recycling for example). In addition, MBT/MHT processes themselves are also very variable: while they all include a mechanical and a biological/heat element, the precise configuration of an individual plant (the sequence of processes, the type of processes, and the degree of refinement of the output materials, such as the grade of screening) can vary significantly. It is very likely that these variations between input materials and the nature and quantity of processes involved in preparing the organic fraction will have an influence on the quality of the resulting material.

Relating input to output quality at such plants is therefore a complex task. Such work has been undertaken in only a few plants in Europe, and only to a limited extent (Amlinger *et al.*, 2004). However, previous pilot studies on small sub-samples in Scandinavia have suggested that representative samples for chemical analysis can be taken at each process stage, but only following extremely rigorous separation and sorting (Cour Jansen *et al.*, 2004; Riber *et al.*, 2007).

The variation in process set-up between plants means that information on chemical quality before, during and after processing is site specific and will provide only limited, if any, generic information. The significance of any information generated by such analyses is also open to wide interpretation. Nonetheless, an improved understanding of how output quality is affected by both the quality of input material and at least some MBT/MHT processes could ultimately lead to improvements in CLO quality and consistency.



Insofar as a typical MBT process for the treatment of organic waste exists, we can assume that there are six key phases (although they may not appear in the same order as listed here), namely:

- arrival;
- screening;
- mechanical separation;
- biological treatment;
- maturation;
- departure.

The work described in this section describes the sampling and analysis of 'typical' MBT/MHT processes at key stages of production to assess how the physical and chemical composition of mixed waste material is affected and to what extent, if at all, the quality of input and output material can be related to each other.

The potential findings of from this assessment could provide several significant advantages to both industry and the Environment Agency. These benefits may include:

- provision of information on how the specific MBT/MHT process is functioning *in practice* (compared to its perceived functioning) through a better understanding of recovery/removal rates of recyclates and other material;
- the provision of data on the sources of specific chemical contamination, allowing MBT/MHT operators to remove or reduce the presence of certain feedstock components or to refine the MBT/MHT process to optimise output quality.
- an indication of the evolution of the chemical composition of material through the MBT/MHT process and an opportunity to understand how the MBT/MHT process and feedstocks influence output quality.

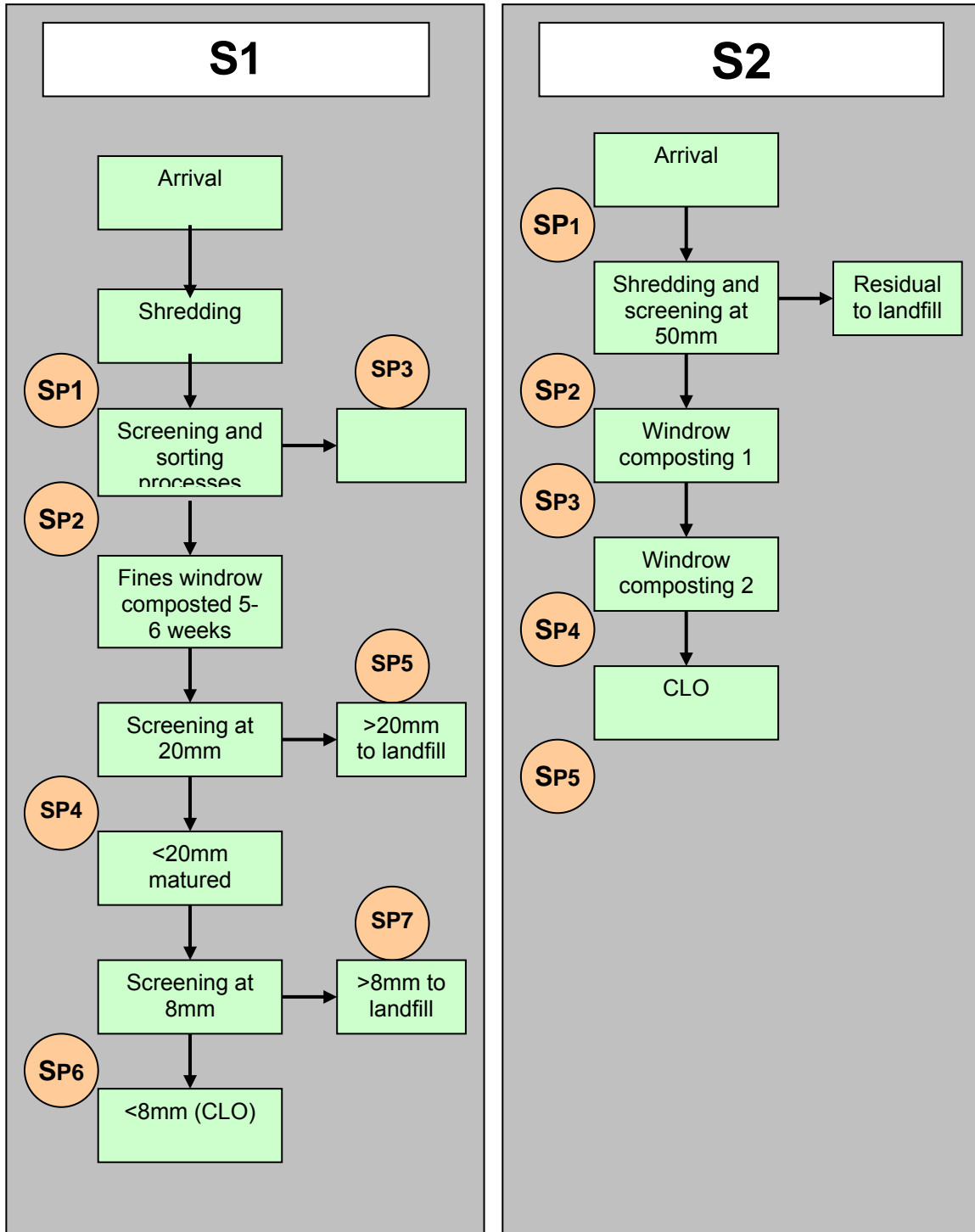
## 4.1 Plant description

This task was conducted with the support of two of the MBT/MHT plants participating in the wider trial (S1 and S2). The aim of the sampling strategy was to trace a single batch of mixed waste through the whole process of each site. Sampling took place:

- prior to treatment;
- at the end of treatment;
- at the key stages in the processes (identified below, and refined to suit the particular process at each site).

The processes undertaken at S1 and S2 are summarised in the flow diagrams for the two sites in Figure 4.1. Details of the site processes are purposely vague so as to maintain the anonymity of plant. For a variety of logistical reasons (timing, distance to the respective plants, co-ordination with analytical laboratories etc.) the majority of the sampling effort was focused on S1. In both cases SP1 (the 'raw' feedstock) was not sampled in practice due to health and safety concerns over the very poor quality of the input material and practical issues of analysing such material in the laboratory.

Figure 4.1 Process flow diagrams of S1 and S2 showing sampling points.



## 4.2 Sampling

At each of the stages described in Table 4.1 the material was sampled using the methodology described below:

- i. A sample representative of the whole (i.e. selected from several sections of the pile and coned and quartered down to a manageable size; typically around 50 kg).
- ii. Where possible, the sample was photographed.
- iii. Where appropriate, a sub-sample of the material was taken for laboratory analysis.
- iv. Where possible the sample was separated out manually and the composition of the sample was recorded. The table was filled with an indication of whether the material was present or absent (visually) from the sample. In some cases it was also possible to weigh the material. The material was weighed on-site when such facilities were available.

The difficulty in obtaining a representative sample of household waste as it passes through an MBT plant is widely acknowledged (Cour Jansen *et al.*, 2004; Riber *et al.*, 2007). It is not physically possible to trace a precise sample through a process, due to the scale of the operation, the gradual refinement of the input material and mixing of the original sample with other material. However, to obtain a broadly representative sample of material that has undergone the same conditions of temperature, moisture and plant operation, we sampled each stage of the process at the time at which the original input material should have reached the stage. This has the advantage of removing some of the issues relating to sampling the same material, but this sampling strategy can never be more than semi-quantitative.

We also experienced a number of logistical challenges because our sampling methodology required us to visit the site several times to take samples. Sometimes staff at the plant had to take samples because the treatment process operated quicker or slower than originally expected. Our interpretation of the analytical results from this sampling exercise acknowledges the semi-quantitative aspect of this approach.

This methodology relies upon the cooperation of site staff with sampling staff. This was discussed in advance with site managers, along with a range of other issues related to health and safety.

The data gathered through this methodology is site specific; they can only be used to make broad generalisations for the wider industry; even where the same, or a very similar process is used by another plant, the data should be viewed and used cautiously. It is widely acknowledged that there is considerable variation in chemicals and concentrations over time, a fact supported by previous research (Environment Agency, 2009). Thus the information in this section should be considered as baseline data. Further sampling and improvements to the sampling strategy in co-operation with site operators would improve the scope and reliability of the information gained.

## 4.3 Analytical methods

The samples collected were subject to a two-stage process. They were first screened into a range of size fractions, then they were screened for a broad range of chemicals.

Few analytical laboratories are prepared to undertake any kind of analytical work on raw MBT/MHT feedstock, primarily on health and safety grounds. However, two

laboratories were willing to size fractionate the samples prior to sending to the laboratories for chemical analysis. Two approaches were used, depending on the laboratory undertaking the work. In the case of the initial feedstock samples (i.e. those taken prior to any pre-treatment) screening was performed only to separate the material into >2 mm and <2 mm fractions. In other cases the size fractions selected were those used in the standard industry specification, PAS100 (BSI: 2005) Annex E (i.e. 31.5 mm, 16 mm, 8 mm, 4 mm, 2 mm, 1 mm).

Given the exploratory nature of the work and the semi-quantitative nature of the sampling, the most technically and economically advantageous approach was to use a chemical screening method to determine the chemical composition of the samples at each stage of the process. We focused the chemical screening on organic chemicals as these have the greatest variability in CLOs and potentially pose the greatest environmental and human health risks (see Chapter 2).

We chose to use a targeted gas-chromatograph mass-spectrometry multi residue (GCMS MR) screen for this purpose. The method is a recently developed interpretative method available at the Environment Agency's National Laboratory Service (Wayne Civil pers. comm.). This new methodology, which has only become available in the last six months, uses 'deconvolution reporting software' which effectively uses the extensive historical analytical database of the NLS as a reference to identify peaks present within the samples. Over 770 potentially hazardous organic chemicals can be identified, including speciated PAHs, triclosan and a number of phthalates. The method is also UKAS accredited.

The results of this screening method are described below separately for each site.

## 4.4 Results and discussion

### 4.4.1 Site S1: general information

At site S1 there were seven planned sampling points through the process from arrival to CLO. In practice the arrival sample could not be handled by laboratories on health and safety grounds, so samples from six sampling points were screened using the analytical method described in Section 4.3. Sieving to specified size fractions produced a total of 19 samples for chemical analysis. The samples are described in more detail in Table 4.1

**Table 4.1 Description of the samples taken at site S1.**

Sampling point	Description	Size fractions	Total samples
1	Input material, mixed MSW; not sampled due to H&S concerns at laboratories. Material characterised by hand picking a representative sample	n/a	0
2	Fine material (<80 mm) following screening, magnetic and ballistic separation	<2 mm, >2 mm	2
3	Residual material (>80 mm) following screening, magnetic, ballistic and optical separation	<2 mm, >2 mm	2
4	Material <20 mm post initial composting	>16 mm >12 mm >8 mm >4 mm, >2 mm >1 mm, <1 mm	7
5	Material >20 mm post initial composting (Landfill)	>31.5 mm	1
6	Material <8 mm following maturation (COMPOST LIKE OUTPUT)	>4 mm, >2 mm, >1 mm, <1 mm	4
7	Material >8 mm following maturation (Landfill)	>31.5 mm, >16 mm, >8 mm	3
		<b>TOTAL</b>	<b>19</b>

#### 4.4.2 Site S1: qualitative analysis of waste composition

LATS compliance requires MBT/MHT input material to be characterised by hand picking and grouping into a range of categories and weighed. We therefore assisted in this process for the relevant batch of material that we wished to assess through the entire process. A large volume sample was removed from the input feedstock using a mechanical loader, mixed thoroughly, then coned and quartered down to a representative sample of approximately 50 kg in weight.

This sample was divided by hand on a 10 mm screen, so that the residual material fell through to a collecting tray below. Besides the sub 10mm fraction, the following categories were identified:

- organic material >10 mm;
- paper/cardboard;
- partially degradable material (e.g. textiles, nappies and composite waste fractions made at least partially from degradable materials, such as wood);
- inert material (such as glass, stones, bricks and ceramics);
- plastic;
- metals.

The sub 10 mm fraction, organic, paper and partially degradable categories are together defined as biodegradable municipal waste (BMW). Once the sample was segregated, weighed and photographed it was returned to the processing stream.

Approximately 60 per cent of the 50 kg sample was BMW, mostly made up of paper, cardboard and organic material. The majority of the non-biodegradable element was made up of plastic (approximately 30 per cent of the total by weight). Inert materials and metals formed relatively small portions of the waste breakdown, while 7.6 per cent of the waste was less than 10 mm in size. According to site staff, this composition was typical of the long-term average for the area, although there are variations according to the time of year.

The separation of material at the hand picking stage allowed us to identify specific items that could be potential sources of contamination identified at later stages during the chemical screening. The large quantity of plastic in the feedstock (by volume as well as weight) was particularly notable. Most of the plastic consisted of fragments of thin plastics, derived from packaging and plastic bags, with the occasional recognisable item, such as a child's ball for example. Other recognisable items included crisp and sweet wrappers, large metal fragments including a pair of pliers, fragments of nappies as well as occasional whole nappies, faeces, animal remains, compact discs, wood fragments, wire and remains of electronic equipment.

A visual examination of the material taken at sampling points 2 and 3 respectively showed that although the screening is relatively coarse there is already a distinct difference in the make up of the two. At this stage the majority of clean plastic, ferrous and non-ferrous metal has been cleared out of the samples through screens, magnets, eddy current and optical separation. These samples were dried and separated into fractions above and below 2 mm by the laboratory.

During the process at S1, the material from sampling points 2 and 3 is combined and subjected to an initial composting process for five to six weeks. After this point the waste has undergone some form of sanitisation with the composting process, therefore a second laboratory agreed to screen the material according to the PAS100 (Annex E) method.

According to this method the sample is sieved sequentially through sieves of 31.5 mm, 16 mm, 12 mm, 8 mm, 4 mm, 2 mm and 1 mm; the mass and percentage of the sample retained at each stage is recorded (BSI:2005). However, at S1 the next step in the processing after the initial composting is to screen the material at 20 mm; the oversize material goes to landfill. Sampling point 5 therefore equates to the >31.5 mm fraction of the oversize material, while the undersize material (sampling point 4) was screened from the >16 mm fraction downwards.

