ORGANIC WASTE - TREATMENT OPTIONS, OPPORTUNITIES AND BARRIERS

A thesis submitted for the degree of Doctor of Engineering

by

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Abstract

There is approximately 14 million tonnes of biodegradable organic waste produced by households in the UK every year which must be treated or disposed of. The EC Directive on Landfill (1999/31/EC), is likely to lead to an increase in composting and anaerobic digestion as methods to treat the waste stream diverted from landfill. Householders play an important role in separating their waste, which, if not performed efficiently can lead to contamination of the organic waste stream, and hence the compost product. A survey is used to determine the attitude and behaviour of householders to waste issues. It was found that residents in the less affluent area were less likely to home compost and had a less favourable attitude towards environmental activities than residents in the affluent area. A comparison of compost from centralised composting schemes treating different organic waste streams found that compost derived from household waste was of a slightly poorer quality than that obtained from gardens/parks waste.

As more waste is recycled as compost, it is becoming increasingly important to find alternative uses for compost. Leachability data are used to determine the environmental availability of Cd, Cu, Pb, and Zn contained in natural compost. Batch sorption data are used to determine uptake of additional Cd, Cu, Pb, and Zn by compost and assess its potential use in remediation work, as an alternative to natural materials such as peat. The relative binding of these additional metals to compost is found to be in the order Pb>Cu≈Cd>Zn. The sorption of metals on compost takes place, at least in part, by exchange of calcium bound to the compost and there is evidence that the sorption occurs in both the humic and non-humic sites in the compost. The use of compost to bind metals in remediation work is discussed.

CONTENTS

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GLOSSARY

Aerobic

In the presence of oxygen

Anaerobic

In the absence of oxygen

Anaerobic Digestion

A complex process by which organic material (e.g. organic waste) is broken down by microorganisms in the absence of oxygen to produce biogas and solid and liquid residues.

Biogas

A mixture of methane (approx. 62%) and carbon dioxide (approx. 38%) along with traces of other gases which is produced during anaerobic digestion.

Centralised composting

The composting process on a large scale often run by local authorities or private businesses

Composting

A complex process by which organic material (e.g. organic waste) is broken down by microorganisms in the presence of oxygen to produce stable solid residues.

DANO drum

A drum which pulverises waste and separates the waste into different sized fractions.

HMIP

Her Majesty's Inspectorate of Pollution

Home composting

The composting process normally carried out by homeowners in their gardens.

NRA

National Rivers Authority

Windrow system

A method of composting by which organic waste is placed in elongated piles (windrows) and aerated naturally through turning of the piles.

EXECUTIVE SUMMARY

1 INTRODUCTION TO THE ENGINEERING DOCTORATE IN ENVIRONMENTAL TECHNOLOGY

The Engineering Doctorate in Environmental Technology Handbook states that:

> *"The Brunel/Surrey Programme is unique in that it has the specific theme of 'Environmental Technology'. The overall Programmes' thesis is that the traditional practices of industry are unsustainable. For 'Sustainable Development' (i.e. the concurrent preservation of a quality environment and sustained living standards) to be viable, a great deal more research into the complete life cycle of products, from obtaining raw materials, through production and use, to disposal or recycling, and eventually the decommissioning of the production facilities is required. Holistic solutions must therefore concentrate on conception and design, since this is where sustainable solutions emerge. This will require a quite different approach to both process and product design for the future. It is also necessary to move public discussions on the environment from an emotive to a more rational level. Until the complexities are more widely understood, there remains the risk of legislation being driven in a way that will ultimately damage the environment it is intended to preserve. Our aim is to provide Engineering Doctors with the necessary skills to balance environmental risk* <u>*along with*</u> *all of the traditional variables of cost, quality, productivity, shareholder value, legislative compliance etc."*

2 HOW DOES THE TREATMENT OF ORGANIC WASTE RELATE TO ENVIRONMENTAL TECHNOLOGY ?

The research described in this thesis concentrates on organic waste generated by households and the options available to treat this waste stream. Currently, all waste generated by households in the UK can be placed in their "dustbin" for collection by the local authority serving their area. In many areas some facilities exist for the recycling of specific materials generated within the home, (e.g. paper and glass), but often little or no facilities are provided by local authorities for the recycling of organic waste. In terms of sustainablility this is a totally inadequate situation.

Three options have been considered for the treatment of organic waste; centralised composting, anaerobic digestion, and home composting. If any of these methods are used to treat organic waste they can have a number of environmental benefits over existing methods of disposal (primarily landfill). These include:

1. Stabilisation of the waste to produce a solid product which can have fertilising properties
2. Reduction in volume of waste
3. Reduced dependence on landfill
4. Reduced dependence on existing materials like peat

In addition, anaerobic digestion produces methane which can be used in heat and electricity generation.

The economics of treating organic waste must also be balanced against the environmental benefits. In terms of costs there would be a benefit gained from not having to pay landfill charges for the waste and if the material could be sold this will also generate additional revenue. For some projects, such as the East Hertfordshire composting project, the savings on landfill can cover the operating costs of a composting site. In contrast, the capital costs of setting up an anaerobic digestion plant can cost millions (£8 million in the case of a proposed plant by WMC Resource Recovery in Kent), but this may be an investment for a long period of time, for example 25 years onwards.

In a similar way to many other waste management issues, the social implications of introducing organic waste management schemes must also be considered. The impact of the public on organic waste treatment schemes should not be underestimated, because their cooperation (for example, in separating their waste) is crucial to the success of any projects. For this reason one of the chapters in the thesis is concerned with the social issues of introducing a home composting scheme and another chapter is concerned with the chemical and physical contamination of composts derived from the organic fraction of household waste.

3 CONTRIBUTION TO KNOWLEDGE

There is approximately 14 million tonnes of biodegradable organic waste produced by households in the UK every year which must be treated or disposed of (Burnley, 1998). New legislation, such as the EC Directive on landfill (1999/31/EC), is likely to cause an increase in composting and anaerobic digestion activities in the coming years. Some of the main difficulties with these methods for treating organic waste generated by households include (1) contamination of compost products, which often occurs as a result of problems in separating organic waste, (2) finding markets for the products. A significant contribution to knowledge is made in this thesis by enhancing the understanding of compost and digestate contamination, and establishing new uses for compost.

The participation of householders is central to the success of composting or anaerobic digestion procedures, because they rely on householders separating their organic waste at source. In the survey, detailed in chapter 2, which focuses on the practice of home composting, it was found that residents in the less affluent area were less likely to home compost and had a less favourable attitude towards environmental activities than residents in the affluent area. This research has proved useful in identifying those specific areas in the community that may be targeted to increase composting practice in the community so that less organic waste is sent to landfill.

Centralised composting and anaerobic digestion schemes also rely on good source separation of waste, however, if this is not performed correctly it can lead to contamination of the organic waste stream and contamination of the final compost. Contamination of the compost could be in the form of physical contamination e.g. glass, plastic or in the form of chemical contamination, such as heavy metal contamination. Analysis of a range of composts prepared at centralised treatment plants, reported in chapter 3, shows that compost derived from the organic fraction of household waste was of slightly poorer quality than that obtained from green waste (gardens, parks and civic amenity site waste).

The agricultural sector is the largest potential user of compost, but for compost to be used as a soil improver/fertiliser the quality of the product is critical. Heavy metal contamination of compost is of particular concern because of possible metal uptake by plants and it is critical to establish the bioavailability of heavy metals in compost. The findings presented in chapter 4 confirm that heavy metals in compost are not readily bioavailable and this chapter reports for the first time about the nature of the possible interactions between heavy metals and compost. The leachability data presented suggest that the metals Pb, Cd, Cu, and Zn are strongly held on the compost and are not easily removed unless harsh treatment conditions are used (for example, high concentrations of nitric acid). To obtain more information on the nature of the compost-metal interactions a series of batch studies of metal uptake were carried out and have been detailed in chapter 5.

Novel research on metal and dye removal by compost is reported in chapter 5. Metal uptake by compost in batch sorption experiments is rapid and most of the uptake of total metal occurs within 1 hour, however, the uptake of methylene blue dye is slower and there is a continual increase over a 24 hour period. The capacity of compost for lead, copper, cadmium, and zinc is approximately 60, 30, 25, and 10 mgg^{-1} respectively and for methylene blue dye is 180 mgg^{-1}.

Evidence from work on peat suggests that the mechanism of pollutant binding to biosorbents such as peat and compost is complex, and chapter 6 investigates the mechanism for heavy metal and dye binding to compost. Leaching experiments and surface characterisation experiments were undertaken to establish a potential mechanism for pollutant binding to compost. The data for calcium exchange are consistent with the metals replacing calcium at exchangeable sites in both the inorganic and organic compost fractions. The fact that compost is effective at removing Pb^{2+}, Cu^{2+} and methylene blue dye, but poor at removing dichromate ions and congo red dye suggests that positively charged species are attracted to the compost. Leaching of the metals from natural compost and compost saturated with Pb and Cu suggest that the metals must be bound by strong interactions to both organic and inorganic fractions. The data for metal sorption to the compost with the humic fraction removed are also consistent with attachment of these metals to both humic and non-humic material.

The strength of the attachment of metals to active sites in the compost provides an opportunity to use it as a replacement for peat and other natural materials in effluent treatment and similar remediation systems. Compost, like peat, would have to be used in the removal of metals or dyes in single use situations and then be disposed of by landfill or incineration unless methods of recycle can be developed. In this use it would, however, replace a natural material and permit at least a single step for recycling of organic waste.

REFERENCES

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CHAPTER ONE

INTRODUCTION

1.1 THE ENGINEERING DOCTORATE IN ENVIRONMENTAL TECHNOLOGY

The Engineering Doctorate in Environmental Technology was established to produce Doctorate level engineers who have undertaken industrially relevant research (Engineering Doctorate Course Handbook, 1998). Following the publication of the White Paper "Realising our potential - A Strategy for Science, Engineering and Technology", and subsequent consultation by the Science and Engineering Research Council (SERC)(now known as EPSRC) with industry, it was apparent that industry wanted graduates educated to Doctorate level, but with an industrial perspective and relevant experience. As a result, the SERC initiated a number of Engineering Doctorate (EngD) programmes, and in 1993 the Brunel/Surrey programme was set up with the underlying theme of "Environmental Technology".

The Brunel/Surrey Engineering Doctorate aims to create graduate Research Engineers with the necessary background knowledge, skills, and experiences to understand the relationship between the environment, technology, and business and apply this understanding to the development, promotion, and execution of corporate strategy.

It is expected that at the end of the programme the Research Engineer will:

- be able to plan and execute flexible, innovative, R&D programmes that respond to customer needs;
- form, work within, and where necessary, lead teams with multidisciplinary backgrounds;
- have expert knowledge in the field of environmental technology and be able to apply techniques that balance social and economic benefit against resource utilisation and environmental impact;
- possess a working knowledge of project management and business methods;
- have excellent communication skills.

The programme differs from the traditional PhD in that Research Engineers are required to produce a portfolio of work over time. This requirement allows the Research Engineer to respond to the needs of industry, for example by undertaking several shorter length projects rather than one longer length project, and to document any work he/she undertakes during the four year period. In addition to this, the Research Engineer is required to attend a number of modular courses (and complete any assessments as part of these courses) to further their professional development within the areas of business, the environment, and engineering.

1.2 ASSESSMENT CRITERIA

In order to be eligible for the award of the degree of Doctor of Engineering, candidates must fulfill the following criteria:

a) Demonstrate evidence of innovation and a contribution to knowledge via research into either: (i) novel understanding of the environmental consequences of systems for providing or using goods or services; or (ii) novel methods of improving the environmental performance of systems for providing or using goods or services thereby contributing to more sustainable development. The test of innovation and contribution to knowledge shall be equal to that required for the award of Doctor of Philosophy.

b) Demonstrate an understanding of the context of the research: this must include the scientific context and, where appropriate should include the commercial and social contexts.

Both a) and b) will be tested at the final *viva voce* examination. Criteria c) to g) will be tested before the final viva.

c) Demonstrate a knowledge of how 'Environmental Technology' can be applied to the industrial sector of the sponsor organisation.
d) Demonstrate the ability to apply project management skills.
e) Demonstrate the ability to present effectively their research work both orally and in written reports.
f) Demonstrate a knowledge of the application of financial planning and control of engineering projects.
g) Demonstrate the ability to work within and lead teams.

1.3 THE RESEARCH SETTING

The EngD programme is jointly funded by the Engineering and Physical Sciences Research Council (EPSRC), formerly SERC, and the UK Environment Agency. At the outset, the sponsoring body was London Waste Regulation Authority (LWRA), however in April 1996 all waste regulation authorities, HMIP and the NRA amalgamated to become the UK Environment Agency. During its existence, the LWRA was the largest waste regulation authority in England, employing some 100 staff, who had the task of regulating London's waste. As part of the recycling and waste minimisation department, the author undertook the role of researching into the treatment of organic waste and continued this work when the Environment Agency was formed.

The Environment Agency was formed to integrate the UK's approach to pollution and regulating activities which may have an impact on the environment. It was formed as part of the Environment Act (1995), and for administrative purposes is composed of eight regions. The author undertook his research as part of the waste regulation function of the Thames region, which covers all of London and some of the home counties.

1.4 AIMS AND OBJECTIVES OF RESEARCH

The overall aim of the research is to consider some of the issues associated with the reduction and treatment of organic household waste. There are many barriers which need to be overcome for organic household waste treatment to be implemented and operated effectively. These range from the social implications of introducing or promoting a treatment scheme, through to the technology used for the treatment and market development/sales of any products.

There is approximately 14 million tonnes of biodegradable organic waste produced by households in the UK every year which must be treated or disposed (Burnley, 1998). This could be achieved through 1) Disposal to Landfill, 2) Incineration, 3) Composting or Anaerobic Digestion. This thesis is concerned with Composting and Anaerobic Digestion as treatment methods for organic waste.

Initially, the current level of composting and factors that influence people to compost must be considered in order to reduce the amount of organic waste. The participation of householders in any scheme is central to the success of composting or anaerobic digestion, and one way householders can help is by separating their waste, however, if this is not performed correctly it can lead to contamination of the organic waste stream and contamination of the final compost. Contamination of the compost could be in the form of physical contamination e.g. glass, plastic or in the form of chemical contamination, such as heavy metal contamination. If compost is contaminated with heavy metals it is expected that the metals will be strongly bound to the compost, however, it is critical to assess the bioavailability of these heavy metals before compost is used in agricultural applications. Furthermore, if metals bind strongly to compost this could be exploited with compost being used as a material to concentrate metals.

A literature review and five individual projects have been undertaken during the course of study. This document will describe the research content of each of these projects and these will be outlined in chapters 2-6. Conclusions drawn from the research will be given in chapter 7.

The remainder of this chapter describes the main treatment techniques for organic waste. This includes a description of the basic principles and science of composting and anaerobic digestion.

Consideration of the social implications of introducing a home composting scheme is the focus of chapter 2. This research was performed in conjunction with the London Borough of Hounslow which was considering introducing a home composting scheme and wanted to find out more information about how residents viewed such a scheme. The research examined two different socio-economic areas within the borough and compared the views of residents on home composting and other waste issues.

Chapter 3 considers some of the main problems associated with compost quality. It provides an analysis of a range of as-supplied compost samples obtained from centralised composting facilities. There is considerable concern within the waste management industry about heavy metal and physical (for example, plastic, glass) contamination of composts and this programme of research concentrates on the levels of these contaminants in compost samples.

Chapters 4 and 5 are concerned with the availability of heavy metals in compost and the use of compost to remove heavy metals and organic dyes from solution respectively.

Chapter 4 reports on the bioavailability of five heavy metals in compost by undertaking a series of leaching experiments on compost obtained from a local authority composting household organic waste. The impetus behind this research comes from the potential use of compost in agricultural and horticulture, which may be affected if heavy metals are readily leached from the compost.

Chapter 5 examines the use of compost for removing heavy metals and dyes from solution. It details research into the use of compost to remove metals and dyes from solution and examines various factors which may affect the removal of these pollutants. Chapter 6 extends this work to consider how heavy metals and dyes are removed and mechanisms for pollutant removal are proposed.

Finally, chapter 7 summarises the main findings of the research and draws the research together in a broader environmental perspective.

1.5 INTRODUCTION TO THE AREA OF RESEARCH - THE TREATMENT OF ORGANIC WASTE

The research described in this thesis is centred around the theme of "The treatment of Organic Waste". It concentrates on organic waste generated by households and the options available to reduce and treat this waste stream. Three methods have been considered in this thesis for the management of organic waste from households a) centralised composting, b) anaerobic digestion, and c) home composting.

Currently, all waste generated by households in the UK can be placed in the "dustbin" for collection by the local authority serving the area. In many areas facilities exist for recycling specific materials generated within the home, (e.g. paper and glass), but little to no provision is made by the local authorities for the recycling of organic waste.

1.5.1 Legislation

In December 1995 the UK Government produced its White Paper, Making Waste Work - a waste strategy for sustainable waste management in England and Wales, (Department of the Environment and Welsh Office, 1995) in which it set out its policy framework for the management of waste. The purpose of this document was to "identify ways in which waste can be managed in a more sustainable way, and set targets for achieving that aim".

One important part of this strategy is the composting process, and the use of composting for treating the organic fraction of solid waste. Waste composting is the aerobic processing of biologically degradable organic wastes, such as garden and kitchen waste, to produce a reasonably stable, granular material, usually also containing valuable plant nutrients (Department of the Environment and Welsh Office, 1995). If some of this material can be composted it will help to reach the primary targets of the waste strategy; that is, to reduce the proportion of controlled waste going to landfill from the current level of 70% to 60% by 2005, and to recover 40% of municipal waste by 2005.

To help reach these primary targets a number of secondary targets have also been set, many of which apply to the area of composting. Firstly, there is the existing target set out in the 1990 Government's White paper on the environment (This Common Inheritance, 1990), to recycle or compost 25% of household waste by the year 2000. There are then three further targets which directly relate to composting:

1. 40% of domestic properties with a garden to carry out composting by the year 2000.
2. All waste disposal authorities to cost and consider the potential for establishing central composting schemes for garden waste and other organic waste.
3. One million tonnes of organic household waste per annum to be composted by the year 2000.

By June 1999, the primary targets to reduce waste going to landfill to 60% and recover 40% of municipal waste had not been met. A rapid expansion in recovery and recycling of waste would be needed in order to meet these targets. There has been considerable progress made to reach the secondary targets relating to compost. The Composting Association reported over 600,000 tonnes of organic household waste being composted in 1998, compared to approximately 200,000 tonnes in 1997 (Gilbert and Slater, 2000), and this figure is continuously expanding as new composting sites are established. The target of 40% of domestic properties with a garden to compost by the year 2000 is difficult to assess since national statistics have not been gathered. Typically, local surveys indicate levels of around 40% in rural areas and 20% in urban areas (The Composting Association, 1997).

It is clear from this discussion that composting can be divided up into two distinct areas: centralised composting and home composting. Centralised composting schemes are typically set up and operated by Local Authorities or private companies as a means of reducing the volume of waste going to landfill and increasing the proportion of waste being recycled. Some Local Authorities separately collect organic waste from the remainder of the waste stream and most provide facilities at civic amenity sites to collect garden waste.

Home composting is performed by individual households. However, many Local Authorities either provide home composting units free-of-charge or at a subsidised rate to reduce the amount of waste that needs collection. In February 1996, the Royal Commission on Environmental Pollution produced its nineteenth report on the sustainable use of soil, in which home composting was encouraged.

In June 1998, the Department of the Environment, Transport and Regions produced "Less Waste: More Value", a consultation paper on the future waste strategy for England and Wales (Department of the Environment, Transport and Regions, 1998). In the section on composting it suggests that many households already compost their garden waste and kitchen scraps, thereby reducing the quantity of biodegradable waste that has to be collected and Local Authorities have helped by subsidising the cost of composting bins.

Large scale composting schemes have proved more problematic, particularly in finding markets for the compost, and the paper invited comments on: (1) How local authorities and producers can overcome market barriers, and (2) How potential purchasers can be encouraged to specify waste-derived compost.

After the consultation process for "Less Waste: More Value", in June 1999 a draft waste strategy "A Way with Waste" was produced with a view to producing a waste management strategy for England, early in the year 2000.

As far as European Legislation is concerned, the European Commission has issued an EC Directive on landfill (1999/31/EC), in which all organic waste will require some pre-treatment before landfilling. Implementing legislation in the UK for this Directive must be in place by 16 July 2001 and it is widely thought that the final waste management strategy for England will include limits on the amount of biodegradable waste going to landfill.

These legislative drivers all help promote the treatment of organic household waste. In addition, there are also a number of environmental advantages that the treatment of organic waste offers over more traditional methods of waste management, such as landfill. These include: (i) reduction in volume of the waste; (ii) removal of organics from landfill, thereby reducing landfill gas and leachate production and preserving landfill void volume; (iii) the production of a useful material for use as a fertiliser/soil additive - this helps to reduce the need for peat-based products.

In addition to composting, another method used to treat organic household waste, is anaerobic digestion. This is a process by which a mixed microbiological culture breakdown organic materials in the absence of oxygen resulting in the generation of biogas together with solid and liquid residues (Institute of Wastes Management (IWM) Anaerobic Digestion working group, 1998, International Energy Agency (IEA) Bioenergy, 1997, Warren Spring Laboratory, 1994). Unlike composting, which produces carbon dioxide and a solid residue, anaerobic digestion produces methane, carbon dioxide and a solid residue. The methane can be collected during the process and utilised for the generation of either heat and/or electricity. Electricity generated from renewable sources has the additional benefit because an extra price is paid under the UK Non-Fossil Fuel Obligation (NFFO).

When all these economic, environmental and legislative drivers - not forgetting the landfill tax - are combined together then the potential for treating organic waste looks promising. However, before this potential is fully tapped there are some important questions and issues which need to be considered. This thesis, will aim to consider some of the many issues which need to be explored with emphasis on the limitations of organic waste treatment and how these may be overcome.

1.6 CENTRALISED COMPOSTING, ANAEROBIC DIGESTION, AND HOME COMPOSTING

1.6.1 Centralised Composting

Centralised composting of household waste involves the collection of waste from a number of homes or premises, and this is subsequently taken to one site where it is composted (typically for 10-26 weeks). If the waste is collected as mixed waste then the organic fraction needs to be separated before or after composting. Nowadays, however, because of potential contamination of the organic waste, householders are generally asked to separate their organic waste and this is collected separately for composting (Organic Reclamation and Composting Association, 1992).

1.6.1.1 Biochemistry

Centralised composting is an aerobic method used to treat organic waste on a large scale. Microorganisms (actinomycetes, bacteria and fungi) are responsible for converting the organic waste into humus-like materials (Golueke, 1991). Under suitable conditions, the action of these microorganisms rapidly generates heat (temperatures of 50-70°C) which can sanitise the material through the destruction of weed seeds and pathogenic bacteria.

The conversion of waste to humus requires the correct balance of nutrients (Golueke, 1991). Moisture, carbon to nitrogen ratio, temperature, and oxygen are the key environmental parameters which need to be controlled. Moisture is required because most decomposition occurs in liquid films surrounding waste particles, however, excessive water reduces oxygen available to microorganisms and slows down the rate of decomposition. Golueke (1991) recommends a minimum moisture content of 50-55% for Municipal Solid Waste (MSW) composting. Moisture contents below 45% and above 75% are known to slow the rate of decomposition. The correct ratio of carbon to nitrogen is essential for microorganism activity and growth. Carbon is the main energy source for microorganisms and nitrogen is needed to make protein which constitutes a large proportion of cell mass in bacteria. Therefore, the ratio of carbon to nitrogen should be kept within the range 20-50:1. The precise ratio will depend on the materials being composted and the availability of these nutrients during the composting process. In composting, the temperature rises rapidly and can easily reach 50-70°C within 72 hours. Optimum rates of decomposition occur within the temperature range 45-59°C, however, generally temperatures above 55°C are required to destroy pathogens. Oxygen is the final parameter which must be monitored. It is closely related to both moisture and temperature. Oxygen levels can be increased through turning the waste, and this process also releases heat.

1.6.1.2 Technology

Composting technology can be split into two areas (1) open air (or non-reactor) systems, and (2) reactor (or in-vessel) systems. The most popular open-air system in the UK is the windrow system (Department of the Environment Transport and Regions, 1998). This requires placing the waste in piles (Figure 1.1), which are typically of the range, 1-3 metres high, 3-6 metres wide, and lengths ranging from several metres upwards. The actual size of the windrow will depend on the characteristics of the compost site, equipment used, waste composted and weather conditions. The waste is turned on regular intervals to allow oxygen in, and heat and carbon dioxide out. Other open-air systems require placing the waste in piles of similar shapes to windrows, but do not involve any turning of the waste. The waste is typically placed over a network of pipes which allows oxygen supply to the waste. In most systems air is forced into the waste to ensure adequate oxygen supply, and this is often triggered automatically through monitoring oxygen or temperature levels in the pile.

Reactor systems are a less popular alternative for composting in the UK, and involve placement of the waste in an enclosed horizontal or vertical container. Horizontal systems can be either static or agitated piles. Static systems generally require waste to be loaded into the system and the compost to be unloaded when the composting process has finished. The degrading waste in the container (or vessel) can then be closely monitored for the critical factors suggested above, and the waste can be aerated when needed (Figure 1.2). Agitated systems usually move the waste continuously to allow air into the waste through turning. Vertical systems are normally greater than 5 metres in height (Figure 1.3). The waste is fed into the system at the top and passes down through several chambers by gravity. Air is normally fed into the bottom of the reactor and flows countercurrent to the waste. It should be noted that there are many different "in-vessel systems" which are commercially available and the control of the degradation process varies from system to system.

Figure 1.1 A Typical Windrow Composting System

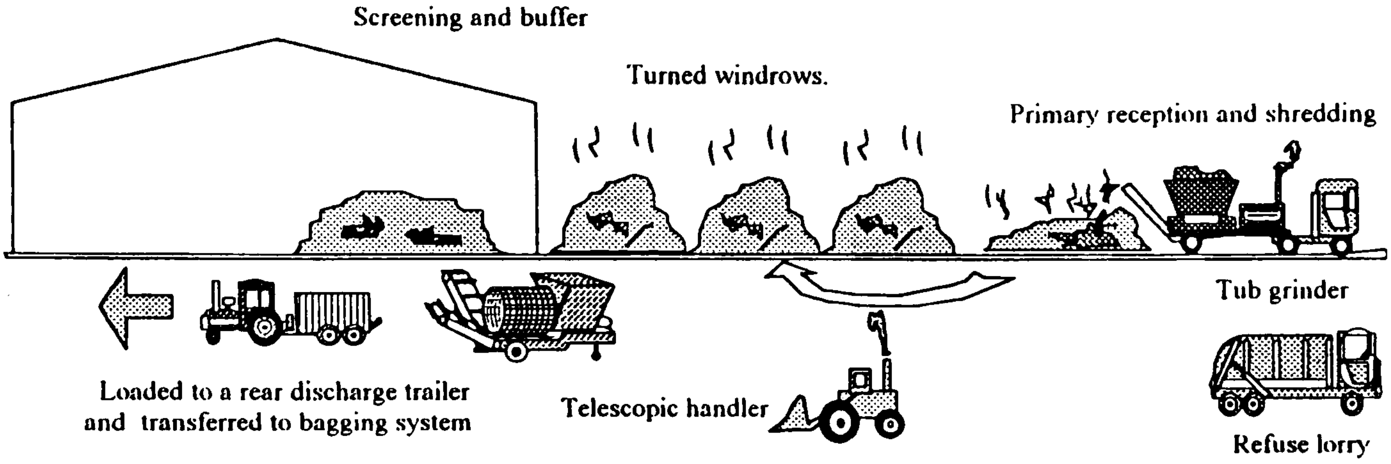


Figure 1.2 Typical Static Reactor System

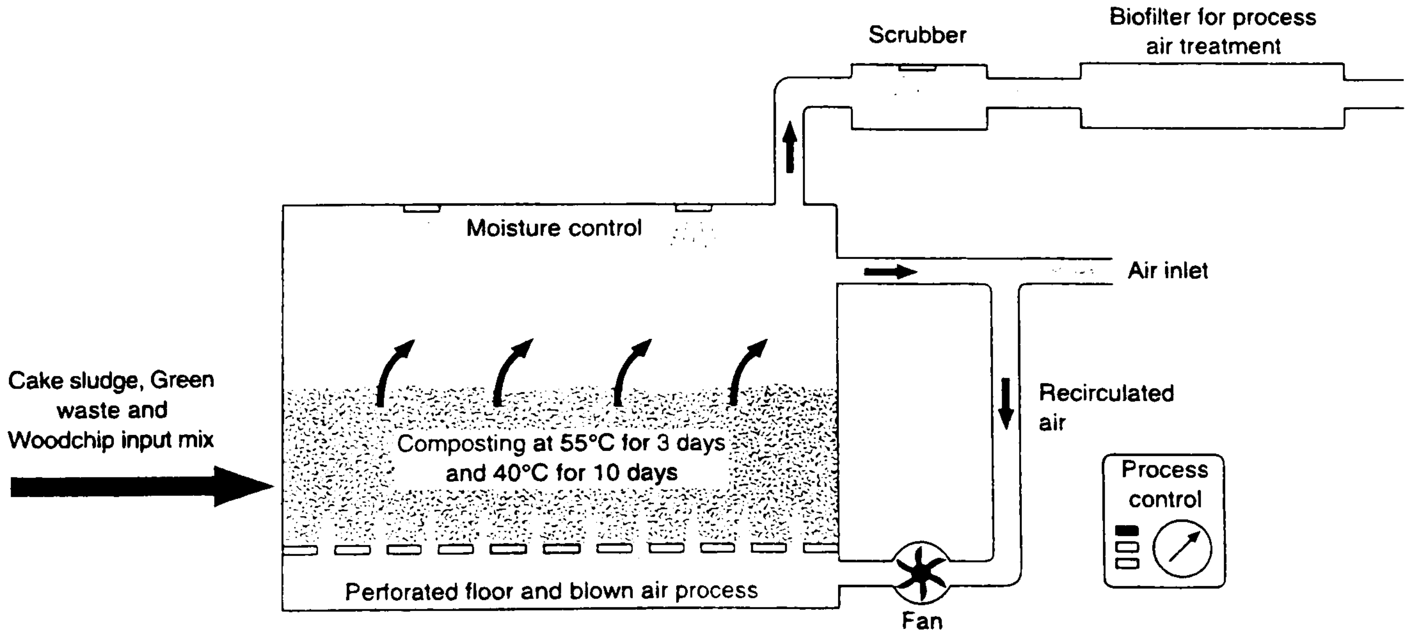
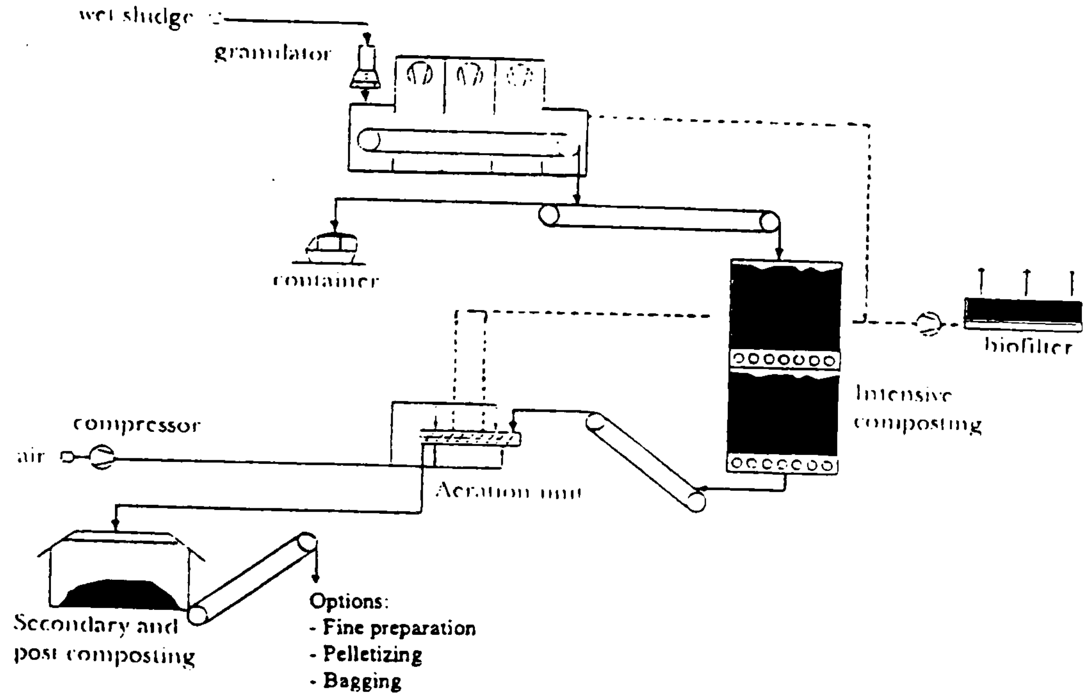


Figure 1.3 Typical Vertical Reactor System



1.6.1.3 The Extent of Centralised Composting in the UK

Composting in the UK has expanded considerably in the 1990's. The Composting Association (1997) produced a summary table of the number of composting plants in the UK and compared the data to that in other countries (Table 1.1)

Table 1.1 Composting Plants in European Countries

Country	1990	1996
France	45	167
Germany	16	340
Austria	16	153
The Netherlands	10	24
UK	4	44

Source: The state of composting in the UK produced by the Composting Association, 1997.

Although the number of plants is considerably less than in some other European countries, it is important to note the considerable increase in the number of UK plants in the six year period from 1990. By 1997, it has been estimated that this number has increased to 47 operational sites, with 6 further sites under construction or consideration. The majority of these sites use the windrow method of composting on a concrete base. From these sites a total of 313,000 tonnes of organic material was composted, of which, 205,000 tonnes came from household waste. This means that in 1997 only 20% of the target of 1 million tonnes of organic household waste per annum to be composted by the year 2000 had been reached. Recently produced data by the Composting Association for 1998 (Gilbert and Slater, 2000), indicate the amount of organic household waste composted during 1998 was in excess of 600,000 tonnes. This sharp increase in the amount of waste composted reflects the increasing awareness and popularity of composting.

1.6.2 Anaerobic Digestion

The collection strategy for the treatment of household waste by anaerobic digestion is similar to that of centralised composting. Once the organic waste is collected it is taken to a digester, where it can be mixed with other organic material (e.g. sewage sludge) and is digested by anaerobic micro-organisms.

1.6.2.1 Biochemistry

Anaerobic digestion is a naturally occurring process where large complex organic molecules are broken down by microorganisms, in the absence of oxygen, to produce mainly carbon dioxide and methane. There are three main stages to anaerobic digestion; hydrolysis, acidogenesis and methanogenesis (IWM anaerobic digestion working group, 1998). The hydrolysis stage involves the conversion of large insoluble organic molecules such as carbohydrates, lipids and proteins into simpler soluble molecules such as simple sugars, long-chain fatty acids, and amino acids. This occurs through hydrolytic bacteria-releasing enzymes which cleave the larger molecules and the nature of this process means the hydrolysis stage of anaerobic digestion is often the rate limiting step.

Acidogenesis is the second stage in anaerobic digestion and the soluble organic molecules formed in hydrolysis are broken down to produce shorter chain organic acids (called volatile fatty acids). Typically, a range of acids from acetic to lactic acid is produced and as a result the pH decreases.

Methanogenesis is the final stage in anaerobic digestion, where the products from acidogenesis are transformed to methane (and carbon dioxide). In addition to producing methane, the methanogenic bacteria are also important in controlling pH by using hydrogen ions produced in the acidogenesis stage.

To allow the biochemistry to proceed without problems, the microorganisms need the correct physical and chemical environments. The essential parameters for this are nutrients, moisture, temperature, and pH.

Certain nutrients are essential to the microorganisms performing the digestion process. Nitrogen is the most important nutrient, which is needed for the growth of methane-forming bacteria at a rate of about 5 kg per tonne of organic waste. Phosphorous is also very important and is needed at a rate of about 1 kg per tonne of organic waste. In addition, a number of micronutrients 'such as iron and magnesium' is needed for key enzymes in the digestion process. The balance of carbon to nitrogen should ideally be between 20-30:1 to achieve maximum methane production. Despite the need for many elements in anaerobic digestion, chemotoxicity can result if excessive build-up of a particular chemical occurs. The anaerobic digestion system is particularly susceptible to high ammonia concentrations and high levels of heavy metals.

Traditionally anaerobic digestion has been performed on a feedstock with a high moisture content (>90%) e.g. sewage sludge. However, the organic fraction of household waste is too dry for anaerobic digestion and water must be added to bring the moisture content to 60-70% so that the waste can undergo the digestion process.

Anaerobic digestion can work at any temperature, however, there are two optimum temperature ranges for anaerobic digestion; the mesophilic temperature range (35-40°C) and the thermophilic temperature range (55-60°C). There are two distinct types of methanogenic bacteria, one of which operates optimally within the mesophilic range and the other which operates optimally within the thermophilic range. The thermophilic temperature range allows a higher rate of waste input into the digester (loading rate) and a shorter retention time of the waste within the digester. However, this must be offset against the increased energy costs required to heat the digester to a higher temperature and the greater sensitivity of the digester to change.

pH Control is very important in anaerobic digestion, because of the different groups of bacteria involved in digestion. The early stages of anaerobic digestion produce volatile fatty acids which result in a lowering of pH. This lowering of pH can inhibit methanogenic bacteria. Therefore, the optimum pH for anaerobic digestion is around neutral pH 7.

1.6.6.2 Technology

There are numerous different commercial anaerobic digestion processes available and the choice of process will depend on site-specific factors. The most important factors are composition of feed waste, the complexity of the process and the markets for the products.

Anaerobic digestion technology can generally be split into two types; wet (low solids) anaerobic digestion and dry (high solids) anaerobic digestion (Warren Spring Lanoratory, 1994). These systems differ in the solid content of the feed waste. High solids systems operate at solids levels of greater than 25%, have less throughput of water, and hence require less tank volume, whereas low solids systems operate at levels of about 3-10% and the waste has a shorter retention time in the digester. The process of digestion may be either continuous flow where the waste is continuously fed into the digester and gas and digestate removed, or batch flow where the waste is left to fully digest before all the digestate is removed at one time.

There are many different types of digester systems for use in anaerobic digestion, however, they have not been developed specifically for treatment of the organic fraction of household waste. Most systems have been developed for other applications such as the treatment of industrial effluents or sewage sludge, and this technology has been adapted for the treatment of the organic fraction of household waste. Comprehensive cover of these digester systems and the commercial processes based on these systems can be found in the literature (IWM Anaerobic Digestion working group, 1998, IEABioenergy, 1997, Warren Spring Laboratory, 1994). In addition, processes which involve two stages have been developed to optimise the differing conditions required by acidogenic and methanogenic bacteria.

1.6.2.3 The Potential for Anaerobic Digestion in the UK

The International Energy Agency (IEA) reported that in 1997 there were more than 115 anaerobic digestion plants operating or under construction using municipal solid waste (MSW) or organic industrial waste as their main feedstock (IEA Bioenergy, 1997). There are also another 40 plants in the planning phase. In addition, there are many more plants treating organic waste generated from other sources such as farms. Despite the use of anaerobic digestion to treat the organic fraction of municipal solid waste in Europe there are no full scale plants operating in the UK which are dedicated to treating the organic fraction of municipal solid waste.

Over the last two decades there has been considerable research in the UK and a number of pilot plants have been constructed. WMC Resource Recovery have developed a process to treat the organic fraction of MSW based on anaerobic digestion (Aubrey, 1994). They operated a demonstration plant from 1981-1984 to show the benefits of this system. The system incorporates the sorting of the waste as well as the anaerobic digestion process and uses a stirred tank reactor. Kent County Council are currently considering the use of this process to treat about 40,000 tonnes of waste in the Ashford area and will cost £8 million (Aubrey, 1994).

A further system has been developed by Thames Waste Management, who have utilised an anaerobic digestion system at an existing site which treats sewage sludge (Wastes Management, March 1997). They tested a treatment method which co-digests sewage sludge with the organic fraction of household waste to produce a digestate and biogas. A trial plant was operated from February to October 1996 using a 3500 m^3 digester which also treated 140 m^3/ day of sewage sludge. The treatment process uses four stages (1) mechanical separation of waste using the DANO rotary drum waste separation equipment (this pulverises the waste and separates it into different sized fractions) , (2) slurrying with sludge, (3) screening to remove non-organic material (4) anaerobic digestion. Thames Waste Management are currently marketing this system in the UK.

A number of other systems have been developed by companies and universities in the UK, but none of these is currently being considered for use in full scale plants in the UK. There are also some local authority councils in the UK considering the use of other anaerobic digestion systems being used in Europe.

1.6.3 Home Composting

The biochemistry of home composting is the same as that of centralised composting, but home composting, as the name suggests, is performed by home owners at their own property. There is therefore no need for transportation of the waste to a particular site to perform the composting process.

There is a wide range of compost bins which are commercially available at a variety of prices (Wastewatch, 1995). Many local authorities in the UK have provided compost bins at a reduced price to encourage households to compost. However, the success of these home composting schemes is often difficult to measure. An attempt to quantify this in terms of socio-economic considerations is covered for one London Borough in chapter 2.

1.6.4 Products of Composting and Anaerobic Digestion

The fundamental difference in the products from composting and anaerobic digestion is the additional generation of methane in anaerobic digestion, which can be collected to produce heat and/or electricity. From both processes, a solid product is produced; a digestate is produced in anaerobic digestion, whereas compost is produced in composting. The composition and quality of digestates and composts is dependent on many factors. Probably the most important factor is the waste feedstock to the process, which will vary with geography, season, climate, and many other interrelated factors.

The composition and quality of the products will determine their potential markets and digestates and composts will be competing in the same markets. Developing markets for the products is known to be one of the most difficult tasks facing compost operators, and to help develop markets, in 1998 the Department of the Environment, Transport and Regions published a guide for producers of waste derived composts, since the sale of compost can impact severely on the economics of composting. In a recent Composting Association survey (The Composting Association, 1997) of compost site operators, over half of those surveyed felt that marketing was a serious problem. The main markets for compost and digestates are thought to be, agriculture, horticulture, and landscaping (Department of the Environment/Environment Agency, 1996). In the UK, many existing compost sites are operated by or on behalf of local authorities and an additional outlet available for the compost is on their parks and gardens.

1.6.5 Differences in Composting and Anaerobic Digestion Costs

1.6.5.1 The Relative Costs of Waste Management in Europe

A review of organic waste treatment has highlighted the difference between the UK and other European countries in their approach to the treatment of the organic fraction of household waste. Other European countries are more active in this area and have more composting and anaerobic digestion facilities to treat organic waste generated by households. The reason for this arises ultimately from economics, which make composting and anaerobic digestion more financially viable. In turn, the economics are affected by national legislation which can change the relative costs of composting and anaerobic digestion compared to landfill. The relative costs of different waste treatment techniques may also be influenced by the availability of landfill space, and countries like the Netherlands with only a small amount of landfill space will obviously charge a higher premium for this space. Furthermore, in countries where the demand for compost is high (for example in Spain where the quality of soil is low) this will increase the need for composting sites.

Currently, the UK differs from many European countries because the cost of landfill is relatively inexpensive. However, the introduction of new legislation by the UK Government has been designed to reflect the true environmental costs of different waste management options. The most direct impact is likely to come from a landfill tax introduced in October 1996, which in April 1999 commanded a fee of £10 per tonne for active waste and £2 per tonne for inactive waste. In addition, the introduction of the European Landfill Directive, in which all organic waste will require pre-treatment, will also force the UK to rethink its approach to the treatment of organic waste.

Although there are many legislative drivers which are likely to make the UK reconsider its position on organic waste treatment, there are also a number of factors which may prevent the expansion of composting and anaerobic digestion. For example, the ban on sewage sludge disposal at sea from 1998 has meant more sewage sludge is now processed to produce a product suitable for use in agriculture. This product will obviously be competing for its market share with compost and digestates produced from the organic fraction of household waste. There are also concerns about the public perception of waste materials and this can also adversely affect marketing of compost and digestates.

1.6.5.2 The Processing Costs of Organic Waste Treatment in the UK

This review has also shown that in the UK composting is being used to treat the organic fraction of household waste, whereas anaerobic digestion is not being used. The reason for this is a combination of technology and economics.

The UK Composting Association (1997) suggested that the cost of composting for a site processing 10,000 tonnes of waste per annum, excluding land costs, is in excess of £200,000. Clearly this figure is dependent on the composting technology used, the type of waste being processed, and other factors such as the throughput of material, and there is considerable variability within the industry. Perhaps the most important cost data are capital costs. These will also vary depending on the site but can be as low as about £100,000 for a site with a throughput of 10,000 tonnes per annum, using the windrow technology. If in-vessel composting is used this will inevitably increase the capital costs.

The cost of anaerobic digestion of the organic fraction of household waste in the UK is difficult to estimate, although the capital costs of different anaerobic digestion processes can be obtained and compared to those costs for composting operations. The WMC process planned for Kent is expected to cost £8 million, and construction costs for a two stage anaerobic digestion plant in Denmark were £5.8 million in 1991 (Noakes, 1995), with the operating costs in the region of £900,000 per annum. The cost data for anaerobic digestion suggest that the process requires significant capital investment in comparison to composting. However, it should be noted that anaerobic digestion does produce biogas which can be used to generate additional revenue in comparison to composting. Furthermore, for water companies in the UK, such as Thames Water, where they currently use anaerobic digestion to treat sewage sludge the adaptation of this technology to treat the organic fraction of household waste will significantly reduce the capital costs of anaerobic digestion.

Overall, for local authorities and private companies wishing to treat the organic fraction of household waste, they appear to have a simple choice. Composting may cost several hundreds of thousand pounds, whereas anaerobic digestion may cost several millions. This is a simplification of the economics of the processes, but illustrates a very valid point.

1.7 CONCLUSION

This chapter introduces the topic of organic waste treatment and begins with an overview of the legislative pressures that have evolved over the past decade in organic waste management. New legislation such as the EC Directive on landfill (1999/31/EC) is likely to cause an increase in composting and anaerobic digestion activities in the coming years. Three methods of organic waste treatment are considered *viz* centralised composting, anaerobic digestion and home composting. Each of these is discussed in terms of biochemistry of its operation, technology used and extent of practice in the UK. Some of the main difficulties with these methods for treating organic waste generated by households, however, include (1) contamination of compost products, which often occurs as a result of problems in separating organic waste, and (2) finding markets for the products. These form the basis of the work described in the thesis.

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CHAPTER TWO

THE SOCIAL IMPLICATIONS OF INTRODUCING A COMPOSTING TREATMENT SCHEME

REFERENCES

2.1 INTRODUCTION

The aim of the work presented in this chapter is to determine the extent of home composting in the London Borough of Hounslow, and to investigate if there is any relationship between the households which carry out home composting and demographic characteristics (such as age, gender, education, property value, home ownership, number of children). Furthermore, it is hoped to establish if there is any relationship between the householder's perception of composting and participation in home composting.

Home composting is performed by individual households, therefore, many Local Authorities either provide home composting units free of charge or at a subsidised rate because it reduces the amount of waste that needs to be collected.

2.2 BACKGROUND RESEARCH

The following section describes the approaches taken to social studies on the environment. It begins by looking at social research on environmental issues, such as waste management, and goes on to describe research on composting.

2.2.1 Waste Management

In the past, the approach towards environmental issues has often been to carry out studies under the broad heading of general environmental concern. Van Liere and Dunlap (1980) reviewed the social bases for environmental concern and concluded that there is a slight correlation between environmental concern and a number of demographic characteristics (e.g. age, social class). In addition to this they also remark on the way that environmental issues have traditionally been dealt with in a generalised context with little attention being placed on specific environmental issues. They recommended that future research could be performed addressing specific environmental issues and policies.

Research into the field of environmental issues and the interaction with the general public has typically been discussed in terms of attitude, behaviour, knowledge and demographic characteristics of the population. As with many of the key factors associated with "environmental issues" which have been studied, there is conflicting evidence as to the importance of knowledge. In a study by Vining and Ebreo (1990) it is shown that knowledge of the environment is related to environmental attitudes and behaviour, but there appears to be no consensus in the literature as to the extent to which knowledge plays a part. Oskamp et al. (1991) stated that the conflicting evidence for the importance of environmental knowledge could be due to differences in the type of information sought when trying to predict environmental knowledge.

Attitude and behaviour are of importance when discussing environmental issues. Again there is contradictory evidence as to how the attitude of an individual impacts on that individual's behaviour. Several studies (De Young, 1990; Vining and Ebreo, 1990; and Oskamp et al., 1991; Taylor and Todd, 1995) indicate that attitude and behaviour are affected by a number of cognitive and psychosocial variables such as perceived cost, benefits, inconveniences, social implications, and knowledge.

As a result of these studies it has been concluded that environmental issues need to be considered in an individual and topic-specific way. Much recent research into waste management behaviour, not surprisingly, has concentrated on recycling. De Young (1986) considered the motivation behind recycling initiatives and found that recycling behaviour was related to personal satisfaction (i.e. reducing wasteful practice and a feeling that it is worthwhile). In another study, De Young (1988-89) looked at barriers to recycling and found that knowledge and inconvenience were factors affecting recycling. It was also discovered (De Young, 1990) that one of the reasons the public recycle is "because it seems like the right thing to do".

Research by Oskamp et al. (1991) and Oskamp et al. (1994) has considered the relationship between demographic variables (age, education etc), knowledge, attitude and behaviour, and kerbside recycling in California.

Another area of waste management that has received attention is the area of waste reduction. The Roper Organisation (1991) published a small amount of information relating to public opinion of source reduction from a survey on the population of America. Even more recently Lober (1996) carried out a study into household source reduction measures. 138 residents from Madison, Connecticut participated in a telephone survey, in which residents were chosen at random from a telephone directory. The participants were then asked a series of questions (both Likert-type questions, where respondents are asked to rank an opinion, and open questions, where respondents can say anything they wish). One of the key findings of this piece of research was that there were very few ways in which households could reduce their generation of waste. However, it was noted that composting could be used to reduce by 25% the amount of waste sent for disposal.

2.2.2 Composting

In comparison to recycling, social research into composting has been relatively untouched. The reason for this could be due to lack of knowledge by the general public.

The few studies of social research into composting have been based on the experiences of the population of Toronto, Canada. In Toronto, there has been a significant programme aimed at promoting home composting in operation for a number of years. The programme was started in 1989 and by 1995 estimates (Steuteville, 1995) have indicated that as many as 30% of Toronto residents were carrying out home composting. The success of this project is largely due to the Province of Ontario subsidising 50% of the purchase price of composting units and publicising the initiative in the local media.

Maclaren (1990) carried out a study into this composting programme using three different survey techniques: personal interviews, mail questionnaires, and telephone follow-ups. Her study involved a questionnaire survey of 734 participants in the composting programme with an aim to identify a number of factors associated with home composting. These included problems with home composting (e.g. odours, flies etc), the number of participants who previously carried out home composting, and if their attitudes and behaviour differed from new composters, and the types of waste composted. An important finding in this study was that new composters and previous composters offered quite different reasons for composting. New composters were more likely to start composting because it reduces waste, however, previous composters cited benefits for the garden as a reason for composting.

A more recent study by McKenzie-Mohr et al. (1995) investigating the practice of composting in Toronto, considered the factors that distinguish households that compost from those that do not. Potential factors that were identified as important were: convenience - both of obtaining a composting unit and carrying out composting, expense of buying the containers, savings from using the compost as a soil improver, and personal satisfaction. To this end 409 residents were asked to participate in a phone survey. Of these 409 people 60 lived in apartments and were excluded from the survey since they were unlikely to practice composting. Of the 349 remaining households 41% (144 households) agreed to participate. The results of the study, report that home composting participants in comparison to non-participants, regard waste reduction as more important, perceive composting as less unpleasant, less inconvenient, less time consuming, recycle glass and cans more frequently, rate satisfaction as higher, rate the development of nutrient rich soil as more important, and report more frequent purchase of products with a recycled content.

2.3 THE STUDY

In the UK, the current situation of social research into home composting is at a fundamental level. Contact with the Department of the Environment (Walters, October 1996) has indicated that there have been no surveys carried out in this country to establish the extent of home composting or the factors which may influence households to participate. Nevertheless, following the publication of the waste strategy (1995), it is important to have a comprehensive measure of the extent of home composting in the UK, the people most likely to take part, and ways of improving participation. This will allow the UK Government to establish whether the objectives of the waste strategy have, or are likely, to be met. It is proposed in this study to establish the extent of home composting practised in the London Borough of Hounslow, if the proportion of households carrying out home composting is dependent on demographic characteristics, and to consider some of the factors which may influence their decision to compost. In short, the hypotheses that will be tested are:

1. Home composting in the London Borough of Hounslow is dependent on demographic characteristics of the household.
2. The extent of home composting is dependent on respondents' perception.

The demographic characteristics to be considered include age, gender, education, property ownership, type of home (such as house/ flat with/without garden), property value (property tax band), ethnic origin, employment and children in household.

To investigate the perception of home composting, the research will examine any differences between those people who participate in home composting and those who do not (based on those people who have heard of home composting). The study will try to assess the similarities or differences in what composters and non-composters perceive as the main inconveniences and main benefits of home composting.

2.4 METHOD

2.4.1 Background

The review area for the survey included households in the London Borough of Hounslow. Hounslow is a Borough situated to the west of London, with a population of around 200,000. Its residents come from a diverse range of social groups, from the affluent and predominantly white suburbs of Chiswick to the less affluent area of Brentford, which contains a high proportion of ethnic minority groups.

The Borough likes to play an active role in promoting the recycling of waste materials and in 1994 commissioned an independent research organisation to evaluate the level of recycling within the borough and ways to improve the recycling rate. This report highlighted the potential for composting of waste (particularly putrescible kitchen waste) within the borough, since 90% of households in the borough have a garden. Following the recommendations from this survey, the Borough has undertaken a small pilot scheme on a number of households; occupants/owners were asked if they would like a "Green Cone" digester for their household putrescible waste. Some difficulties were encountered in preparing the ground to house the digester and there were problems arising from flies around the digester in hot weather. Following take-up of this offer the borough noticed a reduction in the amount of waste generated from households using "Green Cone" digesters.

2.4.2 Sample Selection and Survey Procedure

Two areas within the borough were selected for the survey (Figure 2.1) because of their socio-economic profile, based on the 1991 census data and knowledge acquired within the recycling department of the borough. Isleworth North, an affluent area, and Isleworth South, an area considered to be of comparative lower socio-economic status were selected as the areas from which the participants would be randomly chosen. The Isleworth North area consisted of ten enumeration districts and the Isleworth South area consisted of six. Road names within these areas were randomly selected and a number of households (150) were chosen for the survey from each of the areas.

Prior to the survey, a pilot study was undertaken to test the questionnaire. Fifteen names were randomly chosen from the Brunel University telephone directory and a sample questionnaire sent to the selected participants. This pilot study showed that most of the questions could be understood and that most people completed the questionnaire correctly. However, it was found that some people were confused by the term "home composting" and it was felt necessary to amend the questionnaire to include an additional question of "Have you ever heard of compost or composting?".

The survey was undertaken during the period from 23 September to 24 October 1996. In order to achieve maximum participation in the project a structured questionnaire designed by the author was delivered personally to each individual house. At the time of the delivery the interviewer (the author) introduced the subject of the questionnaire and asked if the householders would complete a questionnaire over the coming week, which would be collected on a pre-arranged date. Therefore, if any householders had any difficulty with the questionnaire the collector (the author) could be of assistance. In the instance when there was no one at home the collector called back on two further occasions. If after this time there was no reply then no questionnaire was given to that address. In the instance that a questionnaire was delivered and the occupants were not around for collection of the questionnaire then the collector called back on a further two occasions. If after this time there was no reply the results of the questionnaire were not included in the survey data collection.

Figure 2.1 - Map of Survey Area

Ridgeway
FT05 is excluded

Worple

Questionnaires were mainly delivered in the evenings when it was anticipated that the greater majority of householders would be at home, although, some questionnaires were delivered in the afternoon.

A copy of the questionnaire designed for this survey is shown in Appendix 1.

Since the survey seeks the response of the household rather than individuals within the household, the survey questionnaire needed to be completed by one person only from each household. It is assumed that one person in the household will have knowledge of the activities in which the household is engaged and represent the views of that household.

2.4.3 Data Analysis

After collection of all the questionnaires, each questionnaire was read and general responses to each question noted. Based on all the responses, each question was individually coded and the data from each questionnaire were entered into a spreadsheet package, Statistical Package for the Social Sciences (SPSS), using these codes. The data were subsequently analysed using the facilities available within the SPSS package.

2.5 RESULTS

2.5.1 Sample and Demographic Information

2.5.1.1 Sample Population "A"

Sample population "A" was selected from the affluent area. 150 Households within the affluent area were asked to participate in the survey, 124 households agreed to complete a questionnaire and 79 completed questionnaires were collected (64% response rate).

The details of key demographic characteristics of the households are presented in Table 2.1.

2.5.1.2 Sample Population "B"

Sample population "B" was selected from the less affluent area. 150 Households in the less affluent area were asked to participate in the survey, 139 households agreed to complete a questionnaire and 76 completed questionnaires were collected (55% response rate).

The details of key demographic characteristics of the households are presented in Table 2.2.

Table 2.1 - Demographic data of household for sample A

Demographic characteristic	Sample A
Age	Mean = 45 Median = 41-50 group ; 10% 21-30, 18% 31-40, 25% 41-50, 25% 51-60, 6% 61-70, 15% 70+.
Children	86% yes, 14% no
Gainfully employed	66% yes, 34% no
Gender	61% female, 38% male, 1% data refused
Own property	92% yes, 8% no
Property tax band	mean = F 0 % A, 2% B, 1%C, 5% D, 13% E, 35% F, 27% G, 3% H, unaccounted for data =14%
Education	18% below GCSE/O level, 11% GCSE/O level, 23% A level, 43% degree level, 4% PhD level, 1% data refused.
Property type	95% house with garden, 5% flat with garden
Ethnic origin	89% white, 1% Black Caribbean, 5% Indian, 1% Other Asian, Other 3%, unaccounted for data 1 %.

For both sample populations a number of households refused to participate in the survey when they were first approached. It should be noted that slightly more households refused to participate in the survey in the affluent area than the less affluent area (26 compared to 11). The majority of these refusals occurred before the subject of the survey was even mentioned, and most households refused to participate as soon as the word survey was mentioned.

Table 2.2 - Demographic data of household for sample B

Demographic characteristic	**Sample B**
Age	Mean = 45 Median = 41-50 group ; 8% 21-30, 26% 31-40, 22% 41-50, 15% 51-60, 15% 61-70, 15% 70+.
Children	79% yes, 21% no
Gainfully employed	34% yes, 66% no
Gender	61% female, 39% male
Own property	34% yes, 66% no
Property tax band	mean = D 1 % A, 1% B, 4% C, 61% D, 4% E, 0% F, 0% G, 0% H, unaccounted for data =29%
Education	51% below GCSE/O level, 28% GCSE/O level, 13% A level, 8% degree level, 0% PhD level.
Property type	100% house with garden
Ethnic origin	91% white, 3% Black Caribbean, 4% black African, 1% Chinese, 1% Anglo-Indian.

2.5.1.3 Combined Data Set

Combined demographic details for all completed questionnaires (Sample "A" (79 completed questionnaires) plus sample "B" (76 completed questionnaires)) can be found in Table 2.3.

Table 2.3 - Demographic characteristics for combined sample data

Demographic characteristic	Sample Data for combined sample (Sample A and B)
Age	Mean = 45 Median = 41-50 group ; 9% 21-30, 22% 31-40, 24% 41-50, 20% 51-60, 10% 61-70, 15% 70+.
Children	83% yes, 17% no
Gainfully employed	50% yes, 50% no
Gender	61% female, 38% male, 1% data refused
Own property	64% yes, 36% no
Property tax band	Mean = E 1% a, 2% b, 3%c, 32% d, 8% e, 18% f, 14% g, 1% h, unaccounted for data =21%
Education	34% below GCSE/O level, 19% GCSE/O level, 18% A level, 26% degree level, 2% PhD level, 1% data refused.
Property type	97% house with garden, 3% flat with garden
Ethnic origin	89.7% white, 1.9% Black Caribbean, 2.6% Indian, 0.6% Other Asian, 1.9% Black African, 0.6% Chinese, Other 1.9%, unaccounted for data 0.6 %.

2.5.2 The Combined Data Set - Composting and Environmental Behaviour

The overall responses (combining sample A and sample B) to questions of general environmental concern and home composting behaviour can be found in Tables 2.4, 2.5, 2.6 and 2.7. To further understand the role of the individual demographic characteristics on home composting each characteristic was sequentially analysed (Tables 2.8-2.14). A statistical analysis of the results is presented in Appendix 2.

Table 2.4 - Combined sample data (sample A +B) for issues of General Environmental Concern

Characteristic	Combined sample data			
	Number of respondents		Percent	
	Yes	No	Yes	No
Do you think there is pollution in your area	138	17	89%	11%
When asked what and where the pollution was, the respondents who mentioned:				
Air pollution in their answer	87	68	56%	44%
Noise pollution in their answer	22	133	14%	86%
Waste in their answer	44	111	28%	72%
Aircraft in their answer	68	87	44%	56%
Vehicles in their answer	94	61	61%	39%
Do you think recycling can reduce pollution	84	71	54%	46%
How often do you purposely purchase recycled materials	23 none of the time 123 some of the time 9 all of the time		15% 79% 6%	
Average number of materials recycled	2.36			
Percent of respondents who recycle paper	114	41	74%	26%
Percent of respondents who recycle glass	100	55	65%	35%
Percent of respondents who recycle cans	61	94	39%	61%
Percent of respondents who recycle textiles	51	104	33%	67%
Percent of respondents who recycle aluminium	33	122	21%	79%
Would you be prepared to separate your waste for recycling	135	20	87%	13%

Table 2.5 - Combined sample data (sample A + B) for composting behaviour

Characteristic	Combined sample data	
	Number of respondents	Percent
Heard of compost/composting	122 yes 33 no	79% 21%
Heard of home composting	105 yes 50 no	68% 32%
Participate in home composting	60 yes 95 no	39% 61%

The respondents who indicated that they had heard of home composting (whether participating or not) were asked to indicate what they thought the main benefits of home composting were. Respondents were asked a closed question in which they were asked to rank three options in terms of what they considered to be the main benefits. Not all respondents to the questionnaire completed this question. 85.7% of respondents completed the question. The data presented (Table 2.6) are based on those responses.

Likewise, respondents who had heard of home composting were asked to indicate what they thought the main inconveniences of composting were. The question format was the same as that for the question concerning benefits of home composting, however, the respondents were asked to rank five possible inconveniences. Again, not all respondents completed this question. 83.8% of respondents completed this question. The data presented (Table 2.7) are based on the completed responses to questions.

The reasons why these questions were relatively poorly answered are not clear. Perhaps the respondents were unclear about the question. They may not have understood some of the terms in the question, the question may have been badly worded, they may not have understood how to answer this question, or they may have found the question too complex to complete. Because many returned questionnaires had ticks in the boxes rather than a ranking number, it can be postulated that many people did not understand how to complete questions of this type rather than mis-understanding the context of the question.

Table 2.6 - Benefits of composting according to respondents who had heard of home composting

Ranking of benefit	**Reducing the amount of household waste**		**Production of a compost which can be used as a soil improver**		**Personal satisfaction**	
	Number of respondents	**Percent**	**Number of respondents**	**Percent**	**Number of respondents**	**Percent**
First	43	47.8%	43	47.8%	4	4.4%
Second	32	35.6%	36	40.0%	22	24.4%
Third	15	16.7%	11	12.2%	64	71.1%

Table 2.7 - Inconveniences of composting according to the respondents who had heard of home composting

Ranking of inconvenience	Obtaining a composting Unit		Time required to compost		Cost of purchasing a unit		Unpleasant odours or pests		The space required to site a composter	
	Number of respondents	Percent	Number of respondents	Percent	Number of respondents	Percent	Number of respondents	Percent	Number of respondents	Percent
First	10	11.4%	6	6.8%	28	31.8%	24	27.3%	18	20.5%
Second	25	28.4%	14	15.9%	17	19.3%	17	19.3%	13	14.8%
Third	16	18.2%	25	28.4%	24	27.3%	7	8.0%	14	15.9%
Fourth	18	20.5%	21	23.9%	14	15.9%	20	22.7%	13	14.8%
Fifth	17	19.3%	20	22.7%	3	3.4%	18	20.5%	28	31.8%

2.3% of respondents indicated that they did not think there were any inconveniences with composting

2.5.3 The Influence of Individual Demographic Characteristics on the Extent of Composting

To assess the influence of individual demographic characteristics on the extent of home composting, each demographic characteristic was considered in detail. Figures 2.2-2.8 (Tabled data are presented as Tables 2.8-2.14 in Appendix 3) show the percentage of respondents from the combined data set (sample A and sample B) who (i) had heard of the phrase/practice of composting, (ii) had heard of home composting and (iii) participated in home composting.

2.5.4 A Comparison of Sample A and Sample B

To analyse if home composting is dependent on sample area the responses were categorised according to the two sample areas (of collection). The two sets of data - sample A and sample B - were analysed for key demographic variables (Table 2.15), issues of general environmental concern (Table 2.16) and home composting behaviour (Table 2.17).

Figure 2.2 - Influence of home ownership on composting

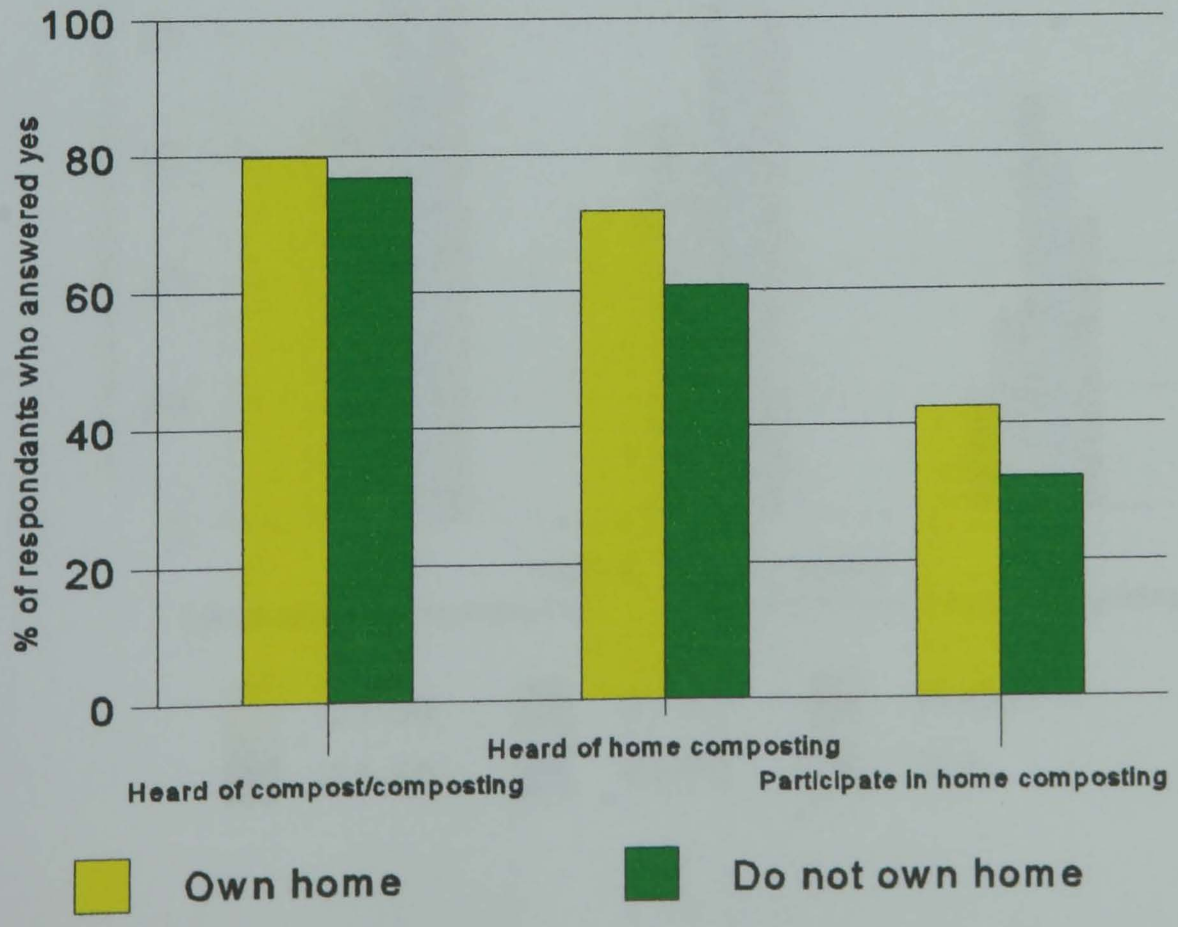

Figure 2.3 - Influence of children on composting behaviour

Figure 2.4 - Influence of age on composting

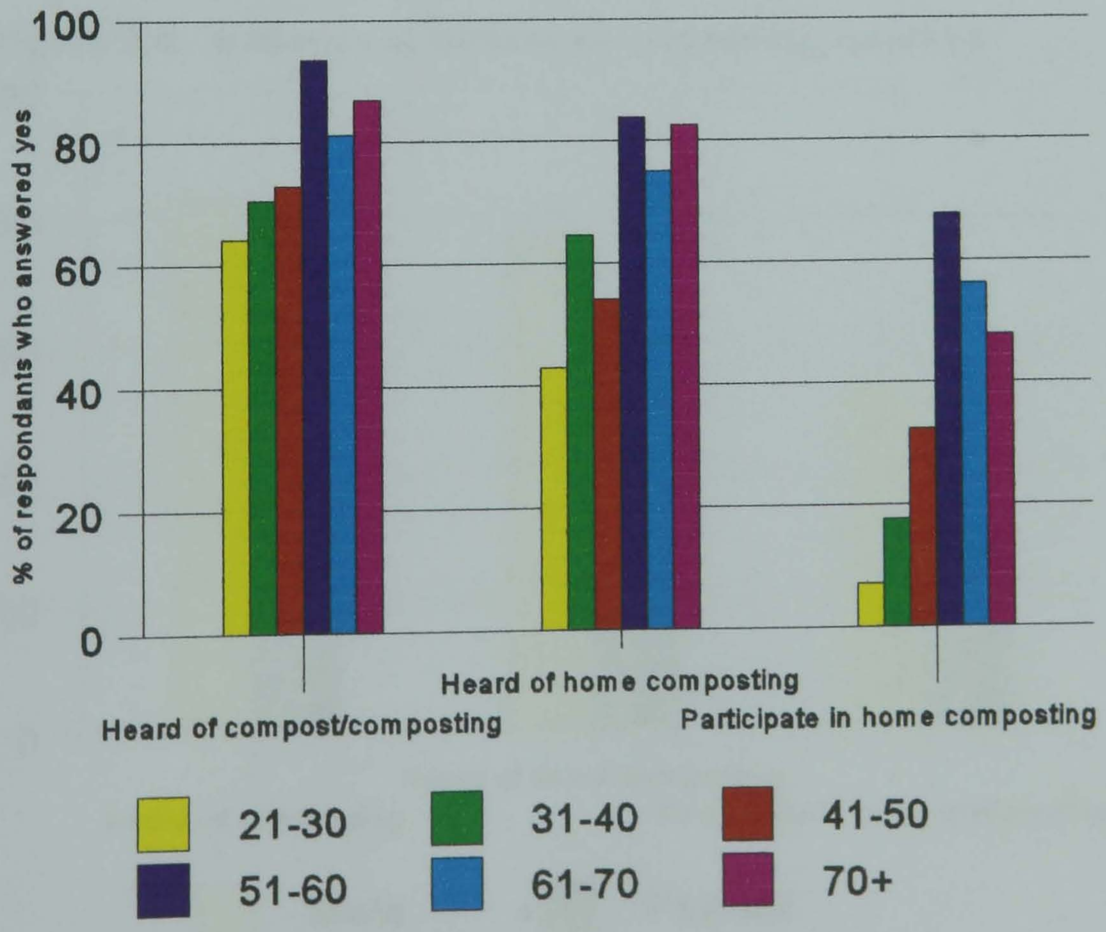

Figure 2.5 - Influence of council (property) tax band on composting behaviour

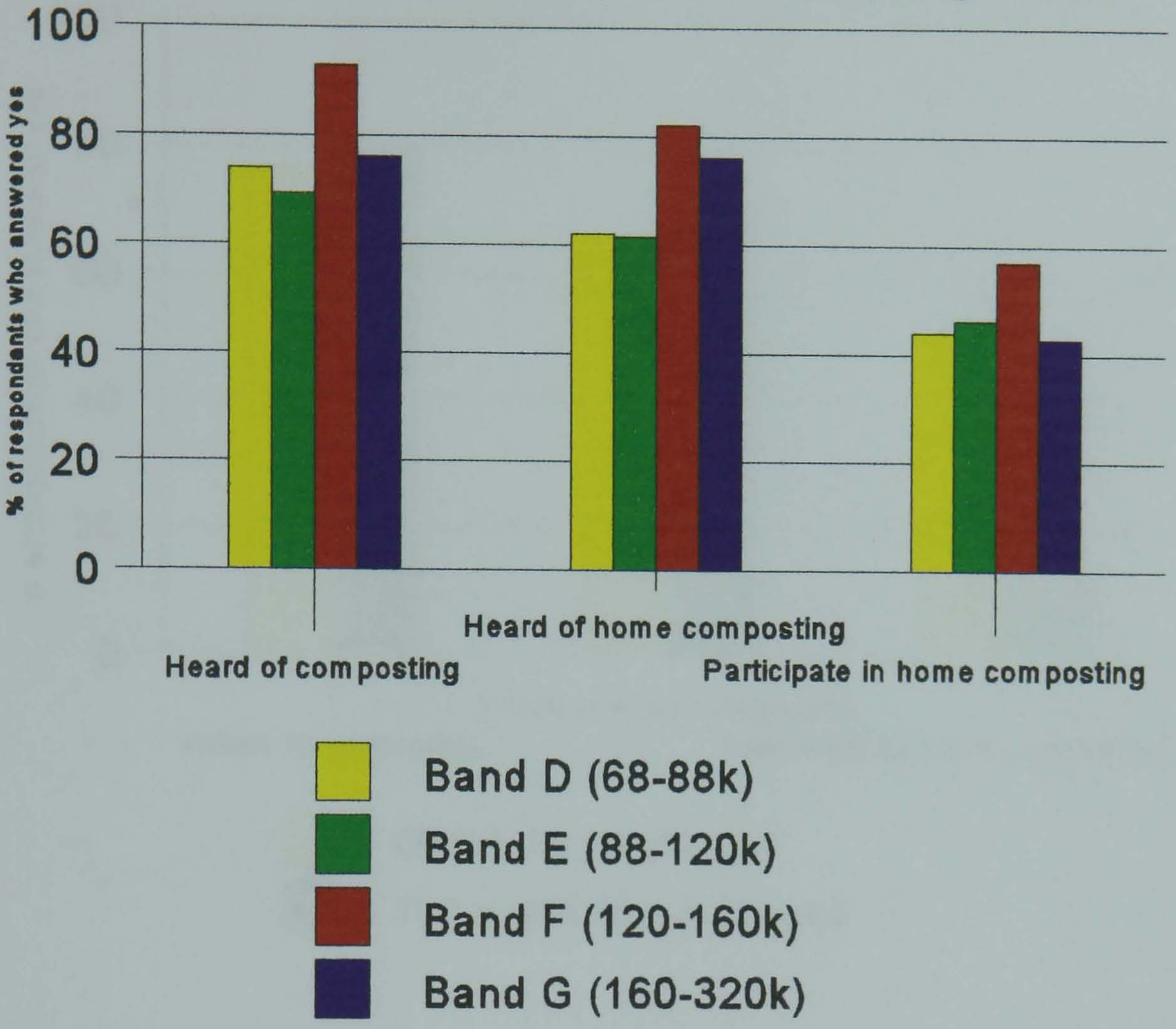

Figure 2.6 - Influence of Gender on composting behaviour

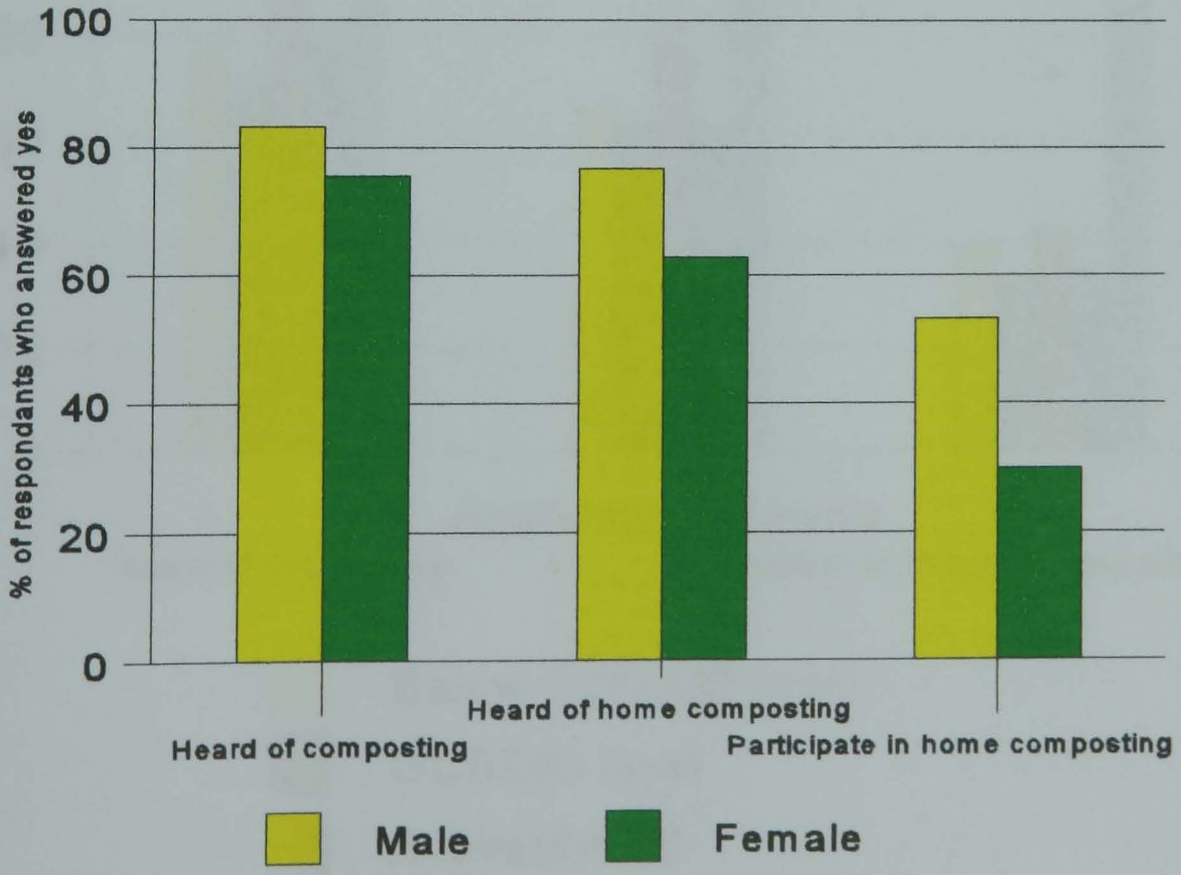

Figure 2.7 - Influence of Gainful employment on composting behaviour

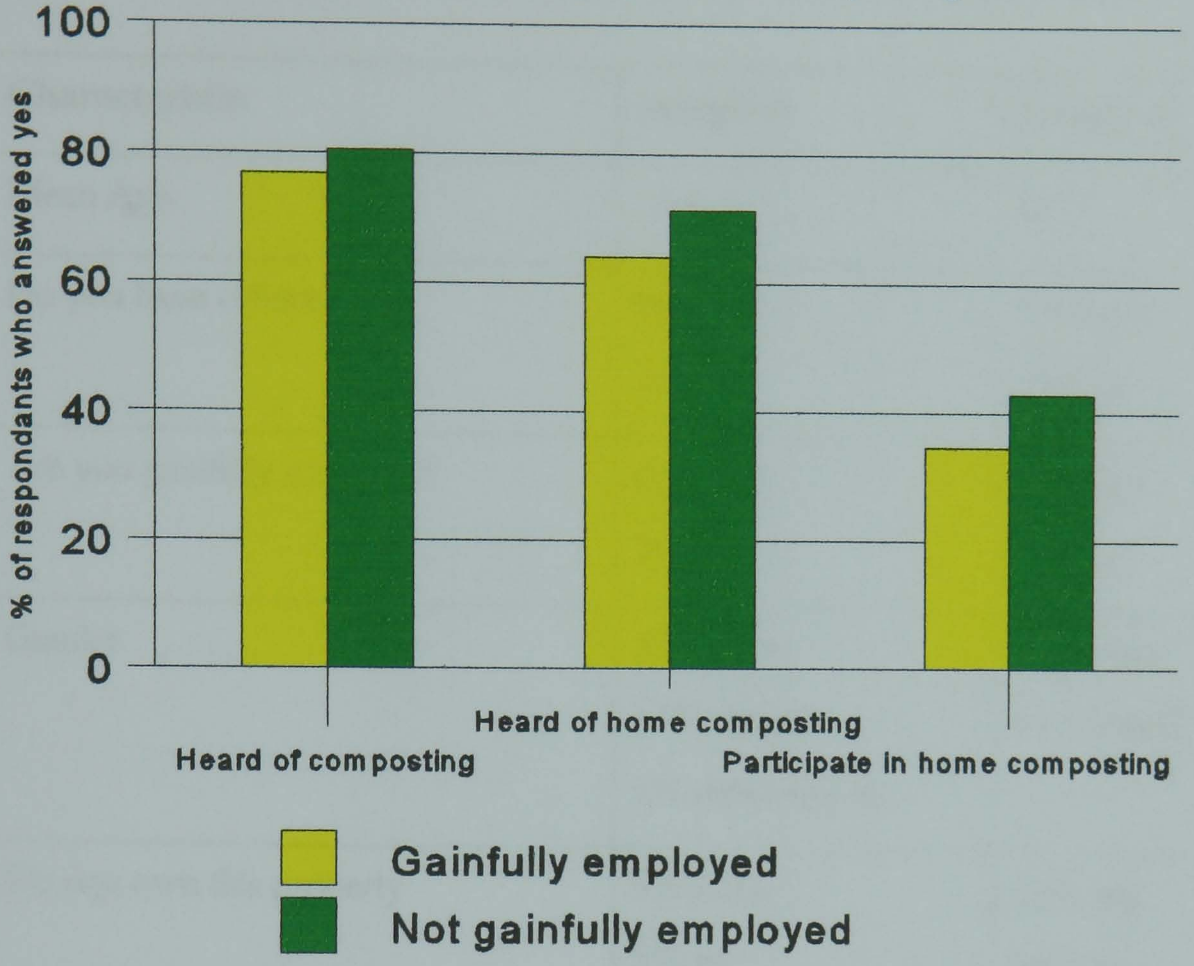

Figure 2.8 - Influence of education on composting behaviour

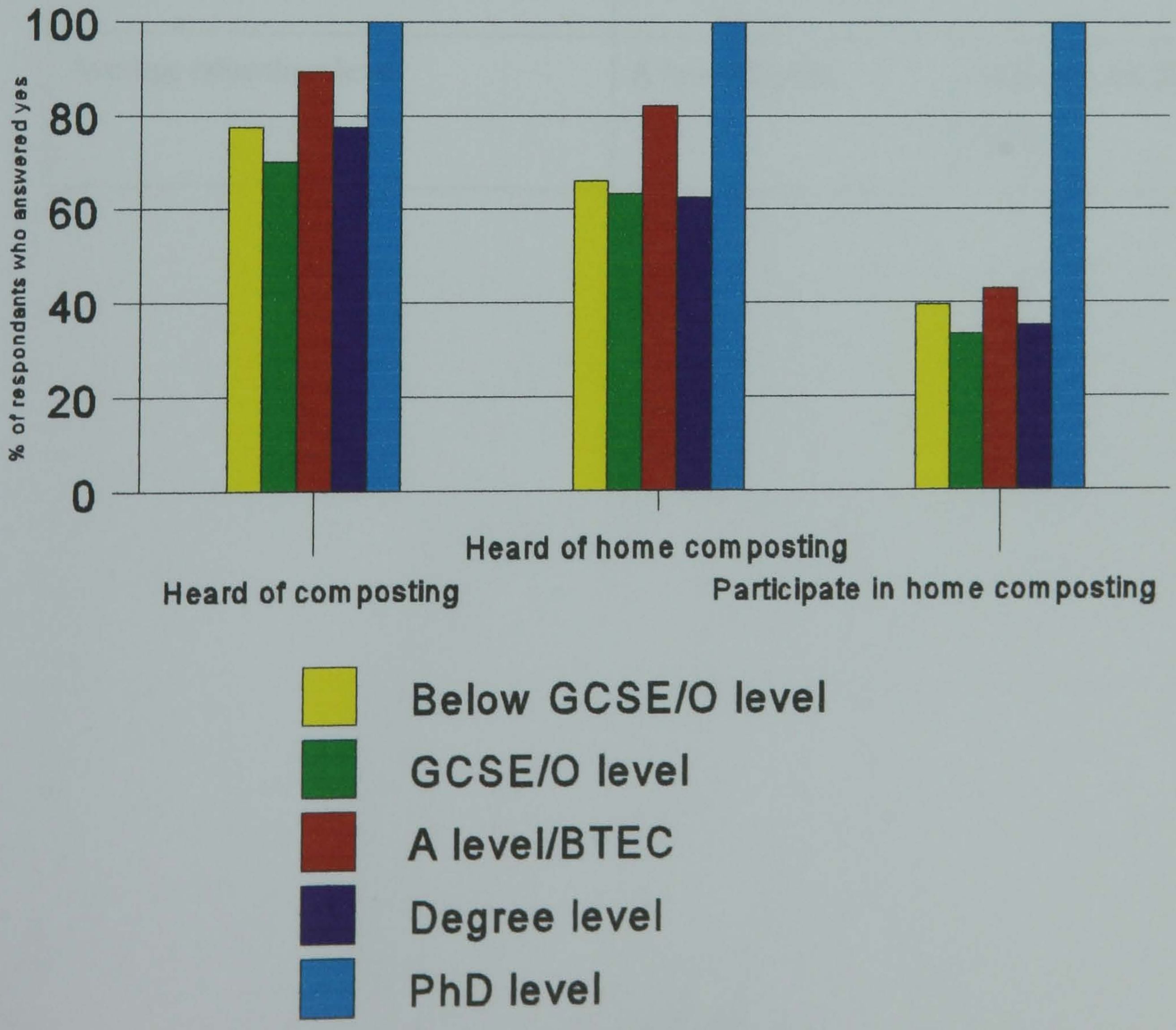

Table 2.15 - A comparison of the demographic characteristics of Sample A and B

Characteristic	**Sample A**	**Sample B**
Mean Age	44.6	44.5
Do you have children	86% yes 14% no	79% yes 21% no
Are you gainfully employed	66% yes 34% no	34% yes 66% no
Gender	38% male 61% female 1% data refused	39% male 61% female
Do you own this property	92% yes 8% no	34% yes 66% no
Average property tax band (1=a,2=b....8=h)	F	D
Average education level	A level-degree	Less than GCSE-GCSE

Table 2.16 - Comparison of sample A and B for issues of General Environmental Concern

Characteristic	Sample A		Sample B	
	Yes	No	Yes	No
Do you think there is pollution in your area	95%	5%	83%	17%
When asked what and where the pollution was, the respondents who mentioned:				
Air pollution in their answer	63%	37%	49%	51%
Noise pollution in their answer	25%	75%	3%	97%
Waste in their answer	39%	61%	17%	83%
Aircraft in their answer	67%	33%	20%	80%
Vehicles in their answer	77%	23%	43%	57%
Do you think recycling can reduce pollution	53%	47%	55%	45%
How often do you purposely purchase recycled materials	16.5% never 75.9% some of time 7.6% all of time		13.2% never 82.9% some of time 3.9 % all of time	
Average number of materials recycled	2.97		1.71	
Percent of respondents who recycle paper	82%	18%	64%	36%
Percent of respondents who recycle glass	82%	18%	46%	54%
Percent of respondents who recycle cans	44%	56%	34%	66%
Percent of respondents who recycle textiles	51%	49%	13%	87%
Percent of respondents who recycle aluminium	29%	71%	13%	87%
Would you be prepared to separate your waste for recycling	93%	7%	80%	20%

Table 2.17 - Comparison of sample A and B on issues of composting

Characteristic	**Sample A**	**Sample B**
Heard of compost/composting	82% yes 18% no	75% yes 25% no
Heard of home composting	72% yes 28% no	63% yes 37% no
Participate in home composting	42% yes 58% no	36% yes 64% no

2.5.4.1 A comparison of Sample A and B in Terms of the Benefits and Inconveniences of Composting

The respondents who indicated that they had heard of home composting were asked to indicate what they thought were the main benefits of home composting. Respondents were asked a closed question in which they were asked to rank three options in terms of what they considered to be the main benefits. Not all respondents to the questionnaire completed this question. 86.0% of respondents in sample A completed this question and in sample B 85.4% of respondents completed the question. The data presented (Table 2.18) are based on these responses.

