A STUDY OF

THE QUALITY OF

WASTE DERIVED COMPOST

IN IRELAND

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Abstract

Analysis of fifty-nine compost quality test results received from twelve composting facilities throughout Ireland, was carried out to determine the overall quality of Irish compost, to compare its quality with compost from other European countries and to use statistical analysis to see if there were any significant correlations between heavy metals in compost. The quality of the compost samples produced from biowaste, green waste, commercial organics and sludge was then compared and classified according to statutory limits for compost quality parameters, stipulated by the Environment Protection Agency and the forthcoming EU Biowaste Directive. The main parameters analysed included the concentration of heavy metals and nutrients and the presence of foreign matter, salmonella and faecal coliforms.

Approximately fifty percent of the biowaste compost samples were classified either as Class I or Class II compost according to the EU standard and in general contained lower amounts of heavy metals when compared to other EU countries. However, high levels of impurities and gravel and stones resulted in a significant amount of samples being classified as stabilised biowaste or as non-conforming to the minimum requirements of proposed Biowaste Directive. Significant correlations were also found between some heavy metals in the biowaste compost, which suggest that single laboratory tests of strongly correlated metals could be carried out in the future. Sanitation requirements were met for nearly all the samples analysed. The biowaste compost contained sufficient amounts of nutrients and had good fertilising capabilities, whereas the green waste compost contained fewer nutrients. Some of the compost samples were also found to be immature which was attributed to a lack of space available at facilities to allow compost to fully mature.

The introduction of a national compost standard along with improved source segregation and processing of feedstock was recommended to ensure the quality of the product and to assist in the development of viable markets and outlets for compost in the future.

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1.0 INTRODUCTION

With increased environmental legislation, higher costs of landfilling (Price, 2001), growing amounts of biodegradable waste (MCOS 2003) and increasing environmental awareness amongst, local authorities, environmental groups and individual people, there is an imminent and growing need to find a cost effective and sustainable method of disposing and recycling of biodegradable waste. Composting is the biological degradation of organic material in the presence of oxygen to carbon dioxide, water and a humic-like end product (Cabrera et al., 1999), which serves as a natural, sustainable, safe and economical method of waste management (de Guardia et al., 2002). Currently the growing interest in composting across Europe reflects this (Favoino, 2000).

The main drivers for composting at a European and National level are the European Union Directive on the Landfill of Waste (99/31/EC) which came into effect in April 1999 and the proposed Directive on the Biological Treatment of Biodegradable Waste (Biowaste Directive) for which a 2nd draft of the working document was issued in February 2001.

1.1 THE EU LANDFILL DIRECTIVE (99/31/EC)

The main aims of the EU Landfill Directive (99/31/EC) are to reduce the amount of biodegradable waste sent to landfill and to decrease the amount of methane and carbon dioxide (greenhouse gases) from being emitted from landfills to the atmosphere. These greenhouse gases significantly contribute to global warming (Price, 2001). The Directive sets statutory targets within a specific time frame for reductions in the amount of biodegradable waste landfilled relative to a 1995 baseline (Table 1.1). All member states are required to fully implement the directive.

Table 1.1 EU Landfill Directive targets for reducing biodegradable waste sent to landfill

Percentage Reduction (With reference to 1995 levels)	Target Year
25%	2006
50%	2009
65%	2016

Source (Price, 2001).

1.2 THE EU BIOWASTE DIRECTIVE

The proposed EU Biowaste Directive aims to promote the biological treatment of biowaste and to help achieve the targets set by the EU Landfill Directive (99/31/EC). The most important provisions of the document is the need for member states to carry out compost quality testing on specified parameters and the need to establish separate collection schemes of biowaste in order to prevent the contamination of biowaste with other polluting wastes, materials and substances (Commission of the European Communities, 2001, DG ENV.A.2). Statutory limits for the presence of heavy metals, micro organic pollutants and foreign matter in compost have being devised. It grades compost and distinguishes it as Class I and Class II compost or stabilised biowaste, based on established critical limits.

1.3 IRISH WASTE MANAGEMENT POLICY

Irish policy on waste management outlined in the document “Changing Our Ways” of 1998 recognises the need to comply with EU legislation and has set out targets to reduce our reliance on landfill and also to reduce the amount of biodegradable waste being disposed of in this way (van der Verf et al., 2002). Within the regional waste management plans implemented in Ireland from 1998-1999, there are plans for developing more composting facilities in addition to the existing sixteen facilities currently in operation. Composting is therefore seen as having an important part to play within integrated waste management planning in order to achieve the targets of the EU Landfill Directive and to decrease Ireland’s over reliance on landfill in an environmentally sustainable manner.

1.4 COMPOSTING OF BIODEGRADABLE WASTE

Apart from its role in waste management, composting provides an opportunity of producing a very valuable end product which can be used in various market sectors. Compost has many benefits and can be used in market sectors such as agriculture or horticulture to improve soil physical and biological properties by acting as a soil conditioner, as a supply of nutrients and as a disease suppressant (Zheljazkov and Warman, 2003). Compost can also be used as a means of sequestering carbon in the soil (Eunomia, 2001).

However, there is concern regarding the presence of organic and inorganic contaminants, visual impurities and pathogens in compost. The main concern is the presence of toxic heavy metals in the compost (Pinamonti et al., 1997). Nevertheless, these can be controlled by ensuring a source-separated feedstock with little contamination and strict control over the composting process (Zheljazkov and Warman, 2003; Fricke and Vogtmann, 1992).

1.5 COMPOST QUALITY TESTING

Compost quality testing is necessary to determine the quality of the compost in order to protect the environment and humans from any harmful substances it may contain, to protect workers, to maintain the composting process and to verify compost attributes (Anon (a), 1998). Results of compost quality testing provide the basis for which recommendations can be made regarding suitable end uses for the product.

The three classes of compost; Class 1, Class II and stabilised biowaste designated by the EU Biowaste Directive are classified according to certain statutory limits for quality parameters which include heavy metals, impurities, gravel and stones and micro organic pollutants such as PCB's and PAH's, details of which are given in Annex III of the proposed Directive (see appendix 1). Micro-organic pollutants are not examined in this study, as facilities did not test for their presence in compost.

The Biowaste Directive also places restrictions on certain classes of compost. Class I compost can be used according to best agronomic practice without any restriction whereas, Class II compost if spread on agricultural land must not exceed 30 tonnes dry matter per hectare on a three-year average. Stabilised biowaste may only be used in land applications, which are not used for food or fodder crop production and is therefore most suitable for landfill restoration or as landfill cover (Commission of the European Communities, 2001, DG ENV.A.2).

Certain market sectors such as the horticultural sector require compost of high quality where there should be no possibility of compost posing threats to plant growth or entering the food chain. The quality of compost is mainly determined by the type and composition of input material and the biological process (Fricke and Vogtmann, 1992, US EPA, 1994).

Currently the cost of compost quality testing deters some facility operators from testing the product. However the EPA require that all composting facilities composting over 5,000 tonnes per annum must have a waste licence and carry out quality testing according to the specifications within the waste license. Quality testing must be carried out on parameters such as heavy metals, maturity, foreign matter and pathogens which are similar to those parameters identified in Annex III of the proposed EU Biowaste Directive.

1.6 COMPOST STANDARDS

Investigations carried out in Europe show that quality and marketing of compost are the most crucial issues facing the composting industry (Barth 2003). Compost standards ensure the quality of the compost destined for the marketplace. There are two types of standards: statutory standards and market driven standards. Statutory standards focus more on environmental protection and implement the ‘precautionary principle’. Market driven standards are not usually legalised, they are voluntary standards, which relate to the attributes of the compost, which are required by a certain sector of the compost market. Compost standards exist in European countries which have well-developed composting systems such as Austria, Germany, Belgium, the Netherlands, Luxembourg and Flanders (Hogg et al., 2002).

There are no compost standards in Ireland at the moment. Waste licences are the main mechanism for controlling composting in Ireland (WRAP, 2002). The quality of compost produced and the need for the introduction of a national compost standard are the most pressing issues facing the composting industry at the moment. The quality of Irish compost needs to be guaranteed so that markets can be developed and that compost can be marketed as a quality product instead of a waste derived product. The introduction of a compost standard will also instil confidence in the segments of the market for which it is destined (Cré - Composting Association of Ireland Teo, 2003).

1.7 AIMS AND OBJECTIVES

The main aims of the research are:

- To collate available data on compost quality currently produced at composting facilities in Ireland.

- To compare the quality of compost to quality specifications stipulated in the EU Biowaste Directive and EPA stipulations for heavy metal content of compost.
- To compare the quality of compost produced in Ireland to compost from other countries.
- To use statistical analysis to see if there are any correlations between heavy metals in the compost.
- To examine the nutrient content of compost and other quality parameters and attempt to link this to its suitability for use in certain sectors such as agriculture and horticulture.
- To compare quality of compost produced from different feedstock.

The objectives of the study is to collect information which will be useful in providing:

- A benchmark against which Irish site operators can compare their results.
- A reference enabling Irish compost quality to be compared to compost from other countries.
- Confidence building measures in the use of compost in sectors such as agriculture and horticulture.
- Solid data, which can be used by Cré Teo to draw up compost quality standards for Ireland.
- Information on any significant correlations between the occurrences of heavy metals in the compost which may reduce the amount of testing required and in turn decrease the cost of compost quality testing.
- Baseline information that would be useful to Teagasc and the Department of Agriculture in deciding the typical nutrient content and guidelines for agricultural use of the compost and in preparation of a Code of Good Agricultural Practice.

2.0 LITERATURE REVIEW

2.1 LOCATION OF COMPOSTING FACILITIES IN IRELAND

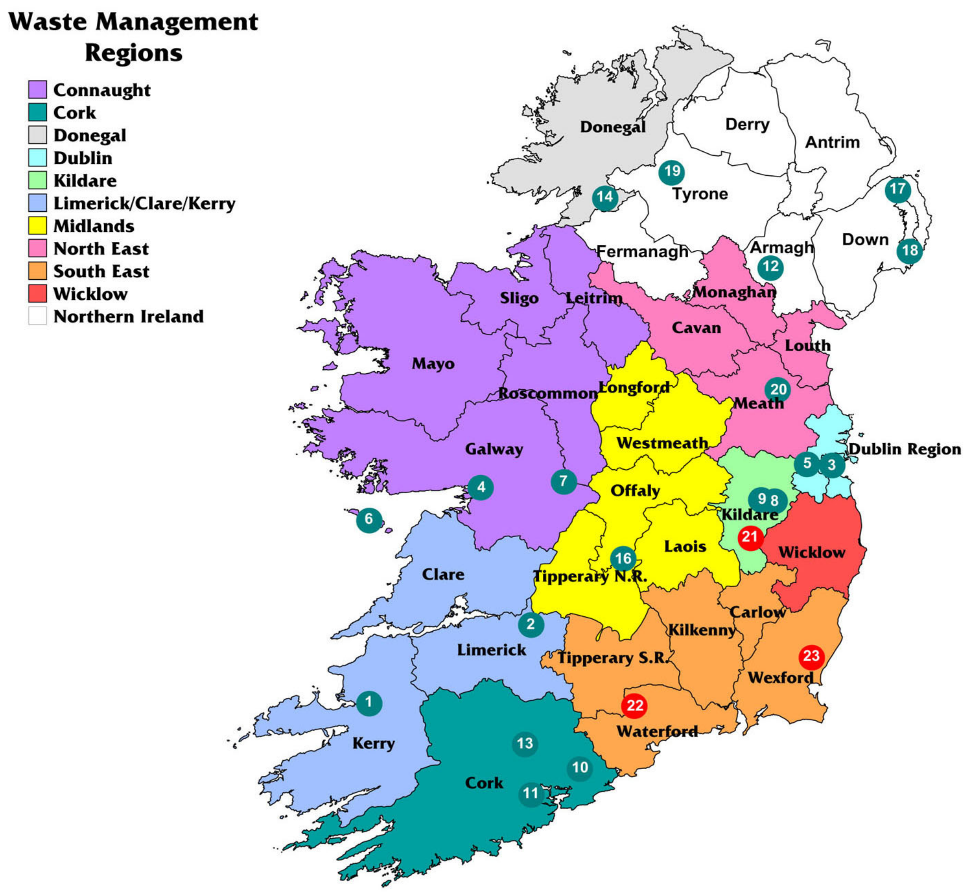
There are currently sixteen composting facilities in operation in the Republic of Ireland (Fig 2.1). Some of these are managed by local authorities through their own activities or through the use of contracted waste processors. Others are managed directly by private waste disposal companies.

2.2 REVIEW OF COMPOSTING FACILITIES

From the map in figure 2.1, it is clear that there is a wide range of composting facilities utilising different feedstock, employing different types of composting technology and with different composting capacities.

2.2.1 Origins Of Feedstock

Materials most commonly composted were found to be biowaste, green waste, commercial organics and sludge. Most biowaste received at composting facilities in Ireland is source segregated household waste. Green waste is usually supplied to composting facilities by local corporation park departments, landscape contractors, waste disposal contractors and the general public. Commercial organic feedstock is collected from food manufacturers, supermarkets and restaurants for composting. The feedstock for sludge composting consists of industrial sludge collected from industry. Sludge arising from municipal wastewater treatment plants is also composted in Ireland, however because no quality test results were available it is not examined in this study. Some composting facilities in Ireland also collect organic material from commercial food manufacturers, supermarkets and restaurants for composting.



ID	FACILITY	CAPACITY_ta	FEEDSTOCK	TECHNOLOGY	CONTACT	ORGANISATION
1	Tralee Composting Site	3,000	Household Organics	Windrow	Environment Section	Kerry County Council
2	Limerick Composting Site	2,000	Household Organics	In-vessel and Windrow	Mr. Martin Sheehan Jnr.	Mr. Binman Ltd.
3	St. Anne's Park Composting Facility	20,000	Green Waste	Windrow	Michael Harvard	Dublin City Council
4	Sandy Road Waste Recovery Facility	5,000	Household Organics	Aerated Pile (VAR System)	Gary O' Loughlin	Galway City Council
5	Lucan Green Waste Composting	5,000	Green Waste	Windrow	Niall Harrington	South Dublin City Council
6	Aran ISlands Recycling Scheme	500	Household Organics	In-vessel (Biosal Unit)	Olwen Gill	Timpeallacht Na NOileáinn
7	Ballinasloe Composting Site	4,000	Household Organics	In-vessel and Aerated Pile (Celtic Composting)	Aengus Breathnach	Galway County Council
8	Silliot Hill, Kildare	5,200	Commercial and Green Waste	VCU In-vessel	Damian Lawlor	Greenstar
9	Kildare Sludge Plant	5,200	Municipal Sludge	TEG In-vessel	Pat White	Jones Environmental
10	CTO Middleton	3,000	Commercial Organics	Windrow	Aidan Stafford	CTO Environmental Solutions Ltd.
11	Kinsale Road Facility	2,000	Green Waste	Windrow	Liam Dromey	Cork City Council
12	Keady Composting Facility	65,000	Organic and Green Waste	Enclosed Aerated and Windrows	Caolan Woods	Natural World Products Recycling
13	McGill Facility	10,000	Commercial Sludges	Enclosed Aerated	Ronan Beasley	McGill Environmental Systems (Irl.) Ltd.
14	Enviro Grind Ltd.	3,000	Green Waste	Windrow	Martin Eves	Enviro Grind Ltd.
16	Shannon Vermicomposting	1,000	Household Organics/Municipal Sludge	Windrow	Peter Ogg	Shannon Vermicomposting
17	Robert Delaney	10,000	Green Waste	Windrow	Robert Delaney	Robert Delaney
18	Down District Council Composting Site	1,800	Household Organics	Windrow	Laurence McQuaid	Down District Council
19	SimproIreland Ltd.	4,000	Green Waste	Windrow	David McElrea	SimproIreland Ltd.
20	Organic Gold	3,000	Municipal Sludge, Cattle Manure	Windrow	John Finnegan	Organic Gold Marketing Ltd.

Fig 2.1 Location and Details of Composting Facilities in Ireland

2.2.2 Composting Technology Employed In Ireland

Windrows remain the most preferred form of composting technology used in Ireland followed by in-vessel and aerated systems (Fig 2.2, see also appendix 2). This is due to a low initial capital investment, low maintenance costs and also because windrows are suitable and are commonly used in the composting of green waste due to its homogenous nature (Brinton and Brinton, 1992). Some facilities also use a mixture of composting technologies deepening on what feedstock they compost.

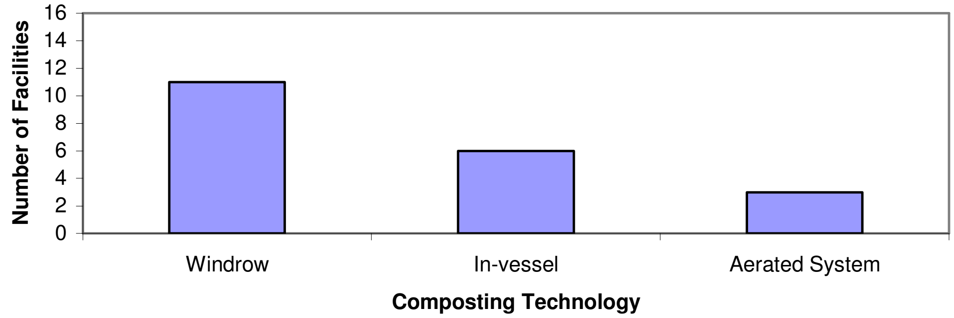


Fig 2.2 Graph showing the number of facilities employing different composting technologies.

2.2.3 Available Capacity And Actual Quantity Of Materials Composted In Ireland

The total available capacity for composting of material in Ireland at present is 71,100 tonnes per annum, while the actual quantity of material composted annually was found to be approximately 61,950 tonnes per annum. Figure 2.3 shows the available capacity and the actual quantity of the various feedstock composted annually.

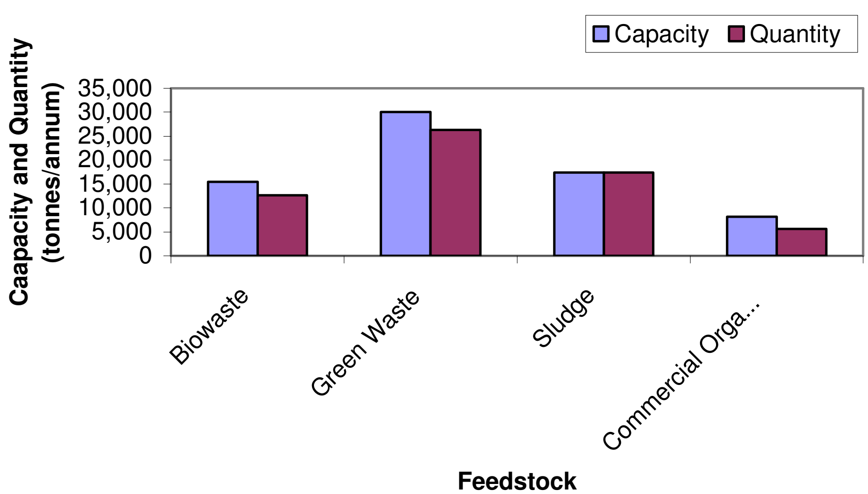


Fig 2.3 Graph of the quantity of different feedstock composted in Ireland against actual available capacity (tonnes/annum).

2.3 PROCESSING FACTORS GOVERNING COMPOST QUALITY

Many factors have an influence on the quality of the compost produced, which include the type of feedstock utilised, the degree of source separation, the amount of pre-processing and post-processing the biological process and the technology employed and finally the maturation stage (Richard, 1992).

2.3.1 Type Of Feedstock Utilised

The type of feedstock used in the composting process, whether it is green waste, biowaste, commercial organics or sludge tends to have an effect on the quality of compost produced. Some feedstocks contain significant amounts of foreign material and contaminants such as heavy metals and are not suitable for composting (Brinton and Brinton, 1992) while others with less contaminants are more suitable for aerobic composting. Green waste has good structure and low to medium moisture content which is suitable for composting, whereas other materials such as biowaste may need to be mixed and bulking agents added to ensure sufficient porosity and moisture content of the feedstock. Otherwise, the composting process will not proceed efficiently, which could have an effect on the quality of the compost produced due to anaerobic conditions occurring (Kepp et al., 2000; Canet and Pomares, 1994).

2.3.1.1 Green Waste

Green wastes are homogenous in nature and contain less nutrients, contaminants and heavy metals compared to other feedstock. Green waste feedstock can therefore produce good quality compost with little contamination. Composted green wastes are not rich in nutrients, which limit their use as fertiliser. However, this lack of nutrients permits compost to be beneficially used in horticulture for the potting of young plants or as mulch (US EPA, 1994).

2.3.1.2 Biowaste

Biowaste consists of the source separated portion of organics from household waste. It has been estimated that biowaste constitutes between 35-40% of municipal waste (Eunomia, 2001). Burnley et al. (1999) carried out research into the composition and biodegradability of municipal waste, which is outlined in table 2.1. He found that biowaste made up 62.2% of the total municipal waste stream. Kepp et al. (2000) studied the composition of biowaste in Holland, which showed variations in the composition for different months. The green waste fraction increased in August due to the collection of more green leaves during summer time. Various studies have shown that source separated biowaste also contains less contaminants in comparison to mixed municipal solid waste (Favoino, 2000; Brinton and Brinton, 1992).

Table 2.1 Compositions and Biodegradability of Municipal Waste

Category	Composition (% by mass)	Biodegradability (%)
Paper and card	32	100
Putrescible material (kitchen and garden waste)	21	100
Textiles	2	50
Fines (particles smaller than 5mm)	7	60
Miscellaneous combustible material	8	50
Miscellaneous non-combustible material	2	0
Ferrous metal	6	0
Non-ferrous metal	2	0
Glass	9	0
Dense plastics	6	0
Film plastics	5	0
Total	100	62.2

Source: (Burnley et al. 1999)

2.3.1.3 Sludge

Sludge, especially industrial sludge, may contain potentially high concentrations of heavy metals and organic micro-pollutants (Lazzari et al., 2000). Sludge has been found to also contain large amounts of pathogens which need to be fully destroyed in the composting process to protect human health (Hoyos et al., 2002).

2.3.2 Source Segregation

Segregation of biowaste at source can help to reduce the amount of contaminants such as plastic, glass and heavy metals in the feedstock material and hence produce a finished compost product of high quality. A doctoral thesis undertaken in Germany into quality of compost from different source materials showed that source separated biowaste compost contained on average a quarter of the heavy metal content of mixed MSW composts (Brinton and Brinton, 1992). Oosthnoek and Smit (1987) also looked at the effect that different separation and pre-processing techniques had on the concentration of heavy metals in the finished product. They found that heavy metal concentrations were lowest in compost samples that had undergone the highest degree of source segregation (Table 2.2). The proposed EU Biowaste Directive has acknowledged the effect source segregation can have on the quality of compost produced and thus one of the most important provisions of the directive is the need for member states to establish separate collection schemes of biowaste. However, even after source segregation, some contaminants will remain in the feedstock and ultimately in the compost due to their ubiquitous nature in the environment (Brinton and Brinton, 1992).

Table 2.2 Effects of different segregation and pre-processing techniques on the concentration of heavy metals in compost

Processing method (mg/kg, dry weight)

Metal	A	B	C	D
Zinc	1,700	800	520	230
Copper	600	270	100	50
Chromium	180	70	40	30
Nickel	110			
Cadmium	7	2.5	1.8	1.0

A. Mixed household waste was composted without preparation. The process took approximately 12 months. After composting, the product was screened and inerts were removed.

B. The collected household waste was separated into two fractions. The process took between two and-a-half and five months for the composting process to be completed.

C. The collected waste was shredded, and then processed, resulting in a fraction to be composted. This fraction was free of most inerts, such as glass and plastics.

D. Wastes were separated at the source. The organic components were collected separately at households. All necessary steps were taken to insure that components containing heavy metals did not enter the organic components.

Source: Oosthnoek and Smit, 1987

2.3.3 Seasonal Variations In Feedstock

Research in Germany also found that the concentration of heavy metals in compost was highest during the winter months, especially December and January. They found that this was often attributable to Christmas wrapping paper and tree decorations found in the waste feedstock. This extra paper may result in a high C:N ratio of the feedstock (Brinton and Brinton, 1992). In the summer season with increased grass trimmings the C:N ratio of the feedstock may decrease. Hence, seasonal variations in the feedstock are an important factor for facility operators to consider and that adjustments are made to the composting process accordingly (The Composting Council of Canada (b), 2000). Identifying seasonal variations in feedstock or in the final composted material is beyond the scope of this study.

2.3.4 Pre-processing And Post-Processing Methods

Pre-processing and post-processing of feedstock may have a significant impact on the quality of the compost produced and the speed at which the process proceeds (US EPA, 1994). Pre-processing usually involves sorting feedstock material, reducing particle size and homogenisation and a variety of feedstock treatments prior to initiating the biological process.

Incoming feedstock material should be sorted and non-compostable material such as plastics, glass and metals removed to reduce or eliminate their presence in the finished product. The amount of sorting depends on the feedstock, the quality of the compost required and the technology involved. Biowaste may require more sorting due to a greater risk of a contaminated feedstock compared to green waste (Richard, 1992). Screens, manual separation, magnetic based separation, eddy current separators, air classifiers, wet separation techniques and ballistic separators can all be used to separate out non-compostables from the feedstock. Separation and size reduction technologies are outlined in appendix 3.

After separation, the particle size of the material may be reduced to increase the surface area to volume ratio of the feedstock. This will increase the surface area on which micro-organisms can act which will in turn, increase the rate of decomposition, facilitate effective mixing and produce a more uniform product (The Composting Council of Canada (a), 2000). However, a balance must be achieved between reducing particle size and maintaining oxygen distribution to maximise the efficiency of the composting process (Richard, 1991).

Feedstock treatments may include mixing of the feedstock or the addition of bulking agents to feedstock such as biowaste as discussed in section 2.3.1.

Post-processing is optional and is usually carried out to increase the quality of the compost as specified by the end-users or by market requirements. Post-processing may involve the compost undergoing further screening to remove any foreign material and size reduction to produce a compost of uniform size. At this stage, testing may also be carried out to check for the quality of the compost (EPA, 1994) and will be discussed in detail further on.

2.3.5 Biological Processing

Once feedstock has undergone pre-processing it is then ready to begin biological processing using a variety of composting technologies. The choice of technology chosen depends on the feedstock, capital and land availability, the desired speed of the process and odour and leachate requirements. The quality of the end product required is also an important factor to consider.

On comparing composting technologies aerated static piles offer more control over the composting process than windrows, while in-vessel systems provide a composting process, which is easier to control and regulate than an aerated static pile system. Richard (1992) argues that it is nearly impossible to evaluate a composting system based on the fact that systems designs are almost always unique with evolving technologies and modifications to meet certain requirements. He states that it is the pre-processing methods of segregation, size reduction and homogenisation and mixing that have the biggest influence on the quality of the compost produced.

The key parameters which are important to consider during the process are: the C:N ratio, moisture content, oxygen availability and temperature (de Guardia et al., 2002). The recommended C:N ratio of feedstock has been reported to be 25:1 to 40:1 (Richard, 1992) but this varies depending on the substrate (Tuomela et al., 2000). Adequate moisture is essential for microbial activity and as a source of oxygen supply. If moisture levels are too low microbial activity will decrease. On the other hand, too much moisture can lead to a lack of aeration and leaching of nutrients with anaerobic conditions occurring. Richard (1992) recommends a minimum moisture content of around 50 to 55% for composting of biowaste. Oxygen and temperature both work together in the composting process, in that, both fluctuate in response to microbial activity, which decreases oxygen availability and increases temperature. Oxygen concentrations of compost heaps must be at least 16-17% (Richard, 1992). The proposed EU Biowaste Directive specifies a temperature of $\geq$55°C for two weeks or $\geq$65°C for one week if windrow composting is employed. During in-vessel composting the temperature should be $\geq$60°C to ensure that sanitary compost is produced at the end of the process (Commission of the European Communities, 2001, DG ENV.A.2).