Following a further period of maturation of five to six weeks, the undersize material was screened further to 8 mm. The oversize fraction from this process is accessed at sampling point 7 (see Table 4.1); this material was destined for landfill and was screened at 31.5 mm and 12 mm. The material less than 8 mm in size is the CLO produced by site S1; this material is that taken from sampling point 6. It was screened by the laboratory at 1, 2 and 4 mm.

#### **4.4.3 Site S1: chemical analysis**

In total, the screening analysis identified 102 chemicals across all of the samples taken from site S1. Many of these were detected in very small quantities and/or infrequently through the range of samples. Of the 102 chemicals, 38 were only registered in one of the 19 samples, while a further 21 chemicals only registered in two or three samples. In most of these cases there was no pattern to the occurrence of the chemicals either in terms of particle size distribution or the stage in the process at which they appeared.

This degree of variability can be explained at least in part by the wide range of materials that are typically found in mixed MSW; however, it is not unreasonable to

suggest that spikes of specific chemicals could be associated with a specific and isolated source of contamination within the source waste material.

Of the remaining 43 chemicals identified, the most significant in terms of the number of samples in which they appeared were bisphenol A, caffeine, n,n-diethyl-m-toluamide (DEET), DEHP, fluoranthene, phenanthrene, pyrene (18 samples), 2-ethylhexyl diphenyl phosphate, campesterol, cholesterol, ibuprofen, sitosterol and triclosan. Some of these substances, such as caffeine, cholesterol and campesterol have not been identified as priority contaminants in CLO and have therefore not been considered further. Of most interest are the chemicals associated with plastics, PAHs and biocides, including bisphenol A, DEET, DEHP, fluoranthene, phenanthrene, pyrene and triclosan. Full data for the most significant chemicals in the screen are shown in Appendix E.

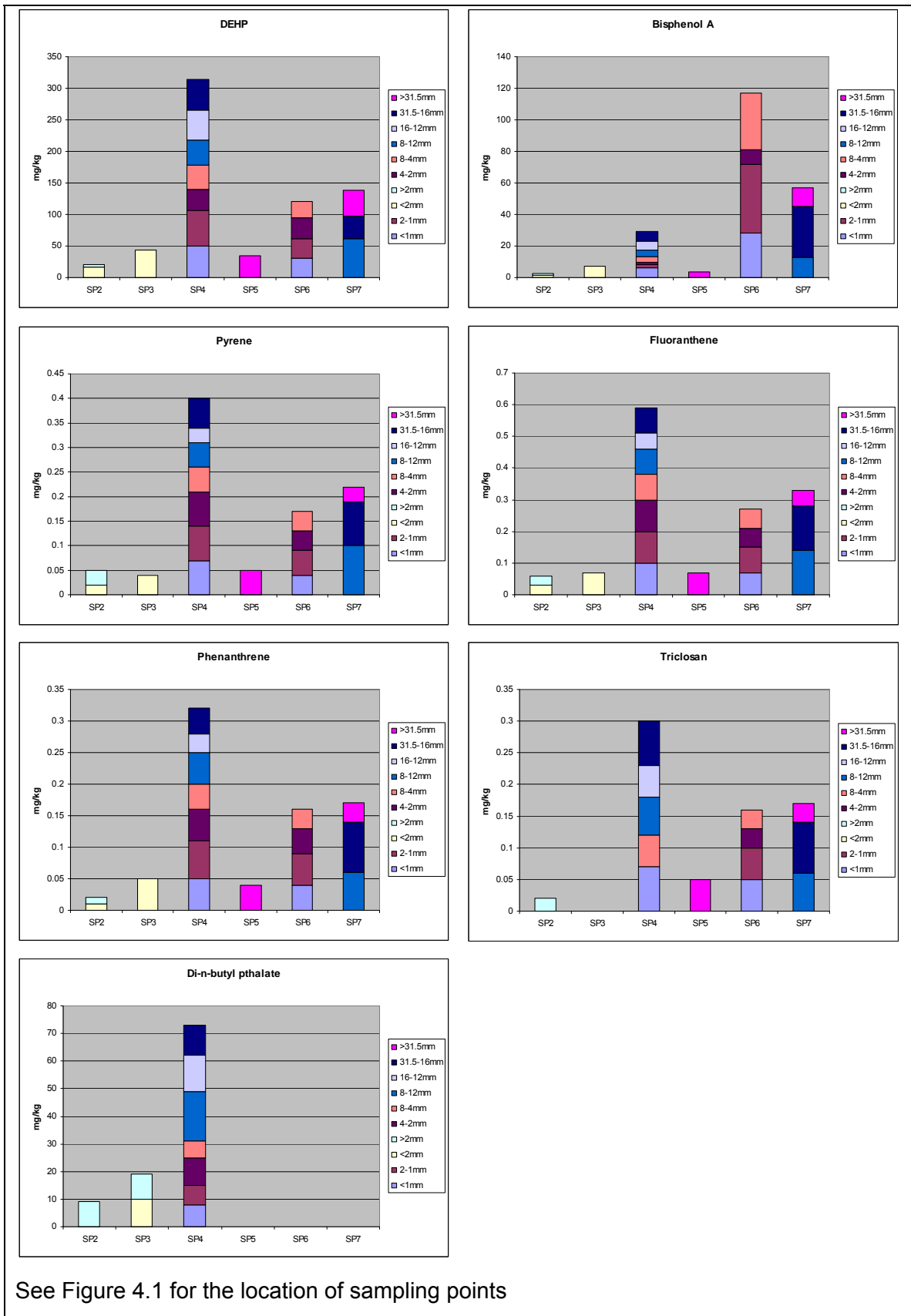
Details of chemical concentrations in a range of particle sizes at the different sampling stages in the process are shown for a range of chemicals in Figure 4.2. There is no consistent pattern in the distribution of chemical concentrations by particle size; this assessment is complicated, however, by the fact that no stage in the process deals with a single particle size fraction. This is partly due to:

- the physical nature of the material at different stages of the process;
- the different protocols used by the two laboratories;
- the process itself, which includes screening at 20 mm and 8 mm and therefore automatically excludes part of the size fractionation.

Nonetheless, there is no consistency or pattern within or between chemicals with regard to concentration and size distribution (see Section 4.4.6).

Patterns do begin to emerge, however, if the concentrations by particle size are grouped together into sampling point stages, as shown in Figure 4.1. There are four distinct patterns among the chemicals assessed at S1:

- i. No presence at the early sampling stages, followed by a presence of the chemical at sampling points 6 and 7.
- ii. Presence of the chemical in the early stages, followed by no detection in sampling points 6 and 7.
- iii. Continuous or near-continuous presence, but with a variable concentration displaying no significant upward or downward trend.
- iv. Continuous or near-continuous presence with a distinct upward trend through the process.



See Figure 4.1 for the location of sampling points

**Figure 4.2** Examples of the distribution of selected chemicals by particle size and sampling points of the S1 process.



The case of *presence followed by no presence* (see ii, above) is illustrated by the graph for di-n-butyl phthalate in Figure 4.2. This pattern (i.e. a presence in samples from points 2–5, but no presence at all in sampling points 6 and 7) is also shown, though less markedly, by other phthalates, including dimethyl phthalate and dicyclohexyl phthalate. Of the phthalates examined in the screening tests, di-n-butyl benzyl phthalate, dibutylphthalate dimethyl phthalate and di-n-octyl phthalate were also measured in the regular monitoring described in Section 0 of this report. In the regular monitoring survey these phthalates are mostly below the limits of detection at S1, although they do register above the detection limit periodically, particularly (but not exclusively) in the later samples (February–March 2009).

The concentrations of the other phthalates monitored are variable. Many samples are below limits of detection (typically  $<0.1 \text{ mg kg}^{-1}$ ). However, diethylhexylphthalate and diisnonylphthalate both registered values well above the limits of detection (up to  $41 \text{ mg kg}^{-1}$  and  $36 \text{ mg kg}^{-1}$ , respectively) on most occasions in the case of diisnonylphthalate and all occasions in the case of diethylhexylphthalate. These values are consistent with DEHP values in the process study and are two orders of magnitude higher than the values for other phthalates monitored in both assessments (see Appendices A and E).

These values suggest that the *presence followed by no presence* pattern observed for the phthalates measured in the screening test may therefore be an artefact perhaps arising from the chemical analysis or from the variability of the samples collected (which is to be expected with mixed MSW).

There is insufficient data available to conclude that at least some phthalates are degraded, physically removed or transformed in some manner during the composting process. It is not possible to state that the same process is responsible for the removal of each of the chemicals exhibiting this behaviour, not least because the observed effect is inconsistent.

However, the evidence does suggest that the process may affect at least some of the phthalates observed. If there is a relationship between different phthalates, or a consistent effect upon phthalates within the process, it is likely to be linked to the removal of plastics. In the case of chemicals which show the opposite trend (i.e. not present until the final sampling points), these are mostly obscure volatile organic compounds, such as the one illustrated.

In the case of PAH, the nine chemicals monitored in the chemical screening method for the process monitoring programme were also measured in the monthly monitoring programme (see Section 2). In general the data for CLO in the screening method were within the range of values found in the monthly monitoring programme, although they were almost always at the lower end of this range.

The final pattern (*continuous, increasing presence*, see iv, above) is illustrated to a greater or lesser extent by the remaining examples in Figure 4.2. There may be some distortion of the data because the results from sampling point 4 (post maturation  $<20 \text{ mm}$ ) contain a wider range of particle sizes and consequently involve a greater range of analyses. If the concentration data for sampling points 6 and 7 (the final CLO fraction and the final residual fraction sent to landfill, respectively) are combined together they have a slightly lower value than for sample points 4 and 5 (post maturation phases).

Given that the majority of the chemicals exhibiting this trend are associated with plastic, we can make two key observations. First, that contamination by these chemicals increases significantly from the early sampling stages, presumably through relative concentration as other elements of the waste are removed and the organic fraction of the waste is reduced in volume through composting. Second, that although the process removes a significant volume of plastic from the final CLO, this does not appear to

produce a corresponding effect in the chemical composition of the output material. In the samples analysed from S1, the plastic content of the final CLO was relatively high.

Since these samples were taken, the S1 process has been refined; it now includes an improved screening at the final stage which has significantly reduced the plastic content in the output CLO. This improvement may have affected the chemical composition of the CLO produced at S1 but we do not have data available as yet to state this categorically.

A notable exception within the group of chemicals displaying an upward trend in concentration is bisphenol A. This substance has a far higher concentration within the CLO sample than at any of the other sampling points in the process (for the other chemicals the combined concentration of the different size fractions from sample point 4 is greater). The total concentrations of bisphenol A are also far higher than those for the other chemicals observed, with the exception of DEHP.

Bisphenol A is widely used in resins and polycarbonate plastics, which suggests that the most likely sources (at least those that can be identified visually) are the plastic and plastic-coated materials in the waste stream. There is no clear explanation for why this trend should occur, aside from the possibility that the process of CLO production has concentrated the bisphenol A through screening and composting.

As implied from the other data, a large quantity of plastic is removed during the process, although significant quantities remain, albeit as relatively small size fractions. It is probable that the process, in reducing the quantity of the organic fraction of the feedstock through composting and removing the larger size material, may effectively increase the concentration of certain chemicals. However, no other chemicals detected in the samples displayed a similar trend. Bisphenol A was not measured in the routine monitoring programme for the output material, so there are no data available for comparison.

#### **4.4.4 Site S2: general information**

Site S2 used a different process involving shredding, screening and windrow composting. A description of the process, and the number and size fractions of samples at each sampling point are shown in Table 4.2.

**Table 4.2 Description of the samples taken at site S2.**

<b>Sampling point</b>	<b>Description</b>	<b>Size fractions</b>	<b>Total samples</b>
1	Input material, mixed MSW; not sampled due to H&S concerns at laboratories.	n/a	0
2	Fine material (<50 mm) following shredding and screening but before initial composting	<2 mm, >2 mm	2
3	Post initial composting period (1-2 weeks)	>31.5 mm >16 mm >12 mm >8 mm >4 mm, >2 mm >1 mm, <1 mm	7
4	Post secondary composting period (1-2 weeks)	>31.5 mm >16 mm >12 mm >8 mm >4 mm, >2 mm >1 mm, <1 mm	7
5	Material twice screened following maturation (COMPOST LIKE OUTPUT)	>8 mm >4 mm, >2 mm >1 mm, <1 mm	5
6	Residual to landfill: no sample analysed	n/a	0
		<b>TOTAL</b>	<b>21</b>

#### 4.4.5 Site S2: chemical analysis

At site S2 a total of 108 different chemicals were identified across all samples. As with the screening of site S1, many of these chemicals were identified in three or fewer samples; a total of 70 of the chemicals identified were eliminated from further consideration on these grounds.

As already explained for S1, the most likely reason for the sporadic appearance of obscure or unusual chemicals in a chemical screen would be a specific source of contamination in the original sample. Nicotine, for example, is not a priority substance, but traces were found in the first sampling point in both size fractions, but not in samples taken from later stages of the process. The most likely source of this chemical in MSW would be cigarette filters. The act of smoking concentrates the chemicals found in the tobacco, including nicotine, into the filter; these could later leach out of the filter into surrounding material once the filter enters the MSW waste stream. Cigarette ends are notoriously persistent in municipal waste because they are resistant to degradation processes; however, they are large enough to be removed through early screening processes.

Of the remaining 38 chemicals that were frequently detected in the S2 samples, a further 12 were excluded from further analysis on the grounds that they were not an environmental priority. This left 26 substances for consideration, mostly PAHs and chemicals associated with plastics, as well as biocides such as DEET. Full data for these chemicals are provided in Appendix F.