Likewise, respondents who had heard of home composting were asked to indicate what they thought were the main inconveniences of composting. The question format was the same as that for the question concerning benefits of home composting, however, the respondents were asked to rank five possible inconveniences. Again, not all respondents completed this question. 82.5% of respondents in sample A completed this question and 86.4% of respondents in sample B completed this question. The data presented (Table 2.19) are based on the responses to completed questions.

Table 2.18 - Perceived benefits of composting based on level of affluence

Ranking of benefit	Reducing the amount of household waste		Production of a compost which can be used as a soil improver		Personal satisfaction	
	Sample A	Sample B	Sample A	Sample B	Sample A	Sample B
First	55.1%	39.0%	42.9%	53.7%	2.0%	7.3%
Second	32.7%	39.0%	46.9%	31.7%	20.4%	29.3%
Third	12.2%	22.0%	10.2%	14.6%	77.6%	63.4%

2.5.5 A Comparison of Composters and Non-composters

Composters and non-composters were compared in terms of their demographic characteristics, general environmental concerns and the way they perceive composting. Tables 2.20, 2.21, 2.22 and 2.23 contain the data for demographic characteristics, general environmental concern, benefits of home composting and inconveniences of home composting respectively.

To try to identify any similarities or differences in the way people who compost and people who do not compost differ in their views on composting, all the respondents who had heard of composting, regardless of whether they participated in home composting, were asked what they considered were the benefits and inconveniences of composting. In a closed question they were asked to rank three benefits of composting and five inconveniences in order of most to least important to them. Not all respondents answered these questions.

Table 2.19 - Perceived inconveniences of composting based on level of affluence

Ranking of inconvenience	Obtaining a composting Unit		Time required to Compost		Cost of purchasing a unit		Unpleasant odours or pests		The space required to site a composter	
	Sample A	Sample B	Sample A	Sample B	Sample A	Sample B	Sample A	Sample B	Sample A	Sample B
First	6.4%	17.1%	6.4%	7.3%	38.3%	24.4%	19.1%	36.6%	27.7%	12.2%
Second	36.2%	19.5%	8.5%	24.4%	23.4%	14.6%	19.1%	19.5%	10.6%	19.5%
Third	23.4%	12.2%	36.2%	19.5%	17.0%	39.0%	6.4%	9.8%	14.9%	17.1%
Fourth	12.8%	29.3%	25.5%	22.0%	17.0%	14.6%	23.4%	22.0%	19.1%	9.8%
Fifth	19.1%	19.5%	21.3%	24.4%	2.1%	4.9%	29.8%	9.8%	25.5%	39.0%

2.1% of respondents in the affluent and 2.4% of respondents in the less affluent areas indicated that they did not think there were any inconveniences in composting.

Table 2.20 - Demographic Characteristics of composters and non-composters

Characteristic	Composters	Non-composters
Mean Age (years)	50.7	40.6
Do you have children	82% yes 18% no	83% yes 17% no
Are you gainfully employed	45% yes 55% no	54% yes 46% no
Gender	53% male 47% female	30% male 70% female
Do you own this property	70% yes 30% no	60% yes 40% no
Average property tax band (1=a, 2=b.....8=h)	E	E
Average education level	GCSE/0 level - A level/BTEC	GCSE/0 level - A level/BTEC

Table 2.21 - Comparison of composters and non-composters on issues of general environmental concern

Characteristic	Composters		Non-composters	
	Yes	No	Yes	No
Do you think there is pollution in your area	93%	7%	86%	14%
When asked what and where the pollution was, the respondents who mentioned:				
Air pollution in their answer	67%	33%	49%	51%
Noise pollution in their answer	20%	80%	11%	89%
Waste in their answer	23%	77%	32%	68%
Aircraft in their answer	55%	45%	37%	63%
Vehicles in their answer	65%	35%	58%	42%
Do you think recycling can reduce pollution	73%	27%	42%	58%
How often purposely purchase recycled materials	13.3% never 78.3% some of time 8.3% all of time		15.8% never 80.0% some of time 4.2% all of time	
Average number of materials recycled	2.80		2.07	
Percent of respondents who recycle paper	83%	17%	67%	33%
Percent of respondents who recycle glass	75%	25%	58%	42%
Percent of respondents who recycle cans	55%	45%	29%	71%
Percent of respondents who recycle textiles	38%	62%	29%	71%
Percent of respondents who recycle aluminium	22%	78%	21%	79%
Would you be prepared to separate waste for recycling	93%	7%	83%	17%

Of the people eligible to answer this question, 57.1% participated in home composting and 42.9% had heard of home composting (but did not participate). Of this group, 85.7% answered the question on benefits of composting, and 83.8% answered the question on inconveniences of composting. Breaking this down further for the question concerning benefits of home composting, 90.0% of those who participated in home composting and 80.0% of those who had heard of home composting (but did not participate) completed the question. Similarly, for the question on inconveniences, 88.3% of those who participated in home composting and 77.8% of those who had heard of home composting (but did not participate) completed the question. All data presented in tables 6.22 and 6.23 are based on completed answers to these questions.

Table 2.22 - Perceived benefits of composting by participants and non-participants

Ranking of benefit	**Reducing the amount of household waste**		**Production of a compost which can be used as a soil improver**		**Personal satisfaction**	
	HHC	**PHC**	**HHC**	**PHC**	**HHC**	**PHC**
First	52.8%	44.4%	44.4%	50.0%	2.8%	5.6%
Second	36.1%	35.2%	38.9%	40.7%	25.0%	24.1%
Third	11.1%	20.4%	16.7%	9.3%	72.2%	70.4%

HHC = Those respondents who had heard of home composting, but do not participate.

PHC = Those respondents who had heard of home composting and consequently do participate.

Table 2.23 - Perceived inconveniences of composting by participants and non-participants

Ranking of inconvenience	Obtaining a composting unit		Time required to compost		Cost of purchasing a unit		Unpleasant odours or pests		The space required to site a composter	
	HHC	PHC	HHC	PHC	HHC	PHC	HHC	PHC	HHC	PHC
First	11.4%	11.3%	5.7%	7.5%	17.1%	41.5%	31.4%	24.5%	34.3%	11.3%
Second	20.0%	34.0%	22.9%	11.3%	22.9%	17.0%	25.7%	15.1%	8.6%	18.9%
Third	17.1%	18.9%	20.0%	34.0%	34.3%	22.6%	14.3%	3.8%	14.3%	17.0%
Fourth	22.9%	18.9%	22.9%	24.5%	20.0%	13.2%	17.1%	26.4%	17.1%	13.2%
Fifth	28.6%	13.2%	28.6%	18.9%	5.7%	1.9%	11.4%	26.4%	25.7%	35.8%

HHC = Those respondents who had heard of home composting, but do not participate.

PHC = Those respondents who had heard of home composting and do participate.

3.8% of the respondents who participated in home composting did not think that there were any inconveniences.

0% of the respondents who had heard of home composting but did not participate thought that there where no inconveniences.

2.6 DISCUSSION

The results have been statistically analysed using the independent t-test (Appendix 2) which allows sample means to be compared. It uses the concept of probability to indicate if the sample means are significantly different or if this difference can be attributed to chance. The discussion which follows will, in part, use the t-test data when interpreting the questionnaire results to decide how significant the differences in the data are.

2.6.1 The Combined Data Set

It can be seen from Table 2.5 that despite 79% of respondents having heard of compost or composting and 68% of respondents having heard of home composting that only 39% of respondents participated in home composting. This means that approximately half of those respondents who had heard of composting were actually participating in home composting. When these figures are compared to data from a similar survey carried out on recycling activities in the borough these figures are slightly higher than the value quoted for composting (33% of households with a garden). Reasons for the slightly higher participation level may be because respondents had a property with a garden, which helps promote composting awareness, and that composters may have been more willing to complete and return the questionnaire than non-composters.

When the people who had heard of home composting (and/or participated) were asked to rank what they considered to be the main benefits of composting (Table 2.6) the same number of respondents (47.8%) ranked reducing the amount of household waste and production of a compost which can be used as a soil improver as their first benefit. However, only 4.4% of respondents ranked personal satisfaction as their first benefit. These data clearly show that personal satisfaction is not a driving force for participating in home composting, but respondents are equally divided as to the main benefit of home composting.

Overall, the cost of purchasing a compost unit is perceived as the main inconvenience with home composting. 31.8% of respondents ranked it as their first inconvenience and only 3.4% of respondents ranking it as their least inconvenience. In contrast, the time required to compost is not considered to be a major inconvenience and only 6.8% of respondents chose this as their first inconvenience. Respondents seemed to vary in their perception of the inconvenience of space required to compost, unpleasant odours/pests, and obtaining a compost unit.

2.6.2 The Influence of Individual Demographic Characteristics on the Extent of Composting

Before considering any general composting differences between sample area A and B it is important to establish the effect of each individual demographic characteristic on composting.

It can be seen from Figure 2.2 that home ownership is important to composting. In this study the findings suggest home owners had a slightly higher knowledge of composting and home composting, but there was an even larger difference between home owners and non-home owners for participation in home composting (42.4% compared to 32.1%). It could be that home owners are more likely to value the property they live in and take greater care of the property (including garden) than non-home owners. Similarly home owners are more likely to have met the basic needs of life, particularly if they have paid off their mortgage, and have more time to spend on leisure activities (such as composting).

Figure 2.3 illustrates the influence of having children on composting activities. More respondents with children have heard of both composting and home composting, but fewer respondents with children actually home compost. It may be that children have heard of composting through schooling and other social activities and have told their parents about composting, but because of the increased time demands of looking after children the parents do not have the time to compost.

It is apparent from Figure 2.4 that knowledge of composting/home composting and participation in home composting is greatest for the 51-60 age group. For the age groups below this category knowledge of composting/home composting is slightly reduced, but participation is reduced even further. For the age groups above the 51-60 category both composting/home composting knowledge and participation is only slightly reduced. For this age group the physical demands of home composting may be too much. In contrast, the younger age groups may be able to meet the physical demands, but for some reason they do not want to compost. It could be that they choose to spend their time doing other leisure activities, rather than composting.

Figure 2.5 indicates the property tax band data for categories D-G, since the majority of respondents had properties in these bands. It can be seen from the graph that respondents in band F had the highest level of knowledge of composting/home composting and highest level of participation in home composting.

It is clear from Figure 2.6 that gender has an influence on home composting practice. Males have more knowledge of composting/home composting and also have a significantly higher participation rate than females. In many households it is the role of the male to care for the garden (since it is regarded as a physical task) and this may explain why males have more knowledge of composting and a higher participation rate.

The data presented in Figure 2.7 indicate that more people who are not gainfully employed have heard of and participate in home composting. It is likely that the reason for this is the large number of retired respondents who fit into the category of not gainfully employed. Figure 2.4 indicated that older respondents (aged 51+) are more likely to compost than younger respondents (aged 21-50) and when combined with the data in figure 2.7 this indicates that older people who are retired are more likely to compost.

Figure 2.8 indicates that there is a higher number of composters in the education bracket of A level/BTEC than any other bracket. However, the education bracket of below GCSE/O level contains a higher number of composters than the GCSE/O level bracket. Again it is likely that many older respondents, who are now retired, left school at an earlier age with fewer formal qualifications and these fit into the category of below GCSE/O level education. From the data in Figure 2.8 there is no clear correlation between knowledge of composting/home composting (or participation in composting) and education level.

It can be concluded from the above discussion there are many factors which may influence an individual's decision to compost. The length of time required to practice composting seems to be a theme linked to many of the demographic characteristics, and would appear to be a constraint to composting, but when asked about the time required to compost many respondents thought that time was a minor inconvenience of composting. The importance of time can be seen when you consider that older people (often retired), whose children have probably left home and who are settled in their home, are the type of people most likely to compost.

2.6.3 Comparison of Sample A and Sample B

2.6.3.1 Demographic Characteristics

Comparison of the two sample areas in terms of socioeconomic characteristics (Table 2.15 and Appendix 2), shows that there is a significant difference between the two areas for the characteristics of gainful employment, owning property, property tax band and education. This confirms that the samples which have been used in this study are different in their socio-economic status. However, there is no significant difference between the samples for age, children in the household, or gender. In addition to this, all respondents had access to gardens and the samples could not be discriminated on this variable.

2.6.3.2 General Environmental Concern

Table 2.16 shows that 95% of respondents in sample A thought that they had pollution in their area, compared to 83% of respondents in sample B. When asked what and where this pollution was, responses could be classified into five groups: the mentioning of air pollution, the mentioning of noise pollution, the mentioning of an aspect of waste (litter, rubbish, refuse), the mentioning of aircraft and the mentioning of vehicles. All responses to this question were covered by this classification. The results showed a significant difference between the two areas for the mentioning of noise pollution, waste, aircraft, and vehicles. For example, 25% of respondents in the affluent area mentioned noise pollution compared to only 3% in the less affluent area.

In general the respondents in sample A were more elaborate in their answers, and this may have been due to more pollution in their area compared to the less affluent area. However, different responses could have been due to more concern and knowledge of pollution being expressed by the more affluent respondents. Equally, each individual has their own view of what constitutes pollution and this may differ considerably between sample A and B respondents. Geographically (refer to Figure 2.1), both sample areas are situated directly below the flight path for Heathrow airport and close to a sewage works (the less affluent area is particularly close). Both areas also have a number of schools, colleges, shops and take-away bars nearby and the level of litter is generally high.

There was no significant difference between the two samples for responses to the question "Do you think recycling can reduce pollution in your area?" 53%of affluent respondents and 55% of less affluent respondents thought that recycling could reduce pollution. Many responses suggested that "they did not think recycling could reduce the type of pollution they had in their area", expressing the view that recycling was only good for reducing certain types of pollution. Of the people who did think recycling could reduce pollution, reasons given ranged from resource re-use, less dependence on other waste management practices (i.e. incineration and landfill), and less refuse, to "I don't know why".

When asked how often they purposely purchased recycled materials, the majority of respondents said some of the time. There was no significant difference between the two samples under study and it is doubtful whether people actually *purposely* purchase recycled materials or whether they occasionally *accidentally* purchase recycled materials (because of price or convenience) and consider this as purposely purchasing recycled materials.

Respondents were asked in a closed question what materials, from a list of five of the most popularly recycled materials, they recycled. Out of these five materials on average the respondents in sample A recycled 2.97 materials and the respondents in sample B recycled 1.71 materials. Differences between the two samples in the number of respondents recycling glass, textiles, paper and aluminium was significant. There was no significant difference in the number of respondents recycling cans in the two samples. There could be many reasons for these differences, but one reason cited by many of the respondents (in both areas) was no recycling facilities nearby. Attitudes, knowledge, time etc. could all be reasons which influenced this result.

Differences in attitude to recycling activities are shown by the responses to the question "Would you be prepared to separate your waste into different parts (e.g. kitchen/garden waste and glass/paper/dry waste) to help recycle ?" 93% of the respondents in sample A were prepared to separate their waste to help recycle compared to 80% of respondents in sample B.

2.6.3.3 Composting

82% of respondents in sample A had heard of compost/composting and 72% had heard of home composting (Table 2.17). This compares to 75% and 63% respectively for respondents in sample B. These results indicate a slight difference between samples in knowledge of composting and home composting, although it is not statistically significant.

42% of respondents in sample A and 36% of respondents in sample B participated in home composting. This indicates a slight difference between the two areas, but this is not statistically significant.

When the people who had heard of home composting (and/or participated) were asked to rank what they considered to be the main benefits of composting (Table 2.18), it was clear that personal satisfaction was not a reason for carrying out composting. Only 2.0% of sample A respondents and 7.3% of sample B respondents thought that personal satisfaction was the main (first) benefit. However, there was a difference of opinion between the samples as to the main benefit of composting. 55.1% of respondents in sample A thought that reducing the amount of household waste was the main benefit, compared to 39.0% in sample B. Whereas 42.9% of respondents in sample A thought that production of a compost which could be used as a soil improver was the main benefit, compared to 53.7% in sample B. These data suggest that respondents in sample A are more concerned about household waste and see reducing household waste as more of a priority than producing a soil improver. Their additional concern for household waste may be due to more knowledge of waste and/or their general attitude towards such issues of environmental concern. On the other hand, the less affluent respondents may view production of a compost material for their own use as a valuable product, which is more important to them than reducing household waste. This could be due to the economic implications of being able to use the compost in place of a potentially expensive compost substitute such as peat.

When the people who had heard of home composting (and/or participated) were asked to rank what they considered to be the main inconveniences of composting (Table 2.19), some general trends were noticed. Some trends applied to both areas and some trends were restricted to an individual area. Considering the general trends of both samples first, a major inconvenience for both areas was the cost of purchasing a composting unit. 38.3% of sample A respondents and 24.4% of sample B respondents ranked this the most inconvenient, while only 2.1% of sample B respondents and 4.9% of sample A respondents ranked this the least of the five inconveniences. This suggests that financial motives have an important impact on the way people view home composting. These results endorse many local authority schemes to promote composting by subsidising the cost of purchasing a composting unit. In contrast, time is not seen as a problem for the respondents of either sample area. Only 6.4% of sample A respondents and 7.3% of sample B respondents view time taken as the main inconvenience of composting.

The space required to compost seems to be viewed as either a very major inconvenience or very minor inconvenience by respondents. Very few respondents (44.6% for affluent area and 46.4% for less affluent area) viewed the amount of space required to compost in the three middle categories of inconvenience. The perception of value of using the space for composting may be related to the skill of an individual as a gardener and this may indicate why respondents either value space as a major or minor inconvenience.

In comparing samples A and B, there are a few interesting features concerning inconveniences with composting. The most notable of these is that a higher percentage of sample B respondents (36.6%) regard unpleasant odours or pests as being the main inconvenience compared to 19.1% for sample A respondents. Similarly, 29.8% of sample A respondents consider unpleasant odours or pests as the least of all the inconveniences listed compared to 9.8% of sample B respondents. Obtaining a composting unit is also slightly more of a concern for sample A respondents than affluent respondents.

2.6.4 The Perception of Composters and Non-composters to the Benefits and Inconveniences of Composting

2.6.4.1 Demographic Characteristics

To determine if there were any similarities or differences between people who compost and people who do not compost a number of t-tests were performed (Table 2.20 and Appendix 2). This analysis showed that there was a significant difference in age between composters and non-composters. The mean age of composters was 50.7, compared to 40.6 for non-composters. This result has important implications because it indicates that younger adults are less inclined to engage in home composting than older adults. There was also a significant difference between composters and non-composters for gender. It would appear from the results that males are more inclined to practice home composting than females.

The study showed that there were no significant differences between composters and non-composters for the demographic variables of children, gainful employment, owning their own property, property tax band and education.

The implications of this study are that it would be worthwhile to promote and encourage younger householders to carry out home composting. Young housewives and mothers could easily be targeted through community activities such as playgroups.

2.6.4.2 General Environmental concern

There was no significant difference between composters and non-composters in their opinion of whether there is pollution in their area. Table 2.21 shows that 93% of composters thought there was pollution in their area compared to 86% of non-composters. Nevertheless, it would appear that composters have a higher degree of awareness of pollution (measured by their response to the question of, if there is pollution what is it and where?). There was a significant difference for composters and non-composters in mentioning of air pollution and aircraft in their answers. 67% of composters mentioned air pollution compared to 49% of non-composters and 55% of composters mentioned aircraft compared to 37% of non-composters. It should also be noted that 20% of composters mentioned noise pollution, 23% mentioned waste and 65% mentioned vehicles, compared to 11%, 32% and 58% respectively for non-composters. It could be that composters spend more of their free time outside (especially in their gardens) and this could contribute to their greater awareness of pollution.

There was a significant difference between composters and non-composters in their response to the question, "can recycling reduce pollution?" 73% of composters believed composting could reduce pollution compared to 42% of non-composters. This result suggests that composters view composting as a form of recycling and feel they are contributing to reducing pollution. However, there was no significant difference in how often composters and non-composters purposely purchase recycled materials.

The enhanced attitude to recycling by composters is further emphasised by the number of materials that composters recycle compared to non-composters. On average, composters recycle 2.80 materials compared to 1.66 for non-composters. There were also significant differences for recycling of individual materials. For example, there were significant differences between composters and non-composters for the recycling of paper, glass and cans. There were only slight differences between composters and non-composters for recycling textiles and aluminium.

There was also a significant difference between composters and non-composters in terms of their willingness to separate their waste for recycling purposes. 93% of composters were prepared to separate their waste for recycling compared to 83% of non-composters.

2.6.4.3 Benefits and Inconveniences of Composting

To try to assess if there is any difference in views towards the benefits of composting by composters and non-composters, all respondents who had heard of home composting were asked to indicate what they considered to be the most and least benefits of home composting. From the results (Table 2.22), it can be seen that those respondents who are already home composting view production of a compost which can be used as a soil improver as more of a benefit than reducing the amount of household waste, but those respondents who are not participating in home composting think the opposite. It is also clear from the results that personal satisfaction is not perceived as being an important benefit of home composting by either composters or non-composters. These results could have important implications for any strategy which tries to promote composting, because emphasising the usefulness of the compost product and its value could be an important method in persuading people to start composting. In addition to this, the results presented may also suggest that current composters have taken up composting primarily as a means of producing a cheap soil improver/fertiliser rather than for the environmental benefits, although they also see that it is a means of recycling.

In a similar way to assessing perceived benefits of composting, both composters and non-composters were asked to indicate what they rated as the most and least inconvenience of home composting. Neither composters nor non-composters regarded obtaining a composting unit as a major inconvenience, and this is shown by only 11.4% of non-composters and 11.3% of composters ranking this as the main inconvenience. Similarly, the time required to compost is not regarded by either group as a major inconvenience, with only 5.7% of non-composters and 7.5% of composters ranking this as their main inconvenience. Cost of purchasing a compost unit is viewed as more of a problem by both groups and this can be seen by only 5.7% of non-composters and 1.9% of composters ranking this as the least inconvenience. It would appear that cost is of more concern to those that participate in composting rather than those that do not (shown by 41.5% of composters compared to 17.1% of non-composters stating cost as the main inconvenience of composting). This is an important finding because it shows that cost of a composting unit is not just perceived as a barrier to non-composters in their attempt to start composting, but it is a real issue of concern even to those that do participate.

Unpleasant odours or pests appear to be a big concern for non-composters, with 31.4% putting this as the main inconvenience of composting. In comparison, those that participate in home composting consider unpleasant odours or pests either to be a big inconvenience or comparatively small inconvenience. For example 24.5% of composters see unpleasant odours or pests as the main inconvenience and 26.4% of composters see unpleasant odours or pests as the least inconvenience. These data suggest that unpleasant odours and pests are a real concern to both composters and non-composters alike, but non-composters may overestimate the degree of unpleasantness from odours and pests.

The space required to site a composter appears only to be an issue of concern for non-composters. 34.3% of non-composters, compared to 11.3% of composters view the space required to site the composter as being the main inconvenience. This suggests that there is a mis-conception by non-composters about the amount of space needed for composting. In any strategy to promote composting the space required to compost must be clearly outlined.

2.7 CONCLUSIONS

This study shows that some areas and sectors of the community are more likely to convert organic waste into compost than others. Residents in the less affluent area are less likely to undertake home composting than residents in the affluent area special attention should be focused on such areas. It is likely that the residents in the less affluent areas are more concerned with the basic material needs of life (food, shelter etc.) than issues of environmental concern and consequently it will be more difficult to promote composting in these areas. By helping people in less affluent areas meet their basic needs (e.g. provide food and shelter) it may be possible to promote recycling, but this could be costly. Composting could also be used to meet the basic needs of households by utilising the compost for future production of food such as fruit and vegetables.

Similarly, targeting of specific groups such as young females to increase their awareness may help increase the number of people composting. Alternatively, targeting young children and educating them about composting may help promote composting. These groups could be penetrated through community schemes such as mother and toddler groups and by distributing information/giving presentations in schools. In addition to this the Council could provide funds for the setting up of composting schemes within establishments such as schools (e.g. as part of science lessons) and this will get young children actively involved in composting.

There are some general trends among composters and non-composters as to the perceived benefits and inconveniences of composting. Cost is an important issue for both groups and financial incentives need to be provided. Reduced price compost bins and promoting the savings that can be made through reduced purchasing of alternative materials are important.

Further research into factors influencing why people compost or do not compost and the reasons behind this is needed to decide on the best method for promoting composting. In particular for Boroughs like Hounslow which have a diverse ethnic community, the influence of ethnicity on composting needs to be established.

This study considered two areas within the borough, which only represent a small proportion of the borough. Although the findings of this study are a useful guide, it is essential to know how representative these areas are of the overall borough, and whether the borough is likely to reach the Government's target for 40% of domestic properties with a garden to be composting by the year 2000. Based on this study the Government's target seems achievable for Hounslow, but it is also important to know if the findings of this research can be applied on the larger scale (i.e. country wide).

Home composting schemes rely heavily on householders, for both waste separation and in carrying out composting. In contrast, centralised composting schemes only rely on householders separating their waste, however, if this is not performed correctly it can lead to contamination of the final compost. Chapter three investigates the extent of contamination of composts derived from waste separated by households.

2.8 RECOMMENDATIONS

To improve the level of home composting in the London Borough of Hounslow and to improve the knowledge of residents the following strategy is recommended:

1. Supply all residents in the borough with general information about composting. In particular information on:
    - A) What composting is.
    - B) What materials can be composted, with emphasis on the fact that putrescible materials can be composted.
    - C) How composting relates to recycling and the environment in general.

D) The production of a useful product for use in the garden as a soil improver/fertiliser.

E) The role that the householder needs to play and what it involves.

F) Perceptions of composting to allay some of the fears that the householder may have (e.g. odours/pests).

This information could be supplied through fliers which are included in any council mailouts (e.g. council tax).

2. For those residents not composting give added incentives to start composting. Concerns have been expressed by both non-composters and composters over the cost of composting units and the Council could provide reduced price compost units, as a way forward. In addition to this the council could purchase several composting units and loan them to residents in the borough on a trial basis. This would reduce the initial cost of home composting and allows those people who are unsure about composting to have a try.

3. It is important to target composters as well as non-composters. Composters may not realise the broad spectrum of materials which can be composted. It would therefore be useful to educate existing composters as to what materials they can and cannot compost. This may reduce the amount of waste the Council needs to collect.

4. Since 90% of households in the Borough have a garden, promoting composting amongst keen gardeners could prove a useful tactic. Again, emphasis should be placed on the fact that composting can be used both for garden waste (leaves, cuttings etc.), and for putrescible kitchen waste (food scraps, vegetable peelings etc.), and that a useful gardening product is produced.

5. Composting could be promoted at local community events such as school fetes, parties and other events organised by specific groups in the community. The Council could supply or sponsor a stall and provide expert advice.

6. The Council could establish a step-by-step strategy aimed at meeting the targets set out in "Making Waste Work - A strategy for sustainable waste management in England and Wales". There are many targets for both centralised composting and also home composting which the Government has decided upon. It would be useful if the Council could evaluate how they fare in respect of these targets.

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CHAPTER THREE

A COMPARISON OF PRODUCTS FROM CENTRALISED TREATMENT SCHEMES

3.1 INTRODUCTION

The work described in this chapter compares the solid products from different centralised composting schemes classified as source-separated household waste, source-separated household waste plus 5% chicken manure, and green waste, and compares the solid products from selected anaerobic digestion and composting schemes.

3.2 A COMPARISON OF COMPOSTS FROM DIFFERENT TREATMENT SCHEMES

The quality of compost obtained from Local Authority operated centralised composting facilities which process the organic fraction of household waste is compared. In all cases of household waste compost studied, the organic fraction has been separated by householders through the use of a dual-bin system where the organic material is separated from the waste stream and placed in one bin with the remainder of the waste stream in a second bin. To allow a comparison to be made in terms of quality of compost produced, analysis of compost from Local Authority run composting schemes treating only gardens, parks and civic amenity site waste have also been included in this study.

The research focuses on centralised composting of source-separated organic waste because this represents one of the most recently developed systems for processing the organic fraction of household waste in the UK. In the past, mixed collection of household waste with mechanical separation of the organic waste (either prior to or after composting) has been undertaken, however, problems have often been encountered with the quality of the final compost so mechanical separation is rarely used today. In a 1994 study performed for the Department of the Environment it was concluded that source-separated waste produces a higher quality (and higher value) product than that produced from mechanically separated waste (Department of the Environment/Environment Agency, 1996). Previous experience in the USA and other European countries has also indicated that source-separation significantly reduces the levels of some contaminants, such as heavy metals, in the final compost (Richard and Woodbury, 1992). The move towards the inclusion of a source-separation stage therefore seems to overcome some of the quality problems associated with mechanical separation techniques.

The compost sites chosen for this study were selected because of their location, in the southern part of England, and the range of feedstocks which these operations utilise.

3.2.1 Sampling and Analysis of Compost

A total of seven compost samples were collected for analysis in February 1996. The various origins of these compost samples are listed in Table 3.1.

Table 3.1 – Source of compost samples

Sample	Geographic origin	Technology employed	Feedstock
EH	Hertfordshire	Shredding	Source separated household waste
E	Erewash	Shredding	Source separated household waste+ civic amenity sites
H	Hampshire	Shredding	Gardens, parks + civic amenity sites
ECO	Dorset	Shredding	Gardens, parks + civic amenity sites
C	Croydon	Shredding and size screening	Gardens, parks + civic amenity sites
OG	Oxfordshire	Shredding	Gardens, parks + civic amenity sites
CM	Castle Morpeth	Shredding	Chicken manure (5%) + source separated household waste

After collection each sample was taken to the research laboratory and subjected to a series of physical, chemical and biological tests. The compost samples used in the study were prepared by coning and quartering the bulk material prior to drying the samples at air temperature for three days and sieving to give a particle size of less than 2mm. The physical and chemical tests on the samples were carried out on two samples, in triplicate, and the biological tests in duplicate.

Fractions of three composts (EH, H and ECO) were selected for growing trials after mixing the fractions with soil.

3.2.2 Methodology

Where available, the methods used for analyses were based on those in the Ministry of Agriculture, Fisheries and Food (MAFF) publication "The Analysis of Agricultural Materials".

3.2.2.1 Physical Parameters

Texture/handling and **Colour** was determined visually and through handling the compost samples.

Moisture Content was determined by drying the compost, in triplicate, over night at 105°C in an oven.

Total Foreign Matter was determined by sieving the dried compost through a 5mm sieve and the sieved fraction through a 2mm sieve. Any stones in the >5mm fraction are removed, weighed, and considered foreign matter. Any plastic, metal, glass, rubber and other foreign inorganic matter in the >2mm fraction is removed, weighed and considered foreign matter.

3.2.2.2 Chemical Parameters

Organic Matter was determined by heating a sample of compost to 550°C in a box-type furnace until a stable weight was attained. The change in weight of the compost after heating at 550°C provides a measure of the organic content of the compost.

Total Carbon and Nitrogen were determined through elemental analysis by MEDAC Ltd.

Total Potassium and Phosphorus were determined by Inductively Coupled Plasma (ICP) Atomic Emission Spectroscopy following digestion of the compost samples in a nitric/perchloric acid mixture. The analysis was peformed by MEDAC Ltd.

Total Magnesium, Copper, Nickel, Cadmium, Zinc and Lead were determined using atomic absorption spectroscopy (AAS) following digestion of the compost samples in a nitric/perchloric acid mixture.

Extractable Magnesium was determined by shaking the compost with a 1M ammonium nitrate solution for 30 minutes. The extracted magnesium was measured by atomic absorption spectroscopy and results presented as mg magnesium per kg of compost.

pH was determined by shaking a 10ml compost sample with 25 ml of water for 15 minutes. The pH of the resulting solution was measured using a standardised pH meter.

Conductivity was determined by shaking 20 ml of compost with 50 ml of a saturated calcium sulphate solution at 20°C for 15 minutes. The solution was filtered and the conductivity of the filtrate measured using a conductivity meter.

Extractable Copper, Nickel, Cadmium, Zinc and Lead were determined by shaking 50 ml of 0.05M ammonium EDTA with compost (10ml) for 1 hour. The solutions were filtered and extractable metal levels analysed by atomic absorption spectroscopy. The results are expressed as mg metal extracted per kg of compost.

3.2.2.3 Germination of Lettuce and Growth of Tomato Seedlings

Germination of Lettuce - Two 7 litre plant pots were filled with a selected compost and soil mixture in a 2:1 ratio. A further two pots were filled with soil only, as a control. Twenty seeds of Webbs Wonderful lettuce were placed in a 4 x 5 pattern in each pot. After two weeks the number of seeds germinated was assessed. After eight weeks the lettuce was harvested and dried and the mean shoot dry matter for the best sixteen plants assessed.

Growth of Tomato Seedlings – Two 7 litre plant pots were filled with a selected compost and soil mixture in a 2:1 ratio. A further two pots were filled with soil only, as a control. Three tomato seedlings were planted in each pot and the height of the seedlings measured. The growth in height of the seedlings after eight weeks was recorded and the mean shoot dry matter measured.

3.2.3 Results

For the purposes of data presentation composts of similar origin have been categorised in terms of physical parameters under the headings green waste (H, ECO, C, and OG), source-separated household waste (EH, E) and source-separated household waste with chicken manure (CM) (Table 3.2) and the corresponding chemical data are presented in Table 3.3.

The results of the growth trials on three composts using tomato seedlings (Gourmet F1 Hybrid), and germination of lettuce (Webbs Wonderful), are presented in Tables 3.4 and 3.5 respectively.

The raw data for all results are presented in Appendix 9.

Table 3.2 - Physical Parameters

Criteria	**Source separated household waste (average for two samples)**	**Source separated household waste + 5% chicken manure (one sample)**	**Green waste (average for four samples)**	**Ecolabel criteria for soil improvers**
Texture/ Handling	Coarse organic material	Fine organic material	Medium organic material	no offensive odours
Moisture content (%)	58	32	36	n/a
Total foreign matter (%)	8.8	0	6.3	no glass, wire, metal or plastic which may be a hazard to human health
Colour	Light Brown	Mid Brown	Mid-Dark brown	n/a

Table 3.3 - Chemical Parameters

Criteria	Source separated household waste (average for two samples)	Source separated household waste + 5% chicken manure (one sample)	Green waste (average for four samples)	Ecolabel criteria for soil improvers
Organic matter (%)	36	43	31	not less than 25%
Total Carbon (%)	13.2	24.6	17.3	n/a
Total Nitrogen (%)	1.0	2.3	1.2	n/a
Total Phosphorous (%)	0.29	0.43	0.23	n/a
Total Potassium (%)	0.82	1.37	0.65	n/a
Total Magnesium (%)	0.33	0.34	0.20	n/a
Extractable Magnesium (mg/kg)	496	864	482	n/a
PH	8.3	7.2	8.2	n/a
Conductivity (µS/cm)	4901	8061	4699	n/a
Total metals content (mg/kg)				
- Copper	108	44	70	75
- Nickel	28	23	22	50
- Cadmium	3.1	0.9	1.0	1.5
- Zinc	279	213	251	300
- Lead	142	57	140	140
Extractable metals content (mg/kg)				
- Copper	39	11	28	n/a
- Nickel	3.2	2.5	3.3	n/a
- Cadmium	0.5	1.1	0.6	n/a
- Zinc	111	77	141	n/a
- Lead	80	33	110	n/a

Table 3.4 - Germination of Lettuce

Sample	**Mean percent germination after two weeks (%)**	**Mean shoot dry matter in grams (per pot of 16 lettuce)**
Soil only	70	6.68
EH + soil (2:1 ratio)	60	1.44
H + soil (2:1 ratio)	90	10.08
ECO + soil (2:1 ratio)	95	11.04

Table 3.5 - Growth of Tomato Seedlings

Sample	**Mean per cent increase in plant height (after 8 weeks)(%)**	**Mean shoot dry matter in grams (per pot of 3 tomatoes)**
Soil only	2096	21.42
EH + soil (2:1 ratio)	658	2.68
H + soil (2:1 ratio)	3120	24.24
ECO + soil (2:1 ratio)	1437	3.66

3.2.4 Errors in Sampling and Analysis of Compost

Compost is formed from waste materials and the quality of the compost is directly dependent on the feedstock waste. Waste materials are, by nature, very variable and any compost formed will therefore be heterogeneous. Indeed, the heterogeneity of compost is one of the attractions for users of the material, however, this property also provides a challenge in analysis of such materials.

In addition to the feedstock waste material, other factors which will affect the quality of the compost are the type of compost technology employed, seasonal and geographical fluctations in waste composition, and weather conditions. For these reasons, compost from the same site will differ from batch to batch and there is even likely to be variation within batches. Therefore, compost analysed in this chapter and subsequent chapters was selected by obtaining representative samples of compost from composting sites. Where possible, this was achieved by selecting one batch (windrow) of compost and randomly selecting shovels of compost from the batch. The compost was then transported back to the laboratory where samples were prepared by coning and quartering, before being dried at room temperature. The dry compost particle size was then reduced by crushing the compost with a pestle and mortar and passing it through a 2 mm sieve.

Errors in sampling and analysis of compost material occur mainly as a result of the heterogeneity of the compost, rather than as a result of any methodology or instrumental errors in analysis and this can be seen from the data presented in Appendix 9. For this reason analysis was performed on two samples to check for reproducibility of results. Typically, errors resulting from the heterogeneity of compost are a factor of 10 higher than errors associated with methodology or instruments.

3.2.5 Discussion

3.2.5.1 Physical Parameters

Colour may be regarded as being superficial in terms of compost quality, however, the appearance of a compost is very important and should not be underestimated. Depending on the market use for compost, the need for a contaminant-free material alone may not be enough, but colour too may be very important. This is probably the most significant characteristic if the compost is to be used for landscaping and by the general public.

Any physical contamination which is highly visible like large stones, glass or plastic may also have a detrimental effect on the handling and texture of the compost and this may deter the buyer. From the tabled data (Table 3.2) the average physical contamination levels (foreign matter) for household waste compost is higher than that of green waste compost. This is not surprising because the household waste feedstock relies more on public cooperation in the separation process than does green waste compost (which comes direct from local gardens, parks and civic amenity sites).

Moisture content of composts varies considerably and can depend on the control of the composting process. Previous work (He et al., 1992) has suggested typical values of moisture content for composts of 20-50%. The moisture content of the composts tested in this study however varied from 32% to 58%, with household waste compost having the highest value. This result could be explained by the heterogeneous nature of household waste which makes management of the compost process more complex. The balance of water, nutrients and temperature are therefore much more difficult to control.

3.2.5.2 Chemical Parameters

The chemical characteristics of a compost are very important if the compost is to be used in agriculture, horticulture or for use by the general public. However, for some applications such as landscaping the chemical characteristics are less important.

The nutrient content of carbon, nitrogen, phosphorous, potassium and magnesium are now considered. Carbon is the fundamental element of living systems, and it has been reported (He et al., 1992) that a typical level of carbon in composts is about 30%. The average carbon levels recorded in this study (13.2, 24.6, and 17.3) are slightly below this value, with the lowest value for household waste compost. There is a need to have adequate levels of carbon and organic matter in the compost because the usefulness of the compost as a soil additive will ultimately depend on these parameters.

Nitrogen and phosphorous levels in composts are generally higher than most soils, but these nutrients in composts may not be available to plants (De Haan, 1981). If composts are to be used as growing media then the nitrogen and phosphorous levels need to be high enough to allow a sufficient quantity of nutrients to become available during plant growth. In this study the average nitrogen and phosphorous levels of compost from household waste were 1.0% and 0.29% respectively, compared to 1.2% and 0.23% for green waste compost. This suggests that compost from household waste does contain sufficient quantities of nitrogen and phosphorous for plant growth.

Unlike the other main plant nutrients, the level of potassium in composts has been found to be lower than that in most soils. However, the bioavailability of potassium from compost is known to be greater than from soils (De Haan, 1981). There is only a small difference between the levels of potassium in green waste compost and household waste compost with household waste having slightly more potassium (0.82% compared to 0.65%).

It should be noted that the levels of carbon, nitrogen, phosphorous and potassium are increased by composting a combination of chicken manure and household waste. This is in agreement with a study performed by El Nadi et al. (1995) who found that chicken manure contains more plant nutrients than compost derived from town refuse.

Magnesium is also an essential macronutrient for plants. In the compost samples analysed the levels of magnesium are higher in the household waste composts than green waste composts (0.33% compared to 0.20%). This can only be beneficial for the fertilising characteristics of the household waste compost.

One indicator that has been used to predict compost stability is pH (Mato et al., 1994). During the composting process low molecular weight organic acids are produced which are subsequently converted into the final products (CO_2 and H_2O). Any organic acids remaining in composts will decrease the pH and therefore indicate incomplete composting. In both the household waste and green waste composts, the average pH levels are slightly alkaline (pH 8.3 and 8.2 respectively), suggesting that they are mature.

Conductivity levels of composts is higher than that of most soils. This can pose a problem because a very high conductivity may lead to phytotoxic effects. It has been suggested (Marschner, 1988) that crop damage occurs in plants when the conductivity value of a compost is greater than $8000\mu S\ cm^{-1}$. It can be seen from the present study that the sample of household waste supplemented with chicken manure as a feedstock has a conductivity in excess of this value. This is likely to be due to more non-conducting material such as silica etc. in the household waste compost and the relatively low pH (7.2) of the chicken manure/household waste compost (El Nadi et al., 1995).

Household waste is likely to contain considerable amounts of table salt and this may increase the conductivity of any compost obtained from it. It is therefore essential that if compost derived from household waste is to be used in agriculture, the compost must be mixed with sufficient quantities of soil to prevent too high a concentration of salt accumulating. The high conductivity values may also limit the use of these composts as potting media for seed germination, but with increased environmental pressure and reduced resources of peat new alternative media are needed, but quality is of prime importance.

As with sewage sludge, where heavy metals pose a big problem, high levels of heavy metals in composts may limit their use in agriculture. High levels of heavy metals may cause inhibitory effects on crop growth and there is the potential for transfer through the food chain. This problem is not helped by the composting process which reduces the volume of organic matter and further concentrates the heavy metals (Leita and de Nobili, 1991).

It should be noted that speciation is the major chemical process that determines the bioavailability of any metal. Metals can exist in many different forms each having a different bioavailability, and may not necessarily depend on the total concentration of the metal in the compost. As a guide to the bioavailability of the metal some results for analysis of heavy metals after extraction with ethylenediaminetetra-acetic acid (EDTA) are given. This is a crude method and the results should be treated with caution when trying to relate the data to bioavailability.

Total heavy metal concentrations of the samples analysed showed some variation between samples of similar origin, but this is not as much as expected when compared to other sources (Mato et al., 1994). It is however apparent that compost derived from household waste has comparatively high levels of all the metals analysed (Cu, Ni, Cd, Pb, Zn). These results are comparable to the results of other reported work (Kirchmann & Widen, 1994, Van Roosemalen et al., 1987, and He et al., 1995) on the composting of household waste from other countries. The higher levels of heavy metals in these samples reflect the high degree of foreign matter present. During the composting process considerable amounts of liquid are produced, therefore heavy metals can leach out from the inert materials and contaminate the organic fraction.

If the heavy metal levels of the organic fraction of household waste are compared to composts derived from gardens, parks and civic amenity site waste, then the former has higher heavy metal concentrations. For the composts derived from gardens, parks and civic amenity waste sites, it should be noted that the lead level is almost as high as that of household waste compost. This may be attributed to lead from vehicle emissions.

If heavy metal concentrations for both greenwaste compost and household waste compost are compared to the criteria defined for the award of an ecolabel (refer to Tables 3.2 and 3.3), the greenwaste compost satisfies all the chemical criteria but the household waste compost does not meet the criteria for copper, cadmium and lead. However, both composts contain considerable quantities of foreign matter (plastics, glass, metal etc.) which could prevent them from achieving an ecolabel, but, it should be noted that ecolabels have been designed so that only a "top" 10% of products can achieve them and as such are very stringent.

3.2.6 Conclusions

If compost derived from the source-separated organic fraction of household waste is compared to compost obtained from garden and parks waste the study suggests that a poorer quality compost is obtained from household waste. Nevertheless, if the quality of the composts derived from the source-separated organic fraction of household waste are compared to the 1989 UK code of practice for agricultural use of sewage sludge then for the heavy metals analysed (which are probably the contaminant of most concern in household waste compost) the source-separated composts comply with every limit.

For markets not requiring a particularly high quality compost, the compost from household waste could be used, for example for landscaping, landfill cover, and possibly top soil and sod production where small amounts of physical and chemical contaminants can be tolerated. On the other hand agriculture, horticulture, silviculture, and bagged compost for retail, require a higher quality of compost where nutrients and contamination are critical. However, a lack of consensus on standards governing the quality of compost mean it is difficult to prove that the compost is of a sufficient quality for its final use. The composting development group set up by the Department of the Environment, Transport and Regions (DETR) commented that there are no formal standards for compost or the composting process (DETR, 1998). Several standards could be applied to compost (for example the EU Eco-label for soil improvers) and there are several programmes currently underway, such as those underway by the European Standards Committee (CEN), which will establish consensus values for compost quality.

The quality of composts derived from household waste could be improved either through human or mechanical effort. For source-separation schemes, the quality of the final product is heavily dependent on the co-operation of householders. Good public relations and education of residents is crucial in the success of such schemes. Source separation may also reduce the need for technology later in the process and could reduce the costs of household waste composting projects.

3.3 A COMPARISON OF COMPOSTS AND DIGESTATES FROM DIFFERENT CENTRALISED TREATMENT SCHEMES

The biological and biochemical principles of both composting and anaerobic digestion are well understood and these remain the same regardless of any changes in feedstock or location. However, the strategy for obtaining the waste prior to these treatment processes may depend on feedstock, location, and a number of other variables such as infrastructure and logistics.

The earlier research in this chapter has considered the quality of materials produced if composting was used as the final treatment method. It is the aim of this section to discuss the options for treating the organic fraction of household waste with respect to anaerobic digestion as the final treatment method. It is hoped to draw together some of the similarities and differences between the two approaches based on the quality of the final digestate/compost product.

3.3.1 Strategies Investigated

Four different strategies were investigated for the collection and treatment of organic waste. The strategies have been selected on the basis of potentially achieving a quality product and the economics of the process. All methods were based on collection of household waste by local authorities, although the precise details of the waste stream collected is dependent on the specific method of collection and treatment. Two methods considered composting as the final treatment process while two methods considered anaerobic digestion as the final treatment process.

Method 1 – Source-separation of the organic fraction of household waste followed by composting

The scheme studied in this project involved householders separating the organic fraction of the waste stream at source and the organic waste being composted at a central location. The local authority collects the organic waste and remaining "dry" fraction of the waste stream once every two weeks on alternate weeks. This scheme has an advantage for local authorities because the collection system is already in place and no additional vehicle or staff purchasing costs are required. However, the main drawback of the scheme is the need for a high degree of public cooperation.

The collected waste is subsequently shredded to smaller-sized particles and composted in windrows with regular turning. The final compost product is ready for use after 12 weeks.

Method 2 – Source-separation of the organic fraction of household waste and the addition of chicken manure (5%) before centralised composting

Although the plant chosen for the source of the compost is at a different location to that described above, the basic methodology is the same with the exception of chicken waste being added to the waste stream. This may be advantageous because it can combine the treatment of chicken waste and household waste thereby stabilising both waste streams. In addition to this chicken manure is easily biodegradable (because of a low carbon/nitrogen ratio) and contains more plant nutrients. This may help ensure the correct balance of nutrients during composting and give rise to a higher nutrient content in the final product.

Method 3 - Source-separation of the organic fraction of household waste followed by anaerobic digestion

There is currently a small number of plants in Europe which can process solely the organic fraction of household waste by anaerobic digestion. The system studied in this scheme is based on the DRANCO (DRy ANaerobic COmposting) technology which originates in Belgium. Source-separated vegetable, fruit, garden and paper waste is collected and subsequently homogenized in a drum. The fraction (<40mm) is mixed with digested residue from the digester, heated and pumped into a digester. After 18 days in the digester the material is dewatered to give a solids content of about 50%. The dewatered material is then matured by aerobic composting for a period of about 10 days. Excess water from the process enters a treatment plant next to the site.

Any biogas produced is either used to produce steam for heating or transformed to electricity.

Method 4 - Mixed collection of household waste followed by co-digestion of fines from a DANO drum with sewage sludge (50:50 ratio)

This is an option which has received very little attention and needs to be fully evaluated. In the example studied mixed household waste is collected and is subsequently transported to a landfill site where it enters a DANO drum (which separates the waste according to size). The fines (< 55mm particles) are then transported to the site housing the digester, where they are periodically loaded into a vibrating drum. The fines drop onto a conveyor at a constant rate and the conveyor takes the waste into a small tank containing sewage sludge. Any light fractions (plastic etc.) and any heavy fractions (metal etc.) are screened off. The remaining portion of the waste is fed to a digester where it is treated anaerobically.

This system yields both a biogas product which may be converted to heat and/or electricity and also a solid residue known as a digestate. In addition to these products this system is important for stabilisation of sewage sludge in the light of the ban in 1998 on disposal at sea. By mixing sewage sludge with the organic fraction of household waste this could be a beneficial treatment for both these waste streams.

3.3.2 Analytical Programme

An analytical programme was undertaken with the aim of establishing the quality of products from the four schemes listed in section 3.3.1.

Sampling from each system was performed on two separate occasions (days) where possible. In the case of methods 2 and 3 sampling only took place at one time. On each sampling occasion a number of random samples were collected (20 x 1 litre samples) and these were sorted at the laboratory to obtain a quantity of material on which analysis could take place.

The samples obtained for methods 1, 2 and 3 were the final mature sample, but the sample obtained for method 4 was directly from the digester and before use may require an additional aerobic stage to fully mature.

Each sample was analysed for a number of parameters (as summarised in Tables 3.6 and 3.7). The methods used for analyses were based on those in the Ministry of Agriculture, Fisheries and Food (MAFF) publication "The Analysis of Agricultural Materials".

3.3.3 Analytical Data

Table 3.6 - Physical parameters

Criteria	**Method 1 (EH) compost**	**Method 2 (CM) compost**	**Method 3 (DR) digestate**	**Method 4 (TW) digestate**	**Soil**
Texture/ Handling	Coarse organic material	Fine organic material	Medium organic material	Medium fibrous organic material	Fine material with some organic matter
Moisture content (%)	59.50 after pressing	32.22	53.39 after pressing	2.75 solids*	n/a
Foreign matter - including stones (% of dry matter)	9.97	0	0.70	0.51	21.5
Colour	Light Brown	Mid Brown	Dark Brown	Dark Brown	Light Brown

* sample taken directly from digester, hence this is the solids content of the digester. The final product will be dewatered and have a much higher solids content.

Table 3.7 - Chemical parameters

Criteria	Method 1 (EH) compost	Method 2 (CM) compost	Method 3 (DR) digestate	Method 4 (TW) digestate	Soil
Organic Matter (%)	37.8	42.87	36.29	67.80	10.59
Total Carbon (%)	15.01	24.59	25.57	33.35	3.41
Total Nitrogen (%)	1.14	2.26	1.67	3.48	0.29
Total Phosphorous (%)	0.38	0.43	0.41	0.45	0.31
Total Potassium (%)	0.98	1.37	0.55	1.42	0.52
Total Magnesium (%)	0.265	0.34	0.26	0.30	0.22
Extractable Magnesium (mg/kg)	515	864	539	482	81
PH	7.9	7.19	7.10	7.97 neat	7.18
Conductivity (µS/cm)	5171	8061	4884	7097	2486
Total Metals content (mg/kg)					
- Copper	136	44	58	812	100
- Nickel	32	23	19	12	30
- Cadmium	4.4	0.9	2.8	1.9	0.8
- Zinc	264	213	336	544	172
- Lead	165	57	134	177	286
Extractable metals content (mg/kg)					
- Copper	46	11	20	197	34
- Nickel	3.4	2.5	4.3	3.9	3.3
- Cadmium	0.1	1.1	0.5	0.7	0.5
- Zinc	103	77	171	213	58
- Lead	72	33	80	74	282

3.3.4 Discussion

3.3.4.1 Analytical Data

The physical and chemical parameters considered for this investigation have been chosen because of their direct relationship with the quality of the products. By considering the physical parameters first this will give an outline of some of the basic properties of composts/digestates which are required if these materials are to be used commercially.

The texture/handling of composts and digestates needs to appeal to the user. Large lumps or coarse material may make application of the compost/digestate difficult. Of the four materials analysed only one material was coarse. It may therefore be at least partially possible to control this parameter through the operation of the composting process (e.g.shredding etc.) and through adequate screening at the end of the process to remove any coarse objects in the compost.

A notable difference between composts and digestates is the more fibrous nature of the digestates. If methods 1 and 3 are considered, they have very similar feedstocks and both rely on source-separation schemes, yet the final material is very different in texture. It could be that anaerobic digestion can treat paper waste better then composting and this gives rise to the fibrous texture.

The moisture content of the final product is dependent on the technology employed during the processing of the waste. Thus, it would be expected that anaerobic digestion and composting would yield products with differing moisture contents. Previous research (He et al., 1992) has indicated that moisture contents of composts and digestates are in the range 20-50%. Since anaerobic digestion requires a high amount of liquid input into the process it might be expected that the products would contain higher water contents. However, elaborate dewatering and drying processes (utilising the biogas generated in the process) can dramatically reduce the water content of the final product. The results presented in this investigation suggest that both composting and anaerobic digestion can give rise to a product with a high moisture content (> 50%) and the operation/management of the process can significantly affect this.

Foreign matter in digestates from anaerobic digestion processes is low (0.51% and 0.70% in the examples above) in comparison to the variable results obtained for compost. These results suggest that anaerobic digestion is less capable of dealing with foreign materials (inerts) and as such the separation processes prior to waste entering the digester have been designed to remove the majority of inert material. The intricate pipework and operation of the digester mean any large inerts may block parts of the digester apparatus and prevent it from operating efficiently.

In comparison, composting is more robust to foreign materials. The composting process uses large scale machinery to shred the waste and turn the windrows and this does not appear to be significantly affected by large inert objects. Although the composting process can physically withstand inert fractions in the organic waste, inert material can have a detrimental effect on the quality of the final compost. The longer the physical contaminants remain in contact with the organic material the more likely that chemical contamination of the final product will occur.

Of all the chemical contaminants, heavy metals pose the biggest problem to composts and digestates. A very prominent feature of the results is the high levels of total and extractable heavy metals associated with the co-digested household waste/sewage sludge sample. Total copper, lead and zinc levels are all significantly higher than those levels found in the other compost and anaerobic digestion samples. These high levels may arise because: (1) digested sewage sludge contains high levels of copper, lead and zinc which are of a similar magnitude (Thames Water, personal communication) to the values given for co-digestion of household waste/sewage sludge given in this study. Therefore co-digestion of household waste with sewage sludge is likely to yield a product with elevated levels of these metals. (2) The organic waste which enters the digester is organic material which has been separated from the remainder of the household waste stream *only* after mixed collection of household waste. This means that considerable contamination of the organic fraction with heavy metals has already taken place before the organic waste enters the digester.

If heavy metal levels of digestates and composts from similar feedstocks are compared (methods 1 and 3) then both methods give a product with comparatively high cadmium, zinc and lead levels. It should be noted that as part of the composting and anaerobic digestion processes that heavy metal levels are further concentrated compared to the incoming raw waste, so that if it is intended that composts and digestates from these systems be used in premium applications (e.g. as a peat replacement in potting media) then the high metal content could prove to be a problem.

It would appear that the addition of chicken manure to household waste prior to composting yields a product with lower heavy metal content. It could be that the chicken manure is a cleaner feedstock than household waste and this reduces the metal levels entering the composting process or it could be that the lower physical contamination level of the feedstock to this process yields a lower chemical contamination level.

Conductivity and pH are often interrelated and can pose problems if they are either very high or very low. Conductivity is particularly important if the compost/digestate is to be used as a growing medium, because plant growth is known to be hindered at high conductivity values (>8000µS)(Marschner, 1988). It can be seen from Table 3.7 that conductivity values for all composts and digestates analysed are significantly higher than for a typical soil sample. Indeed, the anaerobic digestion sample (TW) and the compost sample (CM) have conductivity values close to 8000µS. pH values for all the materials are within the expected pH range of 7-8 and should not restrict the use of compost/digestate.

Contaminant levels of composts and digestates are extremely important if the composts/digestates are to be applied to the land and/or used as a growing medium. It is worth noting there is a difference between a compost/digestate being applied to the soil as a conditioner which adds organic material and bulk to the soil, and a compost to be used as a growing medium/fertiliser which adds both organic matter/bulk to the soil and also valuable nutrients. If the compost/digestate is to be used as a growing medium then the nutrient content of the compost/digestate is of equal importance to the contaminant levels. For the use of a compost/digestate as a soil conditioner or growing medium, organic matter is significant. All composts/digestates contain above 30% organic matter (measured by loss on ignition) and this amount is at least three times higher than the amount of organic matter in soil. The level of organic matter in compost/digestates should therefore not limit their use.

The main fertilising properties of composts/digestates, namely carbon, nitrogen, phosphorous, and potassium are all found to varying levels in the composts/digestates analysed. It is evident from the results presented in Table 3.7 that the level of all these major nutrients are comparatively higher in the compost to which chicken manure has been added. This is reflective of the easier breakdown of chicken manure, which releases high levels of these key elements. Similarly, the magnesium level (both total and extractable) is higher in the compost to which chicken manure has been added.

3.3.4.2 Treatment Method

It is evident from the results that the quality of composts/digestates and the degree of contamination varies depending on the collection strategy and treatment method employed. Previous research (Department of Environment/Environment Agency, 1996 and Richard and Woodbury, 1992) suggested that contamination levels for compost derived from mixed household waste (which has undergone mechanical separation to yield an organic fraction) are higher than those of compost from source-separation schemes targeting the organic fraction of the waste stream.

Similarly, it might be expected that a digestate derived from a mixed waste stream would be of a lower quality than a digestate derived from source-separation schemes. This study does not contradict this thought, however, it is not possible to draw firm conclusions because the mixed waste stream considered in this study is co-digested with sewage sludge. As such, the metal content of this digestate is several times higher than in the other schemes considered.

The metal levels of the digestate obtained from the co-digestion of sewage sludge and household waste are no higher than those obtained from sewage sludge on its own (Thames Water, Personal communication), and in fact the addition of household waste to sewage sludge may even reduce the levels of some heavy metals. This could be very significant for the spreading of sludge onto land which is becoming more important as a result of the 1998 ban on disposal of sewage sludge at sea.

The digestate obtained from the source-separated organic fraction of household waste and the compost of a similar origin (methods 1 and 3) are comparable in terms of nutrient content and contaminants. The heavy metal values are generally lower than those typically found for sewage sludge.

Addition of chicken manure to the source-separated fraction of organic waste increases the levels of nutrients and decreases the level of contaminants. However, unfortunately the resulting compost has a very high conductivity level and this could be phytotoxic.

3.3.5 Conclusions

It can be concluded that composting and anaerobic digestion are possible methods for treating the organic fraction of household waste to produce a compost/digestate of value.

Whether anaerobic digestion or composting is used as the treatment method for organic waste, a good source-separation scheme is needed to help reduce contamination and produce a good quality product. In addition to source-separation it may be beneficial to include mechanical separation immediately prior to the waste being treated. A simple screening system based on separating the waste according to size could significantly reduce contamination of the waste, and add only a small cost to the overall treatment.

Co-digestion of the organic fraction of household waste with sewage sludge could be attractive to water companies with large volumes of sewage sludge to dispose of. Combined stabilisation of these two wastes may make both wastes amenable for spreading onto the land. Addition of the organic fraction of household waste to sewage sludge could increase the biogas yields and therefore generate increased amounts of heat and/or electricity.

If the use of compost specifically as a growing medium/fertiliser is required then the addition of chicken manure to the organic fraction of household waste could prove useful. This can produce a compost with higher levels of key nutrients, although the high conductivity level could be problematic.

High levels of heavy metals in compost are a key concern if the compost is to be used on land. Although composts contain heavy metals, the form of the metals in compost is very important because this could indicate how available the metals are and how readily they leach into the land. Chapter four investigates the bioavailability of heavy metals in compost.

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CHAPTER FOUR

HEAVY METALS IN COMPOST - BIOAVAILABILTY AND EXTRACTION

REFERENCES

4.1 INTRODUCTION

There is increasing concern that although it is important to measure the total content of metals in compost, the main parameter which needs to be measured is the bioavailability of these metals to plants, man, and the environment in general. Metal species come in many different chemical forms each with a different bioavailability to plants and each plant species has a different affinity for each of the chemical forms of that metal. It is therefore not easy to assess what the impact and uptake of a particular chemical form will be by a particular plant or by man either directly or through the food chain.

The aim of this chapter is to establish the bioavailability and potential for removal of five different heavy metals from compost derived from the organic fraction of household waste. This is investigated by undertaking a series of single-stage extractions using a variety of extractants.

4.1.1 The Impact of Trace Metals from Compost

All metals exist in the environment in varying forms and concentrations. Composts derived from household or municipal solid waste (MSW) will also contain trace metals, which if added to the environment and in particular soil will increase the level therein of these trace metals. The level of trace metals in compost will depend on a number of factors including the type of waste composted, the amount of contraries (or non-biodegradable material) in the waste, and the collection/separation strategy for the organic waste. Table 4.1 gives typical levels of some metals found in composts, and the average concentration of those metals found in soils in England and Wales.

If organic waste generated by households is applied to the land, either directly or after stabilisation through composting, then the spreading of the waste or compost is controlled by a number of regulations. The disposal of industrial, household and commercial waste is regulated by the Environmental Protection Act 1990 (EPA) and The Environment Act (1995), in conjunction with various specific regulations such as the Collection and Disposal of Waste Regulations 1988 and the waste management licensing regulations 1994. However, wastes covered by these regulations can be applied to land without a licence if the material is applied "for the purpose of fertilising or otherwise beneficially conditioning that land", although notification of spreading must be given to the Environment Agency.

Table 4.1 - Typical concentrations of trace metals found in MSW composts and average concentrations of trace metals found in soils in England and Wales

Metal	Concentrations typically found in compost (mg/kg of dry compost)	Average Concentrations (mean) found in soils in England and Wales (mg/kg dry matter)
Cadmium	0-5	0.8
Cobalt	5-50	-
Copper	50-600	23
Lead	100-400	74
Zinc	150-1000	97

Source: Data for soil reported in a Soil Geochemical Atlas by McGrath and Loveland, 1992.

This table is meant to be a guide to the levels of trace metals found in composts derived from MSW and are typical of most MSW composts produced worldwide.

Guidelines have been set as to what constitutes a fertiliser (i.e. elements essential for plant growth which will become available within three years of application) and what beneficially conditioning the land involves (i.e. long-term physical improvement of the land), although these guidelines are open to judgement.

There are currently no legal requirements set for levels of contaminants or nutrients in composts in the UK. For trace metals (potentially toxic elements), the best guidelines to follow for land application of composts are those described in the Code of Practice for agricultural use of Sewage Sludge (Department of the Environment, 1989). The main provisions of these regulations are to ensure sewage sludge is not applied in excessive quantities to the land resulting in elevated levels of trace metals in soil and to restrict the rate at which sewage sludge is applied to the soil. As such, specific limits have been set for maximum concentrations of metals allowable in soils and rates at which these metals can be applied (Table 4.2).

Copper, cadmium, lead and zinc are among the metals of most concern in compost (Epstein et al., 1992). In the following section the role of these and other metals of concern found in compost is discussed, with particular attention to the possible adverse effects on plants, animals and man.

Table 4.2 - Maximum permissible concentrations of potentially toxic elements in soil after application of sewage sludge to agricultural land and maximum annual rates of addition

Potentially Toxic Element (PTE)	**Maximum permissible concentrations of PTE in soil (mg/kg dry solids)**				**Maximum permissible average annual rate of PTE addition over a 10-year period (kg/ha)**
	pH 5.0-5.5	pH 5.5-6.0	pH 6.0-7.0	pH >7.0	
Zinc	200	250	300	450	15
Copper	80	100	135	200	7.5
Nickel	50	60	75	110	3
Cadmium	3				0.15
Lead	300				15
Mercury	1				0.1
Chromium	400				15 (provisional)
Molybdenum	4				0.2
Selenium	3				0.15
Arsenic	50				0.7
Fluoride	500				20

4.1.1.1 Copper (Cu)

Copper is essential for plants and animals. It is widely distributed in soils and minerals (often as Cu_2S (calcocite) and $CuFeS_2$ (chalcopyrite). In plants, copper is needed as a nutrient, where, depending on the species, it can be used by enzymes and through photosynthesis. Levels of copper in plants are typically in the range of 2-25 micrograms per gram dry weight. Copper deficiency occurs when concentrations are in the range 2-5 micrograms per gram dry weight and copper toxicity occurs at levels above 25 micrograms per gram dry weight. Cases of copper toxicity are common where copper has been used in the form of copper sulphate as a fertiliser or as a fungicide.

Although soil pH only has a small effect on copper availability (Hesse, 1971), extreme acid conditions are more likely to render copper toxic to plants. Generally, copper is held strongly by the organic matter in the soil, and this helps prevent copper build-up in plants although in some cases copper deficiency can result where the soil is highly organic and the copper is held tightly. For soils which are deficient in copper, copper salts can be added to the soil or sprayed onto the crop (Russell, 1973).

In animals, copper deficiency inhibits haemoglobin formation, and ruminants are known to be particularly vulnerable. Copper toxicity has been observed in sheep grazing on land to which a copper fertiliser has been applied (especially where levels of molybdenum are high), although cases of copper toxicity in humans is rare, even after prolonged exposure to high levels of copper in the atmosphere or diet.

4.1.1.2 Cadmium (Cd)

Cadmium is not essential to either plants or animals. It tends to occur widely in the environment in the mineral form as greenockite (CdS), where it is present in very small amounts. Cadmium can be toxic to both plants and animals. However, because zinc normally occurs with cadmium in soil (at a concentration 70-200 times greater than cadmium), any toxicity to plants is likely to result from high zinc concentrations rather than cadmium (Epstein et al., 1992). The ability of the crop to uptake cadmium is also important and depends on the chemical form of the cadmium and the type of crop. Some crops such as lettuce and tobacco are known to accumulate cadmium, and as such are often used to indicate the bioavailabilty of cadmium (Woodbury, 1992).

The level of cadmium in soil in England and Wales has been set at 3 mg/kg. The reason for this is primarily to prevent cadmium entering the food chain, and most plants are able to grow at this concentration.

Cadmium can be toxic to humans and there have been reports of deleterious effects on humans through both ingestion and inhalation of cadmium. Ingestion of large amounts of cadmium has been shown to cause kidney dysfunction in humans and cases of lung cancer and teratogenesis in animals. The classic case of cadmium toxicity in humans comes from the Japanese farm families who grew rice on flooded soils in fields contaminated with mine wastes. Cadmium was concentrated in the rice and then consumed as a major component of the diet of the farm families which resulted in the so-called cadmium disease Itai-itai.

4.1.1.3 Lead (Pb)

Lead is not essential to plants or animals. It occurs in several mineral forms in the environment. It can be found as the carbonate, cerussite, as the sulphide, galena and as the sulphate, angelsite. Although lead can be toxic to plants, many plants can tolerate high levels of lead in the soil because the soil adsorbs the lead strongly.

Lead is of much more concern to humans, particularly when it is ingested and inhaled. About 30% of inhaled lead is absorbed and about 10% of ingested lead is absorbed by the body and only released extremely slowly. There is therefore the potential for lead to accumulate in the body and lead poisoning can result from prolonged exposure to small doses over many years. In areas where the land is contaminated with lead there have been cases of children ingesting the soil and accumulating high amounts of lead in the body. This can result in lead entering the blood stream which can cause neurobehavioural impairment.

4.1.1.4 Zinc (Zn)

Zinc is essential for plants and animals. It is found naturally in the environment in the minerals sphalerite (the sulphide), smithsonite (the carbonate), calamine and hemimorphite (the silicates). An excess of zinc has been shown to have deleterious effects on plants, by restricting growth, suppressing phosphorous uptake and causing leaf chlorosis. Zinc toxicity has been found where there is a combination of high zinc levels and an acidic soil (Epstein et al., 1992). Zinc deficiency can also occur in plants grown on peat soils, and results in decreased nutrient uptake and synthesis of key proteins.

The zinc requirements of animals is related to the levels of other key nutrients and elements present in the diet. Zinc toxicity in humans is rare. One of the reasons for this is because zinc toxicity in plants occurs before reaching concentrations in tissues that could be harmful to humans.

More importantly zinc deficiency is commonly found in humans and there is growing concern that this could be a serious health problem.

4.1.1.5 Cobalt (Co)

Cobalt is essential to animals, although its function in plants is unknown. It is a relatively rare element and is found in minerals and soils as the minerals cobaltite, smaltite and erythrite.

Gastrointestinal absorption of soluble cobalt compounds is estimated at 25%, although most cobalt is excreted within days. High levels of continual exposure may affect lung function in man, and teratogenic effects have also been observed in animals.

In man, cobalt is needed as an integral part of vitamin B_{12}.

4.2 THE AVAILABILITY OF TRACE METALS IN COMPOSTS

Many trace metals are essential to both plants and animals, but excess of a particular metal may cause adverse effects. When a large quantity of trace metal is present in composts (or soils) the metal saturates the specific sites, within the compost, which may hold it in relatively unavailable forms and the metal is held in a more available and accessible form.

Scientists (see Beckett, 1989 for a discussion of the issues) have made efforts to try to predict bioavailability of trace metals by developing extraction techniques designed to segregate each chemical form of a trace metal into a number of chemical classes. Extraction techniques may be classified as: single extractions and multiple phase extractions. In the first category, water or ethylenediaminetetraacetic acid (EDTA) are often used as the extraction agent because water is a very good solvent and EDTA is good at complexing with trace metals which may otherwise be bound to organic material.

In the second category of multiple stage extractions, 2-7 stages are used to extract different metal species. Typically, metal species are characterised as water soluble, exchangeable, complexed, organically bound, solid particulate and residual metal species. These are classifications developed by scientists (Beckett, 1989) to try to simplify and understand the concept of bioavailability.

Some scientists (Petruzzelli et al., 1992) have taken the alternative approach of separating composts into different physically sized fractions. Either single-stage or multiple-stage extractions are then performed on each of the physical fractions which results in an assessment of the total metal concentrations and the species present in each fraction.

A review of the application of single-stage and multiple-stage extractions from MSW derived composts follow.

4.2.1 Chemical Extraction Procedures

4.2.1.1 Water Extraction (Single-Stage)

Water-soluble metal species are potentially the most damaging of all the metal species in compost. However early research (Leita and De Nobili 1991) indicated that the amount of water-soluble trace metals in compost is very small. These workers considered the level of water-extractable metal content with time of composting. They considered four metals cadmium, copper, lead, and zinc and found a considerable variation of the water-extractable metals as the composting process progressed. They attributed their findings to the affinity of metals to bind to humic and non-humic material, the proportions of which changed during the composting process.

4.2.1.2 Multiple-Stage Extractions

Several workers have concentrated on the development of better extraction techniques using different extraction reagents. Other workers have looked at the use of multiple-stage extraction to determine how metal species change during the course of the composting process.

Bourque et al. (1994) considered various sequential extraction media for heavy metals. They used a multiple-stage extraction procedure which used 1M sodium acetate (NaOAc) (pH 8.2), 1M NaOAc (pH 5.0), 0.04M hydroxylamine hydrochloride ($NH_2OH.HCl$), nitric acid/hydrogen peroxide (HNO_3/H_2O_2) mixture and a hydrochloric/nitric/hydrofluoric acid ($HCl/HNO_3/HF$) mixture. It was assumed that as the extraction procedure progresses the availability of metals to the environment decreases. High concentrations of manganese and zinc were found in the extractant from both the 1M sodium acetate (pH5.0) and 0.04M hydroxylamine hydrochloride extractions, suggesting these metals are relatively available in comparison to copper and chromium which were only found in high concentrations in the nitric acid/hydrogen peroxide and hydrochloric/nitric/hydrofluoric acid fractions respectively.

Many of the multiple-stage extraction procedures have been adapted from those used to extract metals from soils and sewage sludges. One of the first extraction procedures used for composts was developed by Garcia et al. (1990) who used calcium chloride ($CaCl_2$) and diethylenetriaminepentaacetic acid (DTPA) to extract metals from compost during stages in the composting process. As the duration of the composting process was extended, the levels of extractable Cu and Zn increased using the DTPA method, whilst the metal levels of all metals studied (Fe, Cu, Mn, Zn, Ni, and Pb) decreased using the $CaCl_2$ method, suggesting that more trace metals were bound to organic compounds than were held on exchange sites. These data were confirmed in a study by Petruzzelli (1989) who discovered that levels of water-soluble trace metals were low and DTPA extracted far greater levels of trace metals.

Canarutto et al. (1991) considered the extractability of trace metals as the time of composting was increased (over a 60 day period) with different extraction reagents; water, nitric acid (HNO_3) and EDTA. They found that water-soluble trace metals decreased with time of composting and in most cases that trace metals in the water-extractable fraction were higher than in the exchangeable fraction (HNO_3). However, EDTA was the most efficient reagent for extracting trace metals. After 60 days composting, the total amount of trace metals extracted by the three reagents decreased considerably and it was postulated that this was due to complexation of the metals with humified organic compounds.

He et al. (1995) using a number of compost samples extracted trace metals into various fractions: water-soluble, exchangeable (1M potassium chloride (KCl)), complexed (0.1M sodium pyrophosphate ($Na_4P_2O_7$)), organically bound (0.1M sodium hydroxide (NaOH)), mineral particulate (4M HNO_3), and residue. The use of both $Na_4P_2O_7$ and NaOH placed more emphasis on the organically-bound metals. It was concluded that the elements extracted by water, KCl, and $Na_4P_2O_7$ are labile and potentially bioavailable, but the elements extracted by the other fractions are immobile trace elements.

As part of their study it was discovered that in the $Na_4P_2O_7$ and NaOH extracts (which are known to remove organic matter from the compost) trace metal distribution in the fulvic and humic acid fractions was dependent on the individual metal and on the compost. In summary the main conclusions drawn from the study were as follows: more Cu and Cr were recovered in the humic acid fraction than in the fulvic acid fraction, whilst more Mn, Ni, and Zn remained in the fulvic acid fraction than in the humic acid fraction, and distribution of Cd and Pb depended on the extractant used.

In contrast, Canarutto et al. (1991) and Petruzzelli et al. (1980) found that most Cd, Cr, Cu, Ni, Pb, and Zn in compost which was extracted by 0.5M NaOH was found in the fulvic acid fraction. He et al. (1995) believe that these differences maybe a function of the; different composts studied, the differences in the sequence of extractants used, and the concentration of NaOH extactant used.

This brief overview of the approaches used to predict the bioavailability of trace metals in compost, shows that no one extraction method is used as a standard test.

The aim of the current work therefore is to use a selection of reagents to determine how bioavailable trace metals are in compost derived from household waste, and the extent to which extractants could be used to remove metals from compost.

4.3 EXPERIMENTAL

In the current study various extractants were investigated to assess their ability of extracting trace metals from compost. The bioavailability of the trace metals in compost was examined, and the potential for chemical extractants to remove the available metals from compost, tested.

4.3.1 Source Compost and Compost Preparation

The compost used for this study was supplied by East Hertfordshire District Council. The Council, along with North Hertfordshire District council, undertakes a separate collection of organic waste (garden and household) from 1,200 households within the district and all organic waste collected within the districts is composted on a local farm. The composting process takes 12 weeks in total, with the compost being turned on regular occasions to ensure an adequate supply of oxygen. After 12 weeks the compost is fully matured and is screened through a 10mm screen before being ready for use.

Eight 50kg plastic bags of compost were collected from the site. These bags were filled by randomly selecting shovels of compost from a matured windrow (pile) of compost. The compost was transported to the laboratory where samples were prepared by coning and quartering, before being dried at room temperature. The dry compost particle size was then reduced by crushing the compost with a pestle and mortar and passing it through a 2mm sieve.

4.3.2 Analytical Techniques

Compost samples were analysed for metals using a Perkin-Elmer 2380 atomic-absorption spectrophotometer (AAS). All experiments were performed in duplicate and for the extraction experiments both sets of data are shown. The results recorded using the AAS are the average of three readings. Standard concentrations of metal solutions, used to calibrate the instrument and blanks (samples without the analyte) were run with each batch analysed, to test for contamination. In some cases matrix interferences were checked by spiking a known amount of solution with a known amount of metal.

4.3.3 Methodology

A number of extractants were selected, on the basis of their reported use (Beckett, 1989) in extraction studies on soil, sewage sludge and composts. The following extractants were used to extract available metals from compost:

a) Distilled water

b) KCl (1M)

c) Acetic Acid (Distilled Water adjusted to pH 5 with 0.5M Acetic Acid)[1]

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[1] Distilled Water was shaken with compost for 15 minutes. The pH was then adjusted to pH 5 with 0.5M Acetic Acid. The pH was monitored after 1, 3, 6 and 22 hours and controlled (using 0.5M Acetic Acid) at pH 5 ± 0.2 throughout the experiment.

d) Acetic Acid (0.5-3.0M neat)

The following extractants were tested for their ability to extract, characterise and remove metals from compost:

a) Sodium Hydroxide (0.01-1.0M)
b) Sodium Pyrophosphate (0.01-0.10M)
c) Nitric Acid (0.25-6M)
d) Ethylenediaminetetra-acetic acid (EDTA) at pH 5 (0.001-0.05M)
e) Sodium Carbonate (0.1-0.5M)

For both the bioavailability and removal studies, each extractant (100ml) was shaken with compost (10g) at various extractant concentrations for 24 hours. This gave a constant 1:10 w/v ratio of compost:extractant. The resulting suspension was centrifuged for 30 minutes at 3000rpm using a MSE Centaur 1 centrifuge and filtered through a Whatman number 40 filter paper. Using AAS, the filtrate was analysed for the metals cadmium, copper, cobalt, lead and zinc. The residue remaining after extraction was digested with a 1:4 perchloric acid/ nitric acid solution. Compost samples (2.5 grams) were digested by a perchloric acid/nitric acid solution (25 ml) overnight. The following day the mixture was heated to 200°C until oxidation of the mixture was complete. The temperature was then further increased to 240°C to volatilise all the perchloric acid. After cooling 6M hydrochloric acid (10 ml) was added to the residue and the mixture boiled gently for 5 minutes. The solution was filtered, diluted and analysed by AAS. Analysis of the residue should give the total metal content remaining in the compost.

To test the re-usability of various extractants, experiments were set up to treat three separate batches of compost in succession with a single batch of extractant. Initially 100ml of extractant was shaken for 24 hours with 10 g of dry compost. The extractant was then removed by centrifugation and filtration and a small amount of extractant was separated for metal analysis. 55ml of the extractant was then used on 5.5g of fresh compost and the procedure repeated. Finally 30ml of the extractant from this extraction was used on 3g of fresh compost. Throughout the experiment the compost to extractant ratio was constantly maintained at 1:10.

Three different extractants were tested; EDTA at pH 5, sodium pyrophosphate, and nitric acid. All experiments were performed in duplicate and both sets of results are shown. The results expressed are the average of three readings taken by the atomic-absorption sepectrophotometer.

4.3.3.1 Leaching Studies on Compost

The study on the removal of metals from compost was extended to investigate metal removal using a column packed with compost. For each selected extractant a column of compost was prepared and an extractant was passed through the column to mimic removal of metals from a compost windrow. The column had a diameter of 5 cm and length 30 cm and was fitted with a sintered glass filter and tap at the bottom. Dry compost (of <2mm, 100 g) was placed in the column, packing to half the column length, and the extractant (1 litre) was run through the column, keeping the compost saturated with extractant throughout. The flow rate of extractant through the column was controlled by the tap at the botttom of the column and 100ml aliquots of leachate were collected consecutively. It should be noted that some of the extractant was absorbed by the dry compost.

Typical concentrations of **total** metals in the compost have been determined and these (expressed as mg metal per kg dry compost) are: copper, 80; cobalt, 13.5; zinc, 270; lead, 170; cadmium, 1.85.

Various extractants were tested for their ability to remove metals from the compost. The concentrations of metals in each 100 ml extract were determined by AAS and the average concentration of metals from these extracts calculated. The average concentration of metals leached from the column of compost has been converted to mg metal per kg dry compost to allow the percentage of total metal extracted by the column of compost to be expressed.

4.4 RESULTS AND DISCUSSION

The results otained on the extraction of metals from compost are discussed under three separate headings *viz:* a) bioavailability of metals, b) extraction studies for the removal of metals, c) column studies for the removal of metals from compost

4.4.1 Bioavailability of Metals

4.4.1.1 Water Extraction

Several extractants have been selected in an effort to predict the bioavailability of metals in compost. The metal species of most concern are those that are water-soluble. The repeated water extraction results are outlined in Table 4.3. A preliminary investigation showed (Table 4.3) that only low levels of metal were extracted by water after a single 24-hour extraction. Hence, four consecutive 24-hour extractions of metals from compost were performed using 100 ml of fresh distilled water on one batch (10g) of compost. The results show that between 4 and 23% of the total metals in compost are water-soluble (over a 96 hour period), but it should be noted that after each subsequent extraction further metal was leached.

Table 4.3 – Extraction of metals from compost by water

Extraction number (24 hour intervals)	Copper (percent in sample extracted)	Cobalt (percent in sample extracted)	Zinc (percent in sample extracted)	Lead (percent in sample extracted)	Cadmium (percent in sample extracted)
1	1%	0%	1%	2%	8%
2	2%	4%	1%	2%	6%
3	2%	4%	1%	1%	4%
4	3%	7%	1%	1%	5%

4.4.1.2 KCl Extraction

Simple salts are often used to predict "exchangeable" metals in materials. "Exchangeable" metals are said to be those metals that are held by electrostatic forces on negatively-charged sites on the surface of a material (such as compost). If the compost is shaken with an extractant containing cations (e.g. potassium or calcium) then these cations are assumed to displace the metals in the compost. As with the water extractions, it was found that only a small percentage of the total metals in compost were extracted by 1M KCl after one 24-

hour extraction, therefore four consecutive 24-hour extractions with 1M KCl (100 ml) were performed using fresh 1M KCl (100 ml) on one batch of compost (10g). The results, presented in Table 4.4, show that up to 32% of metal is extracted by KCl over a 96 hour period. Again as more extractions are performed on the compost, more metals are released from the compost.

Table 4.4 – Extraction of metals from compost by KCl

Extraction number (24 hour intervals)	Copper (percent in sample extracted)	Cobalt (percent in sample extracted)	Zinc (percent in sample extracted)	Lead (percent in sample extracted)	Cadmium (percent in sample extracted)
1	2%	0	1%	0	12%
2	3%	0	1%	0	7%
3	4%	0	1%	0	5%
4	2%	0	1%	1%	8%

4.4.1.3 Acetic Acid (0.5M) and Water Extraction at pH 5

Acetic acid controlled at specific pH by buffering has been documented (Beckett, 1989) as a well known extractant to predict bioavailability of metals. Because of the weakly acidic properties of the acetic acid leach, the oxides, hydroxides and carbonates of many of the metals will dissolve as hydrated metal ions e.g. $Zn(H_2O)_6^{2+}$ as possibly hydroxide complexes, $Cd(OH)^+$, but in the case of lead, in particular the species responsible for ease of dissolution in the leach is the triacetatoplumbate (II) ion, $Pb(CH_3CO_2)_3^-$ (Grimes et al. , 1995). Lead compounds are generally very insoluble at natural pH values except in the presence of acetate. Indeed, one of the weaknesses of the acetic acid leach is that it over-emphasises the potential bioavailablility of lead. The results presented in Table 4.5, were obtained under conditions where the extractant medium was maintained at pH 5 using acetic acid to adjust the pH of distilled water. It can be seen that extraction levels for cadmium and cobalt are greater than 20%, but for copper, lead and zinc levels of only a few percent were achieved.