At the end of the biological stage stable compost should be produced which refers to the state of organic matter decomposition. A stable product is important so that nitrogen immobilisation does not occur in the soil and that a consistent volume and porosity of the compost is maintained (US Composting Council, 2003).

2.3.6 The Maturation Stage

Once all the material has been composted and is stable it should be allowed to mature. During the maturation stage, remaining micro-organisms utilise available nutrients and microbial activity diminishes as nutrients are depleted (Biey et al., 2000). The maturation stage is relatively long taking between 3 and 6 months. As a result, it can demand a large storage area, which can be problematic for facility operators. It is important to maintain aerobic conditions during maturation to avoid problematic anaerobic odours being produced and to maximise the maturation rate. Facility operators who stack piles of compost too high (greater than 5m) during the maturation stage to minimise the amount of space required, limit the amount of oxygen circulating at the bottom of the pile. If this happens there is a risk of anaerobic conditions occurring and bad smells being given off (Cabanas-Vargas and Stentiford, 2003). Fully mature compost should have an unpleasant smell and a C:N ratio less than 20 (Biey et al., 2000).

2.3.7 Storage

Storage practices can have an effect on compost quality. The most common storage problem is inadequate drainage, which may result in the compost becoming overly saturated (EPA, 1994). Rynk et al., (1992) states that if piles of compost are not kept dry and aerated, anaerobic conditions may occur which could result in odours been given off and the formation of harmful anaerobic by-products.

2.4 EVALUATING COMPOST QUALITY IN RELATION TO PHYSICAL, CHEMICAL AND BIOLOGICAL ATTRIBUTES OF THE COMPOST.

Various parameters, which may have a significant influence on compost quality, are discussed below.

2.4.1 pH

The pH value of compost is important, since applying compost to soil may alter the soil pH and therefore have an effect on the availability of nutrients to plants. Bord na Mona (2003) recommends a range of pH from 6.9-8.3. Efforts will need to be made to lower the pH of compost if it exceeds this range. Lowering the pH will also help reduce ammonia volatilisation and reduce odours (Woods End Research Laboratory, 1998).

2.4.2 Organic Matter

Organic matter is an important ingredient in all soils and has an important role to play in maintaining soil structure, nutrient availability and water holding capacity. It is usually expressed as a percentage of dry weight. There is no absolute value of organic matter, which is ideal for compost. It may range from 30-70% (US Composting Council, 2003). Under the EPA waste-licencing system it is required that compost contain at least 30% organic matter on a dry weight basis.

2.4.3 Moisture Content

Moisture content is a measure of the amount of moisture present in a compost sample and is expressed as a percentage of fresh weight. Compost with low moisture content (<35%) may be too dry and dusty and irritating when handled. Compost with too high a moisture content (>65%) can become too clumpy and difficult too transport which will limit its chances of being marketed as a quality product (US Composting Council, 2003). Consumers will not want to pay for a product with high water content. Biotreat (2003) recommend a moisture range of 45-65%, fresh weight.

2.4.4 Bulk Density

The bulk density of compost is defined as its weight per unit volume and must be maintained within an optimal range, as this is critical in achieving the required water content and to maintain the temperature of the composting process (British Columbia Ministry for Agriculture and Food, 1996). Bord na Mona measures the dry bulk density of compost after drying the sample at 105°C for twelve hours and recommends a range of 120-369 g/L.

2.4.5 Conductivity

Conductivity is the measure of a solutions ability to carry electrical charge, that is, a measure of the soluble salt content of compost. The salt content of compost is due to the presence of sodium, chloride, potassium, nitrate, sulphate and ammonia salts (Brinton, 2003). Some soluble salts may be detrimental to plants whereas, other plant nutrients supplied to plants exist in salt form and are essential for plant growth. Usually compost does not contain quantities of soluble salts which cause concern in landscape applications. Though excessive amounts of soluble salts in compost used in growing media or applied to the land may inhibit crop growth and affect crop yield (Barker, 1997). Bord na Mona (2003) report that the recommended range for conductivity in compost is between 2,000-6,000 µS/cm.

2.4.6 C:N Ratio

The C:N ratio is not a test within itself, it is rather a test for organically bound carbon and for total nitrogen. The ratio of these two can be used to provide an indication of the rate of decomposition of the feedstock and to determine when ripeness has been reached (Anon, 1998). Therefore, C:N ratios should be used in conjunction with some other relevant parameter for testing compost maturity (Wood End Research Laboratory, 1998). The EPA acknowledges this and specifies within a waste licence that the C:N ratio of compost must be below 25.

2.4.7 Nutrient Content Of Compost

Compost contains macro and micronutrients, which are required for plant growth (Zethner et al., 2000). Nitrogen, phosphorous and potassium are the nutrients, which are utilised, in the greatest quantities by plants. Knowledge of the nutrient content of compost is important because the nutrient content of compost can vary widely and also because it allows facility operators to determine an appropriate end use for the compost. The agricultural market demands compost of high nutrient content, whereas compost low in nutrients is well suited for the landscaping sector and for use as mulch (Zethner et al., 2000). In general, nutrients are organically bound within compost and are slowly released over a period of time as a result of microbial activity. This ensures a continuous supply of nutrients to the plant (US Composting Council, 2003). Total nutrient content is usually expressed as a percentage on a dry weight basis. Available plant nutrients are expressed as mg/L on a fresh weight basis. In order words, available nutrient content is measured as the sampled is received (Bord na Mona, 2003). Calcium and magnesium are also usually tested for.

2.4.7.1 Nitrogen

Nitrogen is an essential nutrient for successful plant production. The concentration and availability of nitrogen in compost is a very important factor to be assessed when considering its agronomic value. Knowledge of the concentration of nitrogen in compost is also important due to concern of groundwater pollution from excess NO_3-N (Iglesias- Jiménez, 2001).

Typically more than 90% of nitrogen in compost is organically bound and the most available form to plants is when nitrogen is converted into an inorganic form and exists as NO_3-N (Fricke and Vogtmann, 1994). The amount of total nitrogen and plant available nitrogen depends on the composition of the waste material and the composting process. Körner and Stegmann (2003) state that certain parameters such as pH, temperature and moisture significantly influence the rate of nitrogen turnover from proteins in biowaste to inorganic and organic forms. They found that the highest concentration of ammonia could be measured during the thermophilic stage while mature compost contains more nitrogen in the inorganic form as NO_3-N. Hence, by regulating the composting process, compost with a more predictable nitrate content can be produced.

2.4.7.2 Total Nitrogen (TN)

To report compost as having fertilising capabilities and for it to be used in agriculture the TN content must be over 1%, dry wt (Barker, 1997). If compost contains TN of less than 1%, supplemental nitrogen fertiliser will be required if the compost is to be used as a soil improver or in potting media. If the TN in compost is approximately 0.6% or less there is a chance that nitrogen immobilisation will occur (Fig 2.4). Thus, compost with low TN levels is better used as mulch (Barker, 1997). The typical range of TN in compost is 1.0-3.0%, dry wt. Compost over 3% TN is usually found to be immature and ammoniacal (Barker, 1997).

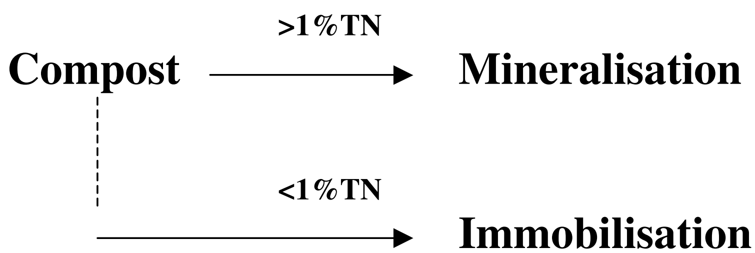


Fig 2.4. Mineralisation – Immobilisation turnover in relation to TN in compost
Source: Barker, 1997

2.4.7.3 Available Nitrogen as NO_3-N

This is the form of nitrogen which is most available to plants. Bord na Mona (2003) recommends a limit of 240 mg/L of NO_3-N for compost, as values over this are unnecessarily high and perhaps even excessive for all crops. Environment Agency (2000) state that compost to be used in horticulture or agriculture is deficient in NO_3-N if it contains less than 15 mg/L. Below is the UK Environment Agency's interpretation of concentrations of available NO_3-N in compost when used in growing media. (Table 2.3).

Table 2.3 Interpretation of available Nitrogen as NO_3-N in compost

NO_3-N (mg/L)	Interpretation
0-15	Deficient
16-25	Low
26-50	Satisfactory for seedling and nursery stock
51-80	Satisfactory for pot plants and bedding plants
81-130	Satisfactory for tomatoes, cucumbers and carnations
131-200	
201-300	Unnecessarily high for all crops
Over 300	Excessive

Source: Environment Agency, 2000

2.4.7.4 Available Nitrogen as NH_4-N

Highest concentrations of NH_4-N are produced in the first few weeks of composting. In fact, the ratio of organic and inorganic forms of nitrogen has been used as a maturity index. At the end of the process a concentration of NO_3-N greater than the concentration of NH_4-N would indicate that the process took place under adequate conditions of aeration and that mature compost was produced (Sánchez-Monederoet al., 2001).

Levels of NH_4-N over 200 mg/L in compost are very high for use in growing media as high concentrations of. NH_4-N in compost may impede seed germination and damage seedlings and soil fauna (Environment Agency, 2000, Barker 1997). Levels of 0-20 mg/L are considered as low to normal for use in growing media. The UK Environment Agency's interpretation of NH_4-N concentration in compost is given in Table 2.4.

Table 2.4 Interpretation of available Nitrogen as NH_4-N in compost

NH_4-N (mg/L)	Interpretation
0-20	Low, normal for composts in use
21-50	Normal
51-100	Normal values for unused composts
101-150	Normal values for unused, high nutrient composts
151-200	High may harm young plants
Over 200	Very high

Source: Environment Agency, 2000

2.4.7.5 Phosphorous

Phosphorous is also an important nutrient for plant growth. Total phosphorous (TP) is usually expressed in terms of percentage concentration per dry weight. Available phosphorus is usually expressed as PO_4-P in mg/L on a fresh weight basis (Bord na Mona, 2003). According to Bord na Mona (2003) the range of TP is usually between 0.4 - 1.1%, dry wt for biowaste and green waste compost and the typical range of PO_4-P is between 50-120 mg/L, fresh wt.

2.4.7.6 Potassium

Potassium is a very abundant nutrient in plants. Potassium in its available form in compost exists as K_2O. The amount of potassium in compost depends on the feedstock but also on the composting process (Barker, 1997). Compost usually does not contain a great concentration of potassium because due to its high water solubility it can be easily leached from the feedstock during the composting process. This may occur especially in uncovered windrows (Fricke and Vogymann, 1994). Bord na Mona (2003) state that the typical range of total potassium (TP) in biowaste and green waste compost is between 0.6-1.7%, dry wt and that the typical range of available potassium in this compost is between 620-2280 mg/L, fresh wt.

2.4.7.7 Calcium and Magnesium

Calcium and magnesium act as bases when they exist as oxides, hydroxides and carbonates. Compost containing these bases, when applied to soil, may counteract soil acidification and vary pH levels making soil nutrients more available to plants (Fricke and Vogtmann, 1992). Compost can also be used to replace peat and be of much benefit in container production of crops, as peat does not contain adequate calcium. The typical range of calcium in compost is between 1.0-4.0%, dry wt and the typical range of magnesium is 0.2-0.4%, dry wt.

2.4.8 Heavy Metals

Depending on the feedstock, heavy metals (copper, zinc, lead, cadmium, mercury, nickel, chromium) and toxic elements (selenium, arsenic, molybdenum) may be found at elevated levels in compost and thus create an environmental concern essentially related to crop quality and human health (Zheljazkov and Warman, 2003; Hassen et al., 2001). As the composting process proceeds organic matter content decreases while the concentration of heavy metals remains the same (except for water soluble metals) thus increasing their concentration in compost. As of yet, there is no consensus amongst researchers regarding the exact uptake of heavy metals by plants, the accumulation of heavy metals in soils and the consequences once they enter the food chain. However, it would appear that metal uptake depends on the soil type, the plant species and the quality of the compost applied to the soil (Eunomia, 2001). This concern has lead to the establishment of statutory limits for heavy metal concentrations in compost by the EPA and EU Biowaste Directive which are given in Annex III of the Directive (see appendix 1). The concentration of these metals in compost is reported in mg/Kg on a dry weight basis by laboratories in Ireland. The EU Biowaste Directive stipulates that heavy metal concentrations must be reported in mg/Kg normalised to an organic matter of 30% because approximately 30% of organic matter in the feedstock is lost during the composting process concentrating the amount of heavy metals in the compost (Rogalski et al., 2002).

2.4.9 Maturity

Maturity is a measure of the degree of completeness of the composting process. Maturity cannot be described by one single property, instead maturity is described by examining two or more compost characteristics (US Composting Council, 2003).

It is important that compost is allow to fully mature so that it can be bagged and sold to the horticultural market. Immature compost will reheat and spoil if it stored for a period of time. Immature composts with high C:N ratios can also cause damage to plants when used in horticulture by tying up available nutrients in the soil (Biey et al., 2000) and by depriving plants of oxygen as shown in Figure 2.5 (Brinton, 2001). On the left side of the photograph are the roots of a plant from immature compost, beside it are plant roots from semi-mature compost and next to those are plant roots from mature compost. To the far right are the roots from the control plant. The damage done to the roots of the plants from the immature compost is quite evident.

Fig 2.5 Plant root damage due to reduced oxygen supply from application of uncured compost.
Source: Brinton, 2001

The damage was done to the roots because compost with too low a C:N ratio can cause phytotoxins to be released which can burn plant roots and thereby inhibit plant growth. It is also important to allow compost to mature due to the fact that, as compost matures over time, the solubility of heavy metals decreases with a subsequent decrease in bioavailability in the environment. The metals become bound to humic compounds, metal oxides and phosphates in the compost when mixed with soil (Chancy 1991).

Two maturity tests most used by Bord na Mona and Biotreat are the self heating test and the oxygen uptake rate test. The Cress tests may also be used to determine maturity.

2.4.9.1 Self Heating Test

The self heating test is one test which can be used to measure maturity of compost. The FCQAO (Federal Compost Quality Assurance Organisation) documents a system whereby composts are assigned an index value which range from I to V, based on levels of maturity, with level V being the most mature and level I the least mature. The EPA states that compost must not reheat upon standing too greater than 20^0C above ambient temperatures. That is, compost must have a maturity index value of V or IV.

Table 2.5 Table showing the classes of stability for the Self Heating Test

Max. Temp Rise Over Ambient	Class of Stability	Description of Stability	Self Heating Potential	Type
0-10^0 C	V	Mature to very mature compost	Very Low	Finished
10-20^0 C	IV	Curing compost	Low	Curing
20-30^0 C	III	Moderately active, immature	Medium	Active Compost
30-40^0 C	II	Very active, unstable compost	Med-High	Active Compost
40-50^0C	I	Fresh raw compost	High	Raw Feedstock

2.4.9.2 Oxygen Uptake Rate

Respiration can be used as an indicator of process performance and on product stability The Specific Oxygen Uptake Rate (SOUR) test measures the maximum rate of oxygen consumption in a water-compost suspension at 30°C. The proposed EU Biowaste Directive specify that the upper limit for oxygen uptake is 1000 mg O_2/kg volatile solids per hour The EPA however specify that the oxygen uptake rate must be less than 150 mg O_2/kg volatile solids per hour which has in practice been very difficult to achieve (McKinley, 2003).

2.4.9.3 Cress Germination Test

The Cress Germination test is recognised by the EPA as another method of determining compost maturity. The cress test is a test to measure percentage seed emergence and relative seedling vigour (US Composting Council, 2003). Under the requirements of a waste licence, germination of cress seeds in compost must be greater than 90% of the germination rate of the control sample.

2.4.10 Foreign Matter

2.4.10.1 Impurities

Impurities in compost consist of the presence of organic or inorganic material that is not readily biodegradable such as plastic, glass and metals. Some of these materials may not be of great concern when using compost in certain agricultural applications or as a landfill cover. However, their presence can decrease the value of the compost because they are of no benefit and are often aesthetically offensive (US Composting Council, 2003). Thus, impurities in noticeable concentrations may especially, inhibit the use of compost in horticulture and landscape gardening. The EU Biowaste Directive specifies a limit of 0.5%, dry wt of impurities greater than 2mm in compost.

2.4.10.2 Gravel and Stones

Gravel and stones not removed from the feedstock during the screening process will end up in the final product and again inhibit the use of compost in certain sectors as above. The EU Biowaste Directive has stipulated a limit of 5%, dry wt of gravel and stones greater than 5mm in compost.

2.4.11 Pathogens

Pathogens may be present in the feedstock in the form of enteric bacteria, viruses and parasites. (Eunomia, 2001). Pathogens may come from faecal material, sanitary tissues or food and / or may also be introduced during the composting process (Eunomia, 2001). The composting process must be adequately controlled to eliminate or reduce pathogens to a level that is below the threshold where the danger of transmitting disease may occur (US Composting Council, 2003). Test results are reported as most probable number (MPN) per gram of compost.

It is a requirement under the proposed EU Biowaste Directive to monitor for pathogens such as faecal coliforms and salmonella. The EU Directive specifies that the concentration of faecal coliforms must be below 1000 MPN/g and that there must be no salmonella present in 50g of total solids.

3.0 METHODOLOGY

3.1 COMPOST QUALITY DATA COLLECTION

The EPA requires facilities composting over 5,000 tonnes of material per annum to carry out compost quality testing. This is stipulated in a facilities' waste license. A letter was sent to facility managers of thirteen composting facilities, currently in operation throughout Ireland, advising them of the research, and requesting them to send the author results of any compost quality testing which they may have carried out on the final product from current and previous years. A satisfactory response rate of 92.3% was achieved. The author had to guarantee complete confidentiality to facility managers regarding all information obtained.

Most of the compost quality testing was carried out by Bord na Mona Laboratories in Kildare and Biotreat Laboratories based in Cork. The main quality parameters analysed were the concentration of heavy metals, total nutrient and available nutrient content, C:N ratios, moisture content, pH, conductivity, dry bulk density, self heating test and oxygen uptake rate test for determining maturity, foreign matter and the presence of faecal coliforms and salmonella.

Data on compost quality was also sought from other countries so that a comparison of Irish compost quality and that of other countries could be made. Published data on compost quality for Austria, Australia and Germany was sited. Raw data on compost quality was obtained from the UK Composting Association.

3.2 ANALYSIS OF DATA

In total, 59 samples of compost quality test results were collected. Test results were received for 32 samples of biowaste compost originating from six composting facilities, 9 green waste compost samples originating from four composting facilities, 7 commercial organic compost samples from two sites and 11 sludge compost samples all originating from the same facility.

Data was separated and stored in four different Excel spreadsheets using Microsoft Excel 2000 (9.0.6926 sp-3) according to the type of feedstock composted. A scheme based on letters to identify the type of compost and a mixture of numbers to identify individual sites and letters again to identify samples from the same site was devised due to the confidentiality clause. The letter B was used to represent biowaste compost, G for green waste compost, C for commercial organic compost and S for sludge compost.

For the most part, both laboratories used the same units for reporting results. Some results were reported on a dry weight basis or a fresh weight basis. When samples were tested as received, the results were subsequently reported on a fresh weigh basis. The only difference in reporting between the laboratories was the units used for the concentration of salmonella. The units were consequently changed by the author and the results reported according to the specification in the EU Biowaste Directive (MPN/50g of total solids). A copy of the style of reporting of compost quality test results for both Laboratories is attached in appendix 4.

Descriptive statistical analysis using Microsoft Excel 2000 (9.0.6926 sp-3) computer package was carried out on all parameters. Comparisons were made between the means of all parameters and statutory limits specified by the EPA and the EU Biowaste Directive for Class I and II compost and for stabilised biowaste to determine the class of each compost sample and to see how many of the samples exceeded the statutory limits. Where no statutory limits were in place for certain parameters, a comparison was made between the calculated means and recommended ranges or values for these parameters as reported in the literature.

A comparison was made between the mean concentrations of heavy metals in the Irish biowaste and green waste compost to heavy metal concentration in similar types of compost from countries such as Germany, Austria, Australia and the UK.

Pearson's product-moment correlation coefficient, r, was calculated to see if there was any correlations between heavy metals in the compost samples using Microsoft Excel 2000 computer package. Scatter graphs for used to illustrate the correlations and the results tabulated. Values of r lie between -1 and +1. There is a strong relationship between the two variables if the value of r is close to either –1 or +1 (Mead et al., 1993).

To see if there was a difference between two means values for some parameters a t-test for two samples assuming unequal variances was carried out. The means were assumed unequal as it was thought that this was the most conservative approach and the least likely to produce a Type 1 error, t-tests give a t value from which the probability is calculated. The P-value gives the probability of the means being significantly different. The degrees of freedom (df) are also given. By testing the difference between the means the Null Hypothesis was tested. The Null Hypothesis states that there is no significant difference between the means. So the hypothesis can be accepted or rejected. A small P value ($P<0.05$) indicated that there was a significant difference between the means. A large P value (>0.05) signified that there was no significant difference between the means (Ludwig and Reynolds, 1988).

Analysis of variance (ANOVA) was carried out where more than two means were compared. ANOVA determines whether there is any probability that there is a significant difference between the means. Again the Null Hypothesis is tested and a small P indicated that there was a significant difference and a large P-value indicated that there was not a significant difference between the means (Ludwig and Reynolds, 1988).

Quality results for individual parameters were not available for all the compost samples. In some cases there were only a very small amount of facilities that tested for certain parameters.

3.3 SITE VISITS

Site visits were made to the following facilities throughout the study:

- The Sandy Road facility in Galway who compost source segregated biowaste.
- The McGill Environmental Systems (Ireland) composting facility in Cork who compost industrial sludge.
- Natural World Products Recycling facility in Armagh, who compost green waste and biowaste.
- A new composting facility in Carrowbrowne, Galway that is currently under construction.

The site visits involved examining the feedstock, the different types of technology employed, segregation and screening processes used and the quality and storage practices of the final product, whilst in consultation with individual facility managers. Interviews were conducted with site managers to discuss various composting issues with emphasis on compost quality and market availability. Photographs were also taken of the composting facilities using a digital camera (see appendix 5).

4.0 RESULTS

4.1 HEAVY METALS

4.1.1 Heavy Metal Content of Biowaste Compost

The concentration of heavy metals in the biowaste compost samples are given in table 4.1. The table shows the number of samples analysed for each metal the minimum, maximum, median and mean concentration of the heavy metals and toxic elements and also the standard deviation. The maximum number of samples analysed was 29, which originated from six composting facilities. Graphs of the concentration of each heavy metal in the individual samples can be found in appendix 5**.**

Table 4.1 Concentration of heavy metals in the biowaste compost

Parameters	Units	No.[1]	Min	Max	Median	Mean	SD [2]
Copper	mg/Kg dm	29	2.5	124	37.2	47.5	35.1
Zinc	mg/Kg dm	29	5.2	361	158	147.8	118.3
Lead	mg/Kg dm	24	7	122	28.1	39.5	32.5
Cadmium	mg/Kg dm	29	0.2	1.02	0.5	0.6	0.3
Mercury	mg/Kg dm	29	0	2.7	0.2	0.4	0.6
Nickel	mg/Kg dm	24	1.9	68	17.5	18.7	16.2
Chromium	mg/Kg dm	24	2	135	13.9	18.7	27.7
Selenium	mg/Kg dm	12	0.5	1	0.6	0.7	0.2
Arsenic	mg/Kg dm	20	0.2	8.3	2.5	3.1	2.7
Molybdenum	mg/Kg dm	12	0.8	3.3	2.1	2.2	0.8

[1] Number of samples tested
[2] Standard Deviation

4.1.1.1 Comparison Of Heavy Metal Concentration In The Biowaste Compost Versus The Critical Limits Specified By The EPA And The EU Biowaste Directive

Below is a discussion on the comparison of concentration of heavy metals in the biowaste compost compared to the critical limits stipulated by the EPA and the EU Biowaste Directive (Table 4.2).

Table 4.2 Critical limits for heavy metals in compost specified by the EPA and EU Biowaste Directive and the percentage of the biowaste compost samples exceeding the limits

Parameters	Units	No.[1]	EPA CL [2]	% Exceeding The CL	Class I CL [3]	% Exceeding The CL	Class II CL [4]	% Exceeding The CL	Stabilised Biowaste[5]	% Exceeding The CL
Copper	mg/Kg dm	29	100	6.9	100	6.9	150	0	600	0
Zinc	mg/Kg dm	29	350	3.5	200	34.5	400	0	1,500	0
Lead	mg/Kg dm	24	150	0	100	8.3	150	0	500	0
Cadmium	mg/Kg dm	29	1.5	0	0.7	37.9	1.5	0	5	0
Mercury	mg/Kg dm	29	1	13.8	0.5	24.1	1	13.8	5	0
Nickel	mg/Kg dm	24	50	8.3	50	8.3	75	0	150	0
Chromium	mg/Kg dm	24	100	4.2	100	4.2	150	0	600	0
Selenium	mg/Kg dm	12	2	0	N/A		N/A		N/A	
Arsenic	mg/Kg dm	20	15	0	N/A		N/A		N/A	
Molybdenum	mg/Kg dm	12	5	0	N/A		N/A		N/A	

[1] Number of samples tested
[2] Critical Limits for heavy metals specified by the Environmental Protection Agency in accordance with Waste Licensing under the Waste Management Act 1996.
[3] Critical Limits for heavy metals proposed by the EU Biowaste Directive (Class I)
[4] Critical Limits for heavy metals proposed by the EU Biowaste Directive (Class II)
[5] Critical Limits for heavy metals proposed by the EU Biowaste Directive (for stabilised biowaste)

Copper

The mean concentration of copper in biowaste compost was found to be 47.5 mg/Kg, which is well below the critical limits specified by the EPA and the EU Biowaste Directive (Fig 4.1, a). Two (6.9%) of the biowaste samples analysed exceeded this limit for EPA and Class I compost. No samples exceeded the limit for Class II compost (Table 4.2).

Zinc

The mean concentration of zinc found in the biowaste compost was calculated to be 147.8 mg/Kg, dm which is below the critical limits specified by the EPA and the EU Biowaste Directive for Class I and Class II compost (Fig 4.1, a). Only one (3.5%) of the samples exceeding the EPA critical limit for zinc. Ten (34.5%) of the samples did not meet Class I requirements. None of the samples exceeded the limit for Class II compost. A high standard deviation for zinc was observed which was the highest for all the metals tested in the biowaste compost (Table 4.1).

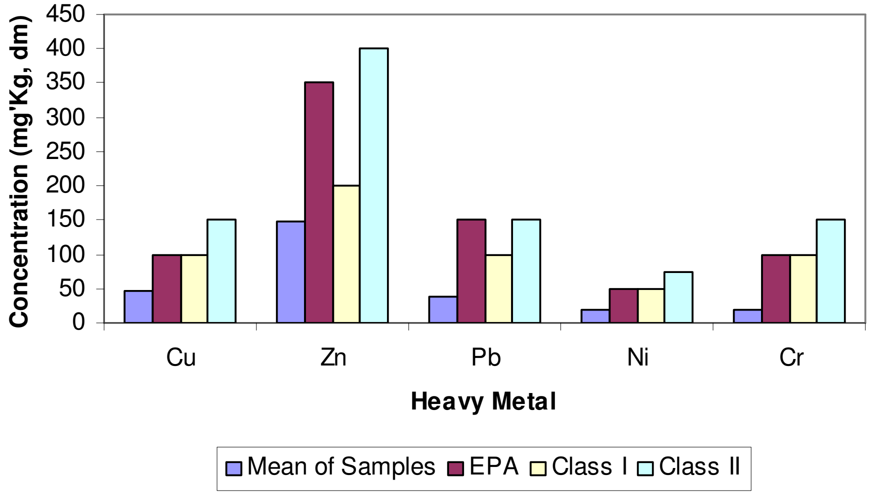
Lead

On a nationwide average, biowaste compost contains 39.5 mg/Kg, which is below the critical limits for the EPA standard and Class I and II compost (Fig 4.1, a) No biowaste compost samples exceeded the EPA requirement. Two (8.3%) of the samples exceeded the critical limit for Class I compost and no samples exceeded the limit for Class II compost (Table 4.2).