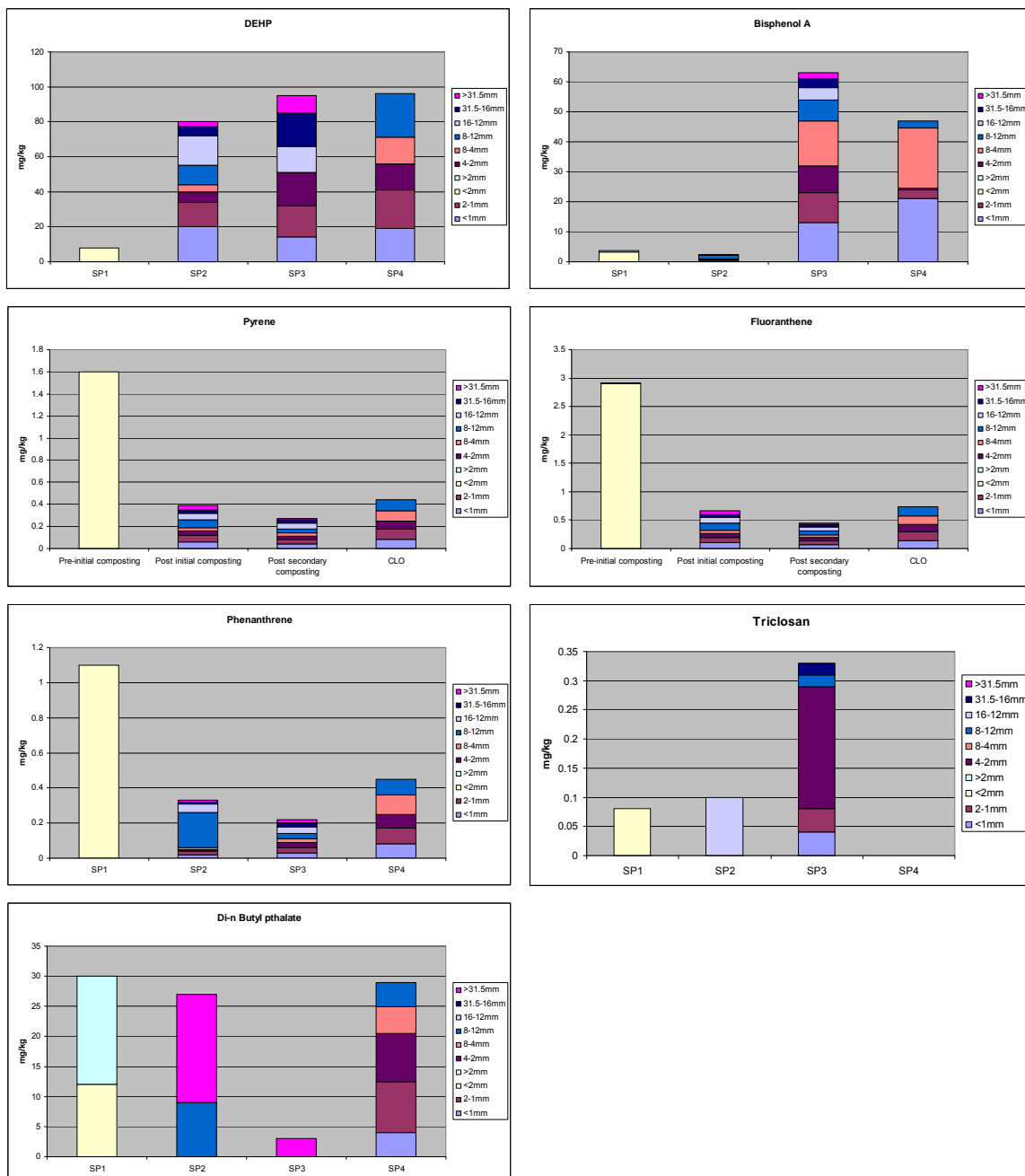
Similar trends to those observed in S1 samples were also observed for samples taken at S2, in particular in relation to bisphenol A and DEHP (which again showed a distinctive (and even more marked) increase in concentration through the process, and

concentrations about two orders of magnitude higher than the other chemicals). The concentration of bisphenol A in the final CLO (sampling point 5) was slightly lower than that in the preceding sample (see Figure 4.3).

Triclosan also showed an increase in concentration through the process, but it was not detected at all in the final CLO, whereas concentrations of pyrene, fluoranthene, phenanthrene and di-n-butyl phthalate showed a falling trend over the process with an increase in the final CLO (Figure 4.3). Some substances were only detected at the final sampling point. A notable difference between the two sites is the higher concentrations of a wider range of PAHs (although many are predominantly found across all size fractions from sampling point 2 and not at any other sampling points). Similar to the results from S1, there is no evidence that chemicals are concentrated in particular size fractions.

Triclosan data in the monthly monitoring programme are broadly consistent with the data in this screening assessment, although the concentrations are more variable (ranging from below limits of detection to almost  $8 \text{ mg kg}^{-1}$ ). Data for PAHs such as phenanthrene and fluoranthene are generally higher in the monthly monitoring programme; however, the data from the screening assessment are at the lower end of the typical range so they are not incomparable.

Four phthalates were analysed in both the monthly monitoring programme and the screening assessment. Dimethylphthalate was not detected in the monthly monitoring and only found once above the limit of detection in the screening analysis; di-n-octyl phthalate was found occasionally at comparable concentrations in each case, while the data for dibutyl phthalate was considerably higher in the screening assessment than in the monthly monitoring ( $3 \text{ mg kg}^{-1}$  as opposed to  $0.9 \text{ mg kg}^{-1}$ ). Diethylhexylphthalate (DEHP) levels were also high in all of the monthly monitoring samples, though not as high as the levels recorded in the input-output experiment. Further details can be found from a comparison of data in Appendices B and F.



**Figure 4.3** Examples of the distribution of selected chemicals by particle size and sampling points of the S2 process.

#### 4.4.6 Conclusions

We undertook this sampling exercise to improve our understanding of how an MBT/MHT process affects the range and concentration of organic micropollutants in the finished CLO product. We also wanted to assess how, if at all, the quality of the input material could be related to the quality of the output product. This work had four specific objectives and we discuss our findings and conclusions under each objective below, using results from both sites S1 and S2.

- **Provide a qualitative analysis of the input waste material in terms of its organic and inorganic content/natural and anthropogenic content,**

The detailed hand picking of the shredded MSW at S1 permitted us to conduct a quantitative as well as qualitative analysis of the input material. Although the majority of the material was classified as biodegradable, it was also extremely heterogeneous, in particular containing a large quantity of various forms of plastic. The content of metal and inert material was relatively low, although significantly higher than the level required for PAS100.<sup>4</sup>

The content of organic material in the sample analysed was approximately 20 per cent. This organic fraction is roughly equivalent to the 'natural' content of the sample, as it included items such as vegetable peelings, plant and animal remains. Very little of the sample could be described as truly 'natural' in origin, as by definition MSW is made up of items discarded by people.

- **Establish the component(s) of the feedstock that might be a source of chemicals identified as being of potential concern in the final CLO product.**

The majority of chemicals identified as significant within the chemical screening are associated mainly with plastics (e.g. DEHP, bisphenol A, other phthalates) and oils, paints, rubber materials and burnt materials (PAH). Items containing these materials and/or subjected to these processes would almost certainly be found in any mixed MSW. Samples from both sites showed evidence of a wide range of plastics, as well as composite materials containing plastic, such as fragments of wire.

Triclosan is another chemical of concern; sanitary products are the primary anthropogenic source of this chemical. There was clear evidence of nappies in the hand picked sample from S1; other sanitary materials also appeared to be present, but could not be clearly identified. The material from S2 was not hand picked so it is not possible to confirm that similar materials were present, although this is highly probable.

A range of other identifiable materials were also observed during the hand picking session at S1, including ferrous and non-ferrous metal fragments, cigarette remains, animal remains and faeces. These components may also be significant sources of the contaminants identified, although the plastic content is the more likely source of most elements found.

It should also be considered that a significant volume of the hand picked material was not easy to identify and a significant quantity was too distorted, too small, too broken or too dirty to identify at all; many sources of contamination may therefore have gone unrecorded during the hand picking.

- **Examine the material at key stages during the plant-specific production process to understand how the process refines the feedstock, especially in relation to organic micropollutant composition.**

The material was examined at several points in the processes at both sites, including post-shredding and screening, post-composting and post-maturation. The processes were not identical and therefore neither were the sampling programmes. The composition of micropollutants did vary at both sites; where a direct comparison was possible, the chemical analysis data were usually within the range of monthly data collected on CLO from the same sites.

In general the micropollutant concentration followed one of four trends through the process; 'present-not present'; 'not present-present'; 'always present, but no clear trend'; 'always present, with a clear upward trend'. Although there was no clear trend

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<sup>4</sup> The sample as examined was not air-dried, as required for the PAS100 analysis; however, the content of inert material was so high that it is unlikely that a dry sample would have met the PAS100 standard.

between chemicals or groups of chemicals, the trends for specific chemicals through the process were notable. Of particular interest was bisphenol A, which appears to increase in concentration over the course of the processes at both sites; a similar, but less pronounced, trend was also observed for DEHP at both sites.

Other chemicals appear to respond differently to processing at the different sites. The concentration of triclosan showed more of an upward trend at site S2, while phenanthrene, anthracene and pyrene all showed a more marked decline in concentration through the process at site S2, whereas at site S1 they showed a slight increase or decrease in concentration through the process.

The concentration of phthalates (other than DEHP) appeared to fall dramatically during processing at both sites, disappearing altogether in the CLO samples. These data were not entirely consistent with data from the monthly monitoring of CLO from the sites (where a direct comparison was possible). A wider range of phthalates was monitored in the monthly programme, and many of these did not display a similar pattern.

The GCMS MR screening method identified around 100 different chemicals in at least one of the samples from each site, although the range of chemicals in each of these samples was not the same. In total, 149 chemicals were identified across both sites, although the vast majority of these were regarded as insignificant because they appeared no more than three times at concentrations above limits of detection at either site, or because they were not a priority chemical for assessment within CLO.

This sampling exercise generated insufficient data at either site to come to any clear conclusions, but it has highlighted issues which justify further investigation. In particular, we recommended further monitoring for bisphenol A, DEHP, a wider range of phthalates, triclosan and PAHs to clarify the data gathering by this project. Improvements in co-ordination between the site, the site staff, the laboratories and the sampling procedure are also recommended to improve the efficiency of the analysis based on practical experience during the project.

- **Establish the influence of material size on chemical concentrations.**

The samples collected at S1 and S2 were sieved to a range of particle sizes (see Table 4.1 and Table 4.2); the individual size fractions were subjected to a chemical screen, the results of which are described in the preceding sections. There is no evidence from the chemical screening that particle size has a significant effect on the concentration of the range of chemicals studied.

Table 4.3 and Table 4.4 show the percentage of the total material in each sieved fraction (where the material was sieved according to the analytical method used in PAS100) of each sample and the concentration of DEHP and bisphenol A for S1 and S2, respectively. As expected, there is not a perfect match between the percentage of material and the percentage of the total chemical concentration in each size category. There is also no distinct relationship between particle size and chemical concentration, nor is there any consistency in the relationship between particle size and chemical concentration between chemicals. This is also true of the other chemicals observed in the screening analysis.

From the available evidence it is not possible to say that size fractionation of the waste material exerts any kind of consistent influence on chemical concentration.

**Table 4.3 The relationship between particle size and DEHP and bisphenol A concentration at different stages of the process at S1.**

<b>S1: DEHP</b>						
<b>Size fraction</b>	<b>Pre-maturation</b>		<b>CLO</b>		<b>Material to landfill</b>	
	<b>Quantity per size fraction (%)</b>		<b>Quantity per size fraction (%)</b>		<b>Quantity per size fraction (%)</b>	
	<b>Material</b>	<b>Chemical</b>	<b>Material</b>	<b>Chemical</b>	<b>Material</b>	<b>Chemical</b>
>31.5 mm					13.39	30.22
>16 mm	14.97	15.29			59.64	25.18
>12 mm	0.36	15.29				
>8 mm	6.48	12.74			26.97	44.60
>4 mm	13.2	12.10	28.26	20.83		
>2 mm	17.76	10.51	19.05	28.33		
>1 mm	18.57	18.15	15.47	25.00		
<1 mm	28.63	15.92	37.23	25.83		

<b>S1: bisphenol A</b>						
<b>Size fraction</b>	<b>Pre-maturation</b>		<b>CLO</b>		<b>Material to landfill</b>	
	<b>Quantity per size fraction (%)</b>		<b>Quantity per size fraction (%)</b>		<b>Quantity per size fraction (%)</b>	
	<b>Material</b>	<b>Chemical</b>	<b>Material</b>	<b>Chemical</b>	<b>Material</b>	<b>Chemical</b>
>31.5 mm					13.39	21.05
>16 mm	14.97	20.55			59.64	56.14
>12 mm	0.36	20.55				
>8 mm	6.48	13.7			26.97	22.81
>4 mm	13.2	11.99	28.26	30.77		
>2 mm	17.76	5.82	19.05	7.69		
>1 mm	18.57	6.85	15.47	37.61		
<1 mm	28.63	20.55	37.23	23.93		



**Table 4.4 The relationship between particle size and DEHP and bisphenol A concentration at different stages of the process at S2.**

<b>S2: DEHP</b>						
<b>Size fraction</b>	<b>Post-initial composting</b>		<b>Post-secondary composting</b>		<b>CLO</b>	
	<b>Quantity per size fraction (%)</b>		<b>Quantity per size fraction (%)</b>		<b>Quantity per size fraction (%)</b>	
	<b>Material</b>	<b>Chemical</b>	<b>Material</b>	<b>Chemical</b>	<b>Material</b>	<b>Chemical</b>
>31.5 mm	14.75	3.75	6.12	10.53		
>16 mm	15.11	6.25	24.01	20		
>12 mm	4.18	21.25	6.2	15.79		
>8 mm	15.19	13.75	15.39	0	5.72	26.04
>4 mm	17.79	5	18.29	0	14.09	15.63
>2 mm	12.37	7.5	11.24	20	17.7	15.63
>1 mm	10.91	17.5	8.46	18.95	20.13	22.92
<1 mm	9.69	25	10.28	14.74	42.26	19.79

<b>S2: bisphenol A</b>						
<b>Size fraction</b>	<b>Post-initial composting</b>		<b>Post-secondary composting</b>		<b>CLO</b>	
	<b>Quantity per size fraction (%)</b>		<b>Quantity per size fraction (%)</b>		<b>Quantity per size fraction (%)</b>	
	<b>Material</b>	<b>Chemical</b>	<b>Material</b>	<b>Chemical</b>	<b>Material</b>	<b>Chemical</b>
>31.5 mm	14.75	0	6.12	3.17		
>16 mm	15.11	10.46	24.01	4.76		
>12 mm	4.18	0	6.2	6.35		
>8 mm	15.19	50.21	15.39	11.11	5.72	5.12
>4 mm	17.79	8.79	18.29	23.81	14.09	42.68
>2 mm	12.37	0	11.24	14.29	17.7	0.98
>1 mm	10.91	14.23	8.46	15.87	20.13	6.4
<1 mm	9.69	16.32	10.28	20.63	42.26	44.81

- **Identify which stages of the process result in the greatest refinement of the material and identify any potential to improve the process to optimise output quality and consistency.**

On the evidence available from site S1, the most effective means of reducing the contamination from organic micropollutants appears to be the removal of plastics from the sample. This appears to be most effectively undertaken through the various screening processes through which it passes.

The evidence available cannot be used to say for certain in what form the contaminants associated with plastics are contained within the CLO (i.e. whether they are still associated with the plastics themselves or whether they have partitioned onto organic fractions within the CLO). This is an important piece of missing knowledge.

Since this project conducted sampling activity at S1, a new screen has been installed in the final stage of the process, which appears to have significantly reduced the actual plastic content. Without further analysis of the material following this amendment, however, it is not possible to say how this improvement has affected the chemical composition of the CLO material.

The process at S2 is also due to undergo significant modernisation and refurbishment within the year. We therefore recommend that a follow-on study should be conducted, based on the experience of this work, to refine the analysis, clarify the results and assess how the changes to the process have improved the chemical composition of the resulting CLO and where this improvement has taken place.