Table 4.5 – Extraction of metals from compost by acetic acid (0.5M) and water at pH5

Sample	Copper (percent in sample extracted)	Cobalt (percent in sample extracted)	Zinc (percent in sample extracted)	Lead (percent in sample extracted)	Cadmium (percent in sample extracted)
1	1%	13%	1%	2%	20%
2	3%	29%	1%	2%	22%

4.4.1.4 Acetic Acid

Acetic acid solutions of different concentrations (0.5-3.0M) without pH control were tested for their ability to extract metals from compost. It can be seen from Table 4.6 that the higher the concentration of acetic acid the greater the overall extraction of metal from the compost. For each of the metals analysed the maximum amount extracted in a single extraction was 5% copper, 30% cobalt, 32% zinc, 15% lead and 48% cadmium.

Table 4.6 – Extraction of metals from compost by acetic acid

Concentration of Acetic Acid	Sample	Copper (percent in sample extracted)	Cobalt (percent in sample extracted)	Zinc (percent in sample extracted)	Lead (percent in sample extracted)	Cadmium (percent in sample extracted)
0.5M	1	3%	14%	15%	6%	33%
	2	3%	13%	13%	4%	25%
1.0M	1	3%	20%	20%	5%	42%
	2	3%	24%	22%	7%	43%
3.0M	1	5%	30%	32%	15%	41%
	2	4%	27%	31%	14%	48%

4.4.2 Extraction Studies for Removal of Metals from Compost

If compost was to be continually applied to soil as a conditioner/fertiliser in a similar way to manure or sewage sludge, then over time there could be a build-up of metals. In the same way, if compost was to be used as the sole growing medium for plants/vegetables, then over time there could be an increase in the concentration of metals in these crops. It may be possible to reduce the build-up of metals by extracting metals from compost before applying the compost to land or growing crops and therefore reduce the levels of metals being applied.

Typically 50% of compost is made up of organic matter, which over time will decompose and subsequently reduce the level of organic matter. If, as is likely, the metals in compost are associated with the organic matter then as this decomposes more metals will be released and become available.

The following discussion will consider the potential metal removal capability of various extractants. It was assumed that many of the metals in compost would be associated with the organic fraction and the extractants chosen were based on their potential ability to extract metals from organic matter.

4.4.2.1 Sodium Hydroxide

Sodium hydroxide is a well known extractant to remove organically bound metals. It is thought that sodium hydroxide mobilises the organic matter from the remainder of the matrix and in doing so it manages to transfer the metals with it. It can be seen from the results in Table 4.7 that for copper, cobalt, and lead that increase in sodium hydroxide concentration from 0.01 to 0.10M increases the amount of metal extracted. It is noted for copper, cobalt, zinc and lead that any further increase in concentration to 1.0M is not reflected as a corresponding increase in metal removed with maximum amounts of metal extracted being 29%, 8%, 1% and 7% for copper, cobalt, zinc and lead respectively. With extraction of cadmium, a level of approximately 30% is achieved under all these sodium hydroxide extraction concentrations.

Table 4.7 – Extraction of metals from compost by sodium hydroxide

Concentration of NaOH	Sample	Copper (percent in sample extracted)	Cobalt (percent in sample extracted)	Zinc (percent in sample extracted)	Lead (percent in sample extracted)	Cadmium (percent in sample extracted)
0.01M	1	5%	1%	1%	1%	23%
	2	5%	0%	1%	1%	29%
0.10M	1	25%	6%	1%	7%	28%
	2	26%	7%	1%	7%	31%
1.0M	1	25%	8%	1%	7%	21%
	2	29%	8%	1%	5%	29%

4.4.2.2 Sodium Pyrophosphate

Sodium pyrophosphate has been used in a similar way to sodium hydroxide for removal of metals bound to or associated with organic matter. Again the precise mode of action of sodium pyrophosphate is not known. It is assumed that sodium pyrophosphate like sodium hydroxide, mobilises the organic matter and hence the metals associated with the organic matter or it could be that the sodium pyrophosphate forms complexes with the metals which are stronger than their existing complexes.

Table 4.8 shows the results obtained during extraction experiments at different concentrations of sodium pyrophosphate. Once again, for all metals studied, maximum metal removal occurs as the concentration is increased up to 0.05M but any further increase in concentration of sodium pyrophosphate does not significantly increase the levels of metal extracted. The maximum amount of metals extracted by sodium pyrophosphate were 30% copper, 20% cobalt, 47% zinc, 19% lead and 29% cadmium.

Table 4.8 – Extraction of metals from compost by sodium pyrophosphate

Concentration of sodium pyrophosphate	Sample	Copper (percent in sample extracted)	Cobalt (percent in sample extracted)	Zinc (percent in sample extracted)	Lead (percent in sample extracted)	Cadmium (percent in sample extracted)
0.01M	1	15%	13%	9%	4%	5%
	2	11%	13%	9%	4%	9%
0.05M	1	28%	12%	42%	14%	25%
	2	30%	20%	44%	19%	29%
0.10M	1	30%	16%	47%	12%	29%
	2	29%	10%	46%	18%	26%

4.4.2.3 Nitric Acid

Nitric acid has been used as an extractant in many different concentrations and has been used to predict a whole host of metal species ranging from those metals that are bioavailable to the total amount of metals in a material (Beckett, 1989). It is assumed that nitric acid can dissolve groups of compounds, such as sulphides, which are difficult to extract with other reagents. Table 4.9 shows the percentage of metals extracted, by nitric acid at various concentrations. In general, the quantity of metal extracted does seem to increase with increasing acid concentration up to a concentration of 3M, beyond which any change in levels extracted is marginal. Furthermore, it should also be pointed out that there are significant differences in the amounts of metal extracted under the same acid concentrations between the individual metals. For example at a concentration of 3M the maximum amounts of metals extracted are 45% copper, 44% cobalt, 78% zinc, 83% lead and 95% cadmium.

Table 4.9 – Extraction of metals from compost by nitric acid

Concentration of nitric acid	Sample	Copper (percent in sample extracted)	Cobalt (percent in sample extracted)	Zinc (percent in sample extracted)	Lead (percent in sample extracted)	Cadmium (percent in sample extracted)
0.25M	1	3%	29%	32%	9%	45%
	2	3%	27%	32%	10%	31%
0.50M	1	10%	37%	51%	44%	65%
	2	11%	37%	50%	41%	54%
0.75M	1	21%	40%	52%	73%	67%
	2	20%	34%	53%	70%	67%
1M	1	25%	36%	66%	64%	86%
	2	22%	37%	75%	67%	91%
3M	1	45%	44%	72%	71%	95%
	2	45%	39%	78%	83%	92%
6M	1	53%	34%	74%	80%	93%
	2	51%	44%	73%	69%	95%

4.4.2.4 EDTA

EDTA is one of the most commonly used extractants because it has been shown to extract a wide variety of metal species (Beckett, 1989) and is a well known complexing agent. The solubility of metals in EDTA is pH-dependent and for most metals the solubility is greatest at around pH 5. Table 4.10 shows the percentage of metals extracted with EDTA at pH 5 (controlled by addition of ammonia). For most metals, an increase in concentration of EDTA, causes a slight increase in the amounts of metals extracted, with the maximum quantities of metals extracted at a concentration of 0.05M being 34% copper, 22% cobalt, 49% zinc, 59% lead and 30% cadmium.

Table 4.10 – Extraction of metals from compost by EDTA

Concentration of EDTA	Sample	Copper (percent in sample extracted)	Cobalt (percent in sample extracted)	Zinc (percent in sample extracted)	Lead (percent in sample extracted)	Cadmium (percent in sample extracted)
0.001M	1	7%	10%	33%	34%	26%
	2	6%	7%	31%	31%	21%
0.005M	1	19%	7%	42%	35%	30%
	2	23%	13%	41%	46%	32%
0.01M	1	20%	14%	40%	50%	24%
	2	24%	12%	43%	51%	37%
0.025M	1	28%	15%	41%	52%	34%
	2	29%	16%	43%	54%	35%
0.05M	1	34%	22%	49%	56%	30%
	2	34%	20%	49%	59%	29%

4.4.2.5 Sodium Carbonate

Sodium carbonate produces a weak alkaline solution which has been used as an extractant for metals. Table 4.11 presents the extraction data for sodium carbonate extractions at different concentrations of sodium carbonate. The maximum amounts of metals extracted by sodium carbonate at a concentration of 0.1M are 37% copper, 12% cobalt, 13% zinc, 7% lead, and 18% cadmium.

Table 4.11 – Extraction of metals from compost by sodium carbonate

Concentration of sodium carbonate	Sample	Copper (percent in sample extracted)	Cobalt (percent in sample extracted)	Zinc (percent in sample extracted)	Lead (percent in sample extracted)	Cadmium (percent in sample extracted)
0.1M	1	37%	12%	13%	7%	18%
	2	26%	10%	11%	6%	12%
0.5M	1	24%	14%	6%	5%	3%
	2	50%	5%	8%	8%	11%

4.4.2.6 The Re-usability of the Best Extractants

The extractants chosen for the re-usability study were EDTA, sodium pyrophosphate, and nitric acid, since these extractants proved most successful in the single extraction experiments.

4.4.2.6.1 EDTA Extraction at pH 5 (Adjusted by Ammonia)

Tables 4.12, 4.13, and 4.14 present the results of metal extraction following re-use of EDTA at different concentrations. In all cases the EDTA, after being used three times, continues to extract some metals from compost. As the concentration of EDTA is increased, higher levels of the metals in the compost are removed.

Table 4.12 – Re-use of 0.001M EDTA in extracting metals from compost

Sample	Extraction Number*	Copper Extracted (mg/l)	Cobalt Extracted (mg/l)	Zinc Extracted (mg/l)	Lead Extracted (mg/l)	Cadmium Extracted (mg/l)
1	1	0.410	0.029	8.12	4.09	0.050
	2	0.529	0.148	14.66	7.82	0.083
	3	0.618	0.217	19.76	9.98	0.117
2	1	0.412	0.070	8.00	3.99	0.045
	2	0.555	0.148	15.10	7.71	0.080
	3	0.469	0.212	16.88	9.87	0.107

* Each extraction was carried out for 24 hours and continued from the previous extraction

Table 4.13 – Re-use of 0.005M EDTA in extracting metals from compost

Sample	Extraction Number*	Copper Extracted (mg/l)	Cobalt Extracted (mg/l)	Zinc Extracted (mg/l)	Lead Extracted (mg/l)	Cadmium Extracted (mg/l)
1	1	0.945	0.109	9.58	6.87	0.050
	2	1.569	0.193	18.50	13.18	0.094
	3	1.628	0.318	26.24	18.06	0.136
2	1	0.931	0.141	10.10	6.69	0.051
	2	1.497	0.218	19.32	12.72	0.092
	3	1.618	0.368	25.78	17.51	0.130

* Each extraction was carried out for 24 hours and continued from the previous extraction

Table 4.14 – Re-use of 0.05M EDTA in extracting metals from compost

Sample	Extraction Number*	Copper Extracted (mg/l)	Cobalt Extracted (mg/l)	Zinc Extracted (mg/l)	Lead Extracted (mg/l)	Cadmium Extracted (mg/l)
1	1	3.835	0.231	12.12	9.92	0.073
	2	5.480	0.378	20.72	15.68	0.115
	3	6.910	0.467	29.12	22.64	0.151
2	1	2.658	0.213	11.36	9.77	0.070
	2	5.875	0.465	27.08	21.64	0.148
	3	6.687	0.481	37.82	23.85	0.176

* Each extraction was carried out for 24 hours and continued from the previous extraction

4.4.2.6.2 Sodium Pyrophosphate

The results of re-using sodium pyrophosphate at concentration of 0.05M are given in Table 4.15. Although the sodium pyrophosphate successfully removes more metal after two cycles, in the third cycle of re-use with some metals, such as zinc and lead, there is evidence that the compost re-adsorbs the metal. Repeated use of sodium pyrophosphate above two cycles would therefore be difficult.

Table 4.15 – Re-use of 0.05M Sodium Pyrophosphate in extracting metals from compost

Sample	Extraction Number*	Copper Extracted (mg/l)	Cobalt Extracted (mg/l)	Zinc Extracted (mg/l)	Lead Extracted (mg/l)	Cadmium Extracted (mg/l)
1	1	2.625	0.192	9.32	2.14	0.006
	2	5.019	0.389	13.72	1.87	0.012
	3	5.639	0.489	12.24	2.03	0.017
2	1	2.627	0.219	9.98	2.05	0.008
	2	9.777	0.378	13.80	1.84	0.007
	3	9.540	0.548	11.38	1.67	0.015

* Each extraction was carried out for 24 hours and continued from the previous extraction

4.4.2.6.3 Nitric Acid Extraction

The results for the re-use of nitric acid at two different concentrations (0.5M and 3M) are illustrated in T\ables 4.16 and 4.17. At a concentration of 3M the nitric acid can be re-used successfully up to three cycles, however at the lower concentration of 0.5M all of the metals studied are re-adsorbed by the compost after two or three extractions. This is likely to be due to the change in pH during the extractions and would mean that nitric acid, at a low concentration, is not re-usable as an extractant for removing metals from compost.

Table 4.16 – Re-use of 0.5M nitric acid in extracting metals from compost

Sample	Extraction Number*	pH	Copper Extracted (mg/l)	Cobalt Extracted (mg/l)	Zinc Extracted (mg/l)	Lead Extracted (mg/l)	Cadmium Extracted (mg/l)
1	1	1.24	0.873	0.532	15.52	13.71	0.125
	2	5.20	0.321	0.670	6.88	1.22	0.136
	3	5.43	0.279	0.600	0.68	1.06	0.129
2	1	1.24	0.868	0.487	17.68	8.77	0.128
	2	5.12	0.344	0.677	6.08	1.09	0.137
	3	5.34	0.391	0.588	0.74	1.06	0.124

* Each extraction was carried out for 24 hours and continued from the previous extraction

Table 4.17 – Re-use of 3M nitric acid in extracting metals from compost

Sample	Extraction Number*	Copper Extracted (mg/l)	Cobalt Extracted (mg/l)	Zinc Extracted (mg/l)	Lead Extracted (mg/l)	Cadmium Extracted (mg/l)
1	1	4.593	0.658	14.96	16.76	0.099
	2	6.970	1.269	32.80	26.67	0.197
	3	9.260	1.596	45.04	31.51	0.285
2	1	4.060	0.591	15.56	12.02	0.107
	2	8.348	1.139	33.72	23.59	0.232
	3	9.364	1.628	46.63	29.65	0.308

* Each extraction was carried out for 24 hours and continued from the previous extraction

4.4.2.7 Optimisation of EDTA

Since EDTA has been shown to be the best extractant during the re-usability studies the effect of pH, compost:extractant ratio and time of extraction was investigated and the results reported

4.4.2.7.1 The Effect of pH on Extraction

The effect of pH of 0.005M EDTA on extraction of metals was investigated by performing experiments at pH 3, 5, 7 and 9. No significant difference in metal extraction (Table 4.18) is observed for the different pH conditions.

Table 4.18 - Extraction of metals from compost with 0.005M EDTA at various pH values

pH value	Sample	Copper (percent extracted)	Cobalt (percent extracted)	Zinc (percent extracted)	Lead (percent extracted)	Cadmium (percent extracted)
3	1	12%	13%	34%	43%	29%
	2	12%	12%	35%	42%	29%
5	1	15%	11%	36%	40%	33%
	2	15%	12%	35%	39%	30%
7	1	15%	12%	37%	38%	29%
	2	14%	11%	35%	39%	30%
9	1	13%	14%	34%	37%	28%
	2	14%	14%	33%	37%	30%

4.4.2.7.2 The Effect of Compost:Extractant Ratio on the Removal of Metals by EDTA

To study the effect of compost:extractant ratio on metal removal, samples of compost in 1:5 and 1:10 ratios were shaken with 0.005M EDTA and the percentage of metal extracted was found to be unaffected by compost:extractant ratio (Table 4.19). At lower compost:extractant ratios, such as 1:1 and 1:2 all the extractant was absorbed by the compost.

Table 4.19 - The effect of compost:extractant ratio on extraction of metals from compost

compost: extractant ratio	Sample	Copper (percent extracted)	Cobalt (percent extracted)	Zinc (percent extracted)	Lead (percent extracted)	Cadmium (percent extracted)
1:10	1	13%	14%	39%	35%	30%
	2	15%	14%	44%	38%	33%
1:5	1	13%	11%	36%	36%	26%
	2	14%	9%	41%	34%	26%

4.4.2.7.3 The Effect of Extraction Time on Removal of Metals by EDTA

To study the effect of length of extraction time with 0.005M EDTA, compost samples were shaken for 2, 4, 6 and 8 hours. The results (Table 4.20) show that for cobalt, zinc, lead and cadmium equilibrium is reached after just two hours.

Table 4.20 - The effect of time on extraction of metals from compost

Extraction time (hours)	Copper (percent extracted)	Cobalt (percent extracted)	Zinc (percent extracted)	Lead (percent extracted)	Cadmium (percent extracted)
2	9%	10%	32%	34%	27%
4	17%	11%	31%	35%	26%
6	10%	15%	38%	39%	27%
8	11%	10%	30%	38%	26%

4.4.3 Leaching Studies on Compost using Column Method

The leaching studies are an extension of the extraction studies and are designed to closely mimic the removal of metals from a windrow of compost.

A preliminary investigation using distilled water is reported followed by more detailed studies using an EDTA leach.

4.4.3.1 Distilled Water

Distilled water was allowed to leach through a column packed with compost at a flow rate of 5 ml per minute and the average concentration of metals (mg/kg) in the leachate determined, with percentage of total metal in compost extracted in parenthesis: copper 0.80 (1%), cobalt 0.55 (4%), zinc 0.82 (<1%), lead 0.7 (<1%), cadmium 0 (0%).

Leachate volume number/ ml	**Copper conc (mg/l) In leachate**	**Cobalt conc (mg/l) In leachate**	**Zinc conc (mg/l) in leachate**	**Lead conc (mg/l) in leachate**	**Cadmium conc (mg/l) of leachate**
100	0.120	0.056	0.123	0.05	0
200	0.090	0.029	0.089	0.11	0
300	0.073	0.034	0.074	0.04	0
400	0.085	0.079	0.075	0.01	0
500	0.056	0.049	0.073	0.06	0
600	0.068	0.087	0.067	0.08	0
700	0.067	0.052	0.072	0.15	0
Average	0.080	0.055	0.082	0.07	0

4.4.3.2 EDTA

The effect of flow rate, EDTA concentration, and repeated use of EDTA was investigated and reported.

4.4.3.2.1 The Effect of Flow Rate

Flow rate 10 ml/min

0.005M EDTA (at pH 5) was allowed to leach through the column at a flow rate of 10ml per minute and the average concentration of metals (equivalent) in mg/kg was determined: copper 2.80 (4%), cobalt not detectable, zinc 31.2 (12%), lead 20.7 (12%), cadmium 0.21 (11%).

Leachate volume number/ ml	conc copper (mg/l) in leachate	Conc cobalt (mg/l) in leachate	conc zinc (mg/l) in leachate	Conc lead (mg/l) in leachate	conc cadmium (mg/l) in leachate	pH value of leachate
100	0.273	not detectable	3.90	2.16	0.023	6.92
200	0.296		2.92	2.26	0.030	6.96
300	0.275		3.22	1.98	0.019	6.95
400	0.297		3.16	2.18	0.019	7.13
500	0.311		3.64	2.28	0.023	7.01
600	0.271		2.82	1.92	0.021	7.17
700	0.238		2.36	2.02	0.015	7.11
800	0.275		2.92	1.78	0.017	7.30
Average	0.280		3.12	2.07	0.021	

Flow rate 5ml/min

0.005M EDTA (at pH 5) was allowed to leach through the column at a flow rate of 5ml per minute, and the average concentration of metals (equivalent) in mg/kg was determined: copper 3.78 (5%), cobalt 0.48 (4%), zinc 48.8 (18%), lead 32.1 (19%), cadmium 0.39 (21%).

Leachate volume number/ml	conc copper (mg/l) in leachate	conc cobalt (mg/l) in leachate	conc zinc (mg/l) in leachate	conc lead (mg/l) in leachate	conc cadmium (mg/l) in leachate
100	0.503	0.040	9.11	5.73	0.091
200	0.450	0.008	7.04	4.13	0.055
300	0.349	0.071	4.64	2.99	0.036
400	0.328	0.064	3.95	2.56	0.026
500	0.319	0.015	3.50	2.44	0.024
600	0.319	0.046	3.10	2.35	0.030
700	0.330	0.037	3.21	2.33	0.026
800	0.428	0.099	4.46	3.16	0.026
Average	0.378	0.048	4.88	3.21	0.039

Flow rate 2 ml/min

0.005M EDTA (at pH 5) was allowed to leach through the column at a flow rate of 2ml per minute and the average concentration of metals (equivalent) in mg/kg was determined: copper 6.42 (8%), cobalt 0.82 (6%), zinc 75.6 (28%), lead 51.1 (30%), cadmium 0.46 (25%).

Leachate volume number/ ml	conc copper (mg/l) in leachate	conc cobalt (mg/l) in leachate	conc zinc (mg/l) in leachate	conc lead (mg/l) in leachate	conc cadmium (mg/l) in leachate	pH value of leachate
100	0.975	0.101	16.06	10.62	0.111	7.15
200	0.735	0.118	11.12	7.03	0.075	7.35
300	0.651	0.129	8.02	5.18	0.046	7.40
400	0.575	0.057	6.14	4.11	0.032	7.39
500	0.568	0.075	4.88	3.73	0.031	7.40
600	0.555	0.057	4.62	3.58	0.027	7.40
700	0.542	0.060	5.02	3.36	0.025	7.40
800	0.531	0.063	4.62	3.24	0.023	7.39
Average	0.642	0.082	7.56	5.11	0.046	

Flow rate 1 ml/min

0.005M EDTA (at pH 5) was allowed to leach through the column at a flow rate of 1ml per minute. Only average reading of leachate taken because the experiment was run for about 24 hours. The average concentration of metals (equivalent) in mg/kg was determined: copper 7.26 (9%), cobalt 0, zinc 68.2 (25%), lead 44.8 (26%), cadmium 0.71 (38%).

Leachate volume number/ ml	conc copper (mg/l) in leachate	conc cobalt (mg/l) in leachate	conc zinc (mg/l) in leachate	conc lead (mg/l) in leachate	conc cadmium (mg/l) in leachate	pH value of leachate
Average leachate from leaching	0.726	not detectable	6.82	4.48	0.071	7.38

In summary reducing the flow rate increases the proportion of metals extracted from the compost. This is likely to be due to increased contact time of the extractant with the compost.

4.4.3.2.2 The Effect of EDTA Concentration on Extraction of Metals

0.001M EDTA

0.001M EDTA (at pH 5) was allowed to leach through the column at a flow rate of approximately 2ml per minute, and the average concentration of metals (equivalent) in mg/kg was determined: copper 2.11 (3%), cobalt 0, zinc 29.2 (11%), lead 11.4 (7%), cadmium 0.30 (16%).

Leachate volume number/ ml	Conc copper (mg/l) In leachate	conc cobalt (mg/l) in leachate	conc zinc (mg/l) in leachate	conc lead (mg/l) in leachate	conc cadmium (mg/l) in leachate	pH value of leachate
100	0.311	not detectable	4.86	1.98	0.048	6.70
200	0.248		3.70	1.44	0.041	6.88
300	0.212		3.10	1.20	0.029	6.94
400	0.188		2.62	1.04	0.029	7.09
500	0.185		2.06	0.82	0.026	7.10
600	0.192		2.42	0.93	0.023	7.20
700	0.167		2.36	0.82	0.021	7.26
800	0.188		2.22	0.90	0.023	7.26
Average	0.211		2.92	1.14	0.030	7.21

0.005M EDTA

0.005M EDTA (at pH 5) was allowed to leach through the column at a flow rate of 2ml per minute, and the average concentration of metals (equivalent) in mg/kg was determined: copper: 6.42 (8%), cobalt 0.82 (6%), zinc 75.6 (28%), lead 51.1 (30%), cadmium 0.46 (25%).

Leachate volume number/ ml	Conc copper (mg/l) In leachate	conc cobalt (mg/l) in leachate	conc zinc (mg/l) in leachate	conc lead (mg/l) in leachate	Conc cadmium (mg/l) In leachate	pH value of leachate
100	0.975	0.101	16.06	10.62	0.111	7.15
200	0.735	0.118	11.12	7.03	0.075	7.35
300	0.651	0.129	8.02	5.18	0.046	7.40
400	0.575	0.057	6.14	4.11	0.032	7.39
500	0.568	0.075	4.88	3.73	0.031	7.40
600	0.555	0.057	4.62	3.58	0.027	7.40
700	0.542	0.060	5.02	3.36	0.025	7.40
800	0.531	0.063	4.62	3.24	0.023	7.39
Average	0.642	0.082	7.56	5.11	0.046	

In summary, the higher the concentration of EDTA, the greater the percentage of metal removed. This is in agreement with the data from the extraction experiments.

4.4.3.2.3 The Effect of Repeated Extraction with EDTA on the Same Compost Batch

Two batches of 0.005M EDTA (at pH 5) were allowed to leach through the same column of compost at a flow rate of 5ml/min.

First Leach:

Leachate volume number/ml	**Conc copper (mg/l) In leachate**	**conc cobalt (mg/l) in leachate**	**Conc zinc (mg/l) in leachate**	**Conc lead (mg/l) in leachate**	**conc cadmium (mg/l) in leachate**
100	0.294	0.151	4.12	2.44	0.048
200	0.384	0.089	5.70	3.46	0.036
300	0.350	0.127	4.92	3.21	0.033
400	0.394	0.114	5.66	3.41	0.040
500	0.330	0.152	4.64	2.97	0.038
600	0.316	0.072	3.34	2.63	0.015
700	0.285	0.085	2.94	2.21	0.028
800	0.307	0.050	2.58	2.15	0.023
Average	0.333	0.105	4.24	2.81	0.033

The average concentration of metals (equivalent) in mg/kg was determined for the first leach as: copper 3.33 (4%), cobalt 1.05 (8%), zinc 42.4 (16%), lead 28.1 (17%), cadmium 0.33 (18%).

Second leach:

Leachate volume number/ ml	**conc copper (mg/l) in leachate**	**conc cobalt (mg/l) in leachate**	**conc zinc (mg/l) in leachate**	**conc lead (mg/l) in leachate**	**conc cadmium (mg/l) in leachate**
100	0.585	0.152	8.86	6.63	0.063
200	0.460	0.147	7.56	4.92	0.045
300	0.432	0.126	6.82	4.14	0.037
400	0.397	0.174	5.60	3.73	0.045
500	0.401	0.131	5.82	3.41	0.040
600	0.391	0.100	5.22	3.35	0.034
700	0.383	0.197	5.42	3.21	0.038
800	0.411	0.147	6.26	3.34	0.036
Average	0.433	0.147	6.45	4.09	0.042

The average concentration of metals (equivalent) in mg/kg was determined for the second leach as: copper 4.33 (5%), cobalt 1.47 (11%), zinc 64.5 (24%), lead 40.9 (24%), cadmium 0.42 (23%)

Although, a second leach increases the amount of metal extracted from the compost, the increase is no more than 8% for any of the metals.

4.4.3.2.4 The Re-usability of EDTA through Compost Columns

0.005M EDTA (at pH 5) was allowed to leach through the column at a flow rate of approximately 2ml/min. After the initial leach, the EDTA was passed through a column of fresh compost to investigate if the EDTA could be re-used.

First Leach:

Leachate volume number/ ml	**Conc copper (mg/l) in leachate**	**Conc cobalt (mg/l) in leachate**	**conc zinc (mg/l) in leachate**	**conc lead (mg/l) in leachate**	**Conc cadmium (mg/l) in leachate**	**pH value of leachate**
100	0.674	Not detectable	9.08	4.67	0.077	7.56
200	0.543		6.42	3.52	0.052	7.31
300	0.504		4.98	2.87	0.039	7.78
400	0.448		3.82	2.37	0.026	7.82
500	0.476		3.46	2.35	0.030	7.96
600	0.461		3.22	2.26	0.029	7.61
700	0.477		2.92	2.06	0.025	7.57
800	0.493		3.18	2.05	0.028	7.48
average	0.510		4.64	2.77	0.038	

The average concentration of metals (equivalent) in mg/kg was determined for the first leach as: copper 5.10 (6%), zinc 46.4 (17%), lead 27.7 (16%), cadmium 0.38 (21%).

Second leach:

Leachate volume number/ ml	conc copper (mg/l) in leachate	Conc cobalt (mg/l) in leachate	conc zinc (mg/l) in leachate	Conc lead (mg/l) In leachate	conc cadmium (mg/l) in leachate	PH value of leachate
100	0.948	0.205	15.16	9.12	0.123	7.01
200	0.774	0.149	12.52	7.69	0.088	7.50
300	0.685	0.160	11.46	6.69	0.070	7.41
400	0.666	0.174	10.86	6.84	0.073	7.49
500	0.691	0.228	10.68	7.09	0.075	7.29
600	0.735	0.208	12.40	8.94	0.082	7.46
average	0.750	0.187	12.18	7.73	0.085	

By comparing the average concentrations of metals in the leachate from the first run and the re-use, it can be seen that there is a much higher level of each metal in the leachate from the second run. These data are consistent with the results from the equilibriation experiments and confirm that re-use of 0.005M EDTA to remove metals from a fresh batch of compost is effective.

4.5 ECONOMIC ASSESSMENT AND AN APPRAISAL OF THE COSTS

The work contained in this chapter has shown that maximum levels of metals removed from compost vary with the nature of the extractant and the metal type. If a method of extraction is to be developed it needs to be both technically and economically viable. Table 4.21 records the maximum amounts of metals removed from compost under different extraction conditions.

If it is assumed that the cost of running a composting operation for treating the organic fraction of household waste (including site overheads but not including use or disposal of the final compost) is approximately the same as the cost of sending that waste to a landfill site, then a rough calculation of the economics of composting can be made. The balance therefore depends on what revenue can be generated by the sale or disposal of the final compost. A typical price for a good quality bagged compost is in the range £2-3 for a 30-60 kg bag. On the other hand if the compost is of a poor quality then it may only be fit for disposal at a landfill site, thus incurring an additional cost to the composting operation. The middle of the road scenario, which often occurs for compost generated from household

Table 4.21 – Maximum amount of metals removed from compost

Extractant	concent -ration	Copper extracted	Cobalt extracted	Zinc extracted	Lead extracted	Cadmium extracted
Sodium Hydroxide	0.01M	5%	1%	1%	1%	29%
	0.1M	26%	7%	1%	7%	31%
	1M	29%	8%	1%	7%	29%
Sodium Pyrophosphate	0.01M	15%	13%	9%	4%	9%
	0.05M	30%	20%	44%	19%	29%
	0.10M	30%	16%	47%	18%	29%
Nitric acid	0.25M	3%	29%	32%	10%	45%
	0.50M	11%	37%	51%	44%	65%
	0.75M	21%	40%	53%	73%	67%
	1M	25%	37%	75%	67%	91%
	3M	45%	44%	78%	83%	95%
	6M	53%	44%	74%	80%	95%
EDTA	0.001M	7%	10%	33%	34%	26%
	0.005M	23%	13%	42%	46%	30%
	0.01M	24%	14%	43%	51%	37%
	0.025M	29%	16%	43%	54%	35%
	0.05M	34%	22%	49%	59%	30%
Sodium Carbonate	0.1M	37%	12%	13%	7%	18%
	0.5M	50%	14%	8%	8%	11%

waste (in the UK) is when the compost is given away free of charge and therefore does not incur a cost or generate revenue (depending on transport arrangements). There is therefore significant potential for treating compost if it can be turned from a poor quality compost, which is only fit for disposal at a landfill site, to a good quality compost which can be bagged and sold to the general public.

Ultimately, compost quality will be dictated by the levels of contamination, and metals are one of the primary concerns. If contamination levels affect compost quality and end-use applications then cost considerations must be made. The remainder of this chapter reviews the cost implications, for a basic scenario, where extractants are used to remove heavy metals from compost.

Nitric acid (3M)

It costs £92.40 for a 25 litre drum of 69% nitric acid (Merck)

To make 1 litre of 3M nitric acid it requires approx 200ml of 69% nitric acid

Therefore a 25 litre drum of 69% nitric acid can make approx. 125 litres of 3M nitric acid

If use 1:10 compost to extractant w/v ratio, then 12.5 kg of compost can be treated for £92.40

So for 1 kg of compost it would cost £7.39 to treat.

If have a 50kg bag of compost this would equate to £370

If the extractant could be re-used this would reduce the cost proportionally, however the costs would still be excessive and this treatment method would not be practical for compost.

EDTA (0.05M)

It costs £367.50 for a 50 kg drum of EDTA

RMM of EDTA is 292.25

To make 1 litre of 0.05M EDTA then require 14.6125g of EDTA

So 50kg of EDTA can make up 3422 litres of 0.05M EDTA

If use 1:10 compost to extractant w/v ratio, then 342.2 kg of compost can be treated for £367.50.

So for 1 kg of compost it would cost £1.07 to treat

If have a 50kg bag of compost this would equate to £53.50

Lower concentrations of EDTA would reduce the cost of EDTA proportionally. Therefore if 0.005M EDTA was used the cost would be £5.35 and if 0.001M EDTA was used the cost would be £1.07 for a 50 kg bag.

Re-usability of the EDTA several times would reduce the cost further. Therefore if 0.005M EDTA was re-used three times this would equate to a cost of £1.78 for a 50kg bag of compost, and if 0.001M EDTA was used three times this would equate to a cost of £0.36 per 50kg bag of compost.

Sodium Pyrophosphate (0.05M)

It costs £483 for a 50kg drum of sodium pyrophosphate decahydrate

RMM of sodium pyrophosphate decahydrate is 446.06

To make 1 litre of 0.05M sodium pyrophosphate then require 22.303g of sodium pyrophosphate decahydrate

So 50 kg of sodium pyrophosphate can make up 2242 litres of 0.05M sodium pyrophosphate

If use 1:10 compost to extractant w/v ratio, then 224.2 kg of compost can be treated for £483

So for 1 kg of compost it would cost £2.15 to treat

If have a 50kg bag of compost this would equate to £107.50

Similarly, if lower concentrations of sodium pyrophosphate where used this would reduce the price proportionally.

Even if sodium pyrophosphate was re-used, this study has shown that it could only be re-used once and this would equate to a cost of £53.75 per 50kg bag of compost. Again his cost would be too high to allow sodium pyrophosphate to be used as a metal extractant for compost.

4.6 CONCLUSIONS

The extraction experiments show that, in general cadmium, copper, cobalt, lead, and zinc are not readily bioavailable in composts derived from the organic fraction of household waste. It is important to note that there is a high degree of variation between metals and some metals are more bioavailable than others. For example, it appears that cadmium is generally more bioavailable than copper.

It has been shown that removal of metals from compost cannot easily be carried out by simple chemical extractions. Often, high concentrations of extractants are needed just to achieve a 50% reduction in the amount of metals in the compost. At such high concentrations of extractants, it would be uneconomic to remove the metals and even at lower concentrations of extractants the economics would appear unfavourable.

It was found that EDTA was the only reagent which could be effectively used to remove metals repeatedly at low concentrations of the extractant. For example, EDTA at a concentration of 0.005M could remove 23% of copper 13% of cobalt, 42% of zinc, 46% of lead and 30% of cadmium. In economic terms, even if the EDTA was to be re-used for a total of three extractions, with no deterioration in its extraction power, this would still involve an equivalent cost of £1.78 for a 50 kg bag of compost. Given that a 50 kg bag of compost typically sells at a price of £2.00 per bag there is little economic benefit.

The results presented in this chapter suggest that the metals in compost are tightly bound to the compost matrix. The strength of the binding of metals to compost could offer an opportunity for compost to be used in removing and concentrating metals from solutions. This property of compost is investigated in chapter five.

Finally, it is important to stress that this research was performed on a compost material obtained from one centralised composting site. Although this site is typical of centralised composting sites treating the organic fraction of household waste, the experiments have not been performed on any other compost materials. Caution must therefore be taken when extrapolating the results to other composts, especially when the compost has been derived from different source waste materials.

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CHAPTER FIVE

THE REMOVAL OF HEAVY METALS AND DYES USING COMPOST FROM CENTRALISED TREATMENT SCHEMES

REFERENCES

5.1 INTRODUCTION

Work carried out on the use of compost to remove metals and dyes from industrial wastewaters is reported for the first time in this chapter. This novel use for compost could potentially open up a new market for compost. The overall aim of this chapter is to assess the ability of compost to remove heavy metals and dyes from solution - the first part of the chapter investigates its use in the removal of heavy metals (cadmium, copper, lead and zinc), and in the second part its use in removing methylene blue dye.

5.1.1 Compost and the Composting Process

Composting is a microbiological process involving the microbial digestion of organic matter (De Bertoldi 1993). The process occurs under aerobic conditions and can be used to treat organic waste, such as garden and kitchen waste generated by households, to produce a compost material which can be used as a soil conditioner or fertiliser. In the UK, over 50% of the household waste stream is biodegradable material (Department of the Environment 1994, Henry Doubleday Research Association, 1995) and if only a small proportion of this waste can be composted it could result in substantial saving of landfill void.

Compost offers some important environmental and economic advantages over some of the other materials, such as activated carbon and peat, which are currently being used for the treatment of wastewaters. Firstly, compost is cheap because it is often derived from waste materials. Most organic waste materials, including those generated in the home, garden and some industries, can be composted to produce a useful end product such as compost. In cases where this waste would otherwise be sent to landfill, composting the waste saves on the landfill costs. In the UK, with increasing legislative and environmental pressures, composting organic waste is becoming more popular, and there is an increase in the number of centralised composting plants. A major barrier to composting is finding a market/use for the end product. In 1998 the Department of the Environment, Transport and Regions set up a composting development group to identify and establish ways of overcoming the problems associated with finding markets for compost (DETR 1998), and in the UK the situation is of such concern, that in some cases composting operations are giving away compost free of charge or for a very small price. This effectively means there is a plentiful supply of compost at a cheap price. Furthermore, composting recycles a waste material to produce the compost rather than removing a raw material from the ground, and finally, composting processes may be carried out in any country where, unlike peat, there is no constraint on the process arising from the proximity or otherwise of the source material.

5.1.2 Theoretical Aspects of Adsorption

Adsorption is a phenomenon that involves the separation of a substance from one phase accompanied by its accumulation or concentration at the surface of another (Weber, 1985). The terminology used to describe adsorption states that the adsorbing phase is the adsorbent, and the material concentrated or adsorbed at the surface of that phase is the adsorbate. Adsorption occurs as a result of binding forces that exist between individual atoms, ions, or molecules of an adsorbate and the surface of the adsorbent. The main types of adsorption are classified as exchange, physical, chemical, and specific. Each of these types although different, all depend on electromagnetic interactions.

Bernardin (1985) states that for a material to be used as an adsorbent there are two basic questions which must be addressed. Firstly, how much adsorbate (material to be removed from solution) can be removed per unit weight of adsorbent (material on which adsorption will occur), and secondly, how long will it take for the removal to occur ?

To address these questions the properties of the adsorbent and adsorbate need to be considered. For the adsorbent, there are three factors which must be taken into account: chemical properties, physical properties and regeneration potential of the adsorbent. The more important chemical properties of the adsorbent include:

1. Adsorption capacity of the adsorbent – which ultimately is the factor which will determine the economic viability of it is an adsorbent.
2. Surface area - the higher the surface area the greater its potential for adsorption.
3. Extractable chemical species - all adsorbents made from natural raw materials contain material, such as metal ions, which can contaminate the liquid they are trying to purify.
4. pH - both the pH of the adsorbent and adsorbate will be crucial to the operation of any adsorption system.

In addition to these chemical properties there are physical properties - the most notable being particle size - and regeneration properties which will affect the operation of the adsorbent and will ultimately determine the economic and environmental viability of an adsorbent.

The first stage in determining the adsorption potential of any material is to construct an adsorption isotherm. This involves a batch equilibrium test to determine the adsorbate adsorbed per unit weight of adsorbent to the amount of adsorbate remaining in solution. In its simplest terms this can involve the shaking (equilibriation) of a known amount of adsorbent (compost) with a known volume and concentration of adsorbate (heavy metal or dye solution).

The adsorption isotherm provides valuable information concerning:

1. Affinity of the adsorbate for the adsorbent
2. Concentration of adsorbate on adsorbent (adsorption capacity of adsorbent)
3. Degree (percentage) of adsorbent removed
4. Sensitivity of adsorbent to adsorbate concentration
5. Effect of parameters such as contact time, pH and temperature

The rate of adsorption of dye onto compost will depend on many parameters and adsorption is likely to go through several stages. Weber (1985) suggested a three-step model for adsorption of solutes from solution by porous adsorbents:

1. Bulk transport of solute in the solution phase to the adsorbent
2. Diffusion of the solute through a hypothetical "film" or hydrodynamic boundary layer; and
3. Diffusion within the pore volume of the adsorbent and/or along pore-wall surfaces to the active adsorption site (intraparticle transport).

Of these three steps it is assumed by Weber that step 3 is rapid with respect to the first two, and therefore insignificant in the context of overall adsorption rate.

5.1.3 Compost Properties

The important point which must be emphasised at the outset is that no two composts are the same. Clearly, if compost can be used to remove heavy metals from wastewaters there could be significant economic and environmental implications. However, the key issue which may limit its use as an adsorbent is the variability and heterogeneity of the feedstock waste material and hence the compost product. Woodbury and Breslin (1992) suggest that the inherent variability of compost is a critical factor that must be considered in quality assurance programs. In particular, the correct sampling and analysis of compost is important to establish validity of results. For example, compost derived from the organic fraction of household waste may differ considerably in its properties compared to compost derived from green waste (gardens and parks waste). Similarly, even within compost obtained from the same compost site there may be batch to batch variation.

The issue of compost heterogeneity and variability is critical in this study and the research by Woodbury and Breslin (1992) has been borne in mind. Nevertheless, this study is designed to investigate the potential of compost for removing metals and dyes from solutions, and the results have been obtained from one batch (windrow) of compost. Although the compost is regarded as typical of windrow compost in the UK, this investigation considers only the capacity, efficiency and influence of pH on metal ion removal by compost. At the outset the investigation was to provide a feasibility study of the potential for compost to remove any metal/s or dyes from solution.

The chemical properties of compost which may make it potentially suitable for removing metals and dyes from solution arise from a mixture of organic and inorganic matter. One of the largest and probably the most important constituent is the organic matter. In composts derived from household waste the organic matter content typically exceeds 25% and may even reach around 50% of the total compost. For example, Gomez (1998) reported organic matter levels of 38% in compost from source-separated municipal putrescible and garden waste. Organic matter is a generic term which refers to groups of organic compounds, which can be divided into two classes: non-humic substances and humic substances. The non-humic substances include those compounds which have recognisable chemical characteristics (structures) and include proteins, amino acids, and sugar acids.

However, most of the organic matter found in composts consists of humic substances. These are brown/black in colour and have high molecular weights (in the region of thousands). A key property of humic substances is their ability to form complexes with metal ions. As early as 1959 Beckwith commented that metals of the first transition series of the periodic table formed complexes with humic substances and that the order of stabilities of the different metal complexes followed that of the Irving-Williams series:

$$Pb^{2+} > Cu^{2+} > Ni^{2+} > Co^{2+} > Zn^{2+} > Cd^{2+} > Fe^{2+} > Mn^{2+} > Mg^{2+}$$

Compost also comprises inorganic matter and this too may provide ligands, for example F^- and OH^-, which can form complexes with metal ions. In addition to the potential for forming complexes the compost could attract metal ions through exchange reactions on the surface (for example, a metal ion displacing a hydrogen ion).

This brief introduction shows that there is a wide variety of sites within the compost which could potentially attract metal ions and dye molecules and the strength of this attraction may vary. Some metal ions may be held in weak exchangeable forms which may be readily displaced, whereas others could be held in much stronger sites which are harder to displace or remove.

5.2 HEAVY METAL REMOVAL BY COMPOST

Heavy metals occur in industrial wastewaters in a wide range of concentrations. Industries which are known to produce waste streams containing large quantities of heavy metals are mining, paint manufacturing, steel production and battery manufacturing to name a few. If these wastewaters were released untreated into the environment they could cause harm to humans, animals, and plants. It is therefore of prime importance to reduce the quantity of heavy metals to an acceptable level which does not cause harm or concern to the public and environment.

There are a number of methods currently available for reducing the levels of heavy metals in wastewaters. The methods most frequently used are adsorption, ion exchange and chemical precipitation. As far as adsorbents are concerned, there has been considerable work undertaken using activated carbon (Marzal et al., 1996, Reed et al., 1994, Netzer and

Hughes, 1984, McKay and Bino, 1987) and more recently peat (Viraghavan, 1991, and Allen et al. 1992, 1994) for removing metals from wastewaters, but limited research has been carried out on the effectiveness of compost for metal removal.

5.2.1 Methodology

Compost used in this study was obtained from a centralised composting plant which composts organic waste material produced by up to 1200 households in East Hertfordshire, UK. The site uses the windrow composting process which takes a total of 12 weeks, with the compost being turned on regular occasions. Finally, at the site the compost is passed through a 10 mm screen before being ready for use.

Eight 50kg plastic bags of compost were collected from the site. The bags were filled by randomly selecting shovels of compost from one matured windrow (pile). The samples were transported to the laboratory where they were prepared by coning and quartering, before being dried at room temperature. The dry compost particle size was then reduced by crushing the compost with a pestle and mortar and passing it through a 2mm sieve.

The metal salts investigated in this study were the sulphates of cadmium, copper, and zinc and lead nitrate. Individual stock solutions of these ions (4000mg/l) were prepared by dissolving the corresponding salts in distilled water. All working solutions were prepared by diluting the stock solution with distilled water.

Batch sorption experiments were run on individual metal systems to investigate the point at which the compost became equilibrated with metal ions, the percentage metal removal with respect to different initial concentrations of metal, the metal removal capacity of the compost and pH effects. Compost (1.0 gram) was shaken with a metal solution (100ml), the mixture was filtered, and analysis of the metal ions remaining in the filtrate was carried out using Atomic Absorption Spectroscopy (AAS). All experiments were carried out in duplicate to confirm reproducibility and the results recorded using the AAS are the average of three readings. For the purposes of clarity only single data sets are presented. Standard concentrations of metal solutions, used to calibrate the instrument and blanks (samples without the analyte) were run with each batch analysed.

5.2.2 Results and Discussion

The effects on metal removal are discussed under the following headings: Time for equilibrium to be attained, percentage metal removal by compost at different solution concentrations, metal removal capacity of compost and the effect of initial solution pH.

5.2.2.1 Time for Equilibrium to be Attained

Figure 5.1 shows the percentage of metal removed by compost (1g) from a 100mg/l solution of metal ions (100ml) for different lengths of time. Metal uptake by compost is rapid and most occurs within one hour, but to ensure equilibrium was attained in all subsequent experiments the studies were performed for 24 hours.

5.2.2.2 Percentage Metal Removal by Compost at Different Solution Concentrations

Figure 5.2 shows the percentage of metal removed by 1 gram of compost when it is presented with a solution containing only one metal at various concentrations. It can be seen that of the four metals investigated, compost has the greatest affinity for lead with affinities for the other metals in the order Pb>Cu>Cd>Zn. It should be noted that of these four metals, lead is known (Beckwith, 1959) to form particularly stable complexes with humic substances, and this may partially explain the large difference in the behaviour of lead and the other metals.

5.2.2.3 Metal Removal Capacity of Compost

Figure 5.3 indicates that 1 gram of compost can remove approximately 60 mg lead, 30 mg copper, 25 mg cadmium, and 10 mg zinc.

5.2.2.4 The Effect of Solution pH

To assess the effect of pH on metal adsorption a series of experiments were run within the initial pH range 2-5 with compost-metal-loading above the capacity of 60 mg lead, 30 mg copper, 25 mg cadmium and 10 mg zinc per gram of compost. This enabled any change in metal loading arising from pH effects alone to be monitored. Separate experiments were carried out using a metal concentration of 80mg lead, 50mg cadmium, 50mg copper, and 20 mg zinc per gram of compost.

Figure 5.1: Time required for metal to reach equilibrium

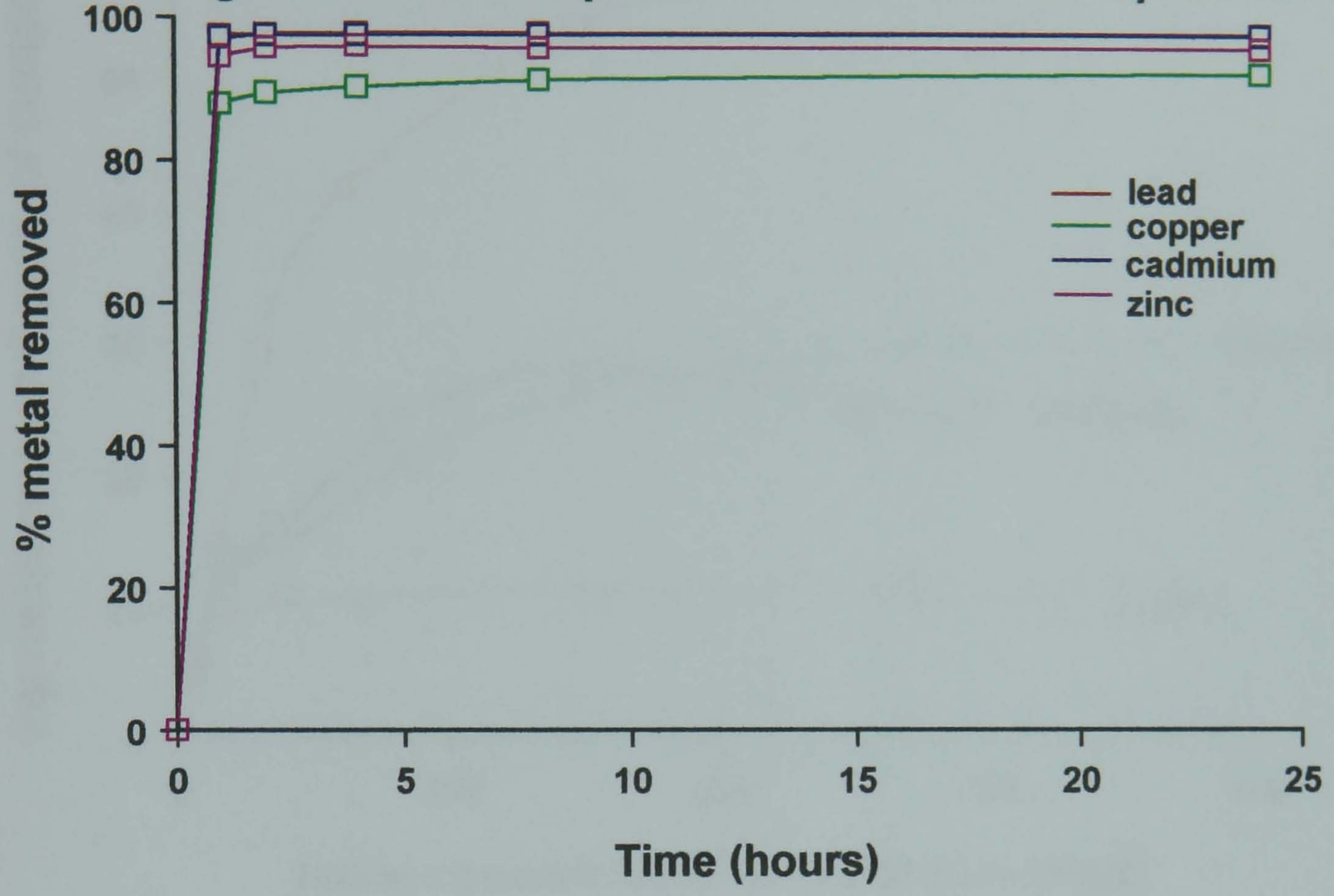
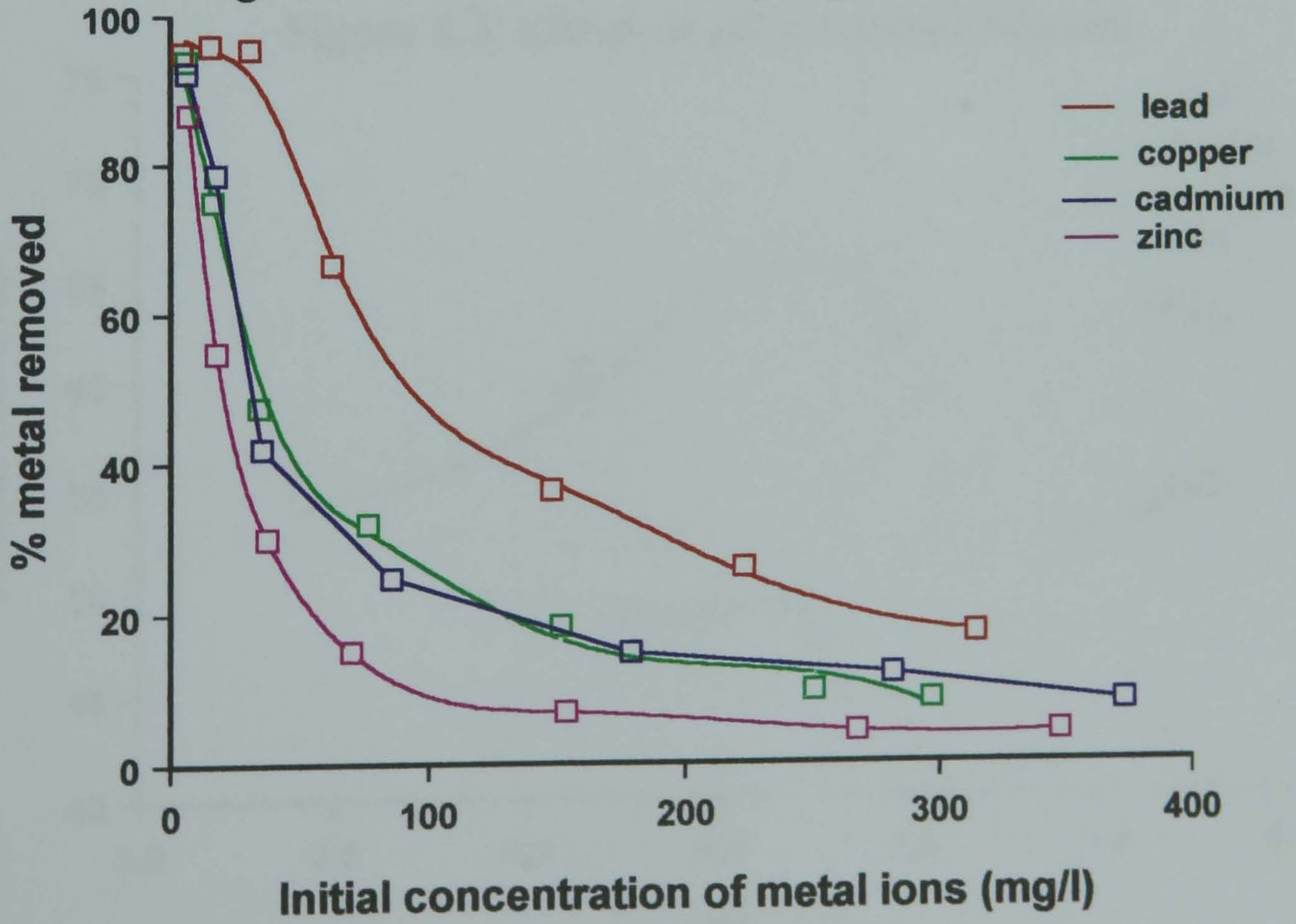


Figure 5.2: metal removal by 1 gram of compost



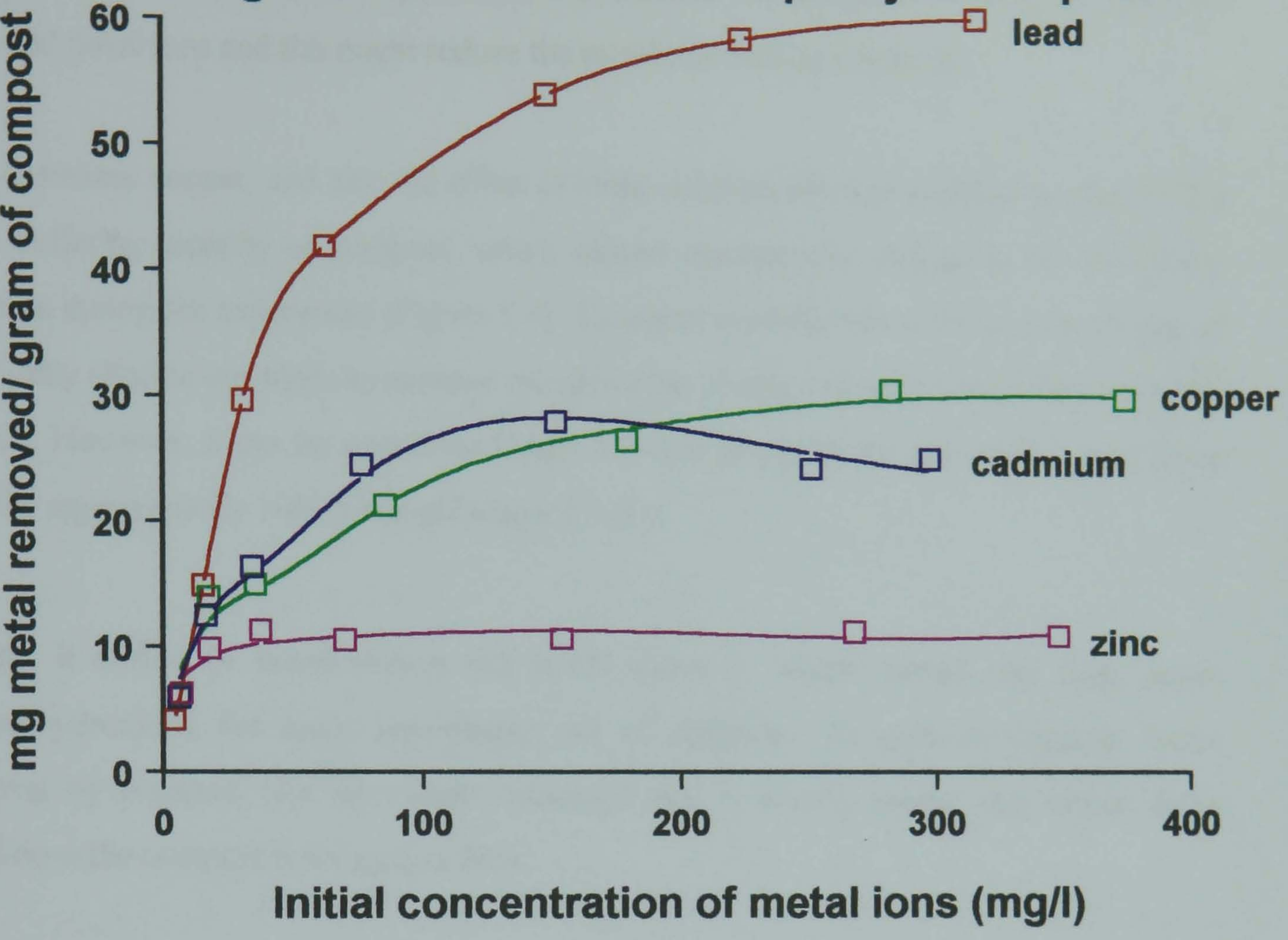


Figure 5.3: metal removal capacity of compost

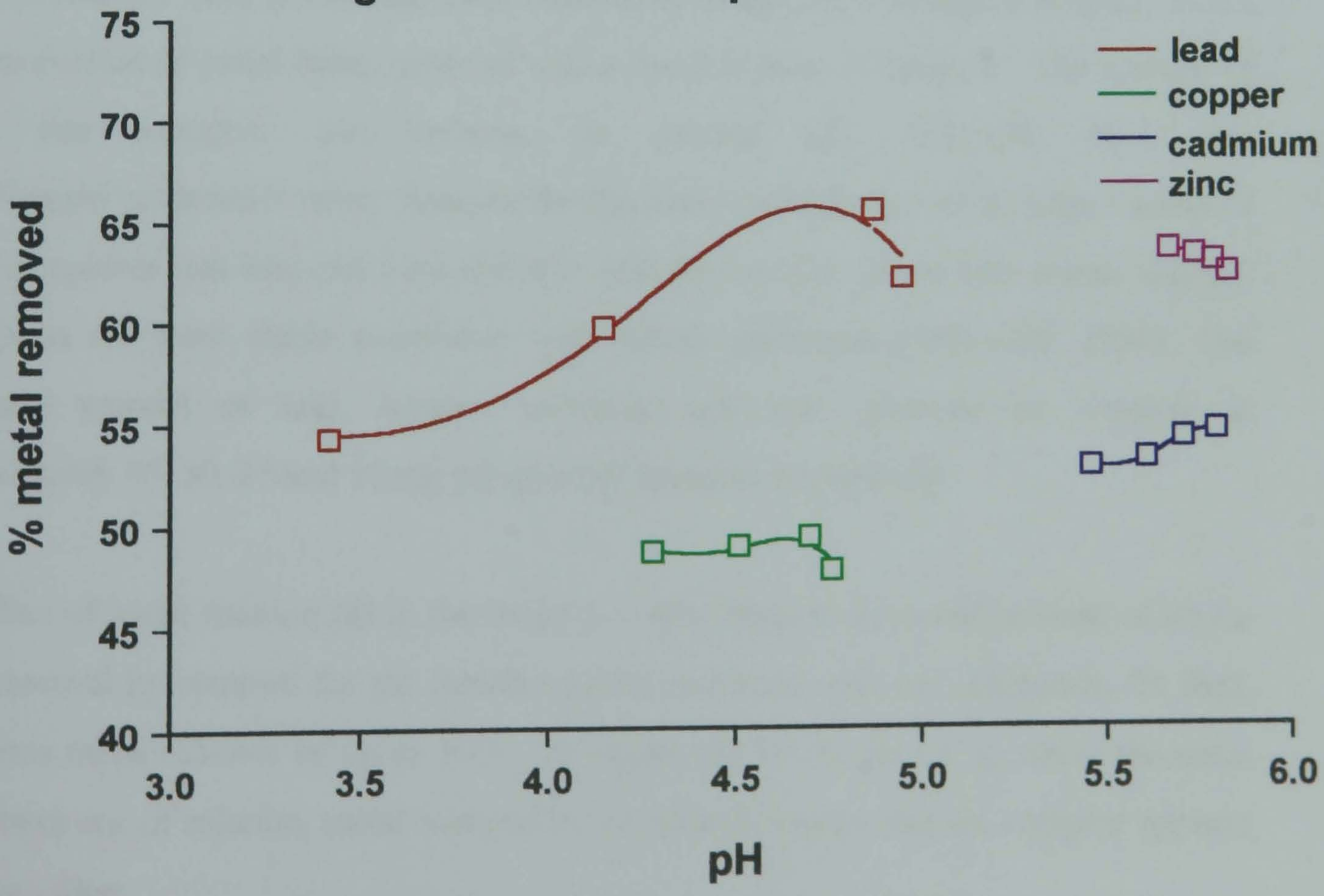


Figure 5.4: Effect of pH on metal removal

It can be postulated that lower pH levels will increase the competition between hydrogen ions and metal ions and this might reduce the metal removal by compost.

For cadmium, copper, and zinc the effect of initial solution pH was minimal because of the high buffering capacity of compost, which caused considerable change in the pH of the solution during the experiment (Figure 5.4). Compost typically has a pH of around neutral or slightly alkaline and tends to increase the pH of the solution closer to neutral by buffering effects. However, it can be seen from Figure 5.4 that changing the pH affects removal of lead by approximately 10% in the pH range 3.5-5.0.

Finally, it should be noted that at pH levels above 5, where metals ions form metal oxides/hydroxides, the metal precipitates out of solution. In such an instance, metal removal by compost (for all metals) increases and it would appear that under these conditions the compost is acting as a filter.

5.2.3 Conclusions

The results presented in this section suggest that compost can remove lead, copper, cadmium, and zinc from solution when the sulphates of cadmium, copper, and zinc and nitrate of lead are used as the salts. The removal of metal ions by compost is rapid, with a high proportion of metal being removed within the first hour of reaction. The amount of metal that compost can remove, at natural pH, followed the order lead>>copper>cadmium>>zinc. Reasons for this order could be due to the large number of stable complexes that lead can form and it is well known that, of the four metals studied, lead forms the most stable complexes with humic substances (Beckwith, 1959). The maximum amount of lead, copper, cadmium and zinc removed by compost is approximately 60, 30, 25 and 10 mg per gram of compost respectively.

The effect of initial solution pH in the range 2-5 was found to have only a small effect on metal removal by compost for the metals copper, cadmium, and zinc. However, for lead, pH affects metal removal by up to 10%. At higher pH levels (above 5), where the metal precipitates out of solution, metal removal by compost increases and the compost appears to act as a filter.

Overall, it can be seen that compost can remove metal ions from solution, but the efficiency and percentage removal of metal will depend at least on the concentration of the metal in solution.

5.3 METHYLENE BLUE REMOVAL BY COMPOST

The textile industry uses a large amount of dyes to permanently colour fibres (both natural and synthetic) in the manufacture of their products. Throughout the dyeing process a large volume of coloured wastewater is produced which needs treatment for the removal of colour. However, variation in the wastewater as a result of changing colour intensity, pH, suspended solids, and temperature, leaves a waste stream which is difficult to treat in an economically viable manner. Furthermore, many dyes are stable to oxidation and light and it is difficult to treat wastewaters containing these dyes using standard waste treatment techniques (McKay et al., 1984).

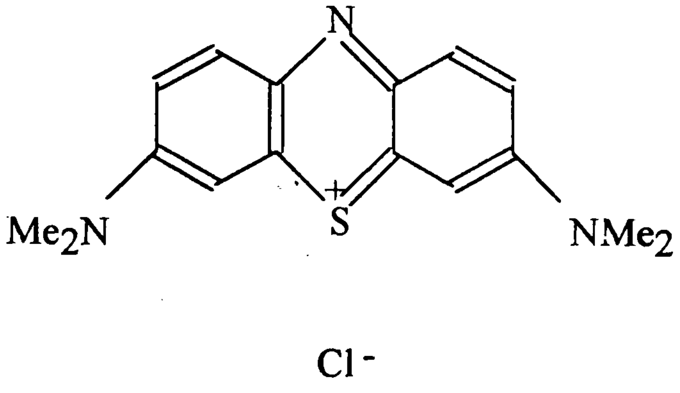
Traditionally, there have been three approaches to remove colour from wastewaters generated by the textile industry; coagulation by aluminium/iron salts, adsorption onto a medium such as activated carbon, and biological oxidation (Asfour et al., 1985). Each particular method has its advantages and disadvantages and should be chosen depending on the characteristics of the waste stream.

Adsorption of dyes onto materials such as activated carbon has received a large amount of attention because of its proven ability to remove dyes and its rapid removal rate. However, due to the relative expense of activated carbon (the cost of which increases proportionally with the quality of the material), and difficulty with regeneration (McKay et al., 1986), over the last few decades other adsorbents have been considered. In particular "natural adsorbents", such as wood and peat have been investigated as potential adsorbents for removal of dyes from wastewaters in both an environmental and economically viable manner (Poots et al., 1976, Allen et al., 1994, and Viraraghavan and Mihial 1995).

To further the search for alternative adsorbents which offer both environmental and economic benefits the current research considers the use of compost derived from household waste as a potential adsorbent for the removal of dyes from wastewaters.

5.3.1 Methylene Blue - Chemistry and Properties

Methylene blue is a thiazine dye. Only five thiazine dyes are known to be still manufactured and all but one are blue or green basic or solvent dyes. Methylene blue, probably the most important of the thiazine dyes, was discovered by Caro in 1876 (Ventakataraman, 1978) and was found to have the structure outlined below. Nowadays, methylene blue is used in the chloride form as a pH indicator and a biological stain, but the zinc chloride double salt is normally used for dyeing. The synthesis of methylene blue uses simple chemical transformations and cheap readily available chemicals.



Thiazine dyes are typically used in dyeing of cellulosic fibres, silk, bast fibres, leather and paper. Methylene blue is used extensively for dyeing and printing cotton on tannin, and to a minor extent for dyeing silk, in spite of the low light fastness characteristic of the basic dyes as a class. Methylene blue lakes are valuable in the nontextile colouring industries (Venkataraman, 1978). The dye has no affinity for unmordanted cotton, but oxycellulose and cellulose-containing mineral matter or combined acid are stained by the dye, and methylene blue absorption under standard conditions is useful for detecting and estimating modification in cellulose.

Chemically, methylene blue can be obtained in its pure form easily. It is often used as an oxidation-reduction indicator and forms an insoluble dichromate and perchlorate.

In medicine, methylene blue is an important stain because it can colour certain parts of living tissue e.g. the peripheral nervous system. It is used widely as a stain in the examination of pathogenic organisms and can also be used as a reagent for testing tubercular infection in milk. The dye has also been used as a mild antiseptic and has even been used as an antimalarial agent.

5.3.2 Methodology

The aim of the work reported in this section is to test the ability of compost to remove methylene blue dye from solution, and the effects of dye concentration, contact time, pH, compost particle size, and compost:dye ratio are also investigated through equilibriation studies. Further experiments were carried out to investigate dye removal by columns of compost at various dye concentrations.

5.3.3 Experimental

Batch sorption experiments were conducted by shaking samples of compost (1.0g) with a volume of dye solution (100ml) of varying concentrations at room temperature on a mechanical shaker. Experiments were performed to investigate the effects of dye concentration, contact time, pH, compost particle size, and compost:dye ratio. After thorough mixing of the sample, each sample was filtered through a 0.45 micrometre glass fibre filter and the dye concentration was analysed by measuring the optical density on a Perkin-Elmer Lambda 9 UV/VIS/NIR spectrophotometer at its λ_{max} wavelength corresponding to maximum absorbance. The value recorded was converted to its appropriate concentration using the calibration graph obtained from the instrument. All experiments were carried out in duplicate to confirm reproducibility and the results recorded using the spectrophotometer are the average of three readings. For the purposes of clarity only single data sets are presented. Standard concentrations of dye solutions, used to calibrate the instrument and blanks (samples without the analyte) were run with each batch analysed.

5.3.4 Results and Discussion

The results to the effect of contact time, removal capacity of compost, pH, compost size, and compost mass, on dye removal are presented in this section. These studies are extended to consider single pass and multiple pass operations for dye removal by compost.

5.3.4.1 Effect of Contact Time

Figure 5.5 shows that equilibrium for methylene blue is only reached after about 48 hours, and to ensure equilibrium was attained in all subsequent experiments, the studies were performed for at least 48 hours. Certainly, at higher concentrations of dye there is considerable change in the amount of dye removed in a period up to 24 hours. Viraraghavan and Mihial (1995) reported that for peat, equilibrium is reached within two hours.

5.3.4.2 Removal Capacity of Compost

The removal capacity for methylene blue by compost is presented in Figure 5.6. It can be seen that compost has a maximum removal capacity of approximately 180 mg methylene blue per gram of compost.

5.3.4.3 Effect of pH

Figure 5.7 illustrates that most dye is removed within the pH range 6-8, and only small differences in dye removal (less than 2%) are observed within the pH range 4-8. However, below pH 4 and above pH 8 dye removal is reduced and at a dye concentration of 5000 mg/l only 28% of dye is removed at pH 2 and 31% at pH 10 compared to 35% at pH 6.

5.3.4.4 Effect of Compost Size

Figures 5.8, 5.9 and 5.10 show the effect of compost size on methylene blue removal at dye concentrations of 100,1000, and 3000mg/l. Three compost sizes were selected (<0.5mm, 0.5-1.0mm, and 1.0-2.0mm), and tested for dye removal. For each dye concentration it was found that the ability of compost to remove dyes decreased with increasing particle size of the compost. Maximum dye removal was achieved using a compost of the smallest compost size (<0.5mm), followed by the 0.5-1.0mm and 1.0-2.0mm sizes respectively. However, the difference in dye removal between the 0.5-1.0mm and 1.0-2.0mm fractions was small.

Figure 5.5: Time required for methylene blue to reach equilibrium

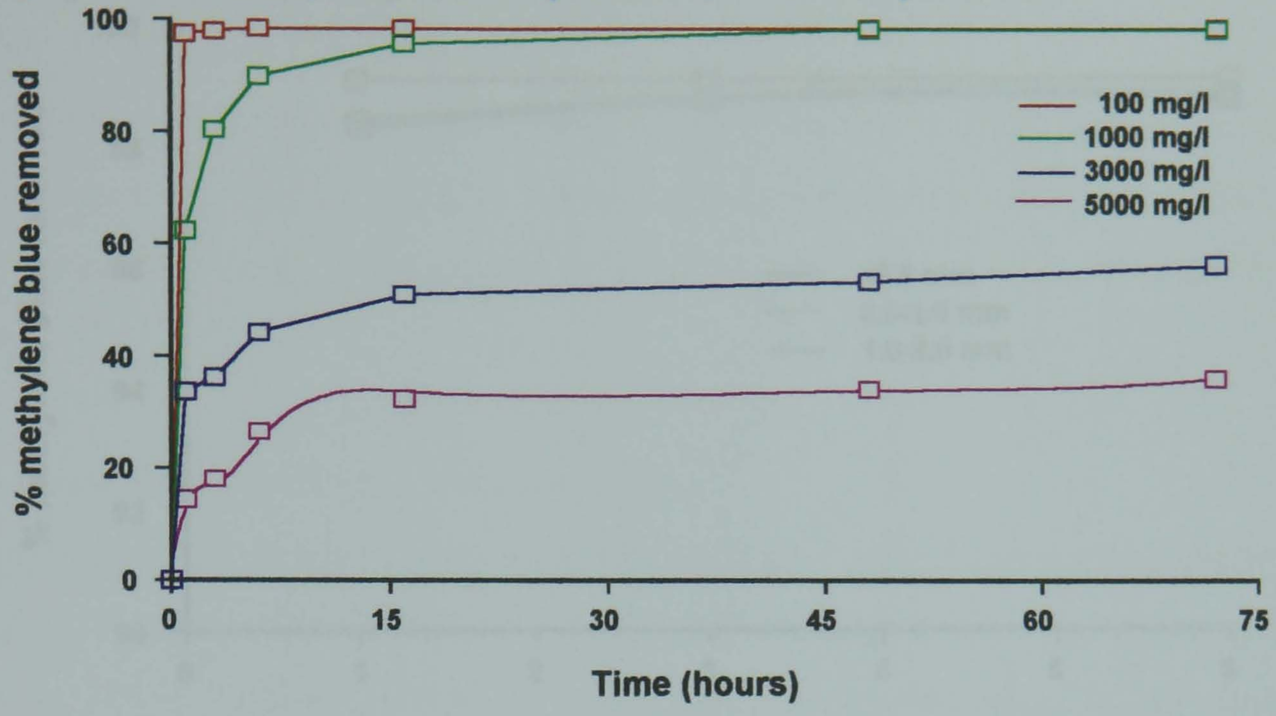


Figure 5.6: Methylene blue removal capacity of compost

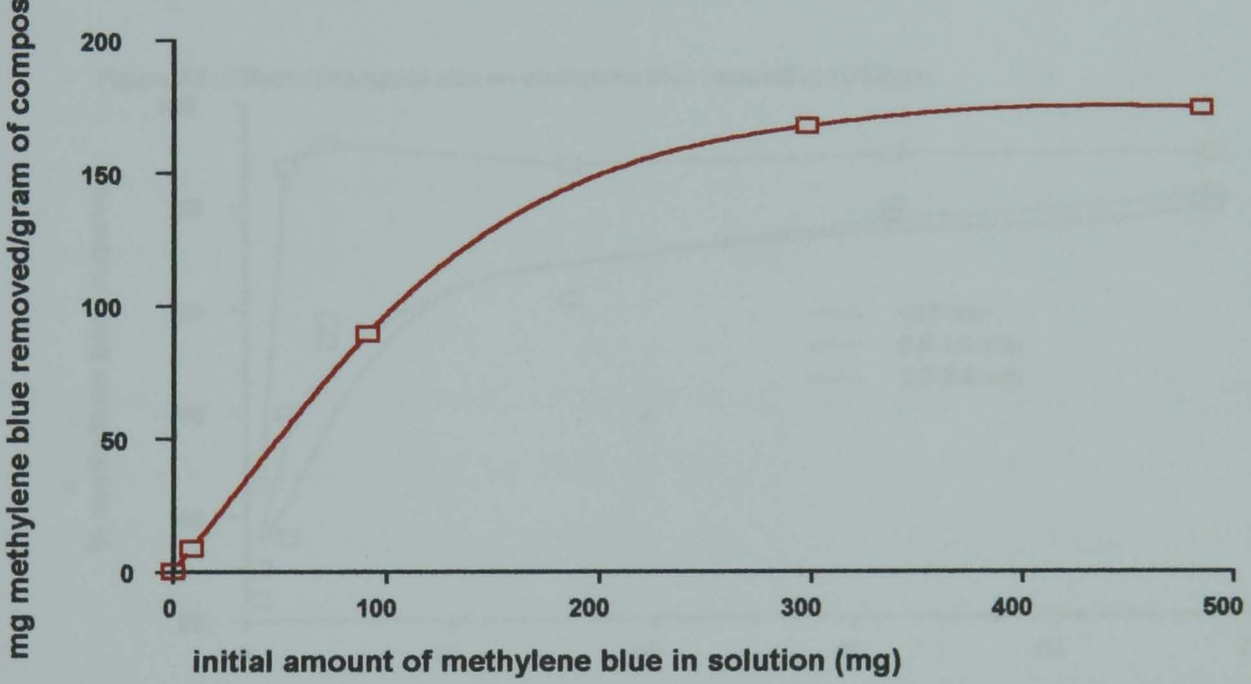


Figure 5.7: Effect of pH on methylene blue removal

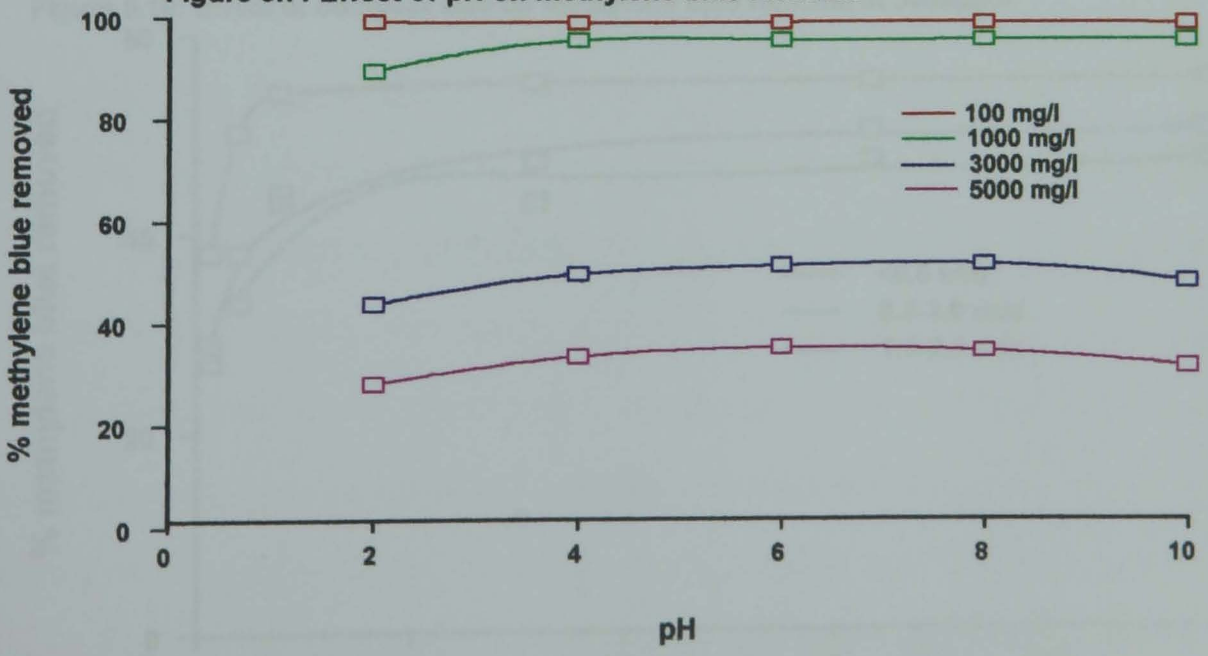


Figure 5.8: Effect of compost size on methylene blue removal at 100ppm

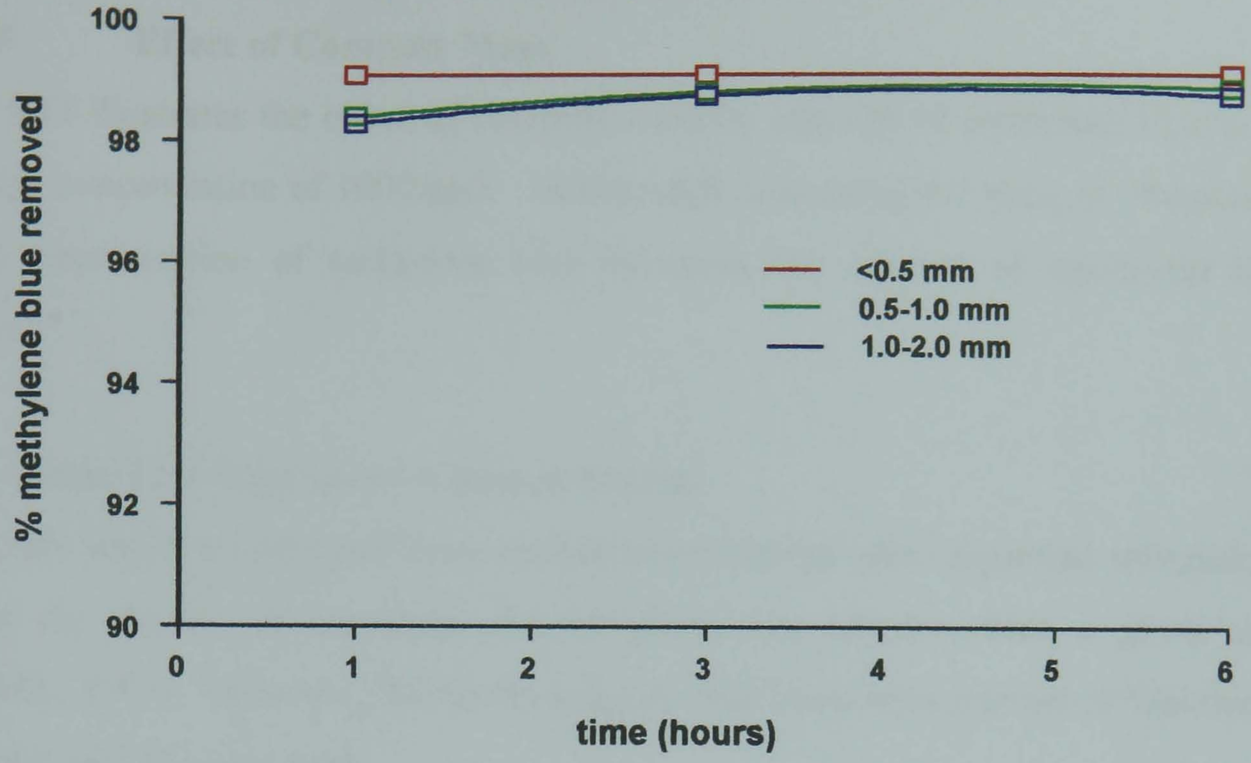


Figure 5.9: Effect of compost size on methylene blue removal at 1000ppm

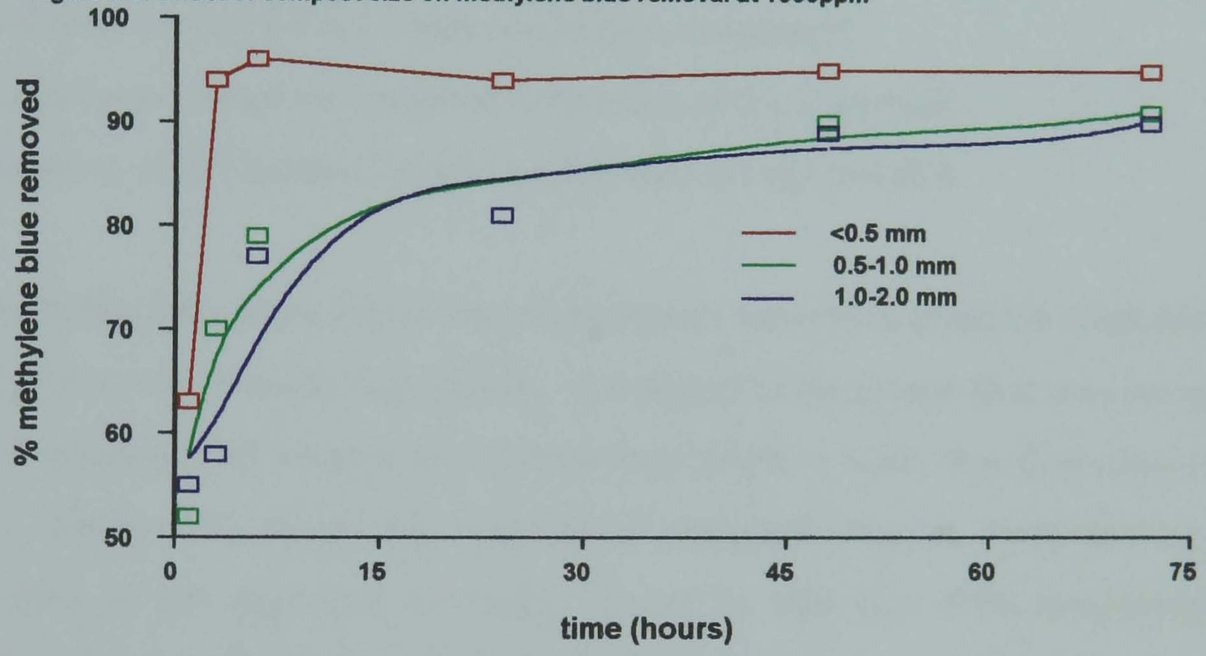
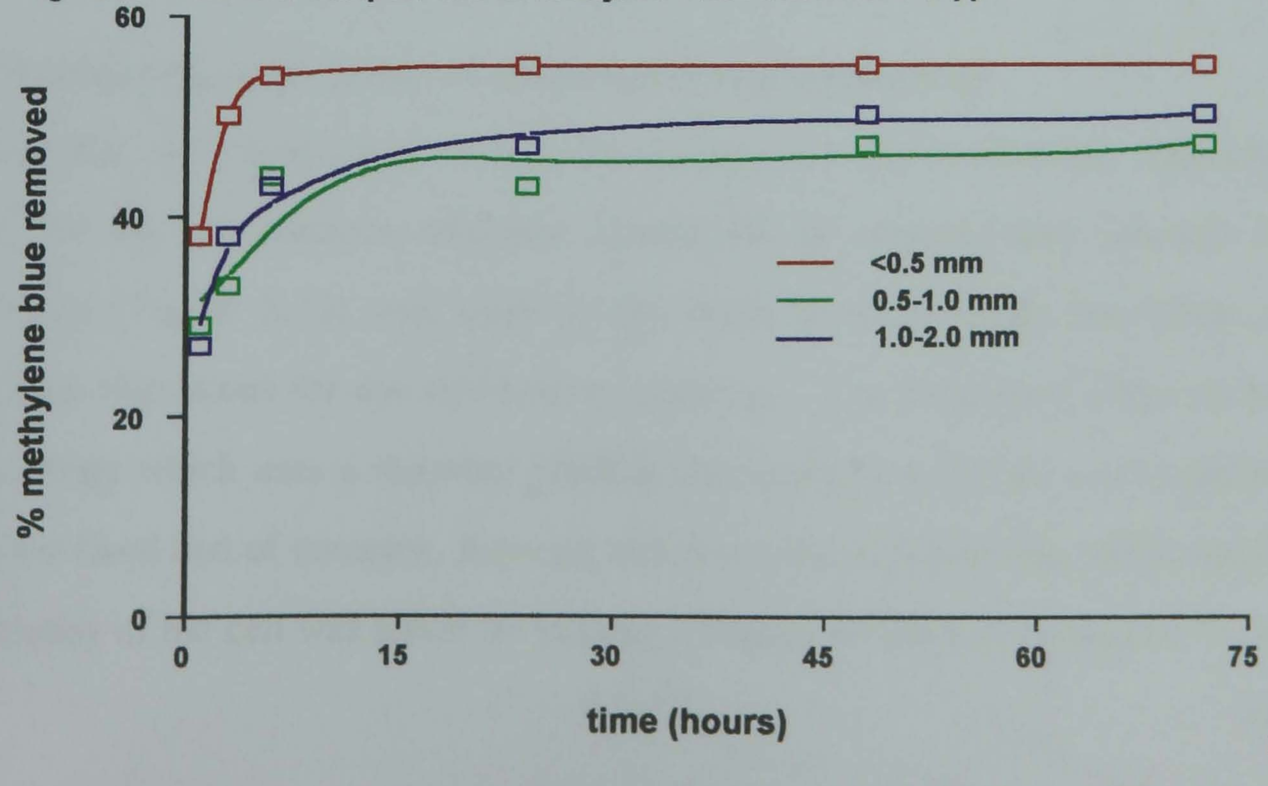


Figure 5.10: Effect of compost size on methylene blue removal at 3000ppm



5.3.4.5 Effect of Compost Mass

Figure 5.11 illustrates the effect of compost mass on removal of methylene blue at an initial dye concentration of 1000mg/l. As expected, increasing the mass of compost at a fixed concentration of methylene blue increases the amount of methylene blue removed.