Cadmium

The mean concentration of cadmium in the biowaste compost was calculated to be 0.6 mg/Kg which is below the EPA requirement for compost and below the limit for Class II compost, however it is only slightly below the critical limit of 0.7 mg/Kg stipulated for Class I compost (Fig 4.1, b). No samples exceeded the limits for EPA compost and Class II compost. Eleven (37.9%) of all the samples exceeded the limit for Class I compost (Table 4.2).

(a)



(b)

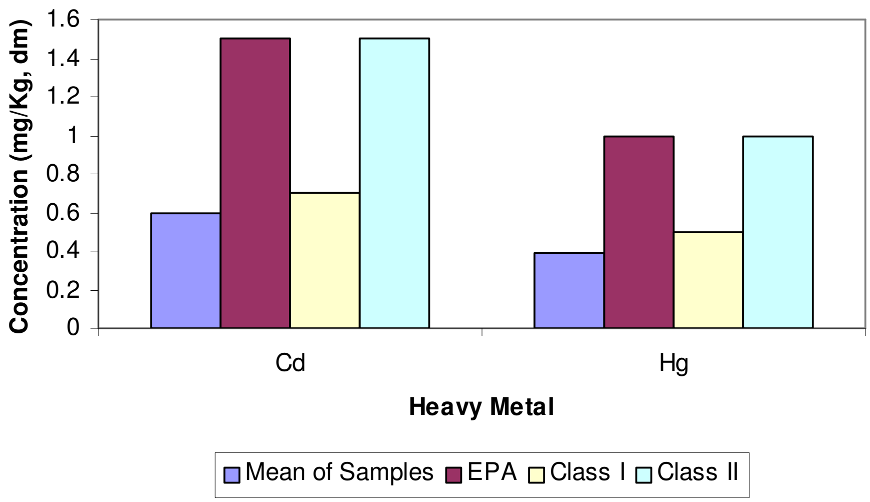


Fig 4.1 (a and b). Graph of mean concentrations of heavy metals in Irish biowaste compost compared to the critical limits specified by the EPA and the proposed Biowaste Directive for Class I and II compost.

Mercury

The mean concentration of mercury in the biowaste compost samples was 0.4 mg/Kg, which is below the critical limits examined (Fig 4.1, b). Four (13.8%) of the samples exceeded the EPA and Class II limit. Seven (24.1%) of the samples exceeded the limit for Class I compost. Samples B4a and B4b showed elevated levels of mercury in the biowaste compost compared to the other samples (Fig 4.2). No explanation was available for the high concentrations of mercury in samples B4a and B4b. All the other samples at this site had relatively low concentrations of mercury compared to samples B4a and B4b, which would suggest that perhaps an analytical error produced these results and therefore biased the mean. According to the EU Biowaste Directive these samples are classified as stabilised biowaste. If these two samples were ignored, a mean concentration of 0.2mg/kg would have been calculated.

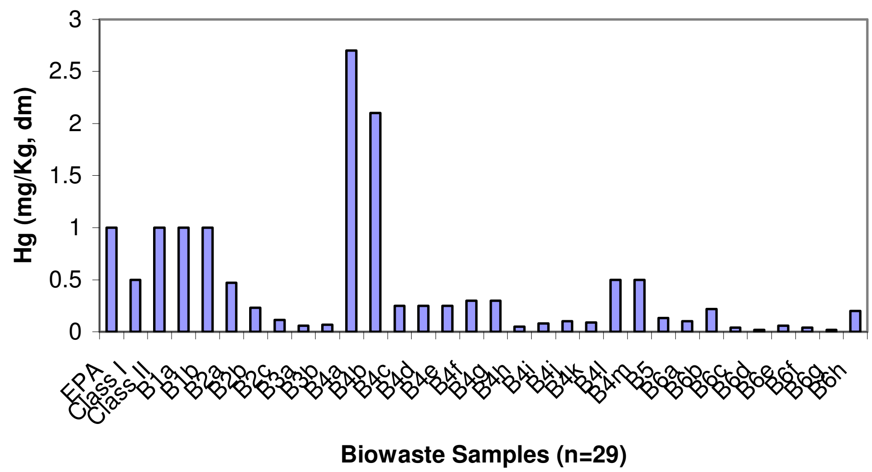


Fig 4.2. Graph of the concentration of Hg (mg/Kg) in the biowaste compost samples

Nickel

The mean concentration of 18.7 mg/Kg of nickel found in the biowaste compost samples was below the critical limits specified by the EPA and the EU Biowaste Directive (Fig 5.1, a). Two (8.3%) of the samples exceeded the EPA limit and the limit for Class I compost. No samples exceeded the limit for Class II compost (Table 4.2). Sample B6a and B5 showed a high nickel concentration of 68 mg/Kg and 52.5 mg/Kg respectively (Fig 4.3) when compared to the mean of 18.7 mg/Kg.

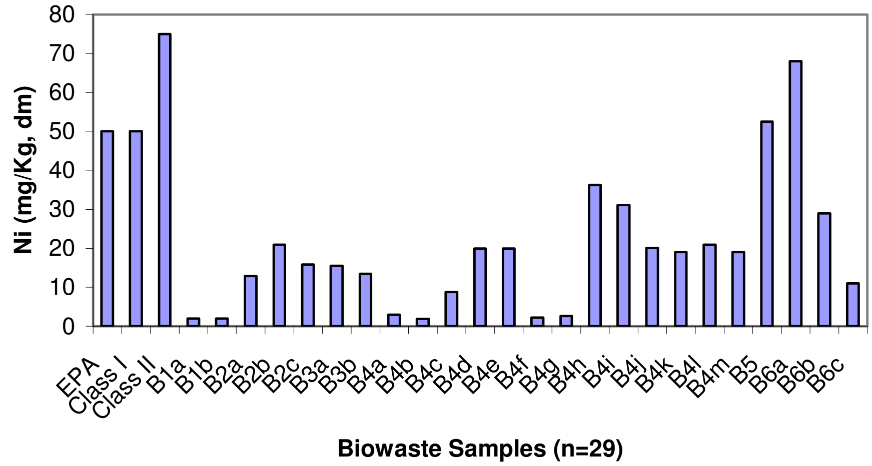


Fig 4.3 Graph of the concentration of Ni in the biowaste compost samples

Chromium

The mean concentration of chromium in the biowaste samples was found to be 18.7 mg/Kg, which is below the critical limits specified by the two standards (Fig 4.4, a). All the samples of biowaste compost tested were below the critical limits for the two standards except for one sample, B5 which had a concentration of 135 mg/Kg (Fig 4.4) and therefore exceeded the limit for EPA and Class I compost.

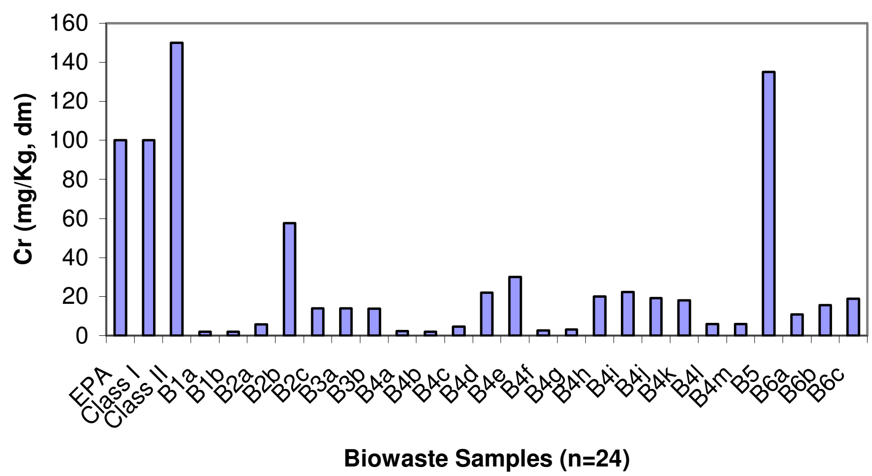


Fig 4.4. Graph of the concentration of Cr (mg/Kg) in the biowaste compost samples

Other Trace Elements

The mean concentrations for selenium, arsenic and molybdenum were found to be 0.7 mg/Kg, 3.1 mg/Kg, and 2.2 mg/Kg respectively. All of these means in particular the mean value for arsenic were below the limits specified by the EPA (Table 4.2 and Fig 4.5).

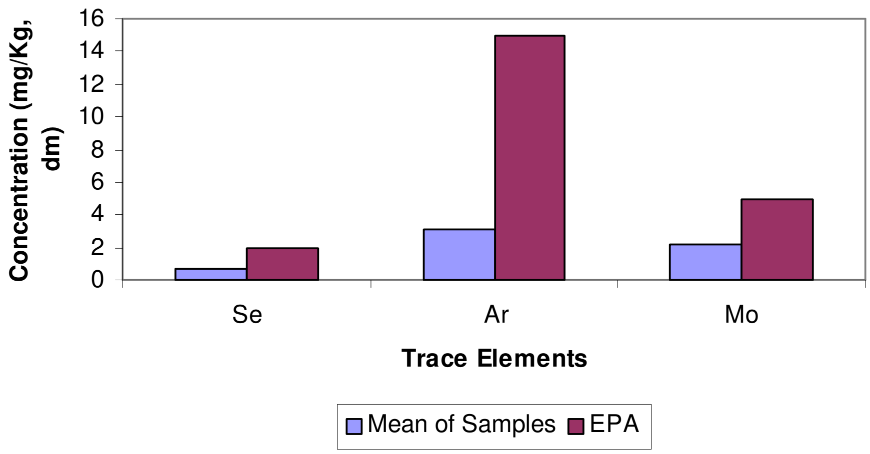


Fig 4.5 Graph of mean concentrations of trace elements in Irish biowaste compared to the critical limits specified by the EPA.

4.1.2 Heavy Metal Content of Green Waste Compost

The heavy metal content of the green waste compost analysed is given in table 4.3. The table shows the number of samples analysed for each metal, the minimum, maximum, median and the mean concentration of the heavy metals in the green waste compost. Standard deviations from the mean concentrations are also given. Altogether, eight samples of green waste compost from four different composting facilities were analysed. Graphs of the concentration of each heavy metal in the individual samples can be found in appendix 5**.**

Table 4.3. Concentration of heavy metals in the green waste compost

Parameters	Units	No.[1]	Min	Max	Median	Mean	SD [2]
Copper	mg/Kg dm	8	1	62.7	35.5	33.3	18.8
Zinc	mg/Kg dm	8	12	301	128	140.1	85.7
Lead	mg/Kg dm	8	1	129	65.6	64	41.9
Cadmium	mg/Kg dm	8	0.5	1.2	1	0.9	0.3
Mercury	mg/Kg dm	8	0.1	0.3	0.3	0.2	0.1
Nickel	mg/Kg dm	8	1	53.1	10.5	15.5	16
Chromium	mg/Kg dm	8	1	148	13.7	31	48

[1] Number of samples tested
[2] Standard Deviation

4.1.2.1 Comparison Of Heavy Metal Concentration In The Green Waste Compost Versus The Critical Limits Specified By The EPA And The EU Biowaste Directive

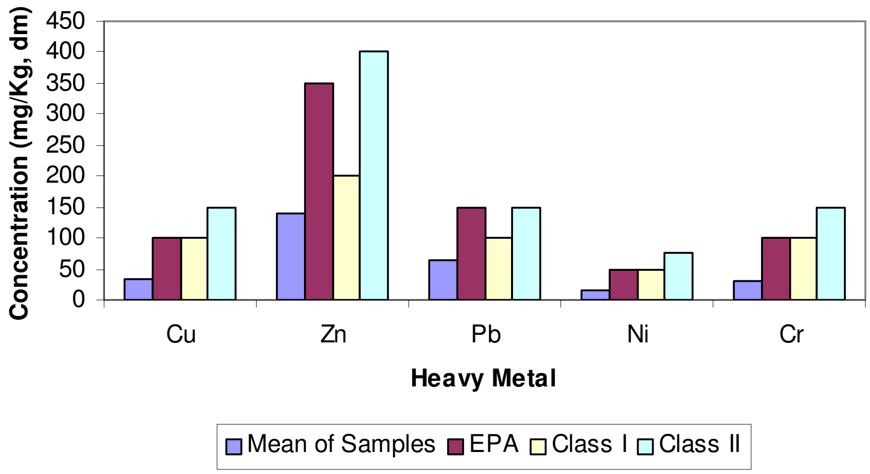
Table 4.4 shows the critical limits specified for heavy metals by the EPA and the EU Biowaste Directive for Class I and II compost and for stabilised biowaste. The percentage of green waste compost samples exceeding the critical limits are also given. Figure 4.6 (a and b) shows a graph of the mean of all the heavy metals in the green waste compost compared to the critical limits stipulated by the two standards.

Table 4.4 Critical limits for heavy metals in compost and the percentage of green waste compost samples exceeding the limits

Parameters	Units	No.[1]	EPA CL [2]	% Exceeding The CL	Class I CL [3]	% Exceeding The CL	Class II CL [4]	% Exceeding The CL	Stabilised Biowaste[5]	% Exceeding The CL
Copper	mg/Kg dm	8	100	0	100	0	150	0	600	0
Zinc	mg/Kg dm	8	350	0	200	12.5	400	0	1,500	0
Lead	mg/Kg dm	8	150	0	100	12.5	150	0	500	0
Cadmium	mg/Kg dm	8	1.5	0	0.7	62.5	1.5	0	5	0
Mercury	mg/Kg dm	8	1	0	0.5	0	1	0	5	0
Nickel	mg/Kg dm	8	50	12.5	50	12.5	75	0	150	0
Chromium	mg/Kg dm	8	100	12.5	100	12.5	150	0	600	0

[1] Number of samples tested
[2] Critical Limits for heavy metals specified by the Environmental Protection Agency in accordance with Waste Licensing under the Waste Management Act 1996.
[3] Critical Limits for heavy metals proposed by the EU Biowaste Directive (Class I).
[4] Critical Limits for heavy metals proposed by the EU Biowaste Directive (Class II).
[5] Critical Limits for heavy metals proposed by the EU Biowaste Directive (for stabilised biowaste)

(a)



(b)

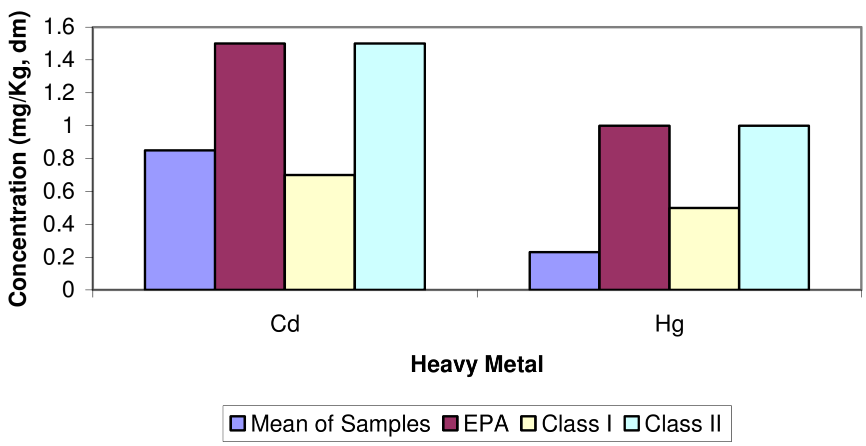


Fig 4.6 (a and b). Graph of mean concentrations of heavy metals in Irish green waste compost compared to the critical limits specified by the EPA and the proposed Biowaste Directive for Class I and II compost.

Copper

The mean concentration for copper in the green waste samples was calculated to be 33.3 mg/Kg. This is well below the critical limits specified by the two standards

(Table 4.4). The standard deviation of 18.8 was also quite low. None of the green waste samples exceeded the critical limits for copper.

Zinc

The mean concentration of Zinc was found to be 140.1 mg/Kg, which is below the critical limits specified, by the EPA and the EU Biowaste Directive. No samples exceeded the limits for the EPA or Class II compost, whereas one (12.5%) of the samples exceeded the limits for Class I compost (Table 4.2).

Lead

The mean concentration of lead in the green waste compost was calculated to be 64 mg/Kg, which is below the critical limits specified by the two standards. No samples exceeded the EPA or Class II compost limit for lead, with one (12.5%) of the samples exceeding the limit for Class I compost (Table 4.4).

Cadmium

The mean concentration of cadmium was found to be 0.9 mg/Kg, which is below the critical limits for EPA and Class II compost with none of the green waste compost samples exceeding these limits. However, the mean concentration of cadmium and five (62.5%) of the samples exceeded the critical limit for Class I compost

Mercury

The mean concentration of mercury in the green waste compost was calculated to be 0.23 mg/Kg, dm. A standard deviation of 0.10 was calculated with no samples exceeding the limits for the two standards.

Nickel

The mean concentration of nickel was found to be 15.5 mg/Kg with one (12.5%) of the samples exceeding the critical limits for EPA and Class I compost. No samples exceeded the limit for Class II compost (Table 4.2). Sample G3 contained a significantly higher level of nickel compared to the other samples as did sample B5 which originated from the same composting facility.

Chromium

The mean concentration of chromium in the green waste compost was found to be 31 mg/Kg, which is below the limits specified by the two standards. One (12.5%) of the samples exceeded the critical limits for EPA and Class I compost whereas, none of the samples exceeded the critical limit for Class II compost. Sample G3 also showed elevated levels of chromium compared to the rest of the samples. (See graph in appendix 5).

4.1.3 Heavy Metal Content of the Commercial Organic Compost

A summary of descriptive statistics for heavy metal concentrations in commercial organic compost are given in table 4.5. The table shows the number of samples analysed for each metal, the minimum, maximum, median and the mean concentration of the heavy metals in the commercial organic compost. Standard deviations from the mean are also given. Seven samples were available for analysis, which originated from two separate composting facilities. Graphs of the concentration of each heavy metal in the individual samples can be found in appendix 5.

Table 4.5. Concentration of heavy metals in the commercial organic compost

Parameters	Units	No.[1]	Min	Max	Median	Mean	SD [2]
Copper	mg/Kg dm	7	20.8	2476	42	392.1	919.1
Zinc	mg/Kg dm	7	10.9	2707	120	476.3	984.7
Lead	mg/Kg dm	7	16	342	37	111.2	125.7
Cadmium	mg/Kg dm	7	0.2	1.6	0.5	0.8	0.5
Mercury	mg/Kg dm	7	0.1	0.3	0.1	0.1	0.1
Nickel	mg/Kg dm	7	2.7	49	9	15.4	17.1
Chromium	mg/Kg dm	7	0.1	116	1.2	19.8	42.7

[1] Number of samples tested
[2] Standard Deviation

4.1.3.1 Comparison of Heavy Metal Concentration in the Commercial Organic Compost Versus the Critical Limits Specified by the EPA and the EU Biowaste Directive

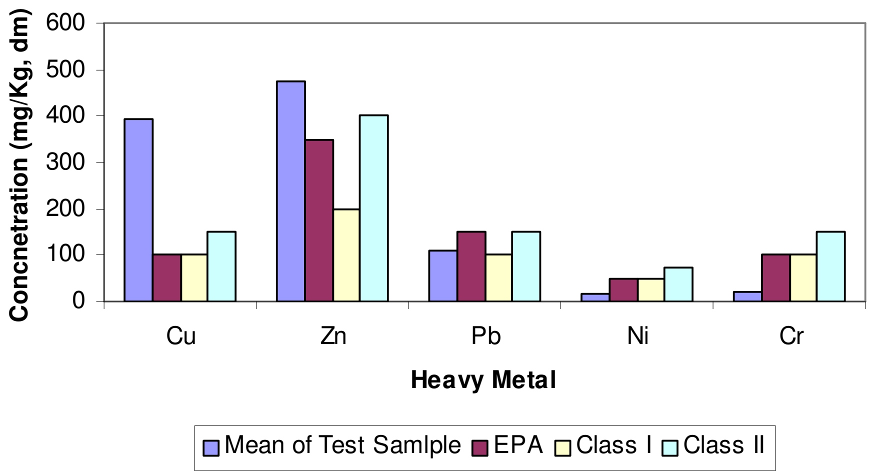
Table 4.6 shows the critical limits for heavy metals specified by the EPA and the EU Biowaste Directive for Class I and II compost, for stabilised biowaste and the percentage of commercial organic compost samples which exceeded the critical limits. Figure 4.7 (a and b) shows a graph of the mean of all the heavy metals in the commercial organic compost compared to the critical limits stipulated by the two standards.

Table 4.6 Critical limits for heavy metals in compost and the percentage of commercial organic compost samples exceeding the limits

Parameters	Units	No.[1]	EPA CL [2]	% Exceeding The CL	Class I CL [3]	% Exceeding The CL	Class II CL [4]	% Exceeding The CL	Stabilised Biowaste[5]	% Exceeding The CL
Copper	mg/Kg dm	7	100	14.3	100	14.3	150	14.3	600	0
Zinc	mg/Kg dm	7	350	14.3	200	14.3	400	14.3	1,500	14.3
Lead	mg/Kg dm	7	150	28.6	100	42.9	150	28.6	500	0
Cadmium	mg/Kg dm	7	1.5	14.3	0.7	42.9	1.5	14.3	5	0
Mercury	mg/Kg dm	7	1	0	0.5	0	1	0	5	0
Nickel	mg/Kg dm	7	50	0	50	0	75	0	150	0
Chromium	mg/Kg dm	7	100	14.3	100	14.3	150	0	600	0

[1] Number of samples tested
[2] Critical Limits for heavy metals specified by the Environmental Protection Agency in accordance with Waste Licensing under the Waste Management Act 1996.
[3] Critical Limits for heavy metals proposed by the EU Biowaste Directive (Class I)
[4] Critical Limits for heavy metals proposed by the EU Biowaste Directive (Class II)
[5] Critical Limits for heavy metals proposed by the EU Biowaste Directive (for stabilised biowaste)

(a)



(b)

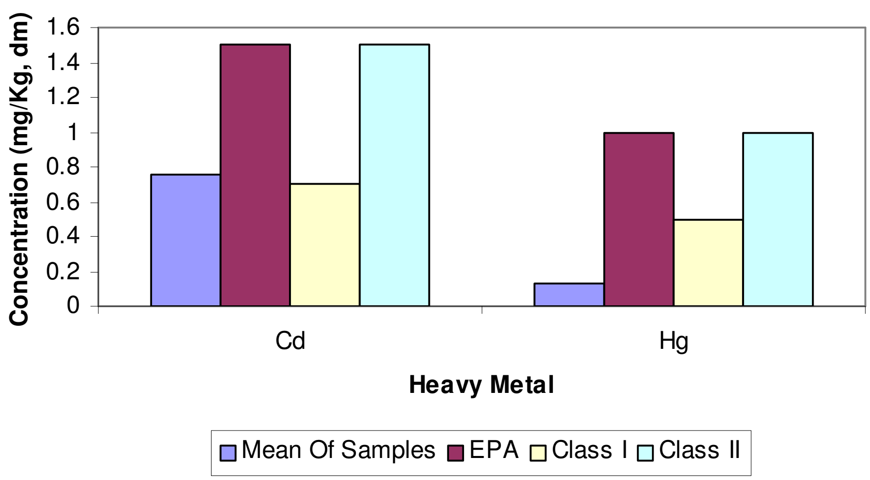


Fig 4.7 (a and b). Graph of mean concentrations of heavy metals in commercial organics compost compared to the critical limits specified by the EPA and the proposed Biowaste Directive for Class I and II Compost.

Copper

The mean concentration of copper in the commercial organic compost was calculated to be 392.1 mg/Kg, which highly exceeds the limits specified by the standards. This was due to sample C1e which had an extremely high concentration of copper at 2476 mg/Kg compared to the other samples and even exceeded the critical limits for stabilised biowaste. The author thinks that because all the other samples at this site contained relatively small concentrations of copper, that perhaps analytical error resulted in such a high figure and therefore biased the mean (Fig 4.8). If the mean of the concentration of copper were calculated without including this sample the mean concentration would have been 44.8 mg/Kg, which is well below the limits for the two standards. Apart from sample C1e no other samples exceeded the limits.

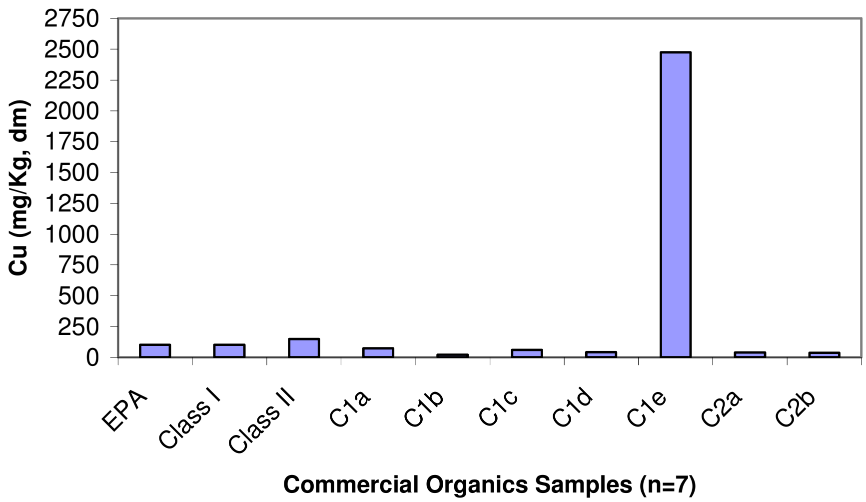


Fig 4.8 Graph of the concentration of Cu in the commercial organic compost samples.

Zinc

The mean concentration of Zinc was also very high at 476.3 mg/kg, which exceeded the critical limits specified by the standards. Again, this was due to sample C1e which had an extremely high concentration of 2707 mg/Kg and was the only sample to exceed the critical limits (Fig 4.9). By ignoring sample C1e the mean was calculated to be 104.5 mg/Kg, which would have been below the critical limits specified by the two standards for zinc, otherwise sample C1e would be classified as stabilised biowaste.

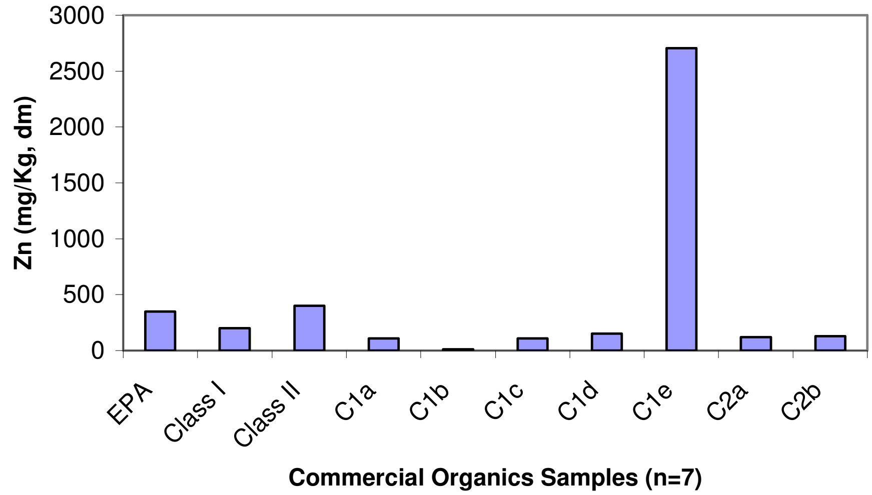


Fig 4.9 Graph of the concentration of Zn (mg/Kg) in the commercial organic compost samples

Lead

The mean concentration of lead in the commercial organic compost was 111.2 mg/kg, which is below the EPA and Class II compost limits but exceeds the limits for Class I compost. Two (8.6%) of the samples exceeded the EPA and Class II compost limits while three (42.9%) of the samples exceeded the critical limit for the concentration of lead in Class I compost. Samples C2a and C2b contained very high levels of lead compared to the commercial organic compost samples from the other composting facility and was classified as stabilised biowaste according to the EU Biowaste Directive (Fig 4.10).