# 5. Conclusions and recommendations

The aim of this project was to assess compost-like output (CLO) from a range of mechanical-biological treatment (MBT) and mechanical-heat treatment plants to provide more information on which to base policy and regulation regarding the application of CLOs to land. The project set four specific objectives that aimed to address uncertainties in the Environment Agency's previous risk assessment (Environment Agency, 2009):

- i. **Estimate exposure concentrations for a prioritised list of chemicals.**  
Monthly sampling and analysis of CLO from four plants would be used to derive estimates of exposure concentrations for a prioritised list of chemicals. These exposure concentrations could be used in an assessment of potential environmental and human health risks from the application of CLO to land. The data would be used to assess the sampling requirements that would be needed to develop a compliance-based approach to CLO application, similar to that used to assess water quality.
- ii. **Improve the accuracy of the current limit values.**  
More accurate limit values would make it possible to assess the potential environmental risks for several priority chemicals.
- iii. **Determine the nitrogen release characteristics of CLO.**  
A pot trial aimed to assess nitrogen release and subsequent uptake of nutrients and metals.
- iv. **Assess the relationship between input feedstock quality and output CLO quality.**  
A chemical analysis of samples as they passed through the process would help to assess the dynamics of organic micropollutants and relationship between the presence of these substances in the input feedstock and their presence in – or removal from – the final CLO.

## 5.1 Monthly sampling, exposure concentrations and limit values

Monthly sampling and analysis of CLO took place at four MBT/MHT plants. Estimates of exposure concentrations for a prioritised list of chemicals were determined and used in an assessment of potential environmental and human health risks.

A range of MBT/MHT plant operators were approached by the project team with regard to participating in the sampling and analysis programme. These approaches resulted in four plants participating in the project. As in previous work, plants have co-operated on the basis that anonymity is maintained: as a result the data from the sites are labelled as sites S1–S4. Sampling began in December 2008 and continued through to March 2009.

A general analysis of the core characteristics of each of the CLO materials was undertaken. The level of physical contaminants (i.e. glass, metal, plastic, stones) was high at all sites; pH varied from slightly alkaline to mildly acidic across the four sites.

Samples from the four sites were analysed for a suite of chemicals: perfluorocarbons and triclosan; dioxins and furans; metals and other elements; polycyclic aromatic hydrocarbons; hydrocarbons; perchlorinated biphenyls; *E. coli* and *Salmonella*.

These analyses revealed that:

- no PCBs were detected in any samples from any sites;
- only one site registered *Salmonella*; all sites registered *E. coli* at least once;
- the presence of hydrocarbons, particularly longer chain hydrocarbons, was unexpectedly high, although the concentrations are below the derived published PNECs;
- published PNECs of these hydrocarbons are widely acknowledged to be of low reliability, so the concentrations of these chemicals in CLO may still be of concern;
- results for all other chemical groups analysed in the samples showed wide variability between elements and between sites.

It was important to prioritise the chemicals which would be the focus of analyses so that the project would remain cost-effective and informative. A prioritisation process was undertaken in the preceding project (Environment Agency, 2009). This process was further refined within this project by taking into account the effect levels of substances, their limits of detection and their environmental behaviour. This evidence-based approach helped to reduce further the list of priority chemicals.

### 5.1.1 Calculating exposure concentrations

It is common practice in risk assessments to use a parameter such as a 'reasonable worst case percentile' (e.g. 90th percentile) to represent the temporal distribution of exposure values. This approach is appropriate if the frequency distribution of a parameter can reasonably be inferred from measurement or theory. However, we may not know or not be able to predict the distributions of some chemicals in CLO; estimates of 90th percentiles may therefore not be a valid method on which to base exposure concentrations.

The results from monthly analyses of outputs were used to determine whether a defensible statistical distribution can be fitted to the data. The calculated 10th and 90th percentile concentrations of priority physical and chemical determinands from the CLO are shown in Table 2.9, Table 2.10 and Table 2.11. These data were used in the assessment of potential chemical risks from the use of CLO.

When attempting to assess the quality of a material against a limit value or standard, it is clearly important to take samples for analysis that are representative of the entire batch. However, the heterogeneity of the input material (and hence some chemicals detected in CLO) was so great that even with relatively large numbers of point samples ( $n = 25$ ) it was not possible to state with confidence for some chemicals that composite samples represented the entire batch.

Using existing analytical data from the earlier precursor project (Environment Agency, 2009a), simple power analyses were used to determine the number of samples that would be required to detect a 10–70 per cent difference from the mean limit value determined from up to 12 samples of CLO taken over one year. As a demonstration, the power analysis was undertaken for cadmium and triclosan (see Table 2.12).

## 5.1.2 Limit values

Previous work (Environment Agency, 2009) has identified the data that would be required to reduce the current uncertainty in CLO risk assessment and provide evidence on which policy could be based. In particular, it is important to establish robust estimates of limit values – soil-based predicted no effect concentrations (PNECs) – with which the final risks associated with a particular exposure scenario can be characterised.

The chemicals given the highest priority in this project were those for which existing limits were highly uncertain and for which relatively high concentrations were present in the CLO. Four chemicals or groups of chemicals were identified as being a priority and for which no current soil-related limit value exists. These chemicals were triclosan, phthalates (especially butylbenzylphthalate, dibutylphthalate and diethylhexylphthalate), PAHs and perfluorooctanesulphonate (PFOS).

PNECs were calculated for these chemicals in order to assess their potential risks to the environment (see Table 2.13). No human health limit values were derived. A number of the limit values are still thought to be highly uncertain (i.e. they have an assessment factor higher than 50 or they are not derived using terrestrial ecotoxicity data).

## 5.2 Pot trial

A pot trial was undertaken to:

- compare the effects of CLO materials applied to soil on N uptake by plants;
- assess the fate of N within soils (i.e. mineralization, immobilisation and leaching);
- assess metal uptake by plants in soils amended with CLO.

The pot trial used CLO from the four sites as well as a green waste compost (GWC), two different soils (sandy and clay loam), two levels of CLO application and two forms of cultivation (fallow and rye grass, which was harvested twice during the trial). A leaching experiment was conducted at the end of the trial (which lasted for a total of 66 days).

The trial was designed to cover the most realistic extreme conditions; it allowed the range of results to be a fair reflection of the likely range of responses under field conditions. The results of the trial are summarised briefly in the following sections.

### 5.2.1 CLO composition

For three materials (from sites S1, S2 and S3), the organic C:N ratio ranged from 9.5 to 11.5, which is typical of natural soil organic matter. For GWC and CLO from S4, the C:N ratio was much higher, indicating the possibility of N immobilisation.

In two cases the mineral N content was very high. S2 contained a particularly high concentration of ammonium. When this material was applied to the pots at a high rate, the addition of available N was enough to supply the entire N uptake requirement for two harvests of grass.

### 5.2.2 Grass growth

N concentrations in the main experiment did not vary widely, so the increased N supply in the immobilisation experiment resulted mainly in more growth and N uptake rather than a higher N concentration without increasing yield.

CLOs from S1, S2 and S3 acted as effective N fertilizers. Yields of grass dry matter and N uptake increased significantly at the high application rate (concentration) of CLO, and in many cases at the low concentration as well. These were the three CLOs with low C:N ratios.

During the first month of the experiment, growth on GWC and S4 was suppressed compared to the control (see Figure 3.4). This effect could be due to short-term immobilisation of available N caused by these materials. The GWC and S4 had high C:N ratios (15.5 and 20.9, respectively). The presence of toxic components in the CLO, or other unfavourable conditions such as high salinity may also be possible causes of the decrease in yield.

### 5.2.3 Potential for N and P leaching from CLO

The leaching experiment used 150 ml water per pot, a volume selected to represent a rainfall event of approximately 2 mm. The soil was at field capacity; on average 99 ml leachate (66 per cent of water applied) was collected.

In pots planted with grass, concentrations of N in the leachate were always very low because the dense network of roots effectively captured mineralised N.

In pots left fallow in the main experiment, net mineralisation was increased by CLO from S1 and S3, while S2 contributed a high initial mineral N input. Therefore, there was increased loss of N due to leaching for these CLOs and a high potential for N mineralisation, particularly in the lighter soil. In the heavier textured soil, N leaching increased only for S3 applied at the high concentration.

Actual concentrations of nitrate in leachate exceeded the permissible concentration for drinking water ( $11.3 \text{ mg N l}^{-1}$ ) in several cases.

We conclude from these observations that CLOs with a high N content do increase the risk of higher N leaching. At the low application concentration (equivalent to  $250 \text{ kg N ha}^{-1}$ ), the concentrations of N in the leachate from fallow pots did not exceed the limit for drinking water. Therefore, the results indicate that CLO may be used as an organic N fertilizer if applied in accordance with existing regulations. However, CLO materials with a high C:N ratio could be applied at elevated concentrations without increasing the risk of leaching.

CLO also adds soluble P to the soil in the form of extractable P. The phosphate-P extracted directly from CLO was in a slightly higher range ( $7\text{--}32 \text{ mg P kg}^{-1}$ ) than the soils used ( $3\text{--}13 \text{ mg P kg}^{-1}$ ). When applied to soil, CLO was normally capable of increasing the extractable P, but it never increased leached P and in many cases caused a highly significant drop in the concentration of leached phosphate-P. This suggests from CLO application does not present an increased risk of P leaching.

### 5.2.4 Mineralisation and immobilisation of N

Mineralisation of N from CLO was shown by the significant increase in N uptake by grass caused by three CLOs (sites S1 and S2 and S3) compared with the control soil.

Net immobilisation might have also occurred in fallow pots with GWC and CLO from S2, but the experimental results do not distinguish between immobilisation and gaseous loss. CLO from S2 added a large amount of ammonium N – potentially a good substrate for immobilisation or ammonia loss. Where GWC was applied, initial mineral N was at a low concentration, so the decline in extractable N is most likely to have been via immobilisation.

The subsidiary immobilisation experiment aimed to assess whether extractable N would decline when extra N was added to the medium from an additional N source. Unfortunately, the wrong CLOs were selected for this subsidiary experiment; CLO from both S1 and S2 had substantial amounts of initial mineral N. In hindsight GWC and S4 would have been better choices.

We observed that fertilizer N significantly increased the grass yield and N uptake, but in fallow soil, fertilizer N lowered the level of net mineralisation. This finding suggests that the presence of fertilizer created a larger mineral N pool, and thus encouraged a higher immobilisation rate. However, the effect of fertilizer N was the same in both CLO treatments and controls, suggesting that material from S1 and S2 did not directly immobilise N.

### **5.2.5 Metal uptake by grass**

CLO applications did not cause any significant increases in the potentially toxic metals Cd, Cu, Ni, Pb, Se, V and Zn. Mn and Mo are the main minor elements whose concentrations in crops are most likely to be affected by CLO application to soil, but our analyses showed that the changes in concentration were not large; decreases could be possible as well as increases.

Our analyses also measured levels of major elements; no large adverse effects were found for the major nutrients Ca, K and Mg. This result suggests that CLO may be useful as a source of Mg. The results for grass P concentration appeared to confirm results found by the leaching experiment i.e. the availability of P is lowered a little by CLO.

## **5.3 MBT/MHT input and output quality**

Two plants agreed to have material sampled periodically during the passage of material through their processes. Samples were analysed for particle size distribution and a chemical screen for a broad range of potential organic contaminants was performed for each sample.

The purpose of this sampling exercise was to improve our understanding of how an MBT/MHT process could affect the range and concentration of organic micropollutants in the finished product and to assess how, if at all, the quality of the input feedstock is related to output quality. The main conclusions relating to the four specific objectives of the work are outlined below.

### **5.3.1 Qualitative analysis of the input waste material**

The hand picking of the shredded MSW at S1 showed that the majority of the material (approximately 60 per cent) was classified as biodegradable. The input feedstock was extremely heterogeneous, in particular containing a large quantity of various forms of plastic. The content of metal and inert material was relatively low.

The content of organic material in the sample analysed was approximately 20 per cent. Very little of the sample could be described as truly 'natural' in origin, as MSW is implicitly made up of what is discarded by people.

### **5.3.2 Establish the potential sources of chemicals of potential concern in the final CLO**

The majority of chemicals identified as significant within the chemical screening are associated mainly with plastics (e.g. DEHP, bisphenol A and phthalates in general), oils, paints, rubber materials, burnt materials (PAHs), and biocides (DEET).

In samples from both sites there was evidence of a wide range of plastics, as well as composite materials containing plastic, such as fragments of wire.

Triclosan is another chemical of concern; anthropogenic sources of this chemical are largely sanitary products.

There was clear evidence of nappies in the hand picked sample from S1; other sanitary materials also appeared to be present but could not be clearly identified. The material from S2 was not hand picked, so it is not possible to confirm that similar materials were present in the S2 feedstock, although this is highly probable.

Other identifiable materials were also observed during the hand picking session at S1, including ferrous and non-ferrous metal fragments, cigarette remains, animal remains and faeces.

A significant volume of the hand picked material was too distorted, too small, too broken or too dirty to identify at all. Many sources of contamination may therefore have gone unrecorded during the hand picking.

### **5.3.3 Examine the material at key stages during the production process to understand how it refines the feedstock**

In general the concentrations of micropollutants followed one of four trends through the process: 'present-not present'; 'not present-present'; 'always present but no clear trend'; 'always present with a clear upward trend'.

Of particular interest is the continuous presence of bisphenol A, which appears to increase in concentration through processes at S1 and S2. A similar, but less pronounced trend was also observed in DEHP at both sites.

The response of other chemical to the MBT/MHT process was different at the two sites. The concentration of triclosan showed more of an upward trend at site S2, while phenanthrene, anthracene and pyrene all showed a more marked decline in concentration through the process at site S2. At S1 these substances showed a slight increase or decrease in concentration through the process.

The concentration of phthalates (other than DEHP) appeared to fall dramatically during the processes at both sites, disappearing altogether in the CLO samples. However, these data were not entirely consistent with data from the monthly monitoring of CLO from the sites where a direct comparison was possible.

The screening method identified approximately 100 different chemicals in at least one of the samples at both sites (although the range of chemicals was not the same). In total, 149 chemicals were detected across both sites. The vast majority of these substances were regarded as insignificant on the grounds that they only appeared



occasionally and/or were not chemicals identified as a priority for assessment within CLO.

The study generated insufficient data at either site to come to any clear conclusions, but there are areas which justify further investigation. In particular, further monitoring is recommended for bisphenol A, DEHP, phthalates, triclosan and PAHs to clarify the information generated in this project.

#### **5.3.4 Establish the influence of material size on chemical concentrations**

There is no evidence from the analyses undertaken that particle size has a significant positive or negative effect on the concentration of any of the chemicals studied. While there is variability in chemical concentration, there is no consistency in this variation.

#### **5.3.5 Identify which stages of the process result in the greatest refinement of the material and identify any potential to improve the process to optimise output quality and consistency.**

On the evidence available from site S1, the most effective means of reducing the contamination from organic micropollutants appears to be the removal of plastics from the sample. This appears to be most effectively undertaken through the various screening processes through which the material passes.