5.3.4.6 Single Pass Operation - Column Studies

Adsorption isotherms obtained from equilibriation studies offer important information such as the amount of adsorbate the adsorbent can adsorb within a given time (Bernardin, 1985). However, Bernardin suggests that there are a number of limitations associated with this approach:

1. Isotherms are carried out under equilibrium conditions
2. Isotherms are based on complete exhaustion of the adsorbent
3. Recycling and Regeneration of the adsorbent are not possible

Given these limitations, some preliminary experiments were performed on a column of compost to determine breakthrough points. A solution of methylene blue was pumped through a 5 gram-packed column of compost (bed depth = 8cm) at a flow rate of 5 ml/minute. Figure 5.12 shows the removal of methylene blue at concentration of methylene blue of 250 mg/l and 500 mg/l. it can be seen that 50% breakthrough occurs after approximately 500 ml of solution for a concentration of methylene blue of 500 mg/l and approximately 1700 ml of solution for a concentration of 250 mg/l.

5.3.4.7 Multiple Pass Operation – Concentrator Cell Technology

A concentrator cell developed within the Centre for Environmental Research designed for the simultaneous complete destruction of organics and removal of heavy metals (Figure 5.13) was used in this work to demonstrate the effect of multiple pass operations for dye removal by compost. The developed concentrator cell technology which uses a chamber holding concentrator material, was modified to contain a fixed bed of compost, through which the dye solution was recirculated. The efficiency of the cell was tested by passing a 50ppm solution of methylene blue

Figure 5.11: Effect of compost mass on removal of 1000 mg/l methylene blue (100ml)

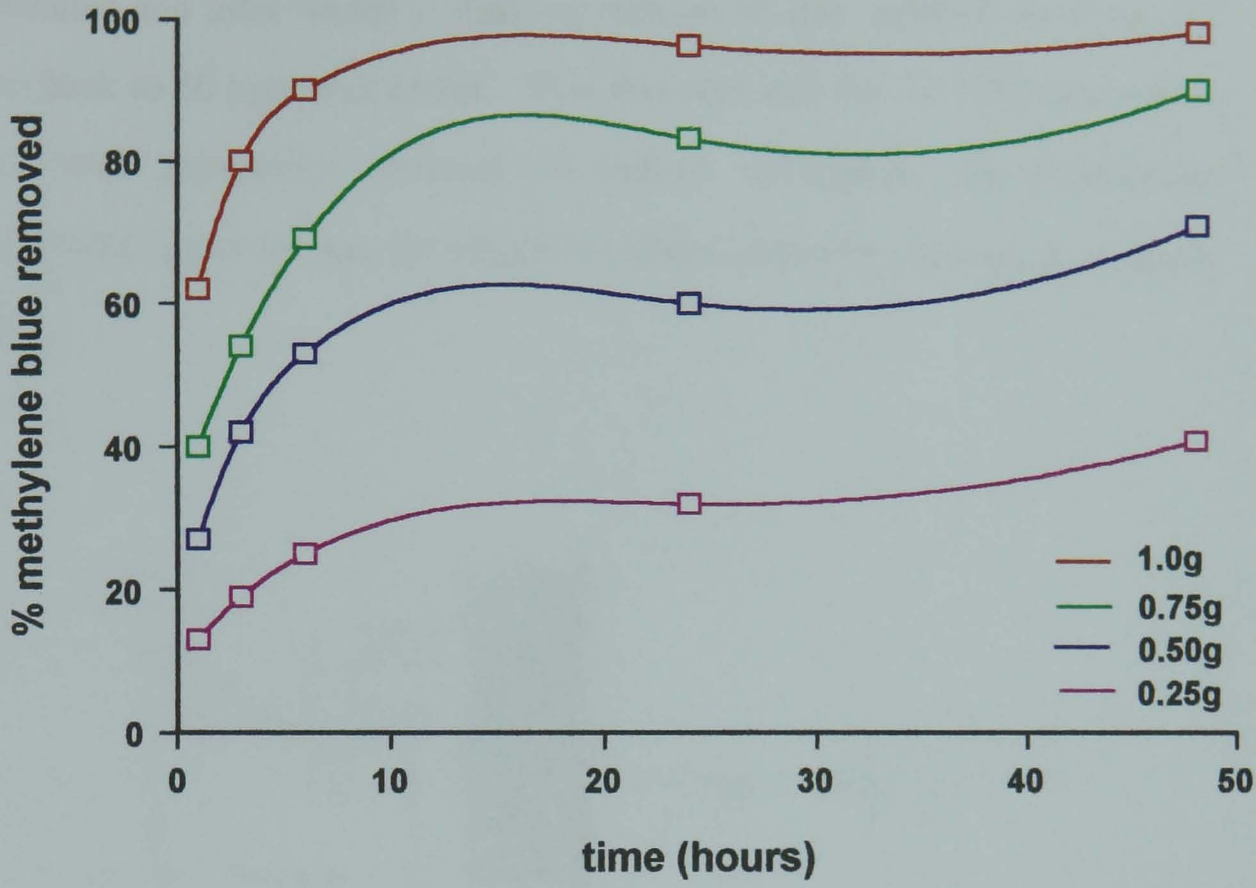
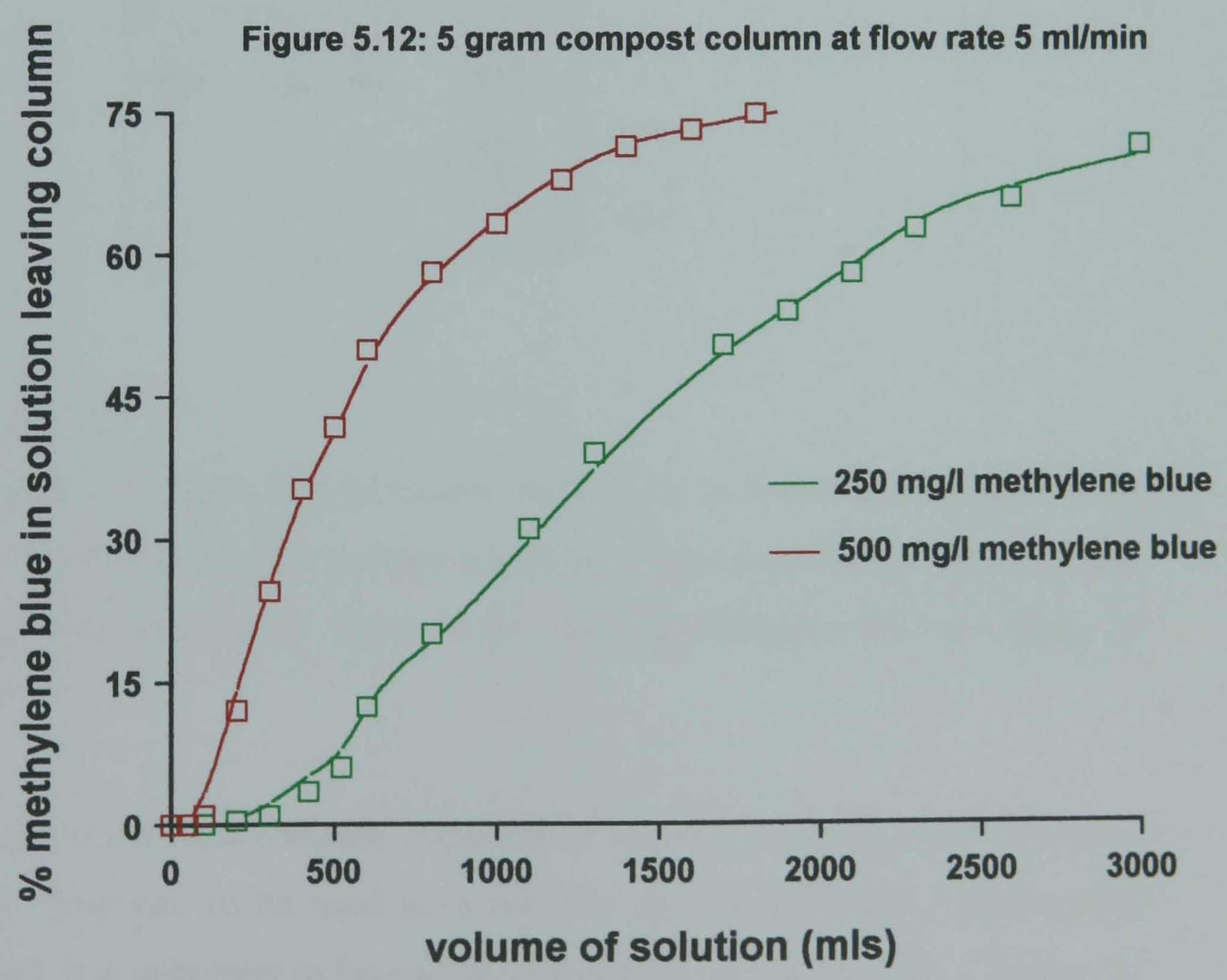
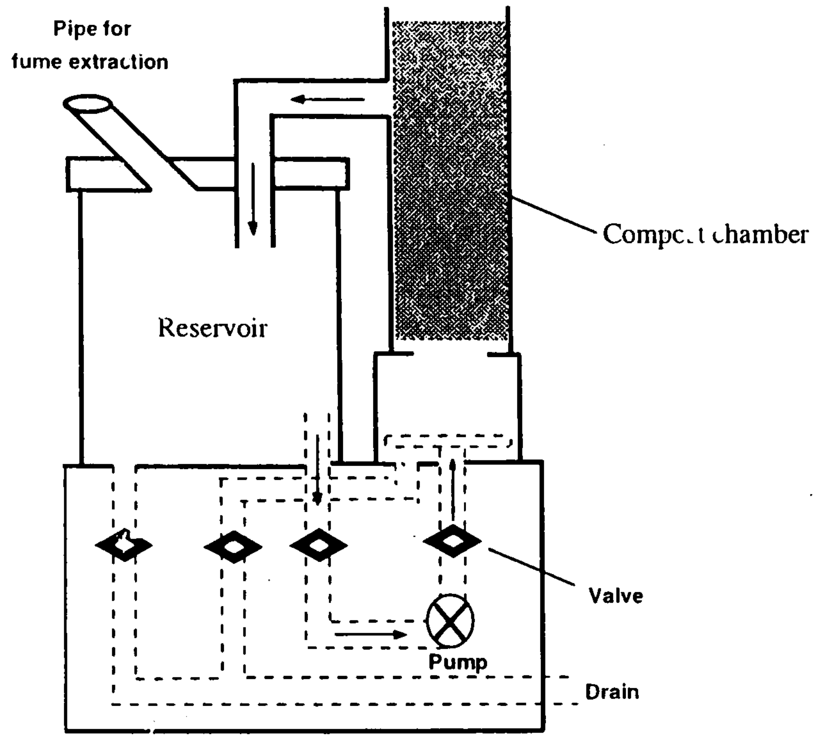


Figure 5.12: 5 gram compost column at flow rate 5 ml/min



dye through a bed of 400 grams of compost. Removal of the colour occurred within 30 minutes and after which a make-up stream of dye solution to bring the concentration back to 50 ppm was added. This was repeated for 12 runs (equivalent to 6 hours) with continuous removal of colour throughout the experiment confirming that the compost was an effective colour remover through a multiple pass operation.

Figure 5.13



5.3.5 Conclusions

The results suggest that compost can remove basic dyes, such as methylene blue, from solution. Compost was found to become equilibrated with the dye after 48 hours and the maximum removal capacity found to be 180 mg methylene blue per gram of compost.

This chapter has shown that compost is capable of removing specific metals and dyes from solution, however, to be used as a material for removing and concentrating metals and dyes, it is important to know how compost performs this task. Chapter six investigates the mechanism of pollutant removal by compost.

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CHAPTER SIX

AN INVESTIGATION INTO THE MECHANISM OF POLLUTANT REMOVAL BY COMPOST

REFERENCES

6.1 INTRODUCTION

In chapter 5 it was demonstrated that compost from a centralised treatment plant can remove metals and dyes from solution. In order to understand the mechanism for metal or dye removal by compost the work described in this chapter seeks to (1) characterise the active fraction of the compost, and (2) examine mechanisms which may be responsible for metal and dye removal.

6.1.1 Past Research

Compost produced in the UK has traditionally been used as a soil improver to add organic matter and small amounts of fertilising chemicals to soil. However, as more pressure is placed on recycling of waste materials it is likely that compost production will increase. As a result, alternative uses for compost are being sought.

It has been shown in chapter 5 that compost has the ability to remove metal ions and dyes from solution. In addition, a recent article in the New Scientist magazine (Pearce, 1997) suggested that compost can be used to remove metal ions, by showing that iron can be removed from river water. To date, the mechanism of this removal is not understood. Proposed mechanisms for the removal of these pollutants include suggestions such as ion exchange, adsorption, precipitation and electrochemical interactions, and biological mechanisms.

6.1.2 Comparison of Compost to other Biosorbents

In order to fully evaluate the ability of compost to remove metals and dyes, it is important to compare it to other materials used for similar purposes. Any comparison must evaluate the material's performance in terms of the capacity for metal or dye removal, along with the environmental and economic implications of their use.

6.1.2.1 Capacity for Removal

Wase et al. (1997) reviewed the literature for removal of various metals by different biosorbents. Selected data from their work on the removal of copper and lead are summarised along with data obtained in this work using compost (Tables 6.1 and 6.2).

For ease of comparison only data for which the maximum adsorption capacity of the material (Q_0), is known are included.

Table 6.1 - Copper removal by biosorbents

Material	**Q_0 (mg/g)**	**Reference**
COMPOST	30	Chapter 5
Activated Carbon	9.22	Ferro-Garcia et al. (1988)
Montmorillonite clay	23.3	No reference given
Kaolin clay	1.40	Farrah et al.(1980)
Sphagnum moss peat	16.4	Ho et al. (1994)
Eutrophicpeat	19.6	Chen et al. (1990)
Oligotrophic peat	6.41	Chen et al. (1990)
Anaerobically digested sludge	49.0	Gould & Geneteli (1978)

Table 6.2 - Lead Removal by biosorbents

Material	**Q_0 (mg/g)**	**Reference**
COMPOST	60	Chapter 5
Montmorillonite clay	71.8	No reference
Kaolin cay	3.93	Farrah et al. (1993)
Sphagnum moss peat	30.7	Ho et al. (1996)
Sphagnum moss peat	61.8	Allen et al. (1992)
Tea leaves	78.7	Tee & Khan (1988)
Moss (*Calymperes delessertii* Besch)	49.9	Low & Lee (1987)

Although there are many limitations of this crude comparison it does give a general indication of how compost compares to other materials. It is particularly worthwhile comparing compost with peat and activated carbon, since these materials are currently being used to remove metals from solution. From the analysis, it can be seen that, for copper and lead, compost compares favourably with other biosorbents in the amount of metals it can remove, with maximum adsorption capacities greater than montmorillonite clay for copper removal and comparable with montmorillonite clay and sphagnum moss peat for lead removal.

6.1.2.2 The Environmental Implications of using Compost in Metal and Dye Removal

In an environmental comparison of compost to other biosorbents it is important to consider the whole life cycle of the material. It is not possible as part of this work to do a detailed examination of the lifecycles of the different biosorbent materials, therefore, a qualitative discussion of the issues will follow.

Compost has the environmental benefit of being made from organic waste materials. The compost used in this study is being produced from a waste material which would otherwise end up in landfill. Therefore, recycling this waste material to produce compost is saving landfill void. Furthermore, compost is a renewable resource, and this is an advantage over materials such as peat and activated carbon. Currently, there is considerable environmental pressure to reduce the destruction of peat bogs and reduce the amount of peat used.

Following its use for metal and dye removal, compost or any other biosorbent must be disposed of. Currently, successful on-site wastewater treatment systems using peat are based on peat being used in one-off applications only, followed by disposal. After use, the methods being used to treat peat involve dewatering and drying the peat before recovering the metals by burning the peat. Combustion of peat is a viable method since the ash content of peat is very small and this results in the formation of metal oxides which can readily be recovered. However, for some metals, such as lead, the oxides disperse in air and precipitate over large areas. For these metals alternative methods of disposing the materials must be considered. Compost is of similar composition to peat and therefore can undergo similar disposal methods as peat.

6.1.2.3 The Economic Implications of using Compost in Metal and Dye Removal

The composting process can be performed by individuals on a small scale or by organisations on a larger scale. Many local authorities are currently undertaking large-scale composting as a method to reach recycling targets set by local authorities. Therefore, more compost is being produced than ever before in the UK, and this material needs to be disposed of or used. High quality compost can be sold to the general public or for use by professional growers, however, much of the compost is likely to be contaminated to varying extent. This is particularly likely when organic waste needs to be separated from the remainder of the waste stream by the general public before it is used in the composting process. Therefore, it is quite feasible that in the future low quality compost will become available at a very low price or even free of charge (especially if it is taken in bulk) as local authorities try to clear space for incoming organic waste. Clearly the price of compost will reflect the current state of the market, however, it is very likely that there will be an excess of supply over demand and this will keep the price low.

Activated carbon varies in price depending on its quality, but it is generally regarded as quite expensive and is considered to be more expensive than peat. The advantages of using activated carbon is that it is less heterogeneous than peat or compost, and it has also been proven that activated carbon can be regenerated and re-used, thereby increasing its useful life. Peat is considered to be a relatively low-cost biosorbent compared to activated carbon, and because of this has established itself as a viable biosorbent for removing a wide range of pollutants from solution. However, as with compost there has been limited success in its regeneration and re-use.

6.1.2.4 Overall Assessment of Compost

Bearing all the above factors in mind, the economic and environmental advantages and disadvantages of using compost must be considered carefully and weighed against other biosorbent materials. Nevertheless, before compost can become a viable alternative to materials like peat or activated carbon a large amount of research needs to be performed on compost. This would enable a more comprehensive analysis of the advantages and disadvantages of using compost.

6.1.3 Peat as a Biosorbent

There have been many reports of materials with biological origin being used to adsorb metal ions. Recently, the literature concerning biosorbents has grown rapidly (Wase et al.1997) in terms of the variety of materials used, the metals investigated, and factors studied. This wealth of information is extremely valuable, however, there are some problems in comparing the effectiveness of these materials.

Probably the most studied biosorbent - particularly over the last two decades - is peat. Many other materials with organic origin have also been researched, however, despite its many similarities with peat, compost has been relatively unresearched. The work on compost has only developed over the last few years and has largely been performed on coir-based compost. For example Guijarro et al. (1996) showed that coir-based compost has a high capacity for nickel removal, and Sharma and Forster (1994) showed that this material could adsorb hexavalent chromium.

Mechanisms for metal removal using biosorbents such as peat are not understood and it is therefore not surprising that a mechanism for the removal of metals by compost has not yet been established. Sharma and Forster (1994) showed that intra-particle diffusion and chemical binding reactions were the rate-controlling steps, but the precise mechanisms of metal binding were not established. To elucidate a mechanism for biosorption of metal ions onto compost, it is worth drawing on the experience gained from the extensive research into the use of peat as a biosorbent. McKay & Allen (1997) suggest that there are several mechanisms by which metal ions may be removed from a solution and attached to a sorbent particle surface. They note that this is particularly the case for many biosorbents because of the complex chemistry of the surfaces. The mechanism may be due to ion exchange, physical sorption, chemi-sorption, chemical reaction, lone-pair electron sharing or donating plus a number of other mechanistic processes (McKay & Allen (1997)).

Peat is a dark brown coloured material, of spongy consistency and is partially fossilised plant matter which is formed in wet areas under partially anaerobic conditions, where the rate of accumulation of plant matter is greater than that of decomposition, since decomposition is incomplete (Wase et al. (1997). This is where peat differs from compost, because compost is formed in fully aerated conditions.

Peat is a heterogeneous material, containing cellulose and lignin as major constituents. Its precise composition will depend on the plant material from which it is formed and factors such as the moisture content, pH and oxygen status of the place in which it is formed. However, its basic chemical composition is made up from many aromatic rings linked together to form a stable material. In comparison to materials like lignin, peat has lost many of its side chains and this allows the development of charged groups which allow for chelation with metal ions. Alcohols, acids, and aldehydes are among the functional groups on peat which can be involved in bonding. Peat also has a very porous structure and this allows for a high surface area.

McKay & Allen (1997) suggest that the nature of metal binding on peat has been extensively investigated, however, a common viewpoint on the exact mechanism of sorption has yet to be reached. One of the main thoughts concerning metal binding onto peat is the involvement of humic acids. Kashirtseva (1960) suggested that humic acids in peat were primarily responsible for its ability to sorb metals. Since then, there have been many other reports (Schnitzer, 1978) which suggest that carboxyl groups on humic acids are responsible for the acid's reaction with divalent metals. Metal ions react with carboxyl groups to form chelate rings, with the release of H^+ ions. Further work on humic acids obtained from lignite and peat was performed by Ong & Swanson (1966) who found that these humic acids were able to complex copper in solution. They found that the complex formed involved carboxylic groups and could be considered a chelating complex similar to that found in soil organic matter. Therefore, humic acids at least played some part in the sorption of copper. However, Ong & Swanson (1966) also removed humic acid from peat and tested the ability of the peat (minus the humic acids) to remove copper. They found that this material was better at removing copper, and explained the result as an increase in surface area in the organic matter that is exposed for metal sorption. Thus, humic acids in their soluble form are responsible for the fixation of metals, but in their solid form have quite different properties and can play only a minor part in the sorption process. Finally, they suggested that the sorption of metal ions by peat and lignite can be considered as an attraction between the negatively-charged surface and a positively-charged metal ion.

6.1.4 Compost

Compost is a complex material which contains both organic and inorganic (mineral) matter. Typically, the organic matter constitutes up to 50% of the compost and this consists of both humic and non-humic substances. The non-humic substances include those compounds which have recognisable chemical characteristics and include proteins, amino acids, and sugar acid. However, most of the organic matter found in composts consists of humic substances. These are brown/black in colour, have high molecular weights (in the region of thousands) and are an array of humic acid, fulvic acid and humin.

Humic substances are known to have a high proportion of anionic (negatively-charged) groups and it would be expected that cationic (positively-charged) species would be attracted to them. For example both methylene blue (basic blue 9) dye and metal ions are positively charged and would be expected to be attracted to the anionic surface of the humic substances. Furthermore, it is possible that exchange adsorption between hydrogen ions on the compost and positively-charged species could occur and this could be a method by which positively-charged species, such as metal ions, become adsorbed onto the compost surface.

A further fraction of compost is the inorganic (or mineral) matter. This fraction of compost also has the potential to interact with metal or dye ions through the formation of complexes or exchange reactions on the surface of the inorganic material. For example, OH^- ions can form complexes with metal or dye ions and exchange reactions can occur with hydrogen ions on the surface of the inorganic matter.

6.1.5 Potential Mechanisms of Binding of Pollutants (Metals and Dyes) to Compost

There are several potential mechanisms for pollutant (metal/dye) binding to compost, including ion-exchange, physical sorption, chelation with acid/alcohol functional groups in the organic (humic) substances, precipitation and surface area phenomenon. The work outlined in this chapter will try to elucidate which of these mechanisms is responsible for pollutant removal by compost, although, it is unlikely that pollutant binding to compost will, exclusively, be one of the above mechanisms. From the literature on other biosorbents it is highly likely that binding of metals to compost will be far more complicated and may involve a combination of mechanisms.

6.2 SINGLE LEACH STUDIES & SURFACE CHARACTERISATION OF COMPOSTS

The work described in this section consists of leach studies on as-supplied compost and leach studies on "ash" obtained from compost after destruction of the organic matter , in order to characterise the active fractions of the compost.

6.2.1 Leach Studies on Compost

Leach studies were performed on compost samples obtained from a centralised composting plant which composts organic waste material, using the following reagents:

> 1M HCl, 1M H_2SO_4, 1M HNO_3, 1M H_3PO_4, 1M NaOH, 0.1M $Na_4P_2O_7$, 0.1M Na_2CO_3, 1M KCl, 1M NH_4Cl, 1M $CaCl_2$, 1M Acetic acid, Acetone, Ethanol, Diethyl Ether, Hexane, NaOH refluxed, HNO_3 at 50°C.

Dry compost (10g) was shaken with an extractant (100 ml) for 1 hour. The compost was separated from the extractant by filtration and the residue remaining after extraction was washed, dried, re-weighed and compared to the initial weight of compost (10g). The extractant and residue were analysed using a variety of techniques including X-ray fluorescence (XRF), Total Organic Carbon (TOC), Scanning Electron Microscopy (SEM), SEM-XRF analysis, Transmission Electron Microscopy (TEM), Thermal Analysis, Infrared Spectrometry, and X-Ray Diffraction. A full description of these techniques is given in the report entitled "The Characterisation & Use of Compost", which can be found in the portfolio.

6.2.1.1 Weight Change

Table 6.3 shows weight changes, measured using a balance, following extraction. The results expressed are the average of three experiments.

Table 6.3 – Weight change of compost following extraction

Extractant	Weight increase/decrease after extraction (percent)
1M HCl	-13
1M H_2SO_4	+14
1M HNO_3	-17
1M H_3PO_4	+6
1M NaOH	+5
0.1M $Na_4P_2O_7$	+1
0.1M Na_2CO_3	-4
1M KCl	+1
1M NH_4Cl	-3
1M $CaCl_2$	-8
1M Acetic acid	-11
Acetone	-1
Ethanol	-1
Diethyl Ether	-5
Hexane	-2
No extractant	-

Note: positive figures indicate an increase in the weight of compost after extraction. Negative figures indicate a weight decrease after extraction

6.2.1.2 Total Organic Carbon

The Total Organic Carbon in the leachate was determined using an O.I. Corporation Model 700 Total Organic Carbon Analyzer. Furthermore the level of organic matter remaining in the compost after extraction was determined by heating the residual compost at 800°C in an oven to destroy all organic matter leaving an "ash". From a comparison of the weight of "ash" with the residual compost the percentage organic matter was determined and the results are given in Table 6.4

Table 6.4 – TOC and organic matter levels following extraction

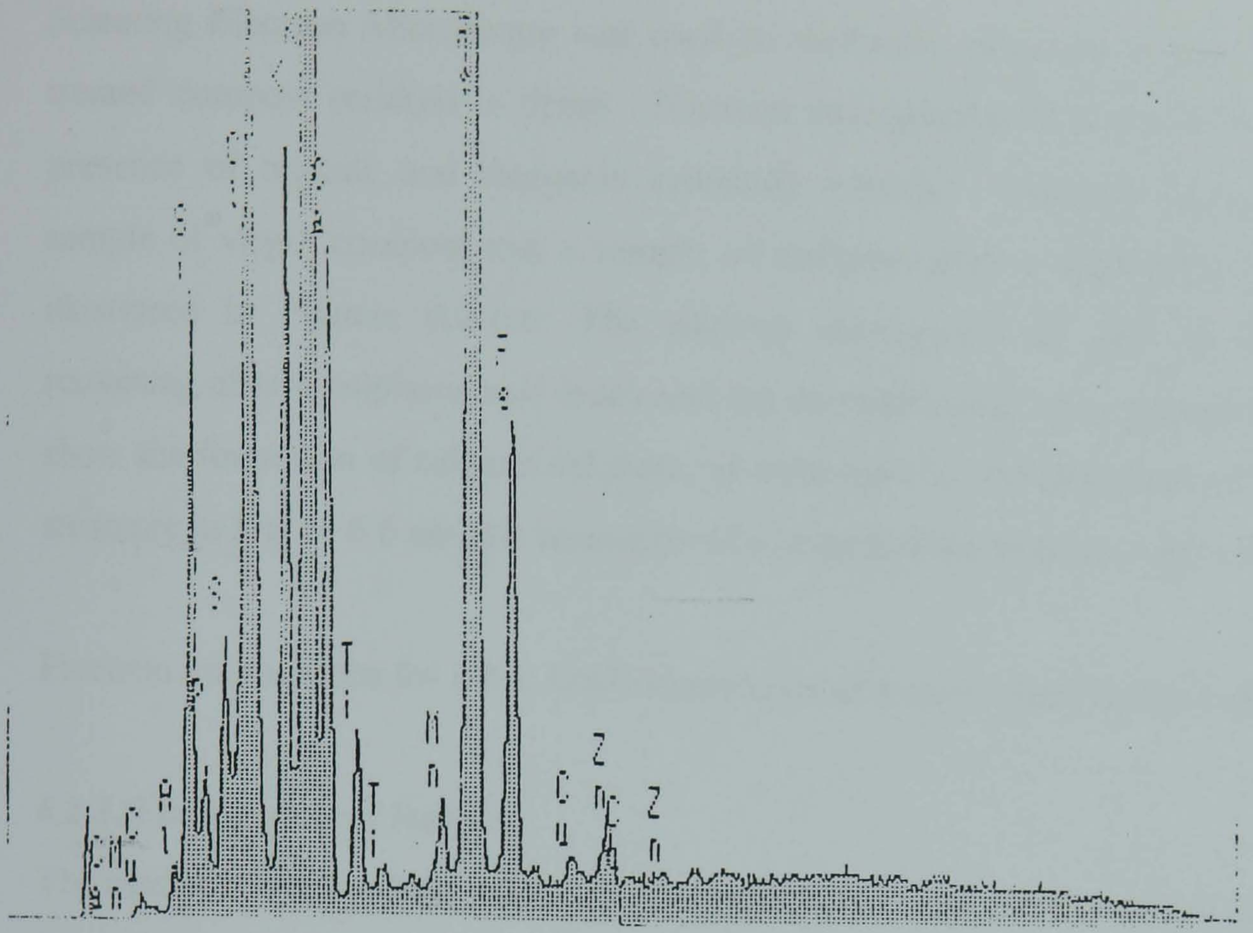
Extractant	TOC leached (as a percentage of total compost)	Organic matter in residue (% of total compost weight) after extraction
1M HCl	1.2	46
1M H_2SO_4	1.1	39
1M HNO_3	1.2	41
1M H_3PO_4	3.0	41
1M NaOH	3.5	29
0.1M $Na_4P_2O_7$	2.7	38
0.1M Na_2CO_3	2.3	38
1M KCl	1.1	50
1M NH_4Cl	1.1	34
1M $CaCl_2$	0.9	46
1M Acetic acid	-	35
Acetone	-	38
Ethanol	-	37
Diethyl Ether	-	40
Hexane	-	35
NaOH refluxed	7.0	26
HNO_3 at 50°C	3.0	43
No extractant	-	42

6.2.1.3 XRF Data

All leachates and residues, when possible, were analysed by XRF to determine the inorganic elements present. A typical XRF analysis of compost is shown in Figure 6.1 and further XRF data for compost residues leached with various reagents are presented in Appendix 4. The peaks in the pattern are indicative of the relative quantities of elements present in the sample.

When organic solvents are used for extraction it is more difficult to detect inorganic elements in a sample and the XRF traces show poor resolution as evidenced in the hexane and acetone leaches. As a result of this limitatation, XRF was not used for the ethanol and diethylether leachates.

Figure 6.1 XRF analysis of compost



6.2.1.4 Variation of Extractant Concentration in Single Leach

For the 1M HCl, 1M H_2SO_4, 1M HNO_3, and 1M NaOH leaches the effect of varying the extractant concentration was investigated. Measurements of weight change, percentage TOC after extraction and the percentage carbon in the residue were made and these data are summarised in Table 6.5.

Table 6.5 –Effect of extractant concentration on compost

Extractant	Weight increase/decrease after extraction (percent)	TOC leached (as a percentage of total compost)	Carbon in residue (% of total compost weight) after extraction
0.5M HCl	-14	1.1	45
1M HCl	-13	1.2	46
2M HCl	-11	1.2	48
0.5M H_2SO_4	+4	1.0	40
1M H_2SO_4	+14	1.1	39
2M H_2SO_4	+27	1.1	50
0.5M HNO_3	-13	1.2	39
1M HNO_3	-17	1.2	41
2M HNO_3	-18	1.8	45
0.5M NaOH	+1	3.0	37
1M NaOH	+5	3.5	29
2M NaOH	+14	3.4	37

6.2.1.5 Scanning Electron Microscopy

Scanning Electron Microscopy was used to study the structure of the compost and treated compost residues in detail. Electron micrographs of compost can show the presence of organic and inorganic (mineral) material. Electron micrographs of a sample of virgin compost and a sample of compost after a sulphuric acid leach are illustrated in Figures 6.2-6.6. The electron micrograph of part of the compost remaining after a sulphuric acid leach and the corresponding x-ray pattern (Figure 6.7) show the formation of calcium sulphate, as evidenced by the formation of the acicular structure in Figure 6.6 and the formation of a large sulphur peak in Figure 6.7.

Electron micrographs for other leach-treated composts are given in Appendix 5.

6.2.1.6 Discussion of Results

The results of the leaching studies are discussed and evidence for active fractions in the compost is given.

Hydrochloric acid leach

The decrease in compost weight after extraction (-13%) and the x-ray fluorescence data suggest that compounds of calcium and iron are being leached from the compost. The electron micrograph (combined with x-ray analysis) is consistent with this finding since no calcium compounds are found in the compost residue after extraction.

As the HCl extractant concentration is increased, there is a small increase in carbon levels in the residue and less weight decrease of the residue after extraction.

Sulphuric acid leach

The x-ray fluorescence data suggest that only small amounts of inorganics have been leached from the compost, however, the sulphur level in the residue has clearly increased. This, together with the observed increase in weight of the compost after extraction (+14%) suggests that sulphur is being taken up as part of the compost. The electron micrograph confirms this suggestion, and it can be seen that the calcium in the compost is reacting with the sulphate to form insoluble calcium sulphate.

Figure 6.2 – As-supplied compost showing the presence of organic material

Figure 6.3 – As-supplied compost showing the presence of mineral material

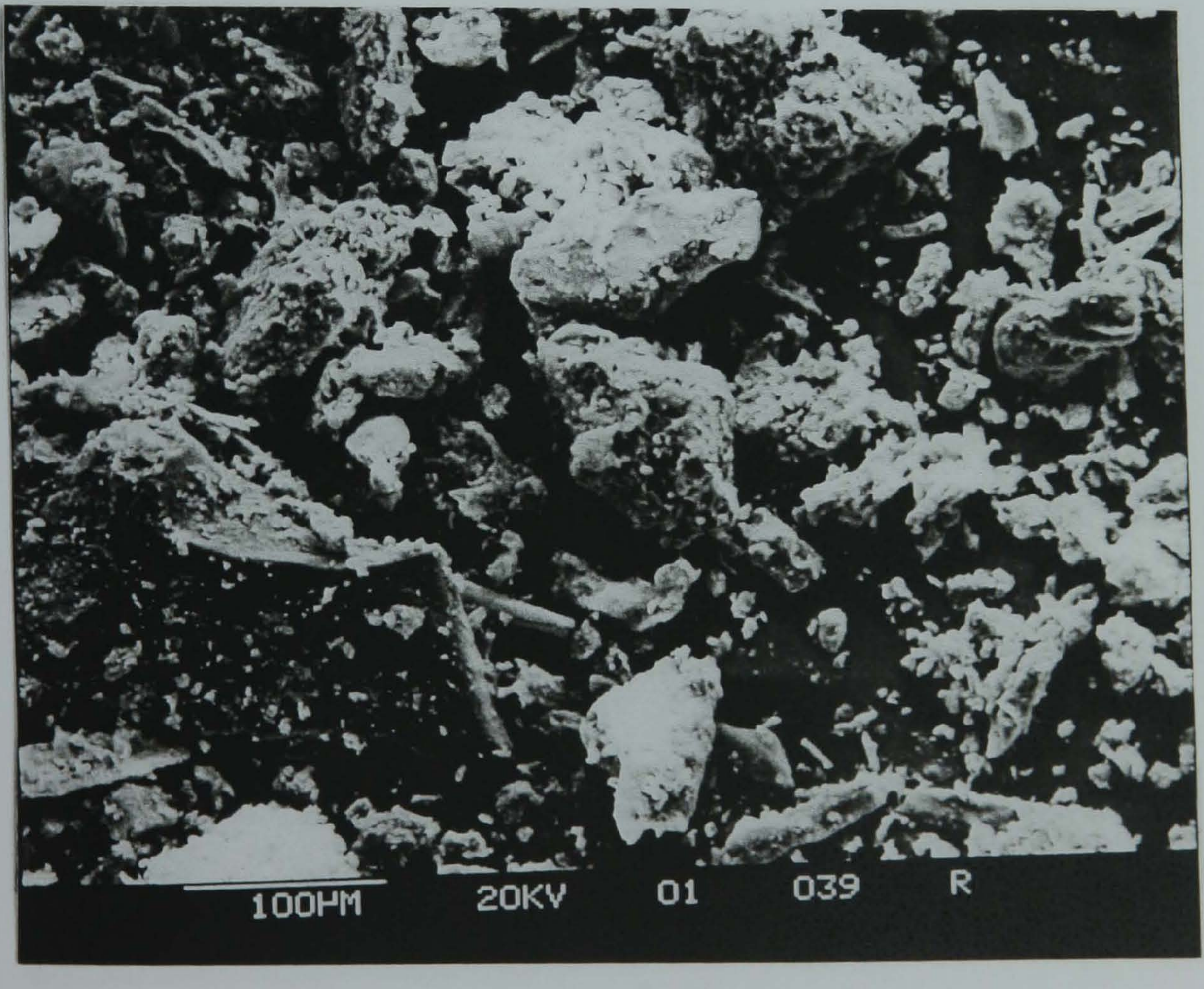


Figure 6.4 – As-supplied compost showing the presence of quartz mineral

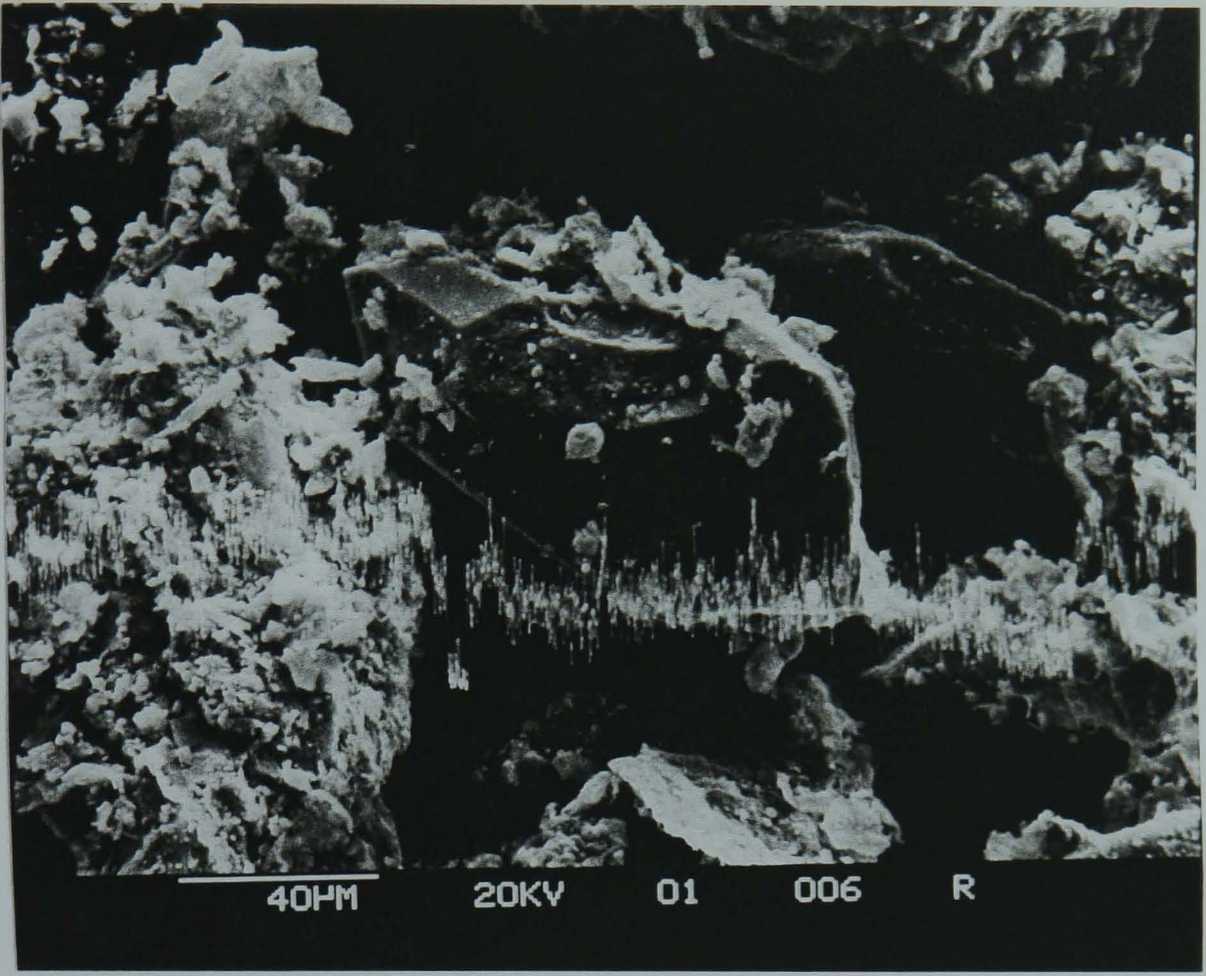


Figure 6.5 – as-supplied compost showing the presence of cellulose fibres

Figure 6.6 – Evidence of calcium sulphate formation following a sulphuric acid leach

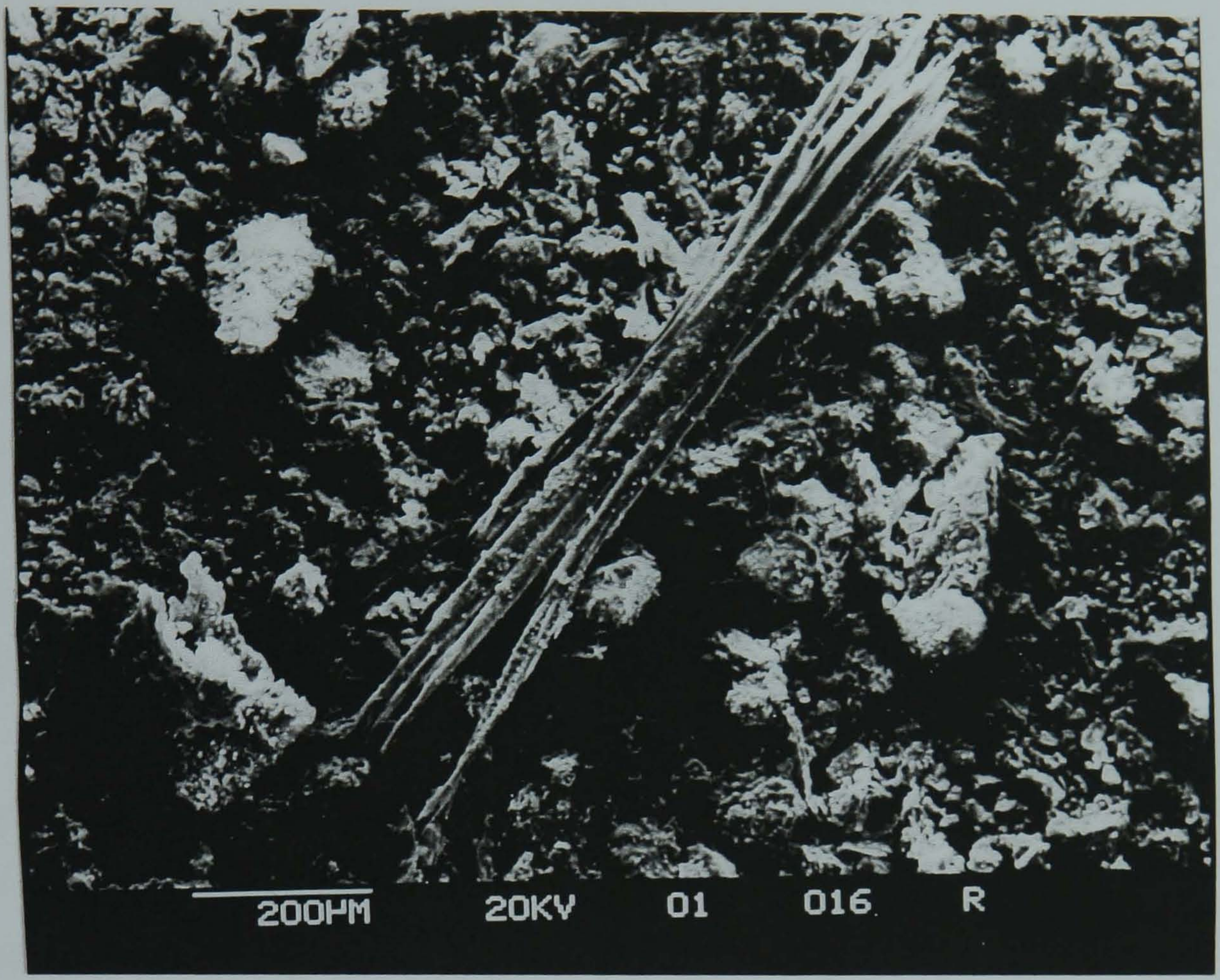
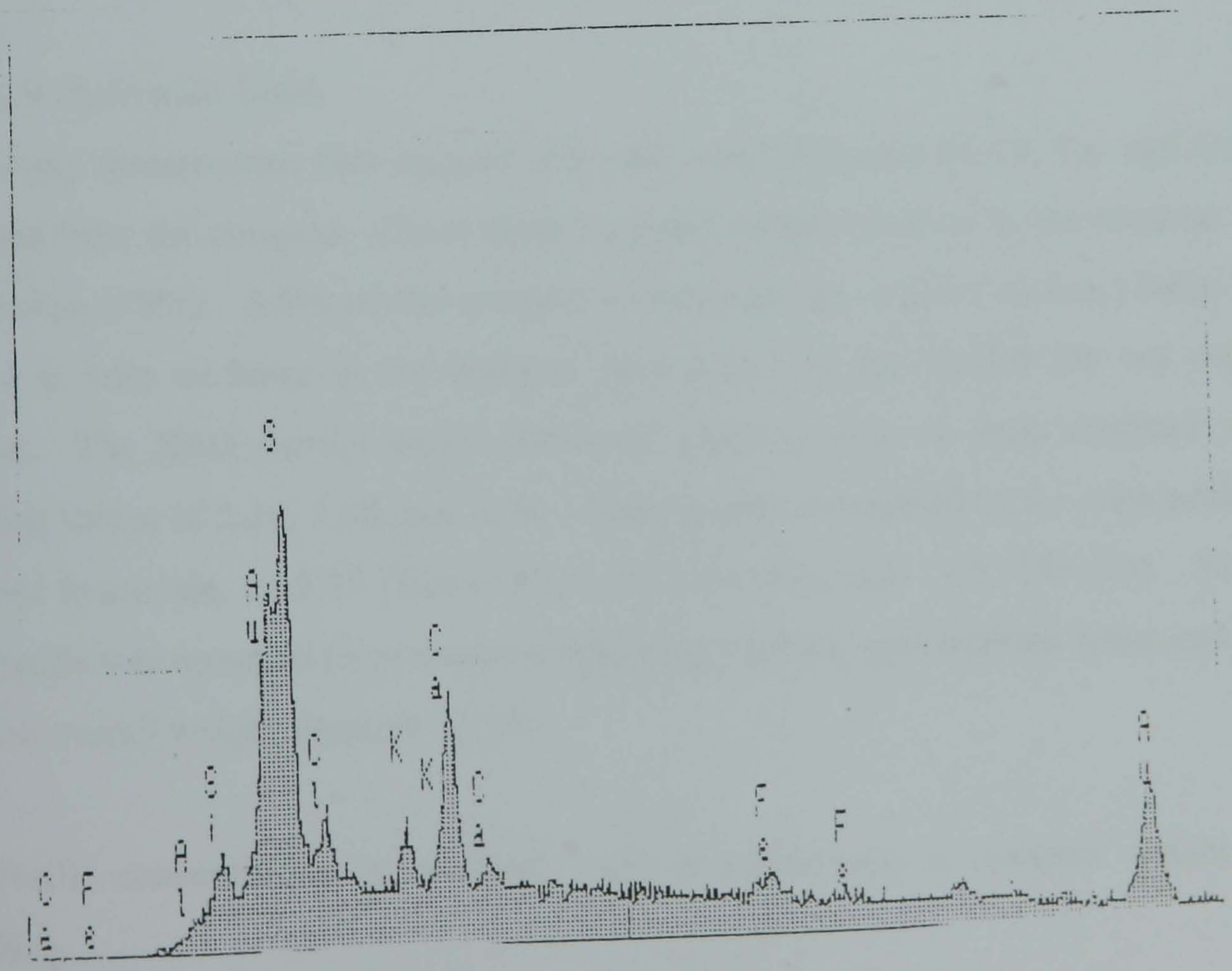


Figure 6.7 – XRF analysis of calcium sulphate fraction of sulphuric acid treated compost



As the H_2SO_4 concentration is increased, there is a large increase in compost weight after leaching, and there is a slightly higher carbon level in the 2 M residue.

Nitric acid leach

The x-ray fluorescence data suggest that calcium is being leached from the compost. This is consistent with the observed weight loss in the compost (-17%). 1.2% of the compost is extracted as organic carbon (Table 6.4). The electron micrograph shows less organic material intact, suggesting that many of the organics are broken down or destroyed during the leach.

As the HNO_3 concentration is increased, there is a larger weight decrease and higher levels of carbon are found in the residue.

Phosphoric acid leach

The x-ray fluorescence data suggest that Ca, Fe, and small amounts of Mn are being leached from the compost. However, there is a weight gain of 6% after extraction. The electron micrograph (combined with x-ray analysis) shows the presence of phosphorous in the residue, but much of the organic component is lost.

Sodium Hydroxide leach

The x-ray fluorescence data suggest that very small amounts of Ca, Fe, and Mn are leached from the compost. There is also a small weight increase in the compost after extraction (+5%). 3.5% of the compost is extracted as organic carbon (Table 6.4). There is little evidence in the electron micrograph of the residue for any organic matter. The XRD pattern shows additional peaks to that of virgin compost at 'd' spacing values of 2.34, 1.68, and 1.58. These peaks correspond to the main peaks for sodium hydroxide, at 2.35 ($I/I_o=100$), 1.70 ($I/I_o=30$), and 1.65 ($I/I_o=25$). Sodium hydroxide was removed from compost following washing with distilled water and there was an overall weight *decrease* of 5%.

As NaOH concentration is increased, there is an increase in compost weight after leaching.

Other inorganic leaching agents

The x-ray fluorescence data for sodium pyrophosphate and sodium carbonate suggest that little is leached from the compost, however, phosphorous levels in the residue from the sodium pyrophosphate leach are increased. For both extractants there is only a small increase in weight of the compost after extraction (1% and 4 %) and the electron micrographs of the residues are very similar to virgin compost.

The x-ray fluorescence data for the potassium chloride, ammonium chloride and calcium chloride leach all show the presence of the leaching agent. For example, the potassium chloride leach clearly shows the presence of both potassium and chlorine. The leachates also show the presence of small amounts of metals, most notably iron, calcium and potassium.

Organic leaching agents

The x-ray fluorescence data for the acetic acid leach suggest that a considerable amount of Ca and K, and a small amount of iron, is leached from the compost. There is also a significant weight loss (-11%) from the compost following extraction with acetic acid and this could be due to the large amount of Ca extracted from the compost.

Due to the limitations of x-ray fluorescence, data on organic leachates is of limited value. The x-ray fluorescence data for the acetone and hexane leach show that only very small amounts of Ca, Mn, and Fe are leached from the compost.

Weight changes after extraction with organic agents were small. With a maximum of 5% weight loss being observed for the diethyl ether leach.

6.2.1.6.1 Evidence for the Formation of Calcium Sulphate following the Sulphuric Acid Leach

The compost residue remaining after a sulphuric acid leach was particularly interesting since it gave an increase in weight, and appeared to incorporate high levels of sulphur. Electron microscopy also indicated that there was aggregated material containing calcium and sulphur and it is asserted that calcium sulphate is being formed during a sulphuric acid leach, and this observation is confirmed by x-ray diffractory measurements.

The residue from the sulphuric acid leach was analysed by XRD and the pattern compared to that of compost which had not been treated with sulphuric acid. The compost treated with sulphuric acid had additional peaks corresponding to d values of 3.56, 2.85, and 2.33. The main reference d values for anhydrous $CaSO_4$ are reported to be 3.50 (I/Io=100), 2.85 (I/Io=33), and 2.33 (I/Io=32). This is clear evidence for the formation of calcium sulphate.

6.2.2 Leach Studies on "ash"

At high temperatures the organic matter of plant material is destroyed - this is therefore a method of fractionating the compost. Extraction of the remaining compost fraction was then undertaken using selected reagents used in the previous leaching studies, and chosen because of the weight change brought about in the leaching on as-supplied compost. All leachates and "ash" were analysed by x-ray fluorescence to identify the inorganics present.

6.2.2.1 Weight Change

Table 6.7 gives data for weight changes to the "ash" after different leach treatments.

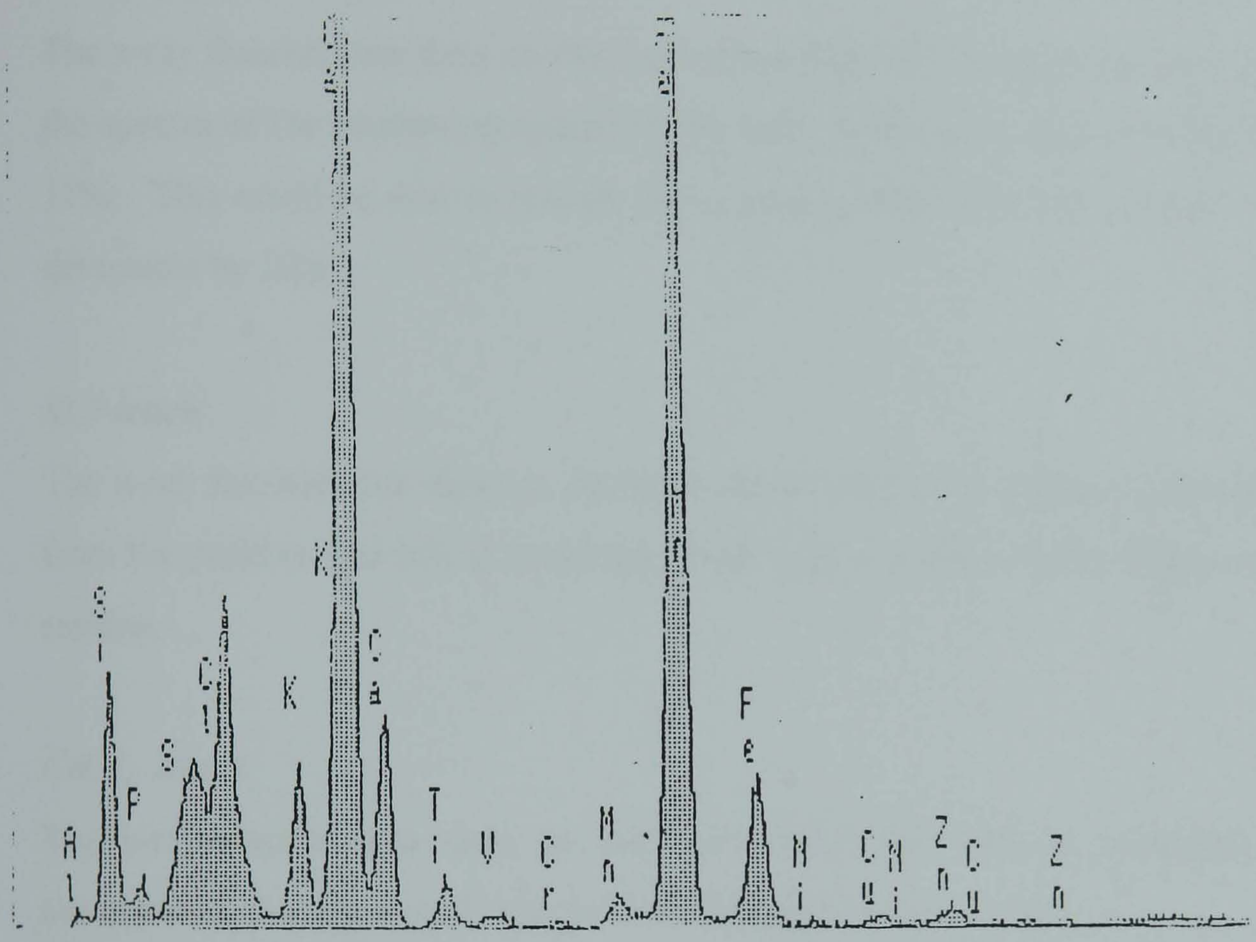
Table 6.7 – Weight change of "ash" following leaching

Extractant	Weight Increase/Decrease after extraction
1M HCl	-29%
1M H_2SO_4	+1%
1M HNO_3	-36%
1M NaOH	+11%
1M KCl	+6%
1M $CaCl_2$	+3%

6.2.2.2 XRF Data on Leach and "ash" after Extraction with Selected Reagents

XRF analysis of the "ash" is presented in Figure 6.8 and used as a reference for comparison of all XRF data. Further XRF data following leaching of the compost with selected reagents is shown in Appendix 6.

Figure 6.8 – XRF analysis of "ash"



6.2.2.3 Discussion of Results

HCl leach

The x-ray fluorescence data show that the residue contains significantly reduced levels of calcium, zinc and copper, but there is an increase in chlorine levels. The leach contains high levels of calcium and iron and this is consistent with the weight loss of 29% from the residue.

H_2SO_4 leach

The x-ray fluorescence data show that the residue has an increased level of sulphur, but the levels of calcium and iron are slightly reduced. Analysis of the leachate shows high levels of iron. These results suggest that calcium and iron compounds are being leached from the residue, but sulphur is being incorporated into the compost and results in the very small weight increase of 1%.

HNO_3 leach

The x-ray fluorescence data show that the residue contains a significantly reduced level of calcium. The leach shows high levels of calcium and iron and this is consistent with the 36% weight loss from the residue.

NaOH leach

The x-ray fluorescence data on the leach show that little is extracted with no change in the spectra of the residue compared to the 'ash', however there is a weight increase of 11%. This could be due to sodium being incorporated into the residue, which is not detectable by XRF.

KCl leach

The x-ray fluorescence data on the leach shows that little evidence of metal extracted from the residue and this is consistent with only a small weight increase (6%) in the residue.

$CaCl_2$ leach

The x-ray fluorescence data on the leach show that little is extracted and this is consistent with only a small weight increase of 3% in the residue.

6.2.3 Conclusions

The leaching studies on compost have shown that certain reagents are better at removing specific chemical species from the compost. It has also been shown that some reagents, such as sulphuric acid, are capable of reacting with fractions of the compost to produce new materials e.g. calcium sulphate.

6.3 POLLUTANT REMOVAL

This section reports a full chemical analysis of the source compost and results of compost surface characterisation studies in order to determine a mechanism for pollutant binding.

6.3.1 Bulk Analysis of Source Compost

The analytical data for bulk composition of the compost was carried out by the analytical service in Elm Farm Research Centre, and are presented in Table 6.8.

Table 6.8 – Analytical data for source compost

Unit	Value	Standards set by Ministry in Germany
Total Nitrogen (% of DM*)	1.18	
Total Phosphorous (% of DM)	0.25	
Total Potassium (% of DM)	0.51	
Total Magnesium (% of DM)	0.20	
Total Carbon (% of DM)	19.8	
C:N Ratio	17:1	
Total Zinc (mg/kg of DM)	158.5	400
Total Copper (mg/kg of DM)	50.7	100
Total Lead (mg/kg of DM)	131.0	150
Total Nickel (mg/kg of DM)	16.6	50
Total Chromium (mg/kg of DM)	21.7	100
Total Cadmium (mg/kg of DM)	0.92	1.5
PH	8.03	
Conductivity (mmhos)	1.20	

*DM= Dry Matter

1 The Nitrogen content of the material is typical for a compost derived from organic waste. The levels of phosphorous and potassium are relatively low.

2 The C:N ratio which is within the range where one would expect the Nitrogen which it contains to be available to plants but will not easily be leached out.

3 In the absence of a standard for the UK with respect to Potentially Toxic Elements (PTE) the PTE levels of the compost have compared with the levels set by the Ministry in Germany for general purpose compost. According to these standards all of the PTE's tested are below the acceptable levels.

4 The pH of the material is slightly high and the material is therefore alkaline and would not suit plants which require an acid soil. The compost could be a useful liming agent where one wished to increase soil pH. The conductivity of the material is low, there should not, therefore, be a problem with salinity. (comments made by Elm Farm Research Centre)

6.3.2 Surface Characterisation

Experiments were performed to investigate mechanisms which could be involved in pollutant binding to compost.

6.3.2.1 Experimental

Samples of compost were saturated with cadmium, copper and lead by shaking the compost (1 gram) with a solution (100ml) of metal (4000mg/l) to ensure complete saturation. The samples were dried and analysed by XRF, XRD, IR, TEM, SEM, and XPS and selected data are presented in Appendix 7.

Further samples (1 gram) of compost were saturated with methylene blue (100ml) and the samples analysed by XRF, XRD and IR.

XRF analysis on treated compost, used to remove metals, confirms that compost contains those metals. For example, XRF analysis of the compost which had been used to remove copper from solution shows the presence of copper.

XRD analysis, on the whole, did not show any additional peaks to virgin compost which could be attributed directly to metal-related species. However, this does confirm that when the metal binds to compost it does not form any crystalline material.

Infrared analysis of compost after it had been saturated with metals did not show any significant change to the infrared spectrum of virgin compost.

The electron micrographs from SEM of the compost did show that the metals (cadmium, copper and zinc) were bound to both organic and mineral parts of the compost.

6.3.2.1.1 Effect of Acid and Alkali on the Removal of Methylene Blue from a Compost Sample that had been Saturated with Methylene Blue

A methylene blue saturated compost sample (1 gram) was treated with H_2SO_4, HCl, NaOH, and distilled water (100ml). The amount of methylene blue removed by each reagent is shown in Table 6.9.

In the saturation stage the compost removed 123 mg of methylene blue per gram of compost.

Table 6.9 – Effect of acid and alkali on the removal of methylene blue from compost

Reagent	mg dye removed per gram of methylene blue saturated compost	pH of sample
1M H_2SO_4	78	0.57
1M HCl	37	0.52
Distilled water	0	6.57
1M NaOH	3.5	13.2

These data show that the removal of the methylene blue dye is achieved more readily under acid conditions (H_2SO_4 and HCl).

6.3.2.1.2 Effect of Acid and Alkali on the Removal of Metals (Lead and Copper) from a Compost Sample that had been Saturated with those Metals

Separate compost samples were deliberately saturated with lead or copper. The dried compost residue (1 gram) was treated with H_2SO_4, HCl, NaOH, and distilled water (100ml) to determine the amount of copper and lead that could be removed. The results for lead and copper removal are given in Tables 6.10 and 6.11 respectively, with higher levels of removal being achieved under acid conditions.

Compost removed 42 mg of lead and 40mg of copper per gram of compost in the saturation stage.

Table 6.10 – Effect of acid and alkali on the removal of lead from compost

Reagent	mg lead removed per gram of lead coated compost	pH of sample
1M HNO_3	39	0.54
1M HCl	34	0.52
Distilled water	2	3.64
1M NaOH	29	13.23

Table 6.11 – Effect of acid and alkali on the removal of copper from compost

Reagent	mg copper removed per gram of copper coated compost	pH of sample
1M H_2SO_4	30	2.23
1M HCl	30	2.35
Distilled water	1	5.51
1M NaOH	13	11.02
1M NaCl	4	8.52

6.3.2.2 Test of Chelation of Metal with Organics

6.3.2.2.1 Oxalic Acid Binding with Metals

Oxalic acid is a simple dicarboxylic acid and therefore has the ability to form chelates with metal ions such as copper or lead. Any evidence of chelation or bonding would be apparent in the infrared spectra of the material. Therefore 100ml of a concentrated copper sulphate solution was shaken with 1 gram of oxalic acid and the resulting precipitate was analysed by infrared spectroscopy. The spectrum is similar to that of the hemihydrate copper (II) salt of oxalic acid. This confirms that simple dicarboxylic acids can react with copper.

6.3.2.2.2 Humic Acid Binding with Metals

To determine the role that humic acids play in pollutant binding to compost, the non-humic fraction of the compost was tested for its ability to remove pollutants (copper, lead and methylene blue). The method for removing humic acids from peat described by Ong & Swanson (1966) was used in this work.

A NaOH solution (2%) was added to a compost sample in the ratio 1 part sample to 5 parts solution by volume and placed in a plastic bottle. The mixture was shaken for 24 hours and then centrifuged. The liquor of each sample was decanted, then filtered successively through glass wool and filter paper. The solid remaining after removal of the humic acids was washed with distilled water and 1N HCl to remove the cations. The samples were further washed with distilled water then dried at room temperature. The dried sample (1.0 gram) was then shaken separately with a copper, lead and methylene blue solution (100ml) to test its ability to remove these pollutants. The results are shown in Figures 6.9, 6.10, and 6.11 respectively.

The data in Figures 6.9, 6.10, and 6.11 show that the removal of humic acid from compost decreases the ability of compost to remove copper, lead and methylene blue by approximately 50% for each pollutant. However, it should be noted that the humic acid-stripped residue is still capable of removing some copper, lead and methylene blue.

6.3.2.3 Test of Ion Exchange

A further mechanism which could be responsible for the removal of metal ions by compost is ion exchange, whereby positive ions on the surface of the compost e.g. H^+ ions are replaced by metal ions such as copper or lead. To test this a number of experiments were performed.

6.3.2.3.1 Analysis of Group I and II Metal Levels in Solution Following Removal of Copper by Compost

To determine whether groups I or II metals are involved in heavy metal exchange, samples of compost (1 gram) were shaken with 4000 ppm copper sulphate solution (100 ml) and the resulting solution analysed for sodium, potassium, calcium, and magnesium. A control experiment with water as a reference in place of copper sulphate solution was also run. The results are given in Table 6.12

Figure 6.9: Removal of copper by compost before and after humic acid removal

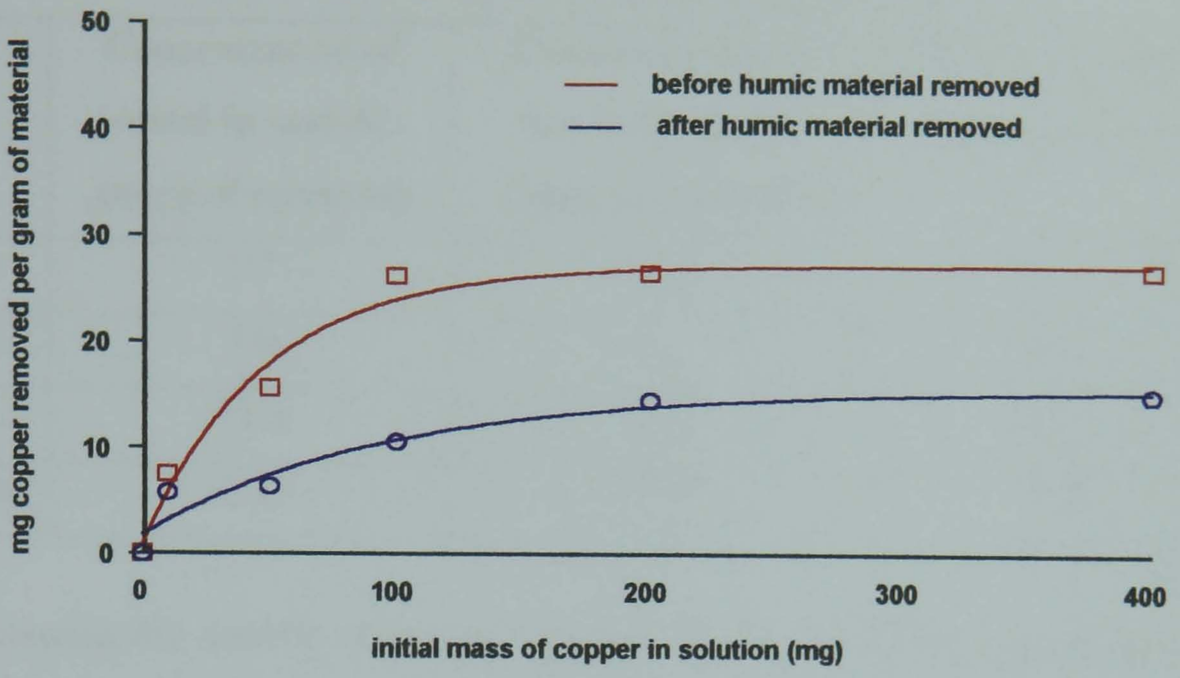


Figure 6.10: Removal of lead by compost before and after humic acid removal

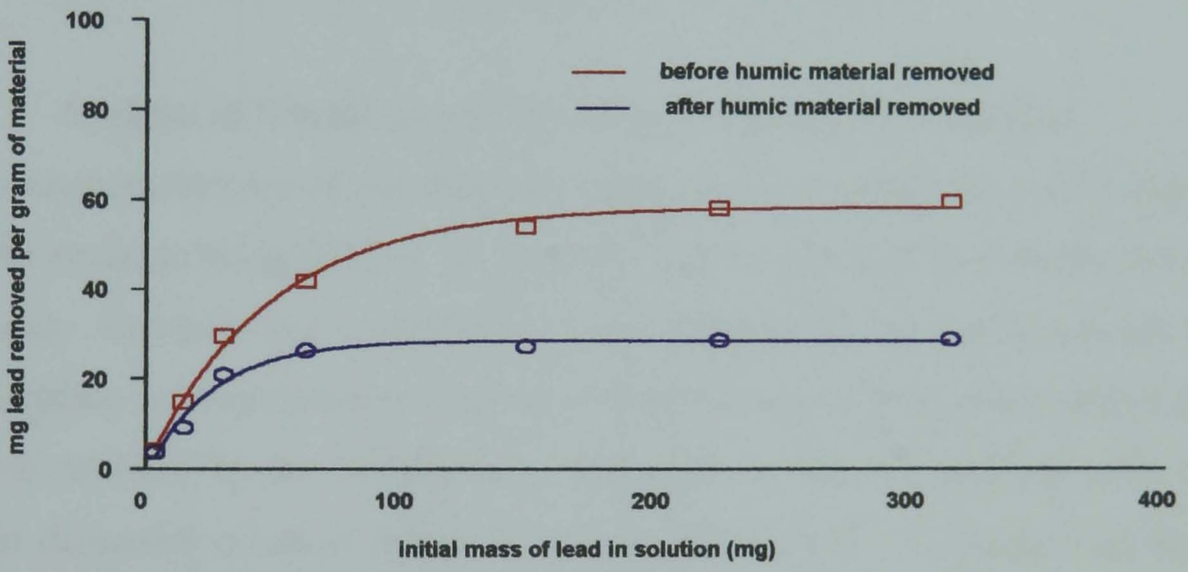


Figure 6.11: Removal of methylene blue by compost before and after humic acid removal

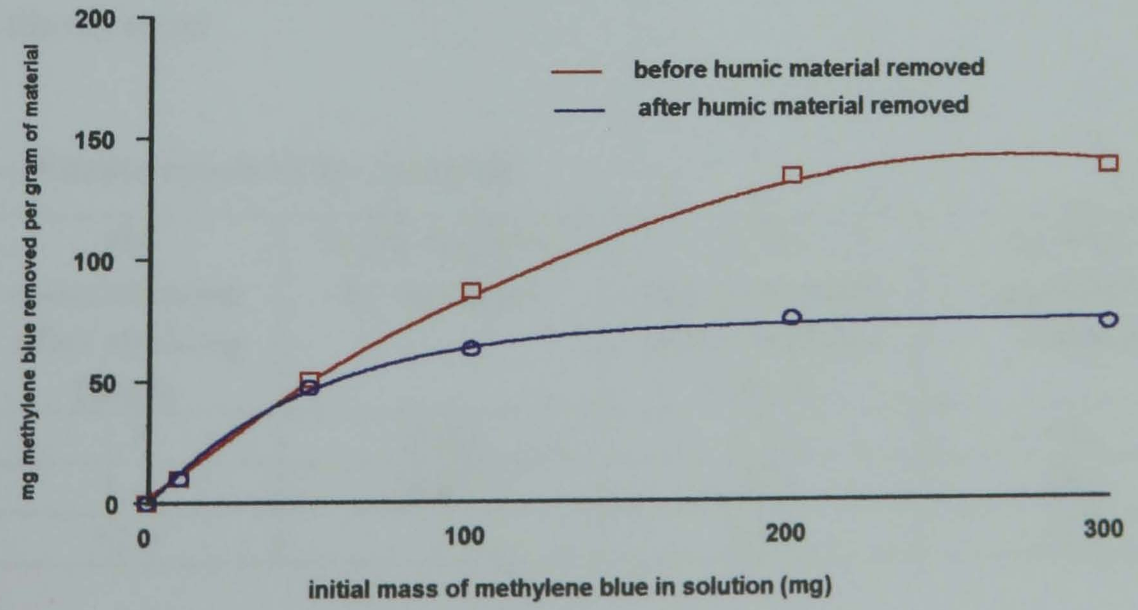


Table 6.12 – Extractability of Group I and II metals from compost

Metal	Concentration of metal in sample (mg/g of compost)	Concentration of metal in control (mg/g of compost)	Difference in metal concentration
Sodium	1.5	1.5	0
Potassium	5.0	4.1	0.9
Calcium	12.6	2.5	10.1
Magnesium	0.45	0.18	0.27

There is a considerable amount of calcium released from the compost suggesting that some of the calcium is replaced by copper. There is further evidence for this from XRF analysis of compost with copper added (appendix 7), which shows a reduction in the intensity of the calcium peak compared to that in the raw compost.

6.3.2.3.2 Analysis of Nitrate Levels after Lead Removal by Compost

To date, the work on removal of metal ions by compost has concentrated on the metal ion, with little attention being given to its counter ion (in the case of lead nitrate this is the nitrate ion). Compost has a capacity of approximately 60 mg lead per gram of compost, therefore, an experiment was run at a concentration of lead where almost all of the lead is removed by the compost (i.e. equivalent to 30 mg lead per gram of compost), to determine compost ability to remove nitrate ions. Compost (1g) was shaken with 300 mg/l lead nitrate solution (100ml) and the nitrate level in solution analysed by ion chromatography (Table 6.13). The data show that no nitrate is removed by the compost.

Table 6.13 – Nitrate removal by compost

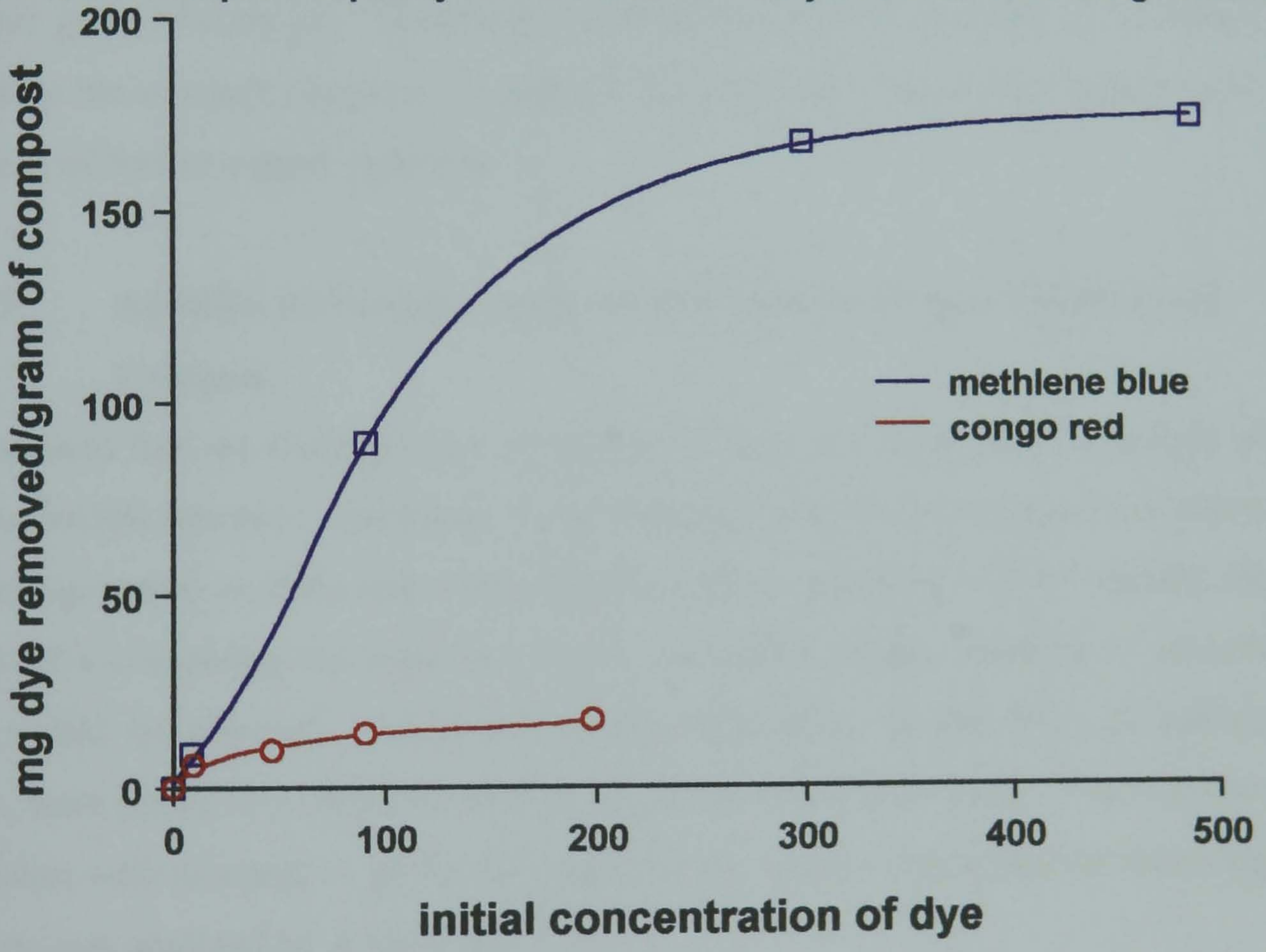
Sample	Pb concentration after shaking (mg/l)	% Pb removed by compost	NO_3- concentration after shaking (mg/l)	% NO_3- removed by compost
1	1.4	96%	25.6	0%
2	1.4	96%	25.6	0%
Blank	32.5	-	25.5	0%

6.3.2.3.3 Removal of Neutral and Positively-charged Dyes

Congo red is a neutral dye and methylene blue is a positively-charged dye. Compost (1 gram) was shaken with each of these dye solutions (100ml) at various concentrations of dye and the amount of dye removed was determined.

Figure 6.12 shows the difference in the ability of compost to remove congo red and methylene blue. In summary, a greater amount of the positively charged dye, methylene blue, was removed than congo red, the neutral dye.

Figure 6.12: Compost capacity for removal of methylene blue and congo red dye



6.3.2.3.4 Removal of Dichromate Ions by Compost

Dichromate ions are negatively charged, therefore, the ability of compost to remove dichromate ions at various concentrations was tested. Compost (1 gram) was shaken with varying concentrations of dichromate ions (100ml) and the results are shown in Table 6.14.

Table 6.14 – Removal of dichromate ions by compost

Initial concentration of Chromium ions (mg/l)	Chromium removed (mg) per gram of compost
1900	0.5
972	1.1
506	1.0
204	0.9
88	0.8

Compost has the ability to remove 60 mg lead per gram of compost and 30 mg of copper per gram of compost. Therefore, it can be seen that the amount of chromium removed by the compost (approx. 1 mg/gram of compost) is small in comparison to the amount of lead or copper removed.

6.3.2.3.5 Addition of Various Amounts of Sodium to Copper Solution and Compost

It is postulated that ion exchange is a reversible process, but adsorption is thought to be an irreversible process. Therefore, if ion exchange was the mechanism responsible for removing metals or dyes from compost it would be expected that by varying the amounts of a competing ion such as sodium, the ability of the compost to remove copper would be affected. Varying amounts of sodium, in the form of sodium chloride, were added to a 500ppm solution of copper chloride (100ml). The solutions were shaken with compost (1 g) for 24 hours and the copper concentration remaining in solution was analysed by AAS (Table 6.15).

It can be seen that copper removal by compost is only slightly affected by the presence of sodium, which suggests that ion exchange only plays a small role, if any, in the binding of copper to compost.

Table 6.15 – Effect of sodium on copper removal by compost

Amount of Na added (grams)	% copper removed from an initial 500ppm solution
0	45.6
0.1	42.3
0.25	38.3
0.50	38.8
0.75	42.3
1.0	38.8
2.5	36.0
5.0	35.6

6.3.3 Studies on Fractionated Compost

In this section investigations on fractionated compost samples following leaching and 'ashing' are reported for lead and methylene blue removal.

6.3.3.1 Removal of Lead and Methylene Blue by Compost following Leaching with Various Acids/Alkalis

Compost was leached with various acids/alkalis and the resulting residue was tested for its ability to remove lead and methylene blue. The amount of lead and methylene blue removed was determined by atomic absorption spectroscopy and UV/VIS spectrophotometry respectively.

6.3.3.1.1 Removal of Methylene Blue by Compost after Compost has been Leached with Reagents

Compost was leached with a number of reagents (tabled below) and the resulting residue was assessed for its ability to remove methylene blue at a concentration of 750 mg/l (Table 6.16), and the pH of the residue measured after removal of the dye.

Table 6.16 – Removal of methylene blue by leached compost

Leaching Reagent	mg methylene blue removed per gram of residue	% methylene blue removed	pH of sample after methylene blue removal
None	62.3	92.3	6.15
HNO_3	12.5	18.5	3.28
HCl	11.5	17.0	3.30
H_2SO_4	40.5	60.0	6.14
H_3PO_4	14.5	21.0	3.97
Acetic acid	49.6	73.5	6.10
$CaCl_2$	61.9	91.6	7.00
NaOH	57.5	85.2	6.41

The results suggest that there is a relationship between percentage dye removal and pH of the residue, with maximum removal corresponding to a pH of 6-7. This pH effect may, however, be induced by the reagent itself, for example, with sulphuric acid treated compost the pH is about 6.

6.3.3.1.2 Removal of Lead by Compost after Compost has been Leached with Reagents

Compost was leached with a number of reagents and the resulting residue was treated for its ability to remove lead from solution at a concentration of 300ppm (Table 6.17).

The results show that sulphuric acid-treated compost is as effective an extractant as the virgin compost in removing lead. Hydrochloric acid treated compost, on the other hand, is poor at removing lead. This would suggest that an ion exchange reaction between hydrogen ions on the compost and lead ions is not responsible for the removal of lead.

Table 6.17 – Removal of lead by leached compost

Leaching Reagent	mg lead removed per gram of residue	% lead removed	pH of sample after lead removal
None	31	99	6.96
HNO_3	22	69	2.89
HCl	4	12	2.40
H_2SO_4	31	98	2.21
H_3PO_4	15	50	2.30
Acetic acid	28	91	4.68
$CaCl_2$	28	93	5.01
NaOH	18	60	10.30

6.3.3.2 The Capacity of As-supplied Compost and "ash" to remove Lead and Methylene Blue Dye

The maximum removal capacity of lead and methylene blue dye by compost (1 gram) and by "ash" (1 gram) was investigated and compared (Tables 6.18 and 6.19 respectively).

Table 6.18 – Lead removal by As-supplied compost and "ash"

Initial concentration of lead solution	Compost		"ash"	
	mg lead removed per gram of compost	% of lead removed	Mg lead removed per gram of "ash"	% of lead removed
Approx. 1000ppm (100ml)	52	62%	76	90%
Approx. 4000ppm (100ml)	50	14%	75	21%

The "ash" was a more efficient medium for lead removal. However, this is likely to be due to a pH effect, since the pH of the "ash" is very high - pH 11, leading to the formation of lead hydroxide species.