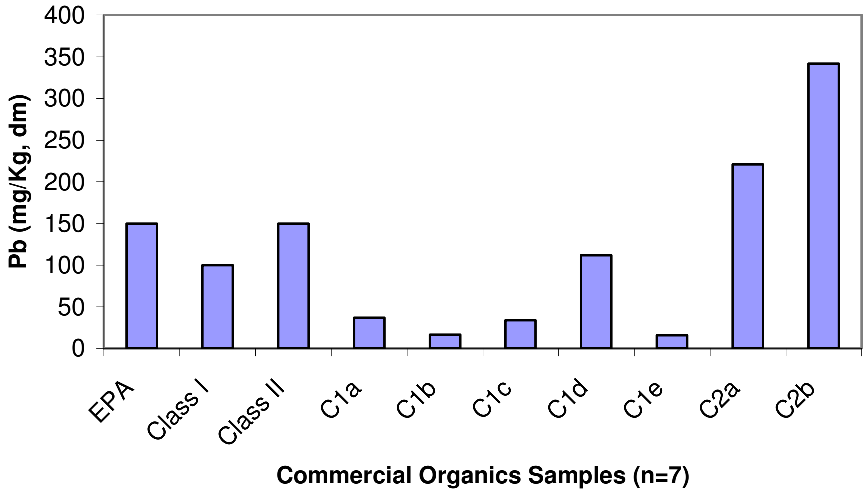


Fig 4.10 Graph of the concentration of Pb (mg/Kg) in the individual commercial organic compost samples

Cadmium

Then mean concentration of cadmium in the commercial organic compost was found to be 0.8 mg/Kg. This is below the limits for EPA and Class II compost while one (14.3%) of the samples exceeded these critical limits (Table 4.6). The mean just exceeded the limit for Class I compost (Fig 4.7, b) while three (42.9%) of the samples were greater than this limit.

Mercury

The mean concentration of mercury in commercial organic compost was calculated to be 0.1 mg/Kg, which is below the critical limits for both standards (Fig 4.7, b). None of the commercial organic compost samples exceeded the critical limits.

Nickel

The mean concentration of nickel in the commercial organic compost was found to be 15.4 mg/Kg, which is below the critical limits stipulated by both standards. None of the samples exceeded the critical limits.

Chromium

The mean concentration of chromium in the samples was 19.8 mg/Kg, which is below the limits stipulated by the two standards (Table 4.6). None of the samples exceeded the limits for Class II compost while one (14.3%) of the samples exceeded the limits for EPA and Class I compost. Sample C2a showed a very high concentration of chromium compared to the other samples (Fig 4.11).

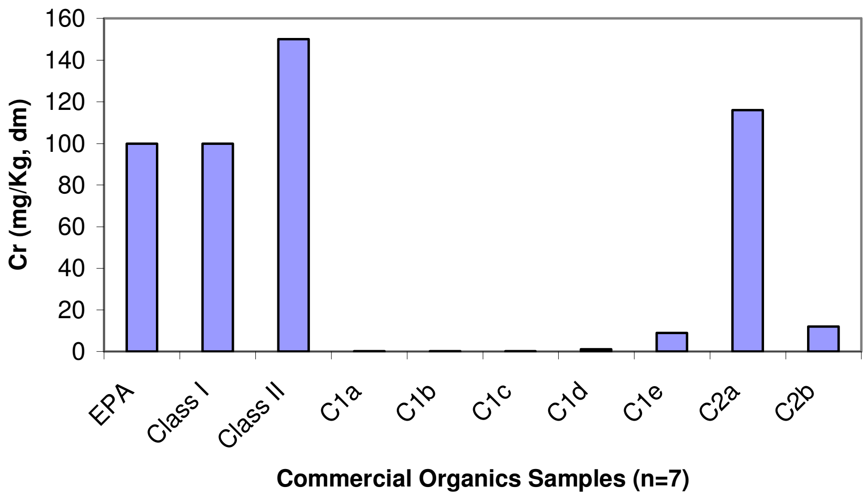


Fig 4.11 Graph of the concentration of Cr (mg/Kg) in the commercial organic compost samples.

4.1.4 Heavy Metal Content of Sludge Compost

A summary of descriptive statistics for heavy metal concentrations in industrial sludge compost are outlined in table 4.7. The table shows the number of samples analysed for each metal, the minimum, maximum, median and the mean concentration of the heavy metals present in the samples. There were eleven samples available for analysis, which all originated from one composting facility.

Table 4.7. Concentration of heavy metals in the sludge compost

Parameters	Units	No.[1]	Min	Max	Median	Mean	SD [2]
Copper	mg/Kg dm	11	3.5	80	5.9	16.6	23.6
Zinc	mg/Kg dm	11	0	553	47	102.1	154.9
Lead	mg/Kg dm	11	0.1	17	4	5.1	4.8
Cadmium	mg/Kg dm	11	0	1	0.3	0.4	0.3
Mercury	mg/Kg dm	11	0	0.3	0.1	0.1	0.1
Nickel	mg/Kg dm	11	0	42	5	8.1	11.4
Chromium	mg/Kg dm	9	2.1	13.7	5.3	6.4	3.8

[1] Number of samples tested
[2] Standard Deviation

4.1.4.1 Comparison Of Heavy Metal Concentration In The Sludge Compost Versus The Critical Limits Specified By The EPA And The EU Biowaste Directive

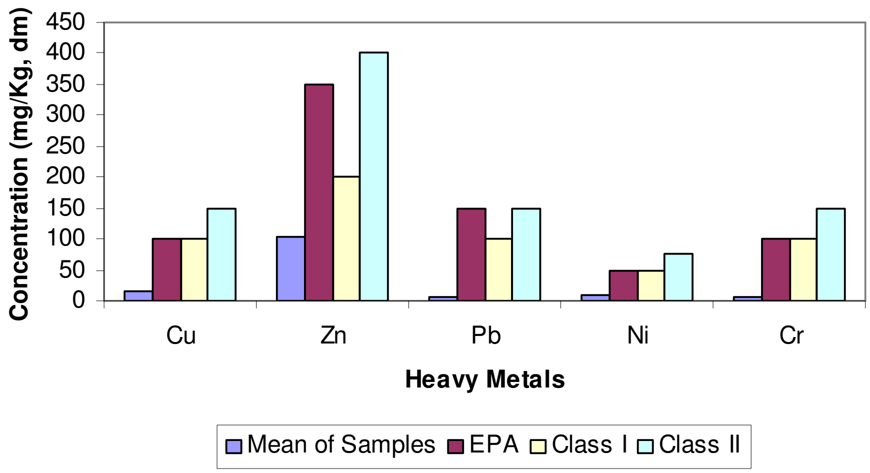
Table 4.8 shows the critical limits specified for heavy metals by the EPA and the EU Biowaste Directive for Class I and II compost and for stabilised biowaste. The percentage of sludge compost samples which exceeded the critical limits are also given. Figure 4.12 shows a graph of the mean of all the heavy metals in the sludge compost compared to the critical limits set out by the EPA and the EU Biowaste Directive for the two standards.

Table 4.8 Critical limits for heavy metals in compost and the percentage of sludge compost samples exceeding the limits

Parameters	Units	No.[1]	CL [2]	% Exceeding The CL	CL [3]	% Exceeding The CL	CL [4]	% Exceeding The CL	Stabilised Biowaste[5]	% Exceeding The CL
Copper	mg/Kg dm	11	100	0	100	0	150	0	600	0
Zinc	mg/Kg dm	11	350	9.1	200	9.1	400	9.1	1,500	0
Lead	mg/Kg dm	11	150	0	100	0	150	0	500	0
Cadmium	mg/Kg dm	11	1.5	0	0.7	9.1	1.5	0	5	0
Mercury	mg/Kg dm	11	1	0	0.5	0	1	0	5	0
Nickel	mg/Kg dm	11	50	0	50	0	75	0	150	0
Chromium	mg/Kg dm	9	100	0	100	0	150	0	600	0

[1] Number of samples tested
[2] Critical Limits for heavy metals specified by the Environmental Protection Agency in accordance with Waste Licensing under the Waste Management Act 1996.
[3] Critical Limits for heavy metals proposed by the EU Biowaste Directive (Class I)
[4] Critical Limits for heavy metals proposed by the EU Biowaste Directive (Class II)
[5] Critical Limits for heavy metals proposed by the EU Biowaste Directive (for stabilised biowaste)

(a)



(b)

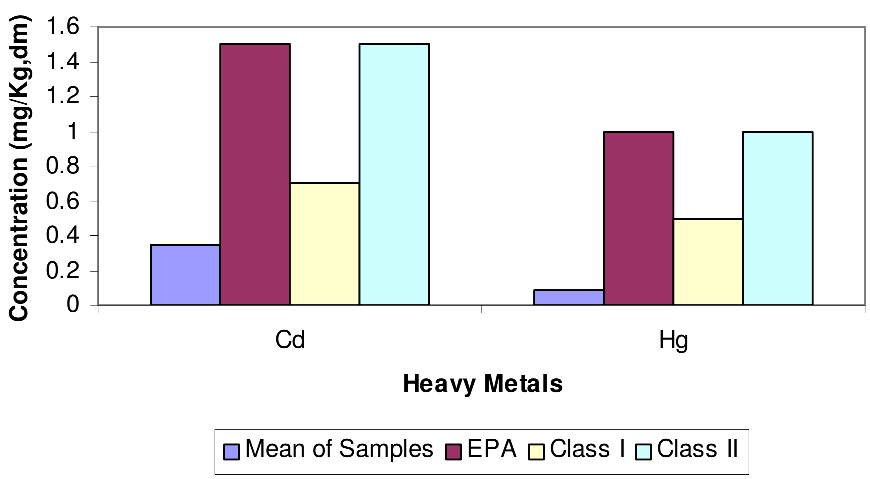


Fig 4.12 (a and b). Graph of mean concentrations of heavy metals in sludge compost compared to the critical limits specified by the EPA and the proposed Biowaste Directive for Class I and II compost.

Copper

The mean concentration of copper was found to be 16.6 mg/Kg, which is below the critical limits specified by the EPA and the EU Biowaste Directive. No samples exceeded the limits.

Zinc

The mean concentration of 102.1 mg/Kg of zinc in the sludge compost was below the critical limits for both standards. One (9.1%) of the samples exceeded the critical limits for both standards. Sample S1g contained a very high concentration of 553 mg/Kg especially compared to the other samples and was classified as stabilised biowaste.

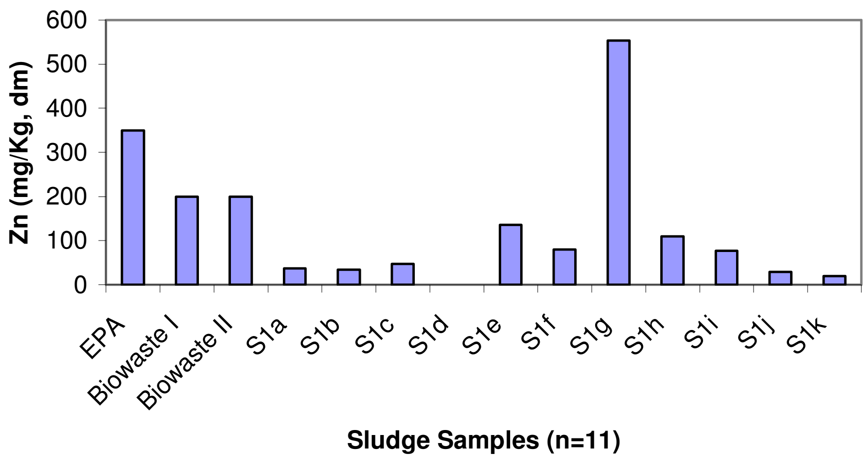


Fig 4.13 Graph of the concentration of Zn (mg/Kg) in the commercial organic compost samples

Lead

The mean concentration of lead was found to be very low at 5.13 mg/Kg in the sludge compost. No samples exceeded the critical limits specified by both standards.

Cadmium

The mean concentration of cadmium was 0.4 mg/Kg, which is below the critical limits stipulated by the EPA and the EU Biowaste Directive. No samples exceeded the EPA limit or the critical limit for Class II compost. One (9.1%) of the samples exceeded the limit for Class I compost.

Mercury

The mean concentration of mercury was found to be 0.1 mg/Kg, which was well below all the critical limits specified by the standards. None of the samples exceeded the limits.

Nickel

The mean concentration of nickel in the sludge compost samples was 8.1 mg/Kg, which is also well below the critical limits, with no samples exceeding the limits stipulated by the two standards.

Chromium

A very low mean concentration of 6.4 mg/Kg of chromium was calculated for the sludge compost. No samples exceeded the specified critical limits.

4.1.5 Correlations Between Heavy Metals

4.1.5.1 Correlations Between Heavy Metals in Biowaste Compost

Using linear regression analysis the strongest correlation was found between nickel and copper (R^2=0.5628). No other significant correlations were observed (Table 4.9).

Table 4.9 Pearson's Correlations Between Heavy Metals in Biowaste Compost

	Cu	Zn	Pb	Cd	Hg	Ni	Cr
Cu	1.00						
Zn	0.56	1.00					
Pb	0.46	0.58	1.00				
Cd	-0.01	-0.21	-0.05	1.00			
Hg	-0.49	-0.58	-0.43	0.50	1.00		
Ni	**0.74**	0.58	0.54	-0.15	-0.40	1.00	
Cr	0.14	0.42	0.62	-0.07	-0.25	0.51	1.00

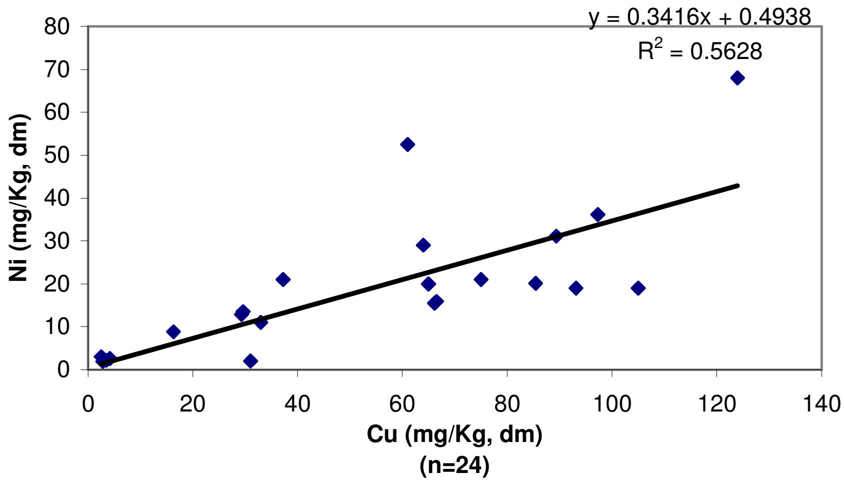


Fig 4.14 Scatter graph showing the correlation between copper and nickel in the biowaste compost

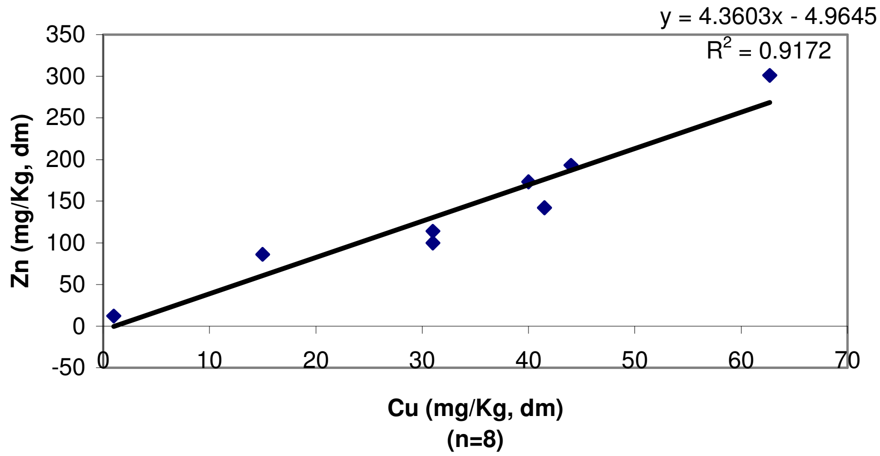
4.1.5.2 Correlations Between Heavy Metals in Green Waste Compost

Correlations were found between zinc and lead (R^2= 0.9288), copper and zinc (R^2=0.9172), copper and lead (R^2=0.875) and finally zinc and nickel (R^2=0.7205), (Table 4.10).

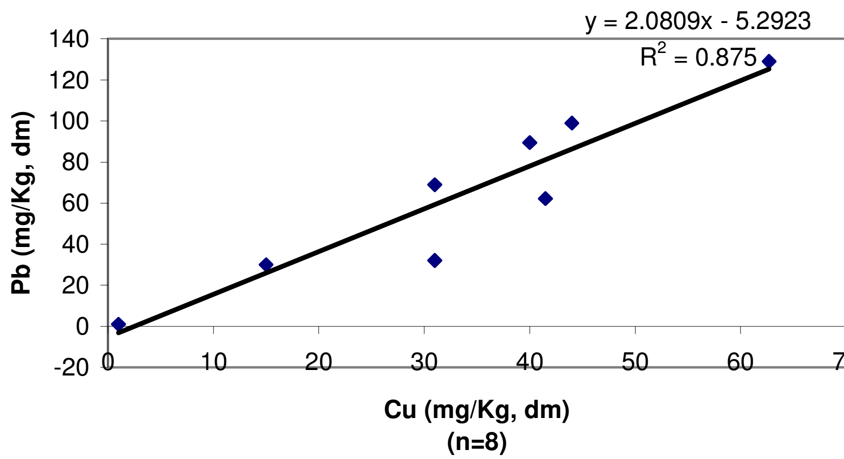
Table 4.10 Pearson's Correlations Between Heavy Metals in Green Waste Compost

	Cu	Zn	Pb	Cd	Hg	Ni	Cr
Cu	1.00						
Zn	**0.96**	1.00					
Pb	**0.94**	**0.96**	1.00				
Cd	0.52	0.55	0.54	1.00			
Hg	-0.16	-0.23	-0.08	-0.65	1.00		
Ni	**0.77**	**0.85**	0.72	0.64	-0.51	1.00	
Cr	0.69	0.78	0.64	0.44	-0.31	**0.95**	1.00

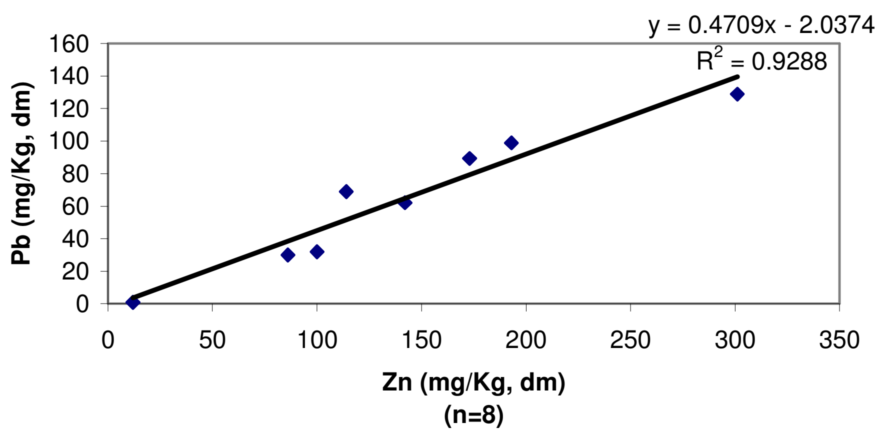
(a)


y = 4.3603x - 4.9645
R^2 = 0.9172
Zn (mg/Kg, dm)
350
300
250
200
150
100
50
0
-50
0
10
20
30
40
50
60
70
Cu (mg/Kg, dm)
(n=8)

(b)


y = 2.0809x - 5.2923
R^2 = 0.875
Pb (mg/Kg, dm)
140
120
100
80
60
40
20
0
-20
0
10
20
30
40
50
60
70
Cu (mg/Kg, dm)
(n=8)

(c)


y = 0.4709x - 2.0374
R^2 = 0.9288
Pb (mg/Kg, dm)
160
140
120
100
80
60
40
20
0
0
50
100
150
200
250
300
350
Zn (mg/Kg, dm)
(n=8)

(d)

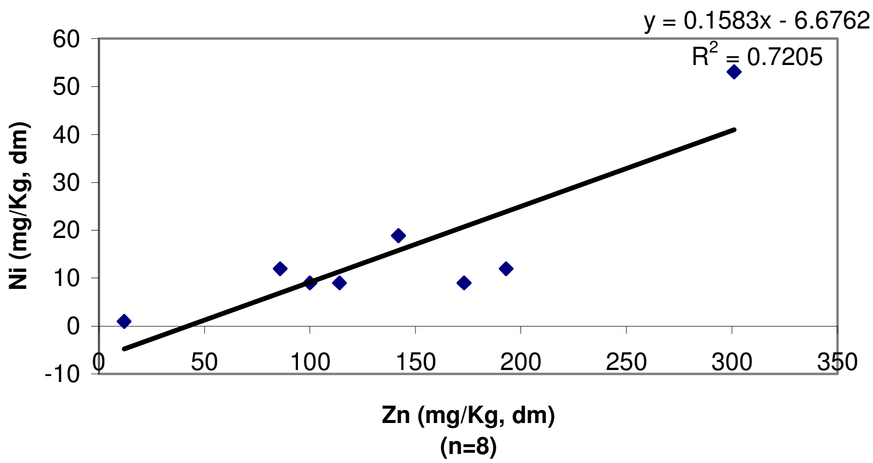


Fig 4.15 (a,b,c,d) Scatter graphs showing significant correlations between heavy metals in green waste compost.

4.1.5.2 Correlations Between Heavy Metals In Commercial Organic Composts

Findings of significant correlations between heavy metals in the commercial organic compost are given in table 4.11.

Table 4.11 Pearson's Correlations Between Heavy Metals In The Commercial Organic Compost

	Cu	Zn	Pb	Cd	Hg	Ni	Cr
Cu	1.00						
Zn	**1.00**	1.00					
Pb	-0.34	-0.31	1.00				
Cd	-0.23	-0.21	-0.13	1.00			
Hg	0.64	0.65	0.40	-0.32	1.00		
Ni	**0.86**	**0.87**	-0.02	-0.31	0.58	1.00	
Cr	-0.12	-0.10	0.45	-0.28	-0.12	0.39	1.00

No significant correlations were found between heavy metals in the commercial organic compost contrary to the findings in Table 4.7. These high correlations values are due to outlier data involving sample C1e, which contained excessive amounts of zinc and copper compared to the other samples. It was thought that this could be due to an error in laboratory reporting of the concentration of heavy metals in sample C1e.

If these outliers were ignored there still was no significant correlations found (Table 4.12).

Table 4.12 Pearson's Correlations Between Heavy Metals In The Commercial Organic Compost

	Cu	Zn	Pb	Cd	Hg	Ni	Cr
Cu	1.00						
Zn	0.43	1.00					
Pb	-0.30	0.51	1.00				
Cd	0.54	0.67	-0.23	1.00			
Hg	-0.19	0.35	0.85	-0.22	1.00		
Ni	-0.28	0.34	0.57	-0.21	0.06	1.00	
Cr	-0.20	0.19	0.44	-0.32	-0.06	0.97	1.00

4.1.5.4 Correlations Between Heavy Metals in Sludge Compost

According to Pearsons's correlation coefficient for lead and mercury (R^2=0.716), a significant correlation was found (Table 4.13). The author advises that this may not be so, due to such a small number of samples being analysed which limited the accuracy of the correlation and due to a few outlier data points as can be seen in figure 4.3.

Table 4.13 Pearson's Correlations for sludge compost

	Cu	Zn	Pb	Cd	Hg	Ni	Cr
Cu	1.00						
Zn	-0.17	1.00					
Pb	0.41	0.20	1.00				
Cd	0.54	-0.07	0.34	1.00			
Hg	0.40	0.01	**0.85**	0.54	1.00		
Ni	-0.16	-0.31	-0.26	0.19	0.26	1.00	
Cr	-0.19	0.07	-0.20	-0.02	-0.38	-0.34	1.00

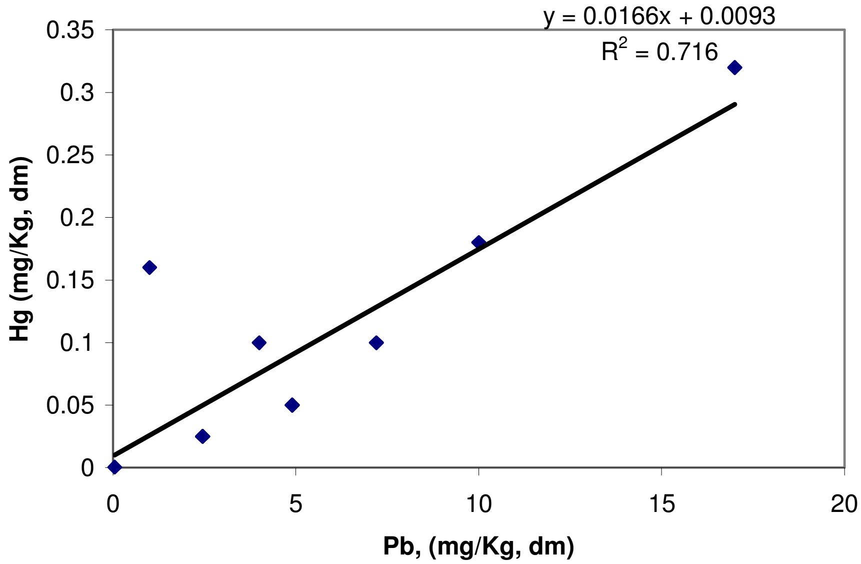


Fig 4.16 Scatter graph showing the correlation between mercury and lead.

4.2 NUTRIENT CONTENT OF COMPOST SAMPLES

Test results for nutrient content were only available for biowaste compost and green waste compost samples. Other facilities, which composted commercial organics and sludge, did not test for this parameter and no results were available. Concentrations of calcium and magnesium were available only for the biowaste compost samples. Descriptive statistics were carried out on these parameters and are presented in table 4.14. Recommended ranges for nutrients in compost are also given and discussed in detail in chapter 5. t-Test's were carried out to see if there were significant differences between the means of some parameters only when the author thought that unbiased means had been calculated.

Table 4.14. Summary of descriptive statistics for nutrient content and availability in the biowaste and green waste compost samples.