Since we conducted the sampling work for this project the operator at S1 has installed a new screen in the final stage of the process; this appears to have significantly reduced the physical plastic content. However, it is unclear from the data available whether the chemicals associated with plastics are still associated with the plastic material itself at this stage of the process or whether they have partitioned onto organic fractions within the material. While the removal of plastics is a significant step forward in the quality of the material, we cannot say whether this physical improvement will be matched with a similar chemical improvement in the resulting CLO.

The process at S2 is also due to be refined significantly within the year. It is recommended that a follow-on study should be conducted, based on the experience of this work, to refine the analysis and provide further information to clarify the results.

### **5.4 Recommendations**

1. A full year of monthly monitoring data would help to reinforce the data already gathered and help to remove any concerns over annual variability in chemical concentrations caused by changes in the composition of the mixed MSW feedstock. However, it is likely that for some chemicals and MBT/MHT outputs this frequency may still not produce enough samples to have a representative indication of chemical concentrations.
2. Refined data would improve the reliability of the effect concentrations and limit values which are derived from the data. Nevertheless, the values developed in this project have improved the accompanying risk assessment and reduced uncertainties.

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# Appendix A: Full data, site S1 (continued)

Site Number	S1			S1			S1		
Sample Number	1			2			3		
Sample Date	09/12/2008			09/12/2008			15/12/2008		
Sample Description									
Compound	PAH	CAS no	Units	test result	test result	test result	test result	test result	
	Acenaphthene		ug kg-1	40	11	75	32		
	Acenaphthylene		ug kg-1	14	<1	43	11		
	Anthanthrene		ug kg-1	<30	<30	600	180		
	Anthracene		ug kg-1	79	20	700	62		
	Benzo(a)anthracene		ug kg-1	160	40	2300	59		
	Benzo(a)pyrene		ug kg-1	56	31	2100	21		
	Benzo(b)fluoranthene		ug kg-1	<200	<200	3000	<200		
	Benzo(e)pyrene		ug kg-1	95	41	1500	64		
	Benzo(ghi)perylene		ug kg-1	40	35	1200	280		
	Benzo(k)fluoranthene		ug kg-1	<100	<100	1400	<100		
	Chrysene		ug kg-1	190	75	2500	94		
	Cyclopenta(cd)pyrene		ug kg-1	<10	<10	650	17		
	Dibenzo(ah)anthracene		ug kg-1	<3	<3	260	63		
	Fluoranthene		ug kg-1	710	260	5800	250		
	Fluorene		ug kg-1	78	<10	64	24		
	Indeno(1,2,3cd)pyrene		ug kg-1	34	<30	1100	110		
	Naphthalene		ug kg-1	28	<10	32	69		
	Perylene		ug kg-1	35	<30	580	<30		
	Phenanthrene		ug kg-1	490	160	2100	110		
	Pentachlorophenol		ug kg-1	<7210	<7360	<1540	<1840		

Site Number	S1			S1			S1		
Sample Number	5			6			7		
Sample Date	21/01/2009			21/01/2009			04/03/2009		
Sample Description									
Compound	PAH	CAS no	Units	test result	test result	test result	test result	test result	
	Acenaphthene		ug kg-1	36		30	40		
	Acenaphthylene		ug kg-1	12		<5	<4		
	Anthanthrene		ug kg-1	<30		<30	<30		
	Anthracene		ug kg-1	82		<90	<90		
	Benzo(a)anthracene		ug kg-1	240		100	100		
	Benzo(a)pyrene		ug kg-1	25		<100	<100		
	Benzo(b)fluoranthene		ug kg-1	230		<200	<200		
	Benzo(e)pyrene		ug kg-1	40		<90	<90		
	Benzo(ghi)perylene		ug kg-1	72		<100	<100		
	Benzo(k)fluoranthene		ug kg-1	170		<430	<470		
	Chrysene		ug kg-1	250		100	100		
	Cyclopenta(cd)pyrene		ug kg-1	73		<50	<40		
	Dibenzo(ah)anthracene		ug kg-1	38		<30	<30		
	Fluoranthene		ug kg-1	810		300	200		
	Fluorene		ug kg-1	41		60	60		
	Indeno(1,2,3cd)pyrene		ug kg-1	52		<30	<30		
	Naphthalene		ug kg-1	25		<50	<40		
	Perylene		ug kg-1	<30		<350	<440		
	Phenanthrene		ug kg-1	470		300	300		
	Pentachlorophenol		ug kg-1	<5730		<11600	<11700		

Site Number	S1			S1			S1		
Sample Number	1			2			3		
Sample Date	09/12/2008			09/12/2008			15/12/2008		
Sample Description									
Compound	PCB	CAS no	Units	test result	test result	test result	test result	test result	
	PCB - 008		ug kg-1	<2	<2	<2	<2		
	PCB - 020		ug kg-1	<2	<2	<2	<2		
	PCB 28		ug kg-1	<2	<2	<2	<2		
	PCB - 035		ug kg-1	<2	<2	<2	<2		
	PCB 52		ug kg-1	<1	<1	<1	<1		
	PCB - 077		ug kg-1	<2	<2	<2	<2		
	PCB 101		ug kg-1	<2	<2	<2	<2		
	PCB - 105		ug kg-1	<1	<1	<1	<1		
	PCB 118		ug kg-1	<1	<1	<1	<1		
	PCB - 126		ug kg-1	<1	<1	<1	<1		
	PCB - 128		ug kg-1	<1	<1	<1	<1		
	PCB 138		ug kg-1	<1	<1	<1	<1		
	PCB - 149		ug kg-1	<1	<1	<1	<1		
	PCB 153		ug kg-1	<1	<1	<1	<1		
	PCB - 156		ug kg-1	<0.9	<0.9	<0.9	<0.9		
	PCB - 169		ug kg-1	<0.9	<0.9	<0.9	<0.9		
	PCB - 170		ug kg-1	<2	<2	<2	<2		
	PCB - 180		ug kg-1	<1	<1	<1	<1		

Site Number	S1			S1			S1		
Sample Number	5			6			7		
Sample Date	21/01/2009			21/01/2009			04/03/2009		
Sample Description									
Compound	PCB	CAS no	Units	test result	test result	test result	test result	test result	
	PCB - 008		ug kg-1	<2		<9	<9		
	PCB - 020		ug kg-1	<2		<9	<9		
	PCB 28		ug kg-1	<2		<9	<9		
	PCB - 035		ug kg-1	<2		<9	<9		
	PCB 52		ug kg-1	<1		<5	<4		
	PCB - 077		ug kg-1	<2		<9	<9		
	PCB 101		ug kg-1	<2		<9	<9		
	PCB - 105		ug kg-1	<1		<5	<4		
	PCB 118		ug kg-1	<1		<5	<4		
	PCB - 126		ug kg-1	<1		<5	<400		
	PCB - 128		ug kg-1	<1		<5	<4		
	PCB 138		ug kg-1	<1		<5	<4		
	PCB - 149		ug kg-1	<1		<5	<4		
	PCB 153		ug kg-1	<1		<5	<4		
	PCB - 156		ug kg-1	<0.9		<5	<4		
	PCB - 169		ug kg-1	<0.9		<4	<4		
	PCB - 170		ug kg-1	<2		<9	<9		
	PCB - 180		ug kg-1	<1		<5	<4		

# Appendix A: Full data, site S1 (continued)

Site Number	S1		S1		S1		S1	
Sample Number	1		2		3		4	
Sample Date	09/12/2008		09/12/2008		15/12/2008		15/12/2008	
Sample Description								
Compound	CAS no	Units	test result		test result		test result	
Hydrocarbons								
Equiv. Carbon No >10-12 Aliphatic fraction		ug kg-1	1120		<300		<300	
Equiv. Carbon No >10-12 Aromatic fraction		ug kg-1	6610		7000		2260	<300
Equiv. Carbon No >12-16 Aliphatic fraction		ug kg-1	10500		4580		780	<300
Equiv. Carbon No >12-16 Aromatic fraction		ug kg-1	26800		15000		1760	4770
Equiv. Carbon No >16-21 Aliphatic fraction		ug kg-1	111000		55000		34800	51300
Equiv. Carbon No >16-21 Aromatic fraction		ug kg-1	63700		53600		56800	64700
Equiv. Carbon No >21-35 Aliphatic fraction		ug kg-1	977000		579000		452000	1220000
Equiv. Carbon No >21-35 Aromatic fraction		ug kg-1	787000		689000		1040000	1610000
Equiv. Carbon No >35-40 Aliphatic fraction		ug kg-1	89300		62300		139000	741000
Equiv. Carbon No >35-40 Aromatic fraction		ug kg-1	97100		54100		445000	224000
Hydrocarbons, Aliphatic extractable C10 - C40 :		ug kg-1	1190000		701000		626000	2020000
Hydrocarbons, Aromatic extractable C10 - C40 :		ug kg-1	981000		819000		1550000	1900000
bons, Total extractable C10 - C40 : Dry Wt (EPH)		ug kg-1	2170000		1520000		2170000	3920000

Site Number	S1		S1		S1		S1	
Sample Number	5		6		7		8	
Sample Date	21/01/2009		21/01/2009		04/03/2009		04/03/2009	
Sample Description								
Compound	CAS no	Units	test result		test result		test result	
Hydrocarbons								
Equiv. Carbon No >10-12 Aliphatic fraction		ug kg-1	<300		<300		<300	
Equiv. Carbon No >10-12 Aromatic fraction		ug kg-1	1900		<300		<300	
Equiv. Carbon No >12-16 Aliphatic fraction		ug kg-1	34400		<300		<300	
Equiv. Carbon No >12-16 Aromatic fraction		ug kg-1	53700		3440		3930	
Equiv. Carbon No >16-21 Aliphatic fraction		ug kg-1	2150000		72800		50600	
Equiv. Carbon No >16-21 Aromatic fraction		ug kg-1	1300000		248000		172000	
Equiv. Carbon No >21-35 Aliphatic fraction		ug kg-1	12600000		1370000		1160000	
Equiv. Carbon No >21-35 Aromatic fraction		ug kg-1	12200000		1260000		1350000	
Equiv. Carbon No >35-40 Aliphatic fraction		ug kg-1	2790000		125000		136000	
Equiv. Carbon No >35-40 Aromatic fraction		ug kg-1	1000000		94400		104000	
Hydrocarbons, Aliphatic extractable C10 - C40 :		ug kg-1	16700000		1570000		1350000	
Hydrocarbons, Aromatic extractable C10 - C40 :		ug kg-1	14500000		1610000		1630000	
bons, Total extractable C10 - C40 : Dry Wt (EPH)		ug kg-1	31200000		3180000		2980000	

Site Number	S1		S1		S1		S1	
Sample Number	1		2		3		4	
Sample Date	09/12/2008		09/12/2008		15/12/2008		15/12/2008	
Sample Description								
Compound	CAS no	Units	test result		test result		test result	
Physical contaminants (%W/W)			w/w/	dry/w	w/w/	dry/w	w/w/	dry/w
% of total sample plastic >2mm		%	8.18	12.83	5.08	8.14	22.7	22.69
Glass > 2mm		%	9.43	14.78	8.55	13.69	10.4	10.4
metal >2mm		%	0.471	0.74	0.313	0.5	0.39	0.39
stones (> 2 mm (w/w) >4mm (dry/w))		%	10.9	17.02	3.48	5.57	2.58	2.58
Other >2mm		%		10.25		14.31		0
Chemical and biological								
Lime Equiv (as CaCO3)		%	7.76		8.7		11.9	
Neutralising value		as CaO equiv	4.35		4.88		6.65	
Compost stability		mgCO2/g OM/d	18		14.2		6.54	
B.O.D.		mg/L	1922		2222		276	
E. coli		cfu/g	3800		2000		<10	
Salmonella			negative		negative		negative	

Site Number	S1		S1		S1		S1	
Sample Number	1		2		3		4	
Sample Date	09/12/2008		09/12/2008		15/12/2008		15/12/2008	
Sample Description								
Compound	CAS no	Units	test result		test result		test result	
Physical contaminants (%W/W)			w/w/	dry/w	dry/w	dry/w	dry/w	dry/w
% of total sample plastic >2mm		%	<0.1	0.09	<0.1	0	0.5	0.5
Glass > 2mm		%	0.6	0.57	0.5	0.48	2.7	2.5
metal >2mm		%	<0.1	0	<0.1	0	<0.1	<0.1
stones (> 2 mm (w/w) >4mm (dry/w))		%	0.6	0.6	0.3	0.33	0.8	1.7
Other >2mm		%		0		0		
Chemical and biological								
Lime Equiv (as CaCO3)		%	13.7		13.6		9.9	
Neutralising value		as CaO equiv	7.7		7.7		5.5	
Compost stability		mgCO2/g OM/d	14.4		1375		18.5	
B.O.D.		mg/L	4651		2771		5852	
E. coli		cfu/g	700		<10		130	
Salmonella			negative		negative		negative	







# Appendix B: Full data, site S2 (continued)

Site Number			S2	S2	S2	S2	S2
Sample Number			1	2	3	4	5
Sample Date			09/12/2008	09/12/2008	15/12/2008	15/12/2008	21/01/2009
Sample Description							
Compound	PAH	CAS no	Units	test result	test result	test result	test result
	Acenaphthene		ug kg-1	120	89	110	60.0
	Acenaphthylene		ug kg-1	62	28	37	<10.0
	Anthanthrene		ug kg-1	160	150	43	<30.0
	Anthracene		ug kg-1	94	59	130	50.0
	Benzo(a)anthracene		ug kg-1	1300	250	580	100
	Benzo(a)pyrene		ug kg-1	1200	110	340	40.0
	Benzo(b)fluoranthene		ug kg-1	3000	570	880	300
	Benzo(e)pyrene		ug kg-1	1400	230	410	50.0
	Benzo(ghi)perylene		ug kg-1	1100	150	370	<30.0
	Benzo(k)fluoranthene		ug kg-1	1200	270	730	<100
	Chrysene		ug kg-1	1700	410	830	100
	Cyclopenta(cd)pyrene		ug kg-1	280	160	200	<10.0
	Dibenzo(ah)anthracene		ug kg-1	320	60	110	<6.00
	Fluoranthene		ug kg-1	1500	640	1500	588
	Fluorene		ug kg-1	160	110	120	50.0
	Indeno(1,2,3cd)pyrene		ug kg-1	530	210	290	<30.0
	Naphthalene		ug kg-1	110	89	57	60.0
	Perylene		ug kg-1	390	93	130	30.0
	Phenanthrene		ug kg-1	640	520	590	405
	Pentachlorophenol		ug kg-1	<3090	<2810	<5610	<2510