Table 6.19 – Methylene blue removal by As-supplied compost and "ash"

Initial concentration of methylene blue solution	Compost		"ash"	
	Mg methylene blue removed per gram of compost	% of methylene blue removed	mg methylene blue removed per gram of "ash"	% of methylene blue removed
Approx. 100ppm (100ml)	9.5	99%	5.9	61%
Approx. 1000ppm (100ml)	93	95%	63	64%
Approx. 3000ppm (100ml)	140	47%	160	53%

The removal of methylene blue by 'ash' is not simple. A UV/Visible spectrum of the solution after dye removal shows that the intensity of the main peak (at 660nm) is reduced, and the peak appears to be shifted. Furthermore, the peak at 500nm is of a slightly higher intensity, and the dye has a redder appearance. It was confirmed that this was due to a pH effect induced by the destruction of the organic matter.

The 'ash' was found to have a pH in the region of pH 11, and at this pH the structure of methylene blue is altered to give a shifted UV/VIS spectrum. This was confirmed by deliberately adjusting the pH of a sample of methylene blue to pH 11 and recording its UV/VIS spectrum.

It has been reported (Venkataraman, 1978) that the increased intensity of the peak at 500nm is due to the dimethylamino groups in methylene blue being forced out of the molecular plane. In the blue form of the dye the positive charge in methylene blue is distributed symmetrically throughout the chromophoric system. However, in the redder form, the fraction of positive charge on the terminal positions is reduced and this results in the hypsochromic spectral shift. It is known that strongly basic anions will induce this effect.

6.4 CONCLUSIONS

A number of general conclusions can be made based on the data produced in this section:

1. Surface characterisation of compost by XRF confirmed the presence of metals (copper, cadmium and lead) on the compost surface. Further examination by SEM showed that the metals were distributed in both organic and mineral parts of the compost.

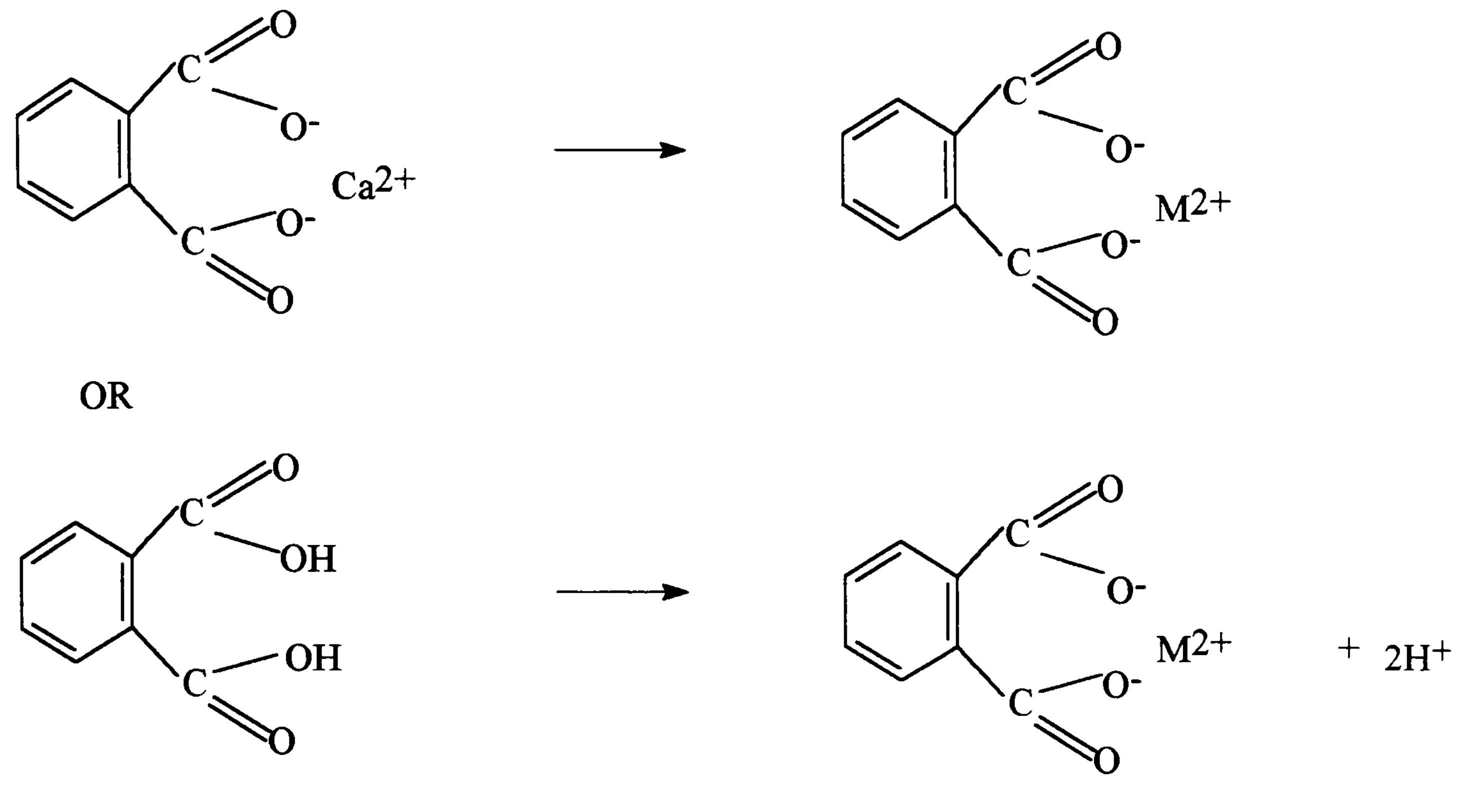
2. Compost is effective at removing positively-charged species, such as Pb^{2+}, Cu^{2+} or methylene blue dye but poor at removing negatively-charged species, such as the dichromate ion and congo red dye.

3. Examination of the leachate following metal (copper) removal shows the presence of large amounts of calcium in the solution. This indicates that some of the copper is replacing calcium in the compost.

4. The addition of sodium chloride to a copper solution has only a small effect on copper removal by compost. This suggests that ion exchange only plays a small role, if any, in binding of copper to compost.

5. The removal of humic material from the compost considerably reduces (by approximately 50%) its ability to remove metals (copper) and methylene blue dye. This suggests that humic acids play an important role in removing metals and methylene blue dye.

Overall, these data suggest that more than one mechanism may be involved in metal removal and methylene blue removal by compost. The data are consistent with the theory that humic acids are involved in metal removal. For example, the mechanism suggested below fits the data.



Where M = Pb, Cu, or Cd

It is likely that other mechanisms are also responsible for metal removal, but, this mechanism is likely to be the primary mechanism.

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CHAPTER SEVEN

CONCLUSIONS

There is approximately 14 million tonnes of biodegradable organic waste produced by households in the UK every year which must be treated or disposed of (Burnley, 1998). New legislation, such as the EC Directive on landfill (1999/31/EC), is likely to cause an increase in composting and anaerobic digestion activities in the coming years. Some of the main difficulties with these methods for treating organic waste generated by households include (1) contamination of compost products, which often occurs as a result of problems in separating organic waste, (2) finding markets for the products.

The participation of householders is central to the success of composting or anaerobic digestion procedures, because they rely on householders separating their organic waste at source. In the survey, detailed in chapter 2, which focused on the practice of home composting, it was found that residents in the less affluent area were less likely to home compost and had a less favourable attitude towards environmental activities than residents in the affluent area. This research has proved useful in identifying those specific areas in the community that may be targeted to increase composting practice in the community so that less organic waste is sent to landfill.

Centralised composting and anaerobic digestion schemes also rely on good source separation of waste, however, if this is not performed correctly it can lead to contamination of the organic waste stream and contamination of the final compost. Contamination of the compost could be in the form of physical contamination e.g. glass, plastic or in the form of chemical contamination, such as heavy metal contamination. Analysis of a range of composts prepared at centralised treatment plants, has shown, in chapter 3 that compost derived from the organic fraction of household waste was of slightly poorer quality than that obtained from green waste (gardens, parks and civic amenity site waste).

The agricultural sector is the largest potential user of compost, but for compost to be used as a soil improver/fertiliser the quality of the product is critical. Heavy metal contamination of compost is of particular concern because of possible metal uptake by plants and it is critical to establish the bioavailability of heavy metals in compost. The findings presented in chapter 4 confirm that heavy metals in compost are not readily bioavailable and this chapter gives the first indication in this thesis to the nature of the possible interactions between heavy metals and compost. The leachability data presented suggest that the metals Pb, Cd, Cu, and Zn are strongly held on the compost and are not easily removed unless harsh treatment conditions are used (for example, high concentrations of nitric acid). To obtain more information on the nature of the compost-metal interactions a series of batch studies of metal uptake were carried out and have been detailed in chapter 5.

Novel research on metal and dye removal by compost is reported in chapter 5. Metal uptake by compost in batch sorption experiments is rapid and most of the uptake of total metal occurs within 1 hour, however, the uptake of methylene blue dye is slower and there is a continual increase over a 24 hour period. The capacity of compost is approximately 60, 30, 25, and 10 mgg^{-1} for lead, copper, cadmium, and zinc respectively and 180 mgg^{-1} for methylene blue dye.

Evidence from work on peat suggests that the mechanism of pollutant binding to biosorbents such as peat and compost is complex, and chapter 6 investigates the mechanism for heavy metal and dye binding to compost. Leaching experiments and surface characterisation experiments were undertaken to establish a potential mechanism for pollutant binding to compost. The data for calcium exchange are consistent with the metals replacing calcium at exchangeable sites in both the inorganic and organic compost fractions. The fact that compost is effective at removing Pb^{2+}, Cu^{2+} and methylene blue dye, but poor at removing dichromate ions and congo red dye suggests that positively charged species are attracted to the compost. Leaching of the metals from natural compost and compost saturated with Pb and Cu suggest that the metals must be bound by strong interactions to both organic and inorganic fractions. The data for metal sorption to the compost with the humic fraction removed are also consistent with attachment of these metals to both humic and non-humic material.

The strength of the attachment of metals to active sites in the compost provides an opportunity to use it as a replacement for peat and other natural materials in effluent treatment and similar remediation systems. Compost, like peat, would have to be used in the removal of metals or dyes in single use situations and then be disposed of by landfill or incineration unless methods of recycle can be developed. In this use it would, however, replace a natural material and permit at least a single step for recycling of organic waste.

RECOMMENDED FUTURE RESEARCH

The research detailed in this thesis provides a basis from which further research can be performed and advanced. Chapter two described a survey in the London Borough of Hounslow and it would be very useful to survey residents in the Borough in the future to establish whether their behaviour and attitude to environmental issues and composting have changed over time. In addition, this survey concentrates on only one Borough, and there may be opportunities to perform similar research in other parts of the UK. This is particularly worthwhile in view of the recent introduction of an EC Directive on landfill.

Chapters four, five and six examined the bioavailability and ease of removal of certain heavy metals from compost. There are many other metals, which have not been investigated in this research that could cause harm to the environment and there is the opportunity to investigate the availability and binding of some of these other metals to compost. The mechanism for metal and dye removal proposed in this research could be tested for its applicability to other metals.

All of the research in chapters four, five and six has been performed on compost obtained from only one composting site which composts source-separated household waste. It would be extremely worthwhile to consider testing other composts obtained from both similar feedstocks and different feedstocks for their ability to remove metals and dyes.

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APPENDIX 1

Hounslow

London Borough of Hounslow
The Civic Centre Lampton Road
Hounslow TW3 4DN

Environmental Services Department
John Evans
Director of Environmental Services

your contact is Andrea Davies
telephone 0181-862 6682
date 19 September 1996
our ref
your ref

Recycled paper

COMPOSTING RESEARCH PROJECT

This is to confirm that Gary Taylor of Brunel University Chemistry Department has been authorised by the Council to conduct research on composting in the borough.

Mr Taylor's research focuses on attitudes towards composting. His findings will be very useful to the Hounslow Recycling Team in developing the Council's composting programme.

Thank you for your co-operation in this project.

Yours sincerely

Andrea Davies

Andrea Davies
Recycling Co-ordinator

rr863

Hounslow

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The Civic Centre Lampton Road
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drea Davies
:ycling Co-ordinator

Telex 9312134103 (HO G) (Put LLA3036 in 1st line of text) Fax 0181-862 5

BRUNEL
UNIVERSITY

Centre for Environmental chemistry

BRUNEL CHEMISTRY

ENVIRONMENT SURVEY IN THE LONDON BOROUGH OF HOUNSLOW

As part of the Borough's commitment to the environment a survey is being carried out to examine the activities which households are engaged in to reduce the amount of waste they send to landfill. The survey is being coordinated by members of Brunel University and your household has been selected for this survey as part of a representative sample. All information which you provide will be treated as confidential.

We would be grateful if you could spare five minutes to complete this questionnaire and the questionnaire will be collected in 1 weeks time. Please answer all questions honestly.

Please complete the following:

Address	
Date	

Please turn over to begin the questionnaire

Q.1 Do you think there is pollution in your area?
If yes, where and what?

Q.2 Do you think recycling can reduce pollution?
If yes. Why?

Q.3 How often do you purposely purchase products made from recycled materials?

All the time ☐ Some of the time ☐ Never ☐

Q.4 Which of the following items do you recycle?

a) Paper ☐
b) Glass ☐
c) Cans ☐
d) Textiles ☐
e) Aluminium ☐
f) None ☐
g) Other, please specify

Q.5 Have you ever heard of compost or composting?

Yes ☐ No ☐

If yes, go to question 6. If no, go to question 10

Q.6 Have you ever heard of home composting?

Yes ☐ No ☐

If yes, go to question 7. If no, go to question 10

Q.7 Do you home compost?

Yes ☐ No ☐

If yes, what materials?

Q.8 What do you think the main benefits of home composting are? (please rank the following in order of importance to you. Number them from 1-3, 1=most important, 3=least important).

a) Reducing the amount of household waste ☐
b) production of compost which can be used as a soil improver ☐
c) Personal satisfaction ☐

Q.9 What do you think the main inconveniences of composting are? (please rank the following in order of importance to you. Number them from 1-5, 1=most important, 5=least important).

a) Obtaining a composting unit ☐
b) Time required to compost ☐
c) Cost of purchasing a unit ☐
d) Unpleasant odours or pests ☐
e) The space required to site a composter ☐

Q.10 Would you be prepared to separate your waste into different parts (e.g.kitchen/garden waste and glass/paper/dry waste) to help recycle?

Yes ☐ No ☐

Q.11 Please could you indicate your level of education?

GCSE/O Level ☐

BTEC/A Level ☐

Degree Level ☐

Other, please specify ☐

Q.12 Are you gainfully employed?

Yes ☐ No ☐

Q.13 Please can you indicate your property tax band?

Band A	☐	Band D	☐	Band G	☐
Band B	☐	Band E	☐	Band H	☐
Band C	☐	Band F	☐		

Q.14 Please could you indicate what type of property you live in?

House with garden	☐	House without garden	☐
Flat with garden	☐	Flat without garden	☐
Bedsit/studio	☐	Other	☐

Q.15 Do you own this property?

Yes ☐ No ☐

Q.16 In which age group do you fall:

21-30 ☐ 31-40 ☐ 41-50 ☐ 51-60 ☐
61-70 ☐ 70+ ☐

Q.17 Do you have any children?

Yes ☐ No ☐

Q.18 Please can you indicate your ethnic origin?

Black Caribbean	☐	Black African	☐
Black Other	☐	Indian	☐
Pakistani	☐	Bangladeshi	☐
Chinese	☐	Other Asian	☐
White	☐	Other	☐

Q.19 Please could you indicate your sex?

Male ☐ Female ☐

If you have any additional comments please write them here.

Thankyou for your participation in this survey.

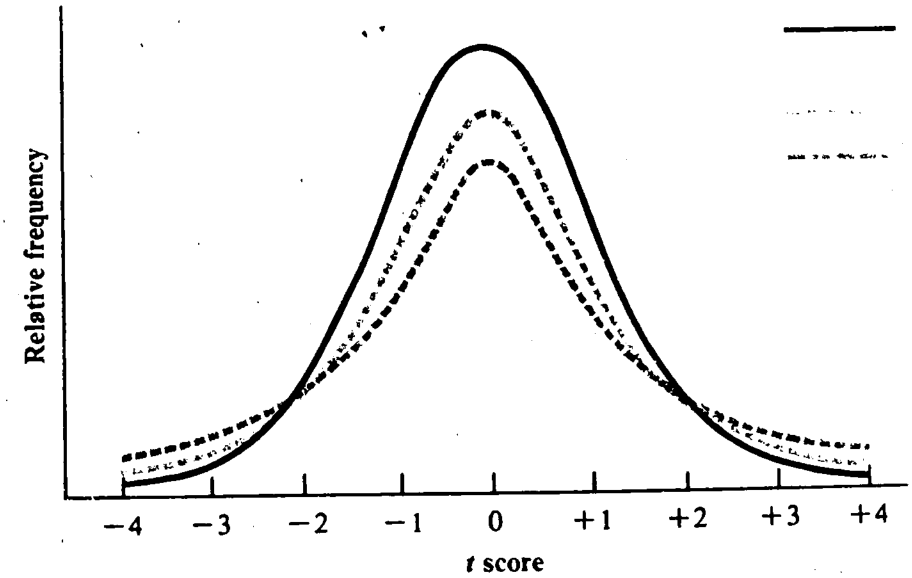
APPENDIX 2

Statistical Analysis of Data based on the students t-test

To statistically test the hypothesis that home composting in the London Borough of Hounslow is dependent on demographic characteristics of the household a sequence of independent sample t-tests were performed on the data. The student's t-test was developed by W.S. Gosset, writing under the pen name of "student". The student's t-test is a practical, quite powerful test widely used in the behavioural sciences. The t-distribution arises when we consider taking a large number of random samples (>30) of the same size, *n*, from a normal distribution with known mean, μ. Then the probability distribution of the statistic

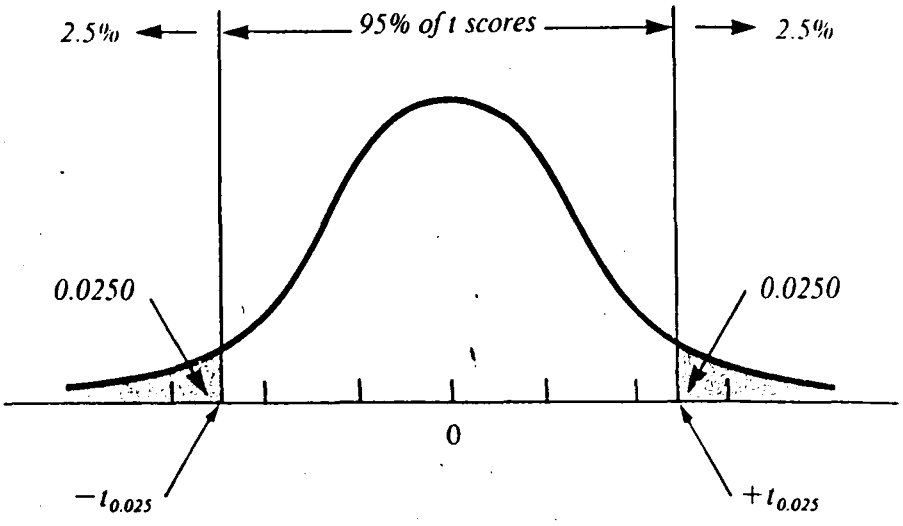
$$t = \frac{x - \mu}{s/\sqrt{n}}$$

may be plotted. It will be symmetrical and unimodal. For different values of *n*, different distributions will be obtained; for large *n* the distribution approaches the standardised normal distribution, while for small n the t-distribution is flatter and has higher tails than the normal distribution.



Sometimes it is desirable to know the value of a population mean, however, it is often not feasible to look at a whole population and a sample is taken. It is often of interest to measure how close the sample mean is to a population mean and the usual way to approach such a problem is to give a range of values for which one is reasonably confident that the range includes the population mean. This interval is termed the *confidence interval.*

It is possible to construct confidence intervals about which there are specified degrees of confidence. For example it is possible to construct a 95% confidence interval.



In practice 95% and 99% confidence intervals are most often used.

The t-test is appropriate when the mean of a null hypothesis population is known and the standard deviation is unknown. In such a case the standard deviation of the population is estimated from the sample standard deviation.

In analysing the survey data generated in this study two samples (A and B) need to be compared on variables such as age, gender etc. In such a case the t-test can be used to compare different scores in two different samples. In the independent sample t-test analysis is performed on the raw scores of each sample. With the t-test, we calculate the mean of each sample and analyse the difference between the sample scores.

The sample scores in one of the conditions can be considered a random sample from a normally distributed population of scores that would result if all the individuals in that population received that condition. If we call the mean of this hypothetical population μ_1 and the standard deviation σ_1. Similarly the sample scores in condition 2 can be considered a random sample from a normally distributed population of scores that would result if all the individuals were given condition 2. We can call the mean of this second population μ_2 and the standard deviation σ_2.

Note that changing the level of the independent variable is assumed to affect the mean of the distribution (μ_2), but not the standard deviation (σ_2) or variance (σ_2^2). Thus, under this assumption, if the independent variable has a real effect, the means of the populations will differ, but their variances will stay the same. Thus, σ_1^2 is assumes equal to σ_2^2. One way in which this assumption would be met is if the independent variable has an equal effect on each individual. A directional alternative hypothesis would predict the samples are random samples from the population where $\mu_1 > \mu_2$ or $\mu_1 < \mu_2$, depending on the direction of the effect. A nondirectional alternative hypothesis would predict μ_1 not equal to μ_2. If the independent variable has no effect,the samples would be random samples from populations where $\mu_1 = \mu_2$, and chance alone would account for the differences between the sample means.

Under these conditions, the sampling distribution of $x_1 - x_2$ has a mean of zero and a standard deviation whose value depends on knowing the variance of the populations from which the samples were taken. Since this value is never known it is estimated using a weighted estimate taken from both samples. When this is done, the resulting statistic is t_{obt}.

$$t_{\text{obt}} = \frac{(\overline{X}_1 - \overline{X}_2) - \mu_{\overline{X}_1 - \overline{X}_2}}{s_{\overline{X}_1 - \overline{X}_2}}$$

$$= \frac{(\overline{X}_1 - \overline{X}_2) - \mu_{\overline{X}_1 - \overline{X}_2}}{\sqrt{s_w^2\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

where s_w^2 = weighted estimate of σ^2 and

$s_{\overline{X}_1 - \overline{X}_2}$ = estimate of $\sigma_{\overline{X}_1 - \overline{X}_2}$ = estimated standard error of the difference between sample means.

The t statistic, then is also used for analysing the data from the two-sample, independent samples experiment. The sampling distribution of t for this design is the same as for the single-sample design, except the degrees of freedom are different. In the independent samples design, df = N-2.

In this study, the data for sample A and sample B were compared on set demographic characteristics, general environmental issues and composting. For each variable, the null hypothesis took the form of:

> "There is *no* difference in the mean *variable* of respondents in the sample A and sample B"

The alternative hypothesis took the form of:

> "There is a difference in the mean *variable* of respondents in sample A and sample B"

Tables A, B, C, D and E outline the basic statistical data for demographic variables, general environmental concern, and composting respectively.

Based on these hypothesis, all statistical data presented is for two-tailed t-tests (i.e. non-directional). Statistical significance (based on the t-test) is represented in the following tables by:

= 95% confident of significance (p<.05)
= 99% confident of significance (p<.01)
= 99.9% confident of significance (p<.001)

To statistically test the hypothesis that home composting is dependent on its perception a similar series of t-tests were performed on the data. The data for composters and non-composters (those that had heard of home composting) were compared using the t-test for demographic variables and general environmental concern.

Table A - Demographic Characteristics of sample A and B

Characteristic	Sample A		Sample B		t-test
	Mean	S.D.	Mean	S.D.	
Age (in decades)	4.46	1.51	4.45	1.56	0.03
Children (1=yes, 0=no)	0.86	0.35	0.79	0.41	1.16
Gainfully employed (1=yes, 0=no)	0.66	0.48	0.34	0.48	4.12###
Gender (1=male, 0=female)	0.38	0.49	0.39	0.49	0.13
Own property (1=yes, 0=no)	0.92	0.27	0.34	0.48	9.32###
Property tax band (1=a,2=b....8=h)	5.94	1.20	3.91	0.59	12.26###
Education	2.04	1.20	0.78	0.96	7.21###

Table B - Comparison of Samples A and B for issues of General Environmental Concern

Characteristic	Sample A		Sample B		t-test
	Mean	S.D.	Mean	S.D.	
Pollution in their area (0=no, 1=yes)	0.95	0.22	0.83	0.38	2.41#
Mention air pollution (0=no, 1=yes)	0.63	0.48	0.49	0.50	1.84
Mention noise pollution (0=no, 1=yes)	0.25	0.44	0.03	1.61	4.31###
Mention waste (0=no, 1=yes)	0.39	0.49	0.17	0.38	3.15###
Mention aircraft (0=no, 1=yes)	0.67	0.47	0.20	0.40	6.74###
Mention vehicles (0=no, 1=yes)	0.77	0.42	0.43	0.50	4.54###
Recycling can reduce pollution (0=no, 1=yes)	0.53	0.50	0.55	0.50	0.26
How often purposely purchase recycled materials (0=never, 1=some of time, 2=all of time)	0.91	0.48	0.91	0.41	0.05
Number of materials recycled	2.97	1.57	1.71	1.36	5.34###
Recycle paper (0=no, 1=yes)	0.82	0.38	0.64	0.48	2.53#
Recycle glass (0=no, 1=yes)	0.82	0.38	0.46	0.50	5.03###
Recycle cans (0=no, 1=yes)	0.44	0.50	0.34	0.48	1.29
Recycle textiles (0=no, 1=yes)	0.51	0.50	0.13	0.34	5.64###
Recycle Aluminium (0=no, 1=yes)	0.29	0.46	0.13	0.34	2.47#
Prepared to separate waste (0=no, 1=yes)	0.93	0.24	0.80	0.40	2.50#

Table C - Comparison of Samples A and B on issues of composting

Characteristic	Sample A		Sample B		t-test
	Mean	S.D.	Mean	S.D.	
Heard of compost/composting (0=no, 1=yes)	0.82	0.38	0.75	0.44	1.10
Heard of home compost (0=no, 1 =yes)	0.72	0.45	0.63	0.49	1.19
Participate in home composting (0=no, 1=yes)	0.42	0.50	0.36	0.48	0.79

Table D - Demographic Characteristics of composters and non-composters

Characteristic	Composters		Non-composters		t-test
	Mean	S.D.	Mean	S.D.	
Age (in decades)	5.07	1.29	4.06	1.55	4.36###
Children (1=yes, 0=no)	0.82	0.39	0.83	0.38	0.24
Gainfully employed (1=yes,0=no)	0.45	0.50	0.54	0.50	1.05
Gender (1=male, 0=female)	0.53	0.50	0.30	0.46	2.93##
Own property (1=yes, 0=no)	0.70	0.46	0.60	0.49	1.28
Property tax band (1=a, 2=b.....8=h)	5.28	1.22	4.86	1.52	1.71
Education	1.47	1.32	1.38	1.22	0.40

Table E - Comparison of composters and non-composters on issues of general environmental concern

Characteristic	Composters		Non-composters		t-test
	Mean	S.D.	Mean	S.D.	
Pollution in their area (0=no, 1=yes)	0.93	0.25	0.86	0.34	1.46
Mention air pollution (0=no, 1=yes)	0.67	0.48	0.49	0.50	2.14#
Mention noise pollution (0=no, 1=yes)	0.20	0.40	0.11	0.31	1.55
Mention waste (0=no, 1=yes)	0.23	0.43	0.32	0.47	1.13
Mention aircraft (0=no, 1=yes)	0.55	0.50	0.37	0.49	2.22#
Mention vehicles (0=no, 1=yes)	0.65	0.48	0.58	0.50	0.88
Recycling can reduce pollution (0=no, 1=yes)	0.73	0.45	0.42	0.50	4.06###
How often purposely purchase recycled materials (0=never, 1=some of time, 2=all of time)	0.95	0.47	0.88	0.43	0.89
Number of materials recycled	2.80	1.40	2.07	1.66	2.82##
Recycle paper (0=no, 1=yes)	0.83	0.38	0.67	0.47	2.33#
Recycle glass (0=no, 1=yes)	0.75	0.44	0.58	0.50	2.25#
Recycle cans (0=no, 1=yes)	0.55	0.50	0.29	0.46	3.19##
Recycle textiles (0=no, 1=yes)	0.38	0.49	0.29	0.46	1.12
Recycle Aluminium (0=no, 1=yes)	0.22	0.41	0.21	0.41	0.09
Prepared to separate waste (0=no, 1=yes)	0.93	0.25	0.83	0.38	2.02#

APPENDIX 3

Table 2.8- Classification of composting in terms of home ownership:

Characteristic	Own home		Do not own home	
	Number of respondents	**Percent**	**Number of respondents**	**Percent**
Heard of compost/composting	79 yes 20 no	79.8 20.2	43 yes 13 no	76.8 23.2
Heard of home composting	71 yes 28 no	71.7 28.3	34 yes 22 no	60.7 39.3
Participate in home composting	42 yes 57 no	42.4 57.6	18 yes 38 no	32.1 67.9

Table 2.9 - Classification of composting in terms of children:

Characteristic	Children		No children	
	Number of respondents	**Percent**	**Number of respondents**	**Percent**
Heard of compost/composting	103 yes 25 no	80.5 19.5	19 yes 8 no	70.4 29.6
Heard of home composting	87 yes 41 no	68.0 32.0	18 yes 9 no	66.7 33.3
Participate in home composting	49 yes 79 no	38.3 61.7	11 yes 16 no	40.7 59.3

Table 2.10 - Classification of composting in terms of age:

Characteristic	Age											
	21-30		31-40		41-50		51-60		61-70		70+	
	Number of respondents	percent	Number of respondents	Percent	Number of respondents	Percent	Number of respondents	Percent	Number of respondents	Percent	Number of respondents	Percent
Heard of compost/ Composting	9 yes 5 no	64.3 35.7	24 yes 10 no	70.6 29.4	27 yes 10 no	73.0 27.0	29 yes 2 no	93.5 6.5	13 yes 3 no	81.3 18.8	20 yes 3 no	87.0 13.0
Heard of home composting	6 yes 8 no	42.9 57.1	22 yes 12 no	64.7 35.2	20 yes 17 no	54.1 45.9	26 yes 5 no	83.9 16.1	12 yes 4 no	75.0 25.0	19 yes 4 no	82.6 17.4
Participate in home composting	1 yes 13 no	7.1 92.9	6 yes 28 no	17.6 82.4	12 yes 25 no	32.4 67.6	21 yes 10 no	67.7 32.3	9 yes 7 no	56.3 43.8	11 yes 12 no	47.8 52.2

Table 2.11 - Classification of composting in terms of property tax band:

Characteristic	Property tax band															
	A		B		C		D		E		F		G		H	
	Number of respondents	Percent	Number of respondents	Percent	Number of respondents	Percent	Number of respondents	Percent	Number of respondents	Percent	Number of respondents	Percent	Number of respondents	Percent	Number of respondents	Percent
Heard of compost/ composting	1 yes 0 no	100 0	1 yes 2 no	33.3 66.6	4 yes 0 no	100 0	37 yes 13 no	74.0 26.0	9 yes 4 no	69.2 30.8	26 yes 2 no	92.9 7.1	16 yes 5 no	76.2 23.8	2 yes 0 no	100 0
Heard of home composting	1 yes 0 no	100 0	1 yes 2 no	33.3 66.6	4 yes 0 no	100 0	31 yes 19 no	62.0 38.0	8 yes 5 no	61.5 38.5	23 yes 5 no	82.1 17.9	16 yes 5 no	76.2 23.8	2 yes 0 no	100 0
Participate in home composting	0 yes 1 no	0 100	0 yes 3 no	0 100	0 yes 4 no	0 100	22 yes 28 no	44.0 56.0	6 yes 7 no	46.2 53.8	16 yes 12 no	57.1 42.9	9 yes 12 no	42.9 57.1	1 yes 1 no	50.0 50.0

Table 2.12 - Classification of composting in terms of Gender:

Characteristic	**Male**		**Female**	
	Number of respondents	**Percent**	**Number of respondents**	**Percent**
Heard of compost/composting	50 yes 10 no	83.3 16.7	71 yes 23 no	75.5 24.5
Heard of home composting	46 yes 14 no	76.7 23.3	59 yes 35 no	62.8 37.2
Participate in home composting	32 yes 28 no	53.3 46.7	28 yes 66 no	29.8 70.2

Table 2.13- Classification of composting in terms of gainfully employed:

Characteristic	**Gainfully employed**		**Not gainfully employed**	
	Number of respondents	**Percent**	**Number of respondents**	**Percent**
Heard of compost/composting	60 yes 18 no	76.9 23.1	62 yes 15 no	80.5 19.5
Heard of home composting	50 yes 28 no	64.1 35.9	55 yes 22 no	71.4 28.6
Participate in home composting	27 yes 51 no	34.6 65.4	33 yes 44 no	42.9 57.1

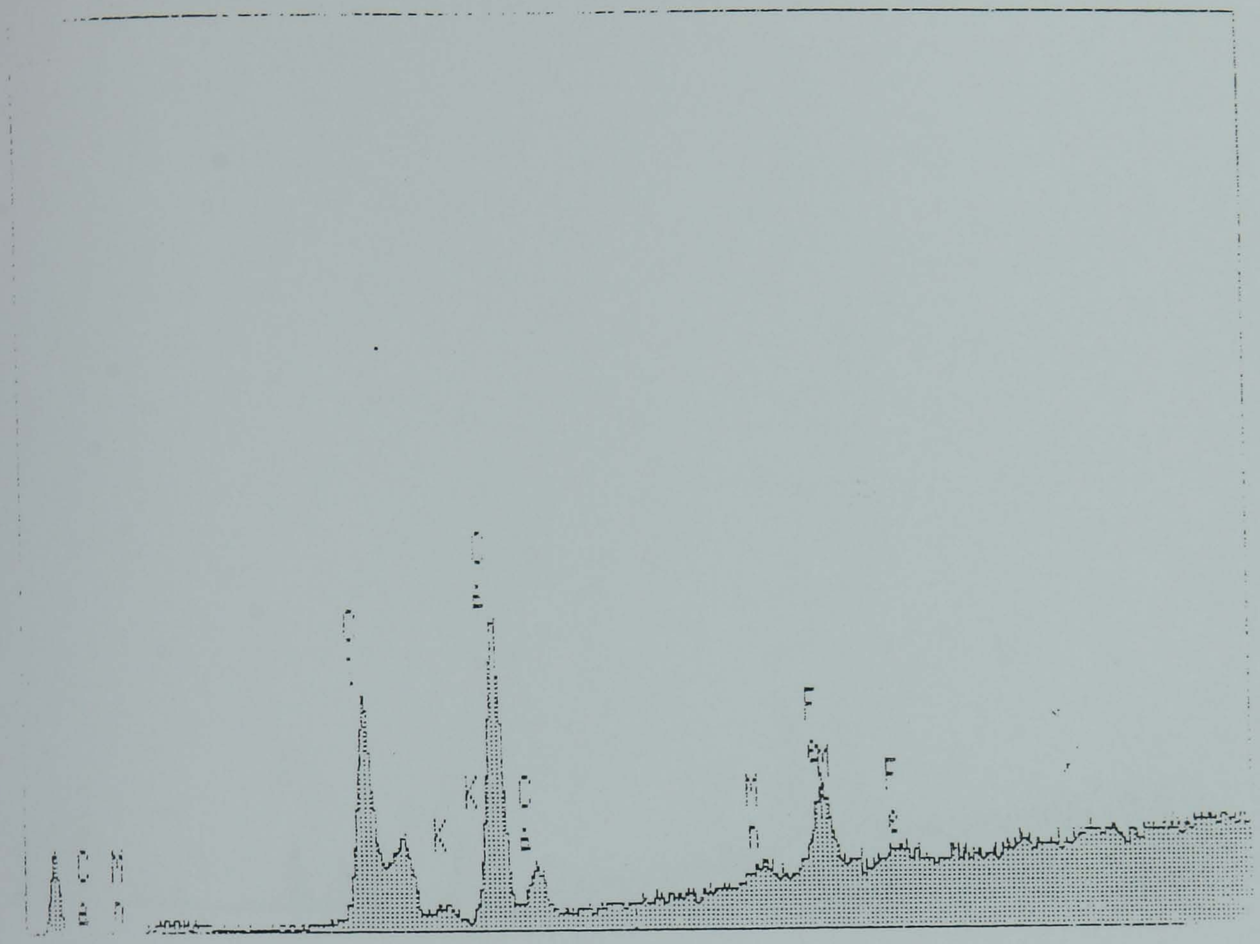
Table 2.14 - Classification of composting in terms of education:

Characteristic	**Education level**									
	Below GCSE/ O level		**GCSE/ O level**		**A Level/ BTEC**		**Degree Level**		**PhD Level**	
	Number of respondents	**Percent**	**Number of respondents**	**Percent**	**Number of respondents**	**Percent**	**Number of respondents**	**Percent**	**Number of respondents**	**Percent**
Heard of compost/ composting	41 yes 12 no	77.4 22.6	21 yes 9 no	70.0 30.0	25 yes 3 no	89.3 10.7	31 yes 9 no	77.5 22.5	3 yes 0 no	100 0
Heard of home composting	35 yes 18 no	66.0 34.0	19 yes 11 no	63.3 26.7	23 yes 5 no	82.1 17.9	25 yes 15 no	62.5 37.5	3 yes 0 no	100 0
Participate in home composting	21 yes 32 no	39.6 60.4	10 yes 20 no	33.3 66.7	12 yes 16 no	42.9 57.1	14 yes 26 no	35.0 65.0	3 yes 0 no	100 0

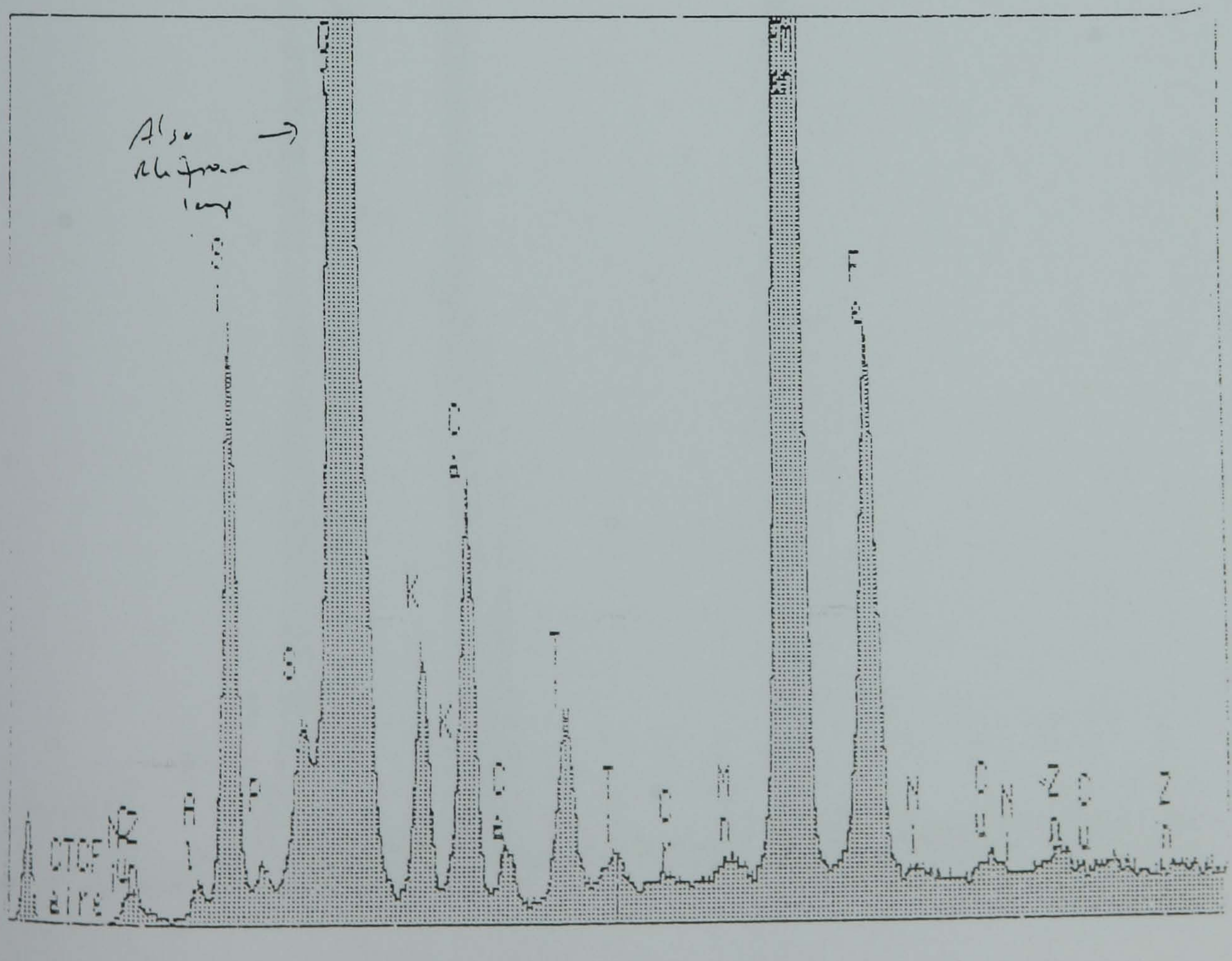
Insufficient data to do a classification based on ethnic origin.