Parameters	Units	No.[1]	Min	Max	Median	Mean	SD [2]	Recommended Range[3]
Biowaste								
Total Nutrients								
TN	% dry wt	26	1.1	3	2.1	2.1	0.5	1.0-3.0 [4]
TP	% dry wt	26	0.2	16	0.4	1.6	3.9	0.4-1.1 [7]
TK	% dry wt	26	0.5	39.5	1.1	3.7	9.5	0.6-1.7 [8]
TMg	% dry wt	9	0.1	0.3	0.2	0.2	0.1	0.2-0.4 [9]
TCa	% dry wt	9	0.4	2.7	1.4	1.5	0.8	1.0-4.0 [10]
Water Soluble Nutrients								
NH_4-N	mg/L fresh wt	26	0	253	17.5	59.9	72.8	500 [5]
NO_3-N	mg/L fresh wt	26	0	400	84.5	146	130.3	240 [6]
PO_4-P	mg/L fresh wt	24	5	154	28	48.9	44.3	50-120 [7]
K_2O	mg/L fresh wt	24	26	2029	1089.5	1112.4	507.4	620-2280 [8]
Green Waste								
Total Nutrients								
TN	% dry wt	9	1.1	4	1.3	1.6	0.9	1.0-3.0 [4]
TP	% dry wt	7	0.2	0.6	0.4	0.4	0.2	0.4-1.1 [7]
TK	% dry wt	7	0.7	6	1.2	2.6	2.4	0.6-1.7 [8]
Water Soluble Nutrients								
NH_4-N	mg/L fresh wt	8	0	6	0.9	1.5	2	500 [5]
NO_3-N	mg/L fresh wt	8	0	252	20.5	44.5	84.4	240 [6]
PO_4-P	mg/L fresh wt	3	8	23	17	16	7.6	50-120 [7]
K_2O	mg/L fresh wt	3	617	2094	922	1211	779.8	620-2280 [8]

1 Number of samples tested
[2] Standard Deviation
[3] Recommended ranges for nutrients in compost
[4] Recommended range of TN in compost (Barker, 1997).
[5, 6] Bord na Mona typical range for available NH_4-N and NO_3-N in compost
[7] Bord na Mona recommended range for TP and available PO_4-P in compost
[8] Bord na Mona recommended range for TK and available K
[9, 10] Recommended range of TMg and TCa in compost (Barker 1997).

4.2.1 Total Nitrogen (TN)

A t-test was carried out to see if there was a significant difference between the mean of the TN for the two types of compost. From the results presented, it is evident that there is no significant difference between the means, t =1.549, 10 df, p=0.152 (Table 4.15).

Table 4.15. t-Test: Two-Sample Assuming Unequal Variances

Between the Means of TN

t-Test	*Biowaste*	*Green Waste*
Mean	2.096	1.589
Df	10	
t Stat	1.549	
P(T<=t) two-tail	0.152	
t Critical two-tail	2.228	

4.2.2 Available Nitrogen as NO_3-N

A t-test was carried out to see if there was a significant difference between the means of NO_3-N of the two types of compost. From the results presented it can be seen there was a highly significant difference, t=5.071, 26 df, p=0.000 (Table 4.16).

Table 4.16. t-Test: Two-Sample Assuming Unequal Variances

Between Means of NO_3-N

t-Test	*Biowaste*	*Green Waste*
Mean	146.038	14.857
Df	26	
t Stat	5.071	
P(T<=t) two-tail	0.000	
t Critical two-tail	2.056	

4.2.3 Available Nitrogen as NH_4-N

A t-test was carried out to see if there was a significant difference between the means of NH_4-N for the two types of compost. From the results presented it can be seen there was a highly significant, t=4.087, 25 df, p=0.000 (Table 4.17).

Table 4.17. t-Test: Two-Sample Assuming Unequal Variances
Between Means of NH_4-N

t-Test	*Biowaste*	*Green Waste*
Mean	59.896	1.450
df	25	
t Stat	4.087	
P(T<=t) two-tail	0.000	
t Critical two-tail	2.060	

4.3 OTHER PHYSICAL AND CHEMICAL PARAMETERS

Other important physical and chemical parameters of the biowaste, green waste and the commercial organic compost are examined below with emphasis on parameters such as C:N ratio, pH, moisture content, organic matter content, conductivity and bulk density. A summary of descriptive statistics for each of these parameters are given in Table 4.18.

Table 4.18. Summary of descriptive statistics for other physical and chemical parameters of the compost samples.

Parameters	Units	No.[1]	Min	Max	Median	Mean	SD [2]	Recommended Range[3]
Biowaste								
C:N ratio		26	12.2	29.5	15	16.5	4	<25[4]
pH	pH-units	26	6.3	8.6	7.7	7.7	0.6	6.9-8.3 [5]
Moisture	% fresh wt	24	22.1	75	48.3	47.2	12.2	45-65% [7]
Organic matter content	% dry wt	24	30	75.5	56.9	58.4	10.8	>30% [8]
Conductivity	µS/cm	26	780	7260	4920	4574	1497.4	2,000-6,000 [9]
Bulk density	g/L fresh wt	13	227	441.6	285.3	306.7	69.3	120-369 [10]
Green Waste								
C:N ratio		9	6.5	29.7	19	18.2	8.4	<25[4]
pH	pH-units	9	6.8	8.5	7.5	7.6	0.5	6.9-8.3 [5]
Moisture	% fresh wt	8	56.6	72.2	65.5	63.8	5.7	45-65% [7]
Organic matter content	% dry wt	9	32	56.4	47	47.5	7.4	>30% [8]
Conductivity	µS/cm	9	636	2660	742	1100.7	693.9	2,000-6,000 [9]
Commercial Organics								
C:N ratio		7	6	21	14	13.8	6.3	<25[4]
PH	pH-units	7	3.7	8.2	6.3	6.09	1.8	6.9-8.3 [5]
Moisture	% fresh wt	7	26	49	38	39	7.9	45-65% [7]
Organic matter content	% dry wt	3	40	75.5	50	55.2	18.3	>30% [8]
Conductivity	µS/cm	3	640	4770	4670	3360	2356.1	2,000-6,000 [9]

[1] Number of samples tested
[2] Standard Deviation
[3] Recommended ranges for compost quality parameters
[4] Limit for C:N ratio specified by the Environmental Protection Agency in accordance with Waste Licensing under the Waste Management Act 1996.
[5] Recommended pH range of compost, Bord na Mona, 2003
[6,7] Recommended range of moisture content, Biotreat, 2003
[8] Minimum limit for organic matter, specified by the Environmental Protection Agency in accordance with Waste Licensing under the Waste Management Act 1996.
[9,10] Recommended ranges for conductivity and dry bulk density, Bord na Mona, 2003

4.3.1 C:N Ratio

An ANOVA test was carried out to see if there was a significant difference between the means of the C:N ratios for the biowaste, green waste and commercial organic compost. From the results presented in table 4.19 it can be seen there was no significant difference between the means, F=1.271, 2 df, p=0.292.

Table 4.19. ANOVA variance between means of C:N ratios for the different types of compost studied.

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between means	78.199	2	39.099	1.271	0.292	3.238

4.3.2 pH Scale

An ANOVA test was carried out to see if there was a significant difference between the means of the pH for the biowaste, green waste and commercial organic compost. From the results presented in table 4.20 it can be seen there was a highly significant difference between the means, F=9.452, 2 df, p=0.000.

Table 4.20. ANOVA variance between pH means for the different compost types studied

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between pH means	14.505	2	7.253	9.452	0.000	3.238

4.3.3 Moisture Content

An ANOVA test was carried out to see if there was a significant difference between the means of the moisture content for the biowaste, green waste and commercial organic compost. From the results presented in table 4.21 it can be seen there was a highly significant difference between the means, F=11.269, 2 df, p=0.000.

Table 4.21 ANOVA variance between means of moisture content in the compost samples

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between moisture means	2537.032	2	1268.516	11.269	0.000	3.259

4.3.4 Organic Matter Content

An ANOVA test was carried out to see if there was a significant difference between the means of the organic matter content for the biowaste, green waste and commercial organic compost. From the results presented in table 4.22 it can be seen there was a significant difference between the means, F=3.402, 2 df, p=0.045.

Table 4.22 ANOVA variance between means of organic matter content in the compost samples

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between organic matter means	784.239	2	392.119	3.402	0.045	3.285

4.3.5 Conductivity

A t-test was carried out to see if there was a significant difference between the means of conductivity for the biowaste and green waste compost. The mean of conductivity for the commercial organic compost was not included as it was felt that it was not a representative mean due to a very small sample number. From the results presented it can be seen there was a highly significant difference between the means, t=9.291, 30 df, p=0.000 (Table 4.23).

Table 4.23. t-Test: Two-Sample Assuming Unequal Variances between means of conductivity for the biowaste and green waste compost

t-Test	*Biowaste*	*Green Waste*
Mean	4574	1100.7
df	30	
t Stat	9.291	
P(T<=t) two-tail	0.000	
t Critical two-tail	2.042	

4.4 MATURITY

4.4.1 Self Heating Test

Five test results for the self heating test were available for the biowaste compost. Four of these were found to be of class stability IV, whilst the other sample was found to be in class III (Table 4.24).

Eight sample test results were available for the green waste compost of which six were found to be in class of stability V and the other two samples were in class of stability III (Table 4.24).

Table 4.24. Self Heating Test Results for the Biowaste and Green Waste Compost

Biowaste Samples	**B4h**	**B4i**	**B4j**	**B4k**	**B5**			
Class of Stability	IV	IV	IV	III	IV			
Green Waste Samples	G1a	G1b	G1c	G1d	G1e	G1f	G2	G3
Class of Stability	V	V	V	V	V	V	III	III

4.4.2 Oxygen Uptake Rate

Table 4.25. Oxygen Uptake Rate test results for the compost samples

Parameters	Units	No.[1]	Min	Max	Median	Mean	SD [2]
Oxygen uptake rate							
Biowaste	mg O_2 kg VS^{-1} h^{-1}	2	1220	1833	N/a	N/a	N/a
Green Waste	mg O_2 kg VS^{-1} h^{-1}	6	43	2024	367.5	608	714.1
Commercial Organics	mg O_2 kg VS^{-1} h^{-}	7	12	226	96.3	116.9	74.9

[1] Number of samples tested
[2] Standard Deviation
[3] Not Applicable

4.4.3 Cress Germination Test

Table 4.26. Summary of descriptive statistics for % cress

Germination test results

Parameters	Units	No.[1]	Min	Max	Mean	Median	SD [2]
Cress Germination Test	%						
Biowaste	%	5	70	100	87.8	88.9	13.
Green Waste	%	2	78	90	84.	84	8.5

[1] Number of samples tested
[2] Standard Deviation

4.5 FOREIGN MATTER

Table 4.27. Summary of descriptive statistics for foreign matter including impurities and gravel and stone in the compost samples.

Parameters	Units	No.[1]	Min	Max	Median	Mean	SD [2]
Biowaste							
Impurities	%(> 2 mm)	21	0	11	0.6	1.8	3
Gravel and Stone	%(> 5 mm)	19	0	24	3.9	6	6.8
Green Waste							
Impurities	%(> 2 mm)	8	0	11	0.1	1.5	3.9
Gravel and Stones	%(> 5 mm)	7	0.1	6.2	2	2.6	2.2
Commercial Organics							
Impurities	%(> 2 mm)	3	0	0.4	0.4	0.3	0.2
Gravel and Stones	%(> 5 mm)	3	4.8	8	7	6.6	1.6

[1] Number of samples tested
[2] Standard Deviation

4.6 PATHOGENS

Results for the presence of faecal coliforms and salmonella were available for the biowaste and green waste compost. Some descriptive statistics are given in table 4.28.

Table 4.28. Summary of descriptive statistics for the presence of pathogens in the compost samples

Parameters	Units	No.[1]	Min	Max	Median	Mean	SD [2]
Biowaste							
Faecal coliforms	MPN/g of total solids	21	3	1100	4	112.2	263.2
Salmonella	Absent in 50 g	21	0	3200	0	286.51	906.9
Green Waste							
Faecal coliforms	MPN/g of total solids	6	3	688	60	221.7	300.6
Salmonella	Absent in 50 g	6	0	0	0	0	0

[1] Number of samples tested
[2] Standard Deviation

4.7 OVERALL QUALITY OF THE BIOWASTE AND GREEN WASTE COMPOST

The overall quality of twenty samples of the biowaste compost and eight samples of green waste compost were analysed according to the statutory limits specified in Annex III of the EU Biowaste Directive (Table 4.29 and 4.30).

Table 4.29 shows each sample classification according to heavy metal content, whether it passed or failed the specifications for the impurities and gravel and stones content of compost, and the overall classification of the sample. Non-conforming samples exceeded all the statutory limits according to the EU Biowaste Directive.

Table 4.29 Classification of biowaste compost samples according to the EU Biowaste Directive

Sample	Heavy Metals	Impurities <0.5% Class I and II	Impurities <3.0% Stabilised Biowaste	Gravel and Stones (<5.0 %)	Overall Classification
B1a	Class II	P	P	P	Class II*
B1b	Class II	P	P	P	Class II*
B2a	Class I	F	P	P	SB
B2b	Class I	F	P	P	SB
B2c	Class II	P	P	F	SB
B3a	Class II	F	P	P	SB
B3b	Class I	F	P	P	SB
B4a	SB	F	P	P	SB
B4b	SB	F	F	P	Non conforming*
B4c	Class I	P	P	P	Class I
B4d	Class I	F	P	P	SB
B4e	Class I	F	F	F	None
B4f	Class I	P	P	F	SB
B4g	Class I	P	P	F	SB
B4h	Class I	P	P	F	SB
B4i	Class II	F	F	N/a	Non conforming
B4j	Class II	P *	P	P *	Class II
B4k	Class II	P	P	P	Class II
B4l	Class II	P	P	F	SB
B4m	Class II	P	P	F	SB

* Failed sanitation requirements as specified in Annex II of the EU Biowaste Directive

SB: Stabilised Biowaste

It can be seen that when all the parameters were considered only one sample was classified as Class I compost, four as Class II compost and twelve as stabilised biowaste and that three of the samples were non-conforming and exceeded all the statutory limits stipulated for these parameters. However, two of the samples classified as Class II compost failed the sanitation requirements of the Biowaste Directive.

On comparing eight of the green waste compost samples for overall compost quality it was found that three (37.5%) of the samples could be classified as Class I compost and three (37.5%) samples as Class II compost. One of the samples (12.5%) was classified as stabilised biowaste and one (12.5%) of the samples was non-conforming to the statutory limits specified by the standard (Table 4.29).

Table 4.30 Classification of green waste compost samples according to the EU Biowaste Directive

Sample	Heavy Metals	Impurities <0.5% Class I and II	Impurities <3.0% Stabilised Biowaste	Gravel and Stones (<5.0 %)	Overall Classification
G1a	Class II	P	P	P	Class II
G1b	Class I	P	P	P	Class I
G1c	Class II	P	P	P	Class II
G1d	Class II	P	P	P	Class II
G1e	Class I	P	P	P	Class I
G1f	Class I	P	P	P	Class I
G2	Class I	P	P	F	SB
G4	N/A	F	F	N/A	Non conforming

N/A: test results not available
SB: stabilised biowaste

5.0 DISCUSSION

5.1 HEAVY METALS

The concentration of heavy metals in compost is of serious concern and is one of the main quality criteria, which mostly restricts the use of compost in agriculture (Pinamonti, et al., 1997). Classifying compost into certain quality classes according to the EU Biowaste Directive, and restricting its use, serves to protect the environment and human health, as heavy metals may bioaccumulate and enter the food chain if applied to agricultural crops in the form of contaminated compost. (Veeken and Hamelers, 2002; Zheljazkov and Warman, 2003).

5.1.1 Overview Of Classification Of Compost Samples According To Heavy Metal Content

5.1.1.1 Quality Of Biowaste Compost Samples

Twenty-four samples of biowaste compost were completely analysed for the concentration of all the heavy metals in the compost. According to the EU Biowaste Directive and after taking an allowed 20% deviation from statutory limits of samples which failed to conform to any given limit for heavy metal concentration, ten (41.7%) of the biowaste compost samples met the requirements of the Biowaste Directive and can be classified as Class I compost. Twelve samples (50%) can be classified as Class II compost. Nineteen (79.2%) of the samples met the requirements for heavy metal content in compost as specified by the EPA. No deviation from the EPA statutory limits was allowed for. Two (8.3%) samples were contaminated with too high a concentration of mercury and did not meet the requirements of the two standards and were classified as stabilised biowaste (Table 5.6). These findings were very promising and show that heavy metal contamination of biowaste compost is not of major concern to the composting industry however, every effort should be made to continue to decrease heavy metal contamination of compost and thereby increase compost quality. No major restrictions will be placed on the use of the biowaste compost samples examined apart from the two samples classified as stabilised biowaste.

5.1.1.2 Quality Of Green Waste Compost Samples

Eight samples of green waste compost were analysed for the presence of heavy metals in the compost. Four (50%) of the green waste compost samples were be classified as Class I compost and the other four (50%) as Class II compost. Seven (87.5%) of the samples met the requirements of the EPA standard. One sample (G3) failed to meet the EPA requirement due to excessive amounts of chromium (Table 5.1).

Samples B5 and G3 which originated from the same site, contained elevated levels of nickel and chromium. This could be due to contamination of the feedstock with metal or glass (Reinhofer et al., 2002) or perhaps due to the use of machinery such as shredders and screeners which may have contained a nickel-chromium alloy and that ‘rub off’ between the machinery and the compost may account for the contamination (Fricke et al., 1992).

5.1.1.3 Quality Of Commercial Organic Compost

Eleven samples of organic compost were analysed for the presence of heavy metals. One of the commercial organic compost samples can be classified as Class I compost while three (42.9%) of the samples can be classified as Class II compost Three (42.9%) of the samples met the requirements of the EPA standard. Three (42.9%) samples were too contaminated and exceeded the requirements of both standards and were therefore classified as stabilised biowaste (Table 5.1).

5.1.1.4 Quality Of Sludge Compost

Nine (81.8%) of the eleven samples of sludge compost samples could be classified as Class I compost and one (9.1%) of the samples as Class II compost. Ten (90.9%) of the samples met the requirements for EPA compost, while one of the sludge compost samples exceeded all the critical limits for the two standards and was classified as stabilised biowaste (Table 5.1).

Table 5.1 The number and percentage of samples of each type of compost which met the heavy metal requirements as stipulated by the EPA and the EU Biowaste Directive

Standard	Biowaste Compost (n=24)	Green Waste Compost (n=8)	Commercial Organic Compost (n=7)	Sludge Compost (n=11)
EPA	19 (79.2%)	7 (87.5%)	3 (27.3%)	10 (90.9%)
Class I	10 (41.7%)	4 (50%)	1 (14.3%)	9 (81.8%)
Class II	12 (50%)	4 (50%)	3 (27.3%)	1 (9.1%)
Stabilised Biowaste	2 (8.3%)	0 (0%)	2 (27.3%)	1 (9.1%)
Non-conforming to both standards	0 (0%)	0 (0%)	1 (14.3%)	0 (0%)

5.1.2 A Comparison Of Mean Heavy Metal Content For The Different Types Of Compost Analysed.

Sludge compost contained the least amount of contamination when concentrations of all the heavy metals were take into account albeit, all samples originated from one composting facility. Commercial organic compost contained significantly greater amounts of copper, zinc and lead compared to the other types of compost (Table 5.2). It contained similar concentrations of cadmium, mercury, nickel and chromium compared to the biowaste and green waste compost.

On comparing the biowaste compost and the green waste compost, biowaste compost contained greater amounts of copper, zinc, mercury and nickel, whereas the green waste compost contained higher concentrations of lead, cadmium and chromium. The concentration of lead was significantly higher which could be attributable to lead being released into the air from car exhausts and industry, and then undergoing deposition from the air onto soils and because green waste compost contains a certain proportion of soil, lead could be introduced into the composting process in this way, and subsequently into the end product. Green waste and biowaste compost contained approximately similar amounts of copper and zinc.

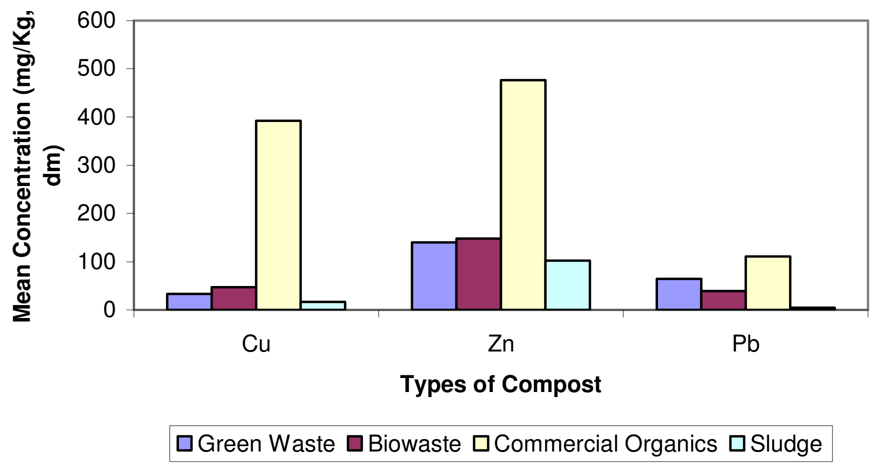
Green waste compost contained slightly higher concentrations of chromium compared to the other types of compost. Sludge compost contained the least amount. The concentration of nickel was similar in all the types of compost except again for the sludge compost where it was at its lowest concentration (Fig 5.1, b).

All the compost contained favourable concentrations of mercury, which were all below the critical limit for Class I compost according to the EU Biowaste Directive. The biowaste compost contained the greatest concentration of mercury with the sludge compost having the least concentration. The green waste compost contained the greatest amount of cadmium, followed by the commercial organic compost. The sludge compost contained the least amount of cadmium. The biowaste and sludge compost can be classified as Class I compost. The other types of compost can be classified as Class II compost or as meeting the EPA standard for cadmium.

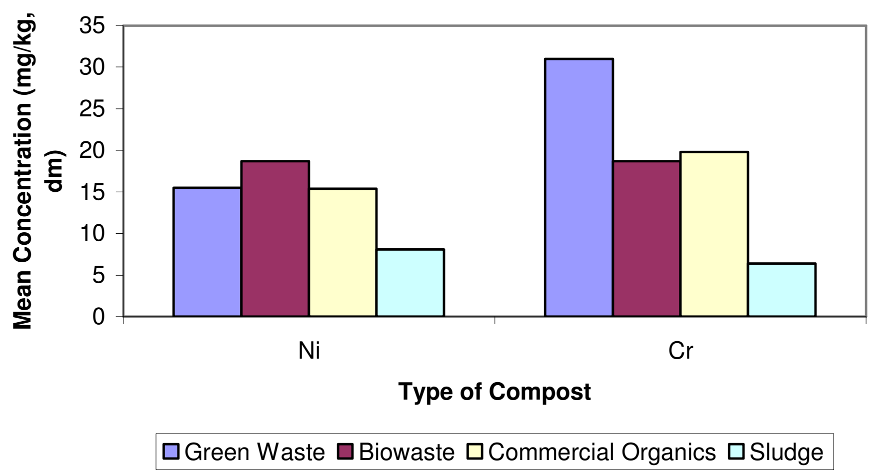
Table 5.2 Mean concentration of heavy metals in the different types of compost analysed

Parameters	Units	Biowaste Compost	Green Waste Compost	Commercial Organic Compost	Sludge Compost
Copper	mg/Kg dm	47.5	33.3	392.1	16.6
Zinc	mg/Kg dm	147.8	140.1	476.3	102.1
Lead	mg/Kg dm	39.5	64.0	111.2	5.1
Cadmium	mg/Kg dm	0.6	0.9	0.8	0.4
Mercury	mg/Kg dm	0.4	0.2	0.1	0.1
Nickel	mg/Kg dm	18.7	15.5	15.4	8.1
Chromium	mg/Kg dm	18.7	31.0	19.8	6.4

(a)



(b)



(c)

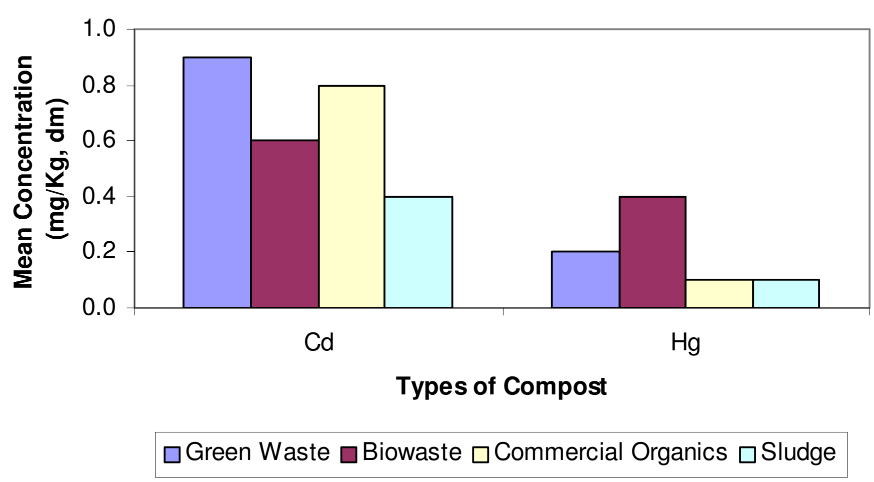
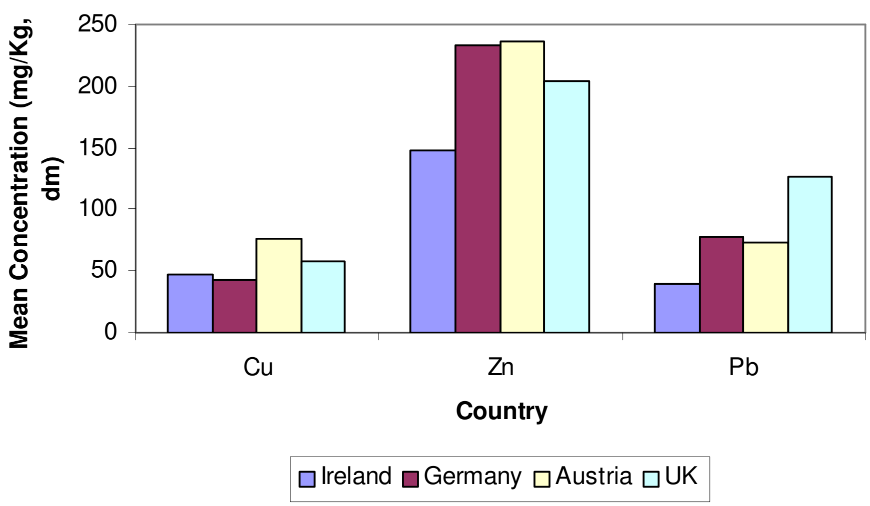


Fig 5.1 (a,b,c) Graph of the mean concentration of heavy metals in the different types of compost analysed

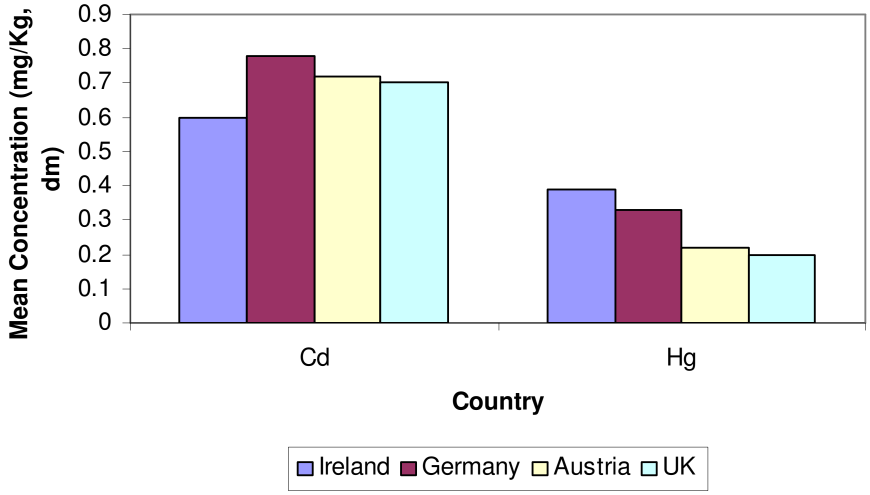
5.1.3 Heavy Metals in Irish Biowaste Compost Compared to Composts from Other Countries

On comparing the means of heavy metal concentrations, it was found that Irish biowaste compost compares favourably with compost from Germany, Austria and the UK. Irish biowaste compost contained the lowest concentration of zinc, lead and cadmium. Concentrations of zinc and lead were distinctly lower (Fig 5.2, a). This could be attributed to the fact that these countries are more heavily industrialised and perhaps have a higher housing density which may increase the amount of contamination by heavy metals in biowaste compost. Irish biowaste compost however, contained the highest concentration of mercury (Fig 5.2, b) perhaps due to the two erroneous sample results.