Site Number			S2	S2	S2	S2	S2
Sample Number			6	7	8	9	10
Sample Date			21/01/2009	04/03/2009	04/03/2009	04/03/2009	04/03/2009
Sample Description							
Compound	PAH	CAS no	Units	test result	test result	test result	test result
	Acenaphthene		ug kg-1	90.0	20	20	30.0
	Acenaphthylene		ug kg-1	<2.00	<4	<4	<2.00
	Anthanthrene		ug kg-1	<30.0	<30	<30	<30.0
	Anthracene		ug kg-1	100	<90	<80	80.0
	Benzo(a)anthracene		ug kg-1	200	200	200	200
	Benzo(a)pyrene		ug kg-1	80.0	<100	<100	<60.0
	Benzo(b)fluoranthene		ug kg-1	400	<200	<200	<200
	Benzo(e)pyrene		ug kg-1	100	<90	<80	50.0
	Benzo(ghi)perylene		ug kg-1	<60.0	<100	<100	<60.0
	Benzo(k)fluoranthene		ug kg-1	100	<530	<500	480
	Chrysene		ug kg-1	200	200	200	300
	Cyclopenta(cd)pyrene		ug kg-1	<20.0	<40	<40	30.0
	Dibenzo(ah)anthracene		ug kg-1	40.0	<30	<20	<10.0
	Fluoranthene		ug kg-1	660	600	600	845
	Fluorene		ug kg-1	200	50	60	50.0
	Indeno(1,2,3cd)pyrene		ug kg-1	80.0	<30	<30	<30.0
	Naphthalene		ug kg-1	20.0	80	50	50.0
	Perylene		ug kg-1	<60.0	<950	<920	<60.0
	Phenanthrene		ug kg-1	570	400	400	490
	Pentachlorophenol		ug kg-1	<3100	<11000	<9890	<2600

Site Number			S2	S2	S2	S2	S2
Sample Number			1	2	3	4	5
Sample Date			09/12/2008	09/12/2008	15/12/2008	15/12/2008	21/01/2009
Sample Description							
Compound	PCB	CAS no	Units	test result	test result	test result	test result
	PCB - 008		ug kg-1	<2	<2	<2	<2.00
	PCB - 020		ug kg-1	<2	<2	<2	<2.00
	PCB 28		ug kg-1	<2	<2	<2	<2.00
	PCB - 035		ug kg-1	<2	<2	<2	<2.00
	PCB 52		ug kg-1	<1	<1	<1	<1.00
	PCB - 077		ug kg-1	<2	<2	<2	<1.00
	PCB 101		ug kg-1	<2	<2	<2	<1.00
	PCB - 105		ug kg-1	<1	<1	<1	<1.00
	PCB 118		ug kg-1	<1	<1	<1	<0.900
	PCB - 126		ug kg-1	<1	<1	<1	<0.900
	PCB - 128		ug kg-1	<1	<1	<1	<2.00
	PCB 138		ug kg-1	<1	<1	<1	<2.00
	PCB - 149		ug kg-1	<1	<1	<1	<1.00
	PCB 153		ug kg-1	<1	<1	<1	<1.00
	PCB - 156		ug kg-1	<0.9	<0.9	<0.9	<1.00
	PCB - 169		ug kg-1	<0.9	<0.9	<0.9	<1.00
	PCB - 170		ug kg-1	<2	<2	<2	<2.00
	PCB - 180		ug kg-1	<1	<1	<1	<1.00

Site Number			S2	S2	S2	S2	S2
Sample Number			6	7	8	9	10
Sample Date			21/01/2009	04/03/2009	04/03/2009	04/03/2009	04/03/2009
Sample Description							
Compound	PCB	CAS no	Units	test result	test result	test result	test result
	PCB - 008		ug kg-1	<4.00	<9	<8	<4.00
	PCB - 020		ug kg-1	<4.00	<9	<8	<4.00
	PCB 28		ug kg-1	<4.00	<9	<8	<4.00
	PCB - 035		ug kg-1	<4.00	<9	<8	<4.00
	PCB 52		ug kg-1	<2.00	<4	<4	<2.00
	PCB - 077		ug kg-1	<2.00	<9	<8	<2.00
	PCB 101		ug kg-1	<2.00	<9	<8	<2.00
	PCB - 105		ug kg-1	<2.00	<4	<4	<2.00
	PCB 118		ug kg-1	<2.00	<4	<4	<2.00
	PCB - 126		ug kg-1	<2.00	<4	<4	<2.00
	PCB - 128		ug kg-1	<4.00	<4	<4	<4.00
	PCB 138		ug kg-1	<4.00	<4	<4	<4.00
	PCB - 149		ug kg-1	<2.00	<4	<4	<2.00
	PCB 153		ug kg-1	<2.00	<4	<4	<2.00
	PCB - 156		ug kg-1	<2.00	<4	<4	<2.00
	PCB - 169		ug kg-1	<2.00	<4	<4	<2.00
	PCB - 170		ug kg-1	<2.00	<9	<8	<2.00
	PCB - 180		ug kg-1	<2.00	<4	<4	<2.00

# Appendix B: Full data, site S2 (continued)

Site Number	S2		S2		S2		S2		S2
Sample Number	1		2		3		4		5
Sample Date	09/12/2008		09/12/2008		15/12/2008		15/12/2008		21/01/2009
Sample Description									
Compound	CAS no	Units	test result	test result	test result	test result	test result	test result	test result
Hydrocarbons									
Equiv. Carbon No >10-12 Aliphatic fraction		ug kg-1	<300	1850	<300				<0.300
Equiv. Carbon No >10-12 Aromatic fraction		ug kg-1	970	<300	955				1.16
Equiv. Carbon No >12-16 Aliphatic fraction		ug kg-1	8990	6860	2130				0.643
Equiv. Carbon No >12-16 Aromatic fraction		ug kg-1	14700	11700	7780				3.44
Equiv. Carbon No >16-21 Aliphatic fraction		ug kg-1	41100	29500	49500				42.4
Equiv. Carbon No >16-21 Aromatic fraction		ug kg-1	130000	89500	269000				598
Equiv. Carbon No >21-35 Aliphatic fraction		ug kg-1	585000	410000	1160000				946
Equiv. Carbon No >21-35 Aromatic fraction		ug kg-1	1090000	809000	2610000				2780
Equiv. Carbon No >35-40 Aliphatic fraction		ug kg-1	75800	82800	337000				123
Equiv. Carbon No >35-40 Aromatic fraction		ug kg-1	307000	169000	167000				241
Hydrocarbons, Aliphatic extractable C10 - C40		ug kg-1	1710000	531000	1550000				1110000
Hydrocarbons, Aromatic extractable C10 - C40		ug kg-1	1540000	1080000	3050000				3630000
bons, Total extractable C10 - C40 : Dry Wt (EPH)		ug kg-1	2250000	1610000	4600000				4740

Site Number	S2		S2		S2		S2		S2
Sample Number	6		7		8		9		10
Sample Date	21/01/2009		04/03/2009		04/03/2009		04/03/2009		04/03/2009
Sample Description									
Compound	CAS no	Units	test result	test result	test result	test result	test result	test result	test result
Hydrocarbons									
Equiv. Carbon No >10-12 Aliphatic fraction		ug kg-1	<0.300	<300	<300	1.99			1.30
Equiv. Carbon No >10-12 Aromatic fraction		ug kg-1	0.667	<300	<300	0.511			0.386
Equiv. Carbon No >12-16 Aliphatic fraction		ug kg-1	0.890	<300	<300	3.98			4.83
Equiv. Carbon No >12-16 Aromatic fraction		ug kg-1	2.51	2630	2820	14.9			7.05
Equiv. Carbon No >16-21 Aliphatic fraction		ug kg-1	43.0	75900	60500	33.6			37.6
Equiv. Carbon No >16-21 Aromatic fraction		ug kg-1	321	483000	422000	100			87.1
Equiv. Carbon No >21-35 Aliphatic fraction		ug kg-1	1050	2490000	1660000	1230			1770
Equiv. Carbon No >21-35 Aromatic fraction		ug kg-1	2070	2360000	2120000	1480			1220
Equiv. Carbon No >35-40 Aliphatic fraction		ug kg-1	106	198000	117000	199			193
Equiv. Carbon No >35-40 Aromatic fraction		ug kg-1	222	119000	111000	243			220
Hydrocarbons, Aliphatic extractable C10 - C40		ug kg-1	1200000	2750000	1840000	1470000			2000000
Hydrocarbons, Aromatic extractable C10 - C40		ug kg-1	2620000	2960000	2660000	1840000			1540000
bons, Total extractable C10 - C40 : Dry Wt (EPH)		ug kg-1	3820	5720000	4500000	3310			3540

Site Number	S2		S2		S2		S2		S2
Sample Number	1		2		3		4		5
Sample Date	09/12/2008		09/12/2008		15/12/2008		15/12/2008		21/01/2009
Sample Description									
Compound	CAS no	Units	test result	test result	test result	test result	test result	test result	test result
Physical contaminants (%W/W)			w/w/	w/w/	w/w/	w/w/	w/w/	w/w/	w/w/
% of total sample plastic >2mm		%	0.734	0.73	0.29	1.27	2.8	2.85	<0.1
Glass > 2mm		%	3.46	3.46	4.67	4.67	7.7	7.74	4.1
metal >2mm		%	<0.1	0.02	3.54	3.54	<0.1	0	<0.1
stones (> 2 mm (w/w) >4mm (dry/w))		%	1.01	1.01	1.27	0.29	2.7	2.7	0.7
Other >2mm		%		1.26		3.98		0.34	0
Chemical and biological									
Lime Equiv (as CaCO3)		%	10.3		10.3		9.9		9.9
Neutralising value		as CaO equiv	5.75		5.8		5.6		5.6
Compost stability		mgCO2/g OM/d	22.6		17.8		14.3		15.8
B.O.D.		mg/L	2703		543		3301		3451
E.coli		cfu/g	40		<10		10		600
Salmonella			negative		negative		negative		negative

Site Number	S2		S2		S2		S2		S2
Sample Number	6		7		8		9		10
Sample Date	21/01/2009		04/03/2009		04/03/2009		04/03/2009		04/03/2009
Sample Description									
Compound	CAS no	Units	test result	test result	test result	test result	test result	test result	test result
Physical contaminants (%W/W)			dry/w/	dry/w/	dry/w/	dry/w/	dry/w/	dry/w/	w/w/
% of total sample plastic >2mm		%	6.4		0.7		0.6		0.54
Glass > 2mm		%	16.6		6		7.2		8.82
metal >2mm		%	<0.1		<0.1		<0.1		0
stones (> 2 mm (w/w) >4mm (dry/w))		%	9.16		2.5		0.5		3.73
Other >2mm		%							1.14
Chemical and biological									
Lime Equiv (as CaCO3)		%	9.71		7.8		9.5		
Neutralising value		as CaO equiv	5.45		4.4		5.3		
Compost stability		mgCO2/g OM/d	20.2		23.7		24.6		21.7
B.O.D.		mg/L	10802		5802		5902		
E.coli		cfu/g	1000		<10		<10		<10
Salmonella			negative		negative		negative		negative





Appendix C: Full data, site S3 (continued)

Site Number		S3	S3	S3	S3	S3
Sample Number		1	2	3	4	5
Sample Date		09/12/2008	09/12/2008	21/01/2009	21/01/2009	20/02/2009
Sample Description						
Compound						
PAH	CAS no	Units	test result	test result	test result	test result
Acenaphthene		ug kg-1	<0.1	38	12	60.0
Acenaphthylene		ug kg-1	<1	10	28	60.0
Anthanthrene		ug kg-1	32	<30	200	<30.0
Anthracene		ug kg-1	43	67	250	220
Benzo(a)anthracene		ug kg-1	140	130	710	210
Benzo(a)pyrene		ug kg-1	61	95	440	100
Benzo(b)fluoranthene		ug kg-1	270	380	840	405
Benzo(e)pyrene		ug kg-1	86	120	320	100
Benzo(ghi)perylene		ug kg-1	83	73	400	<30.0
Benzo(k)fluoranthene		ug kg-1	<100	220	650	<100
Chrysene		ug kg-1	120	200	790	170
Cyclopenta(cd)pyrene		ug kg-1	<10	12	190	<10.0
Dibenzo(ah)anthracene		ug kg-1	14	<3	73	<6.00
Fluoranthene		ug kg-1	230	700	2500	891
Fluorene		ug kg-1	27	19	30	100
Indeno(1,2,3cd)pyrene		ug kg-1	56	<30	520	30.0
Naphthalene		ug kg-1	120	720	180	170
Perylene		ug kg-1	61	39	430	220
Phenanthrene		ug kg-1	170	340	600	697
Pentachlorophenol		ug kg-1	<6350	<5230	<6000	<2890

Site Number		S3	S3	S3	S3	S3
Sample Number		6	7	8	9	10
Sample Date		21/01/2009	04/03/2009	04/03/2009	04/03/2009	04/03/2009
Sample Description						
Compound						
PAH	CAS no	Units	test result	test result	test result	test result
Acenaphthene		ug kg-1	90.0	60	60	100
Acenaphthylene		ug kg-1	70.0	10	<4	<2.00
Anthanthrene		ug kg-1	<30.0	<30	<30	<30.0
Anthracene		ug kg-1	200	<90	<90	60.0
Benzo(a)anthracene		ug kg-1	240	90	<90	80.0
Benzo(a)pyrene		ug kg-1	200	<100	<100	80.0
Benzo(b)fluoranthene		ug kg-1	352	<200	<200	300
Benzo(e)pyrene		ug kg-1	100	<90	<90	100
Benzo(ghi)perylene		ug kg-1	<30.0	<100	<100	<60.0
Benzo(k)fluoranthene		ug kg-1	<100	<190	<350	200
Chrysene		ug kg-1	180	100	<100	100
Cyclopenta(cd)pyrene		ug kg-1	<10.0	<50	<40	<20.0
Dibenzo(ah)anthracene		ug kg-1	<6.00	<30	<30	<10.0
Fluoranthene		ug kg-1	925	<90	<90	300
Fluorene		ug kg-1	100	100	90	200
Indeno(1,2,3cd)pyrene		ug kg-1	<30.0	<30	<30	<30.0
Naphthalene		ug kg-1	230	500	200	200
Perylene		ug kg-1	100	200	<100	<60.0
Phenanthrene		ug kg-1	702	400	400	410
Pentachlorophenol		ug kg-1	<2990	<11600	<11200	<2300