APPENDIX 4

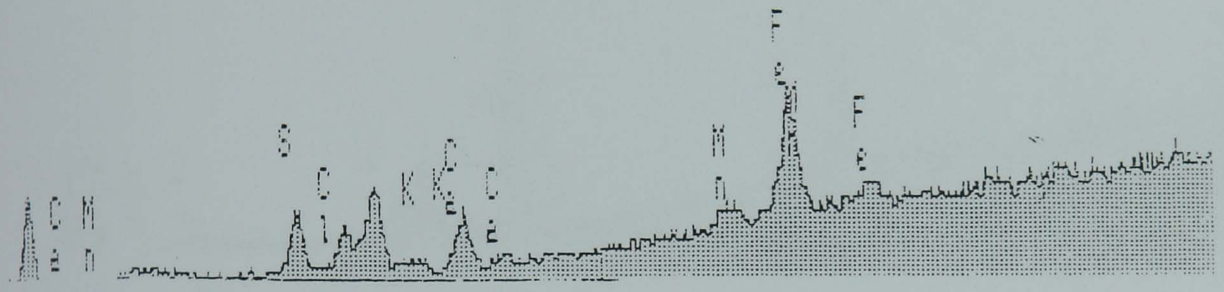
Hydrochloric acid Leach



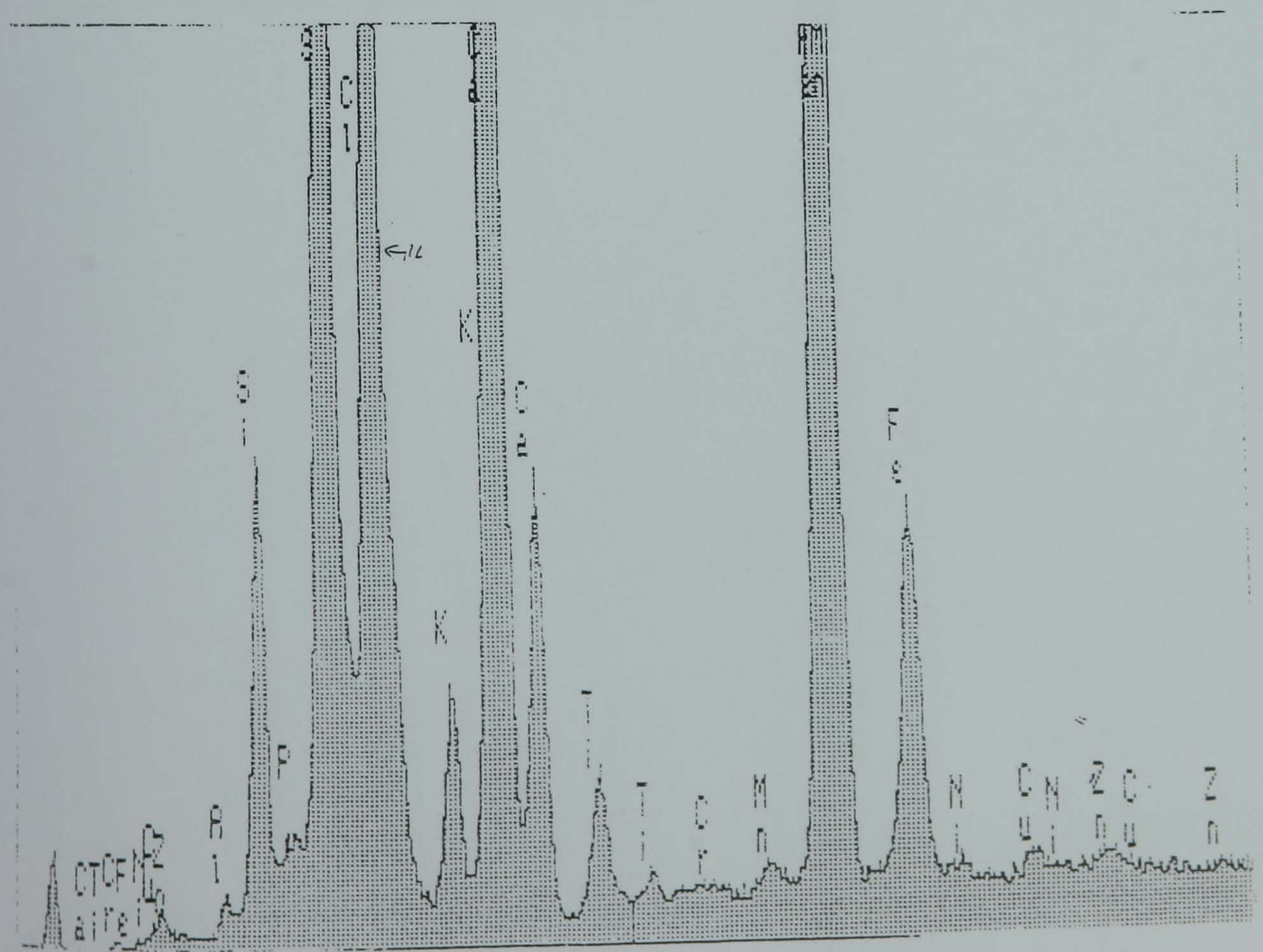
Hydrochloric acid residue



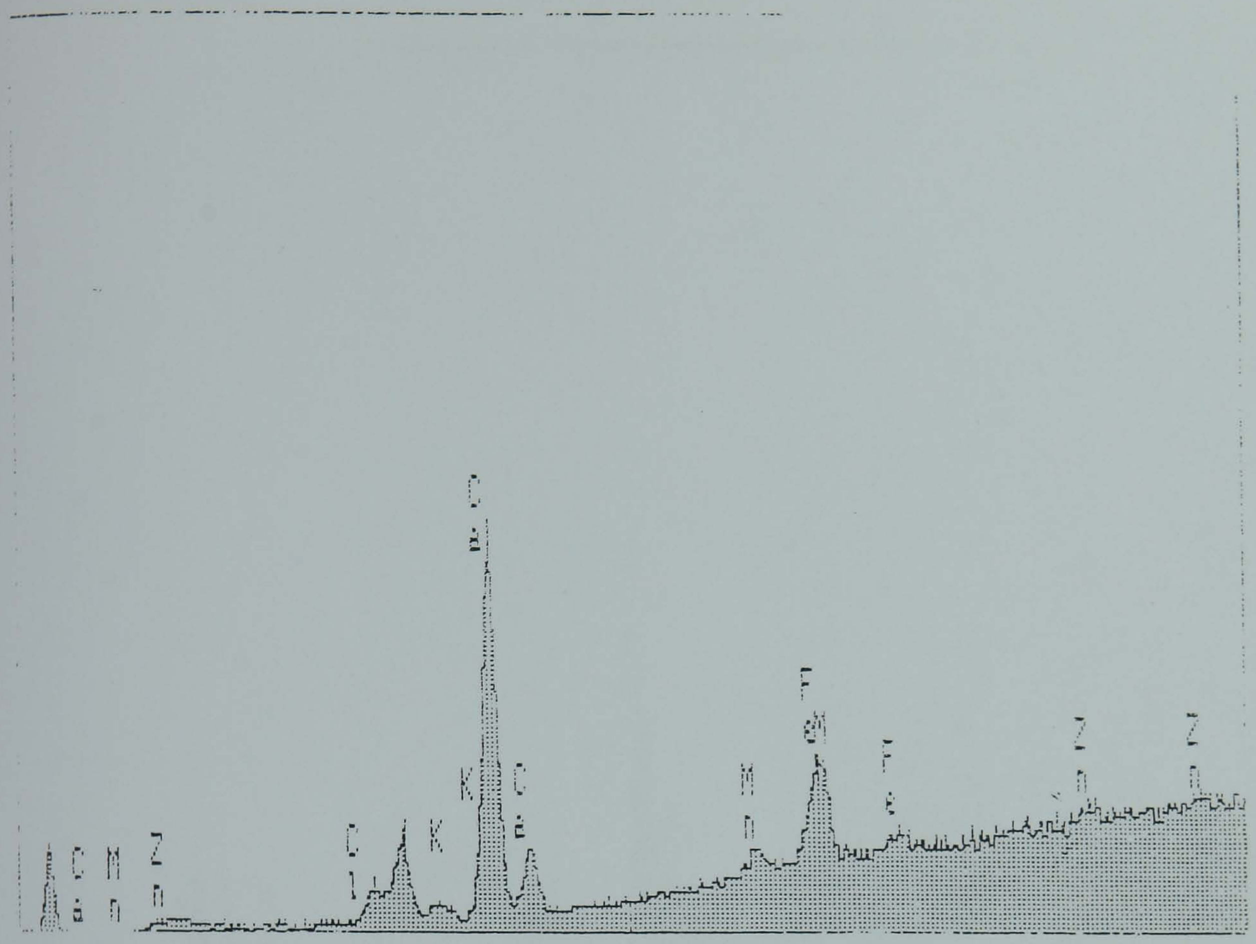
Sulphuric acid Leach



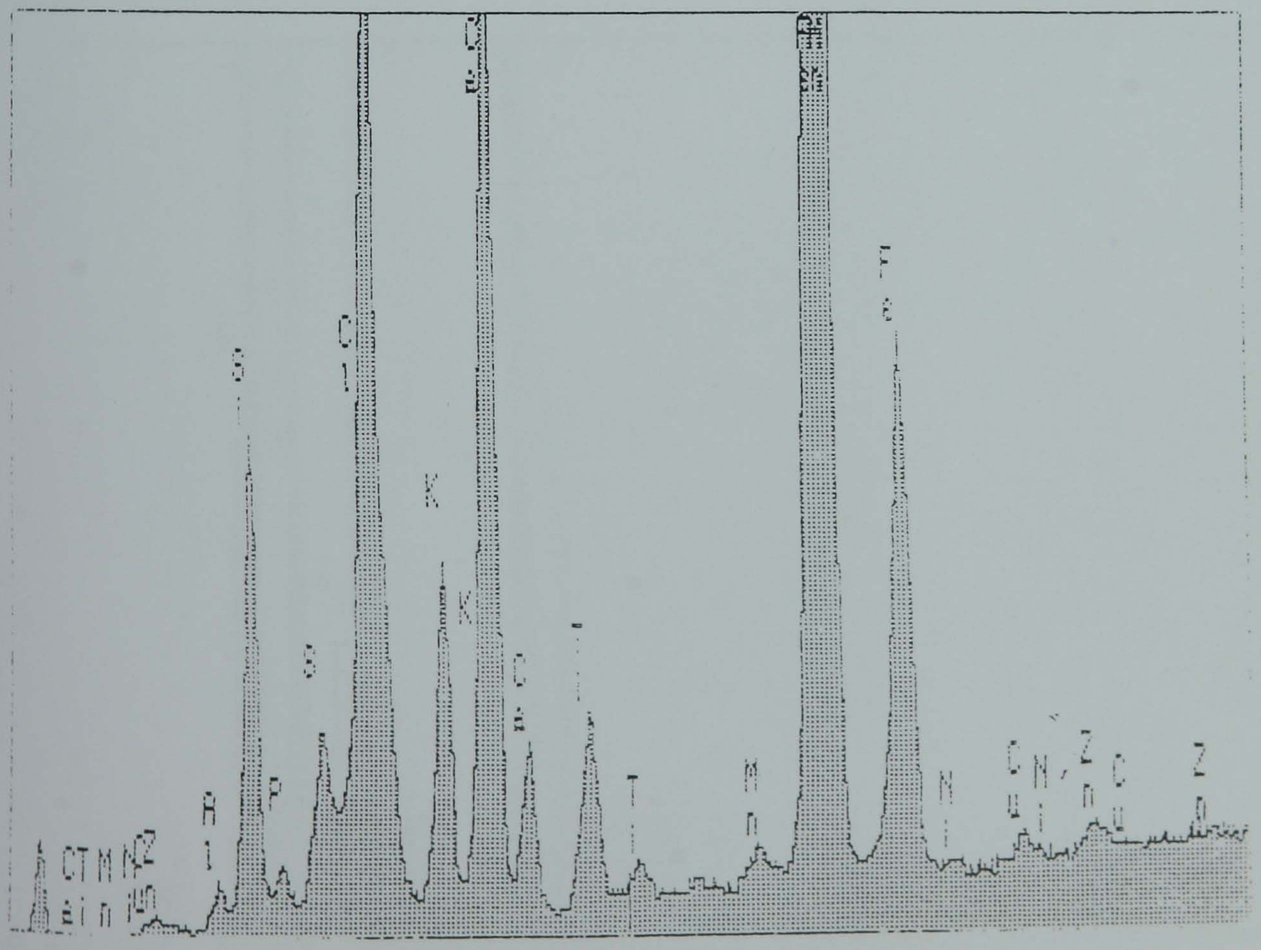
Sulphuric acid residue



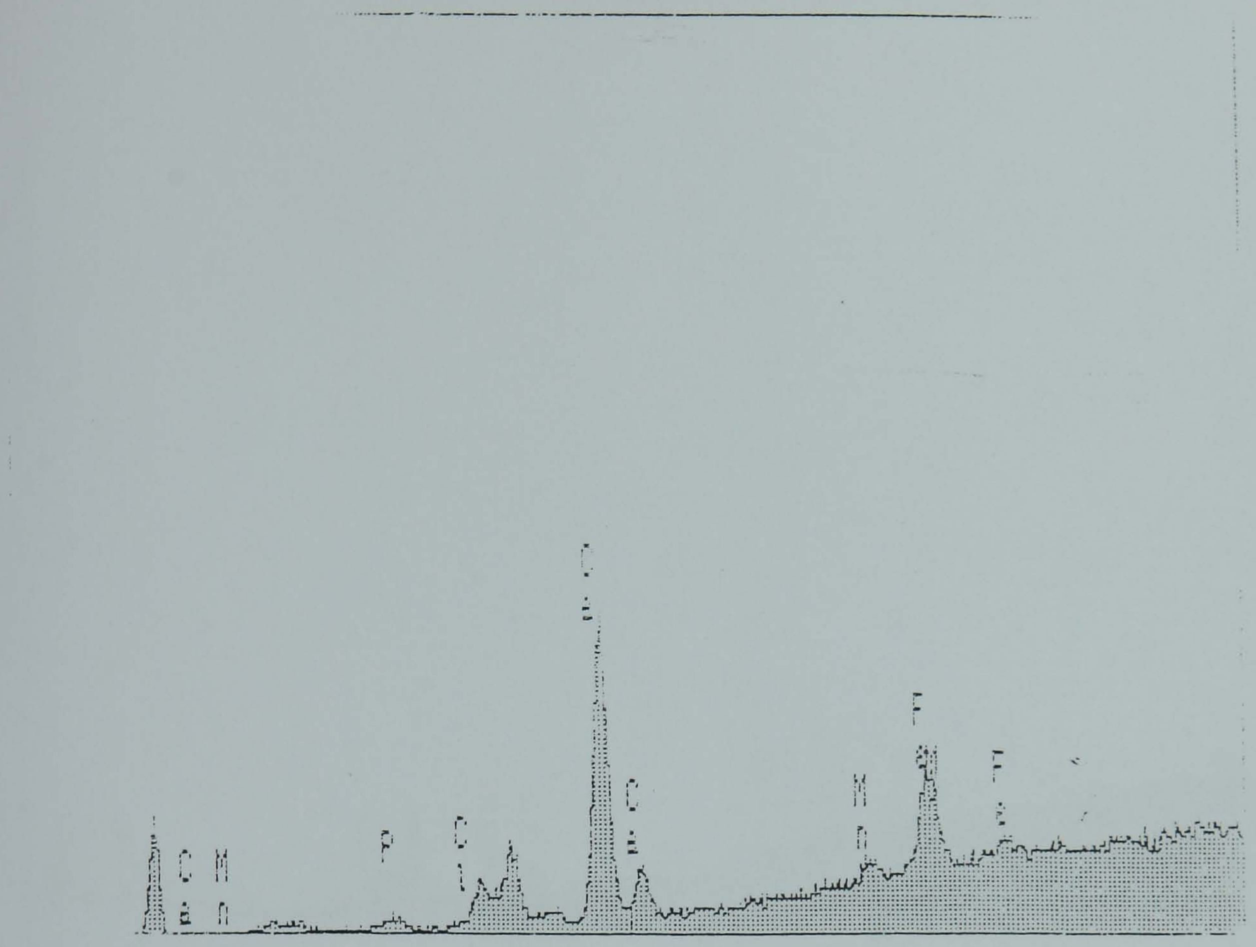
Nitric acid Leach



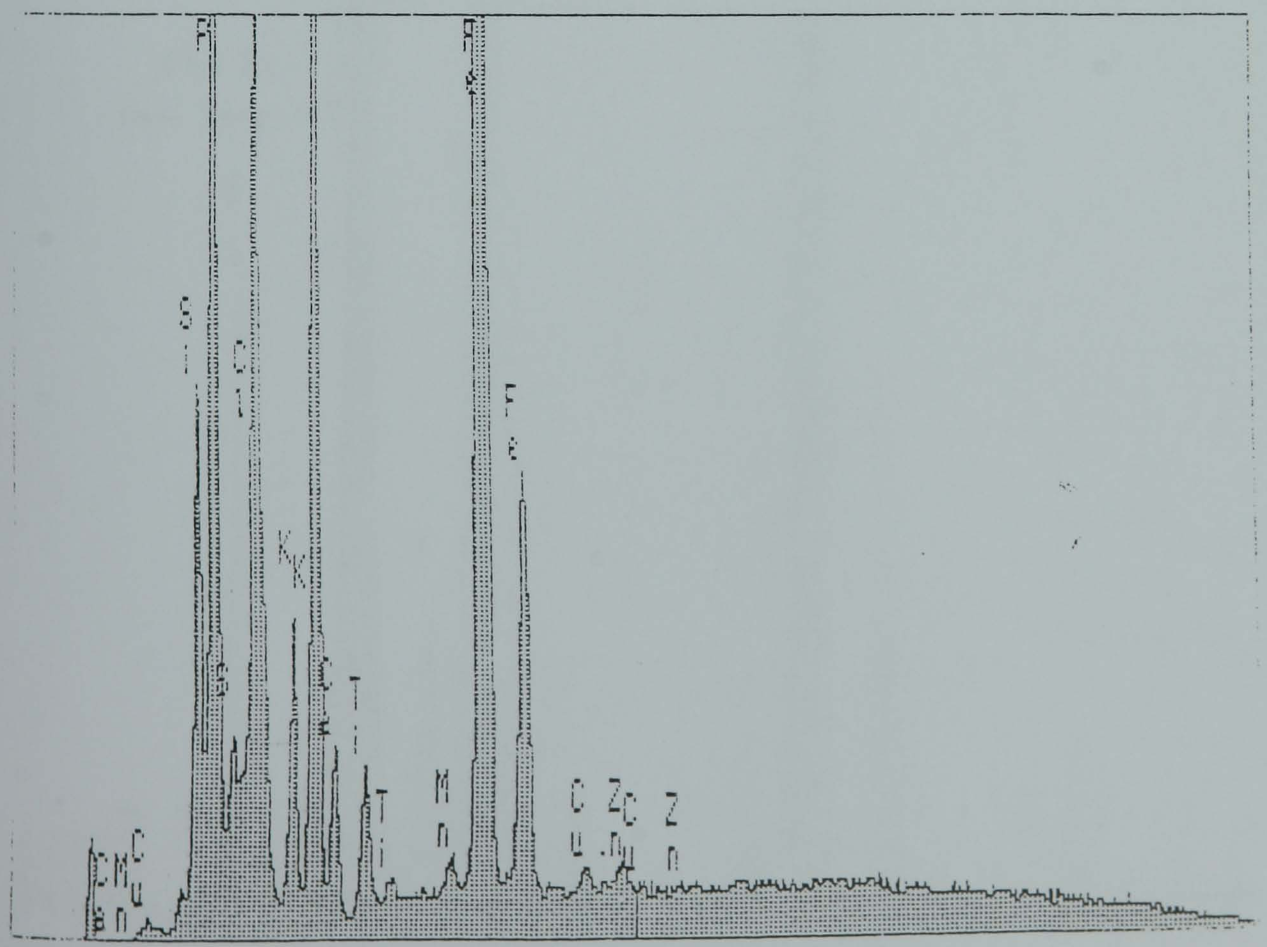
Nitric acid residue



Phosphoric acid Leach

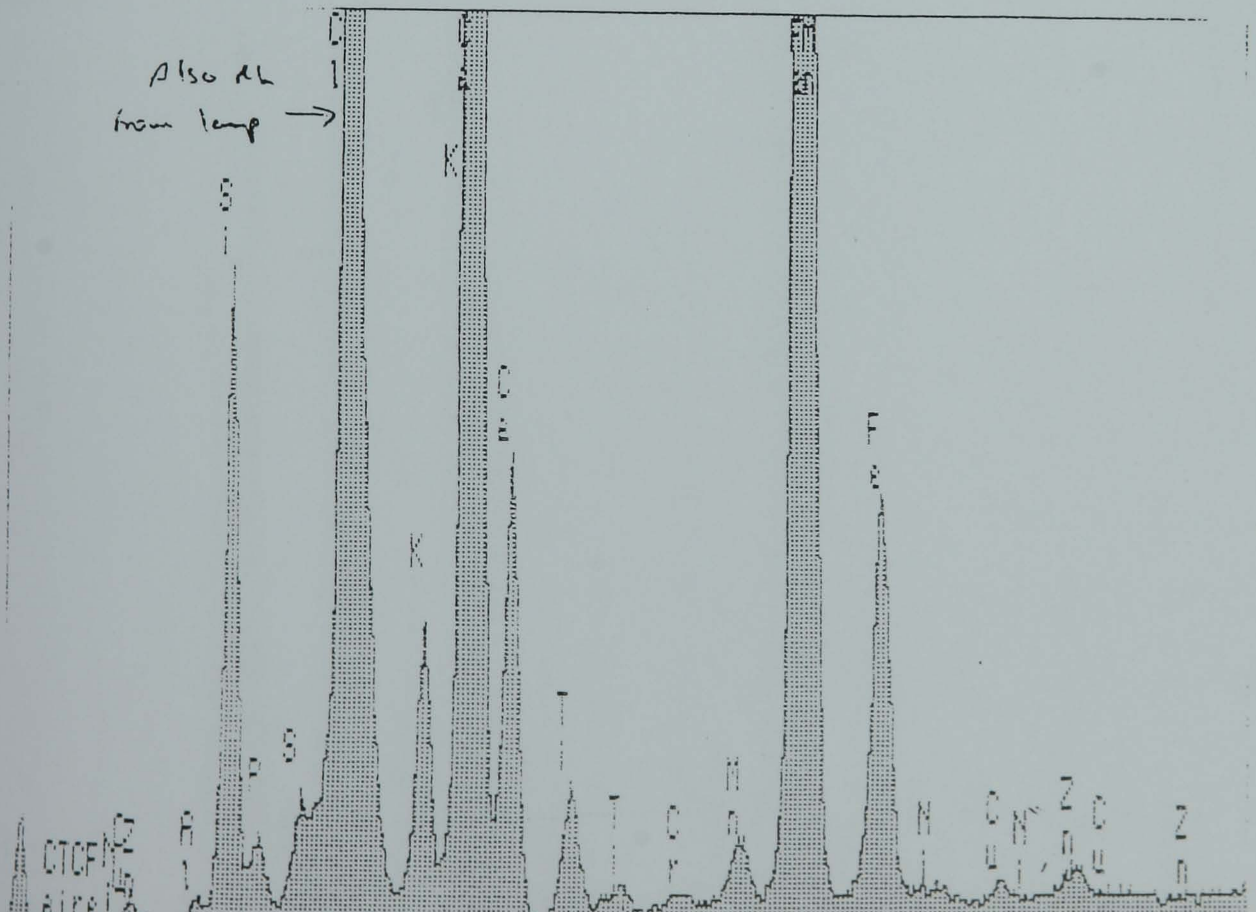


Phosphoric acid residue

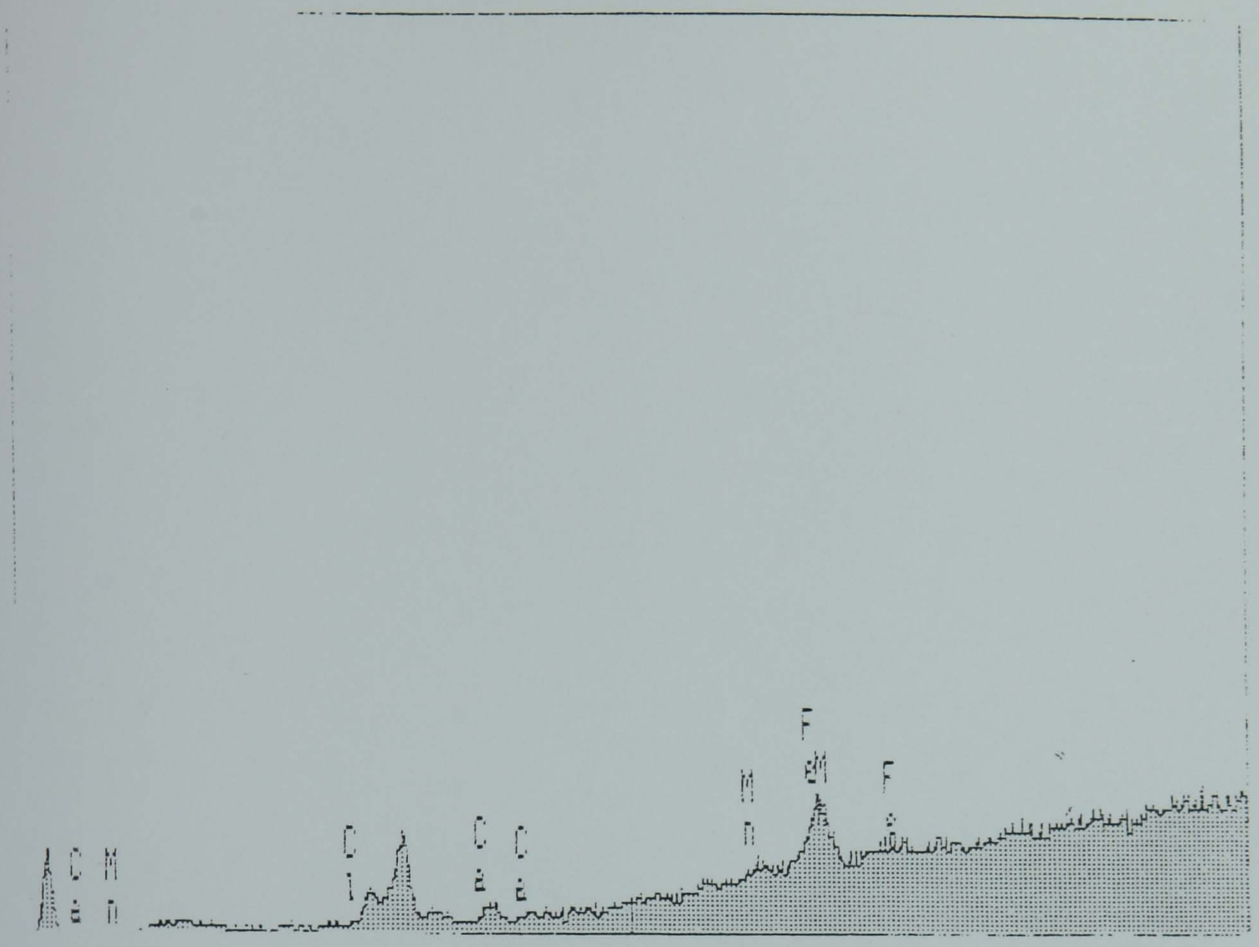


Sodium Hydroxide Leach

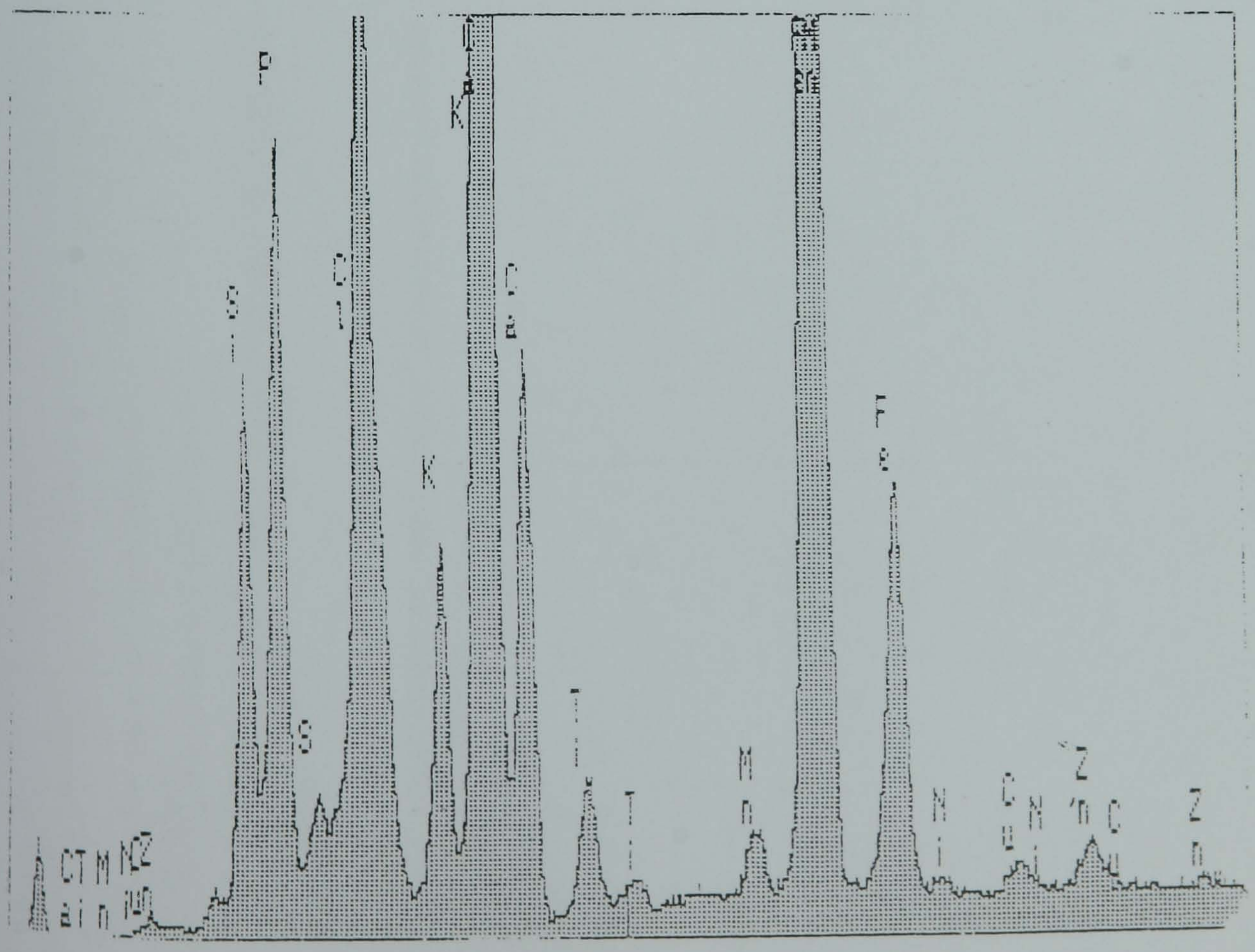
Sodium Hydroxide residue


Also Rh from lamp →

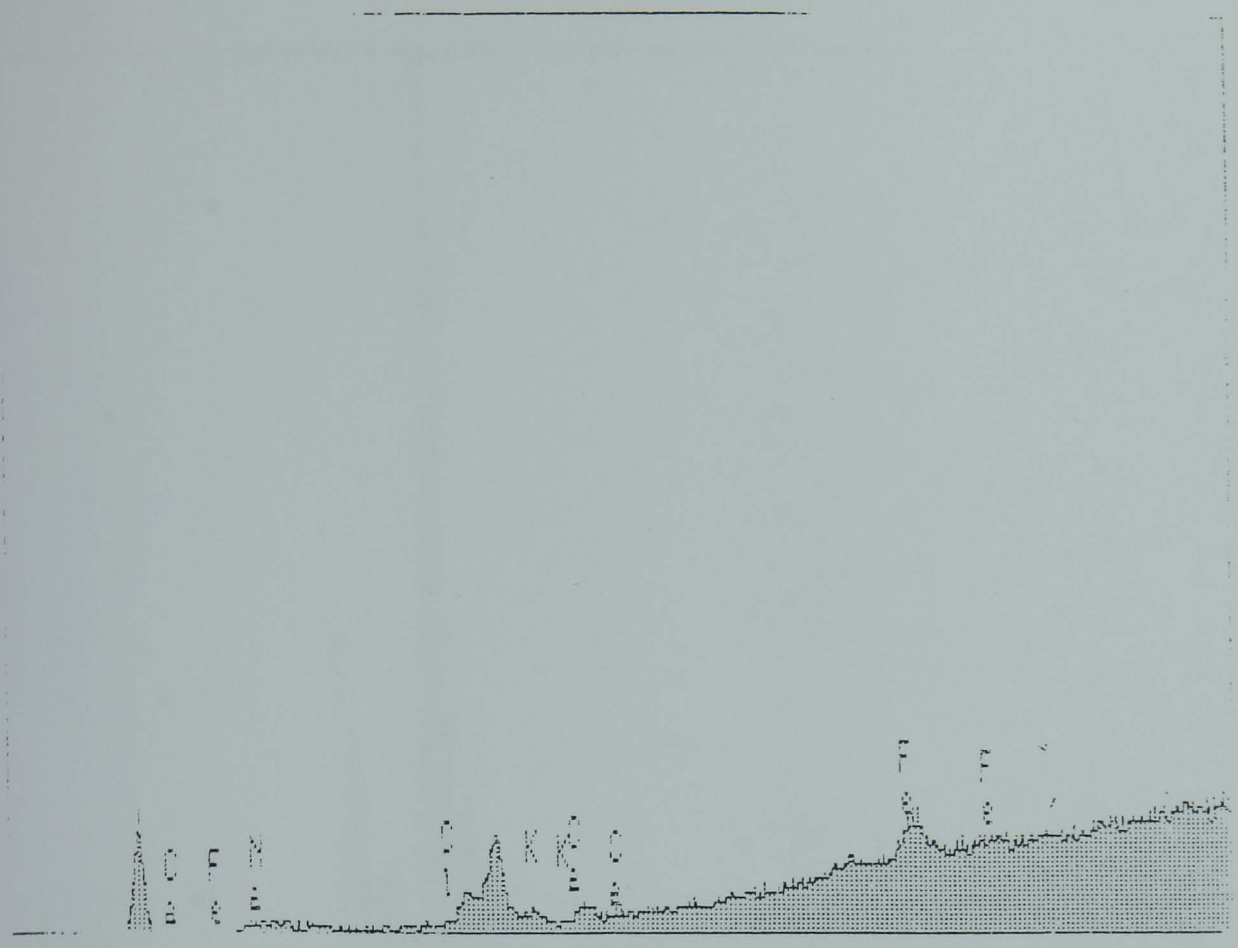
Sodium Pyrophosphate Leach



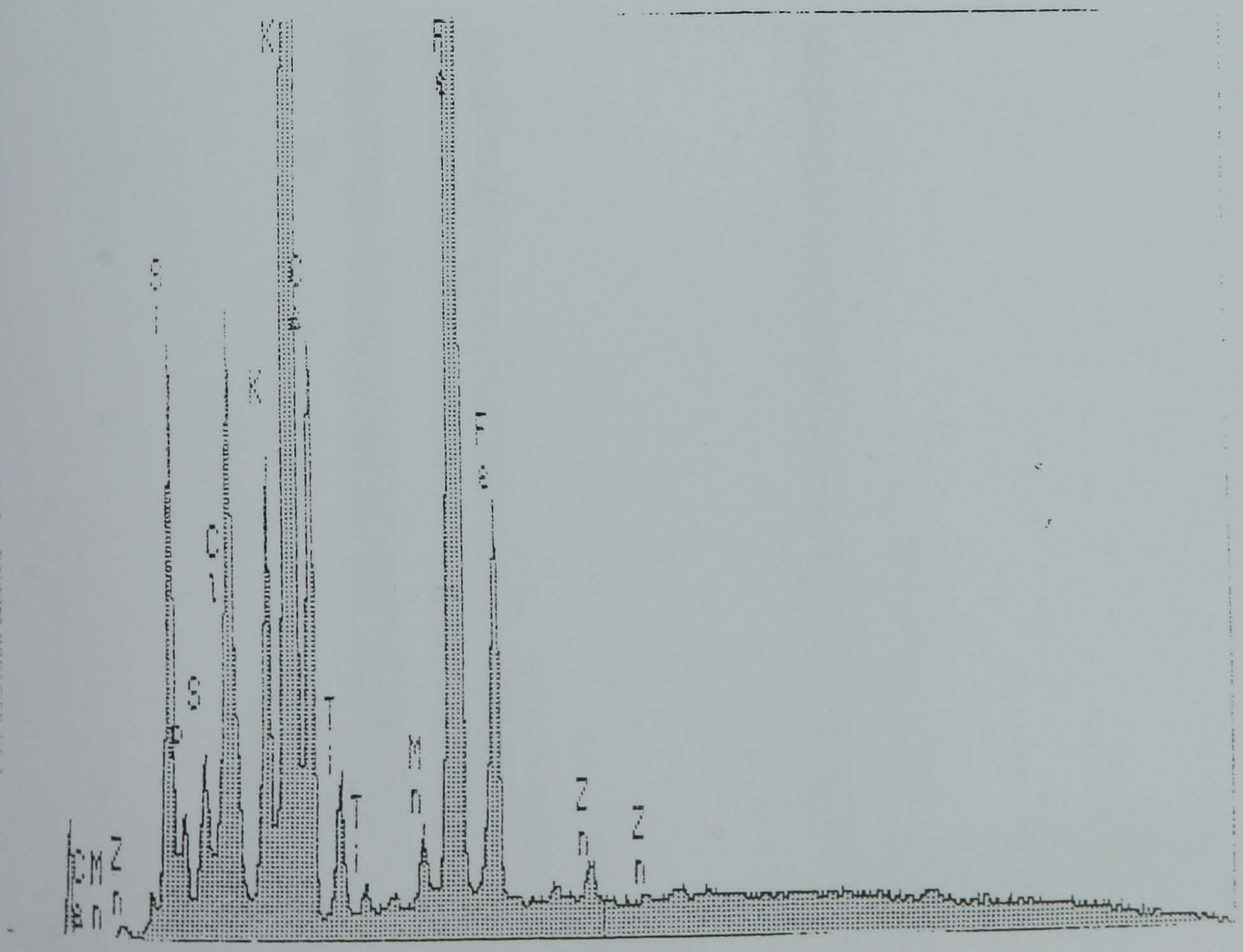
Sodium Pyrophosphate residue



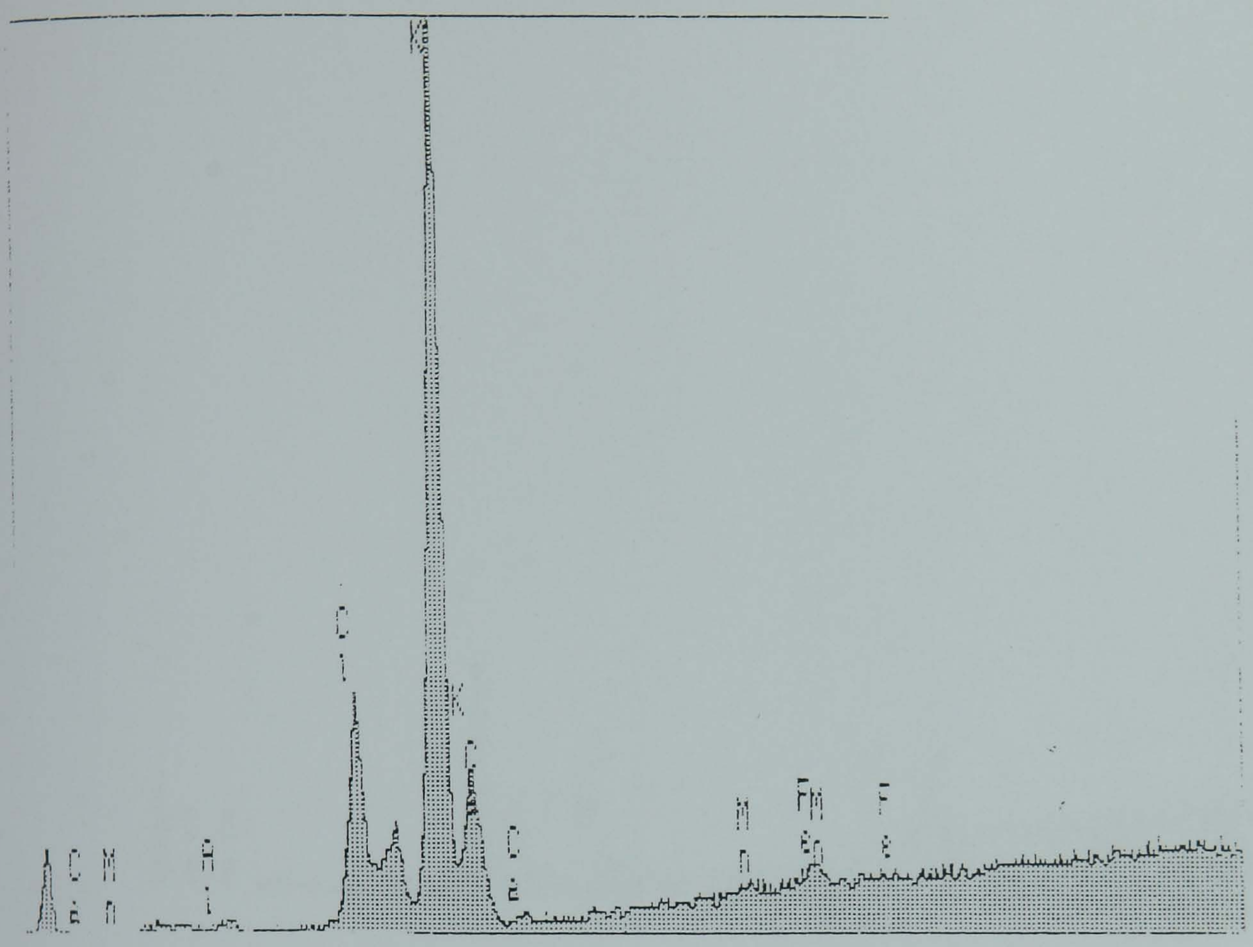
Sodium Carbonate Leach



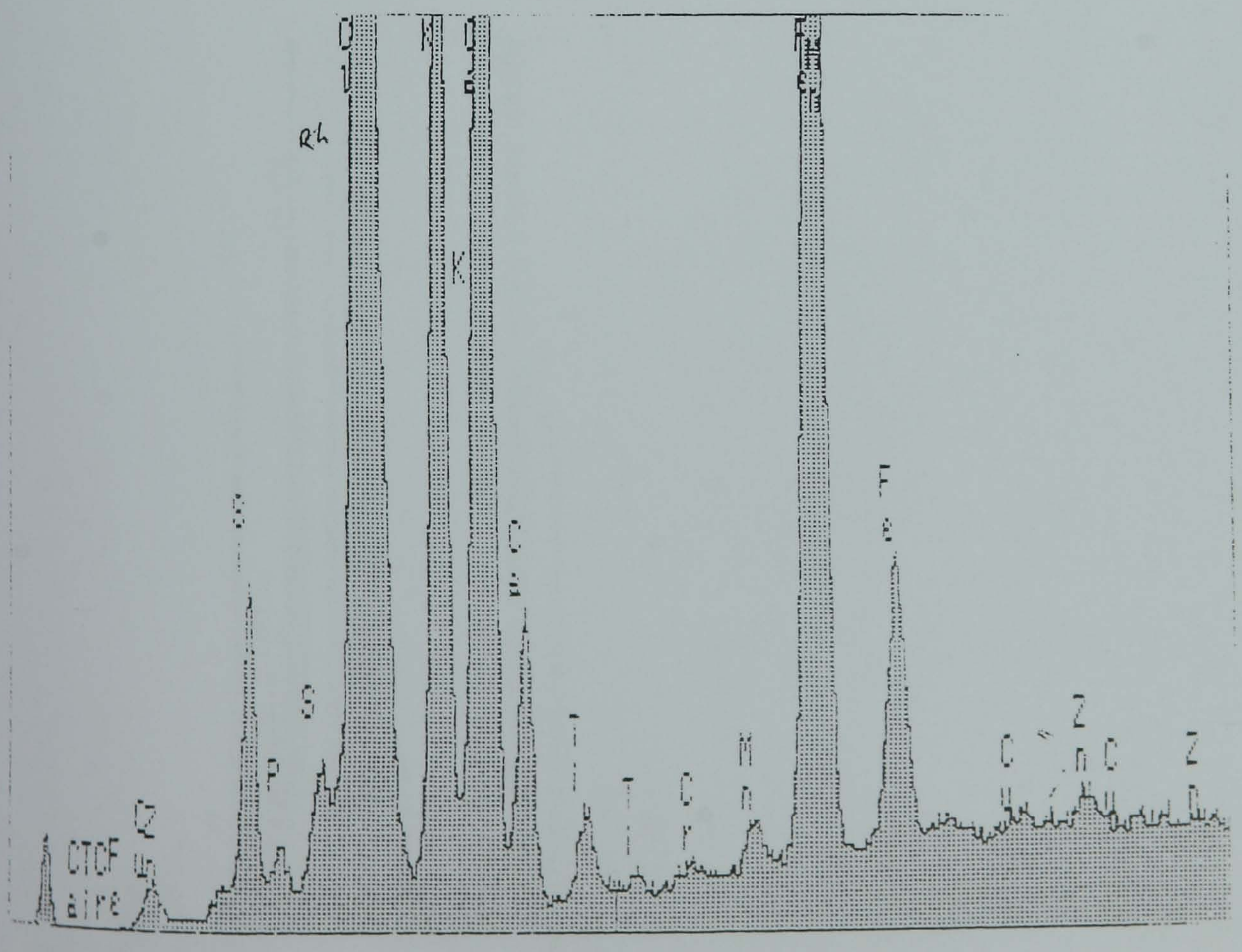
Sodium Carbonate residue



Potassium Chloride Leach

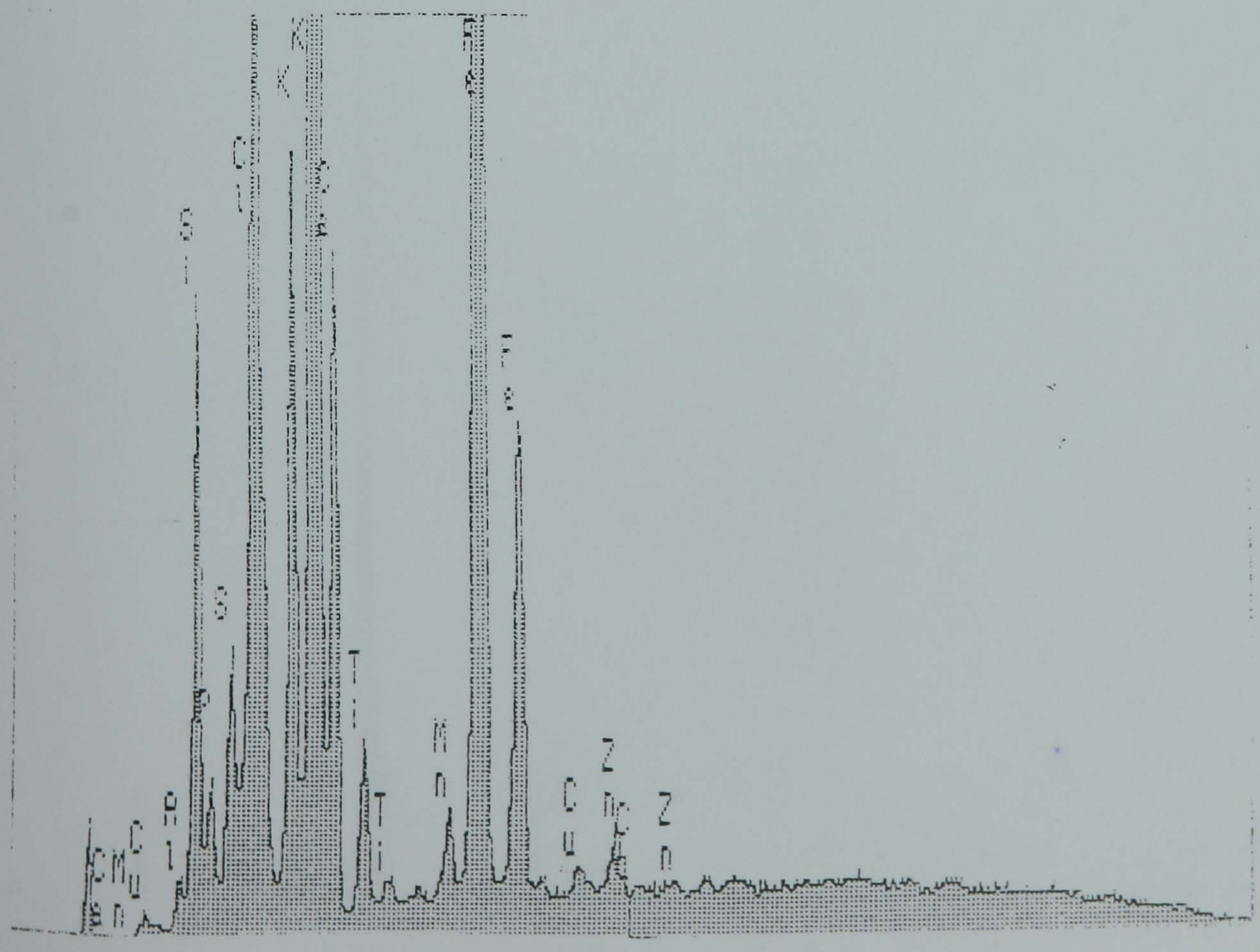


Potassium Chloride residue

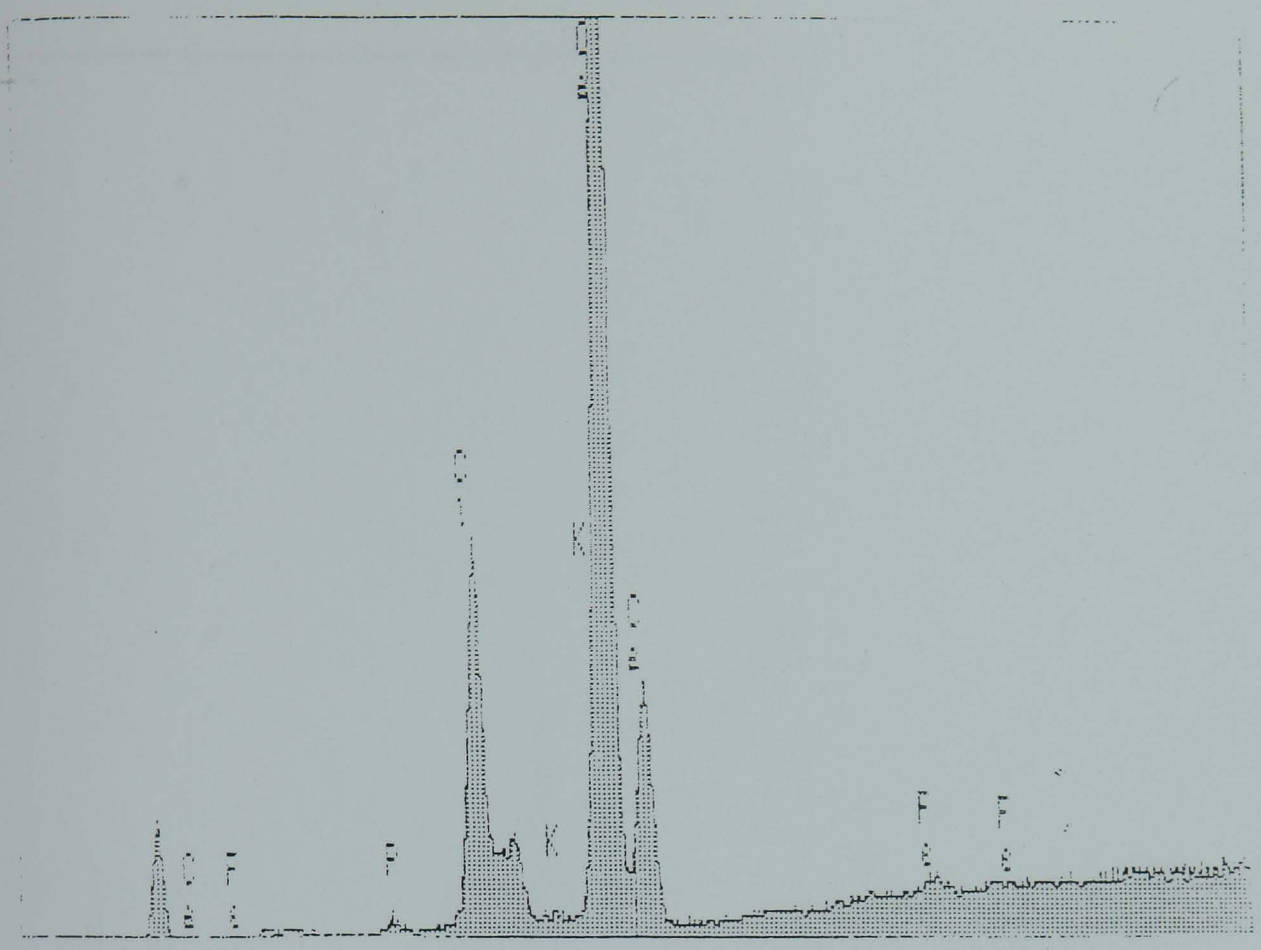


Ammonium Chloride Leach

Ammonium Chloride residue

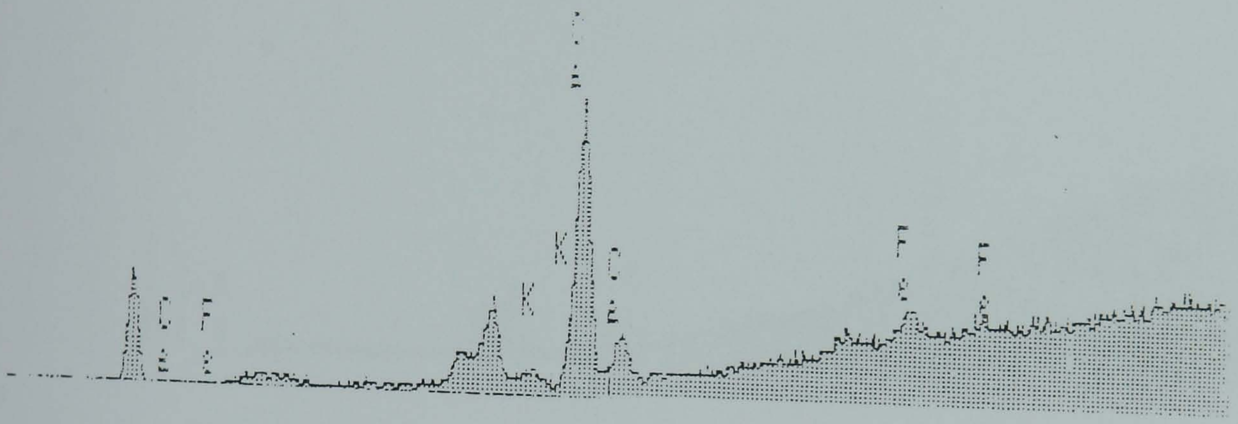


Calcium Chloride Leach

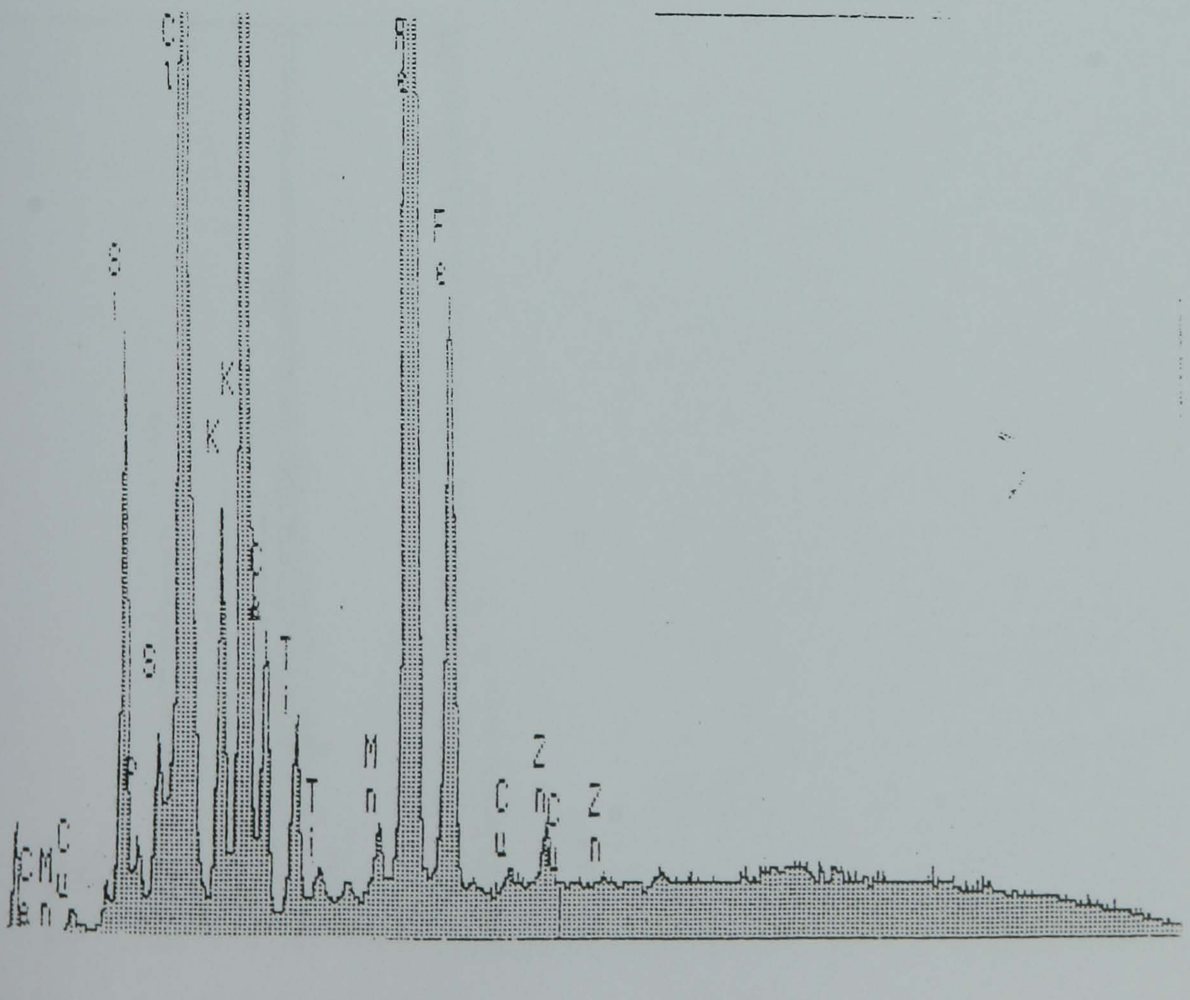


Calcium Chloride residue

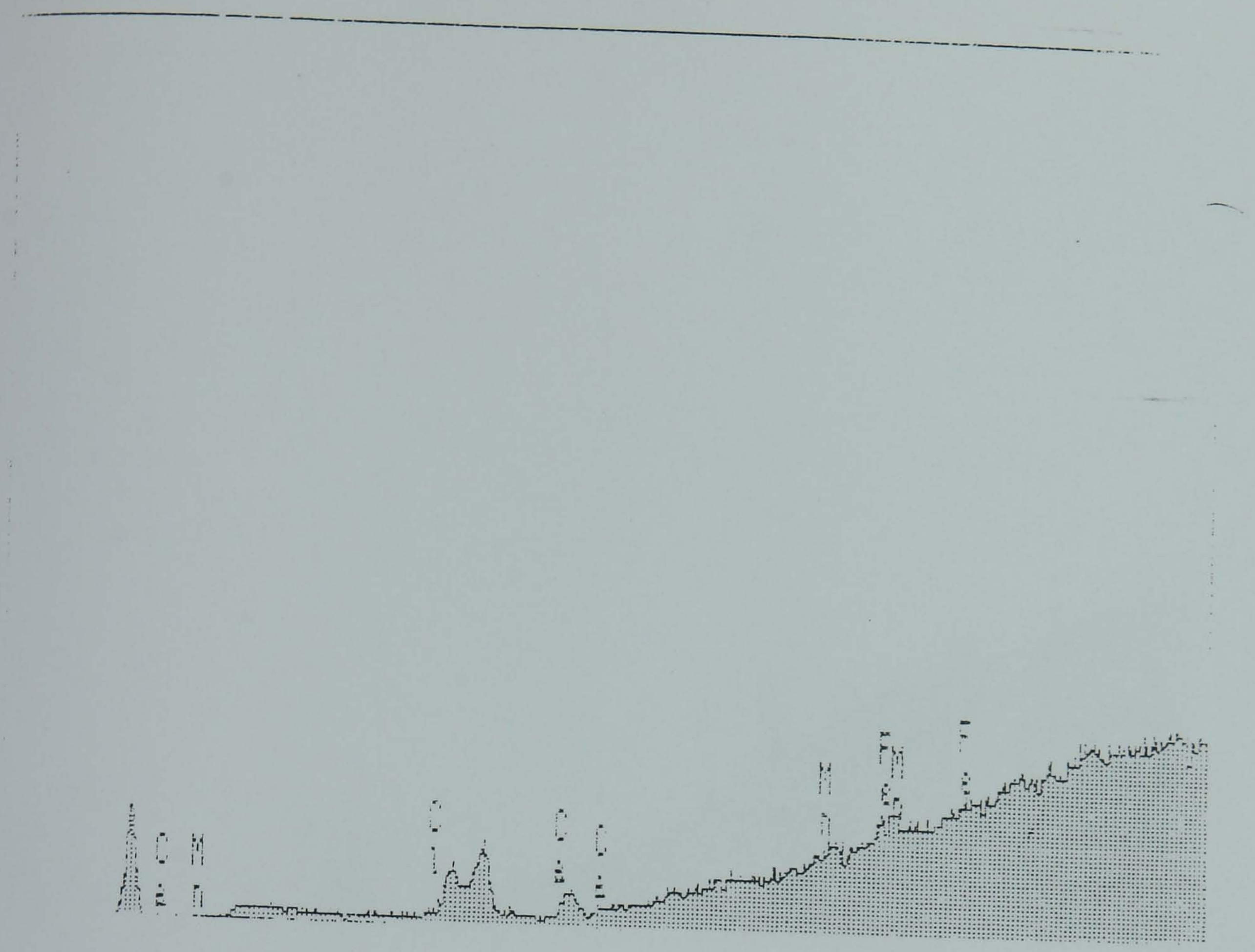
Acetic acid Leach



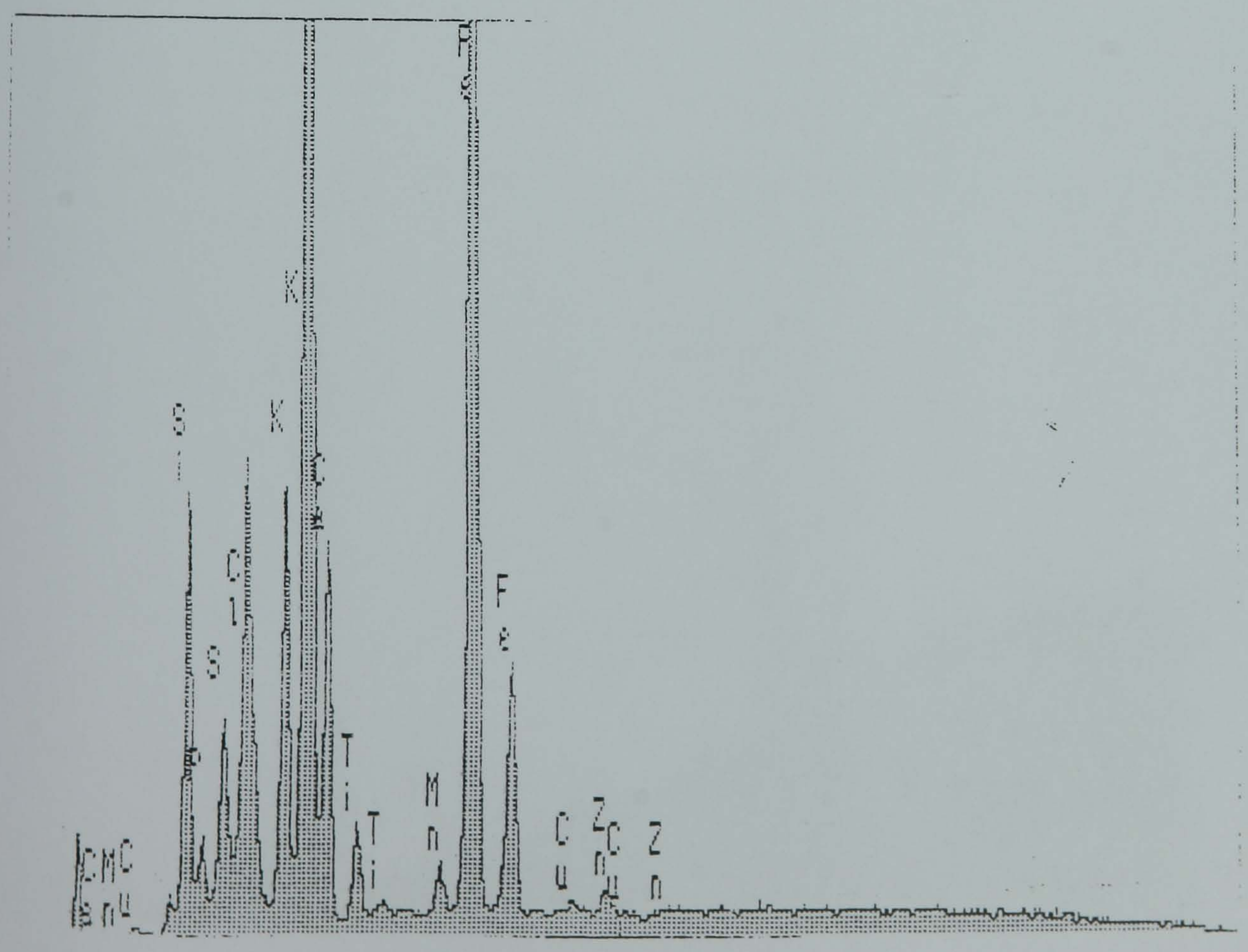
Acetic acid residue



Acetone Leach

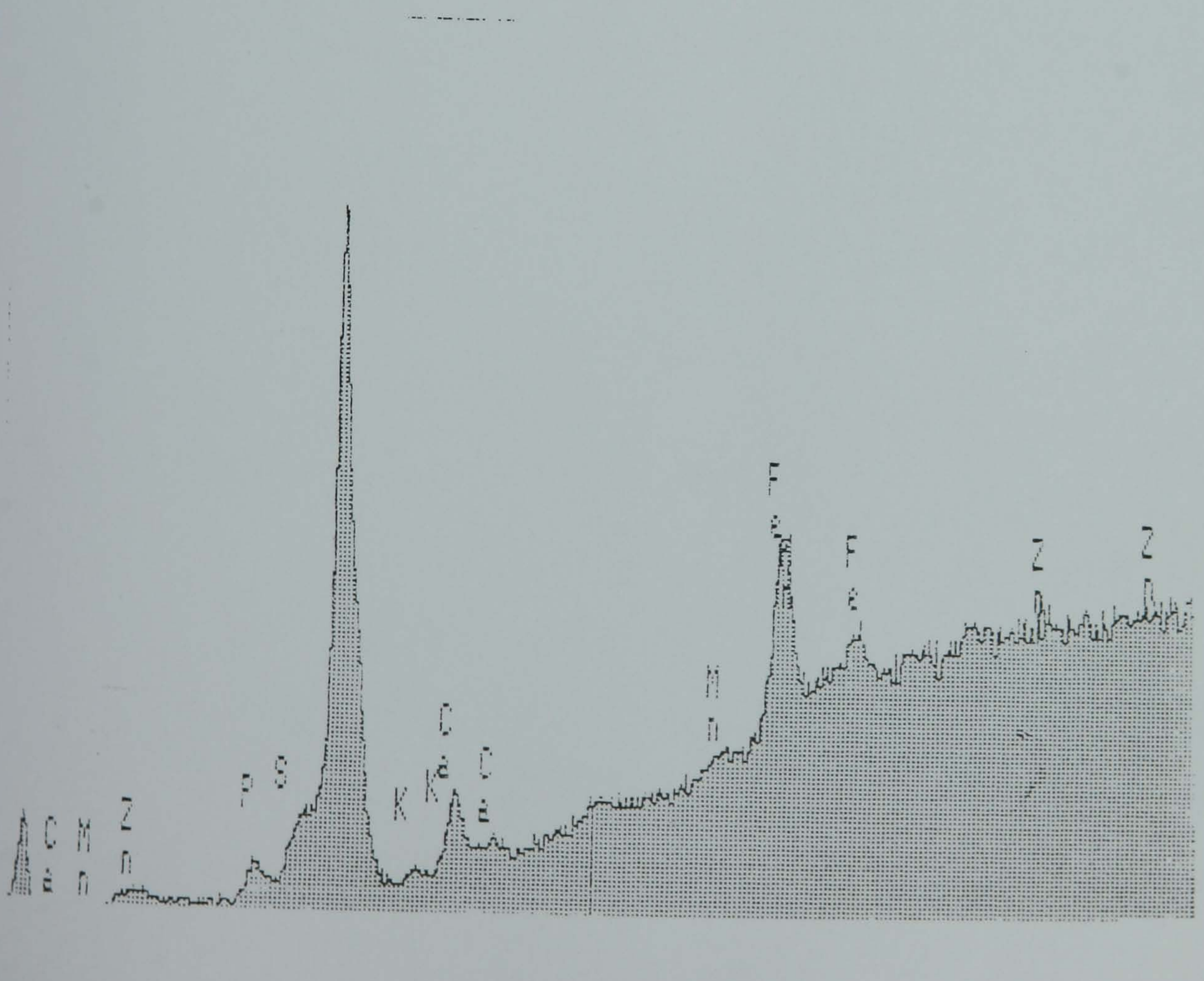


Acetone residue



Hexane Leach

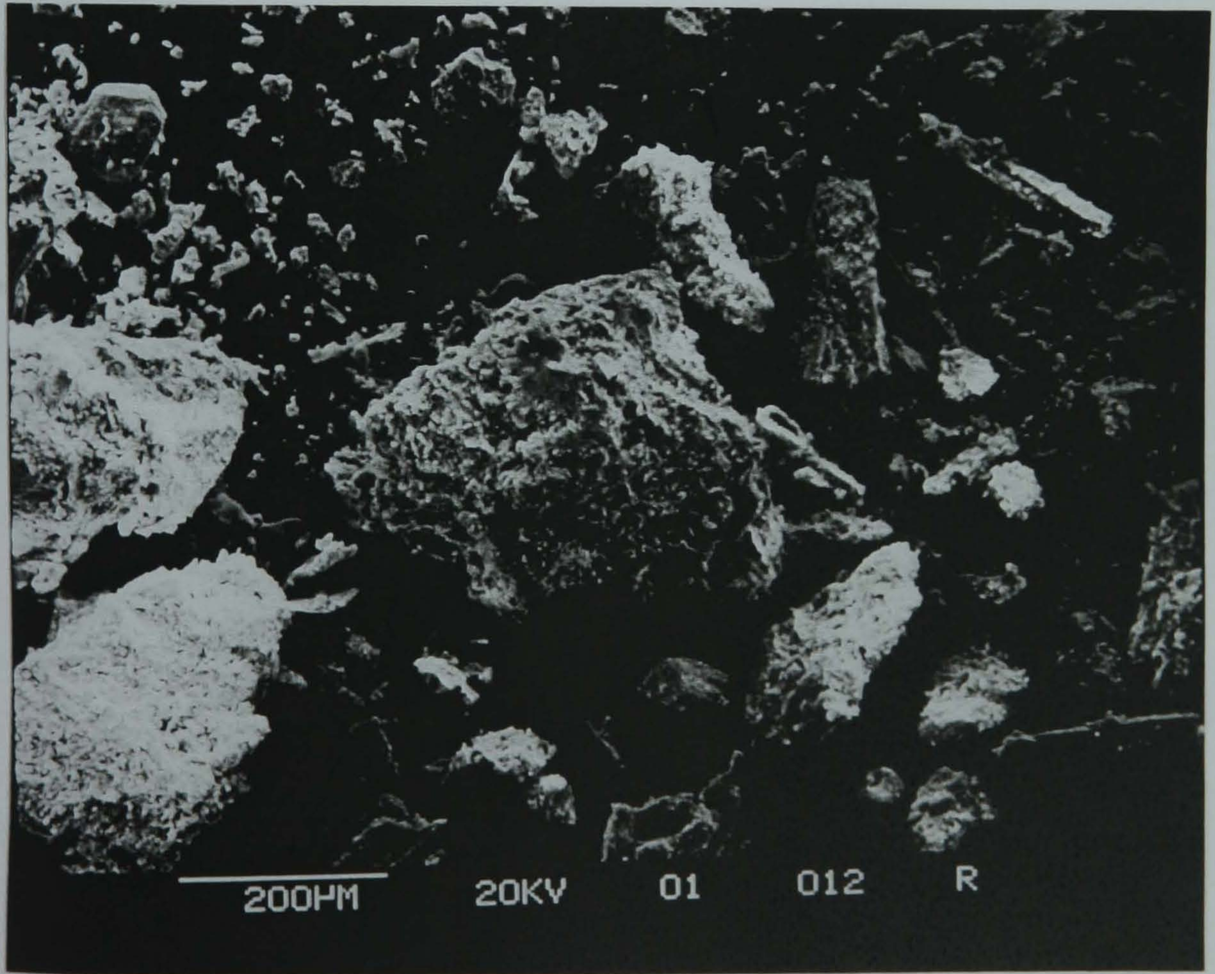
Hexane residue



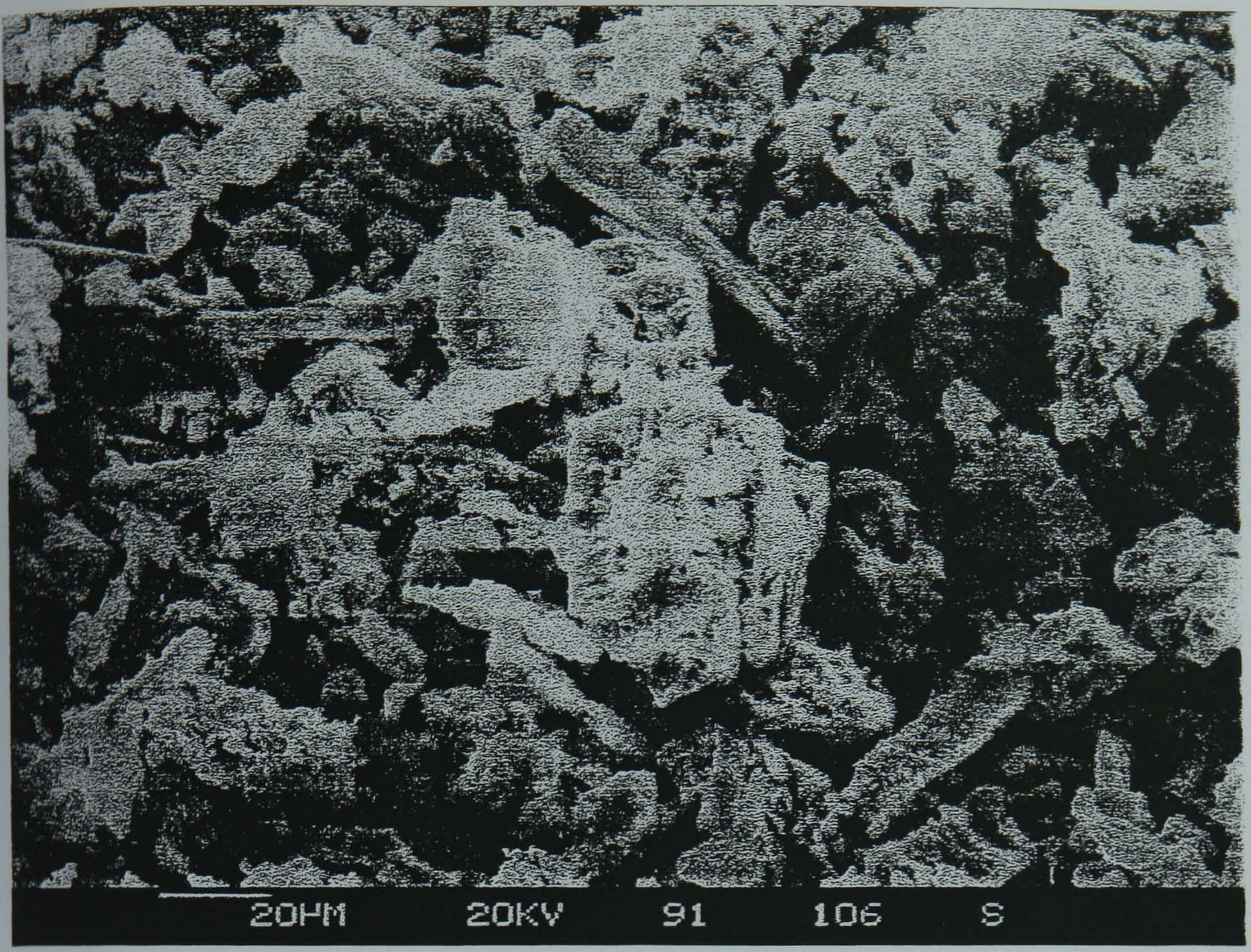
APPENDIX 5

Hydrochloric acid residue

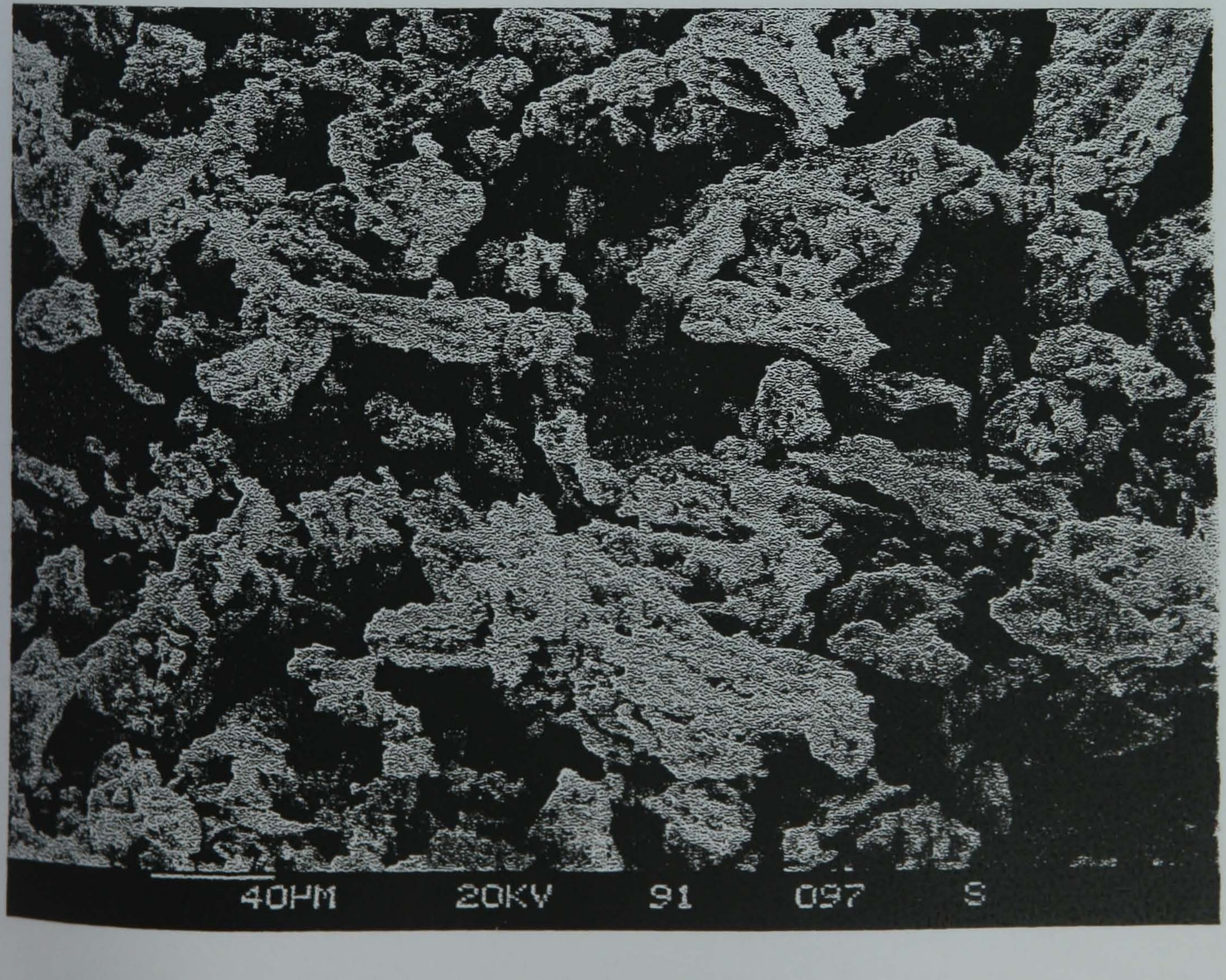
Sulphuric acid residue



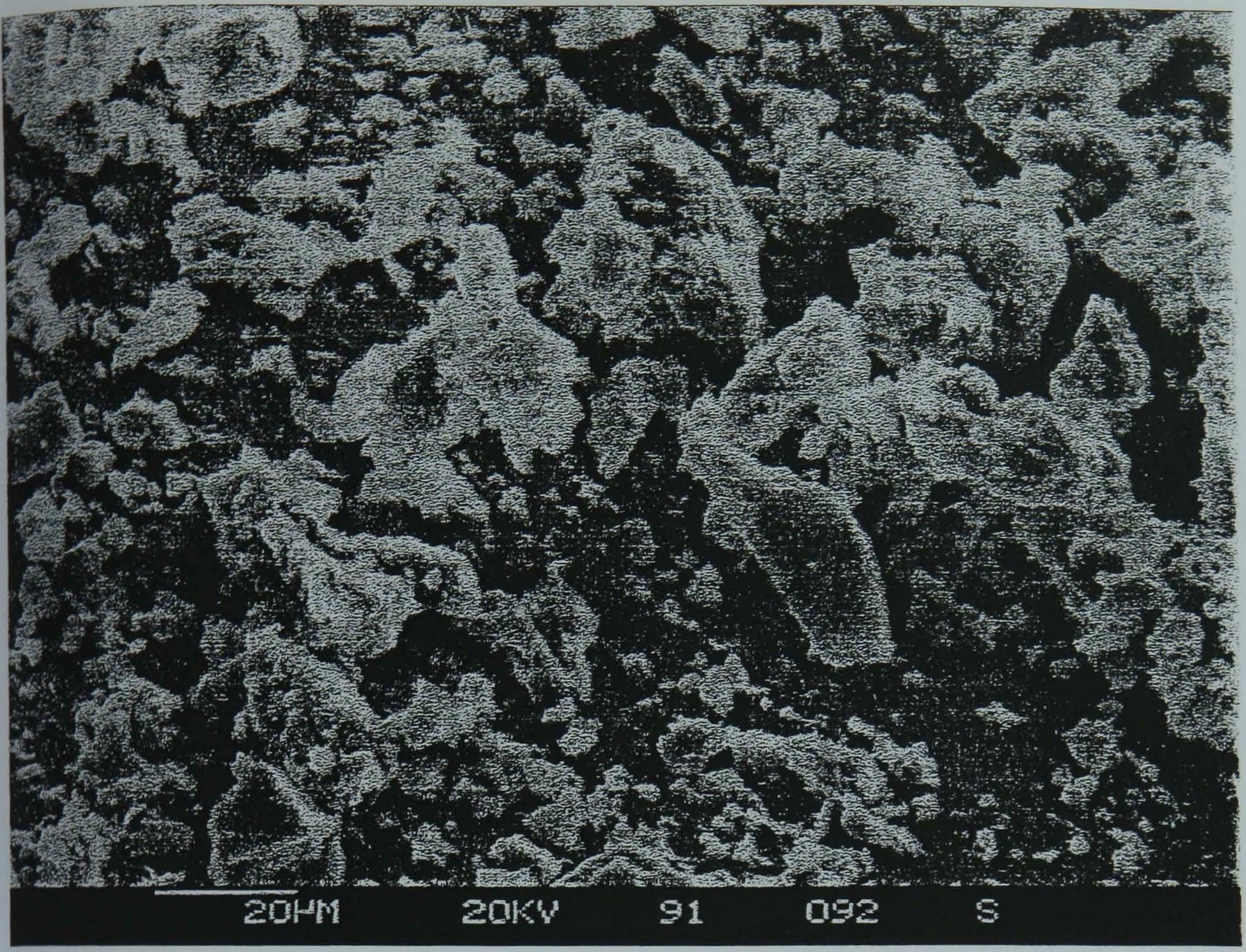
Nitric acid residue



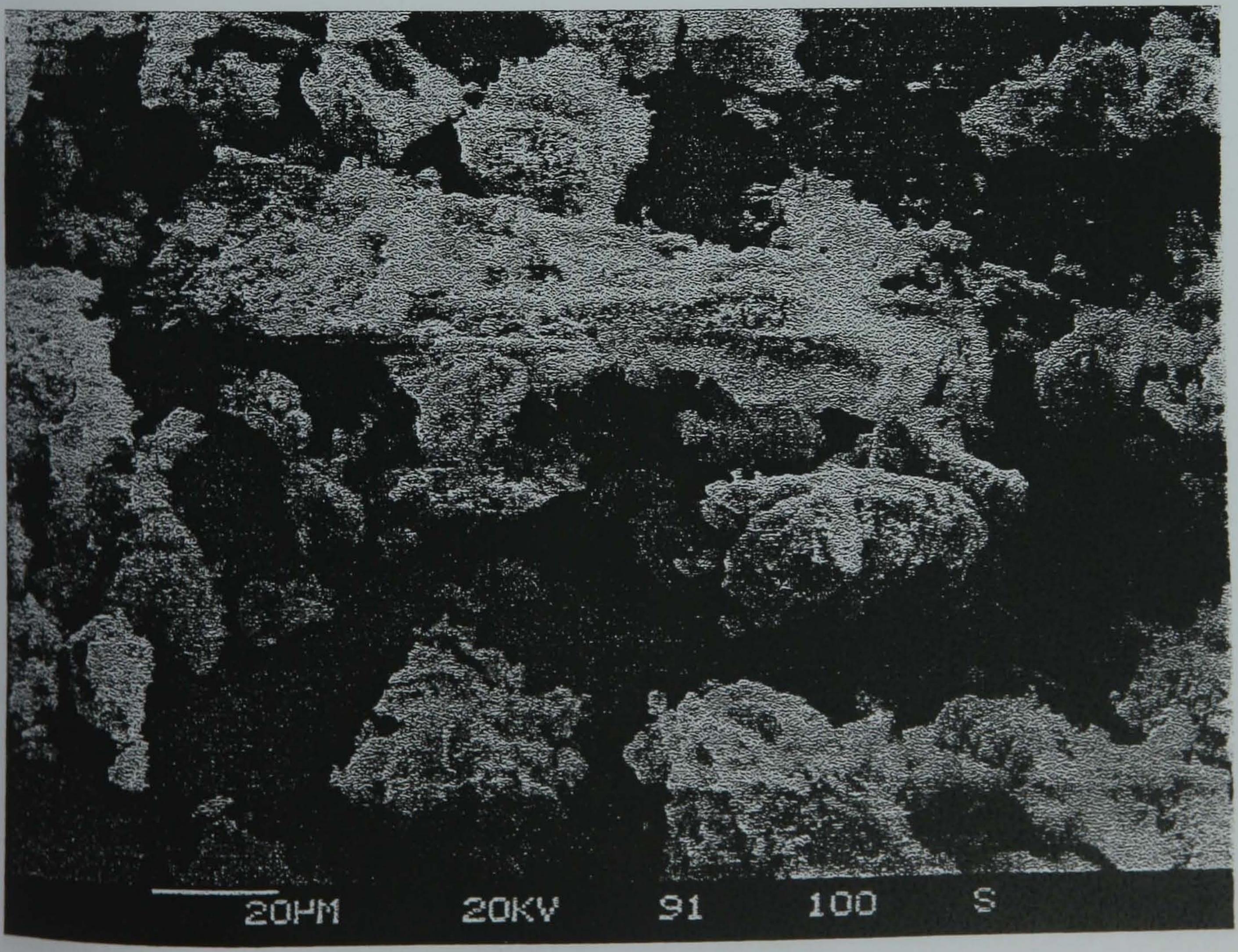
Phosphoric acid residue



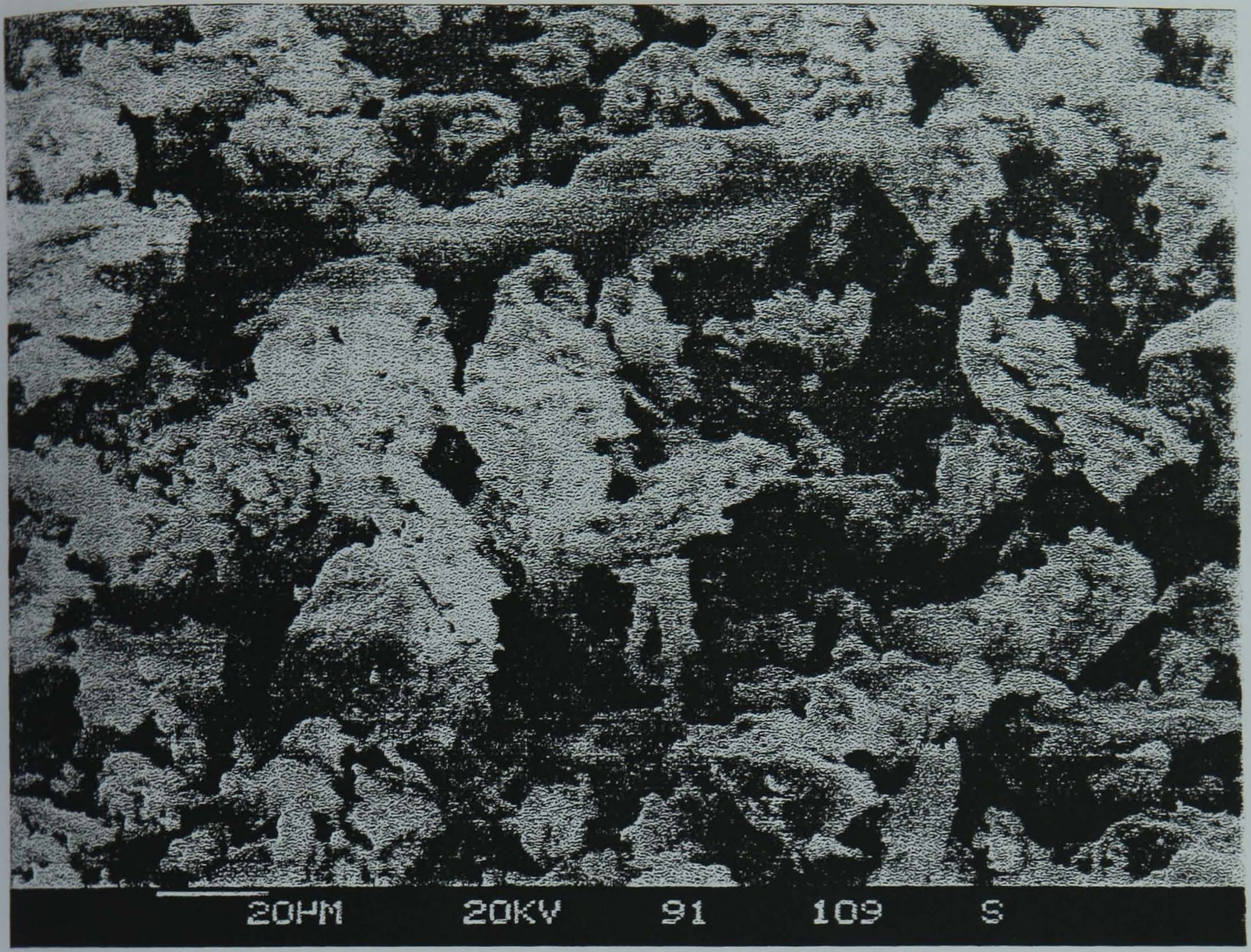
Sodium Hydroxide residue



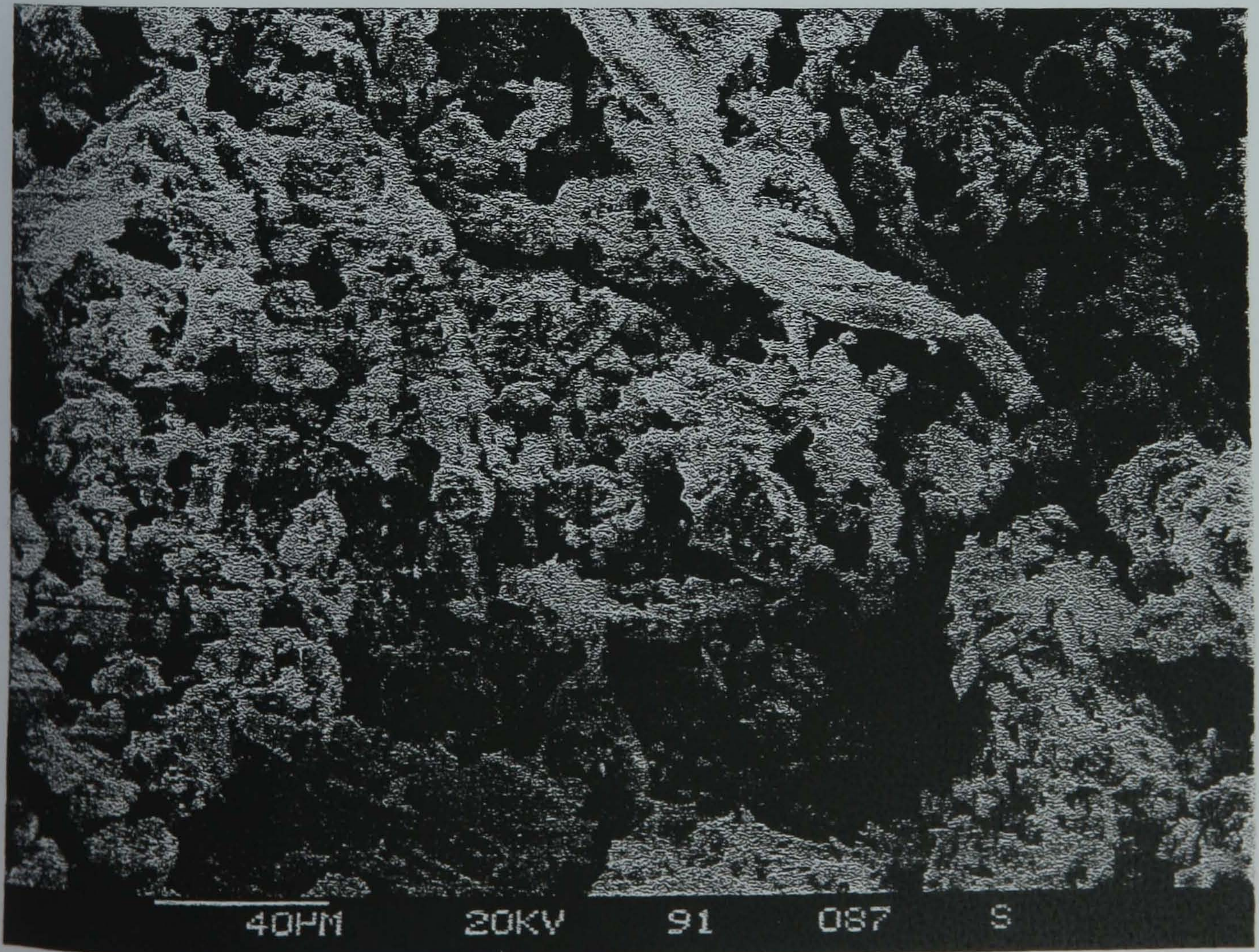
Sodium Pyrophosphate residue



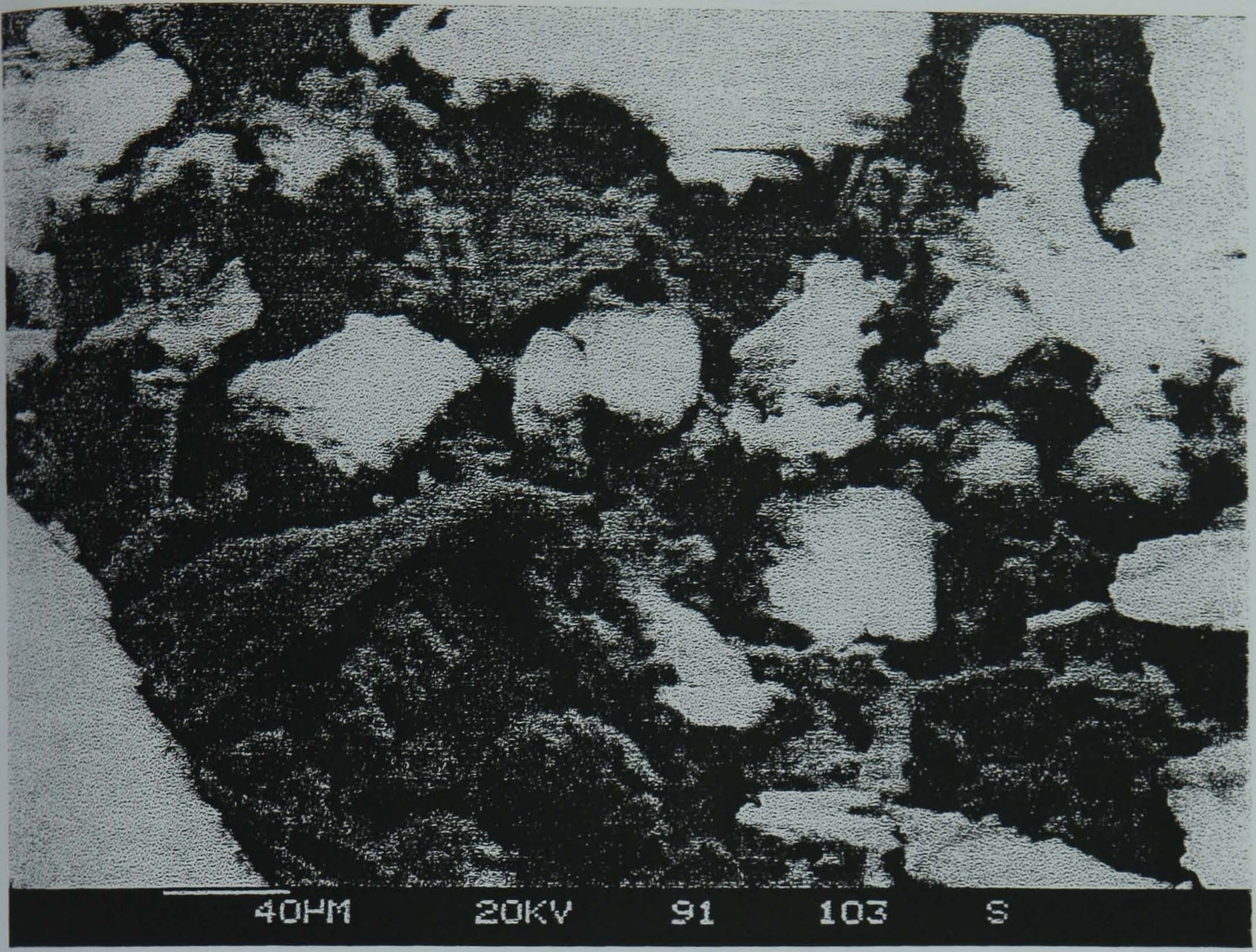
Sodium Carbonate residue



Potassium Chloride residue

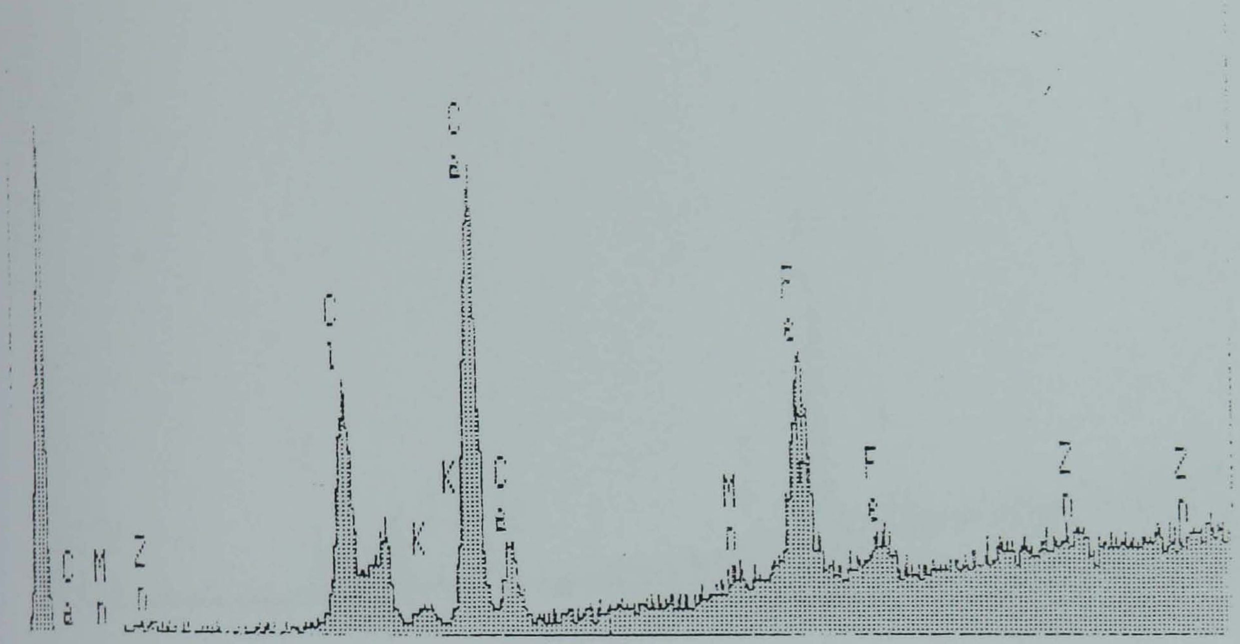


Calcium Chloride residue

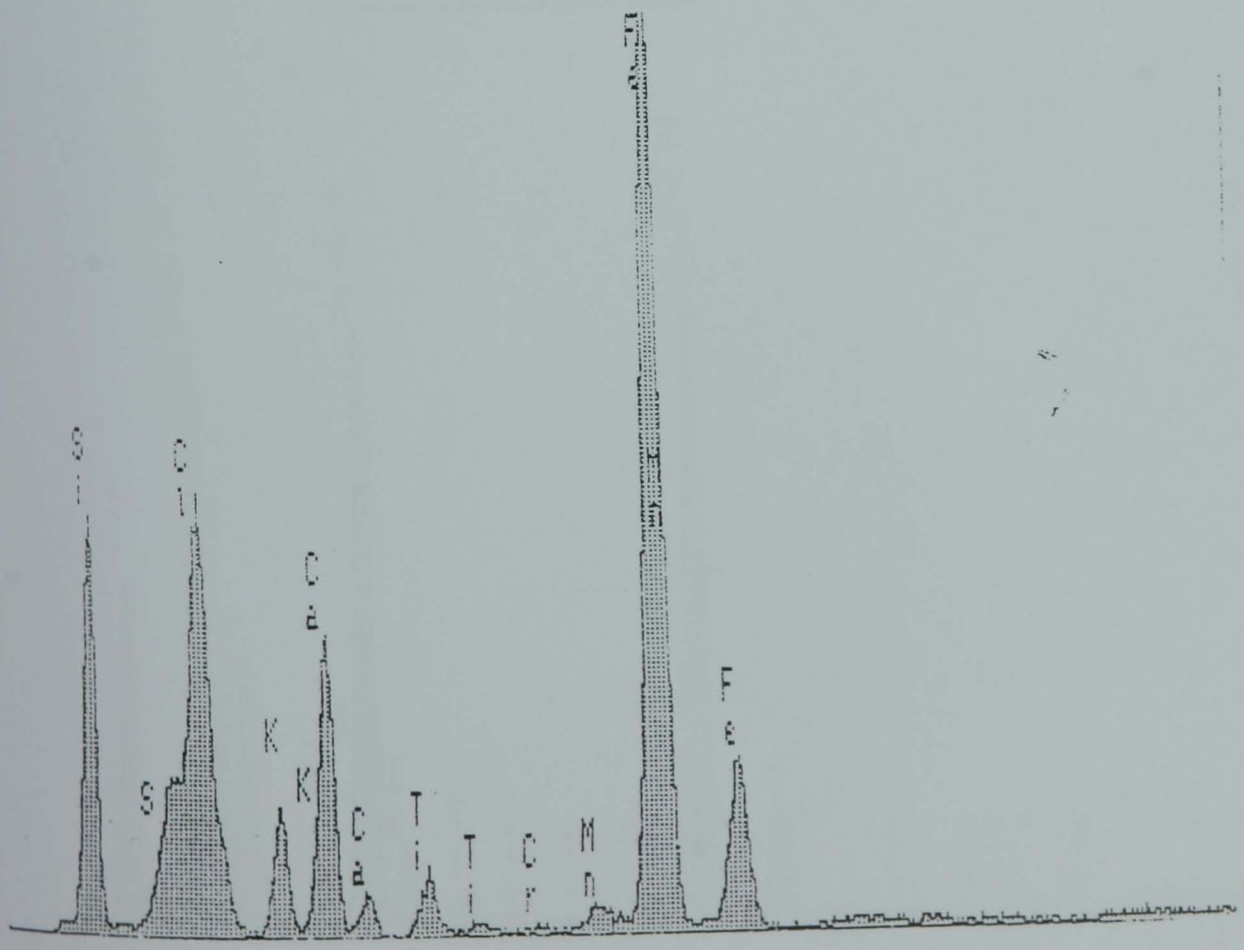


APPENDIX 6

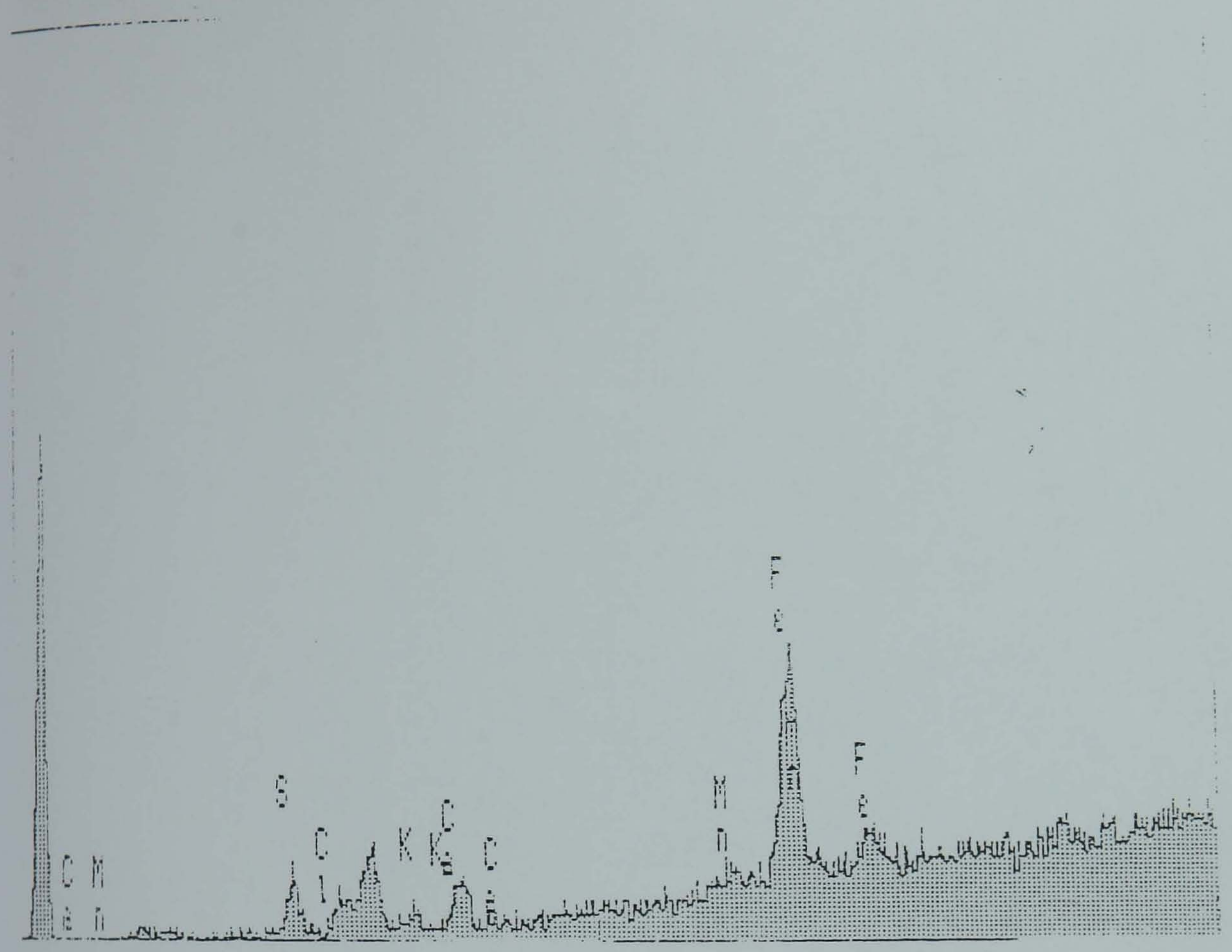
Hydrochloric acid Leach



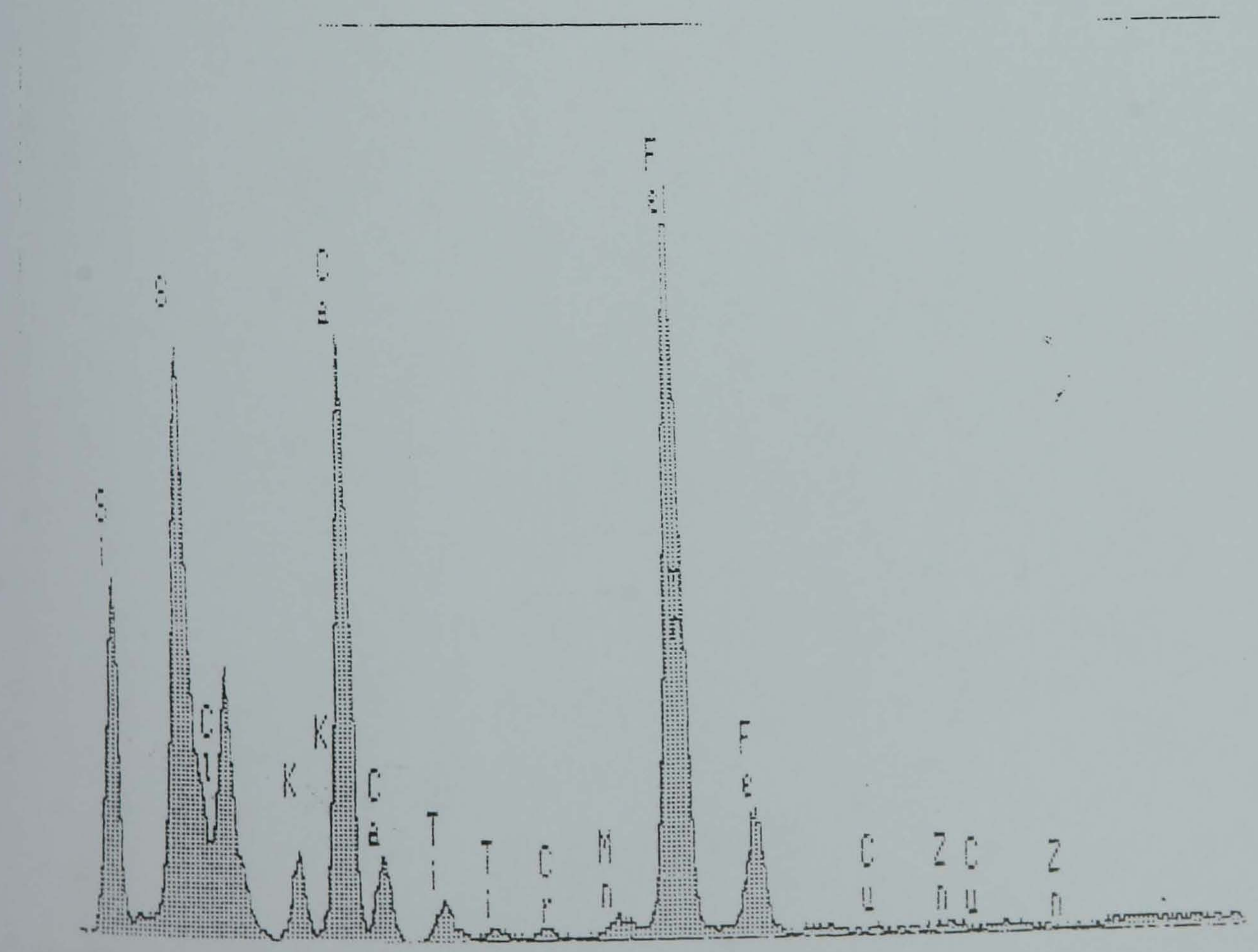
Hydrochloric acid residue



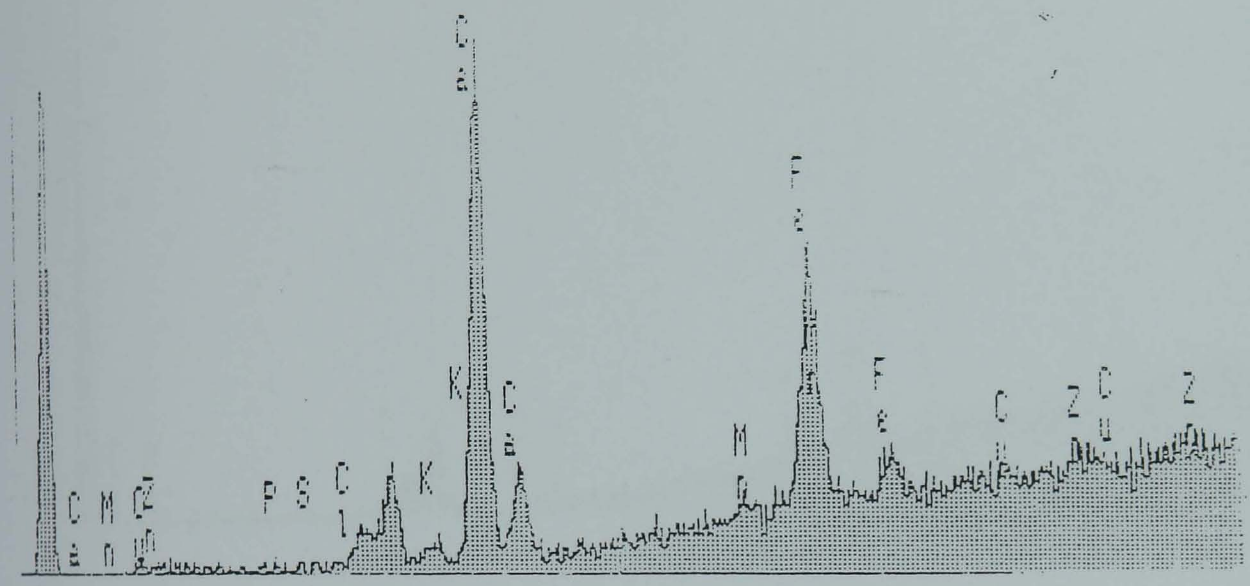
Sulphuric acid Leach



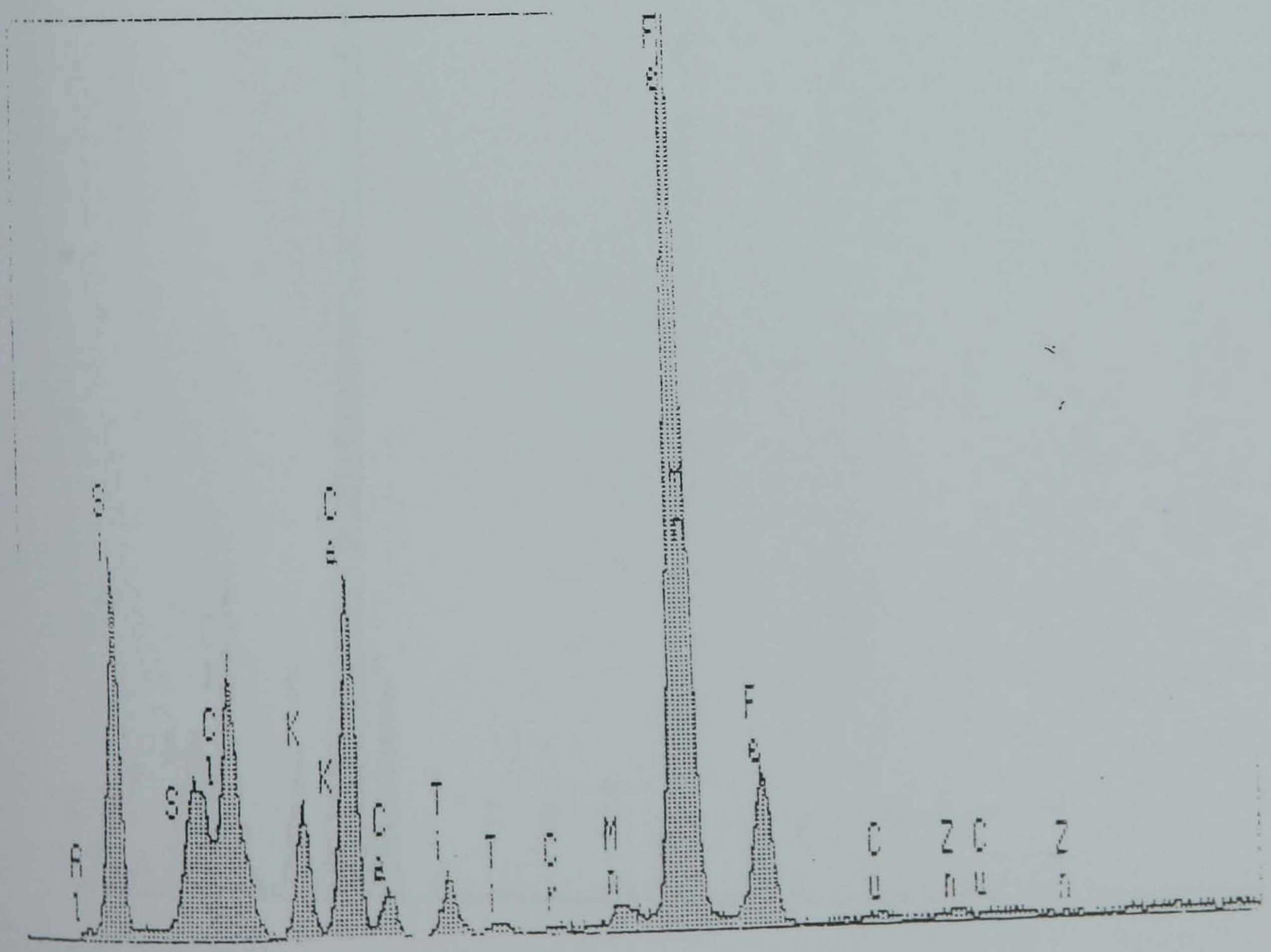
Sulphuric acid residue



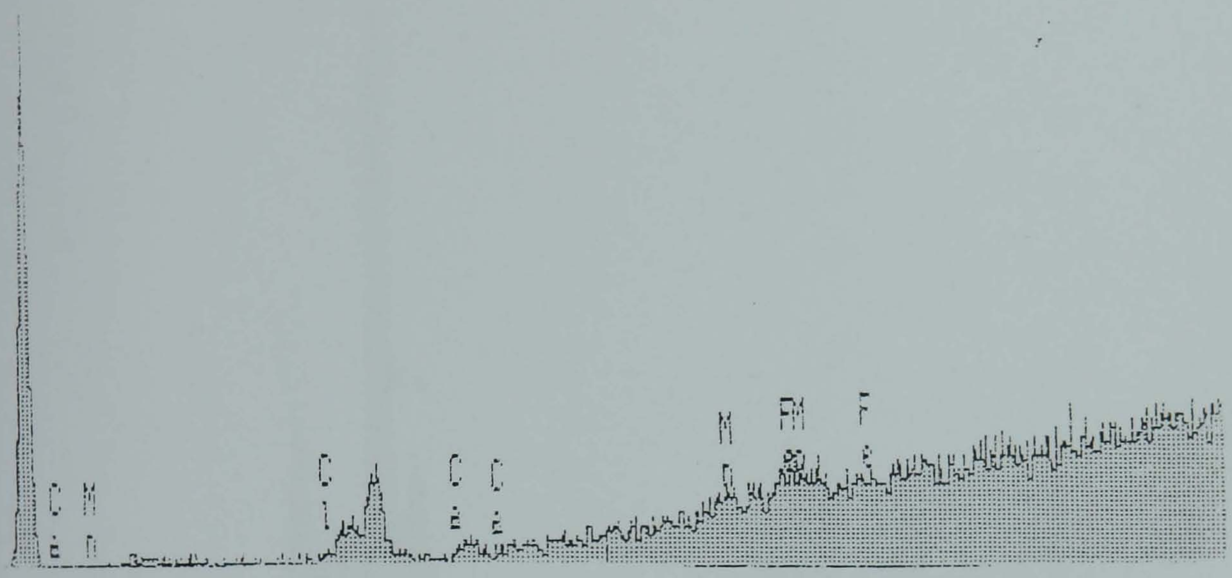
Nitric acid Leach



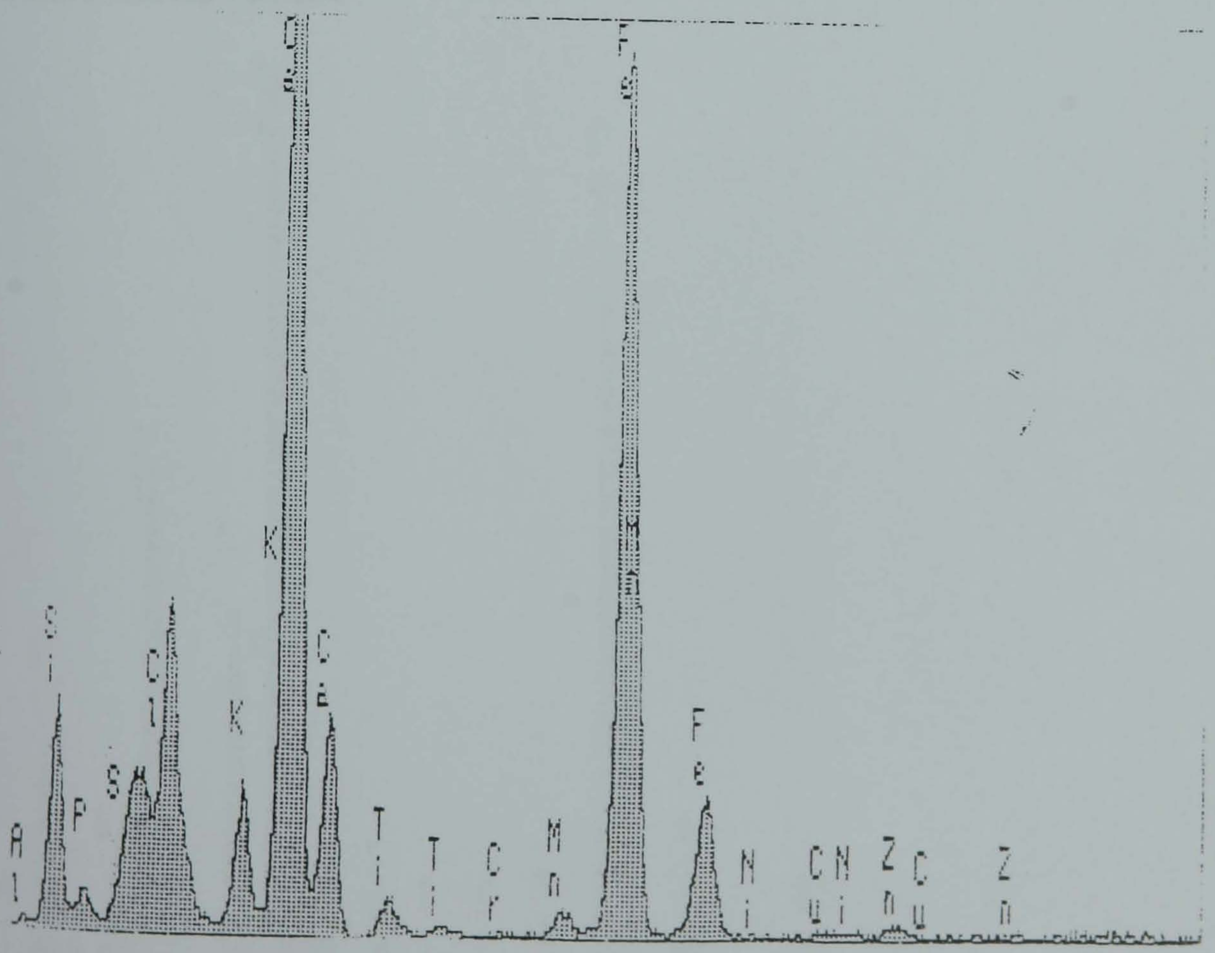
Nitric acid residue



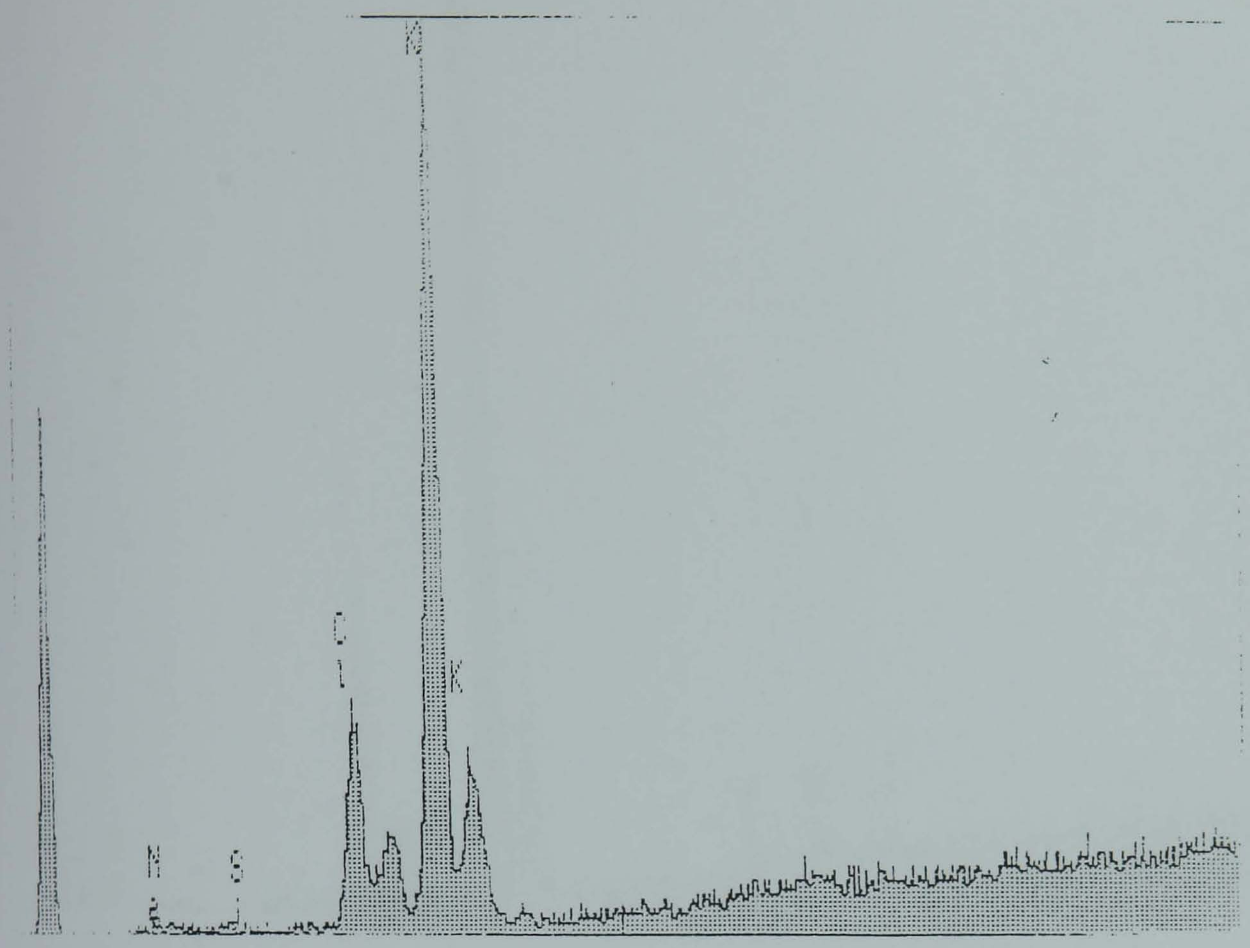
Sodium Hydroxide Leach



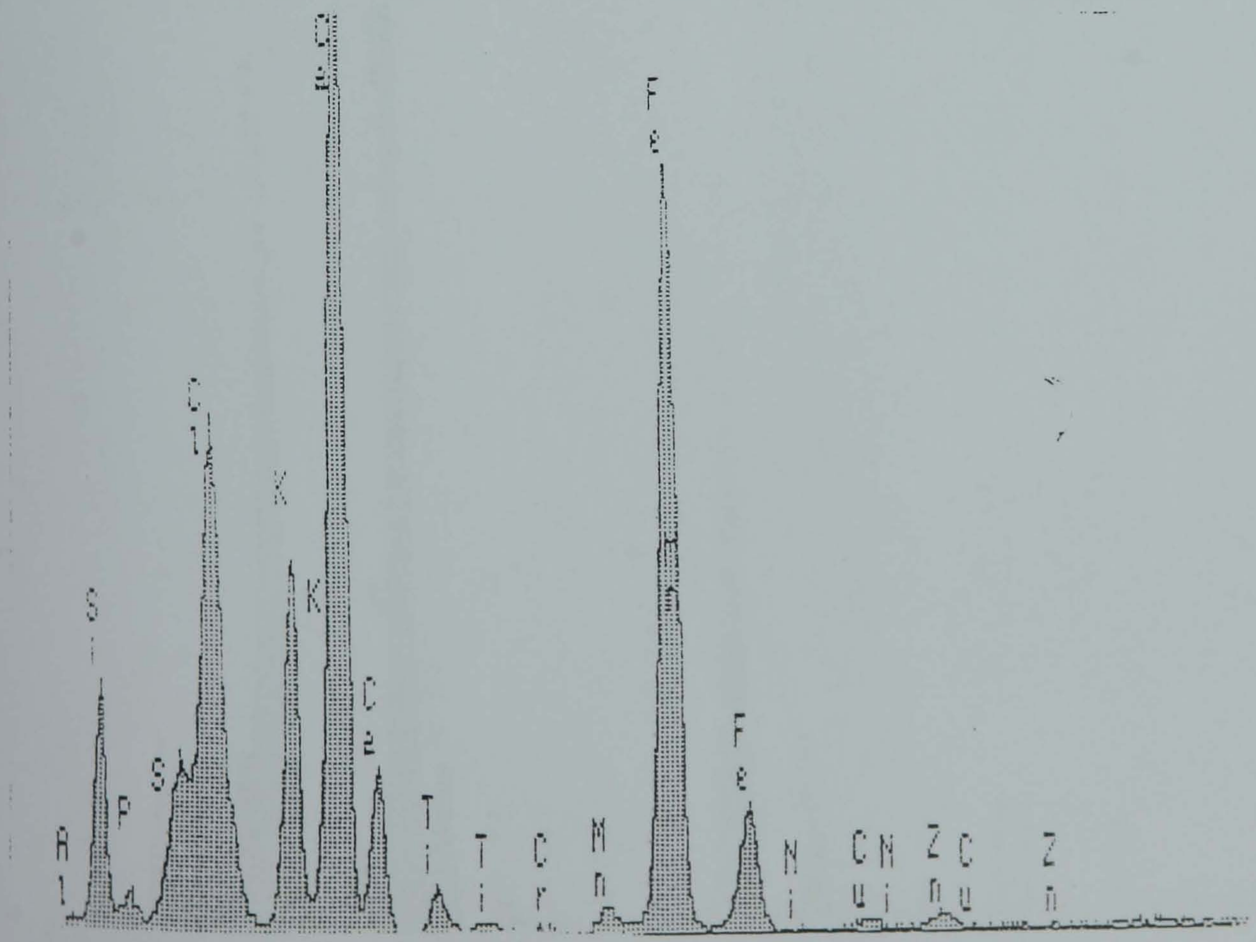
Sodium Hydroxide residue



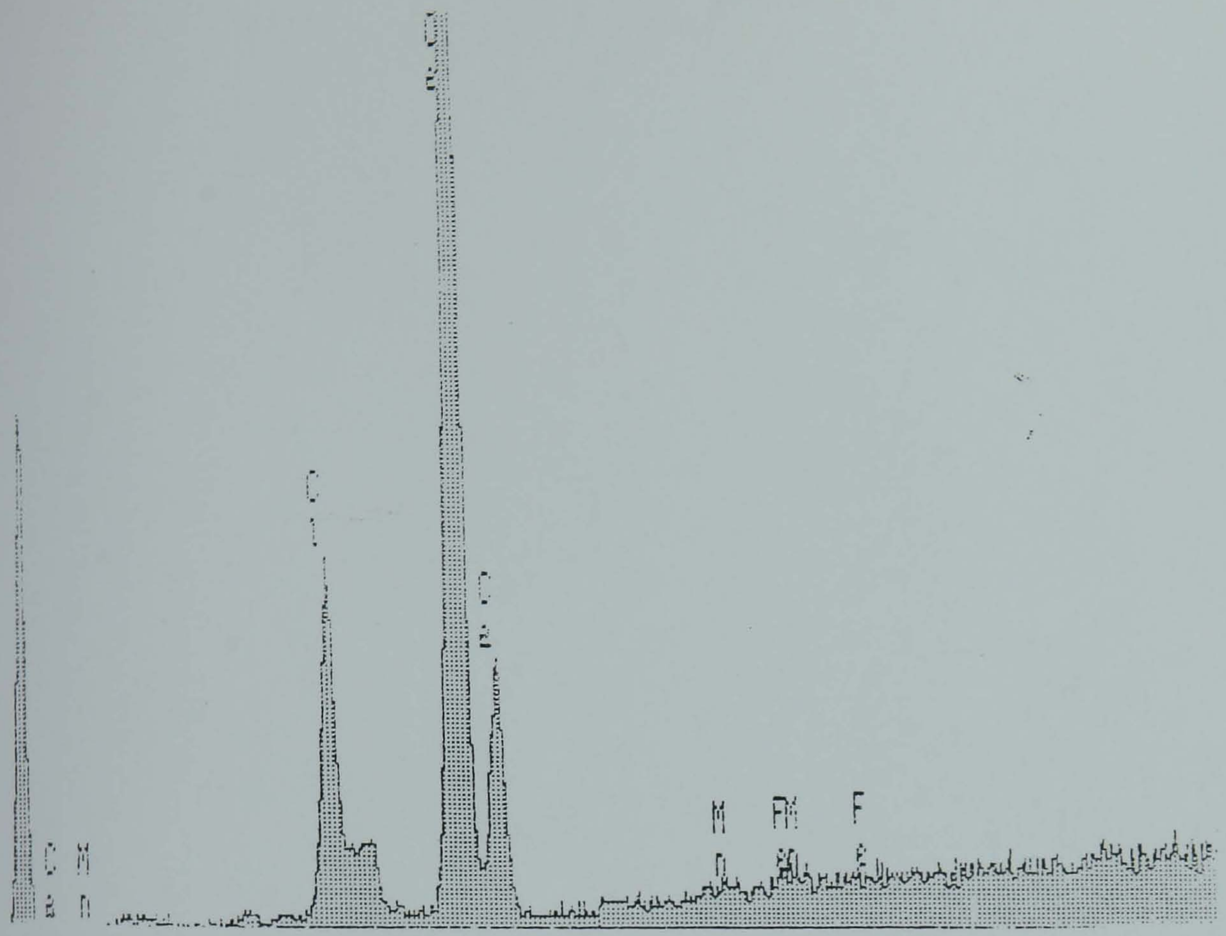
Potassium Chloride Leach



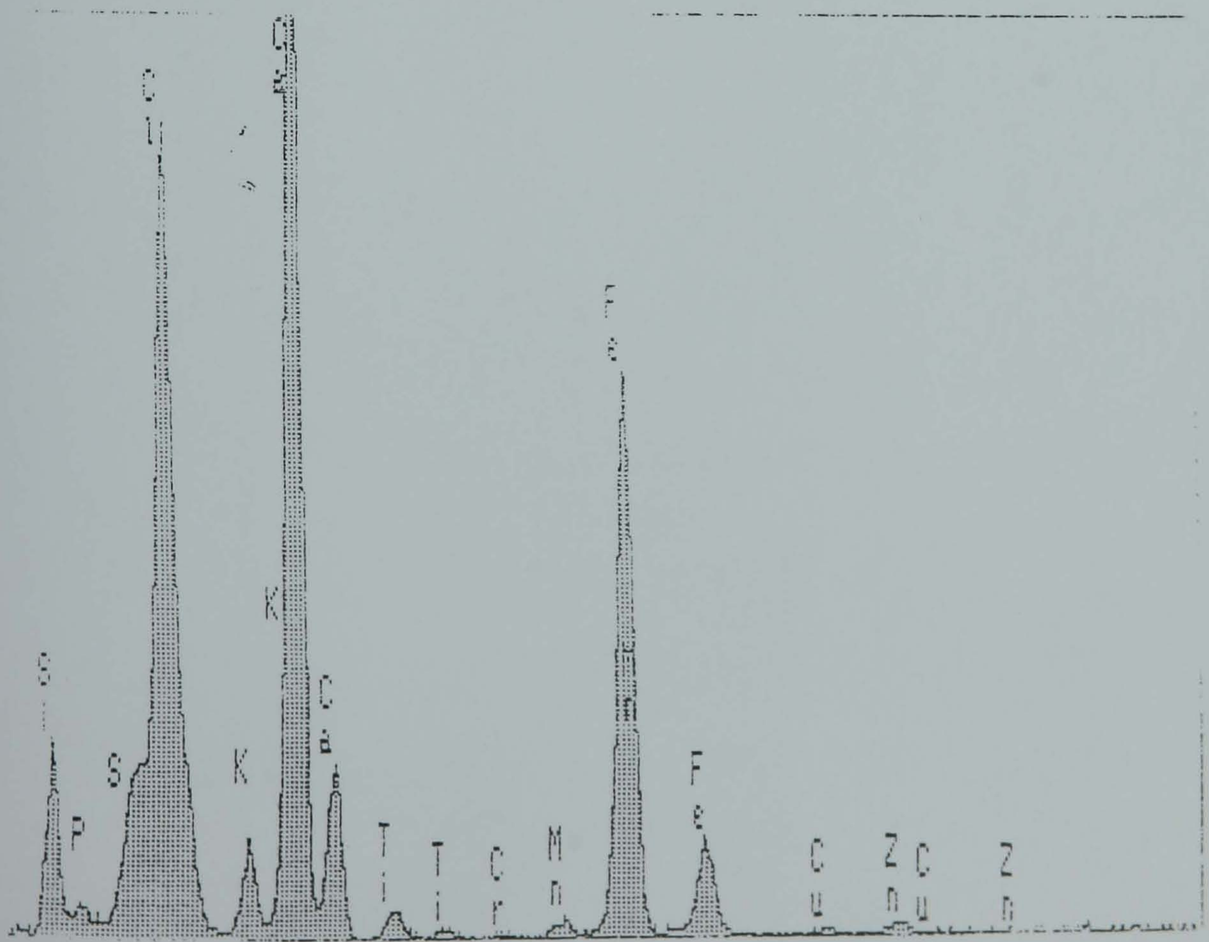
Potassium Chloride residue



Calcium Chloride Leach

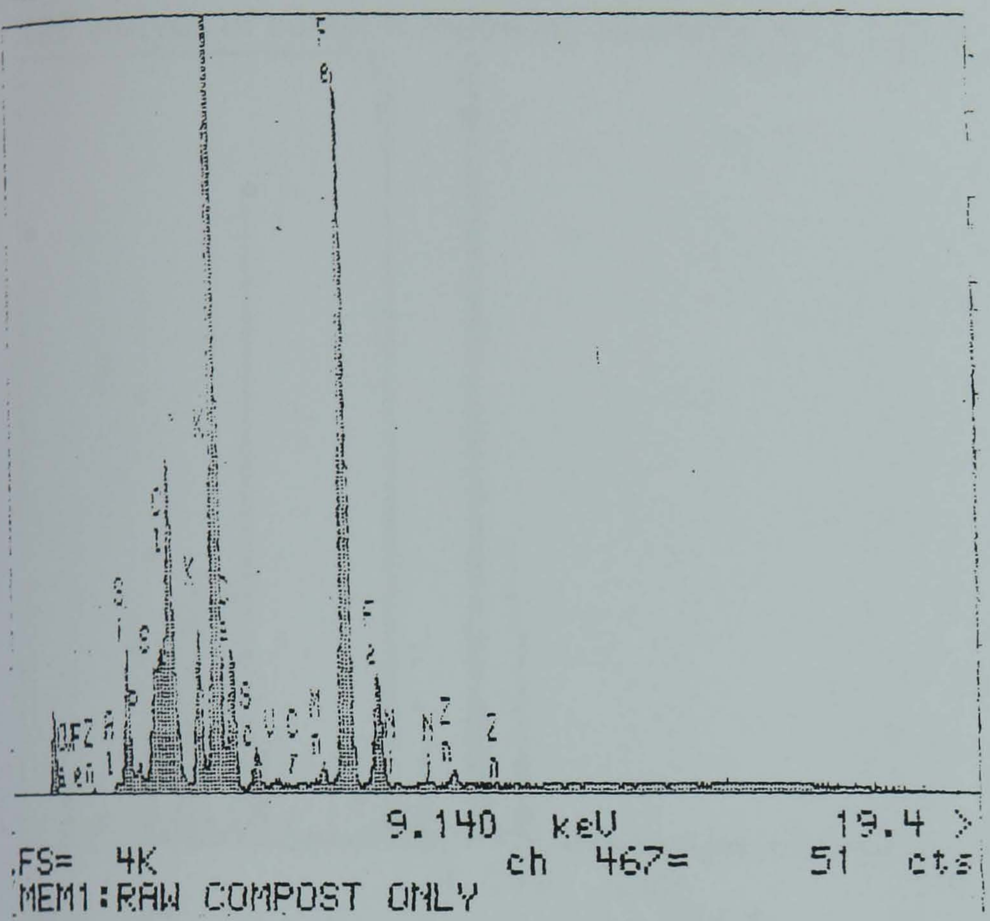


Calcium Chloride residue



APPENDIX 7

XRF analysis of untreated compost



```
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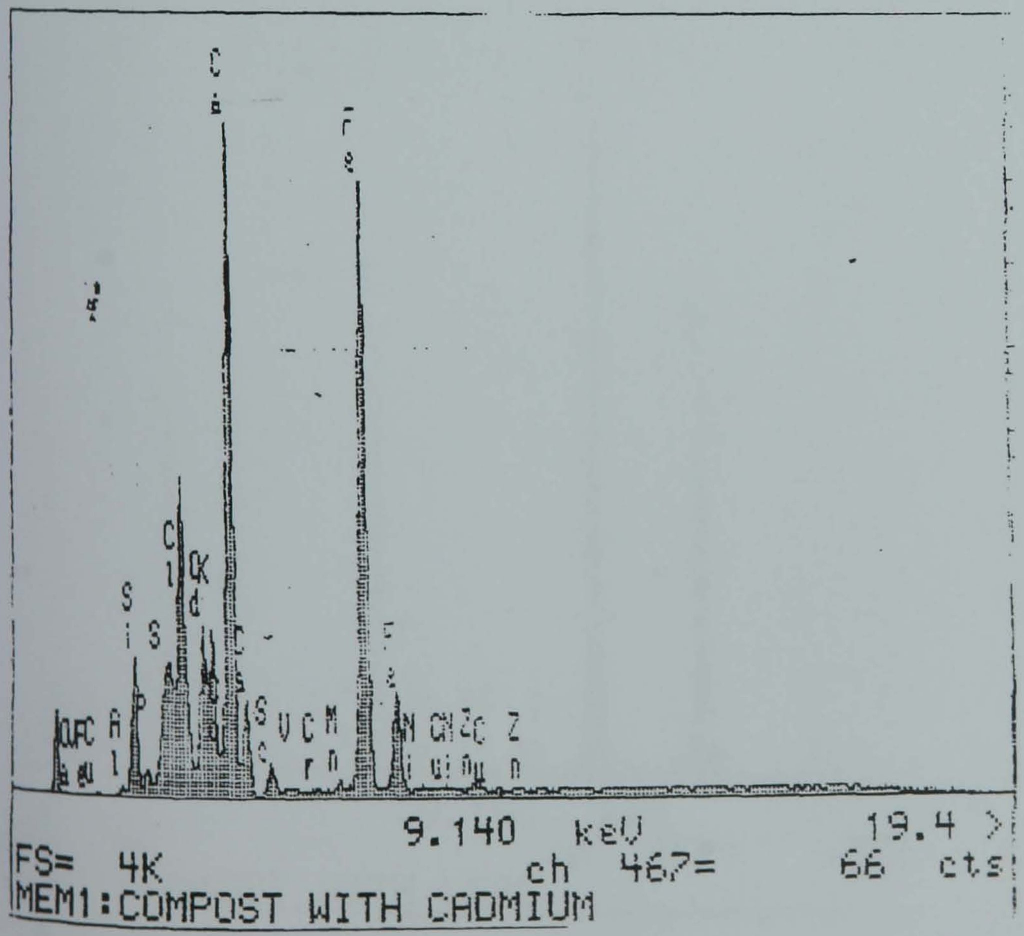
FS=  4K                  ch  467=          51   cts
MEM1:RAW COMPOST ONLY
```