(a)



(b)



* It was thought that the mean concentration of mercury (mg/Kg) in the Irish biowaste compost was quite high due to two possibly erroneous sample results analysed.

(c)

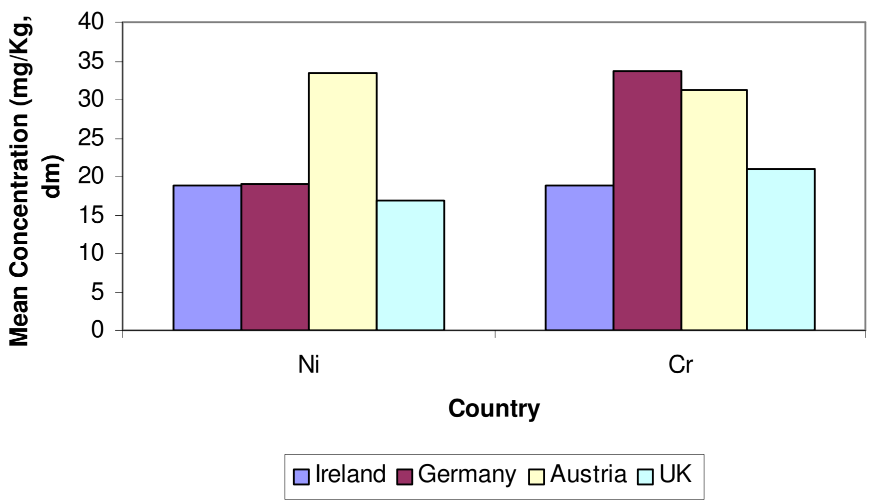
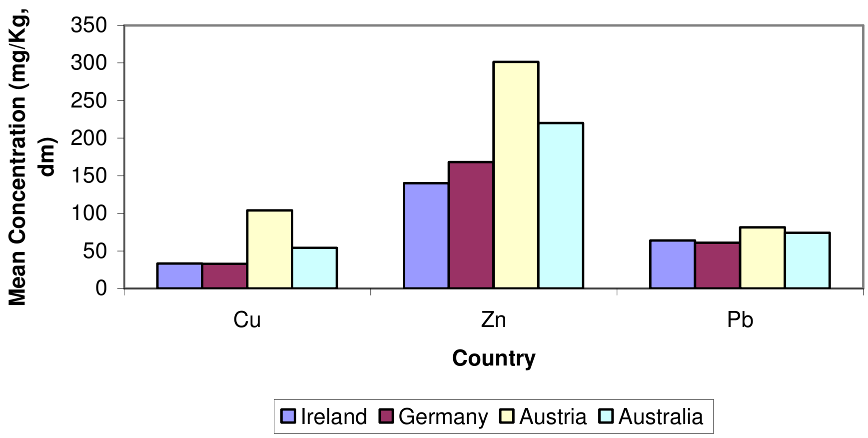


Fig 5.2 (a, b, c). Graph of concentration of heavy metals in Irish biowaste compost compared to heavy metal concentrations in green waste compost from other countries. Source: Fricke, 1994, Amlinger, 2001, UK Composting Association, 2003.

5.1.4 Heavy Metals In Irish Green Waste Compost Compared To Compost From Other Countries

As with biowaste compost, green waste compost again compares favourably on comparing heavy metal concentrations in green waste compost from other countries namely Germany, Austria and Australia. Irish green waste compost had similar or more often, lower concentrations of heavy metals (Fig 5.3, a). Cadmium is an exception to this as Irish green waste compost contained a slightly higher concentration of this heavy metal compared to the other countries examined (Fig 5.3, b).

(a)



(b)

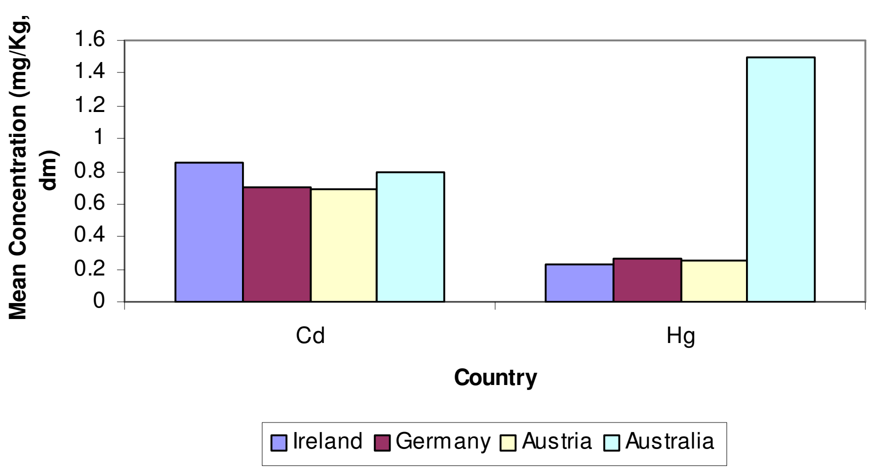


Fig 5.3 (a and b). Graph of concentration of heavy metals in Irish green waste compost compared to heavy metal concentrations in green waste compost from other countries.

Source: Fricke, 1994, Amlinger, 2001, Wilkinson et al., 2002.

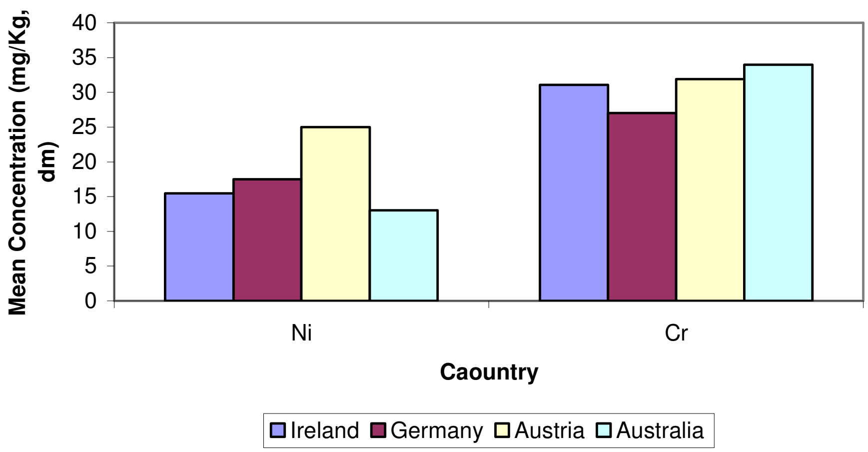


Fig 5.4 (c). Graph of concentration of heavy metals in Irish green waste compost compared to heavy metal concentrations in green waste compost from other countries.

Source: Fricke, 1994, Amlinger, 2001, Wilkinson et al., 2002.

5.1.5 Correlations Between Heavy Metals

The most significant correlation between heavy metals in the biowaste compost was found between nickel and copper (R^2 = 0.5628). However this correlation was not very strong. Significant correlations were found between copper and zinc (R^2=0.9172), copper and lead (R^2=0.875), zinc and lead (R^2= 0.9288) in the green waste compost. Similar correlations between these heavy metals were also found in other studies on compost quality (Prasad, 2003 and Reinhofer et al., 2002). Another correlation was found between zinc and nickel (R^2=0.7205) in the green waste compost, which also supports Prasad (2003) findings in which he found a similar correlation between these heavy metals (R^2= 0.8692).

Overall, the most significant correlations were found between some of the heavy metals in the green waste compost. This supports findings from other studies and presents more evidence that some heavy metals do in fact occur together. These findings may allow laboratories to limit heavy metal testing and therefore carry out single tests for pairs of strongly correlated heavy metals. This would in turn, limit the costs of quality testing for facility operators. The accuracy of the findings of this research was limited due to the fact that only a small number of compost samples were available for analysis. More detailed research into correlations between metals in compost is required on a larger scale, whilst also considering the time of year and the season in which the feedstock is composted.

5.2 NUTRIENT CONTENT OF COMPOST SAMPLES

5.2.1 Total Nitrogen (TN)

A favourable mean of 2.1% TN was found in the biowaste compost. All the samples were within the recommended range (Fig 5.5).

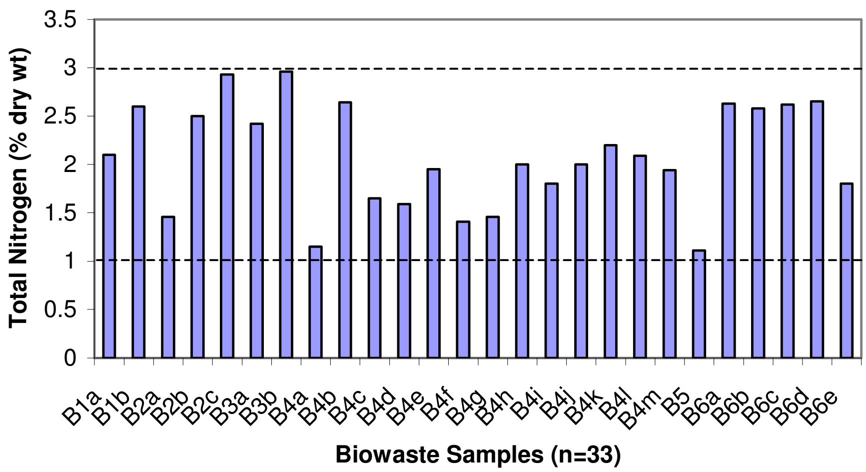


Fig 5.5 Graph of the TN (%) for each of the biowaste compost samples showing recommended threshold levels.

A mean of 1.6% TN was found in the green waste compost. One (11.1%) of the samples exceeded the upper threshold of the recommended range (Fig 5.6). Sample G1a contained a high amount of TN especially when compared to sample G1b, which is from the same site.

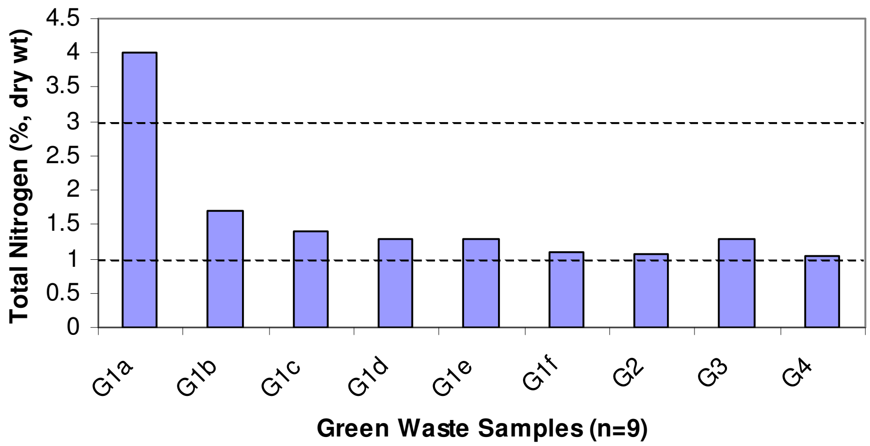


Fig 5.6 Graph of the TN (%) for each of the green waste compost samples showing recommended threshold levels.

On comparing the values of the means there was no significant differences between TN in the biowaste and green waste compost (p=0.15). All of the samples analysed for both types of compost contained more than 1% TN. Thus, both composts can be considered to have fertilising capabilities and can be used in agriculture. Irish biowaste and green waste compost could also potentially be used in container production of crops as the TN content also exceeds the typical level of 1.5% TN required for growing crops in this way (Barker, 1997)

5.2.2 Available Nitrogen as NO_3-N

The mean NO_3-N values for the biowaste compost samples was found to be 146 mg/L which is below the recommended upper threshold level of 240 mg/L. Eight samples (30.8%) of the biowaste compost exceeded the recommended limit (Fig 5.7) and therefore, according to Bord na Mona (2003), contained excessive amounts of NO_3-N. Two samples (7.7%) of the biowaste compost contained less than the recommended minimum level of 15 mg/L (Fig 5.7). Therefore, because of such a low nutrient concentration these compost samples would be better used as mulch (Barker, 1997).

A high standard deviation of 130.3 was calculated which showed a lot of variation around the mean. It can be seen from figure 5.7 that variations in the concentration of NO_3-N existed between sites and also between samples of biowaste compost from the same site. This is evident on examining compost samples from facility B4 and B6.

This variation indicates that the composting process at these facilities were not fully controlled with different rates of mineralisation of organic nitrogen occurring and compost of different maturity levels been produced.

The high variation in the concentration of NO_3-N in compost from site B4 and B6 meant that each compost sample would have to be looked at individually and an appropriate end use for the product be selected accordingly. For use in horticulture for example, some of the compost samples from site B4 and B6 were suitable for seedling and nursery plants, some for potting plants and bedding plants, while others were more suitable for crops such as tomatoes and cucumbers (Environment Agency, 2000). Site B4 and B6 obviously lack consistency in producing a product of uniform quality and content.

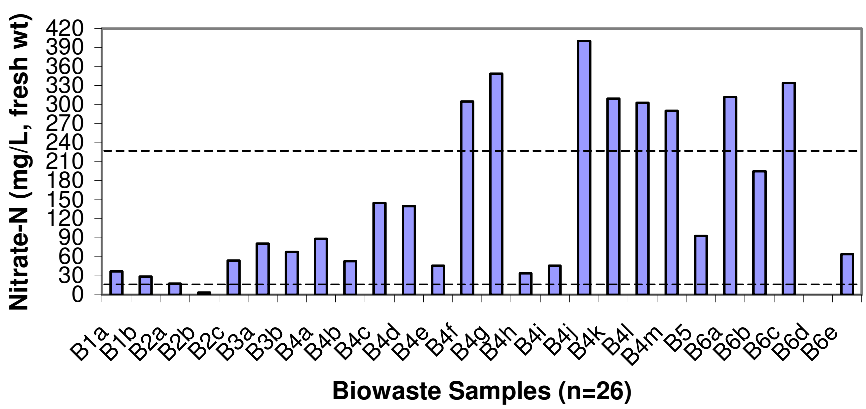


Fig 5.7. Graph of the concentration of NO_3-N (mg/L) in the biowaste compost samples showing recommended threshold levels.

The mean concentration of NO_3-N in the green waste compost was 44.5 mg/L, which is below the recommended upper threshold and above the lower threshold. However, one (12.5%) of the samples was above the recommended upper threshold and contained excessive amounts of NO_3-N. It should be noted that Sample G3 contained an extremely high concentration of NO_3-N which could be due to laboratory error and therefore was biased towards the mean. If sample G3 was ignored the unbiased mean would be 14.9 mg/L, which is slightly below the recommended lower threshold for the concentration of NO_3-N in compost. Two (25%) of the samples of the green waste compost were totally deficient in NO_3-N and again should be used as mulch (Fig 5.8).

Overall, considering the unbiased mean the green waste compost was quite low or deficient in available NO_3-N for use in growing media.

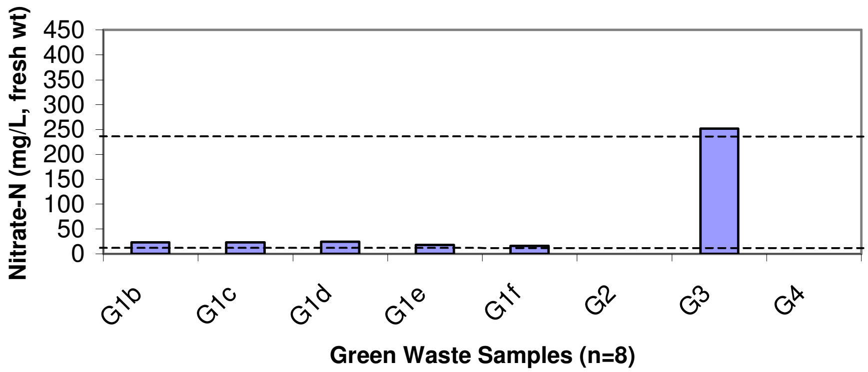


Fig 5.8 Graph of the NO_3-N concentration (mg/L) for each of the green waste compost samples showing recommended threshold levels.

A t-test was performed which concluded that the mean of the two samples were highly significantly different (p=0.000), and that the biowaste compost samples contained a greater amount of available NO_3-N compared to the green waste compost.

5.2.3 Available Nitrogen as NH_4-N

The mean value of NH_4-N was 59.9 mg/L in the biowaste compost. This is below the upper threshold of 200 mg/L. Two samples (7.7%) of the biowaste compost exceeded this threshold (Fig 5.9).

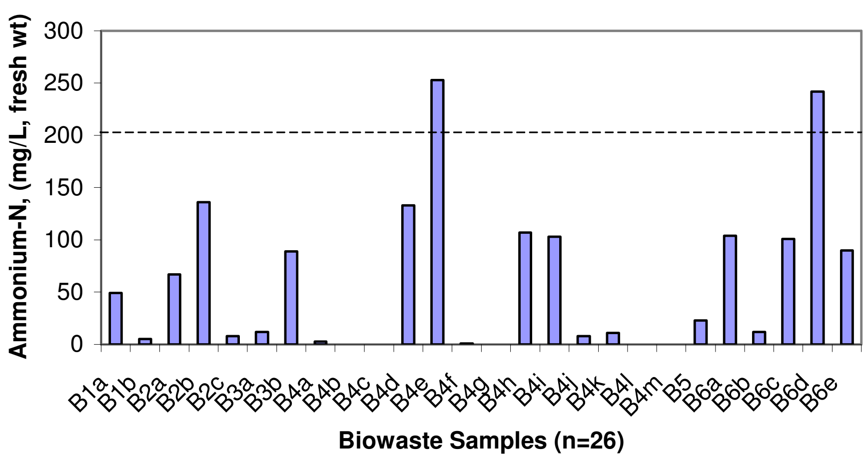


Fig 5.9 Graph of the NH_4-N concentration (mg/L) for each of the biowaste compost samples showing recommended threshold levels.

The mean concentration of NH_4-N in the green waste compost was 1.5 mg/L, which is well below the recommended upper threshold level. All the green waste samples were below this threshold level (Fig 5.10).

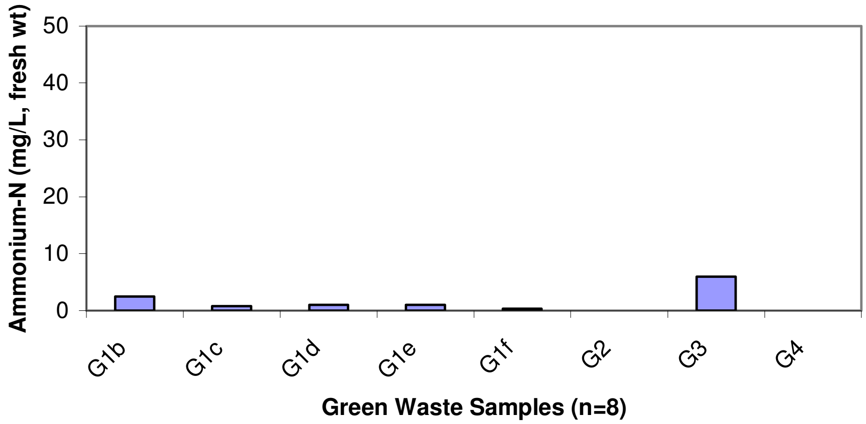


Fig 5.10 Graph of the NH_4-N concentration (mg/L) for each of the green waste compost samples

A t-test was carried out which indicated that there was a highly significant difference between the means ($p=0.000$) and that the biowaste compost contained a significantly higher amount of NH_4-N compared to the green waste compost.

The mean values of NH_4-N in the biowaste and green waste compost samples indicate that they contain low to normal values for use in horticulture and agriculture (Environment Agency, 2000).

On comparing the concentration of NO_3-N and NH_4-N in the biowaste compost samples it can be seen that some of the samples, for example B1a, B2b, B4e, B4h, B4i and B33 contained more NH_4-N than NO_3-N indicating that the composting process may not have been complete and that immature compost was produced. (Fig 5.7 and Fig 5.9). The concentration of NO_3-N was higher then the concentration of NH_4-N in the green waste compost samples indicating that these samples were mature (Sánchez-Monedero et al., 2001). Samples G3 and G4 contained no NO_3-N or NH_4-N (Fig.5.8 and 5.10).

5.2.4 Total Phosphorous (TP)

The average TP content was found to be 1.6% for the biowaste compost, which exceeds the typical upper threshold of 1.1%. Eleven (42.3%) of the biowaste compost samples had levels of TP outside of the recommended range. Samples B1a and B1b showed exceptionally high levels for TP content which could be due to an analytical or reporting error which biased the mean TP value (Fig 5.11). If TP values for samples B1a and B1b were ignored, the mean value for TP would then be 0.5%, which is within the typical range.

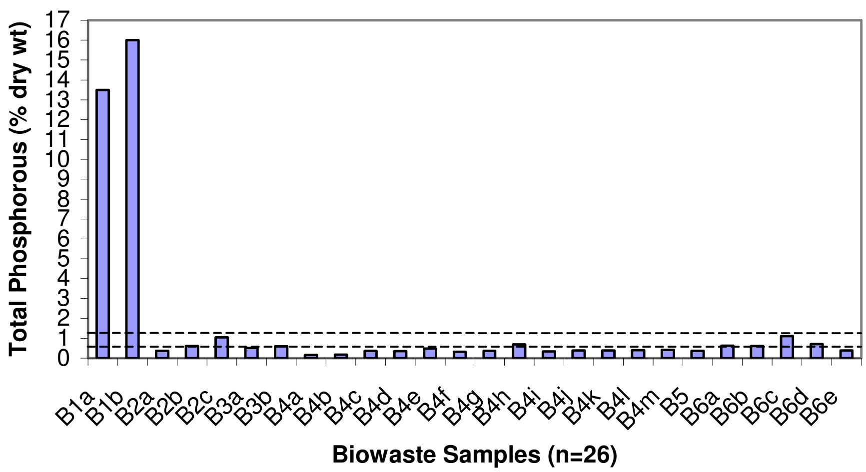


Fig 5.11 Graph of the TP (%) for each of the biowaste compost samples showing recommended threshold levels.

The mean of TP for the green waste compost was 0.4% which is just at the recommended lower threshold level of 0.4%. Two (28.6%) of the green waste compost samples were below the lower threshold level (Fig 5.12).

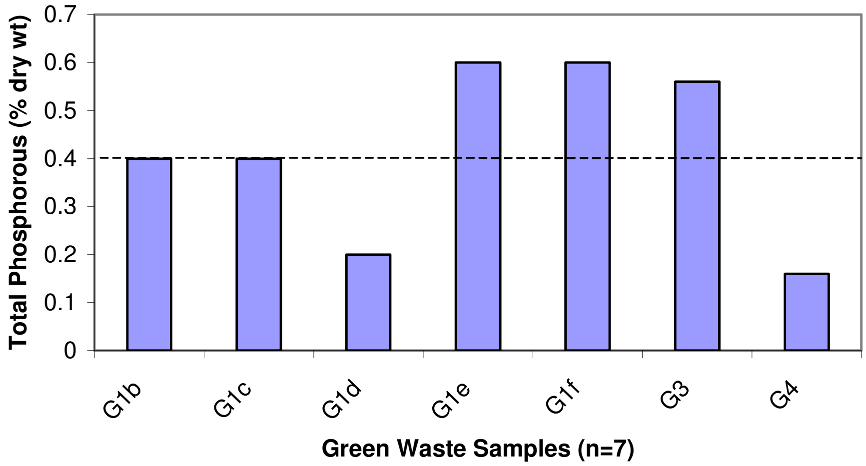


Fig 5.12 Graph of the TP (%) for each of the green waste compost samples showing the recommended lower threshold level.

A t-test was carried out to see if there was a significant difference between the unbiased means of TP for the two types of compost. From the results presented it can be seen there was no significant difference, t=0.928, 12 df, p=0.371 (Table 5.3). Overall, according to Bord na Mona (2003) and on considering the unbiased means, TP was quite low in both composts.

Table 5.3 t-Test: Two-Sample Assuming Unequal Variances for unbiased means of TP

t-Test	*Biowaste*	*Green Waste*
Mean	0.495	0.417
df	12	
t Stat	0.928	
P(T<=t) two-tail	0.371	
t Critical two-tail	2.179	

5.2.5 Available Phosphorous as PO_4-P

The mean of the PO_4-P content of the biowaste compost (48.9 mg/L) was found to be quite low and just below the typical lower threshold level of 50 mg/L. Fifteen (62.5%) of the biowaste compost samples were below the lower threshold level, while two (8.3%) of the samples exceeded the upper threshold level of 120 mg/L of the typical range (Fig 5.13).

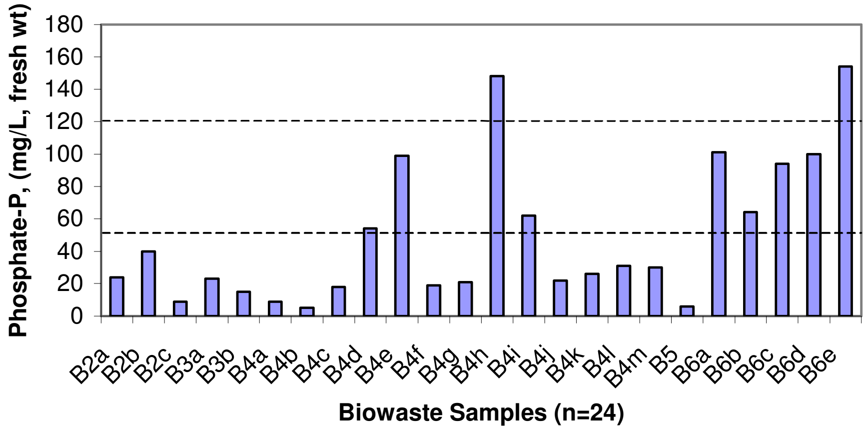


Fig 5.13 Graph of PO_4-P (mg/L) content of the biowaste compost samples showing recommended threshold levels.

The mean of the PO_4-P content of the green waste compost was calculated to be 16 mg/L however, it must be noted that since there were only three samples available for analysis, this value may not accurately represent the nationwide mean of PO_4-P in green waste compost. It was found that all the samples (100%) of the green waste compost did not contain the typical minimum threshold concentration of PO_4-P (Fig 5.14).

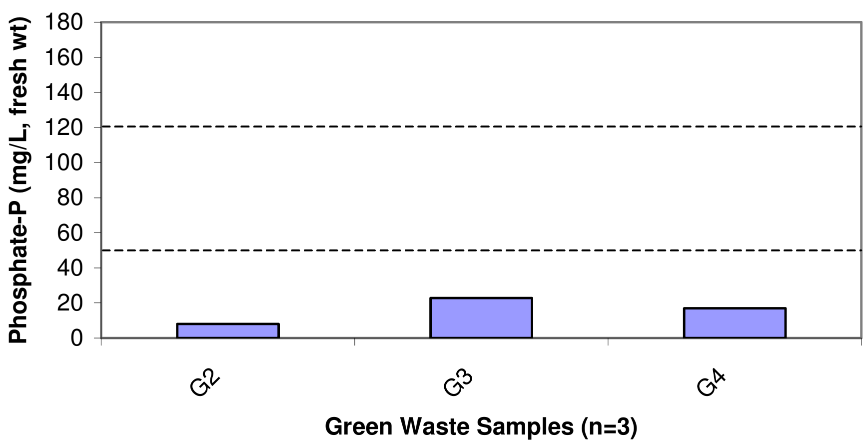


Fig 5.14 Graph of PO_4-P (mg/L) content of the green waste compost samples showing recommended threshold levels.