Site Number		S3	S3	S3	S3	S3
Sample Number		1	2	3	4	5
Sample Date		09/12/2008	09/12/2008	21/01/2009	21/01/2009	20/02/2009
Sample Description						
Compound						
PCB	CAS no	Units	test result	test result	test result	test result
PCB - 008		ug kg-1	<2	<2	<2	<2.00
PCB - 020		ug kg-1	<2	<2	<2	<2.00
PCB 28		ug kg-1	<2	<2	<2	<2.00
PCB - 035		ug kg-1	<2.0	<2	<2	<2.00
PCB 52		ug kg-1	<1	<1	<1	<1.00
PCB - 077		ug kg-1	<2	<2	<2	<1.00
PCB 101		ug kg-1	<2	<2	<2	<1.00
PCB - 105		ug kg-1	<1	<1	<1	<1.00
PCB 118		ug kg-1	<1	<1	<1	<0.900
PCB - 126 -1		ug kg-1	<1	<1	<1	<0.900
PCB - 128		ug kg-1	<1	<1	<1	<2.00
PCB 138		ug kg-1	<1	<1	<1	<2.00
PCB - 149		ug kg-1	<1	<1	<1	<1.00
PCB 153		ug kg-1	<1	<1	<1	<1.00
PCB - 156		ug kg-1	<0.9	<0.9	<0.9	<1.00
PCB - 169		ug kg-1	<0.9	<0.9	<0.9	<1.00
PCB - 170		ug kg-1	<2	<2	<2	<2.00
PCB - 180		ug kg-1	<1	<1	<1	<1.00

Site Number		S3	S3	S3	S3	S3
Sample Number		6	7	8	9	10
Sample Date		21/01/2009	04/03/2009	04/03/2009	04/03/2009	04/03/2009
Sample Description						
Compound						
PCB	CAS no	Units	test result	test result	test result	test result
PCB - 008		ug kg-1	<2.00	<9	<9	<4.00
PCB - 020		ug kg-1	<2.00	<9	<9	<4.00
PCB 28		ug kg-1	<2.00	<2	<2	<4.00
PCB - 035		ug kg-1	<2.00	<9	<4	<4.00
PCB 52		ug kg-1	<1.00	<5	<4	<2.00
PCB - 077		ug kg-1	<1.00	<9	<9	<4.00
PCB 101		ug kg-1	<1.00	<9	<9	<4.00
PCB - 105		ug kg-1	<1.00	<5	<4	<2.00
PCB 118		ug kg-1	<0.900	<940	<1400	<2.00
PCB - 126 -1		ug kg-1	<0.900	<5	<2200	<2.00
PCB - 128		ug kg-1	<2.00	<5	<4	<4.00
PCB 138		ug kg-1	<2.00	<5	<4	<4.00
PCB - 149		ug kg-1	<1.00	<5	<4	<2.00
PCB 153		ug kg-1	<1.00	<5	<4	<2.00
PCB - 156		ug kg-1	<1.00	<4	<4	<2.00
PCB - 169		ug kg-1	<1.00	<4	<4	<2.00
PCB - 170		ug kg-1	<2.00	<9	<9	<4.00
PCB - 180		ug kg-1	<1.00	<5	<4	<2.00

# Appendix C: Full data, site S3 (continued)

Site Number			S3		S3		S3		S3
Sample Number			1		2		3		4
Sample Date			09/12/2008		09/12/2008		21/01/2009		21/01/2009
Sample Description									
Compound									
	Hydrocarbons	CAS no	Units	test result	test result	test result	test result	test result	test result
	Equiv. Carbon No >10-12 Aliphatic fraction		ug kg-1	7970	7450	419			<0.300
	Equiv. Carbon No >10-12 Aromatic fraction		ug kg-1	18700	38500	2270			30.1
	Equiv. Carbon No >12-16 Aliphatic fraction		ug kg-1	49000	21300	3940			32.6
	Equiv. Carbon No >12-16 Aromatic fraction		ug kg-1	15400	25100	2190			182
	Equiv. Carbon No >16-21 Aliphatic fraction		ug kg-1	163000	127000	18500			102
	Equiv. Carbon No >16-21 Aromatic fraction		ug kg-1	210000	121000	18300			1950
	Equiv. Carbon No >21-35 Aliphatic fraction		ug kg-1	1890000	1390000	198000			1590
	Equiv. Carbon No >21-35 Aromatic fraction		ug kg-1	1790000	947000	91100			5880
	Equiv. Carbon No >35-40 Aliphatic fraction		ug kg-1	395000	61100	35200			113
	Equiv. Carbon No >35-40 Aromatic fraction		ug kg-1	145000	134000	25200			681
	Hydrocarbons, Aliphatic extractable C10 - C40		ug kg-1	2500000	1610000	256000			1840000
	Hydrocarbons, Aromatic extractable C10 - C40		ug kg-1	2180000	1270000	139000			8720000
	bons, Total extractable C10 - C40 : Dry Wt (EPH)		ug kg-1	4680000	2870000	395000			10600

Site Number			S3		S3		S3		S3
Sample Number			6		7		8		9
Sample Date			21/01/2009		04/03/2009		04/03/2009		04/03/2009
Sample Description									
Compound									
	Hydrocarbons	CAS no	Units	test result	test result	test result	test result	test result	test result
	Equiv. Carbon No >10-12 Aliphatic fraction		ug kg-1	<0.300	934	<300		2.32	1.87
	Equiv. Carbon No >10-12 Aromatic fraction		ug kg-1	16.9	13800	8190		28.4	7.92
	Equiv. Carbon No >12-16 Aliphatic fraction		ug kg-1	16.3	17600	14000		12.7	11.7
	Equiv. Carbon No >12-16 Aromatic fraction		ug kg-1	69.7	61400	11300		29.7	20.3
	Equiv. Carbon No >16-21 Aliphatic fraction		ug kg-1	92.5	104000	137000		53.9	50.3
	Equiv. Carbon No >16-21 Aromatic fraction		ug kg-1	2470	528000	431000		1150	393
	Equiv. Carbon No >21-35 Aliphatic fraction		ug kg-1	1020	946000	1040000		651	721
	Equiv. Carbon No >21-35 Aromatic fraction		ug kg-1	5660	3260000	2510000		7970	5660
	Equiv. Carbon No >35-40 Aliphatic fraction		ug kg-1	89.5	52000	83300		82.3	99.5
	Equiv. Carbon No >35-40 Aromatic fraction		ug kg-1	491	137000	196000		199	195
	Hydrocarbons, Aliphatic extractable C10 - C40		ug kg-1	1220000	1120000	1280000		802000	884000
	Hydrocarbons, Aromatic extractable C10 - C40		ug kg-1	8720000	4000000	3160000		9380000	6270000
	bons, Total extractable C10 - C40 : Dry Wt (EPH)		ug kg-1	9930	5120000	4430000		10200	7160

Site Number			S3		S3		S3		S3			
Sample Number			1		2		3		4			
Sample Date			09/12/2008		09/12/2008		21/01/2009		21/01/2009			
Sample Description												
Compound												
	Physical contaminants (%W/W)	CAS no	Units	test result	test result	test result	test result	test result	test result			
	% of total sample plastic >2mm		%	9.31	11.66	0.89	1.13	0.1	0.12	<0.1	0	1.01
	Glass > 2mm		%	10.7	13.43	6.32	8.01	4.9	4.92	4.8	4.79	8.02
	metal >2mm		%	0.1	0	<0.1	0.02	<0.1	0	<0.1	0	0.63
	stones (> 2 mm (w/w) >4mm (dry/w))		%	7.43	9.31	6.59	8.36	0.7	0.74	0.9	0.92	1.6
	Other >2mm		%		12.28		9.01		0		0	
	<b>Chemical and biological</b>											
	Lime Equiv (as CaCO3)		%	7.5		7.31		8.4		8.5		8.31
	Neutralising value		as CaO equiv	4.21		4.1		4.7		4.8		4.66
	Compost stability		mgCO2/g OM/d	18.4		28.1		28.7		34.3		24.3
	B.O.D.		mg/L	3202		3172		17151		19951		17502
	E.coli		cfu/g	21000		1750000		390000		1250000		35900
	Salmonella			negative		positive		positive		positive		positive

Site Number			S3		S3		S3		S3			
Sample Number			6		7		8		9			
Sample Date			21/01/2009		04/03/2009		04/03/2009		04/03/2009			
Sample Description												
Compound												
	Physical contaminants (%W/W)	CAS no	Units	test result	test result	test result	test result	test result	test result			
	% of total sample plastic >2mm		%	1.1		0.9		2.5		0		0
	Glass > 2mm		%	3.1		6.1		7.5		12.61		11.07
	metal >2mm		%	<0.1		<0.1		<0.1		0		0
	stones (> 2 mm (w/w) >4mm (dry/w))		%	<0.1		12.9		4.2		1.82		1.35
	Other >2mm		%							0		0
	<b>Chemical and biological</b>											
	Lime Equiv (as CaCO3)		%	7.96		8.9		7.4				
	Neutralising value		as CaO equiv	4.46		5		4.1				
	Compost stability		mgCO2/g OM/d	24.8		23.1		24.1		31.6		24.5
	B.O.D.		mg/L	20352		18902		20352				
	E.coli		cfu/g	280000		53000		140000		4000		14300
	Salmonella			positive		positive		positive		positive		negative







# Appendix D: Full data, site S4 (continued)

Site Number	S4			S4			S4		
Sample Number	1			2			3		
Sample Date	09/12/2008			09/12/2008			16/01/2009		
Sample Description									
Compound	PAH	CAS no	Units	test result	test result	test result	test result	test result	
Acenaphthene			ug kg-1	670	100	850		30.0	
Acenaphthylene			ug kg-1	18	<1.0	36		<30.0	
Anthanthrene			ug kg-1	<30	<30	37		<30.0	
Anthracene			ug kg-1	310	43	920		50.0	
Benzo(a)anthracene			ug kg-1	340	74	740		70.0	
Benzo(a)pyrene			ug kg-1	160	35	390		30.0	
Benzo(b)fluoranthene			ug kg-1	790	<200	960		200	
Benzo(e)pyrene			ug kg-1	170	42	420		40.0	
Benzo(ghi)perylene			ug kg-1	53	<6	90		<30.0	
Benzo(k)fluoranthene			ug kg-1	400	<100	560		<100	
Chrysene			ug kg-1	350	83	890		80.0	
Cyclopenta(cd)pyrene			ug kg-1	130	43	220		70.0	
Dibenzo(ah)anthracene			ug kg-1	18	<3	<3		<6.0	
Fluoranthene			ug kg-1	970	200	2700		270	
Fluorene			ug kg-1	420	90	680		40.0	
Indeno(1,2,3cd)pyrene			ug kg-1	31	<30	210		<30.0	
Naphthalene			ug kg-1	860	83	460		200	
Perylene			ug kg-1	330	<30	580		<30.0	
Phenanthrene			ug kg-1	790	140	1700		361	
Pentachlorophenol			ug kg-1	<9140	<9360	<5180		<3860	

Site Number	S4			S4			S4		
Sample Number	6			7			8		
Sample Date	16/02/2009			09/03/2009			09/03/2009		
Sample Description									
Compound	PAH	CAS no	Units	test result	test result	test result	test result	test result	
Acenaphthene			ug kg-1	<30.0	300	400	200	200	
Acenaphthylene			ug kg-1	<30.0	20	10	6.00	<2.00	
Anthanthrene			ug kg-1	<30.0	<30	<30	<30.0	<30.0	
Anthracene			ug kg-1	40.0	100	200	100	200	
Benzo(a)anthracene			ug kg-1	90.0	300	300	420	340	
Benzo(a)pyrene			ug kg-1	<40.0	<110	<100	100	100	
Benzo(b)fluoranthene			ug kg-1	200	<200	<330	300	<200	
Benzo(e)pyrene			ug kg-1	40.0	100	90	100	70.0	
Benzo(ghi)perylene			ug kg-1	<40.0	<100	<100	<70.0	<60.0	
Benzo(k)fluoranthene			ug kg-1	<100	<410	<450	300	200	
Chrysene			ug kg-1	100	400	400	300	320	
Cyclopenta(cd)pyrene			ug kg-1	<10.0	<50	<40	20.0	<20.0	
Dibenzo(ah)anthracene			ug kg-1	<8.00	<30	<20	<10.0	<10.0	
Fluoranthene			ug kg-1	400	820	810	1010	1150	
Fluorene			ug kg-1	70.0	300	400	200	200	
Indeno(1,2,3cd)pyrene			ug kg-1	<30.0	<30	30	<30.0	<30.0	
Naphthalene			ug kg-1	200	300	400	300	360	
Perylene			ug kg-1	<40.0	<100	<100	<70.0	100	
Phenanthrene			ug kg-1	467	830	830	1050	1100	
Pentachlorophenol			ug kg-1	<3910	<10200	<13600	<3000	<2900	

Site Number	S4			S4			S4		
Sample Number	1			2			3		
Sample Date	09/12/2008			09/12/2008			16/01/2009		
Sample Description									
Compound	PCB	CAS no	Units	test result	test result	test result	test result	test result	
PCB - 008			ug kg-1	<2	<2	<2		<2.00	
PCB - 020			ug kg-1	<2	<2	<2		<2.00	
PCB 28			ug kg-1	<2	<2	<2		<2.00	
PCB - 035			ug kg-1	<2	<2	<2		<2.00	
PCB 52			ug kg-1	<1	<1	<1		<1.00	
PCB - 077			ug kg-1	<2	<2	<2		<1.00	
PCB 101			ug kg-1	<2	<2	<2		<1.00	
PCB - 105			ug kg-1	<1	<1	<1		<1.00	
PCB 118			ug kg-1	<1	<1	<1		<0.900	
PCB - 126			ug kg-1	<1	<1	<1		<0.900	
PCB - 128			ug kg-1	<1	<1	<1		<2.00	
PCB 138			ug kg-1	<1	<1	<1		<2.00	
PCB - 149			ug kg-1	<1	<1	<1		<1.00	
PCB 153			ug kg-1	<1	<1	<1		<1.00	
PCB - 156			ug kg-1	<0.9	<0.9	<0.9		<1.00	
PCB - 169			ug kg-1	<0.9	<0.9	<0.9		<1.00	
PCB - 170			ug kg-1	<2	<2	<2		<2.00	
PCB - 180			ug kg-1	<1	<1	<1		<1.00	

Site Number	S4			S4			S4		
Sample Number	6			7			8		
Sample Date	16/02/2009			09/03/2009			09/03/2009		
Sample Description									
Compound	PCB	CAS no	Units	test result	test result	test result	test result	test result	
PCB - 008			ug kg-1	<3.00	<9	<8	<4.00	<4.00	
PCB - 020			ug kg-1	<3.00	<9	<8	<4.00	<4.00	
PCB 28			ug kg-1	<3.00	<9	<8	<4.00	<4.00	
PCB - 035			ug kg-1	<3.00	<9	<8	<4.00	<4.00	
PCB 52			ug kg-1	<1.00	<5	<4	<2.00	<2.00	
PCB - 077			ug kg-1	<1.00	<9	<8	<2.00	<2.00	
PCB 101			ug kg-1	<1.00	<9	<8	<2.00	<2.00	
PCB - 105			ug kg-1	<1.00	<5	<4	<2.00	<2.00	
PCB 118			ug kg-1	<1.00	<5	<4	<2.00	<2.00	
PCB - 126			ug kg-1	<1.00	<5	<4	<2.00	<2.00	
PCB - 128			ug kg-1	<3.00	<5	<4	<4.00	<4.00	
PCB 138			ug kg-1	<3.00	<5	<4	<4.00	<4.00	
PCB - 149			ug kg-1	<1.00	<5	<4	<2.00	<2.00	
PCB 153			ug kg-1	<1.00	<5	<4	<2.00	<2.00	
PCB - 156			ug kg-1	<1.00	<4	<4	<2.00	<2.00	
PCB - 169			ug kg-1	<1.00	<4	<4	<2.00	<2.00	
PCB - 170			ug kg-1	<2.00	<9	<8	<2.00	<2.00	
PCB - 180			ug kg-1	<1.00	<5	<4	<2.00	<2.00	