XRF analysis of compost following saturation with cadmium



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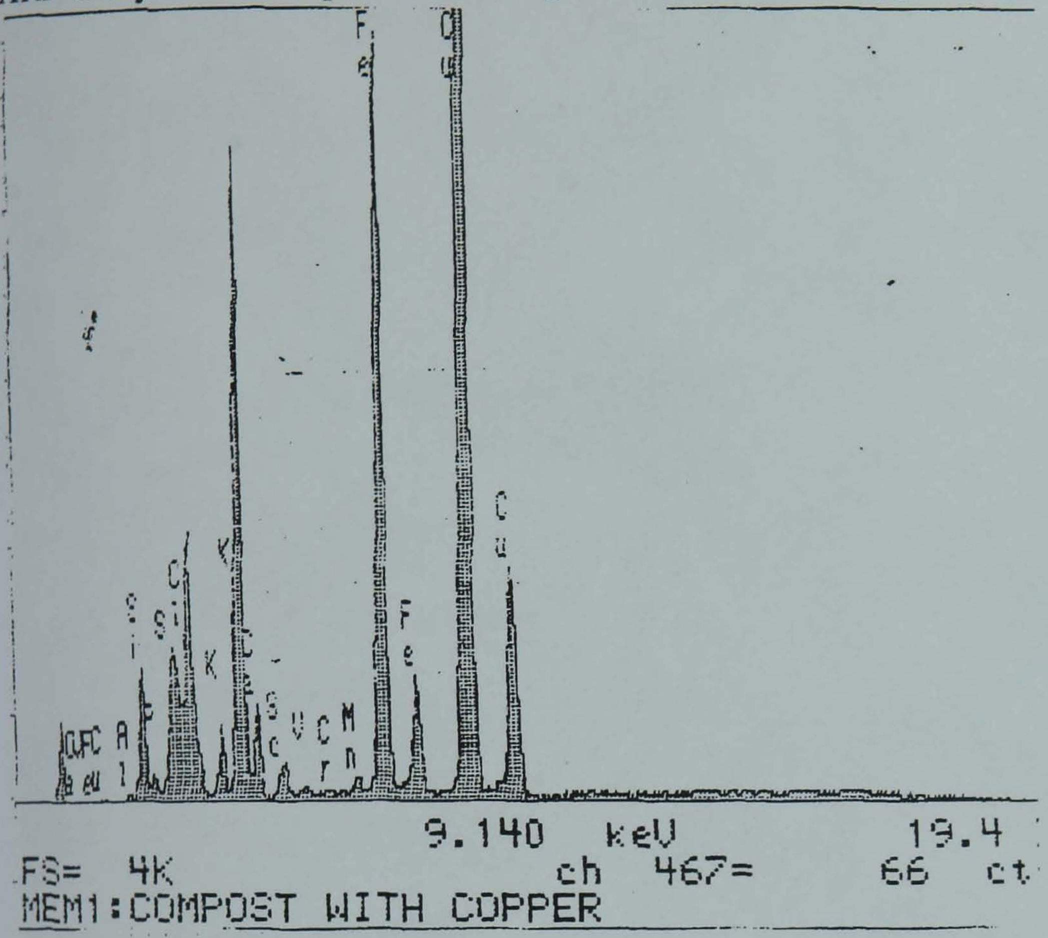
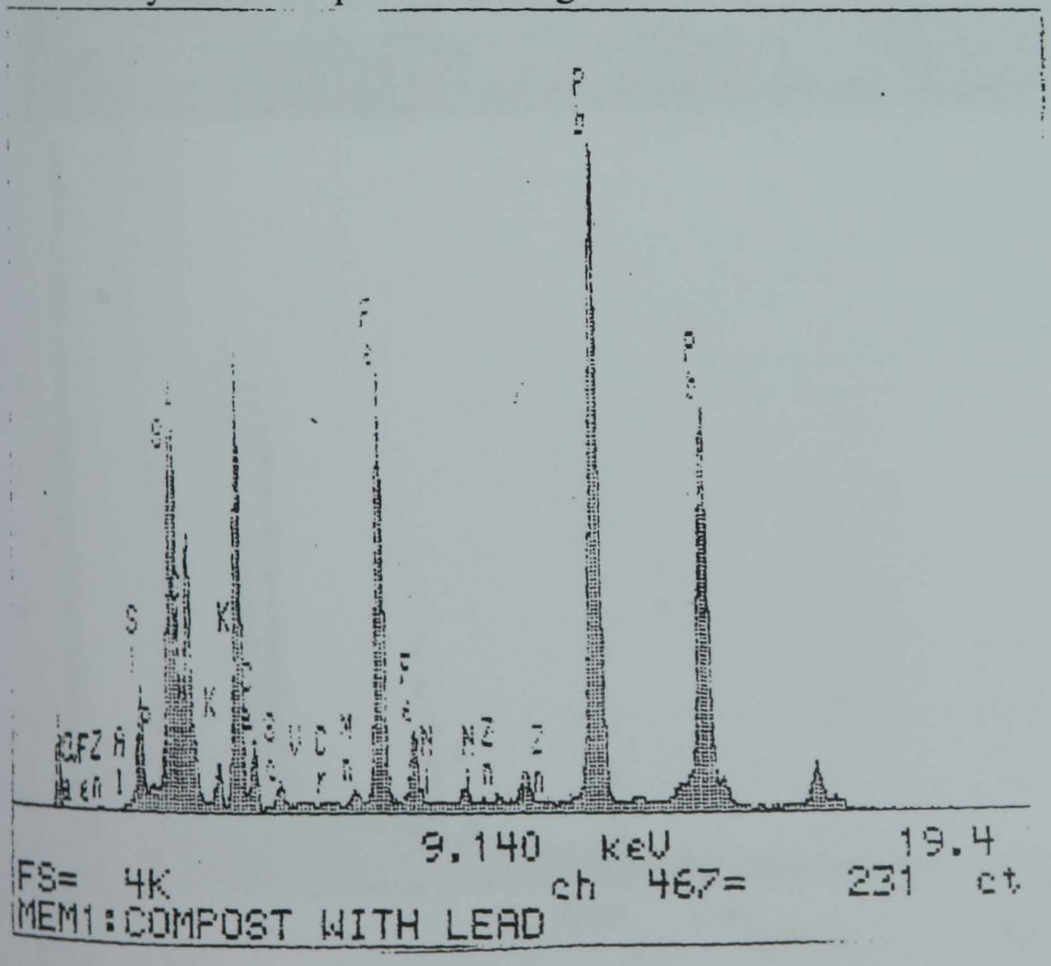
                    9.140   keV              19.4 >
FS=  4K                  ch  467=          66   cts
MEM1:COMPOST WITH CADMIUM
```

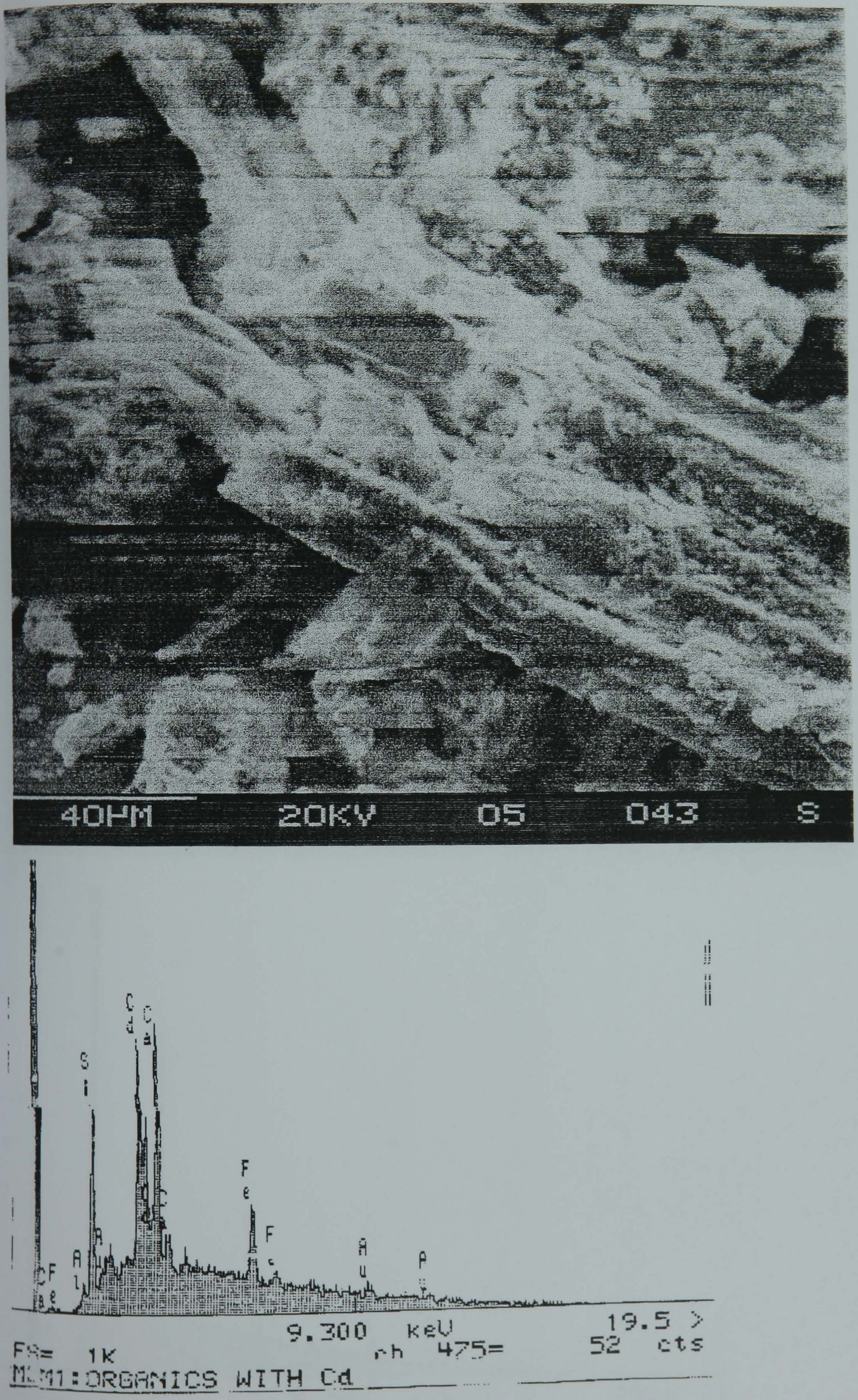
XRF analysis of compost following saturation with copper



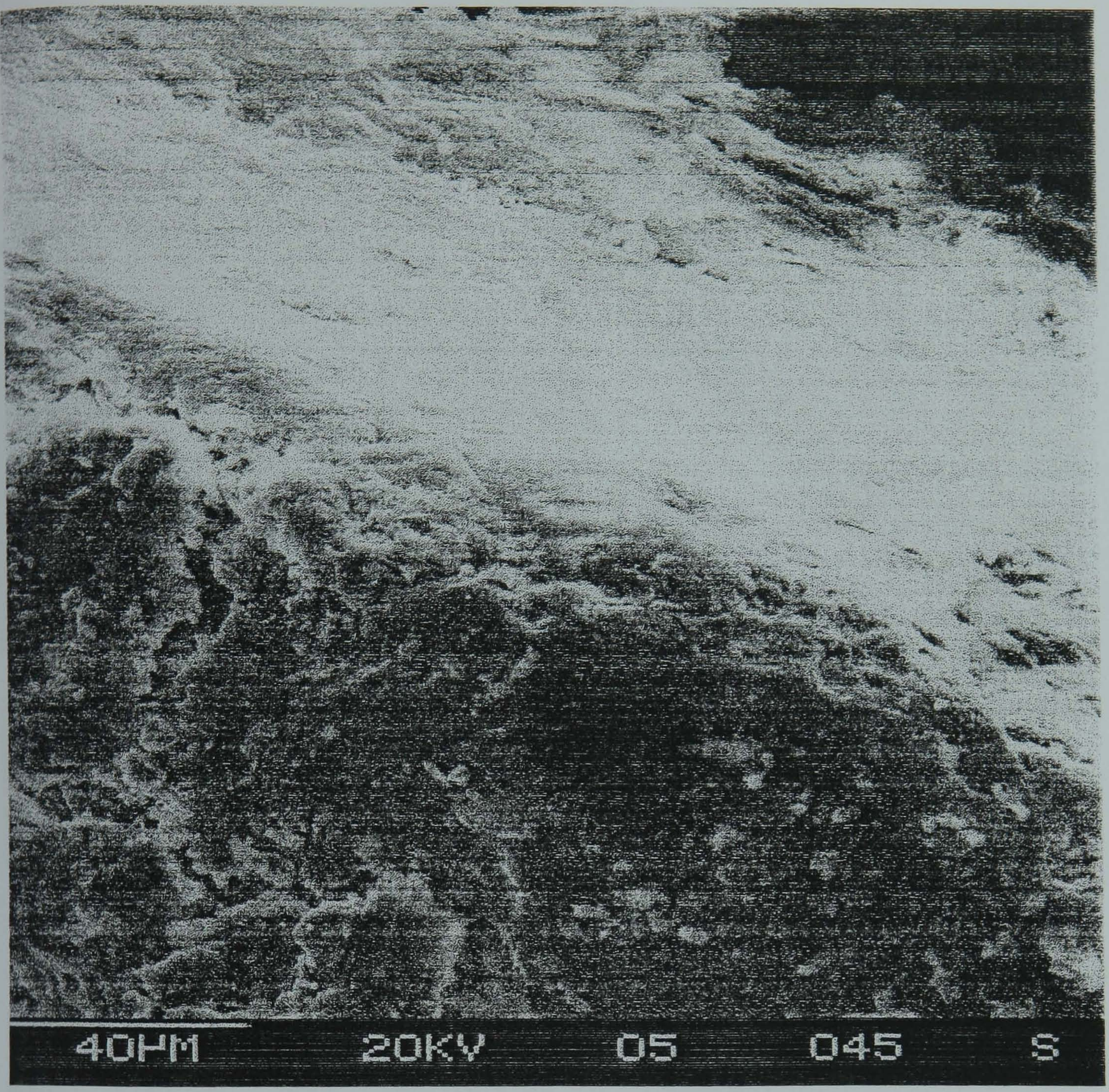
XRF analysis of compost following saturation with lead

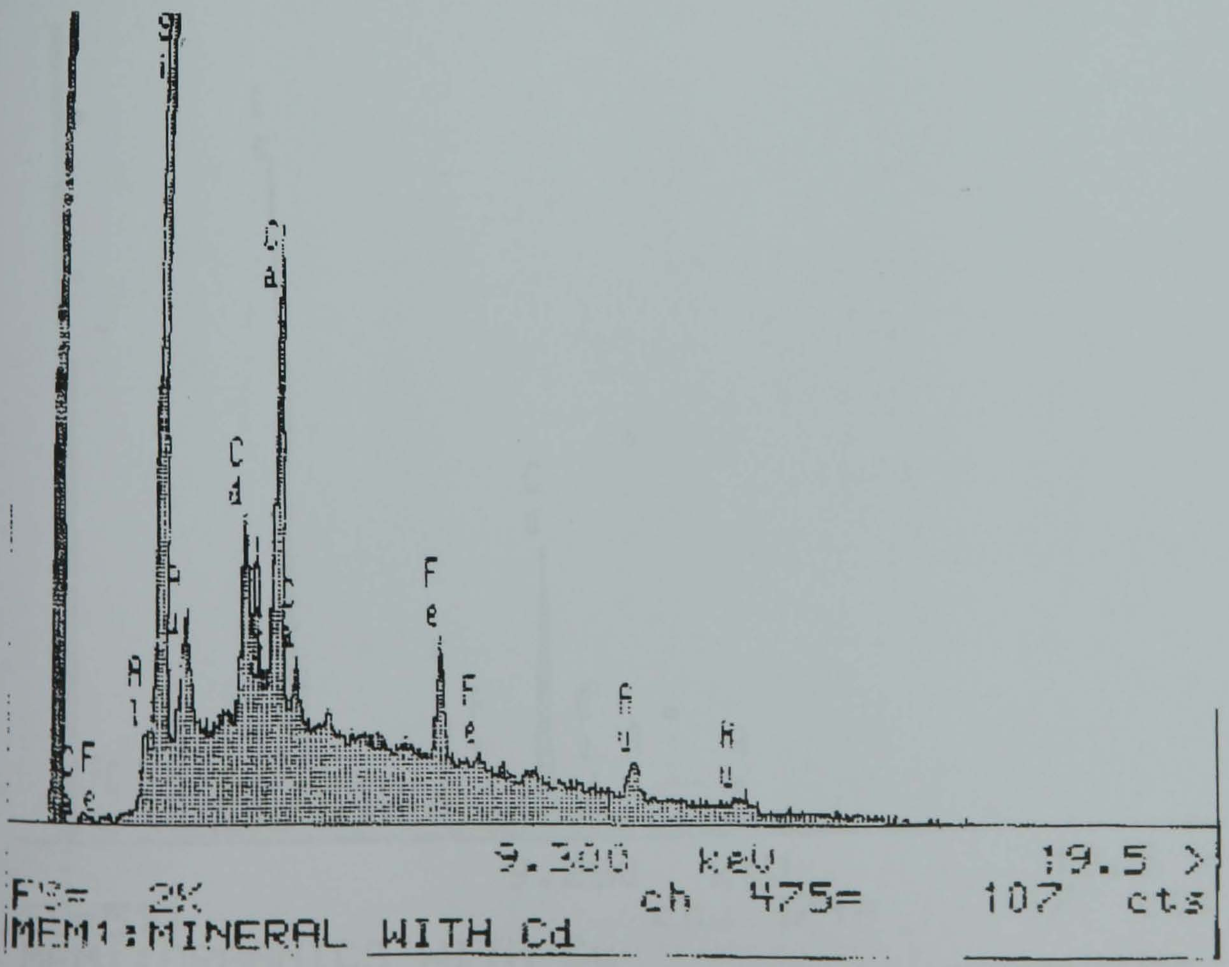


SEM and corresponding XRF of organic material in compost with cadmium

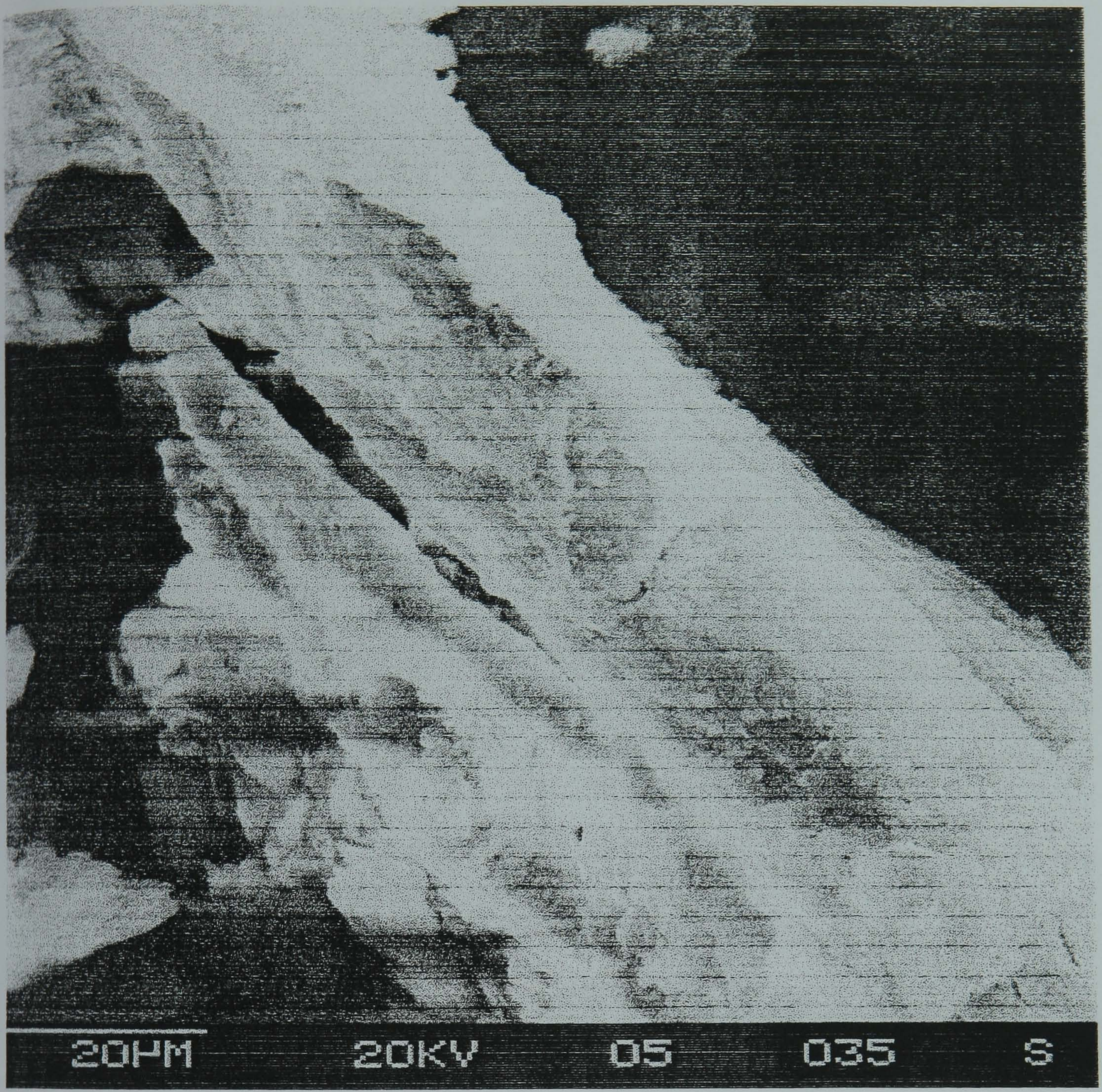


SEM and corresponding XRF of mineral material in compost with cadmium

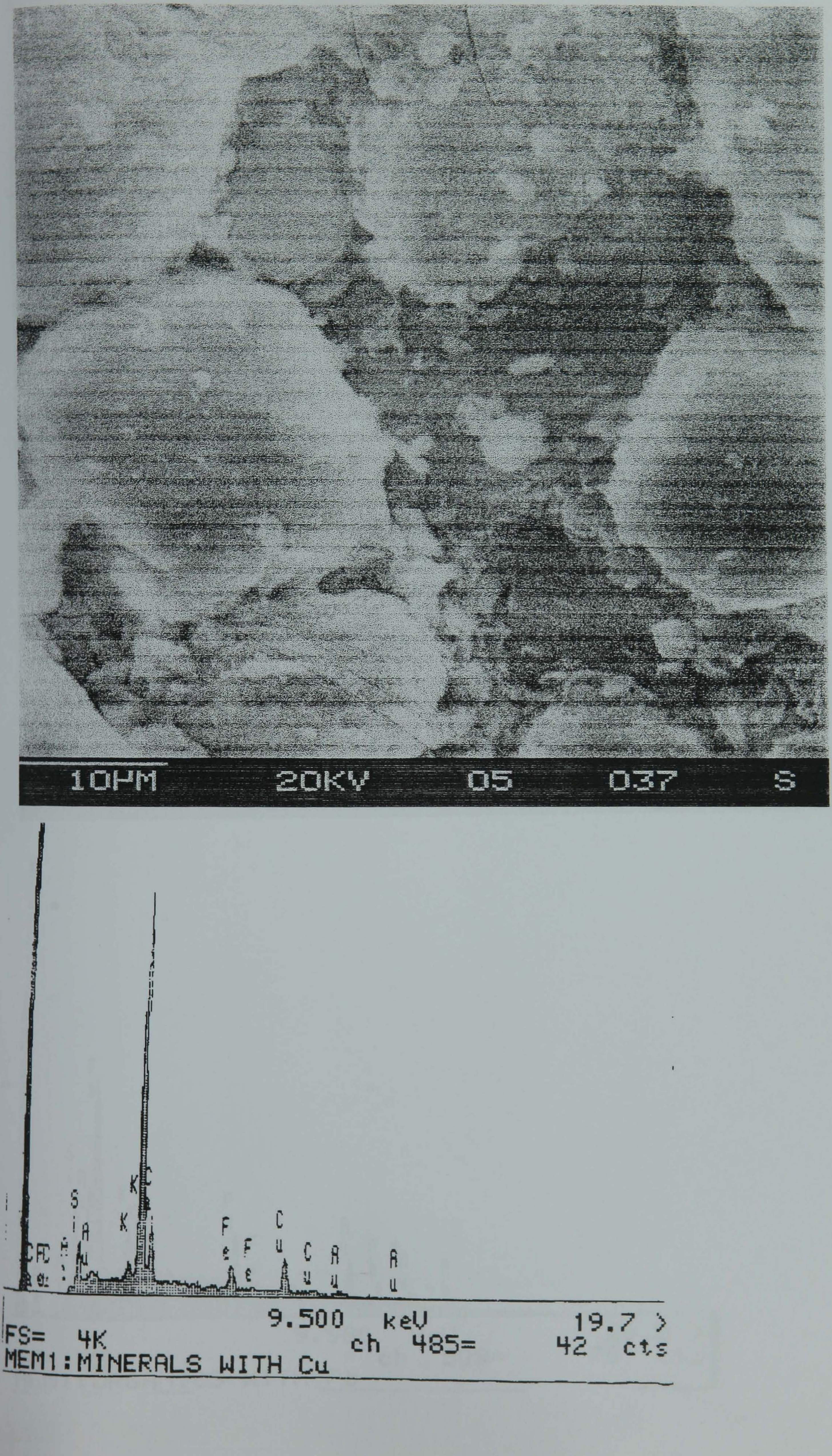




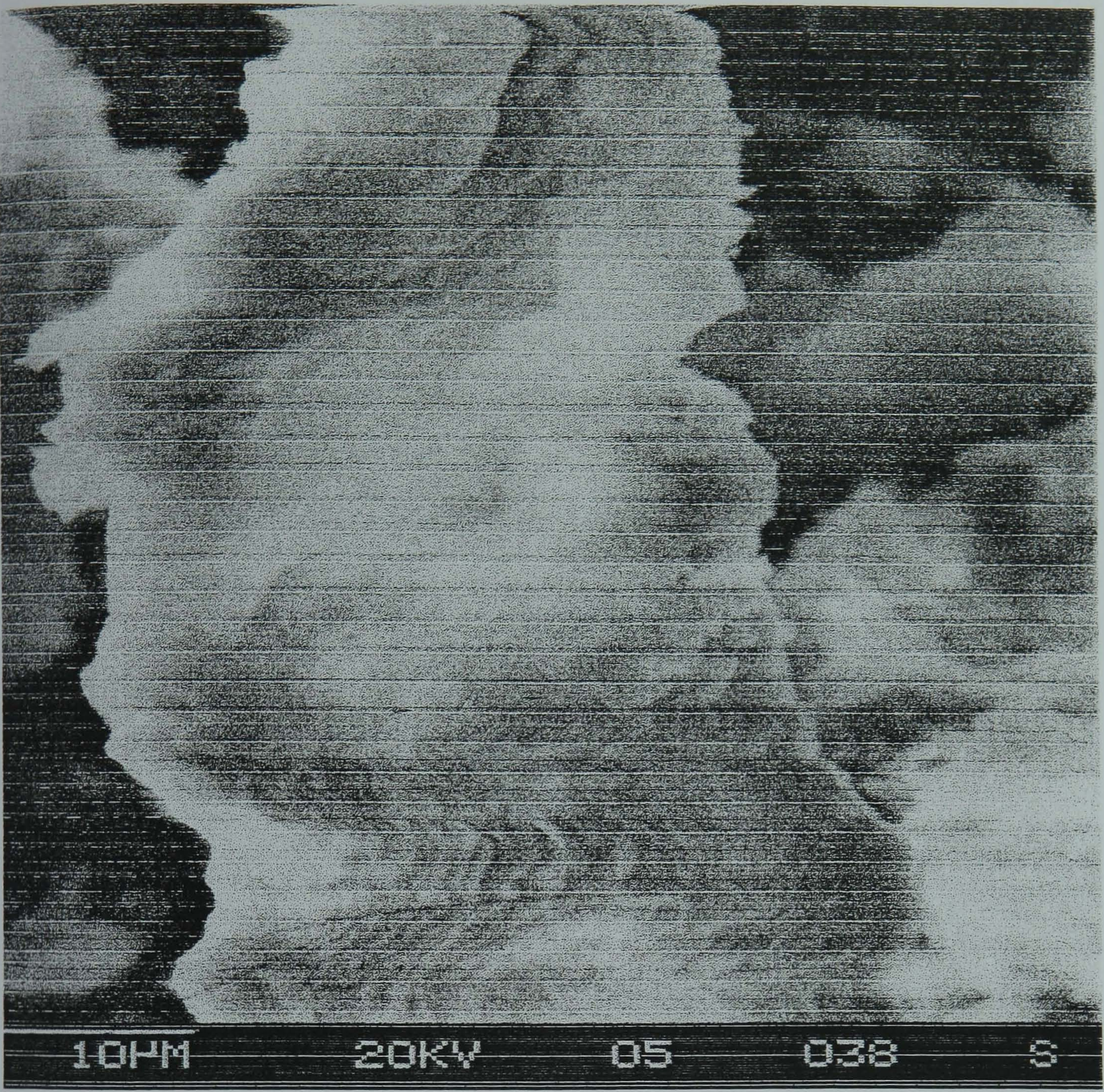
SEM and corresponding XRF of organic material in compost with copper

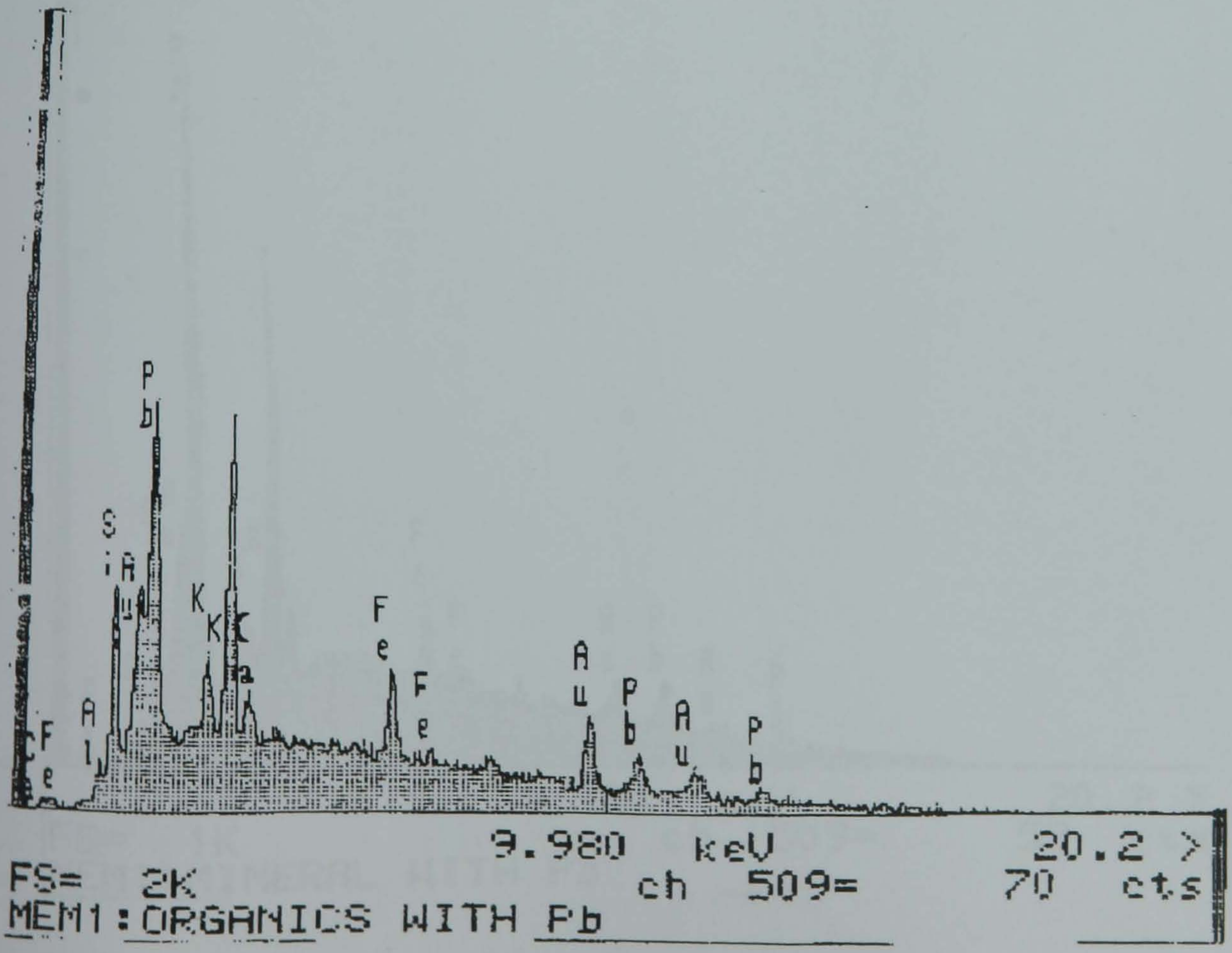


SEM and corresponding XRF of mineral material in compost with copper

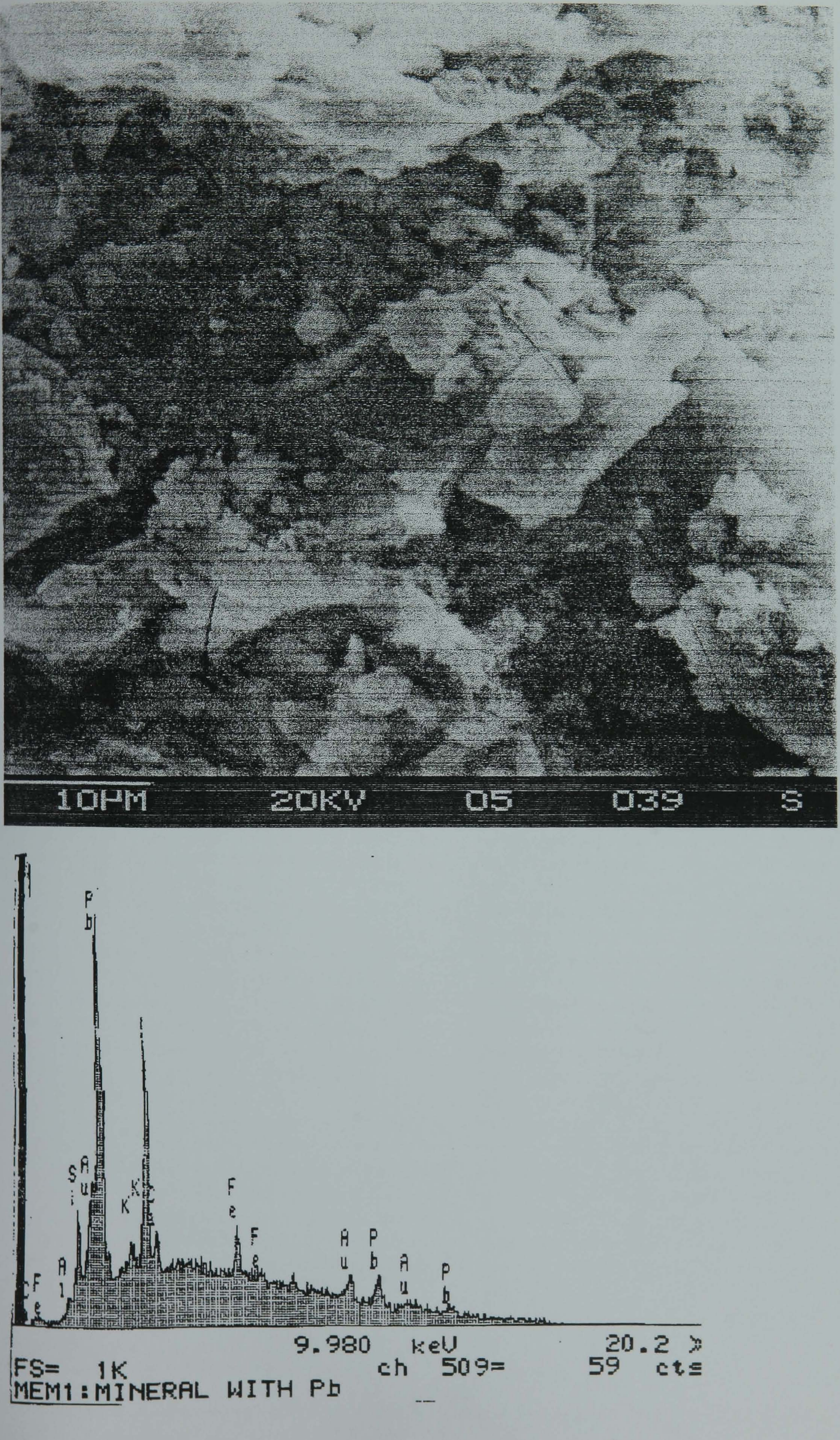


SEM and corresponding XRF of organic material in compost with lead





SEM and corresponding XRF of mineral material in compost with lead



APPENDIX 8

Journal of Chemical Technology and Biotechnology *J Chem Technol Biotechnol* 74:1125–1130 (1999)

The availability and binding of heavy metals in compost derived from household waste

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[2]*Environment Agency, Wah Kwong House, 10 Albert Embankment, London, SE1 7TJ, UK*

Abstract: Organic waste can be recycled as compost which has traditionally been used as a soil improver. As more waste is recycled as compost, it is becoming increasingly important to find alternative uses for compost. Leachability data are used to determine the environmental availability of Cd, Cu, Pb, and Zn contained in natural compost. Batch sorption data are used to determine uptake of additional Cd, Cu, Pb, and Zn by compost and assess its potential use in remediation work, as an alternative to natural materials such as peat. The relative binding of these additional metals to compost is found to be in the order Pb > Cd ≈ Cu > Zn. The sorption of metals on compost takes place, at least in part, by exchange of calcium bound to the compost and there is evidence that the sorption occurs in both humic and non-humic sites in the compost. The use of compost to bind metals in remediation work is discussed.

Keywords: compost; heavy metals; availability; binding; remediation

1 INTRODUCTION

Composting is a biological process involving the microbial digestion of organic matter under aerobic conditions.[1] It is a method of recycling organic waste, such as garden and kitchen waste generated by households, to produce a material which is used as a soil conditioner or fertiliser. Typically, 20% of the household waste stream is made up of organic material from kitchen and garden waste, and any proportion of this waste that can be composted should result in savings in landfill void. Compost production, however, has increased rapidly over the past decade and this has resulted in such a large increase in available compost that many producers have encountered difficulties in finding markets for the material. Alternative uses will have to be found for compost to maintain the recycling advantage. In this work we show that it is difficult to remove the heavy metals present in natural compost and report on investigations to determine how metals bind to compost to assess one of the potential alternative uses; namely as an adsorbent for heavy metals in polluted water systems.

Although there are many reports on the use of peat for metal removal[2–5] very little work has been reported on metal uptake on compost which should behave in a similar manner while avoiding the depletion of natural resources. The few reported studies on the use of compost for metal removal have been carried out on coir-based compost and this material has been shown to have a high capacity for nickel[6] and to adsorb hexavalent chromium.[7]

Natural composts contain small quantities of heavy metals and because of perceived problems arising from the potential bioavailability of these metals in soil conditioners a number of studies have been carried out to determine the leachability of metals from natural compost. Water-soluble species are potentially the most damaging heavy metal components of compost but Leita and De Nobili[8] showed that the amount of water-soluble trace metals in compost is very small. In studies of compost containing the four metals cadmium, copper, lead, and zinc, however, they did find considerable variation in the water-extractable metal fraction as the composting process progressed. They attributed their observations to the relative affinity of metals for the humic and non-humic material, the proportions of which change during the composting process. A number of multiple stage extraction procedures have also been developed to remove metals from compost as a means of predicting availability.[9–13] These extraction procedures usually involve the use of extractants which are known to be efficient at removing metals from organic matter but the approaches used in these studies are varied and no one extraction method has been developed as a standard test.

Compost consists of a mixture of organic and inorganic matter and the organic matter can be divided into two classes: non-humic substances and humic

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Contract/grant sponsor: UK Environment Agency.
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substances. The non-humic substances include those compounds which have recognisable chemical characteristics and include proteins, amino acids, and carboxylic acids derived from sugars. Most of the organic matter, however, consists of humic substances which have high molecular weights, are brown/black in colour and have a strong affinity to complex metal ions. As early as 1959, Beckwith[14] commented that many metals formed complexes with humic substances and that the order of stabilities of the different metal complexes followed that of the Irving–Williams series: $Pb^{2+} > Cu^{2+} > Ni^{2+} > Co^{2+} > Zn^{2+} > Cd^{2+} > Fe^{2+} > Mn^{2+} > Mg^{2+}$.

The inorganic fraction of the compost may also contain anions such as Cl^- and OH^-, which can form complexes with metal ions and chemically bound groups such as hydroxyl groups that can take part in ion exchange reactions at the surface.

2 EXPERIMENTAL

The compost used for this study was supplied by East Hertfordshire District Council, who collect the organic waste (mainly household and garden waste) separately from the remainder of the household waste stream prior to composting. The Council operate a centralised composting plant which uses the windrow method of composting. A number of random samples of compost were taken from a matured windrow of compost for laboratory studies. The compost samples used in the study were prepared by coning and quartering the bulk material prior to drying the samples at air temperature and sieving to give a particle size less than 2 mm. The water content of the compost prior to drying was 32%. Characterisation of the compost gave the following parameters (analytical data are expressed with respect to dry matter): organic matter 34.1%; total carbon 19.8%; total nitrogen 1.18%; total phosphorus 0.25%; total potassium 0.51%; total magnesium 0.20%; total zinc 158.5 mg kg^{-1}; total copper 50.7 mg kg^{-1}; total lead 131.0 mg kg^{-1}; total nickel 16.6 mg kg^{-1}; total chromium 21.7 mg kg^{-1}; total cadmium 0.92 mg kg^{-1}; pH 8.03; conductivity 1.20 mmhos; and carbon:nitrogen ratio 17:1.

Compost derived from household waste will always contain some metals and the material used in this study contains the metals lead, copper, cadmium and zinc that are the subject of this study. The leachability of these metals was investigated using a series of extractants that have been used in similar studies of other materials. The extractants used were distilled water, and solutions of potassium chloride, acetic acid at pH 5, sodium hydroxide, sodium pyrophosphate, nitric acid, ethylenediaminetetra-acetic acid (EDTA) at pH 5, and sodium carbonate. This range of extractants would show how the metals were bound to compost and indicate whether the metal species were water-soluble, exchangeable, complexed, organically bound or held as solid particulate.

Samples of compost (10 g) were shaken with each extractant (100 cm^3) for 24 h at 21 °C. The resulting mixture was centrifuged for 30 min at 3000 rpm and filtered to remove solid and any suspended material from the filtrate prior to analysis for cadmium, copper, lead and zinc by Atomic Absorption Spectroscopy (AAS). The washed solid residue remaining after extraction was digested with a nitric acid/perchloric acid solution to solubilise all of the inorganic fraction and permit the determination of total metals by AAS. All leaching experiments were performed in triplicate. The total amount of metals in the compost was determined by adding the metal level in the extractant

Table 1. Metals leached from natural compost by contact with reagents for 24 h with shaking

Extractant	*Concentration of extractant (mol dm^{-3})*	*Copper extracted (% of total)*	*Zinc extracted (% of total)*	*Lead extracted (% of total)*	*Cadmium extracted (% of total)*
Distilled water	–	1	1	2	8
Potassium chloride	1	2	1	0	12
Acetic acid at pH 5	–	1	1	2	20
Sodium hydroxide	0.01	5	1	1	29
	0.1	26	1	7	31
	1	29	1	7	29
Sodium pyrophosphate	0.01	15	9	4	9
	0.05	30	44	19	29
	0.10	30	47	18	29
Nitric acid	0.25	3	32	10	45
	0.50	11	51	44	65
	0.75	21	53	73	67
	1	25	75	67	91
	3	45	78	83	95
	6	53	74	80	95
EDTA at pH 5	0.001	7	33	34	26
	0.005	23	42	46	30
	0.01	24	43	51	37
	0.025	29	43	54	35
	0.05	34	49	59	30

Table 2. Variation in metal removal with time by compost (1 g) in contact with 100 cm^3 of 100 mg dm^{-3} metal solution

Time (h)	*% copper removed*	*% zinc removed*	*% lead removed*	*% cadmium removed*	*% dichromate removed*
1	88.0	94.6	97.5	97.2	6.8
2	89.5	95.8	97.8	97.6	7.4
4	90.4	96.1	97.9	97.7	7.6
8	91.4	95.8	97.9	97.7	7.6
24	92.4	95.9	97.9	97.7	7.7

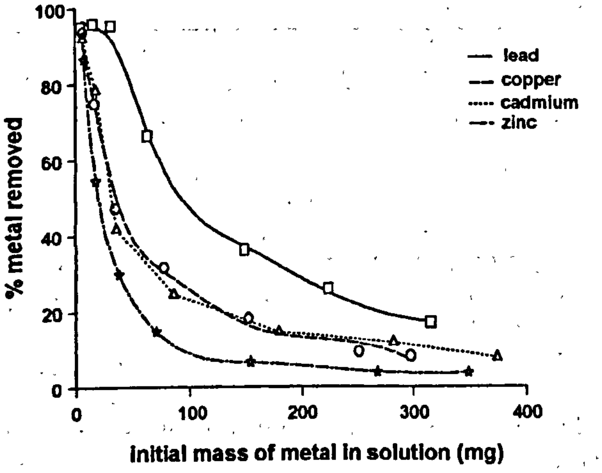

Figure 1. The removal of metals by compost (1 g) after shaking for 24 h.

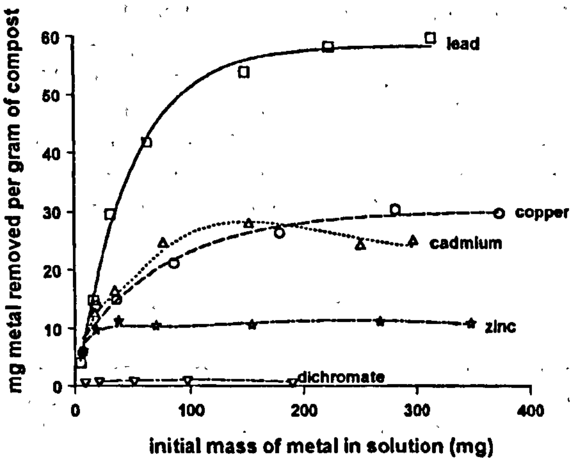

Figure 2. The capacity of compost to remove metals from solution (24 h contact).

(the leached metals) to the metal level in the residue. The data for the percentage of metals leached are shown in Table 1.

Batch sorption experiments were performed to determine the affinity of compost for the four metals: cadmium, copper, lead, and zinc. Individual stock solutions of metal ions (4000 mg dm^{-3}) were prepared by dissolving the corresponding salts – cadmium, copper and zinc sulfates and lead nitrate – in deionised water. All working solutions were prepared by diluting the stock solution with deionised water. Compost (1 g) was shaken with a metal solution (100 cm^3), the mixture was filtered, and analysis of the metal ions remaining in the filtrate was carried out by AAS. Confirmation of the uptake of metals on the compost was obtained by X-ray fluorescence analysis of the filtrand. Experiments were carried out in triplicate to investigate: (1) the time taken for the compost to become equilibrated with metal ions; (2) the percentage metal removed with respect to different initial concentrations of metal; (3) the capacity of the compost for the metals, and (4) the effects of pH on metal uptake.

The amount of metal sorbed by compost (1 g) from a 100 mg dm^{-3} solution of metal ions (100 cm^3) for different lengths of time is shown in Table 2 and the data for sorption of the dichromate anion are also included. The variation in the percentage uptake of the metals after 24 h with increasing initial metal concentration over the range 0 to 4000 mg dm^{-3} was studied and the results are shown in Fig 1. The total capacity of the compost for Pb, Cu, Cd, Zn and dichromate was determined by equilibrium studies and the results are shown in Fig 2. To assess the effect of pH on metal adsorption, studies were made in the pH range 2–5 on compost in contact with metal solutions giving a metal loading above the capacity shown in Fig 2. The data obtained for pH studies at metal concentrations equivalent to 80 mg lead, 50 mg cadmium, 50 mg copper, and 20 mg zinc per gram of compost – concentrations which exceed the capacity of compost – are presented in Table 3.

Table 3. Effect of pH on metal sorption by compost (1 g) in contact with metal solution for 24 h

pH	*% copper removed from solution containing 50 mg copper*	*% zinc removed from solution containing 20 mg zinc*	*% lead removed from solution containing 80 mg lead*	*% cadmium removed from solution containing 50 mg cadmium*
2	48.7	63.9	54.3	52.9
3	48.9	63.3	59.7	53.2
4	49.4	63.0	65.5	54.2
5	47.7	62.4	62.2	54.6

Table 4. Leachability of lead and copper from saturated compost (1 g) in contact with 100 cm^3 of reagent for 24 h

Reagent	*% lead recovered*	*% copper recovered*
1 mol dm^{-3} HNO_3	93	90
1 mol dm^{-3} HCl	81	75
Distilled water	5	3
1 mol dm^{-3} NaOH	69	33

To determine the leachability of lead and copper following saturation with these metals, samples of the saturated compost (1 g) were treated with HNO_3, HCl, NaOH, and distilled water (100 cm^3) for 24 h. The results are presented in Table 4.

Batch sorption experiments were performed to determine the uptake of copper and lead on the non-humic acid fraction of the compost. The humic acids were removed from the compost samples using a modification of the method described by Ong and Swanson.[15] A 2% NaOH solution was added to a compost sample in the ratio one part sample to Five parts solution by volume. The mixture was shaken for 24 h in plastic bottles and then centrifuged. The liquor from each sample was decanted and filtered successively through glass wool and filter paper. The solid remaining after removal of the humic acids was washed with distilled water and 1 mol dm^{-3} HCl to remove cations, and finally further washed with distilled water and dried at room temperature.

The diluted stock solutions of copper and lead (100 cm^3) were shaken for 24 h with either compost (1 g) or non-humic acid compost fraction (1 g). The solutions were then filtered and the concentrations of copper and lead in the filtrate determined by AAS. The results are presented in Figs 3 and 4.

To determine whether any group I or II metals are involved in heavy metal exchange samples of compost (1 g) were shaken with a 4000 mg dm^{-3} copper sulfate solution (100 cm^3) and the resulting solution analysed for sodium, potassium, calcium, and magnesium. The results are compared with those from a control using deionised water in Table 5.

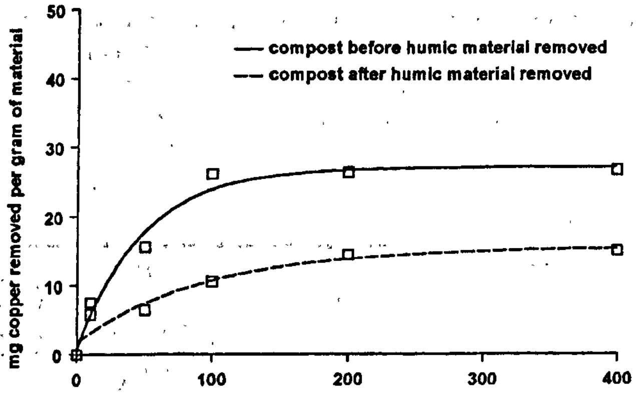

Figure 3. Removal of copper by compost before and after humic acid removal (24 h contact).

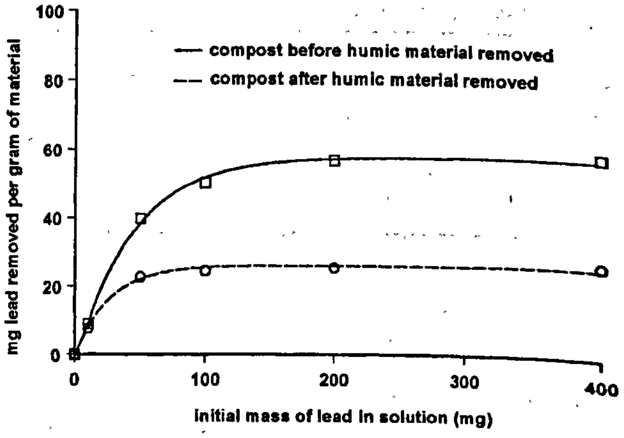

Figure 4. Removal of lead by compost before and after humic acid removal (24 h contact).

3 RESULTS AND DISCUSSION

The reagents used in the study as leach solutions for removal of metals from natural compost provide models for metal availability under different conditions. They fall into two groups: (1) water, potassium chloride solution, and acetic acid at pH 5, which mimic bioavailability; and (2) sodium hydroxide, sodium pyrophosphate, and EDTA solution, that give a measure of the strength of the metal–compost bonds and the ease of extraction of metals from the compost. Metals leached by water are the most available while those removed by a potassium chloride solution predict exchangeable metal levels, ie those that are held by electrostatic forces at negative surface sites. Acetic acid solutions at pH 5 are widely used as models for extractability in landfill conditions where the acid can arise from bacterial activity. Acetic acid provides a measure of extractable metal species that are soluble under weakly acid conditions or which form strong complexes with the acetate ligand. Both sodium hydroxide and sodium pyrophosphate solutions are used to obtain data on the amount of metal that is bound to organic matter. Nitric acid and EDTA solutions (pH 5) are used to determine the total amount of metal that can be removed under strong acid and strong complexing conditions respectively.

The reagents sodium hydroxide, sodium pyrophosphate, nitric acid and EDTA solution (pH 5) were

Table 5. Displacement of groups I and II metals from compost (1 g) by copper solution (100 cm^3 of 4000 mg dm^{-3} concentration) and deionised water after contact for 24 h

Metal	*Amount of metal removed from compost by copper sulfate (mg g^{-1} of compost)*	*Amount of metal removed from compost by deionised water (mg g^{-1} of compost)*
Sodium	1.5	1.5
Potassium	5.0	4.1
Calcium	12.6	2.5
Magnesium	0.45	0.18

used at varying concentrations. This indicated if there was an upper concentration limit above which little or no further metal was removed by the extractant. The data for the percentage of metals extracted from natural compost are presented in Table 1. Upper concentration limits for sodium hydroxide and sodium pyrophosphate were found to be $0.1 \mathrm{mol\,dm^{-3}}$ and $0.05 \mathrm{mol\,dm^{-3}}$ respectively, however, with nitric acid and EDTA (pH 5) the results depended on the metal being extracted, but generally show an increase in metal extracted with reagent concentration.

The amounts of copper, zinc, and lead extracted from the compost in water, potassium chloride solution, and acetic acid solution are low. The fact that lead is not extracted by acetic acid under these conditions is significant because it has a strong tendency to dissolve as the triacetatolead (II) ion,[16] $Pb(CH_3CO_2)_3^-$, and this means that it must be held in the compost by strong bonds. All three of these solutions leach higher percentages of the total cadmium present as would be expected from the general solubility of cadmium-containing species.

The data from the nitric acid leach provide information on the amount of metal that can be extracted without completely destroying the organic matter and solubilising the compost. For all of the metals studied the amount extracted increases as the nitric acid concentration is raised from $0.25 \mathrm{mol\,dm^{-3}}$ and the maximum extractability data were copper 53%, zinc 78%, lead 83%, and cadmium 95%. The leach data for EDTA solutions show that not all the extractable metal can be removed in this complexing media, suggesting that a substantial proportion of the metal present is held in the compost by strong bonding interactions.

There are two possible types of strong interaction between metals and compost phases: (1) the incorporation of heavy metals within the lattices of the inorganic fraction; and (2) strong complexing interactions with potential ligands in the organic fraction. For natural compost the data for copper leaching in both the sodium hydroxide and sodium pyrophosphate leach suggest that about 30% of this metal could be associated with the organic matter. Neither zinc nor lead is easily extracted from the compost in sodium hydroxide, but are partially removed (about 44% and 19% respectively) in sodium pyrophosphate. This suggests that some or both of these metals are bound to the organic phases but that their leachability is dependent on the nature of the chemical reactions breaking these bonds.

The results of the leach studies suggest that the metals in compost are tightly bound to the compost matrix, and are not easily removed unless harsh conditions are used (for example, high concentrations of nitric acid). To obtain more information on the nature of the compost–metal interactions a series of batch studies of metal uptake were carried out.

Metal uptake by compost in batch sorption experiments is rapid and most occurs within 1 h (Table 2). After 1 h, 97.5% of lead, 97.2% of cadmium, 94.6% of zinc and 88% of copper was removed by compost (1 g) from a solution of metal ($100 \mathrm{cm^3}$) at a concentration of $100 \mathrm{mg\,dm^{-3}}$; and after 24 h 97.9% of lead, 97.7% of cadmium, 95.9% of zinc and 92.4% of copper was removed. The mixture was assumed to have reached equilibrium after 24 h. Figure 1 shows how the percentage removal of individual metals varies with initial concentration of metal ions and Fig 2 shows that the capacity of the compost is approximately 60, 30, 25, and $10 \mathrm{mg\,g^{-1}}$ for lead, copper, cadmium, and zinc respectively. The results are consistent with a decrease in affinity of the compost for the metals in the order $Pb > Cu > Cd > Zn$.

Changes in pH in the range 2–5 (Table 3) have only a small effect on the removal of Zn, Cd, and Cu. For copper, maximum metal removal of 49.4% occurs at pH 4 and minimum metal removal of 47.7% occurs at pH 5. For cadmium, maximum metal removal of 54.6% occurs at pH 5, with a minimum of 52.9% at pH 2. For zinc, maximum metal removal of 63.9% occurs at pH 2 and minimum removal of 62.4% at pH 5. For lead removal, the effect of pH is more pronounced with optimum metal removal of 65.5% at pH 4, which reduced to 54.3% at pH 2 and 62.2% at pH 5. Extraction under conditions above pH 5 would have to take account of possible basic salt or hydroxide precipitates that could be removed by compost in a filtering action.[17]

The nature of the interaction between the heavy metals and the compost can be inferred from the leachability, calcium exchange, and compost fractionating studies. Leachability data suggest that the metals Pb, Cd, Cu, and Zn are strongly held on the compost. The data for calcium exchange are consistent with the metals replacing calcium at exchangeable sites in both the inorganic and organic compost fractions. The fact that the dichromate anion is not extracted by the compost (Fig 2) suggests that electrostatic attachment to positive sites at the compost surface is not a significant factor. Leaching of the metals from natural compost and compost saturated with Pb and Cu suggest that the metals must be bound by strong interactions to both inorganic and organic fractions. The data for metal sorption to the compost with the humic fraction removed (Figs 3 and 4) are also consistent with attachment of these metals to both humic and non-humic material.

The strength of the attachment of metals to active sites in the compost provides an opportunity to use it as a replacement for peat and other natural materials in effluent treatment and similar remediation systems. Composting offers the flexibility of being carried out wherever organic waste is produced and the introduction of a landfill tax in the UK will help with the economics of composting. Compost, like peat, would have to be used in the removal of metals in single use situations and then be disposed of by landfill or incineration unless methods of recycle can be developed. In this use it would, however, replace a natural material and permit at least a single step for recycling of organic waste.

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APPENDIX 9

CHAPTER 3 DATA

Data for metals expressed as mg/l are from an Atomic Absorption Spectrophotometer. The Atomic Absorption Spectrophotometer was programmed to take three measurements and provide the average of the three measurements in mg/l.

Data for moisture and foreign matter were obtained by measuring the mass of compost before and after the experiment on a balance measuring to a sensitivity of 0.01g.

The data for organic matter were obtained by measuring the mass of compost before and after heating on a balance measuring to a sensitivity of 0.0001g and due to the limited apparatus available single measurements were performed on two separate samples.

The analysis for Carbon, Nitrogen, Potassium and Phosphorous were undertaken by MEDAC Ltd.

The analysis for pH and conductivity were undertaken using a pH meter and a conductivity meter.

Moisture (grams lost by drying a 100 gram sample)

	EH	E	CM	ECO	C	OG	H
Sample 1	59.50	58.10	32.22	37.13	35.97	35.71	38.31
	59.48	57.94	32.11	37.36	35.96	35.82	38.22
	59.52	58.01	32.33	36.95	35.72	35.82	38.24
Sample 2	58.40	57.32	30.93	35.71	35.14	34.33	36.93
	58.51	57.44	30.92	35.98	35.22	34.11	36.82
	58.54	57.26	31.09	35.97	35.16	34.69	36.46

Foreign Matter (grams from a 100 gram sample)

	EH	E	CM	ECO	C	OG	H
Sample 1	9.97	7.71	0	4.74	3.87	6.95	9.46
	9.91	7.67	0	4.74	3.79	6.86	9.44
	10.03	7.74	0	4.73	3.86	7.04	9.48
Sample 2	9.59	7.32	0	4.52	3.56	6.32	8.93
	9.62	7.41	0	4.58	3.42	6.38	8.95
	9.65	7.39	0	4.54	3.58	6.36	8.96

Organic Matter Analysis

	EH			E		
	Mass compost before (g)	Mass of compost lost after heating (g)	% organic matter	Mass compost before (g)	Mass of compost lost after heating (g)	% organic matter
Sample 1	5.0312	1.9018	37.80	4.9955	1.7140	34.31
Sample 2	4.8956	1.7814	36.39	4.8704	1.6193	33.25

	CM			ECO		
	Mass compost before (g)	Mass of compost lost after heating (g)	% organic matter	Mass compost before (g)	Mass of compost lost after heating (g)	% organic matter
Sample 1	4.9814	2.1297	42.87	4.9938	1.0359	20.74
Sample 2	5.0764	1.8939	37.31	4.9603	1.0953	22.08

	C			OG		
	Mass compost before (g)	Mass of compost lost after heating (g)	% organic matter	Mass compost before (g)	Mass of compost lost after heating (g)	% organic matter
Sample 1	5.0563	2.3265	46.01	5.0021	1.5099	30.19
Sample 2	4.8604	2.1094	43.40	5.1408	1.6941	32.95

	H		
	Mass compost before (g)	Mass of compost lost after heating (g)	% organic matter
Sample 1	5.0484	1.3750	27.24
Sample 2	4.8939	1.1852	24.22

Total Carbon (%)
Analysis by MEDAC Ltd (average data for two samples)

EH	E	CM	ECO	C	OG	H
15.01	11.46	24.59	11.76	26.03	19.92	11.67

Total Nitrogen (%)
Analysis by MEDAC Ltd (average data for two samples)

EH	E	CM	ECO	C	OG	H
1.14	0.93	2.26	0.37	1.37	1.64	1.01

Total Potassium (%)
Analysis by MEDAC Ltd (average data for two samples)

EH	E	CM	ECO	C	OG	H
0.98	0.66	1.37	0.40	0.65	0.81	0.72

Total Phosphorous (%)
Analysis by MEDAC Ltd (average data for two samples)

EH	E	CM	ECO	C	OG	H
0.38	0.20	0.43	0.15	0.26	0.26	0.23

Total Magnesium

Data expressed in mg/l are the average of three measurements on a sample (2 g) following digestion with acid and making up to 50 ml volume. The data is also expressed as g Magnesium per kg of compost.

	EH		E		CM		ECO	
	mg/l	g/kg	mg/l	g/kg	mg/l	g/kg	mg/l	g/kg
Sample 1	1.06	2.65	1.58	3.95	1.36	3.40	0.464	1.16
Sample 2	1.01	2.52	1.54	3.85	1.41	3.51	0.448	1.12

	C		OG		H	
	mg/l	g/kg	mg/l	g/kg	mg/l	g/kg
Sample 1	0.80	2.00	1.04	2.60	0.88	2.20
Sample 2	0.77	1.93	1.12	2.80	0.97	2.42

Extractable Magnesium

The data in mg/l is mg Magnesium extracted per litre of compost and is the average of three measurements. The data is also expressed as mg magnesium extracted per kg of compost.

	EH			E			CM		
	Density (g/ml)	mg/l	mg /kg	Density (g/ml)	mg/l	mg /kg	Density (g/ml)	mg/l	mg /kg
Sample 1	0.74	381	515	0.79	376	476	0.81	700	864
Sample 2	0.74	362	489	0.79	361	458	0.81	712	879

	C			OG			H		
	Density (g/ml)	mg/l	mg /kg	Density (g/ml)	mg/l	mg /kg	Density (g/ml)	mg/l	mg /kg
Sample 1	0.69	431	625	0.92	274	298	0.73	416	570
Sample 2	0.69	406	588	0.92	251	273	0.73	405	555

	ECO		
	Density (g/ml)	mg/l	mg /kg
Sample 1	0.80	347	434
Sample 2	0.80	381	476

pH

	EH	E	CM	ECO	C	OG	H
Sample 1	7.91	8.68	7.49	8.53	8.16	7.94	8.38
	7.91	8.67	7.19	8.54	8.17	7.94	8.38
	7.90	8.68	7.19	8.53	8.16	7.94	8.39
Sample 2	7.83	8.81	7.10	8.39	8.01	7.77	8.21
	7.83	8.80	7.10	8.39	8.01	7.76	8.22
	7.83	8.80	7.10	8.40	8.01	7.76	8.22

Conductivity (µS/cm)

	EH	E	CM	ECO	C	OG	H
Sample 1	5170	4631	8061	4697	4036	4893	5171
	5172	4631	8060	4699	4034	4890	5170
	5171	4630	8061	4696	4036	4895	5171
Sample 2	5082	4491	7978	4723	4083	4921	5025
	5078	4491	7975	4724	4084	4922	5027
	5084	4492	7980	4723	4088	4926	5028

Total metal content

Data expressed in mg/l are the average of three measurements on a sample (2.5 g) following digestion with acid and making up to 50 ml volume. The data is also expressed as mg metal per kg of compost.

Copper (mg/kg)

	EH		E		CM		ECO		C		OG		H	
	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Sample 1	6.81	136	4.04	81	2.22	44	1.89	38	6.55	131	3.06	61	2.56	51
Sample 2	6.14	123	3.72	74	1.89	38	1.91	38	6.78	136	2.89	58	2.41	48

Nickel (mg/kg)

	EH		E		CM		ECO	
	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Sample 1	1.600	32	1.223	24	1.124	23	0.616	12
Sample 2	1.352	27	1.259	25	1.063	21	0.501	10

	C		OG		H	
	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Sample 1	1.199	24	1.852	37	0.924	18
Sample 2	1.314	26	1.694	34	0.997	20

Cadmium (mg/kg)

	EH		E		CM		ECO	
	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Sample 1	0.220	4.4	0.090	1.8	0.047	0.9	0.035	0.7
Sample 2	0.150	3.0	0.075	1.5	0.050	1.0	0.044	0.9

	C		OG		H	
	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Sample 1	0.055	1.1	0.064	1.3	0.047	0.9
Sample 2	0.062	1.2	0.055	1.1	0.038	0.8

Zinc (mg/kg)

	EH		E		CM		ECO	
	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Sample 1	13.22	264	14.70	294	10.64	213	9.32	186
Sample 2	12.17	243	17.84	357	10.82	216	8.62	172

	C		OG		H	
	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Sample 1	15.22	304	13.86	277	11.86	237
Sample 2	14.54	290	12.68	254	11.74	235

Lead (mg/kg)

	EH		E		CM		ECO	
	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Sample 1	8.25	165	5.93	119	2.83	57	4.12	82
Sample 2	7.42	148	6.59	132	2.99	60	4.49	90

	C		OG		H	
	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Sample 1	10.98	220	6.12	122	6.82	136
Sample 2	10.30	206	6.54	131	6.90	138

Extractable metals content

The data in mg/l is mg Magnesium extracted per litre of compost and is the average of three measurements. The data is also expressed as mg magnesium extracted per kg of compost.

Copper (mg/kg)

	EH			E			CM		
	Density (g/ml)	mg/l	mg /kg	Density (g/ml)	mg/l	mg /kg	Density (g/ml)	mg/l	mg /kg
Sample 1	0.74	34	46	0.79	25	32	0.81	9	11
Sample 2	0.74	37	50	0.79	25	32	0.81	10	12

	C			OG			H		
	Density (g/ml)	mg/l	mg /kg	Density (g/ml)	mg/l	mg /kg	Density (g/ml)	mg/l	mg /kg
Sample 1	0.69	30	43	0.92	16	17	0.73	20	27
Sample 2	0.69	32	46	0.92	15	16	0.73	18	25

	ECO		
	Density (g/ml)	mg/l	mg /kg
Sample 1	0.80	19	24
Sample 2	0.80	17	21

Zinc (mg/kg)

	EH			E			CM		
	Density (g/ml)	mg/l	mg /kg	Density (g/ml)	mg/l	mg /kg	Density (g/ml)	mg/l	mg /kg
Sample 1	0.74	76	103	0.79	95	120	0.81	62	77
Sample 2	0.74	96	130	0.79	91	116	0.81	56	69

	C			OG			H		
	Density (g/ml)	mg/l	mg /kg	Density (g/ml)	mg/l	mg /kg	Density (g/ml)	mg/l	mg /kg
Sample 1	0.69	118	171	0.92	96	104	0.73	109	149
Sample 2	0.69	122	177	0.92	91	99	0.73	120	164

	ECO		
	Density (g/ml)	mg/l	mg /kg
Sample 1	0.80	112	140
Sample 2	0.80	110	138

Lead (mg/kg)

	EH			E			CM		
	Density (g/ml)	mg/l	mg /kg	Density (g/ml)	mg/l	mg /kg	Density (g/ml)	mg/l	mg /kg
Sample 1	0.74	53	72	0.79	69	87	0.81	27	33
Sample 2	0.74	52	70	0.79	75	95	0.81	29	36

	C			OG			H		
	Density (g/ml)	mg/l	mg /kg	Density (g/ml)	mg/l	mg /kg	Density (g/ml)	mg/l	mg /kg
Sample 1	0.69	95	138	0.92	70	76	0.73	90	123
Sample 2	0.69	83	120	0.92	72	78	0.73	88	121

	ECO		
	Density (g/ml)	mg/l	mg /kg
Sample 1	0.80	81	101
Sample 2	0.80	74	93

Germination of lettuce

Soil

	Number seeds germinated (out of 20)	Total dry mass of lettuce after 8 weeks (g)	Mean shoot dry matter (g)
Sample 1	14	106.88	6.68
Sample 2	15	112.37	7.02

EH and Soil

	Number seeds germinated (out of 20)	Total dry mass of lettuce after 8 weeks (g)	Mean shoot dry matter (g)
Sample 1	12	23.05	1.44
Sample 2	12	28.53	1.78

H and Soil

	Number seeds germinated (out of 20)	Total dry mass of lettuce after 8 weeks (g)	Mean shoot dry matter (g)
Sample 1	18	161.28	10.08
Sample 2	19	179.24	11.20

ECO and Soil

	Number seeds germinated (out of 20)	Total dry mass of lettuce after 8 weeks (g)	Mean shoot dry matter (g)
Sample 1	19	176.66	11.04
Sample 2	19	181.15	11.32

Growth of Tomato Seedlings

Soil

	Mean % increase in height	Total shoot dry matter of 3 seedlings (g)	Mean shoot dry matter (g)
Sample 1	2096	64.27	24.42
Sample 2	2116	65.32	21.78

EH and Soil

	Mean % increase in height	Total shoot dry matter of 3 seedlings (g)	Mean shoot dry matter (g)
Sample 1	658	8.05	2.68
Sample 2	702	8.51	2.84

H and Soil

	Mean % increase in height	Total shoot dry matter of 3 seedlings (g)	Mean shoot dry matter (g)
Sample 1	3120	72.72	24.24
Sample 2	3461	81.95	27.32

ECO and Soil

	Mean % increase in height	Total shoot dry matter of 3 seedlings (g)	Mean shoot dry matter (g)
Sample 1	1437	10.99	3.66
Sample 2	1583	11.61	3.87

Moisture (grams lost by drying a 100 gram sample)

	DR	TW
Sample 1	53.40 53.26 53.51	2.74 2.75 2.75
Sample 2	52.81 52.93 52.92	2.70 2.71 2.71

Foreign Matter (grams from a 100 gram sample)

	DR	TW
Sample 1	0.69 0.70 0.70	0.51 0.51 0.51
Sample 2	0.63 0.64 0.63	0.49 0.49 0.48

Organic Matter

	DR			TW		
	Mass compost before (g)	Mass of compost lost after heating (g)	% organic matter	Mass compost before (g)	Mass of compost lost after heating (g)	% organic matter
Sample 1	5.0083	1.8175	36.29	3.3982	2.304	67.80
Sample 2	5.1085	1.8763	36.73	4.0582	2.7939	68.84

	Soil		
	Mass compost before (g)	Mass of compost lost after heating (g)	% organic matter
Sample 1	5.0897	0.5391	10.59
Sample 2	4.9610	0.4963	10.00

Total Carbon, Nitrogen, Phosphorous and Magnesium

Analysis by MEDAC Ltd (Average data in % provided)

	DR	TW	Soil
Total Carbon	25.57	33.35	3.41
Total Nitrogen	1.67	3.48	0.29
Total Phosphorous	0.41	0.45	0.31
Total Magnesium	0.55	1.42	0.52

Total Magnesium

Data expressed in mg/l are the average of three measurements on a sample (2 g) following digestion with acid and making up to 50 ml volume. The data is also expressed as g Magnesium per kg of compost.

	DR		TW		Soil	
	mg/l	g/kg	mg/l	g/kg	mg/l	g/kg
Sample 1	1.02	2.55	1.22	3.05	0.88	2.21
Sample 2	1.02	2.56	1.24	3.11	0.81	2.04

Extractable Magnesium

The data in mg/l is mg Magnesium extracted per litre of compost and is the average of three measurements. The data is also expressed as mg magnesium extracted per kg of compost.

	DR			TW			Soil		
	Density (g/ml)	mg/l	mg /kg	Density (g/ml)	mg/l	mg /kg	Density (g/ml)	mg/l	mg /kg
Sample 1	0.56	302	539	0.61	294	482	0.88	81	92
Sample 2	0.56	313	559	0.61	279	457	0.88	74	84

pH

	DR	TW	Soil
Sample 1	7.10 7.11 7.09	7.97 7.97 7.96	7.18 7.18 7.18
Sample 2	7.02 7.03 7.03	7.89 7.90 7.90	7.23 7.23 7.22

Conductivity (µS/cm)

	DR	TW	Soil
Sample 1	4880 4886 4886	7093 7097 7100	2484 2486 2487
Sample 2	4863 4859 4866	7014 7018 7019	2424 2425 2425

Total Metals

Data expressed in mg/l are the average of three measurements on a sample (2.5 g) following digestion with acid and making up to 50 ml volume. The data is also expressed as mg metal per kg of compost.

Copper

	DR		TW		Soil	
	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Sample 1	2.88	58	40.8	812	5.2	100
Sample 2	2.83	56	39.8	792	6.4	124

Nickel

	DR		TW		Soil	
	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Sample 1	0.953	19	0.98	12	1.89	30
Sample 2	0.814	16	0.91	11	2.03	41

Cadmium

	DR		TW		Soil	
	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Sample 1	0.149	2.8	0.114	1.9	0.058	0.8
Sample 2	0.114	2.1	0.098	1.6	0.064	0.9

Zinc

	DR		TW		Soil	
	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Sample 1	16.78	336	27.2	544	8.6	172
Sample 2	16.24	325	24.4	488	9.0	180

Lead

	DR		TW		Soil	
	mg/l	mg/kg	mg/l	mg/kg	mg/l	mg/kg
Sample 1	7.50	134	9.05	177	14.51	286
Sample 2	7.04	141	9.89	194	15.31	302

Extractable Metals

The data in mg/l is mg Magnesium extracted per litre of compost and is the average of three measurements. The data is also expressed as mg magnesium extracted per kg of compost.

Copper

	DR			TW			Soil		
	Density (g/ml)	mg/l	mg /kg	Density (g/ml)	mg/l	mg /kg	Density (g/ml)	mg/l	mg /kg
Sample 1	0.56	11	20	0.61	120	197	0.88	30	34
Sample 2	0.56	12	21	0.61	98	161	0.88	32	36

Nickel

	DR			TW			Soil		
	Density (g/ml)	mg/l	mg /kg	Density (g/ml)	mg/l	mg /kg	Density (g/ml)	mg/l	mg /kg
Sample 1	0.56	2.4	4.3	0.61	2.4	3.9	0.88	2.9	3.3
Sample 2	0.56	2.8	5.0	0.61	2.6	4.3	0.88	3.1	3.5

Cadmium

	DR			TW			Soil		
	Density (g/ml)	mg/l	mg /kg	Density (g/ml)	mg/l	mg /kg	Density (g/ml)	mg/l	mg /kg
Sample 1	0.56	0.3	0.5	0.61	0.4	0.7	0.88	0.4	0.5
Sample 2	0.56	0.3	0.5	0.61	0.5	0.8	0.88	0.4	0.5

Zinc

	DR			TW			Soil		
	Density (g/ml)	mg/l	mg /kg	Density (g/ml)	mg/l	mg /kg	Density (g/ml)	mg/l	mg /kg
Sample 1	0.56	96	171	0.61	130	213	0.88	51	58
Sample 2	0.56	103	184	0.61	118	193	0.88	44	50

Lead

	DR			TW			Soil		
	Density (g/ml)	mg/l	mg /kg	Density (g/ml)	mg/l	mg /kg	Density (g/ml)	mg/l	mg /kg
Sample 1	0.56	45	80	0.61	45	74	0.88	248	282
Sample 2	0.56	47	84	0.61	49	80	0.88	239	272

CHAPTER 4 DATA

Data for metals expressed as mg/l are from an Atomic Absorption Spectrophotometer. The Atomic Absorption Spectrophotometer was programmed to take three measurements and provide the average of the three measurements in mg/l.

Water Extraction

Copper

Time (hours)	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
24	1	0.093	0.93	2.5767	3.944	76.53	1
	2	0.076	0.76	2.2132	3.644	82.32	1
48	1	0.150	1.50	2.4631	3.366	68.33	2
	2	0.109	1.11	2.0312	3.077	75.74	1
72	1	0.146	1.46	2.6123	3.797	72.67	2
	2	0.172	1.72	2.6486	3.931	74.20	2
96	1	0.242	2.42	2.5149	3.803	75.61	3
	2	0.213	2.13	2.7232	3.899	71.40	3

Cobalt

Time (hours)	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
24	1	0	0	2.5767	0.707	13.72	0
	2	0	0	2.2132	0.596	13.46	0
48	1	0.045	0.45	2.4631	0.591	12.00	4
	2	0.049	0.49	2.0312	0.455	11.20	4
72	1	0.056	0.56	2.6123	0.667	12.77	4
	2	0.065	0.65	2.6486	0.653	12.33	5
96	1	0.103	1.03	2.5149	0.640	12.72	7
	2	0.096	0.96	2.7322	0.700	12.85	7

Lead

Time (hours)	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
24	1	0.29	2.9	2.5767	7.35	143	2
	2	0.37	3.7	2.2132	6.98	158	2
48	1	0.41	4.1	2.4631	8.96	182	2
	2	0.32	3.2	2.0312	6.43	158	2
72	1	0.26	2.6	2.6123	9.30	178	1
	2	0.21	2.1	2.6486	8.93	169	1
96	1	0.15	1.5	2.5149	8.21	163	1
	2	0.18	1.8	2.7232	8.76	161	1

Cadmium

Time (hours)	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
24	1	0.013	0.13	2.576	0.074	1.44	8
	2	0.012	0.12	2.2132	0.070	1.58	7
48	1	0.010	0.10	2.4631	0.073	1.48	6
	2	0.011	0.11	2.0312	0.066	1.62	6
72	1	0.006	0.06	2.6123	0.091	1.74	3
	2	0.005	0.05	2.6486	0.070	1.32	4
96	1	0.008	0.08	2.5149	0.076	1.51	5
	2	0.010	0.10	2.7232	0.096	1.76	5

Zinc

Time (hours)	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
24	1	0.14	1.4	2.5767	13.45	261	1
	2	0.16	1.6	2.2132	11.73	265	1
48	1	0.24	2.4	2.4631	13.68	278	1
	2	0.18	1.8	2.0312	10.51	259	1
72	1	0.22	2.2	2.6123	13.68	262	1
	2	0.19	1.9	2.6486	14.35	271	1
96	1	0.24	2.4	2.5149	13.72	273	1
	2	0.26	2.6	2.7232	15.20	279	1

1M KCl Extraction

Copper

Time (hours)	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
24	1	0.181	1.81	2.3267	2.502	75.26	2
	2	0.145	1.45	2.1496	3.081	71.67	2
48	1	0.213	2.13	2.5723	3.778	73.44	3
	2	0.174	1.74	2.5139	4.086	81.27	2
72	1	0.298	2.98	2.1473	3.428	79.82	4
	2	0.267	2.67	1.9264	2.675	69.43	4
96	1	0.205	2.05	2.4632	4.097	83.16	2
	2	0.163	1.63	2.2169	3.513	79.23	2

Cobalt

Time (hours)	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
24	1	0	0	2.3267	0.616	13.24	0
	2	0	0	2.1496	0.607	14.12	0
48	1	0	0	2.5723	0.846	16.44	0
	2	0	0	2.5139	0.702	13.96	0
72	1	0	0	2.1473	0.581	13.53	0
	2	0	0	1.9264	0.505	13.11	0
96	1	0	0	2.4632	0.678	13.76	0
	2	0	0	2.2169	0.574	12.95	0

Lead

Time (hours)	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
24	1	0	0	2.3267	7.60	163	0
	2	0	0	2.1496	6.54	152	0
48	1	0	0	2.5723	9.07	176	0
	2	0	0	2.5139	8.64	172	0
72	1	0	0	2.1473	6.91	161	0
	2	0	0	1.9264	6.50	169	0
96	1	0.16	1.6	2.4632	8.51	173	1
	2	0	0	2.2169	8.01	181	0

Cadmium

Time (hours)	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
24	1	0.024	0.24	2.3267	0.081	1.74	12
	2	0.019	0.19	2.1496	0.071	1.65	10
48	1	0.012	0.12	2.5723	0.079	1.54	7
	2	0.012	0.12	2.5139	0.087	1.73	6
72	1	0.007	0.07	2.1473	0.063	1.47	5
	2	0.010	0.10	1.9264	0.069	1.79	5
96	1	0.014	0.14	2.4632	0.077	1.56	8
	2	0.016	0.16	2.2169	0.073	1.65	9

Zinc

Time (hours)	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
24	1	0.180	1.80	2.3267	13.23	284	1
	2	0.243	2.43	2.1496	11.46	267	1
48	1	0.137	1.37	2.5723	13.93	271	1
	2	0.265	2.65	2.5139	12.67	252	1
72	1	0.197	1.97	2.1473	11.71	273	1
	2	0.164	1.64	1.9264	11.22	291	1
96	1	0.132	1.32	2.4632	13.00	264	1
	2	0.191	1.91	2.2169	11.45	258	1

Acetic acid and water extraction at pH5

Copper

Sample	Extractant data		Residue data			% extracted
	mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50 ml of digestion acid	mg/kg of compost	
1	0.076	0.76	1.5237	3.577	117.38	1
2	0.378	3.78	1.9673	4.818	122.45	3

Cobalt

Sample	Extractant data		Residue data			% extracted
	mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50 ml of digestion acid	mg/kg of compost	
1	0.162	1.62	1.5237	0.343	11.26	13
2	0.410	4.10	1.9673	0.395	40.04	29

Lead

Sample	Extractant data		Residue data			% extracted
	mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50 ml of digestion acid	mg/kg of compost	
1	0.34	3.4	1.5237	5.79	190.0	2
2	0.34	3.4	1.9673	7.01	178.2	2

Cadmium

Sample	Extractant data		Residue data			% extracted
	mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50 ml of digestion acid	mg/kg of compost	
1	0.024	0.24	1.5237	0.029	0.95	20
2	0.024	0.24	1.9673	0.034	0.86	22

Zinc

Sample	Extractant data		Residue data			% extracted
	mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50 ml of digestion acid	mg/kg of compost	
1	0.40	4.0	1.5237	9.06	297.3	1
2	0.28	2.8	1.9673	10.32	262.39	1

Acetic Acid Extraction

Copper

Concentration	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
0.5M	1	0.239	2.39	3.2100	4.761	74.16	3
	2	0.223	2.23	2.6728	3.890	72.77	3
1.0M	1	0.256	2.56	3.4200	6.460	94.44	3
	2	0.279	2.79	3.0754	5.335	86.74	3
3.0M	1	0.440	4.40	3.3076	5.658	85.53	5
	2	0.438	4.38	2.7432	5.272	96.09	4

Cobalt

Concentration	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
0.5M	1	0.175	1.75	3.2100	0.698	10.87	14
	2	0.168	1.68	2.6728	0.624	11.67	13
1.0M	1	0.228	2.28	3.4200	0.604	8.83	20
	2	0.262	2.62	3.0754	0.511	8.31	24
3.0M	1	0.334	3.34	3.3076	0.505	7.64	30
	2	0.292	2.92	2.7432	0.430	7.84	27

Lead

Concent-ration	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
0.5M	1	0.95	9.5	3.2100	9.79	152.49	6
	2	0.74	7.4	2.6728	8.77	164.06	4
1.0M	1	1.07	10.7	3.4200	13.59	198.68	5
	2	1.31	13.1	3.0754	11.06	179.81	7
3.0M	1	2.66	26.6	3.3076	9.84	148.75	15
	2	2.76	27.6	2.7432	9.33	170.06	14

Cadmium

Concent-ration	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
0.5M	1	0.057	0.57	3.2100	0.075	1.17	33
	2	0.039	0.39	2.6728	0.063	1.18	25
1.0M	1	0.040	0.40	3.4200	0.038	0.56	42
	2	0.047	0.47	3.0754	0.039	0.63	43
3.0M	1	0.063	0.63	3.3076	0.061	0.92	41
	2	0.063	0.63	2.7432	0.038	0.69	48

Zinc

Concent-ration	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
0.5M	1	4.124	41.2	3.2100	15.20	236.76	15
	2	3.824	38.2	2.6728	14.02	262.27	13
1.0M	1	6.445	64.5	3.4200	17.44	254.97	20
	2	5.865	58.7	3.0754	12.76	207.45	22
3.0M	1	9.184	91.8	3.3076	12.76	192.89	32
	2	8.764	87.6	2.7432	10.62	193.57	31

Sodium Hydroxide Extraction

Copper

Concent-ration	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
0.01M	1	0.370	3.70	3.0423	4.638	76.22	5
	2	0.367	3.67	2.9935	4.635	77.42	5
0.10M	1	2.594	25.94	2.1199	3.257	76.82	25
	2	2.473	24.93	2.329	3.367	72.28	26
1.0M	1	2.502	25.02	1.4205	2.167	73.68	25
	2	2.406	24.06	2.3633	2.808	59.40	29

Cobalt

Concent-ration	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
0.01M	1	0.016	0.16	3.0423	0.827	13.59	1
	2	0	0	2.4935	0.852	14.23	0
0.10M	1	0.083	0.83	2.1199	0.555	13.09	6
	2	0.086	0.86	2.329	0.531	11.40	7
1.0M	1	0.148	1.48	1.4705	0.511	17.38	8
	2	0.140	1.40	2.3633	0.734	15.53	8

Lead

Concent-ration	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
0.01M	1	0.08	0.8	3.0423	17.45	286.8	1
	2	0.08	0.8	2.9935	10.63	177.6	1
0.10M	1	1.31	13.1	2.1199	7.55	178.1	7
	2	1.45	14.5	2.329	9.35	200.7	7
1.0M	1	1.48	14.8	1.4705	5.47	186.0	7
	2	0.90	9.0	2.3633	8.42	178.1	5

Cadmium

Concent-ration	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
0.01M	1	0.013	0.13	3.0423	0.027	0.44	23
	2	0.015	0.15	2.9935	0.022	0.37	29
0.10M	1	0.026	0.26	2.1199	0.029	0.68	28
	2	0.025	0.25	2.3290	0.026	0.56	31
1.0M	1	0.018	0.18	1.4705	0.020	0.68	21
	2	0.017	0.17	2.3633	0.020	0.42	29

Zinc

Concent-ration	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
0.01M	1	0.053	0.53	3.0423	15.07	247.7	1
	2	0.056	0.56	2.9935	13.71	229.0	1
0.10M	1	0.138	1.38	2.1199	6.88	155.2	1
	2	0.120	1.20	2.3290	6.71	144.1	1
1.0M	1	0.202	2.02	1.4705	7.51	255.4	1
	2	0.261	2.61	2.3633	10.74	227.2	1

Sodium Pyrophosphate Extraction

Copper

Concent-ration	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
0.01M	1	1.391	13.91	2.4283	3.786	77.97	15
	2	1.141	11.41	1.7599	3.282	93.24	11
0.10M	1	2.812	28.12	1.8224	2.627	72.08	28
	2	2.967	29.67	2.3547	3.334	70.79	30
1.0M	1	3.1298	31.29	1.7322	2.588	74.70	30
	2	3.012	30.12	1.8948	2.836	74.64	29

Cobalt

Concentration	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
0.01M	1	0.166	1.66	2.4283	0.535	11.02	13
	2	0.160	1.60	1.7599	0.384	10.91	13
0.10M	1	0.151	1.51	1.8224	0.413	11.33	12
	2	0.263	2.63	2.3547	0.483	10.26	20
1.0M	1	0.194	1.94	1.7322	0.353	10.19	16
	2	0.114	1.14	1.8998	0.409	10.76	10

Lead

Concentration	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
0.01M	1	0.61	6.1	2.4283	7.76	159.8	4
	2	0.90	90.	1.7599	7.29	207.1	4
0.10M	1	2.74	27.4	1.8224	6.38	175.0	14
	2	3.95	39.5	2.3547	8.04	170.7	19
1.0M	1	1.99	19.4	1.7322	4.71	135.9	12
	2	3.17	31.7	1.8998	5.37	141.3	18

Cadmium

Concentration	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
0.01M	1	0.008	0.08	2.4283	0.071	1.46	5
	2	0.011	0.11	1.7599	0.039	1.11	9
0.10M	1	0.029	0.29	1.8224	0.171	4.69	25
	2	0.040	0.40	2.3547	0.047	1.00	29
1.0M	1	0.034	0.39	1.7322	0.033	0.95	29
	2	0.078	0.78	1.8998	0.085	2.24	26

Zinc

Concentration	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
0.01M	1	2.3	23	2.4283	10.68	219.9	9
	2	2.54	25.4	1.7599	8.58	243.8	9
0.10M	1	10.56	105.6	1.8244	5.36	147.1	42
	2	11.32	113.2	2.3547	6.72	142.7	44
1.0M	1	11.64	116.4	1.7322	4.60	132.8	47
	2	11.88	118.8	1.8998	5.26	138.4	46

Nitric Acid Extraction

Copper

Concentration	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
0.25M	1	0.286	2.86	1.8016	3.368	93.47	3