5.2.6 Total Potassium (TK)

The average content of TK in the biowaste compost was found to be 3.7%, which is quite high compared to other values quoted in the literature (Barker, 1997, Bord na Mona, 2003). Samples B1a and B1b showed extremely high levels of TK compared to the other samples which could be due to laboratory error and therefore biased the mean (Fig 5.15). If TK values for samples B1a and B1b were ignored, the mean of the other samples of the biowaste compost would have been 1.1% and within the typical range of 0.6-1.7 % (Bord na Mona, 2003). Four samples (15.4%) of the biowaste compost samples were found to be outside of the typical range (Fig 5.15).

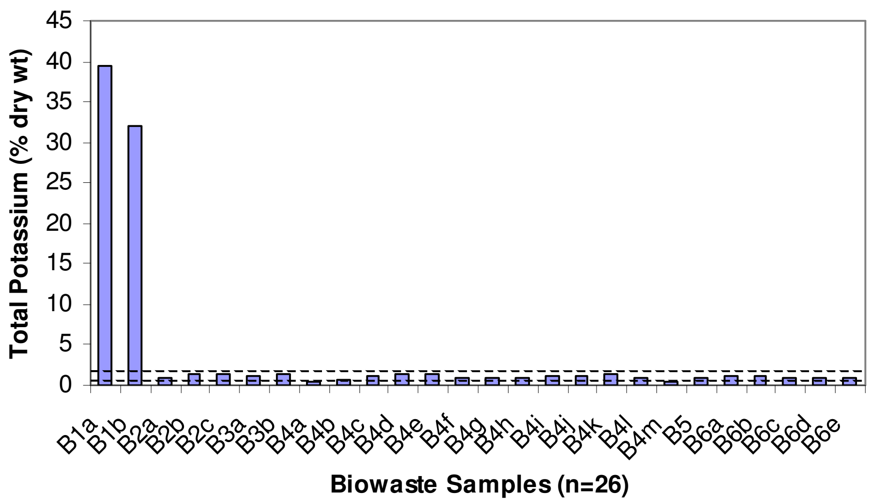


Fig 5.15 Graph of the TK (%, dry wt) in the biowaste compost samples showing recommended threshold levels.

The mean of the TK in the green waste was 2.6%, which is greater than the upper threshold level of the typical range. Samples G1e and G1f showed very high concentrations of TK, which had a big influence on the mean value of TK (Fig 5.16). Three (42.9%) of the samples of green waste compost were found to exceed the typical upper threshold level of 1.7% (Fig 5.16).

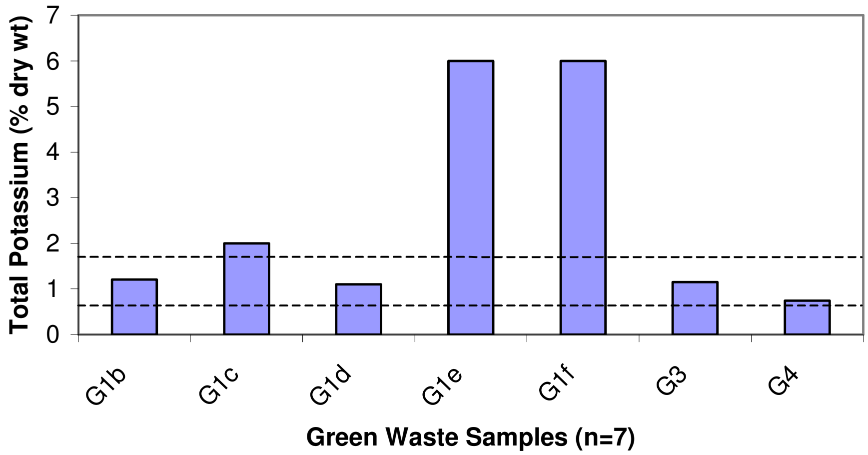


Fig. 5.16 Graph of the TK (%) in the green waste compost samples showing recommended threshold levels.

5.2.7 Available Potassium

The average content of available K in the biowaste compost was found to be 1112.4 mg/L, which is within the typical range of 620-2280. None of the samples exceeded the upper threshold level while three samples (12.5%) of the biowaste compost were below the lower threshold level (Fig 5.17).

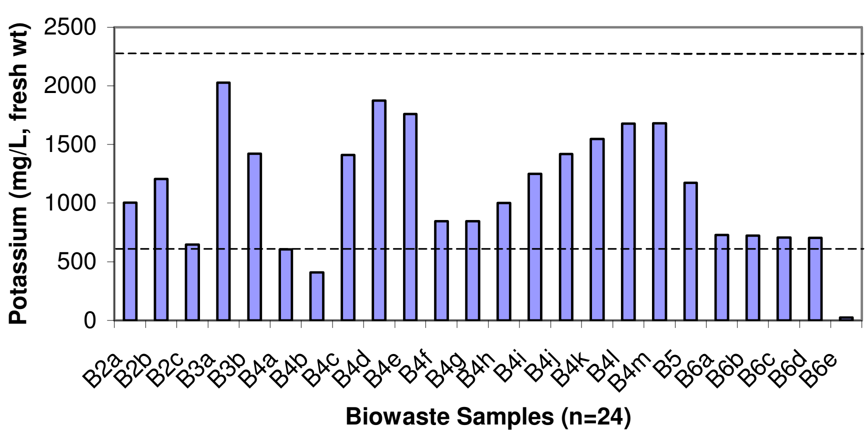


Fig 5.17 Graph of available K (mg/L) in the biowaste compost samples showing recommended threshold levels.

In the green waste compost the mean concentration of 1211 mg/L of available K was calculated which is also within the typical range. Only three samples of the green waste compost were available for analysis, therefore this may not reflect a very accurate mean value. One (33.3%) of the green waste compost samples was below the lower threshold level of 620 mg/L.

5.2.8 Magnesium

The mean of the total concentration of magnesium in the biowaste compost samples was found to be 0.2%, which is just within the typical range of 0.2-0.4%. Five samples (55.6%) of the biowaste compost samples were found to be below the lower threshold level (5.18). The concentration of the total magnesium in the compost is quite low and is probably due to a low concentration of magnesium in the feedstock material (Barker, 1997).

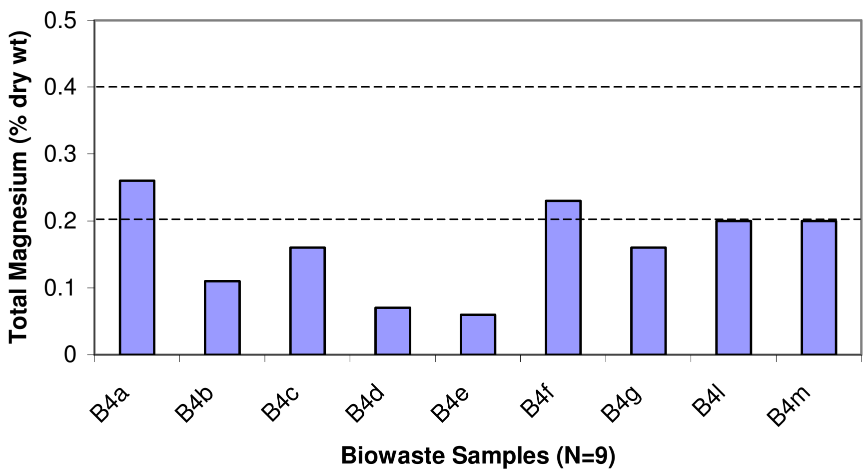


Fig 5.18 Graph of the total magnesium (%) for each of the biowaste compost samples showing recommended threshold levels.

5.2.9 Calcium

The mean of the total concentration of calcium in the biowaste compost samples was calculated to be 1.53%, which is within the typical range of 1.0-4.0%. Two samples (22.2%) of the biowaste compost samples were found to be below the lower threshold level (Fig 5.19).

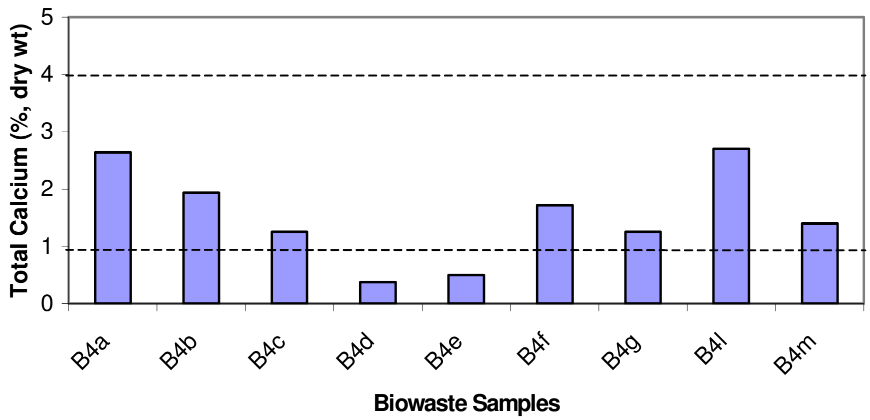


Fig 5.19 Graph of the total calcium (%) for each of the biowaste compost samples showing recommended threshold levels.

5.3 OTHER PHYSICAL AND CHEMICAL PARAMETERS

Results of analysis of other important physical and chemical parameters of the biowaste, green waste and the commercial organic compost are discussed below.

5.3.1 C:N Ratio

In this study the mean of the C:N ratio for the biowaste compost was calculated to be 16.5, which is below the recommended limit of 25 stipulated by the EPA. Only one sample (3.9%) of the biowaste compost was found to be in excess of the EPA limit which is an indication that this sample is immature compared to the other samples.

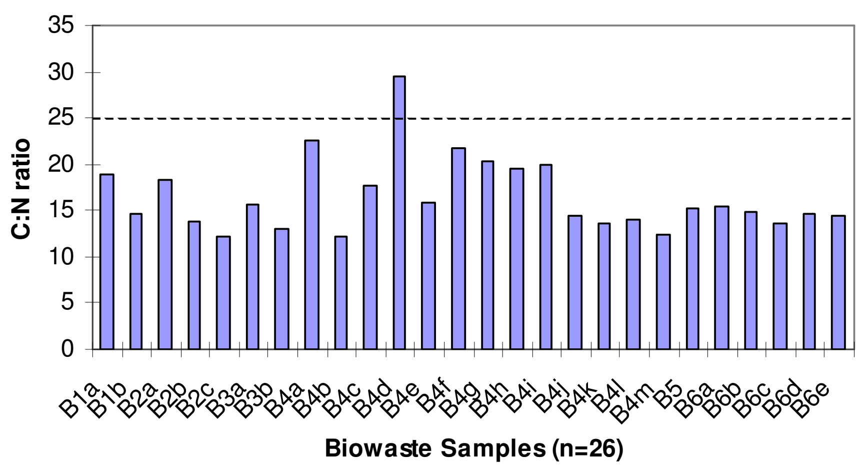


Fig 5.20 Graph of the C:N ratios of the biowaste compost samples showing recommended threshold levels.

In the green waste compost the mean of the C:N ratio was calculated to be 18.2 which is below the EPA limit. Three samples (33.3%) were equal to or exceeded the EPA limit and are most likely to be immature compost samples (Fig 5.21).

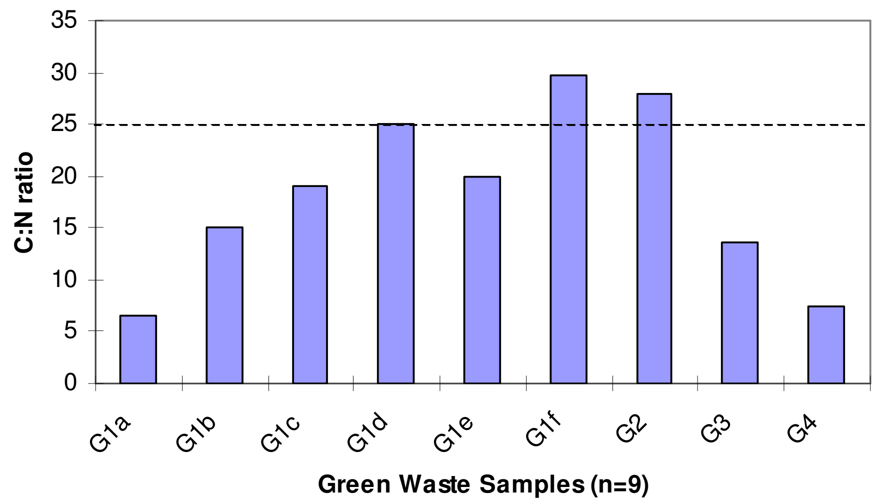


Fig 5.21 Graph of the C:N ratios of the green waste compost samples showing recommended threshold levels.

The mean of C:N ratio for the commercial organic compost was found to be 13.8 with no samples found to exceed the EPA limit (Fig 5.22). Therefore, according to the EPA all the commercial organic compost samples are most likely to be mature.

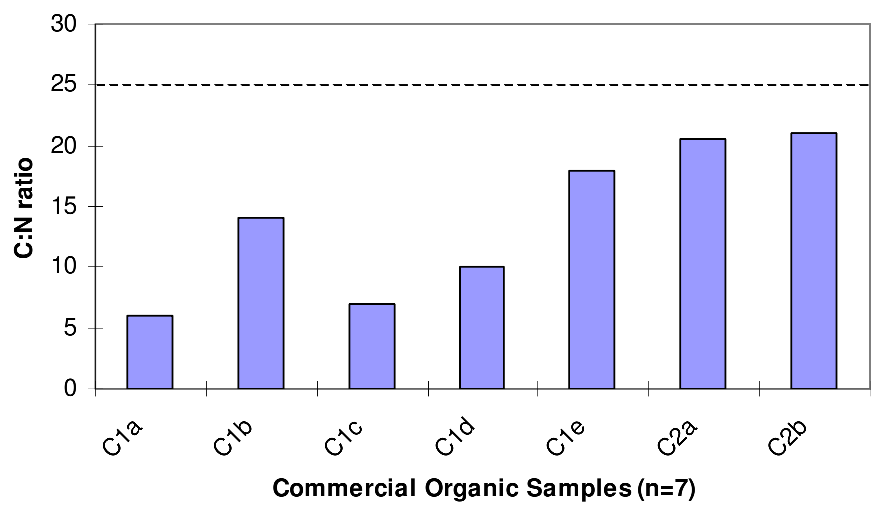


Fig 5.22 Graph of the C:N ratios of the commercial organic compost samples showing recommended threshold levels.

5.3.2 pH Scale

The recommended range of pH for compost is between 6.9-8.3 (Bord na Mona, 2003). The mean of the pH for the biowaste compost was found to be 7.7, which is within the recommended range. Six samples (23.1%) were outside of the recommended range (Fig 5.23).

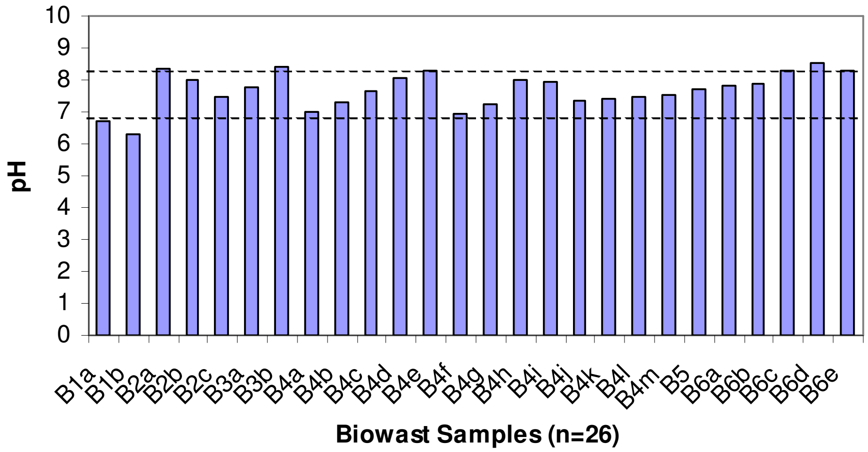


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Fig 5.23 Graph of the pH for the biowaste compost samples showing recommended threshold levels.

The mean of the green waste compost was found to be 7.6, which is also within the recommended range. Two samples (22.2%) were outside of the range (Fig 5.24).

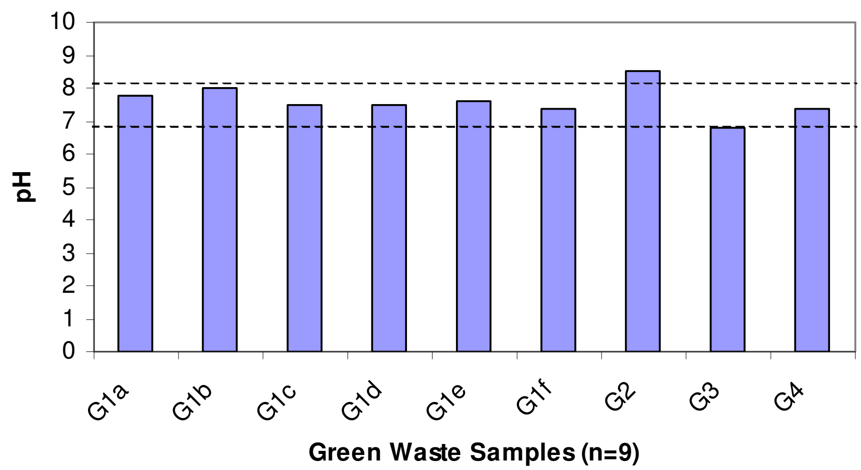


Fig 5.24 Graph of the pH of the green waste compost samples showing recommended threshold levels.

In the commercial organic compost samples the mean was found to be 6.1, which is below the typical range. Four (57.1%) of the samples were outside of the range with most of these samples being quite acidic (Fig 5.25).

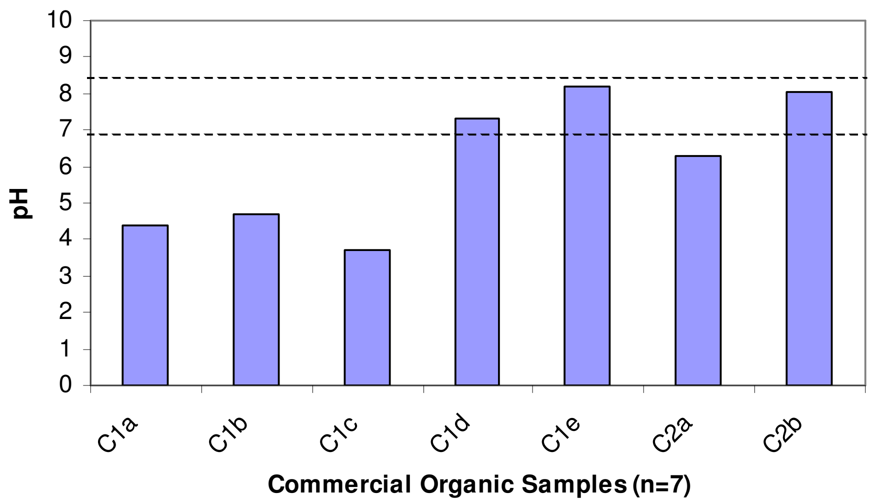


Fig 5.25 Graph of the pH of the commercial organic compost samples showing recommended threshold levels.

On comparing the means of pH there was a highly significant difference between the means of the pH analysed for the different types of composts (p=0.000). The commercial organic compost was the most acidic, which could be due to a greater amount of food scraps such as fruit peelings in the feedstock, or the composting process not having gone to full completion.

5.3.3 Moisture Content

The mean of the moisture content for the biowaste compost samples was found to be 47.2%, which is within the recommended range of 45-65%. Nine (37.5%) of the samples were outside of the recommended range (Fig 5.26). Two of the samples were found to be too wet, while seven of the samples did not contain adequate moisture levels. In comparison to other parameters, there was not as much variation in moisture content between samples from the same site.

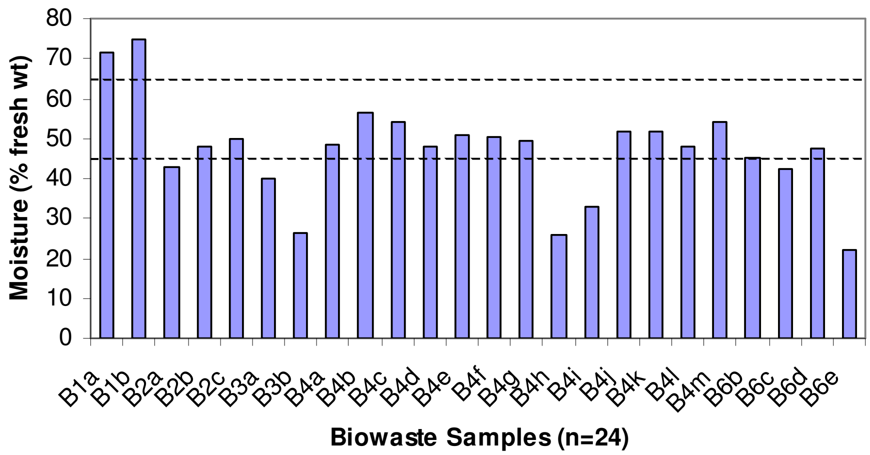


Fig 5.26 Graph of the moisture content (%) of the biowaste compost samples showing recommended threshold levels.

In the green waste compost samples the mean of the moisture content was 63.8%, which is quite high and just within the recommended moisture range. Four (50%) of the samples slightly exceeded the upper limit of the range (Fig 5.27).

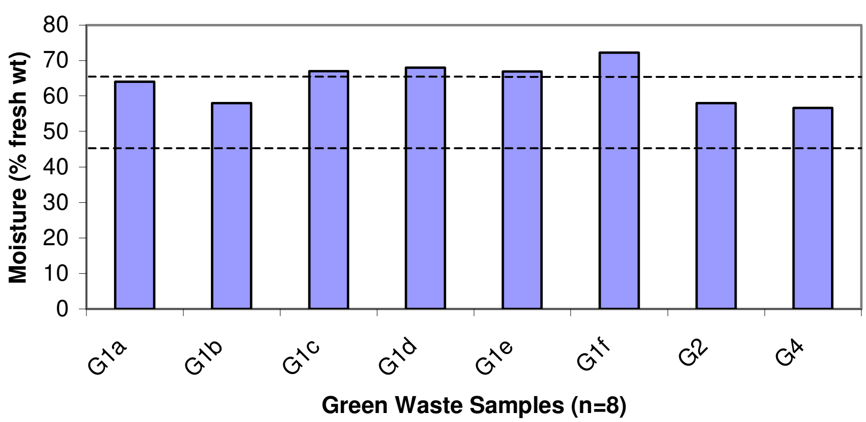


Fig 5.27 Graph of the moisture content (%) of the green waste compost samples showing recommended threshold levels.

In the commercial organic compost samples the mean moisture content was 39%, which is not within the recommended range. Five (71.4%) of the samples were outside of the range. Site C1 used windrow composting technology while site C2 used in–vessel composting technology. Variation in some quality parameters would be expected using windrow technology, as there is limited control over the process.

However, the variation in moisture levels at site C2 was unexpected, as in-vessel technology offers more control over the composting process and should produce compost of more uniform quality than when using windrow technology (Brinton, 1992).

The same inconsistency in quality can be seen from Figure 5.28 where there was also a marked variation in the pH of the compost from site C2. One of the samples had a pH of 6.3 and the other a pH of 8.02.

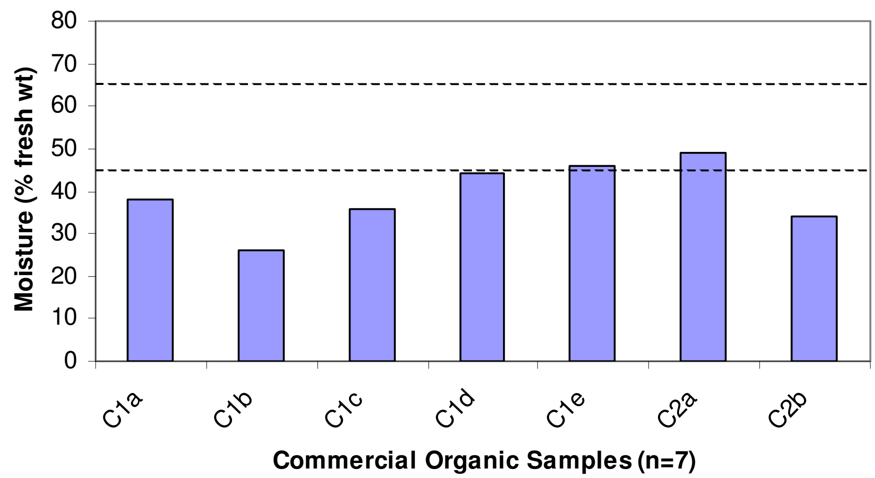


Fig 5.28 Graph of the moisture content (%) of the commercial organic compost samples showing recommended threshold levels.

On comparing the means of moisture content for the biowaste, green waste and the commercial organic waste, a highly significant difference between the means was found (p=0.000). The green waste compost being the wettest and the commercial organic compost the driest. Green waste feedstock composted in out-door windrows often tends to have higher moisture content to feedstock that is composted in enclosed conditions (Brinton and Brinton, 1992).

5.3.4 Organic Matter Content

The mean content of organic matter in the three types of composts analysed were all greater than the lowest critical threshold level of 30% as specified by the EPA.

Only one of the biowaste compost samples was found to be just slightly below the minimum critical threshold level. All the other individual samples of compost were found to be above this critical level (Fig 5.29).

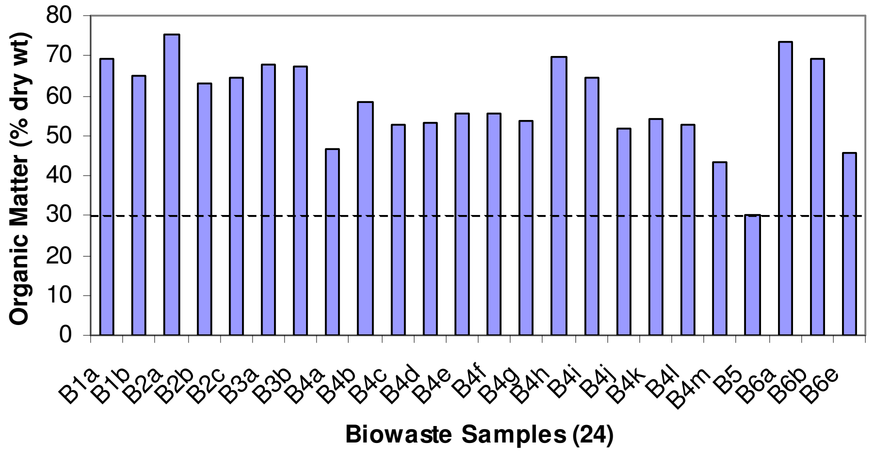


Fig. 5.29 Graph of the organic matter content (%) of the biowaste compost samples showing recommended threshold levels.

There was only a slightly significant difference between the mean values of organic matter in the three types of compost investigated ($p= 0.045$).

5.3.5 Conductivity

Bord na Mona state that the recommended range for conductivity in compost is between 2,000-6,000 µS/cm. In the biowaste compost the mean conductivity of 4574 µS/cm was within this range. Four samples (15.4%) of the biowaste compost were outside of this range (Fig 5.30).