# Appendix D: Full data, site S4 (continued)

Site Number			S4		S4		S4		S4	
Sample Number			1		2		3		4	
Sample Date			09/12/2008		09/12/2008		16/01/2009		16/01/2009	
Sample Description										
Compound										
	CAS no	Units	test result		test result		test result		test result	
Hydrocarbons										
Equiv. Carbon No >10-12 Aliphatic fraction		ug kg-1	30500		22300		31900			4.89
Equiv. Carbon No >10-12 Aromatic fraction		ug kg-1	25700		31800		46000			64.0
Equiv. Carbon No >12-16 Aliphatic fraction		ug kg-1	38600		44100		53400			17.8
Equiv. Carbon No >12-16 Aromatic fraction		ug kg-1	38300		48500		71800			38.4
Equiv. Carbon No >16-21 Aliphatic fraction		ug kg-1	198000		223000		236000			104
Equiv. Carbon No >16-21 Aromatic fraction		ug kg-1	271000		305000		412000			434
Equiv. Carbon No >21-35 Aliphatic fraction		ug kg-1	2320000		2590000		3530000			1280
Equiv. Carbon No >21-35 Aromatic fraction		ug kg-1	2870000		3630000		2890000			5420
Equiv. Carbon No >35-40 Aliphatic fraction		ug kg-1	56700		96100		409000			133
Equiv. Carbon No >35-40 Aromatic fraction		ug kg-1	282000		474000		260000			485
Hydrocarbons, Aliphatic extractable C10 - C40 :		ug kg-1	2650000		2970000		4260000			1540000
Hydrocarbons, Aromatic extractable C10 - C40 :		ug kg-1	3480000		4490000		3670000			6450000
bons, Total extractable C10 - C40 : Dry Wt [EPH]		ug kg-1	6130000		7460000		7930000			7990

Site Number			S4		S4		S4		S4	
Sample Number			6		7		8		9	
Sample Date			16/02/2009		09/03/2009		09/03/2009		30/03/2009	
Sample Description										
Compound										
	CAS no	Units	test result		test result		test result		test result	
Hydrocarbons										
Equiv. Carbon No >10-12 Aliphatic fraction		ug kg-1	4.87		13300		27100		12.7	4.40
Equiv. Carbon No >10-12 Aromatic fraction		ug kg-1	58.8		23200		24300		27.8	20.1
Equiv. Carbon No >12-16 Aliphatic fraction		ug kg-1	20.9		23300		31600		24.0	12.8
Equiv. Carbon No >12-16 Aromatic fraction		ug kg-1	43.5		37300		34200		21.3	17.6
Equiv. Carbon No >16-21 Aliphatic fraction		ug kg-1	118		130000		183000		93.1	43.2
Equiv. Carbon No >16-21 Aromatic fraction		ug kg-1	418		396000		445000		224	175
Equiv. Carbon No >21-35 Aliphatic fraction		ug kg-1	1600		1620000		2210000		1860	94.8
Equiv. Carbon No >21-35 Aromatic fraction		ug kg-1	3650		2510000		2410000		4000	2790
Equiv. Carbon No >35-40 Aliphatic fraction		ug kg-1	163		153000		194000		169	164
Equiv. Carbon No >35-40 Aromatic fraction		ug kg-1	347		183000		219000		357	279
Hydrocarbons, Aliphatic extractable C10 - C40 :		ug kg-1	1910000		1940000		2650000		2160000	1170000
Hydrocarbons, Aromatic extractable C10 - C40 :		ug kg-1	4520000		3150000		3140000		4630000	3280000
bons, Total extractable C10 - C40 : Dry Wt [EPH]		ug kg-1	6430		5090000		5780000		6790	4450

Site Number			S4		S4		S4		S4	
Sample Number			1		2		3		4	
Sample Date			09/12/2008		09/12/2008		16/01/2009		16/01/2009	
Sample Description										
Compound										
	CAS no	Units	test result		test result		test result		test result	
Physical contaminants (%W/W)										
% of total sample plastic >2mm		%	1.79	3.71	1.71	3.61	0.4	0.37	0.4	0.44
Glass > 2mm		%	0.757	1.57	0.666	1.4	3.5	3.5	3.9	3.93
metal >2mm		%	0.186	0.39	0.387	0.82	<0.1	0	<0.1	0
stones (> 2 mm (w/w) >4mm (dry/w))		%	1.14	2.36	0.201	0.42	0.7	0.71	1.4	1.38
Other >2mm		%		0		0		0		0
Chemical and biological										
Lime Equiv (as CaCO3)		%	2.16		2.05		8.6		5.6	5.03
Neutralising value		as CaO equiv	1.21		1.15		4.8		3.1	2.83
Compost stability		mgCO2/g OM/d	14		28.2		insufficient sample		22	25.3
B.O.D.		mg/L	2972		2582		18801		19451	20202
E.coli		cfu/g	50		130		40		10	<10
Salmonella			negative		negative		negative		negative	negative

Site Number			S4		S4		S4		S4	
Sample Number			6		7		8		9	
Sample Date			16/02/2009		09/03/2009		09/03/2009		30/03/2009	
Sample Description										
Compound										
	CAS no	Units	test result		test result		test result		test result	
Physical contaminants (%W/W)										
% of total sample plastic >2mm		%	1.78		1.8		1.9		1.24	2.61
Glass > 2mm		%	4.27		2		0.2		3.57	3.57
metal >2mm		%	0.351		<0.1		0.2		0.265	<0.1
stones (> 2 mm (w/w) >4mm (dry/w))		%	1.99		0.8		3.6		1.41	2.15
Other >2mm		%								
Chemical and biological										
Lime Equiv (as CaCO3)		%	5.84		6.1		5.5		7.58	8.02
Neutralising value		as CaO equiv	3.28		3.4		3.1		4.25	4.5
Compost stability		mgCO2/g OM/d	26.5		26.9		26		24.5	23.4
B.O.D.		mg/L	1422		18402		16852		19653	19502
E.coli		cfu/g	60		10		20		10	<10
Salmonella			negative		negative		negative		negative	negative

## Appendix E: Input-output data, site S1

Chemical	SAMPLING POINT MATERIAL SIZE SAMPLE CODE	2		3		5	4						6				7			
		<2mm	>2mm	<2mm	>2mm	>31.5mm	31.5-16mm	16-12mm	>8mm	8-4mm	4-2mm	2-1mm	<1mm	8-4mm	4-2mm	2-1mm	<1mm	>31.5mm	31.5-16mm	16-8mm
		C0989804	C0989805	C0989806	C0989807	C0935150	C0935151	C0935152	C0935153	C0935154	C0935155	C0935156	C0935157	C0989818	C0989819	C0989820	C0989821	C0989822	C0989823	C0989824
	Cas#																			
1H-Pyrrole-2-carboxaldehyde	-												0.13	0.12	0.09	0.05	0.28	0.18	0.23	
2-Ethylhexyl diphenyl phosphate	1241947	0.05	0.06	0.43		0.26	0.38	0.21	0.42	0.28	0.6	0.56	0.34	0.1	0.13	0.18	0.08		0.12	0.52
Benzaldehyde	-											0.11		0.09	0.13	0.12			0.07	0.09
Benzamide	-													0.15	0.08		0.16	0.16	0.17	0.14
Benzeneacetamide	-													0.13	0.1		0.13	0.15	0.17	
Benzo[a]anthracene	56553	0.04	0.03			0.04	0.06							0.06					0.1	0.22
Chrysene	218019	0.01		0.03		0.03	0.05			0.04	0.05				0.03				0.08	0.17
Di-n-butyl phthalate	84742		9	10	9		11	13	18	6	10	7	8							
Dicyclohexyl phthalate	84617					0.39				0.53		0.59	0.88							
Fluoranthene	206440	0.03	0.03	0.07		0.07	0.08	0.05	0.08	0.08	0.1	0.1	0.1	0.06	0.06	0.08	0.07	0.05	0.14	0.14
Indeno[1,2,3-cd]pyrene	193395	0.06	0.05	0.07								0.15								0.19
N,N-Diethyl-m-toluamide (DEET)	134623	0.27	0.3	0.4	0.07	0.18	0.26	0.15	0.22	0.22	0.32	0.55	0.64	0.11	0.23	0.35	0.31	0.21	0.26	0.33
Phenanthrene	85018	0.01	0.01	0.05		0.04	0.04	0.03	0.05	0.04	0.05	0.06	0.05	0.03	0.04	0.05	0.04	0.03	0.08	0.06
Pyrene	129000	0.02	0.03	0.04		0.05	0.06	0.03	0.05	0.05	0.07	0.07	0.07	0.04	0.04	0.05	0.04	0.03	0.09	0.1
Styrene	100425						0.65	0.8	0.65		0.3	0.74	0.9							0.44
Triclosan	3380345		0.02			0.05	0.07	0.05	0.06	0.05			0.07	0.03	0.03	0.05	0.05	0.03	0.08	0.06
Vanillin	-													0.22	0.06		0.23	0.2	0.19	0.33
Benzophenone	119619	0.16		1	0.09	0.43	0.5	0.3	0.03	0.54	0.76	1	0.73	0.4	0.6	0.8	0.64	0.55	1	1
Bisphenol A	80057	1.7	0.8	7	0.28	3.5	6	6	4	3.5	1.7	2	6	36	9	44	28	12	32	13
DEHP	117817	17	3	44		35	48	48	40	38	33	57	50	25	34	30	31	42	35	62

**NOTE:** This table does not show those chemicals that were detected infrequently or that are not considered relevant in the context of the report. For more details see Section 0.

# Appendix F: Input-Output data, site S2

LAB REPORT REF NO	20014076										20013998										20014561										20015176				
	SAMPLING POINT										3										4										5				
	MATERIAL SIZE	>2mm	<2mm	>31.5mm	31.5-16mm	16-12mm	>8mm	8-4mm	4-2mm	2-1mm	<1mm	>31.5mm	31.5-16mm	16-12mm	>8mm	8-4mm	4-2mm	2-1mm	<1mm	>8mm	8-4mm	4-2mm	2-1mm	<1mm	>8mm	8-4mm	4-2mm	2-1mm	<1mm						
SAMPLE LAB CODE	C989809	C989808	C0988167	C0988168	C0988169	C0988170	C0988171	C0988172	C0988173	C0988174	C0989810	C0989811	C0989813	C0989812	C0989814	C0989815	C0989816	C0989817	C0989825	C0989826	C0989827	C0989828	C0989829												
Chemical/Cas#																																			
2,4-Dimethyl aniline	95681										0.01			0.02	0.01	0.01																			
2-ethylhexyl diphenyl phosphate	1241947		0.14			0.17	0.12			0.07	0.05	0.24	0.06		0.48	0.08	0.14	0.24	0.48	0.26	0.37	0.53	0.44												
Anthracene	120127				0.06			0.01	0.01	0.02	0.02							0.04																	
Benzo[a]anthracene	56553		2.9	0.12	0.12				0.22	0.15	0.2			0.07		0.05	0.08	0.06	0.09	0.08									0.08						
Benzo[a]pyrene	50328		1.5	0.13			0.08		0.14	0.22	0.27							0.09		0.05									0.08						
Benzo[b]fluoranthene	205992		3.4	0.21	0.21				0.14	0.46	0.78	0.37		0.09			0.11												0.15						
Benzo[ghi]perylene	191242		1.5	0.08					0.12	0.21	0.28	0.32																							
Benzo[k]fluoranthene	207089		0.24	0.06	0.1	0.14	0.07	0.15	0.3	0.03	0.04				0.03	0.04	0.08	0.04											0.06						
Benzophenone	119619		0.4	0.07	0.08	0.09	0.57	0.13	0.07	0.07	0.12	0.09	0.06	0.14	0.18	0.17	0.12	0.14	0.22	0.21	0.74	1.2	0.72	0.71	0.63										
Bisphenol A	80057		0.38	3.3		0.25		1.2	0.21		0.34	0.39	2	3	4	7	15	9	10	13	2.4	20	0.46	3	21										
Chrysene	218019		1.5						0.1	0.12							0.06	0.03	0.07	0.06	0.04	0.07	0.06												
DEHP	117817		8	3	5	17	11	4	6	14	20	10	19	15			19	18	14	25	15	15	22	19											
Di-n-butyl phthalate	84742		18	12	18		9						3							4	4.4	8	8.5	4											
Diethylene glycol	111466		0.21	0.38		0.29									0.05	0.03	0.03		0.05	0.02	0.04								0.06						
Fluoranthene	206440		0.01	2.9	0.06	0.05	0.1	0.13	0.06	0.07	0.09	0.1	0.02	0.05	0.07	0.07	0.05	0.07	0.07	0.17	0.15	0.12	0.16	0.14					0.01						
Fluorene	86737		0.01	0.08		0.01									0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02				0.01						
Friedelan-3-one								23	21	17	13			2	15	3.6	5.8												12						
Indeno[1,2,3-cd]pyrene	193395		4.2	0.21	0.38	0.3	0.26	0.3	0.54										31	0.2	0.17	0.1	0.17	0.25											
N,N-Diethyl-m-toluamide (DEET)	134623		0.63	1.4		0.02	0.1	0.04	0.01	0.02	0.02	0.03	0.02	0.08	0.06	0.07	0.05	0.06	0.07	0.11	0.12	0.19	0.39	0.16	0.2										
o-cresol(2-Methylphenol)	94587											0.04	0.02	0.03	0.03				0.02																
p-Cresol(4-Methylphenol)	106445		0.62	0.15	0.07		0.04								0.04		0.03		0.04	0.1	0.07	0.05	0.1												
Phenanthrene	85018		1.1	0.01	0.01	0.05	0.2	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.04	0.03	0.03	0.03	0.03	0.09	0.11	0.08	0.09	0.08											
phenanthrenol, 4b,5,6,7,8,8a,9,10-octahydro-4b,8,8-trimethyl-1-(1-methylethyl)-, (4bS-trans)-														2	0.9	3	1	2.2	1.8																
Pyrene	129000		1.6	0.04	0.03	0.06	0.07	0.03	0.04	0.06	0.06	0.01	0.03	0.05	0.04	0.03	0.03	0.04	0.04	0.1	0.09	0.07	0.1	0.08											
Totarol				5	3.4			3	5.8		3.7																								
Triclosan	3380345		0.08			0.1								0.02			0.21	0.04	0.04																

**NOTE:** This table does not show those chemicals that were detected infrequently or are not considered relevant in the context of the report. For more details see Section 0.

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