	2	0.231	2.31	1.9780	3.022	76.39	3
0.5M	1	0.817	8.17	1.4284	2.035	71.23	10
	2	0.762	7.62	1.7213	2.090	60.71	11
0.75M	1	1.809	18.09	1.4940	1.593	53.31	21
	2	1.564	15.64	2.1560	2.682	62.20	20
1.0M	1	2.11	21.1	2.8906	3.637	62.91	25
	2	1.70	17.0	3.0898	3.791	61.35	22
3.0M	1	3.63	36.3	2.9302	2.556	43.61	45
	2	3.30	33.0	2.5375	2.047	40.33	45
6.0M	1	4.40	44.0	2.2012	1.701	38.64	53
	2	4.04	40.4	2.0732	1.624	39.17	51

Cobalt

Concent-ration	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
0.25M	1	0.423	4.23	1.8016	0.371	10.30	29
	2	0.383	3.83	1.9780	0.411	10.39	27
0.5M	1	0.590	5.90	1.4284	0.282	9.87	37
	2	0.533	5.33	1.7213	0.317	9.21	37
0.75M	1	0.648	6.48	1.1494	0.222	9.66	40
	2	0.604	6.04	2.1560	0.379	8.79	34
1.0M	1	0.100	1.00	2.8906	0.530	9.17	36
	2	0.070	0.70	3.0898	0.550	8.90	37
3.0M	1	0.600	6.00	2.9303	0.440	7.51	44
	2	0.460	4.60	2.5375	0.360	7.09	39
6.0M	1	0.330	3.30	2.2012	0.450	10.22	34
	2	0.630	6.30	2.0732	0.330	7.96	44

Lead

Concent-ration	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
0.25M	1	1.57	15.7	1.8016	6.07	168.56	9
	2	1.73	17.3	1.9780	6.18	156.22	10
0.5M	1	8.17	81.7	1.4284	2.92	102.21	44
	2	7.52	75.2	1.7213	3.76	109.20	41
0.75M	1	18.46	184.6	1.1494	1.54	67.00	73
	2	12.16	121.6	2.1560	2.22	51.50	70
1.0M	1	15.03	150.3	2.8906	7.44	128.70	64
	2	12.62	126.2	3.0898	3.91	63030	67
3.0M	1	12.69	126.9	2.9303	3.06	52020	71
	2	11.41	114.1	2.5375	1.19	23040	83
6.0M	1	11.81	118.1	2.2012	1.31	29080	80
	2	11.87	118.7	2.0732	2.21	53.30	69

Cadmium

Concentration	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
0.25M	1	0.093	0.93	1.8016	0.041	1.14	45
	2	0.041	0.41	1.9780	0.036	1.91	31
0.5M	1	0.122	1.22	1.4284	0.019	0.67	65
	2	0.084	0.84	1.7213	0.025	0.73	54
0.75M	1	0.125	1.25	1.1494	0.014	0.61	67
	2	0.103	1.03	2.1560	0.022	0.51	67
1.0M	1	0.143	1.40	2.8906	0.008	0.14	91
	2	0.098	1.00	3.0898	0.009	0.15	86
3.0M	1	0.176	1.80	2.9303	0.008	0.14	95
	2	0.114	1.10	2.5375	0.007	0.14	92
6.0M	1	0.179	1.79	2.2012	0.006	0.14	93
	2	0.181	1.81	2.0732	0.004	0.10	95

Zinc

Concentration	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
0.25M	1	8.98	89.8	1.8016	6.97	193.4	32
	2	9.13	91.3	1.9780	7.70	194.6	32
0.5M	1	13.14	131.4	1.4284	3.65	127.7	51
	2	13.39	133.9	1.7213	4.57	132.7	50
0.75M	1	15.05	150.4	1.1494	31.3	136.1	52
	2	13.85	138.5	2.1560	5.29	122.7	53
1.0M	1	18.16	181.6	2.8906	5.45	94.3	66
	2	17.56	175.6	3.0898	3.68	59.6	75
3.0M	1	20.88	208.8	2.9303	4.71	80.4	72
	2	19.08	190.8	2.5375	2.70	53.2	78
6.0M	1	19.62	196.2	2.2012	3.01	68.4	74
	2	18.72	187.2	2.0732	2.91	70.2	73

EDTA Extraction

Copper

Concentration	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
0.001M	1	0.573	5.73	2.5391	3.706	72.98	7
	2	0.671	6.71	2.3194	4.534	97074	6
0.005M	1	1.340	13.40	2.8470	3.290	57.78	19
	2	1.270	12.60	3.2706	2.841	43.42	23
0.01M	1	1.576	15.76	2.2427	2.883	64.28	20
	2	1.732	17.32	2.4563	2.654	54.02	24
0.025M	1	2.322	23.22	2.3113	2.791	60.38	28
	2	2.294	22.94	2.2193	2.544	57.32	29
0.050M	1	2.664	26.64	2.0011	2.110	52.72	34
	2	2.676	26.76	2.6274	2.750	52.33	34

Cobalt

Concentration	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
0.001M	1	0.110	1.10	2.5391	0.524	10.32	10
	2	0.078	0.78	2.3194	0.451	9.72	7
0.005M	1	0.107	1.07	2.8470	0.820	14.40	7
	2	0.149	1.49	3.2706	0.642	9.81	13
0.01M	1	0.159	1.59	2.2427	0.451	10.05	14
	2	0.121	1.21	2.4563	0.440	8.96	12
0.025M	1	0.216	2.16	2.3113	0.545	11.79	15
	2	0.239	2.39	2.2193	0.560	12.62	16
0.050M	1	0.293	2.93	2.0011	0.415	10.37	22
	2	0.249	2.49	2.6274	0.518	9.86	20

Lead

Concentration	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
0.001M	1	5.07	50.7	2.5391	5.02	98.85	34
	2	5.35	53.5	2.3194	5.44	117.27	31
0.005M	1	7.47	74.7	2.8470	8.02	140.85	35
	2	7.09	70.9	3.2706	5.49	83.93	46
0.01M	1	7.27	72.7	2.2427	3.28	73.13	50
	2	6.95	69.5	2.4563	3.31	67.38	51
0.025M	1	8.55	85.5	2.3113	3.67	79.39	52
	2	9.11	91.1	2.2193	3.47	78.18	54
0.050M	1	10.05	100.5	2.0011	3.14	78.46	56
	2	9.87	98.7	2.6274	3.66	69.65	59

Cadmium

Concentration	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
0.001M	1	0.046	0.46	2.5391	0.066	1.30	26
	2	0.029	0.29	2.3194	0.050	1.08	21
0.005M	1	0.030	0.30	2.8470	0.041	0.72	30
	2	0.042	0.42	3.2706	0.059	0.90	32
0.01M	1	0.051	0.51	2.2427	0.072	1.61	24
	2	0.062	0.62	2.4563	0.051	1.04	37
0.025M	1	0.061	0.61	2.3113	0.055	1.19	34
	2	0.073	0.73	2.2193	0.061	1.37	35
0.050M	1	0.085	0.85	2.0011	0.078	1.95	30
	2	0.057	0.57	2.6274	0.073	1.39	29

Zinc

Concentration	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
0.001M	1	8.70	87.0	2.5391	9.048	178.20	33
	2	9.43	94.3	2.3194	9.667	208.40	31
0.005M	1	11.23	112.3	2.8470	8.840	155.25	42
	2	10.38	103.8	3.2706	9.620	147.07	41
0.01M	1	10.42	104.2	2.2427	6.988	155.80	40
	2	12.32	123.2	2.4563	8.076	164.40	43
0.025M	1	11.20	112.0	2.3113	7.548	163.30	41
	2	10.41	104.1	2.2193	6.130	138.10	43
0.050M	1	14.16	141.6	2.0011	5.900	147.42	49
	2	12.90	129.0	2.6274	7.160	136.26	49

Sodium Carbonate Extraction

Copper

Concentration	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
0.1M	1	3.32	33.2	2.7969	3.21	57.38	37
	2	2.66	26.6	3.0686	4.61	75.12	26
0.5M	1	1.57	15.7	2.7317	2.79	51.07	24
	2	3.06	30.6	3.9682	2.39	30.11	50

Cobalt

Concentration	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
0.1M	1	0.167	1.67	2.7969	0.709	12.67	12
	2	0.124	1.24	3.0686	0.720	11.73	10
0.5M	1	0.192	1.92	2.7317	0.645	11.81	14
	2	0.066	0.66	3.9682	0.921	11.60	5

Lead

Concentration	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
0.1M	1	1.10	11.0	2.7969	7.98	142.66	7
	2	1.18	11.8	3.0686	11.75	191.46	6
0.5M	1	0.74	7.4	2.7317	7.78	142.40	5
	2	1.10	11.0	3.9682	9.90	124.74	8

Cadmium

Concentration	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
0.1M	1	0.033	0.33	2.7969	0.084	1.50	18
	2	0.023	0.23	3.0686	0.103	1.68	12
0.5M	1	0.006	0.06	2.7317	0.096	1.76	3
	2	0.016	0.16	3.9682	0.107	1.35	11

Zinc

Concentration	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
0.1M	1	3.00	30.0	2.7969	11.68	208.80	13
	2	2.66	26.6	3.0686	13.08	213.13	11
0.5M	1	1.60	16.0	2.7317	12.86	235.38	6
	2	1.36	13.6	3.9682	14.82	186.73	8

pH EDTA

Copper

Ph	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
3	1	1.184	11.84	3.8446	6.640	86.35	12
	2	0.983	9.83	3.6218	5.252	72.64	12
5	1	1.048	10.84	4.3375	5.219	60.16	15
	2	1.014	10.14	4.0112	4.701	58.60	15
7	1	1.166	11.66	5.1170	6.676	65.23	15
	2	1.232	12.32	4.9322	7.310	74.10	14
9	1	0.952	9.52	5.2896	6.662	62.97	13
	2	1.022	10.22	5.2676	6.727	63.85	14

Cobalt

PH	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
3	1	0.178	1.78	3.8446	0.892	11.60	13
	2	0.146	1.46	3.6218	0.800	11.04	12
5	1	0.136	1.36	4.3375	0.944	10.88	11
	2	0.172	1.72	4.0112	0.972	12.12	12
7	1	0.160	1.60	8.1170	1.156	11.30	12
	2	0.164	1.64	4.9322	1.263	12.80	11
9	1	0.168	1.68	5.2896	1.138	10.76	14
	2	0.143	1.43	5.2676	0.921	8.74	14

Lead

PH	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
3	1	7.69	76.9	3.8446	7.71	100.3	43
	2	6.97	69.7	3.6218	6.98	96.4	42
5	1	6.26	62.6	4.3375	8.27	95.3	40
	2	6.74	67.4	4.0112	8.32	103.7	39
7	1	6.19	61.9	5.1170	10.55	103.1	38
	2	5.62	56.2	4.9322	8.70	88.2	39
9	1	5.74	57.4	5.2896	10.33	97.6	37
	2	6.73	67.3	5.2676	11.94	113.3	37

Cadmium

PH	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
3	1	0.053	0.53	3.8446	0.099	1.29	29
	2	0.049	0.49	3.6218	0.088	1.21	29
5	1	0.052	0.52	4.3375	0.093	1.07	33
	2	0.058	0.58	4.0112	0.108	1.35	30
7	1	0.051	0.51	5.1170	0.127	1.24	29
	2	0.054	0.54	4.9322	0.126	1.28	30
9	1	0.054	0.54	5.2896	0.144	1.36	28
	2	0.039	0.39	5.2676	0.095	0.90	30

Zinc

PH	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
3	1	8.98	89.8	3.8446	13.31	173.1	34
	2	8.12	81.2	3.6218	10.84	149.6	35
5	1	8.78	87.8	4.3375	13.77	158.7	36
	2	9.32	93.2	4.0112	13.75	171.4	35
7	1	9.10	91.0	5.1170	16.05	156.8	37
	2	8.61	86.1	4.9322	15.51	157.2	35
9	1	8.50	85.0	5.2896	17.47	165.1	34
	2	8.95	89.5	5.7267	20.88	182.3	33

EDTA Compost/Extractant Ratio

Copper

Ratio	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
1:10	1	1.125	11.25	2.0686	3.084	74.54	13
	2	1.346	13.46	2.5324	3.760	74.24	15
1:5	1	1.822	9.11	3.2935	4.157	63.11	13
	2	1.493	7.47	2.8961	2.642	45.61	14

Cobalt

Ratio	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
1:10	1	0.172	1.720	2.0686	0.437	10.56	14
	2	0.161	1.610	2.5324	0.511	10.09	14
1:5	1	0.271	1.355	3.2935	0.705	10.70	11
	2	0.214	1.070	2.8961	0.651	11.24	9

Lead

Ratio	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
1:10	1	6.18	61.8	2.0686	4.82	116.50	35
	2	6.82	68.2	2.5324	5.69	112.34	38
1:5	1	11.74	58.7	3.2935	6.84	103.84	36
	2	10.13	50.65	2.8961	5.81	100.31	34

Cadmium

Ratio	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
1:10	1	0.056	0.56	2.0686	0.055	1.33	30
	2	0.072	0.72	2.5324	0.074	1.46	33
1:5	1	0.096	0.48	3.2935	0.090	1.37	26
	2	0.111	0.56	2.8961	0.091	1.57	26

Zinc

Ratio	Sample	Extractant data		Residue data			% extracted
		mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
1:10	1	9.78	97.8	2.0686	6.36	153.7	39
	2	11.02	110.2	2.5324	7.01	138.4	44
1:5	1	18.82	94.1	3.2935	11.08	168.2	36
	2	16.78	83.9	2.8961	6.87	118.6	41

EDTA Extraction Time

Copper

Time (hours)	Extractant data		Residue data			% extracted
	mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
2	0.785	7.85	2.8582	4.341	75.94	9
4	1.602	16.02	2.9865	4.586	76.78	17
6	1.125	11.25	3.7155	7.814	105.15	10
8	1.072	10.72	3.5012	6.186	88.34	11

Cobalt

Time (hours)	Extractant data		Residue data			% extracted
	mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
2	0.130	1.3	2.8582	0.692	12.11	10
4	0.157	1.6	2.9865	0.771	12.91	11
6	0.203	20.	3.7155	0.888	11.95	15
8	0.133	1.3	3.5012	0.828	11.82	10

Lead

Time (hours)	Extractant data		Residue data			% extracted
	mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
2	6.19	61.9	2.8582	6.86	120.01	34
4	6.75	67.5	2.9865	7.33	122.72	35
6	7.29	72.9	3.7155	8.62	116.00	39
8	7.43	74.3	3.5012	8.57	122.39	38

Cadmium

Time (hours)	Extractant data		Residue data			% extracted
	mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
2	0.049	0.49	2.8582	0.077	1.35	27
4	0.065	0.45	2.9865	0.076	1.27	26
6	0.046	0.46	3.7155	0.097	1.31	27
8	0.045	0.45	3.5012	0.090	1.29	26

Zinc

Time (hours)	Extractant data		Residue data			% extracted
	mg/l in extractant	mg/kg of compost	Mass of sample (g)	mg/l in 50ml of digestion acid	mg/kg of compost	
2	7.82	78.2	2.8582	9.44	165.14	32
4	7.80	78.0	2.9865	10.36	173.45	31
6	8.46	84.6	3.7155	10.14	136.46	38
8	6.16	61.6	3.5012	10.13	144.66	30

CHAPTER 5 DATA

Data for metals expressed as mg/l are from an Atomic Absorption Spectrophotometer. The Atomic Absorption Spectrophotometer was programmed to take three measurements in mg/l.

Data for dyes expressed as mg/l are from an UV/VIS Spectrophotometer. The UV/VIS Spectrophotometer was programmed to take three measurements in mg/l.

Effect of Time on metal removal

Lead removal

Time/hours	mg/l in blank	Sample 1		Sample 2	
		mg/l in sample	% metal removed	mg/l in sample	% metal removed
1	68.3	1.68	97.54	1.49	97382
	68.4	1.66	97 .57	1.51	97.79
	68.3	1.69	97.53	1.48	97.83
2	68.4	1.54	97.75	1.55	97.73
	68.5	1.52	97.78	1.53	97.77
	68.3	1.52	97.78	1.52	97.77
4	68.4	1.46	97.87	1.49	97.82
	68.4	1.43	97.91	1.48	97.84
	68.3	1.43	97.90	1.46	97.86
8	68.2	1.41	97.93	1.47	97.84
	68.3	1.43	97.92	1.47	97.85
	68.3	1.44	97.89	1.48	97.83
24	68.4	1.40	97.95	1.43	97.91
	68.3	1.41	97.94	1.40	97.95
	68.2	1.42	97.92	1.40	97.95

Copper removal

Time/hours	mg/l in blank	Sample 1		Sample 2	
		mg/l in sample	% metal removed	mg/l in sample	% metal removed
1	79.4	9.54	87.98	9.32	88.25
	79.10	9.48	88.02	9.27	88.28
	79.30	9.50	88.02	9.27	88.31
2	79.35	8.31	89.53	8.20	89.67
	79.25	8.28	89.55	8.19	89.67
	79.10	8.31	89.49	8.24	89.58
4	79.25	7.63	90.37	7.49	90.55
	79.05	7.61	90.37	7.44	90.59
	79.45	7.65	90.37	7.48	90.59
8	79.30	6.78	91.45	6.97	91.21
	79.40	6.79	91.45	6.93	91.27
	79.35	6.85	91.37	6.94	91.25
24	79.20	6.02	92.40	5.86	92.60
	79.25	6.08	92.33	5.92	92.53
	79.05	6.04	92.36	5.84	92.61

Cadmium removal

Time/hours	mg/l in blank	Sample 1		Sample 2	
		mg/l in sample	% metal removed	mg/l in sample	% metal removed
1	57.9	1.59	97.25	1.53	97.36
	57.6	1.61	97.20	1.51	97.38
	57.8	161	97.22	1.52	97.37
2	57.8	1.36	97.65	1.32	97.72
	58.1	1.35	97.67	1.30	97.76
	58.0	1.38	97.62	1.31	97.77
4	57.5	1.30	97.74	1.33	97.69
	57.9	1.31	97.74	1.30	97.75
	57.7	1.29	97.76	1.31	97.73
8	57.8	1.31	97.73	1.30	97.75
	57.9	1.30	97.75	1.28	97.79
	57.8	1.29	97.77	1.32	97.72
24	57.9	1.30	97.75	1.29	97.77
	57.6	1.30	97.74	1.28	97.78
	57.8	1.30	97.75	1.29	97.77

Zinc removal

Time/hours	mg/l in blank	Sample 1		Sample 2	
		mg/l in sample	% metal removed	mg/l in sample	% metal removed
1	63.2	3.41	94.60	3.59	94.32
	63.4	3.39	94.65	3.57	94.37
	63.6	3.38	94.69	3.56	94.44
2	63.3	2.64	95.83	2.87	95.47
	63.4	2.61	95.88	2.84	95.52
	63.4	2.65	95.82	2.91	95.41
4	63.5	2.46	96.13	2.44	96.16
	63.2	2.44	96.14	2.48	96.08
	63.4	2.43	96.17	2.47	96.10
8	63.4	2.67	95.79	2.69	95.76
	63.4	2.68	95.77	2.71	95.73
	63.5	2.69	95.76	2.68	95.78
24	63.1	2.58	95.91	2.72	95.69
	63.4	2.56	95.96	2.72	95.71
	63.4	2.59	95.91	2.73	95.69

Metal removal capacity of compost

Lead removal by compost (Sample 1)

mg/l lead in blank solution	mg/l lead in sample	Difference between blank and sample	mg lead removed/g of compost	% lead removed
45.1	1.04	44.06	4.41	97.76
45.1	1.03	44.07	4.41	97.69
45.0	1.02	43.98	4.40	97.73
155	6.32	148.68	14.87	95.92
155	6.34	148.66	14.87	95.90
154	6.32	147.68	14.77	95.90
310	13.92	296.08	29.61	95.51
311	13.88	297.12	29.71	95.53
310	13.92	296.08	29.61	95.51
628	209.5	418.5	41.85	66.64
626	209.0	417	41.7	66.61
628	209.0	419	41.9	66.72
1482	942	540	54.0	36.44
1484	938	546	54.6	36.79
1482	940	542	54.2	36.57
2236	1652	584	58.4	26.12
2240	1648	492	49.2	26.12
2236	1952	584	58.4	26.12
3148	2604	544	54.4	17.28
3152	2600	552	55.2	17.51
3156	2612	544	54.4	17.24

Lead removal by compost (Sample 2)

mg/l lead in blank solution	mg/l lead in sample	Difference between blank and sample	mg lead removed/g of compost	% lead removed
45.1	0.99	44.11	4.41	97.80
45.1	0.98	44.12	4.41	97.83
45.0	0.99	44.01	4.40	97.80
155	6.42	148.58	14.86	95.86
155	6.40	148.60	14.86	95.87
154	6.42	147.58	14.76	95.83
310	17.36	292.64	29.26	94.40
311	17.40	293.60	29.36	94.41
310	17.44	292.56	29.26	94.37
628	198.0	430.0	43.0	68.47
626	198.5	427.5	42.75	68.29
628	198.0	430.0	43.0	68.47
1482	968	514	51.4	34.68
1484	960	524	52.4	35.31
1482	962	520	52.0	35.09
2236	1616	620	62.0	27.72
2240	1620	620	62.0	27.68
2236	1612	624	62.4	27.91
3148	2560	588	58.8	18.68
3152	2548	604	60.4	19.16
3156	2552	604	60.4	19.14

Copper removal by compost (Sample 1)

mg/l copper in blank solution	mg/l copper in sample	Difference between blank and sample	mg copper removed/g of compost	% copper removed
65.12	5.024	60.096	6.01	92.28
65.12	5.021	60.099	6.01	92.29
65.14	5.026	60.114	6.01	92.28
177.1	38.0	139.1	13.91	78.54
177.3	38.1	139.2	13.92	78.51
177.2	38.3	138.9	13.89	78.39
355.9	206.8	149.1	14.91	41.89
355.7	206.4	149.3	14.93	41.97
355.7	206.3	149.4	14.94	42.00
858	646	212	21.2	24.72
859	647	212	21.2	24.67
858	645	213	21.3	24.83
1794	1529	265	26.5	14.77
1793	1527	266	26.6	14.84
1792	1526	266	26.6	14.84
2820	2485	335	33.5	11.88
2838	2489	339	33.9	11.99
2820	2481	339	33.9	12.02
3736	3438	298	29.8	7.98
3736	3429	307	30.7	8.22
3742	3431	311	31.1	8.31

Copper removal by compost (Sample 2)

mg/l copper in blank solution	mg/l copper in sample	Difference between blank and sample	mg copper removed/g of compost	% copper removed
65.12	4.872	60.248	6.02	92.52
65.12	4.868	60.252	6.03	92.52
65.14	4.869	60.271	6.03	92.52
177.1	36.1	141.0	14.10	79.62
177.3	36.4	140.9	14.09	79.47
177.2	36.5	140.7	14.07	79.40
355.9	219.3	136.6	13.66	38.38
355.7	219.1	136.6	13.66	38.40
355.7	219.6	136.1	13.61	38.26
858	609	249	24.9	29.02
859	610	249	24.9	28.99
858	609	249	24.9	29.02
1794	1489	305	30.5	17.00
1793	1490	303	30.3	16.90
1792	1490	302	30.2	16.85
2820	2459	361	26.1	12.80
2838	2457	371	37.1	13.12
2820	2463	357	35.7	12.65
3736	3412	324	32.4	8.67
3736	3410	326	32.6	8.73
3742	3408	334	33.4	8.93

Cadmium removal by compost (Sample 1)

mg/l cadmium in blank solution	mg/l cadmium in sample	Difference between blank and sample	mg cadmium removed/g of compost	% cadmium removed
62.8	3.86	58.94	5.89	93.85
62.4	3.82	58.52	5.86	93.88
62.6	3.84	58.76	5.88	93.87
166.1	41.6	124.5	12.45	74.96
166.4	41.3	125.1	12.51	75.18
166.3	41.9	124.4	12.44	74.8
343.5	180.5	163	16.3	47.45
344.5	182.5	162	16.2	47.02
345.0	179.0	166	16.6	48.12
767.5	522.5	245	24.5	31.92
766.0	523.0	243	24.3	31.72
766.0	521.5	244.5	24.43	31.92
1519	1240	279	27.9	18.37
1523	1243	280	28.0	18.38
1518	1239	279	27.9	18.38
2510	2268	242	24.2	9.64
2516	2262	254	25.4	10.10
2514	2264	250	25.0	9.94
2974	2724	250	75.0	8.41
2972	2720	252	25.2	8.48
2974	2718	256	25.6	8.61

Cadmium removal by compost (Sample 2)

mg/l cadmium in blank solution	mg/l cadmium in sample	Difference between blank and sample	mg cadmium removed/g of compost	% cadmium removed
62.8	3.69	59.11	5.91	94.12
62.4	3.68	58.72	5.87	94.10
62.6	3.64	58.96	5.90	94.19
166.1	39.8	126.3	12.63	76.04
166.4	39.2	127.2	12.72	76.44
166.3	39.4	126.9	12.69	76.31
343.5	185.0	158.5	15.85	46.14
344.5	184.5	160	16.00	46.44
345.0	181.5	163.5	16.35	47.4
767.5	526.0	241.5	24.15	31.47
766.0	526.5	239.5	23.95	31.27
766.0	529.5	236.5	23.65	30.87
1519	1281	238	23.8	15.67
1523	1281	242	24.2	15.89
1518	1275	243	24.2	16.01
2510	2284	226	22.6	9.00
2516	2286	230	23.0	9.14
2514	2290	224	22.4	8.91
2974	2712	262	26.2	8.81
2972	2718	254	25.4	8.55
2974	2716	258	25.4	8.68

Zinc removal by compost (Sample 1)

mg/l zinc in blank solution	mg/l zinc in sample	Difference between blank and sample	mg zinc removed/g of compost	% zinc removed
72.1	9.6	62.5	6.25	86.69
72.2	9.7	62.3	6.23	86.53
71.9	9.7	62.2	6.22	86.51
179.5	81.25	98.25	9.83	54.74
178.5	80.75	97.75	9.78	54.76
180.0	80.5	99.50	9.95	55.27
376.5	263.5	113	11.3	30.01
374.5	262.0	112.5	11.3	30.04
375.0	262.0	113	11.3	30.13
702	597	105	10.5	14.96
704	596	108	10.8	15.34
706	600	106	10.6	15.01
1540	1434	106	10.6	6.88
1548	1430	118	11.8	7.62
1544	1434	110	11.0	7.12
2678	2566	112	11.2	4.18
2690	2562	128	12.8	4.76
2682	2566	116	11.6	4.33
3480	3360	120	12.0	3.45
3472	3364	108	10.8	3.11
3472	3360	112	11.2	3.23

Zinc removal by compost (Sample 2)

mg/l zinc in blank solution	mg/l zinc in sample	Difference between blank and sample	mg zinc removed/g of compost	% zinc removed
72.1	8.9	63.2	6.32	87.66
72.2	8.9	63.1	6.31	87.64
71.9	8.9	63.0	6.3	87.62
179.5	82.0	97.5	9.75	54.32
178.5	83.0	95.5	9.75	53.5
180.0	83.0	97.0	9.7	53.89
376.5	258.5	118	11.8	31.34
374.5	259.0	115.5	11.55	30.84
375.0	259.0	116	11.6	29.33
702	589	113	11.3	16.10
704	590	114	11.4	16.19
706	591	115	11.5	16.29
1540	1425	114	11.4	7.40
1548	1422	126	12.6	8.14
1544	1422	122	12.2	8.14
				7.90
2678	2554	124	12.4	4.63
2690	2574	116	11.6	4.31
2682	2558	124	12.4	4.62
3480	3372	108	10.8	3.10
3472	3360	112	11.2	3.23
3472	3356	116	11.6	3.34

Effect of pH on Metal removal

The data expressed is the average of three measurements taken by the Atomic Absorption Spectrophotometer

Lead

Initial pH	Sample	Final pH	Concentration of metal in control (mg/l)	Concentration of metal in sample (mg/l)	% metal removed
2	1	3.42	812	371.2	54.29
	2	3.34	812	407.2	49.85
3	1	4.15	812	327.0	59.73
	2	4.63	812	311.3	61.66
4	1	4.87	812	279.8	65.54
	2	4.95	812	275.7	66.05
5	1	4.95	813	307.2	62.21
	2	4.91	813	296.7	63.51

Copper

Initial pH	Sample	Final pH	Concentration of metal in control (mg/l)	Concentration of metal in sample (mg/l)	% metal removed
2	1	4.28	480.5	246.6	48.68
	2	4.31	480.5	263.5	45.16
3	1	4.41	461.8	235.9	48.92
	2	4.39	461.8	247.9	46.32
4	1	4.70	440.4	222.8	49.41
	2	4.65	440.4	212.8	51.68
5	1	4.76	428.3	223.9	47.72
	2	4.74	428.3	227.6	46.86

Cadmium

Initial pH	Sample	Final pH	Concentration of metal in control (mg/l)	Concentration of metal in sample (mg/l)	% metal removed
2	1	5.46	331.5	156.5	52.80
	2	5.41	331.5	168.0	49.32
3	1	5.61	332.5	155.6	53.20
	2	5.64	332.5	175.9	47.10
4	1	5.71	336.0	153.8	54.23
	2	5.73	336.0	147.4	56.13
5	1	5.80	346.5	157.3	54.60
	2	5.69	346.5	155.6	55.09

Zinc

Initial pH	Sample	Final pH	Concentration of metal in control (mg/l)	Concentration of metal in sample (mg/l)	% metal removed
2	1	5.67	761	277.0	63.60
	2	5.69	761	278.4	63.42
3	1	5.74	774	284.0	66.31
	2	5.70	774	286.0	63.05
4	1	5.79	769	284.4	63.02
	2	5.81	769	282.6	63.25
5	1	5.83	815	306.2	62.43
	2	5.88	815	301.8	62.97

Effect of Time on Methylene Blue Removal

Methylene Blue Removal (100 mg/l) - Sample 1

Time (hours)	mg/l in blank	mg/l in sample	Difference	mg removed per gram of compost	% dye removed
1	89	2.20	86.80	8.68	98
	89	2.30	86.70	8.67	97
	90	2.25	87.75	8.78	98
3	89	1.80	87.20	8.72	98
	89	1.80	87.20	8.72	98
	89	1.85	87.15	8.72	98
6	89	1.30	87.70	8.77	99
	89	1.35	87.65	8.77	98
	89	1.30	87.70	8.77	99
24	89	1.30	87.70	8.77	99
	89	1.30	87.70	8.77	99
	89	1.30	87.70	8.77	99
48	89	1.30	87.0	8.77	99
	90	1.25	88.75	8.88	99
	89	1.25	87.75	8.78	99
72	89	1.30	87.70	8.77	99
	89	1.25	87.75	8.78	99
	89	1.25	87.75	8.78	99

Methylene Blue Removal (100 mg/l) - Sample 2

Time (hours)	mg/l in blank	mg/l in sample	Difference	mg removed per gram of compost	% dye removed
1	89	2.40	86.60	8.66	97
	89	2.35	86.65	8.67	97
	90	2.40	87.60	8.76	97
3	89	1.75	87.25	8.72	98
	89	1.70	87.360	8.73	98
	89	1.70	87.30	8.73	98
6	89	1.40	87.60	8.76	98
	89	1.35	87.65	8.77	98
	89	1.35	87.65	8.77	98
24	89	1.30	87.70	8.77	99
	89	1.35	87.65	8.77	98
	89	1.30	87.70	8.77	99
48	89	1.30	87.70	8.77	99
	90	1.30	88.70	8.87	99
	89	1.30	87.70	8.77	99
72	89	1.35	87.65	8.77	98
	89	1.30	87.70	8.77	99
	89	1.35	87.65	8.77	98

Methylene Blue Removal (1000 mg/l) - Sample 1

Time (hours)	mg/l in blank	mg/l in sample	Difference	mg removed per gram of compost	% dye removed
1	910	342.5	567.5	56.75	62
	910	345	565	56.5	62
	915	345	570	57.0	62
3	905	180	725	72.5	80
	910	178.8	731.2	73.1	80
	910	180	730	73.0	80
6	915	91.5	823.5	82.4	90
	915	92	823	82.3	90
	910	91.5	818.5	81.9	90
24	910	38	872	87.2	96
	910	37.5	872.5	87.3	96
	910	38	872	87.2	96
48	910	15	895	89.5	98
	915	14.5	900.5	90.1	98
	910	15	895	89.5	98
72	905	16	889	88.9	98
	910	15	895	89.5	98
	910	15	895	89.5	98

Methylene Blue removal (1000 mg/l) - Sample 2

Time (hours)	mg/l in blank	mg/l in sample	Difference	mg removed per gram of compost	% dye removed
1	910	330	580	58.0	64
	910	335	575	57.5	63
	910	332.5	582	58.28	64
3	905	200	705	70.5	78
	910	202.5	707.5	70.8	78
	910	200	710	71.0	78
6	915	99	816	81.6	89
	915	99	816	81.6	89
	910	99	811	81.1	89
24	910	31	879	87.9	97
	910	31.5	878.5	87.9	97
	910	32	878	87.8	96
48	910	17	893	89.3	98
	915	17.5	897.5	89.8	98
	910	17.5	892.5	89.3	98
72	905	18	887	88.7	98
	910	17.5	892.5	89.3	98
	910	17.5	892.5	89.3	98

Methylene Blue Removal (3000 mg/l) - Sample 1

Time (hours)	mg/l in blank	mg/l in sample	Difference	mg removed per gram of compost	% dye removed
1	2983	1975	1008	100.8	34
	2983	1975	1008	100.8	34
	3000	1988	1012	101.2	34
3	3000	1900	1100	110.0	37
	2983	1900	1083	108.3	36
	2983	1900	1083	108.3	36
6	3000	1670	1330	133.0	44
	3000	1660	1340	134.0	45
	2983	1660	1323	132.3	44
24	3000	1460	1540	154.0	51
	2983	1460	1523	152.3	51
	3000	1460	1540	154.0	51
48	3000	1388	1612	161.2	54
	3000	1400	1600	160.0	53
	3000	1388	1612	161.2	54
72	2983	1310	1673	167.3	56
	2983	1310	16732	167.3	56
	3000	1320	1680	168.0	56

Methylene Blue Removal (3000 mg/l) - Sample 2

Time (hours)	mg/l in blank	mg/l in sample	Difference	mg removed per gram of compost	% dye removed
1	2983	2050	933	93.3	31
	2983	2050	933	93.3	31
	3000	2043	957	95.7	32
3	3000	1975	1025	102.5	34
	2983	1963	1020	102.0	34
	2983	1975	10085	100.8	34
6	3000	1580	1420	142.0	47
	3000	1590	1410	141.0	47
	2983	1580	1403	140.3	47
24	3000	1490	1510	151.0	50
	2983	1490	1493	149.3	50
	3000	1490	1510	151.0	50
48	3000	1300	1700	170.0	57
	3000	1313	1687	168.7	56
	3000	1300	1700	170.0	57
72	2983	1230	1753	175.3	59
	2983	1240	1743	174.3	58
	3000	1240	1760	176.0	59

Methylene Blue Removal (5000 mg/l) - Sample 1

Time (hours)	mg/l in blank	mg/l in sample	Difference	mg removed per gram of compost	% dye removed
1	4850	4150	700	70.0	14
	4850	4175	675	67.5	14
	4850	4150	700	70.0	14
3	4875	3975	900	90.0	18
	4850	3975	875	87.5	18
	4850	3975	875	87.5	18
6	4850	3567	1283	128.3	26
	4850	3567	1283	128.3	26
	4875	3550	1325	132.5	27
24	4850	3283	1567	156.7	32
	4825	3283	1542	154.2	32
	4850	3283	1567	156.7	32
48	4825	3200	1625	162.8	34
	4825	3217	1608	160.8	33
	4850	3200	1650	165.0	34
72	4850	3100	1750	175.0	36
	4850	3100	1750	175.0	36
	4825	3117	1708	170.8	36

Methylene Blue Removal (5000 mg/l) - Sample 2

Time (hours)	mg/l in blank	mg/l in sample	Difference	mg removed per gram of compost	% dye removed
1	4850	4275	575	57.5	12
	4850	4275	575	57.5	12
	4850	4250	600	60.0	12
3	4875	3975	900	90.0	18
	4850	3975	875	87.5	18
	4850	4000	850	85.0	18
6	4850	3617	1233	123.3	25
	4850	3617	1233	123.3.	25
	4875	3600	1275	127.5	26
24	4850	3500	1350	135.0	28
	4825	3483	1342	134.2	27
	4850	3483	1367	136.7	28
48	4825	3250	1575	157.5	33
	4825	3250	1575	157.5	33
	4850	3233	1617	161.7	33
72	4850	2967	1883	188.3	39
	4850	2967	1883	188.3	39
	4825	2983	1842	184.2	38

Effect of pH on Methylene Blue removal

Methylene Blue removal (100 mg/l)

pH	mg/l in blank	Sample 1		Sample 2	
		mg/l in sample	% removed	mg/l in sample	% removed
2	97.5	0.65	99.3	0.75	99.2
	97.5	0.65	99.3	0.75	99.2
	97.0	0.70	99.3	0.80	99.2
4	93.5	0.95	99.0	0.80	99.1
	93.0	0.95	99.0	0.85	99.1
	93.5	0.95	99.0	0.80	99.1
6	91.5	0.75	99.0	0.95	99.0
	91.5	0.75	99.0	0.90	99.0
	91.5	0.70	99.2	0.90	99.0
8	83.0	0.80	99.0	0.85	99.0
	83.0	0.75	99.1	0.90	98.9
	83.5	0.75	99.1	0.90	98.9
10	82.5	0.95	98.8	0.85	99.0
	83.0	0.90	98.9	0.90	98.9
	82.5	0.90	98.9	0.90	98.9

Methylene Blue Removal (1000 mg/l)

pH	mg/l in blank	Sample 1		Sample 2	
		mg/l in sample	% removed	mg/l in sample	% removed
2	985	100.0	90	94.5	90
	985	101.0	90	94.0	91
	980	100.5	90	94.0	90
4	925	41.5	96	53.5	94
	925	41.5	96	54.0	94
	925	41.0	96	54.0	94
6	980	44.0	96	54.0	95
	980	44.0	96	54.0	95
	990	44.5	96	54.0	95
8	980	43.0	96	50.5	95
	975	42.5	96	50.0	95
	975	43.0	96	50.0	95
10	965	43.0	96	46.5	95
	970	43.5	96	46.0	95
	970	43.5	96	46.0	95

Methylene Blue Removal (3000 mg/l)

pH	mg/l in blank	Sample 1		Sample 2	
		mg/l in sample	% removed	mg/l in sample	% removed
2	3017	1700	44	1650	45
	3017	1683	44	1667	45
	3000	1683	44	1667	44
4	3067	1550	51	1500	51
	3050	1550	49	1500	51
	3050	1550	51	1517	50
6	3033	1483	51	1450	52
	3017	1483	51	1450	52
	3033	1500	51	1450	52
8	3050	1483	49	1467	51
	3033	1500	51	1467	51
	3050	1500	51	1483	50
10	2983	1550	48	1567	49
	2983	1567	47	1567	48
	2983	1567	47	1550	49

Methylene Blue Removal (5000 mg/l)

pH	mg/l in blank	Sample 1		Sample 2	
		mg/l in sample	% removed	mg/l in sample	% removed
2	4900	3525	28	3475	29
	4900	3525	28	3450	30
	4900	3550	28	3475	29
4	1925	3200	35	3200	35
	1925	3200	35	3225	35
	1950	3175	36	3225	35
6	4875	3200	34	3175	35
	4900	3200	35	3175	35
	4900	3200	35	3175	35
8	4950	3250	34	3200	35
	4950	3225	35	3200	35
	4925	3250	34	3225	35
10	4850	3300	32	3400	30
	4825	3325	31	3375	30
	4825	3325	31	3375	30

Effect of Compost Size on Methylene Blue Removal

Methylene Blue Removed (100 mg/l)

Compost size (mm)	Time (hours)	mg/l in blank	Sample 1		Sample 2	
			mg/l in sample	% removed	mg/l in sample	% removed
<0.5	1	87.5	0.80	99.1	0.95	98.9
		87.5	0.80	99.1	0.95	98.9
		87.0	0.85	99.0	0.90	99.0
	3	88.0	0.80	99.1	0.85	99.0
		88.0	0.80	99.1	0.80	99.1
		88.5	0.85	99.0	0.80	99.1
	6	87.5	0.80	99.1	0.85	99.0
		88.0	0.80	99.1	0.85	99.0
		88.0	0.80	99.1	0.80	99.1
0.5-1.0	1	87.5	1.40	98.9	1.55	98.2
		87.5	1.45	98.3	1.60	98.2
		87.0	1.40	98.4	1.60	98.2
	3	88.0	1.05	98.8	0.95	98.9
		88.0	1.00	98.9	0.95	98.9
		88.5	1.00	98.9	1.00	98.9
	6	87.5	1.00	98.9	1.15	98.7
		88.0	1.00	98.9	1.20	98.7
		88.0	1.05	98.8	1.15	98.8
1.0-2.0	1	87.5	1.50	98.3	1.70	98.1
		87.5	1.50	98.3	1.70	98.1
		87.0	1.55	98.2	1.70	98.0
	3	88.0	1.10	98.8	1.05	98.8
		88.0	1.15	98.7	1.10	98.8
		88.5	1.10	98.8	1.1.	98.7
	6	87.5	1.10	98.7	1.00	98.9
		88.0	1.10	98.8	1.10	98.9
		88.0	1.10	98.8	1.10	98.8

Methylene Blue Removed (1000 mg/l) for compost size <0.5mm

Time (hours)	mg/l in blank	Sample 1		Sample 2	
		mg/l in sample	% removed	mg/l in sample	% removed
1	970	362.5	63	387.5	60
	970	362.0	62	390.0	60
	970	362.5	63	390.0	60
3	970	58.0	94	74.0	92
	965	58.0	94	74.0	92
	970	58.0	94	73.5	92
6	975	37.5	96	50.5	95
	970	38.0	96	50.5	95
	970	38.0	96	51.1	95
24	965	58.8	94	52.5	95
	965	58.8	94	52.5	95
	960	60.0	94	53.0	95
48	965	52.5	95	51.5	95
	960	53.8	94	51.5	95
	965	52.5	95	51.5	95
72	965	52.5	95	49.5	95
	960	51.3	95	50.0	95
	965	52.5	95	50.0	95

Methylene Blue Removed (1000 mg/l) for compost 0.5-1.0mm

Time (hours)	mg/l in blank	Sample 1		Sample 2	
		mg/l in sample	% removed	mg/l in sample	% removed
1	970	462.5	52	430.0	56
	970	460.0	53	427.5	56
	970	460.0	53	427.5	56
3	970	290.0	70	312.5	68
	965	295.0	69	315.0	67
	970	292.5	70	312.5	68
6	975	187.5	81	167.5	83
	970	187.5	81	170.0	83
	970	185.0	81	170.0	83
24	965	207.5	78	210.0	78
	965	206.3	79	208.8	78
	960	207.5	78	208.8	78
48	965	100.0	90	121.3	87
	960	100.0	90	122.5	87
	965	100.0	90	122.5	87
72	965	88.0	91	95.0	90
	960	87.5	91	96.3	90
	965	88.0	91	96.3	90

Methylene Blue Removal (1000 mg/l) for compost size1.0-2.0mm

Time (hours)	mg/l in blank	Sample 1		Sample 2	
		mg/l in sample	% removed	mg/l in sample	% removed
1	970 970 970	435 435 437.5	55 55 55	407.5 410.0 407.5	58 58 58
3	970 965 970	405 407.5 407.5	58 58 58	382.5 382.5 380.0	61 60 61
6	965 965 960	225.0 225.0 223.8	77 77 77	262.5 262.5 262.5	73 73 73
24	975 970 970	180.0 182.5 182.5	82 81 81	165.0 165.5 165.5	83 83 83
48	965 960 965	107.5 106.3 106.3	89 89 89	101.3 101.3 102.5	90 90 90
72	965 960 965	96.0 94.8 96.0	90 90 90	96.0 96.0 96.0	90 90 90

Methylene Blue Removal (3000 mg/l) for compost size <0.5mm

Time (hours)	mg/l in blank	Sample 1		Sample 2	
		mg/l in sample	% removed	mg/l in sample	% removed
1	3333 3333 3317	2067 2050 2067	38 38 38	1950 1933 1933	41 42 42
3	3333 3317 3317	1667 1667 1667	50 50 50	1767 1750 1750	47 47 47
6	3300 3317 3317	1517 1500 1500	54 55 55	1633 1633 1617	51 51 51
24	3050 3050 3050	1367 1367 1383	55 55 55	1350 1367 1367	56 55 55
48	3050 3033 3050	1383 1383 1383	55 54 55	1417 1433 1417	54 53 54
72	3033 3033 3033	1367 1350 1367	55 55 55	1400 1400 1383	54 54 54

Methylene Blue Removal (3000 mg/l) for compost size0.5-1.0

Time (hours)	mg/l in blank	Sample 1		Sample 2	
		mg/l in sample	% removed	mg/l in sample	% removed
1	3333	2367	29	2267	32
	3333	2367	29	2250	33
	3317	2350	29	2250	33
3	3333	2217	33	2117	36
	3317	2217	33	2133	36
	3317	2217	33	2133	36
6	3300	1867	43	1867	43
	3317	1850	44	1867	44
	3317	1850	44	1850	44
24	3050	1750	43	1650	46
	3050	1750	43	1667	45
	3050	1733	43	1667	45
48	3050	1633	46	1600	48
	3033	1617	47	1600	47
	3050	1633	46	1617	47
72	3033	1633	46	1583	48
	3033	1633	46	1583	48
	3033	1617	47	1583	48

Methylene Blue Removal (3000 mg/l) for compost size 1.0-2.0

Time (hours)	mg/l in blank	Sample 1		Sample 2	
		mg/l in sample	% removed	mg/l in sample	% removed
1	3333	2417	27	2600	22
	3333	2400	28	2583	23
	3317	2400	28	2583	22
3	3333	2067	38	2150	35
	3317	2083	37	2133	36
	3317	2067	38	2133	36
6	3300	1883	43	1850	44
	3317	1883	43	1850	44
	3317	1883	43	1850	44
24	3050	1617	47	1567	49
	3050	1617	47	1567	49
	3050	1600	48	1550	49
48	3050	1500	51	1517	50
	3033	1483	51	1533	49
	3050	1483	51	1533	50
72	3033	1483	51	1450	52
	3033	1483	51	1433	53
	3033	1483	52	1450	52

Effect of Compost Mass on Methylene Blue Removal

Methylene Blue Removal (1000 mg/l) mass 0.25g

Time (hours)	mg/l in blank	Sample 1		Sample 2	
		mg/l in sample	% removed	mg/l in sample	% removed
1	970	845	13	815	16
	970	845	13	810	16
	970	840	13	815	16
3	965	790	18	775	20
	970	795	18	770	21
	970	790	19	770	21
6	970	725	25	735	24
	965	725	25	740	23
	970	725	25	735	24
24	1005	685	32	670	33
	1000	680	32	665	34
	1000	690	31	665	34
48	1000	590	41	615	39
	1000	585	42	615	39
	995	585	41	615	38

Methylene Blue Removal (1000 mg/l) mass 0.5g

Time (hours)	mg/l in blank	Sample 1		Sample 2	
		mg/l in sample	% removed	mg/l in sample	% removed
1	970	705	27	735	24
	970	705	27	735	24
	970	710	27	740	24
3	965	565	41	600	38
	970	560	42	605	38
	970	560	42	600	38
6	970	455	53	485	50
	965	455	53	485	50
	970	455	53	490	50
24	1005	400	60	380	62
	1000	405	60	375	63
	1000	400	60	380	62
48	1000	290	71	315	69
	1000	290	71	320	68
	995	290	71	320	68

Methylene Blue Removal (1000 mg/l) mass 0.75g

Time (hours)	mg/l in blank	Sample 1		Sample 2	
		mg/l in sample	% removed	mg/l in sample	% removed
1	970	585	40	555	43
	970	585	40	555	43
	970	580	40	555	43
3	965	450	53	485	50
	970	445	54	480	51
	970	450	54	480	51
6	970	305	69	325	66
	965	300	69	320	67
	970	300	69	325	66
24	1005	172.5	83	170	83
	1000	172.5	83	172.5	83
	1000	175	83	170	83
48	1000	100	90	96	90
	1000	99.5	90	97	90
	995	100	90	96	90

Compost column (5 g) at a flow rate of 5 ml/min - starting concentration of methylene blue 250 mg/l

Volume through column (ml)	Sample 1 concentration of methylene blue (mg/l) exiting column	Sample 2 concentration of methylene blue (mg/l) exiting column
Starting concentration of methylene blue	250 250 250	250 250 250
100	0 0 0	0 0 0
200	1.0 1.0 1.0	1.50 1.50 1.50
300	2.40 2.45 2.40	2.95 2.90 2.95
420	8.65 8.65 8.60	10.35 10.35 10.40
520	15.0 15.0 15.0	17.5 17.4 17.5
600	31.0 30.5 30.5	30.0 30.5 30.5
800	50.0 50.0 50.0	48.8 48.8 48.8
1100	77.5 76.3 77.5	81.3 81.3 82.5
1300	97.5 97.5 98.8	91.3 91.3 91.3
1700	126.3 125.0 125.0	113.8 112.5 113.8
1900	135.0 137.5 135.0	128.8 128.8 127.5
2100	145.0 145.0 143.8	141.3 140.0 141.3
2300	156.3 156.3 155.0	157.5 157.5 157.5
2600	165.0 165.0	168.8 167.5

	165.0	168.8
3000	178.8 177.5 178.8	185.0 187.5 186.3

Compost column (5 g) at a flow rate of 5 ml/min - starting concentration of methylene blue 500 mg/l

Volume through column (ml)	Sample 1 concentration of methylene blue (mg/l) exiting column	Sample 2 concentration of methylene blue (mg/l) exiting column
Starting concentration	490 490 490	490 490 490
50	2.40 2.45 2.40	1.95 1.95 1.90
100	4.80 4.85 4.85	4.30 4.25 4.30
200	58.5 58.5 58.0	61.5 61.5 62.0
300	130.0 127.5 130.0	125.0 122.5 122.5
400	172.5 172.5 172.5	165.0 162.5 165.0
500	205.0 205.0 207.5	210.0 205.0 207.5
600	245.0 245.0 245.0	255.0 252.5 252.5
800	285.0 285.0 287.5	315.0 317.5 315.0
1000	310.0 310.0 310.0	332.5 332.5 330.0
1200	332.5 335.0 332.5	347.5 347.5 347.5
1400	350.0 350.0 347.5	362.5 360.0 362.5
1600	360.0 362.5	367.5 370.0

	360.0	370.0
1800	367.5 365.0 367.5	375.0 375.0 377.5
2000	370.0 370.0 370.0	380.0 382.5 380.0

CHAPTER 6 DATA

Data for metals expressed as mg/l are from an Atomic Absorption Spectrophotometer. The Atomic Absorption Spectrophotometer was programmed to take three measurements and provide the average of the three measurements in mg/l.

Data for dyes expressed as mg/l are from an UV/VIS Spectrophotometer. The UV/VIS Spectrophotometer was programmed to take three measurements and provide the average of three measurements in mg/l.

Data for TOC levels expressed as mg/l are from a TOC Analyser. The TOC Analyser was programmed to take three measurements and provide the average of three measurements in ppm (the equivalent of mg/l) on each sample.

Data for organic matter levels are obtained by measuring the mass of compost before and after heating on a balance measuring to a sensitivity of 0.0001g and due to the limited apparatus available single measurements were performed.

Weight Change of Compost Following Extraction

Extractant	Sample	Mass of compost before extraction (g)	Mass of compost after extraction (g)	% change
1M HCl	1	10.0139	8.7608	-13
	2	10.0043	8.7532	-11
	3	10.0112	8.6451	-14
1M H_2SO_4	1	9.8990	10.9932	+11
	2	10.0177	11.3875	+14
	3	10.0022	11.7162	+17
1M HNO_3	1	9.8932	8.2013	-17
	2	10.0102	8.2101	-18
	3	10.0050	8.3598	-17
1M H_3PO_4	1	10.0097	10.6585	+6
	2	9.9425	10.5420	+6
	3	10.0242	10.7130	+7
1M NaOH	1	9.9821	10.4314	+5
	2	10.0413	10.6121	+6
	3	10.0012	10.4495	+5
0.1M $Na_4P_2O_7$	1	9.9967	10.0602	+1
	2	10.0211	10.0632	+1
	3	10.0079	10.1090	+1
0.1M Na_2CO_3	1	10.0018	9.5927	-4
	2	9.9876	9.7316	-3
	3	9.9932	9.4186	-6
1M KCl	1	10.0156	10.0398	+1
	2	10.0111	10.0732	+1
	3	10.0314	10.1042	+1
1M NH_4Cl	1	10.0321	9.8142	-4
	2	10.0042	9.8314	-2
	3	10.0071	9.7273	-3
1M $CaCl_2$	1	10.0214	9.2983	-7
	2	9.9713	9.0444	-9
	3	9.9924	9.1124	-9
1M Acetic acid	1	10.0201	8.8929	-13
	2	10.0063	8.7614	-12
	3	10.0149	8.9283	-11
Acetone	1	9.9921	9.9104	-1
	2	10.0905	9.9803	-1
	3	9.9871	9.8642	-1
Ethanol	1	10.0014	9.9049	-1
	2	10.0321	9.8023	-2
	3	10.0153	9.8904	-1
Diethyl Ether	1	9.9981	9.6493	-3
	2	10.0020	9.5373	-5
	3	9.9912	9.3142	-7
Hexane	1	10.0275	9.7926	-2
	2	9.9730	9.6421	-3
	3	10.0018	9.8182	-2

TOC Level Following Extraction

Extractant	mg/l in extractant	Grams extracted from 10g sample	% extracted
1M HCl	1.23	0.12	1.2
1M H_2SO_4	1.11	0.11	1.1
1M HNO_3	1.18	0.12	1.2
1M H_3PO_4	3.02	0.30	3.0
1M NaOH	3.50	0.35	3.5
0.1M $Na_4P_2O_7$	2.67	0.27	2.7
0.1M Na_2CO_3	2.34	0.23	2.3
1M KCl	1.11	0.11	1.1
1M NH_4Cl	1.12	0.12	1.1
1M $CaCl_2$	0.92	0.09	0.9
NaOH refluxed	7.02	0.70	7.0
HNO_3 at 50°C	3.04	0.3	3.0

Organic Matter Level Following Extraction

Extractant	Mass of compost before heating (g)	Mass of compost after heating (g)	% organic matter
1M HCl	0.6513	0.3497	46
1M H_2SO_4	0.6782	0.4119	39
1M HNO_3	0.7698	0.4569	41
1M H_3PO_4	1.4874	0.8784	41
1M NaOH	0.8010	0.5684	29
0.1M $Na_4P_2O_7$	0.5816	0.3609	38
0.1M Na_2CO_3	1.4051	0.8757	38
1M KCl	0.6636	0.3287	50
1M NH_4Cl	1.6047	1.0606	34
1M $CaCl_2$	1.2565	0.6823	46
1M Acetic acid	1.1571	0.7549	35
Acetone	1.1303	0.7004	38
Ethanol	1.2916	0.8097	37
Diethyl Ether	1.2242	0.7385	40
Hexane	0.9989	0.6544	35
NaOH refluxed	1.1390	0.8367	26
HNO_3 at 50°C	0.9997	0.5715	43
No extractant	4.7897	2.8060	42

Effect of Extractant Concentration on Weight Change

Extractant	Sample	Mass of compost before extraction (g)	Mass of compost after extraction (g)	% change
0.5M HCl	1	10.1034	8.5149	-16
	2	9.8845	8.4758	-14
	3	9.9932	8.8382	-11
2M HCl	1	9.8641	9.1046	-8
	2	9.9183	8.4316	-15
	3	9.9422	8.8083	-11
0.5M H_2SO_4	1	10.0613	10.6132	+6
	2	9.9214	10.3481	+4
	3	9.6832	10.0058	+3
2M H_2SO_4	1	10.0659	12.9431	+29
	2	9.3587	11.9223	+27
	3	9.5724	11.9381	+25
0.5M HNO_3	1	9.8409	8.5507	-13
	2	10.0143	8.7124	-13
	3	10.1119	8.7015	-14
2M HNO_3	1	10.0683	8.3129	-17
	2	9.9560	8.1482	-18
	3	9.9714	8.3067	-17
0.5M NaOH	1	9.8833	9.9302	+1
	2	9.7812	9.8321	+1
	3	10.0146	10.1243	+1
2M NaOH	1	9.7832	10.8412	+11
	2	9.6147	10.9590	+14
	3	10.0132	11.7145	+17

Effect of Extractant Concentration on TOC Level

Extractant	mg/l in extractant	Grams extracted from 10g sample	% extracted
0.5M HCl	1.13	0.11	1.1
2M HCl	1.22	0.12	1.2
0.5M H_2SO_4	1.04	0.10	1.0
2M H_2SO_4	1.08	0.11	1.1
0.5M HNO_3	1.21	0.12	1.2
2M HNO_3	1.76	0.18	1.8
0.5M NaOH	3.03	0.30	3.0
2M NaOH	3.34	0.34	3.4

Effect of Extractant Concentration on Organic Matter Levels

Extractant	Mass of compost before heating (g)	Mass of compost after heating (g)	% organic matter
0.5M HCl	1.2376	0.6835	45
2M HCl	1.1705	0.6106	48
0.5M H_2SO_4	1.4936	0.8930	40
2M H_2SO_4	0.9849	0.4960	50
0.5M HNO_3	1.0046	0.6132	39
2M HNO_3	1.0477	0.5738	45
0.5M NaOH	1.1093	0.6995	37
2M NaOH	1.2133	0.7633	37

Weight change of "Ash" Following Leaching

Extractant	Mass of compost before extraction (g)	Mass of compost after extraction (g)	% change
1M HCl	4.9370	3.4852	-29
1M H_2SO_4	5.0078	5.0723	+1
1M HNO_3	4.9573	3.2256	-36
1M NaOH	5.0611	5.1092	+1
1M KCl	5.0795	5.3734	+6
1M $CaCl_2$	5.1714	5.3553	+3

Effect of Acid and Alkali on Methylene Blue Removal from Compost

Reagent	Sample 1			Sample 2		
	Methylene Blue removed (mg/l)	Methylene Blue removed (mg/g of compost)	pH	Methylene Blue removed (mg/l)	Methylene Blue removed (mg/g of compost)	pH
1M H_2SO_4	780	78	0.78	710	71	0.64
1M HCl	365	37	0.52	395	40	0.54
Distilled water	0	0	6.57	0	0	6.83
1M NaOH	35	3.5	13.20	31	3.1	13.41

Effect of Acid and Alkali on Lead Removal from Compost

Reagent	Sample 1			Sample 2		
	lead removed (mg/l)	lead removed (mg/g of compost)	pH	lead removed (mg/l)	lead removed (mg/g of compost)	pH
1M HNO_3	385.5	39	0.54	370.5	37	0.51
1M HCl	341.5	34	0.52	341.5	34	0.53
Distilled water	17.0	2	3.64	31	3	3.21
1M NaOH	290	29	13.23	299.5	30	13.78

Effect of Acid and Alkali on Copper Removal from Compost

Reagent	Sample 1			Sample 2		
	lead removed (mg/l)	lead removed (mg/g of compost)	pH	lead removed (mg/l)	lead removed (mg/g of compost)	pH
1M H_2SO_4	300	30	2.23	289	29	2.59
1M HCl	297	30	2.35	301	30	2.43
Distilled water	10.25	1	5.51	12.5	1	5.87
1M NaOH	130	13	11.02	125	13	10.82
1M NaCl	37.5	4	8.52	42.5	4	8.78

Removal of Copper by Compost Before and After Humic Acid Removal

Initial concentration of copper (mg/l)	Sample	Final concentration of copper (mg/l)	Difference (mg/l)	Copper removed (mg/g compost)
86.5	Compost before 1	11.8	74.7	7.47
	Compost before 2	12.7	73.8	7.38
	Compost after 1	28.1	58.4	5.84
	Compost after 2	29.4	57.1	5.71
427	Compost before 1	271	156	15.6
	Compost before 2	264	163	16.3
	Compost after 1	363	64	6.4
	Compost after 2	381	46	4.6
882	Compost before 1	620	262	26.2
	Compost before 2	578	304	30.4
	Compost after 1	776	106	10.6
	Compost after 2	782	100	10.0
1765	Compost before 1	1500	265	26.5
	Compost before 2	1560	205	20.5
	Compost after 1	1620	145	14.5
	Compost after 2	1605	160	16.0
3760	Compost before 1	3490	270	27.0
	Compost before 2	3530	240	24.0
	Compost after 1	3610	150	15.0
	Compost after 2	3620	140	14.0

Removal of Lead by Compost Before and After Humic Acid Removal

Data for removal of lead by compost before humic acid removal is given in the data for lead removal in Chapter 5.

Initial concentration of lead (mg/l)	Sample	Final concentration of lead (mg/l)	Difference (mg/l)	Lead removed (mg/g compost)
45.0	Compost after 1	8.3	36.8	3.68
	Compost after 2	6.6	38.4	3.84
152.5	Compost after 1	60.4	92.1	9.21
	Compost after 2	49.2	103.3	10.33
305	Compost after 1	95.4	209.6	20.96
	Compost after 2	128.6	176.4	17.64
644	Compost after 1	380	264	26.4
	Compost after 2	382	262	26.2
1512	Compost after 1	1239	273	27.3
	Compost after 2	1208	304	30.4
2360	Compost after 1	2072	288	28.8
	Compost after 2	2081	279	27.9
3204	Compost after 1	2913	291	29.1
	Compost after 2	2920	284	28.4

Removal of Methylene Blue by Compost Before and After Humic Acid Removal

Initial concentration of Methylene Blue (mg/l)	Sample	Final concentration of Methylene Blue (mg/l)	Difference (mg/l)	Methylene Blue removed (mg/g compost)
100	Compost before 1	0.6	99.4	9.94
	Compost before 2	0.9	99.1	9.91
	Compost after 1	0.3	99.7	9.97
	Compost after 2	0.6	99.4	9.94
510	Compost before 1	6	504	50.4
	Compost before 2	4	506	50.6
	Compost after 1	7	473	47.3
	Compost after 2	11	469	46.9
900	Compost before 1	32	868	86.8
	Compost before 2	48	852	85.2
	Compost after 1	270	630	63.0
	Compost after 2	250	650	65.0
1900	Compost before 1	563	1337	133.7
	Compost before 2	497	1403	140.3
	Compost after 1	1150	750	75.0
	Compost after 2	1186	814	81.4
2850	Compost before 1	1475	1375	137.5
	Compost before 2	1425	1425	142.5
	Compost after 1	2200	650	65.0
	Compost after 2	2125	725	72.5

Extractablility of Group I and II Metals from Compost

Metal	mg/l in control	mg/g in compost	Sample 1			Sample 2		
			mg/l in extract	mg/g in compost	Diff-erence	mg/l in extract	mg/g in compost	Diff-erence
Na	15.4	1.5	15.4	1.5	0	14.7	1.5	0
K	41.3	4.1	50.0	5.0	0.9	51.1	5.1	0.1
Ca	24.75	2.5	126.0	12.6	10.1	124.7	12.5	10.0
Mg	1.75	0.18	4.5	0.45	0.27	4.0	0.4	0.22

Methylene Blue and Congo Red Removal by Compost

The data for Methylene Blue is given in the data for Chapter 5.

Initial concentration of Congo Red (mg/l)	Sample	Final concentration of Congo red in sample (mg/l)	Congo Red removed (mg/l)	Congo Red removed (mg/g of compost)
94	1	34	62	6.2
	2	38	56	5.6
465	1	368	97	9.7
	2	380	85	8.5
905	1	765	140	14.0
	2	730	175	17.5
1980	1	1805	175	17.5
	2	1795	185	18.5

Removal of Dichromate Ions by Compost

Initial concentration of Dichromate Ions (mg/l)	Sample	Final concentration of Dichromate Ions in sample (mg/l)	Dichromate Ions removed (mg/l)	Dichromate Ions removed (mg/g of compost)
1900	1	1895	5	0.5
	2	1895	5	0.5
972	1	962	11	1.1
	2	954	18	1.8
506	1	496	10	1.0
	2	476	30	3.0
204	1	195	9	0.9
	2	196	8	0.9
88	1	80	8	0.8
	2	80	8	0.8

Effect of sodium on copper removal by compost

Initial concentration of copper = 433 mg/l

Amount of Sodium added (g)	Sample 1			Sample 2		
	mg/l in extract	mg/g in compost	% copper removed	mg/l in extract	mg/g in compost	% copper removed
0	235	198	45.6	243	190	43.9
0.10	250	183	42.3	272	161	37.2
0.25	267	166	38.3	278	155	35.8
0.50	265	168	38.8	290	143	33.0
0.75	250	183	42.3	269	164	37.9
1.0	265	168	38.8	277	156	36.0
2.5	277	156	36.0	298	135	31.2
5.0	279	154	35.6	293	140	32.3

Removal of methylene Blue by Compost After leaching with reagents

Initial concentration of Methylene Blue = 675 mg/l

Data only available for single samples. The data is the average of three measurments.

Leaching Reagent	mg/l in extract	mg/l removed	% methylene Blue removed
None	52	623	92.3
HNO_3	550	125	18.5
HCl	560	115	17.0
H_2SO_4	270	405	60.0
H_3PO_4	530	145	21.0
Acetic Acid	179	496	73.5
$CaCl_2$	56	619	91.6
NaOH	100	575	85.2

Removal of Lead by Compost After leaching with reagents

Initial concentration of Lead = 312.5 mg/l for None, HNO_3, HCl and H_2SO_4

Initial concentration of Lead = 304.0 mg/l for H_3PO_4, Acetic Acid, $CaCl_2$ and NaOH

Data only available for single samples. The data is the average of three measurments.

Leaching Reagent	mg/l in extract	mg/l removed	% methylene Blue removed
None	310.9	31.1	99
HNO_3	215.5	21.6	69
HCl	38	3.8	12
H_2SO_4	305.6	30.6	98
H_3PO_4	153.5	15.4	50
Acetic Acid	276.5	27.7	91
$CaCl_2$	282	28.2	93
NaOH	181.5	18.2	60

Lead Removal by Compost and "Ash"

Initial concentration of Lead (mg/l)	Sample	Final concentration of Lead in sample (mg/l)	Lead removed (mg/l)	Lead removed (mg/g of compost)	% Lead Removed
840	Compost 1	320	520	52	62
	Compost 2	350	490	49	58
	Ash 1	80	760	76	90
	Ash 2	70	770	77	92
3600	Compost 1	3100	500	50	14
	Compost 2	3100	500	50	14
	Ash 1	2850	750	75	21
	Ash 2	2750	850	85	24

Methylene Blue Removal by Compost and "Ash"

Initial concentration of Methylene Blue (mg/l)	Sample	Final concentration of Methylene Blue in sample (mg/l)	Methylene Blue removed (mg/l)	Methyelene Blue removed (mg/g of compost)	% Methylene Blue Removed
96	Compost 1	1	95	9.5	99
	Compost 2	1	95	9.5	99
	Ash 1	37	59	5.9	61
	Ash 2	40	56	5.6	58
980	Compost 1	50	930	93	95
	Compost 2	70	910	91	93
	Ash 1	350	630	63	64
	Ash 2	310	670	67	68
2990	Compost 1	1590	1400	140	47
	Compost 2	1440	1550	155	52
	Ash 1	1390	1600	160	53
	Ash 2	1340	1650	165	55