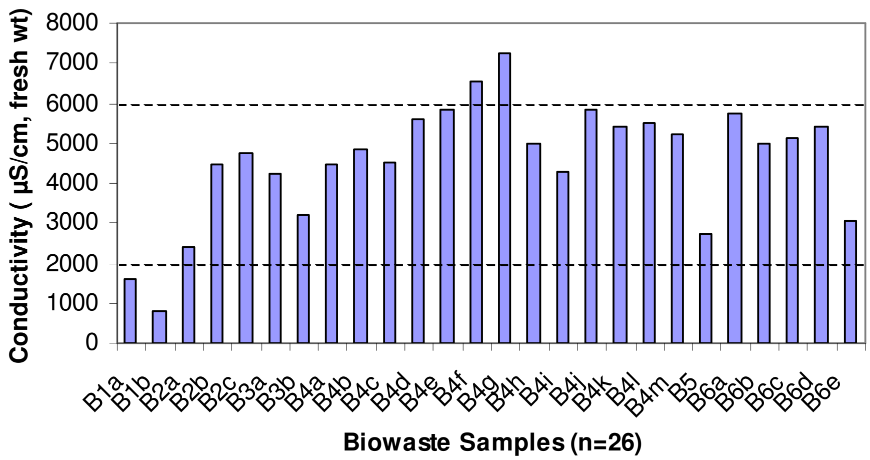


Fig. 5.30 Graph of the conductivity (µS/cm) of the biowaste compost samples showing recommended threshold levels.

The mean of the conductivity for the green waste compost was 1100.7 µS/cm. Eight samples (88.9%) of the green waste compost were below the lower threshold of the desirable range (Fig 5.31).

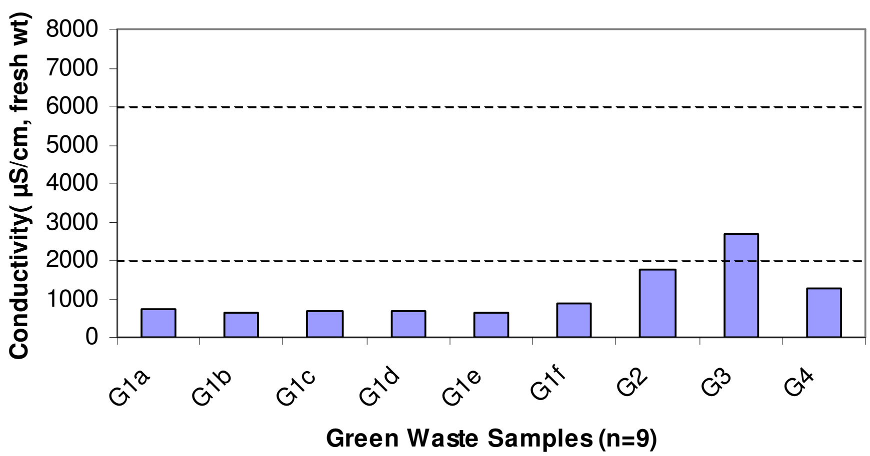


Fig. 5.31 Graph of the conductivity (µS/cm) of the green waste compost samples

The mean of the commercial organic compost was 3360 µS/cm, however only three samples were available for analysis in this study. One of the samples (33.3%) of the commercial organic compost was below the lower limit of the range.

There was a highly significant difference between the means of conductivity for the biowaste compost and the green waste compost (p=0.000). This could be due to the difference in input materials but also due to leaching of salts in the uncovered windrows used for composting the green waste (Fricke and Vogtmann, 1994).

5.3.6 Dry Bulk Density

Results for bulk density were only available for thirteen samples of the biowaste compost. The mean of the bulk density was calculated to be 306.7 g/L, which is within the recommended range of 120-369 g/L. Two samples (15.4%) exceeded the upper threshold of the recommended range (Fig 5.32).

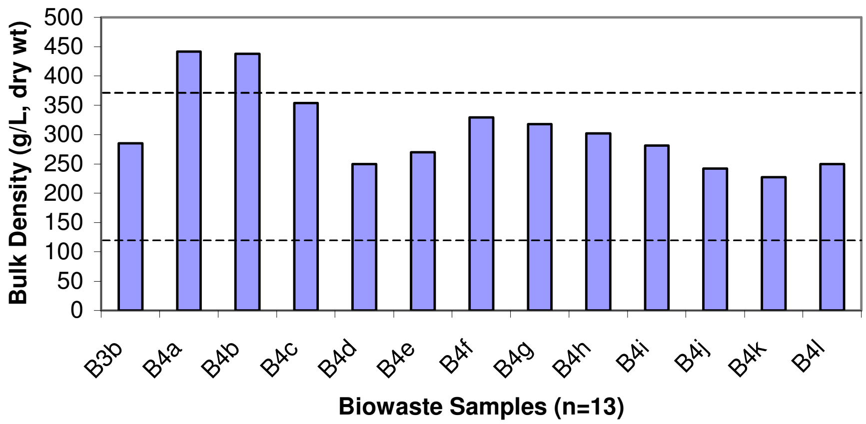


Fig 5.32 Graph of the bulk density (g/L) for the biowaste compost samples showing recommended threshold levels.

5.4 MATURITY

5.4.1 Self Heating Test

Of the five test results available for biowaste compost, four (80%) samples were found to be of class stability IV that is described by the self heating test as curing compost and is below the critical limit set out by the EPA. The other biowaste compost sample was found to be in class III that is described as moderately active, immature compost, which reheats to a temperature above 20°C of the ambient temperature and hence exceeds the critical limit.

Six (75%) of the sample test results available for the green waste compost were found to be in class of stability V that is described as a mature to very mature compost with the maximum temperature rise less than 20°C above the ambient temperature. Two (25%) of the samples were found to be in class of stability III which is described as a moderately active, immature compost.

The samples of compost with a class of stability of III are not suitable for use in horticulture due to the potential for self heating. For example, if this compost was bagged and stored in a shed for six months, as it often is, there is a high risk of it reheating and spoiling (Environment Agency, 2000).

Therefore, according to the self heating test results there was evidence that the green waste compost samples were more mature than the biowaste compost samples. This indicates that the green waste underwent a more complete composting process and was allowed to mature for longer.

5.4.2 Oxygen Uptake Rate

Both of the biowaste compost samples (B1a, B1b) analysed for this quality parameter exceeded the limit of 1000 mg O_2 kg VS^{-1} h^{-1} indicating immature compost samples. It was thought that the high amount of NH_4-N compared to NO_3-N for sample B1a, indicated immature compost (section 5.2.3). This supports the findings of the oxygen uptake rate test.

The mean of the oxygen uptake rate test result for green waste compost was below the limit with only one sample exceeding it, indicating that the remainder of the compost samples were mature according to the EU Biowaste Directive.

The mean of the oxygen uptake rate test result for commercial organic compost was also below the limit with no samples exceeding it.

According to the oxygen uptake rate test results, there is evidence again that the green waste compost samples were generally more mature than the biowaste compost samples. Although it should be noted that only two biowaste samples test results for this parameter were available.

5.4.3 Cress Germination Test

In the biowaste compost a mean germination rate of 87.8% was calculated which is below the minimum threshold level of 90% by the EPA. Three (60%) of the samples were below the minimum critical level.

In the green waste compost only two samples were available for analysis and both of these did not meet the specified requirement.

5.4.4 Summary of Maturity Findings

On looking at the self heating test results and the oxygen uptake rate test results, none of the seven biowaste compost samples were found to be fully mature while eleven out of fourteen samples of the green waste compost samples were found to be mature. On visiting various composting facilities and following discussions with facility operators it was evident that sometimes there was not enough adequate storage space available on site to allow the compost to fully mature which made process management very difficult to maintain and in turn may result in poor quality, immature compost being produced.

5.5 FOREIGN MATTER

5.5.1 Impurities

The mean content of impurities (1.8%) in the biowaste compost was found to be greater than the limit of 0.5%. Eleven (52.4%) of the biowaste compost samples exceeded this limit (Fig 5.33). Three was a considerable amount of variation in the presence of impurities in the compost at site B4. Sample B4b, B4d, B4e, B4h and B4i contained excessive amounts of impurities while some of the other compost samples at this site contained levels of impurities below the limit. The high amount of impurities was probably due to the facility composting feedstock, which contained too many impurities due to insufficient source segregation. Increased preliminary screening and post process screening may have helped in reducing the amount of impurities present in the compost. Compost samples at site B1 contained zero impurities in the compost samples.

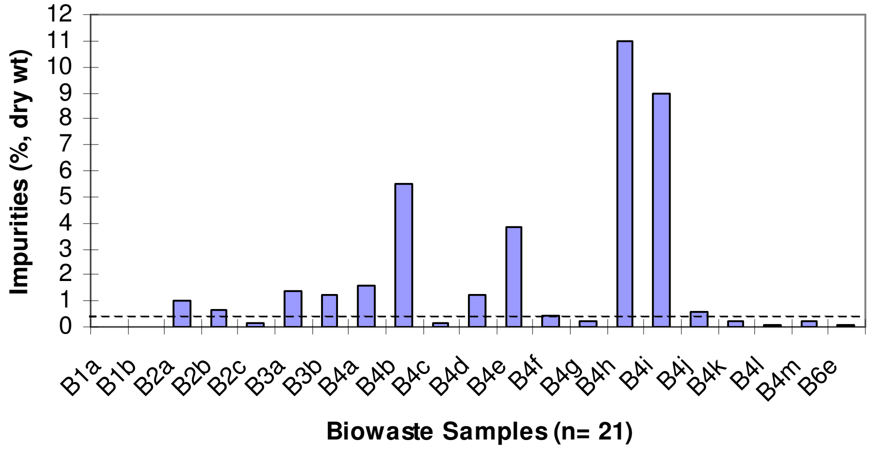


Fig 5.33 Graph of impurities (%) in the biowaste compost samples showing the statutory limit specified by the EU Biowaste Directive.

In the green waste compost the mean of 1.5% of impurities found in the compost also exceeded the critical limit. However, this high mean was due to sample G4 which contained excessive amounts of impurities (Fig 5.34). Sample G4 (12.5% of the samples) was the only sample to exceed the limit. All the other samples of green waste compost contained zero or small amounts of impurities

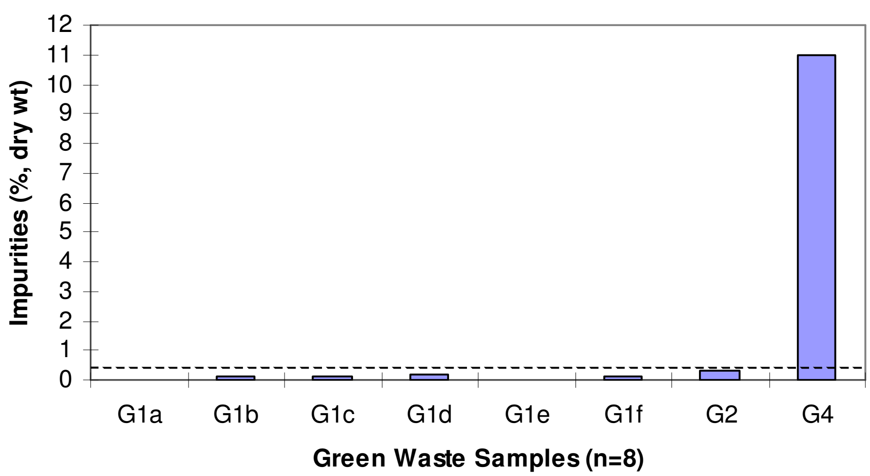


Fig 5.34 Graph of impurities (%) in the green waste compost samples showing the statutory limit specified by the EU Biowaste Directive.

There were only three samples available for the commercial organic compost, which contained a mean of 0.28% impurities, which is below the critical limit. None of the samples exceeded the limit.

The biowaste compost contained a significantly higher percentage (52.4%) of samples exceeding the statutory limit compared to the green waste compost (12.5%). This is often attributable to the fact that green waste compost contains a more homogenous feedstock (US EPA, 1994) compared to biowaste compost and will in turn contain significantly less impurities as this study as shown.

5.5.2 Gravel and Stones

The number of samples which exceeded statutory limits specified by the EPA and the EU Biowaste Directive are given in Table 5.4.

Table 5.4 Samples Exceeding the Statutory Limits Specified by the EPA and EU Biowaste Directive

Parameters	Units	No.[1]	SD [2]	CL[3]	% Exceeding the CL
Biowaste					
Impurities	%(> 2 mm)	21	3	<0.5	52.4
Gravel and Stone	%(> 5 mm)	19	6.8	<5	36.8
Green Waste					
Impurities	%(> 2 mm)	8	3.9	<0.5	12.5
Gravel and Stones	%(> 5 mm)	7	2.2	<5	14.3
Commercial Organics					
Impurities	%(> 2 mm)	3	0.2	<0.5	0
Gravel and Stones	%(> 5 mm)	3	1.6	<5	66.7

In the biowaste compost the mean (6%) of gravel and stones present in the compost slightly exceeded the statutory limit of 5%. Seven samples (36.8%) exceeded this limit. A lot of variation in the percentage content of gravel and stones was also evident in site B4 where some samples such as B4e, B4f, B4g, B4l and B4m greatly exceeded the critical limit while other samples at this site were below the limit (Fig 5.35).

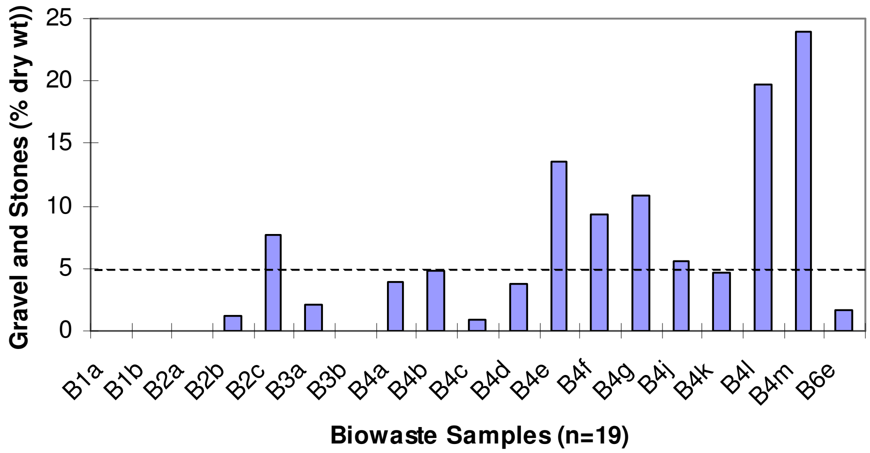


Fig 5.35 Graph of gravel and stones content (%) in the biowaste compost samples showing the statutory limit specified by the EU Biowaste Directive.

In the green waste compost a favourable mean of 2.6% of gravel and stones was calculated which is below the critical limit. One sample (14.3%) was found to exceed the limit (Fig 5.36).

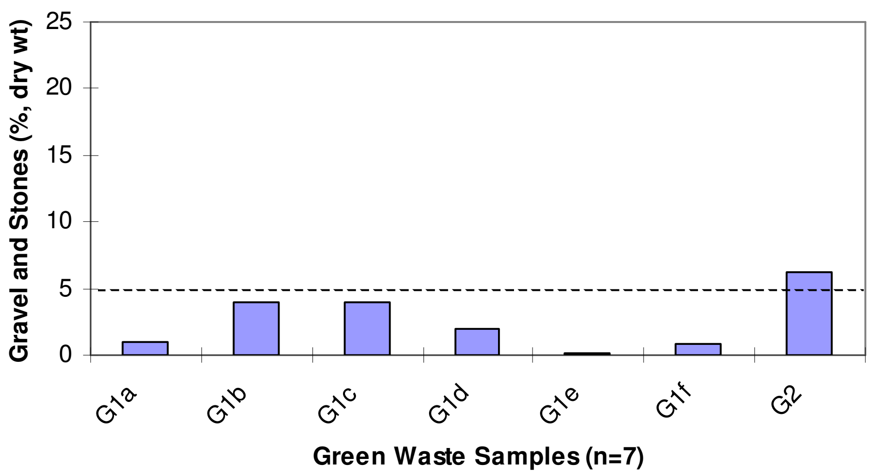


Fig 5.36 Graph of gravel and stones content (%) in the green waste compost samples showing the statutory limit specified by the EU Biowaste Directive.

Only three commercial organic compost samples were available for analysis and hence this small sample number only gives a slight indication of the presence of gravel and stones in the compost. The mean value was found to be 6.6% which is over the statutory limit. Two out of the three samples exceeded the limit.

Statistical analysis showed that on comparing the means of gravel and stones in the biowaste and green waste compost there was no significant difference between the means (p=0.068).

5.6 PATHOGENS

5.6.1 Faecal Coliforms

In the biowaste compost the mean number of coliforms was calculated to be 112.2 MPN/g, which is well below the limit of 1000 MPN/g. Only one sample (4.8%) of the biowaste compost was found to exceed the critical limit (Fig 5.37).

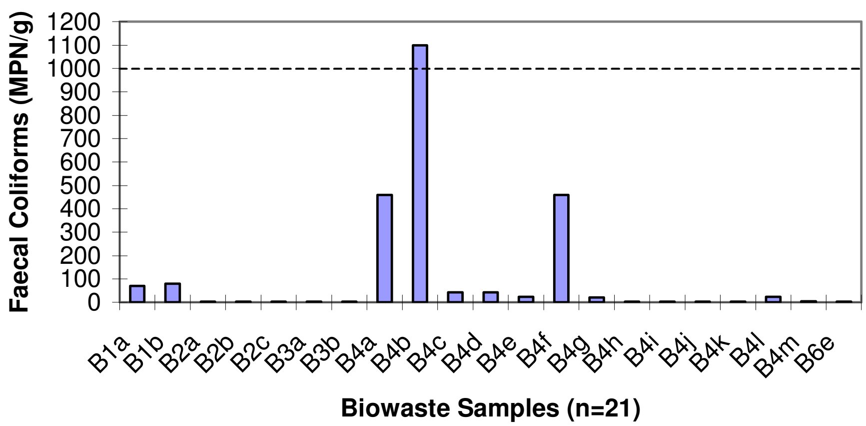


Fig 5.37 Graph of the presence of faecal coliforms (MPN/g) in the biowaste compost samples showing the statutory limit specified by the EU Biowaste Directive.

The green waste compost had a slightly higher mean of 221.67 MPN/g, which is also below the critical limit. None of the individual samples exceeded the limit as can be seen from Figure 5.38.

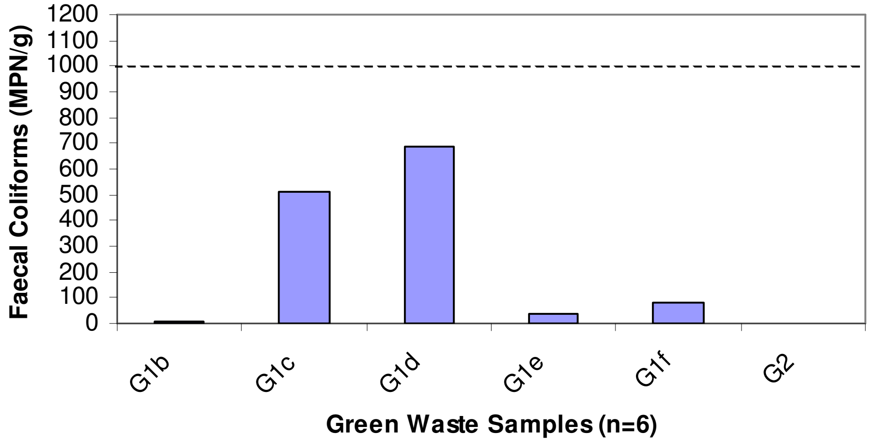


Fig 5.38 Graph of the presence of faecal coliforms (MPN/g) in the green waste compost samples showing the statutory limit specified by the EU Biowaste Directive.

5.6.2 Salmonella

In the biowaste compost the mean concentration of salmonella was found to be 286.5 MPN/50g which was due to salmonella present in two (9.5%) of the biowaste samples. The two samples B1a and B1b originated from the same site with the cause of the contamination due to the presence of chickens located near the composting site, which have since been removed from the vicinity (Gill, 2003). Salmonella was absent in all the other biowaste samples. No Salmonella was present in the other biowaste compost samples.

No salmonella was found in the green waste compost, which is compliant with the sanitation requirements of the EU Biowaste Directive.

5.7 OVERALL QUALITY OF IRISH COMPOST

From the analysis carried out it was evident that the heavy metal content of Irish compost is not a serious factor affecting compost quality. Heavy metal content was more or less similar in the biowaste and green waste compost.

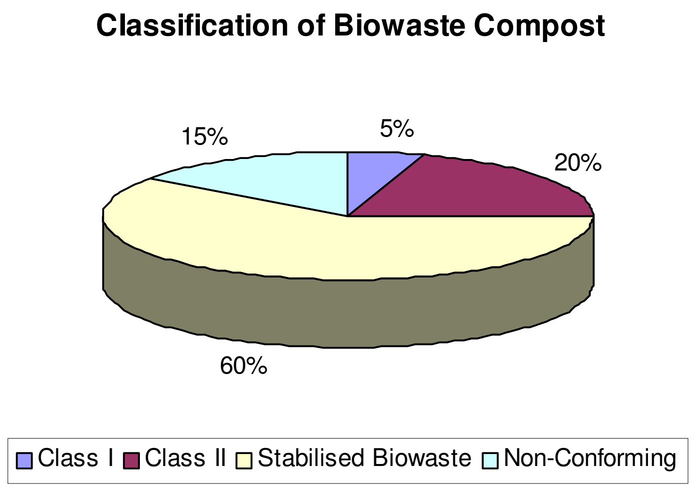
Many of the biowaste compost samples were classified as Class I or Class II compost according to the EU Biowaste Directive. However, when other quality parameters such as impurities and gravel and stones were considered the quality of the compost decreased significantly. Compost samples which would otherwise have been classed as Class I or Class II compost, were then classified as stabilised biowaste or non-conforming samples (Table 5.5). These classifications could seriously deter the sale of compost in certain sectors of the markets in which it can be used. Stabilised biowaste is very often used as a landfill cover or in landfill restoration and has very little added market value. Care has to be taken here to avoid a loophole in which biodegradable waste finds its way back into landfills (Favoino, 2000).

Overall, the quality of the green waste compost was higher than the biowaste compost due to lower amounts of impurities and gravel and stones in the samples analysed and a greater maturity of the compost samples The green waste compost therefore will be a lot easier to market and with less restrictions if it is to be used in agriculture.

As the quality of compost can vary so much, as seen in this study, it is important to choose feedstock whilst adjusting processing procedures, according to a pre-determined end use of the compost (Rogalaski et al., 2002).

Table 5.5 Summary of the overall classification of samples of biowaste and green waste compost according to the EU Biowaste Directive.

Standard	**Biowaste Compost (n=20)**	**Green Waste Compost (n=8)**
Class I	1 (5%)	3 (37%)
Class II	4 (20%)	3 (37%)
Stabilised Biowaste	12 (60%)	1 (13%)
Non-conforming to both standards	3 ((15%)	1 (13%)



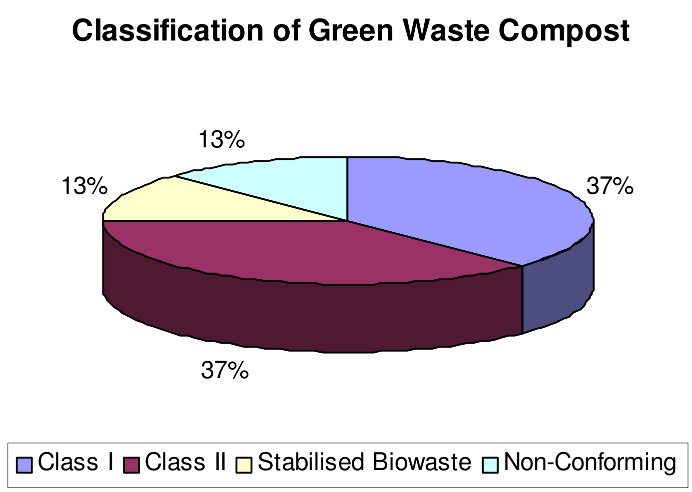


Fig 5.39 Graphs showing the percentage classes of Biowaste and Green waste compost according to the proposed EU Biowaste Directive.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Heavy Metal Content of the Compost

On classifying the biowaste and green waste compost according to the specifications of the EU Biowaste Directive, according to heavy metal content, the green waste compost was of a slightly better quality. Nearly half of the samples of both types of compost were classified as Class I and the other half as Class II compost. However, two (8.3%) of the biowaste samples were non-conforming to the statutory limits specified by the standard. There was no major concern regarding heavy metal content of biowaste and green waste compost. Commercial organic compost contained the highest concentration of heavy metals. One (9.1%) of the samples was classified as Class I compost and three (42.9%) of the samples as Class II compost. Three (42.9%) of the samples were classified as stabilised biowaste and three (42.9%) as non-conforming. Only one facility was analysed for heavy metal content of sludge compost, with low concentrations of heavy metals occurring although, one of the samples was classified as non-conforming.

- **Correlations Between Heavy Metals**

The most significant correlations between heavy metals were found between copper and zinc, copper and lead, zinc and lead and zinc and nickel in the green waste compost. These findings may allow laboratories to limit heavy metal testing and therefore carry out single tests for pairs of strongly correlated heavy metals. This would in turn, limit the costs of compost quality testing for facility operators. No significant correlations were found between heavy metals in the biowaste or commercial organic compost.

- **Heavy Metal Content of Irish Compost Compared to Compost from Other Countries**

Irish biowaste compost compared most favourably with biowaste compost from Germany, Austria and the UK on comparing heavy metal content. However, the mercury content was slightly elevated in comparison to these countries. It is thought that this may be due to outlier data of two samples caused by analytical error in the laboratory. Irish Green waste compost green contained similar, or more often, lower concentrations of heavy metals when compared to green waste compost from Germany, Austria and Australia.

- **Variability Between Heavy Metal Concentrations in the Compost Samples**

A lot of variability especially in the biowaste compost was found between sites and within sites when analysing the heavy metal content of the composts. It was thought that variability in heavy metal concentrations, within sites, may have been caused by a range of /or a mixture of factors which include; inadequate control over the composting process, seasonal factors having an influence on heavy metal concentrations, or batches of feedstock coming from specific areas where there is relatively high levels of contamination.

- **Nutrient Content**

The biowaste compost contained adequate amounts of TN and available NO_3-N and could be considered as having fertilising capabilities and be used as an organic fertiliser in agriculture and in container production of crops. The green waste compost also contained sufficient amounts of TN however, some of the green waste compost samples were quite low or deficient in available NO_3-N for use in growing media and therefore, it was recommended that the green waste compost be used as mulch. The biowaste compost contained sufficient amounts of available NO_3-N for use in growing media, although a lot of variation in NO_3-N concentrations was found between sites and within sites. More regulated control over the biological process especially with regard to pH, temperature, and moisture will have an influence on nitrogen turnover from organic forms into inorganic forms and therefore allow compost to be produced with more predictable fertilising capabilities (Körner and Stegmann 2003). The concentration of TP and available PO_4-P was found to be quite low in the biowaste and green waste compost. The biowaste and green waste compost contained adequate to high concentrations of potassium. High potassium concentrations of these composts could restrict its use in growing media, especially where young plants are concerned. Biowaste compost contained sufficient amounts of calcium required for plant growth. However, it contained low concentrations of magnesium.

- **Maturity**

None of the biowaste samples were found to be fully mature, while eleven of the green waste samples were found to be mature. The area needed for compost storage especially during the maturation stage was very often not available at biowaste compost facilities. This will make process management very difficult and can result in a low quality product that has not reached full maturity and thereby, limit its marketability.

- **Foreign Matter**

High levels of impurities and gravel and stones in the biowaste compost caused significant problems and resulted in a lot of the samples which may otherwise have been classified as Class I or Class II compost according to heavy metal concentrations, being classified as stabilised biowaste or worse again as non-conforming samples. Because of such classifications the biowaste compost could incur severe restrictions in its use. Such concentrations of impurities may especially, inhibit the use of compost in horticulture and landscape gardening. The presence of impurities and gravel and stones was not as significant in the green waste compost. Only one of the samples which was classified as Class I compost according to heavy metal content, was subsequently, classified as stabilised biowaste because of too a high a content of gravel and stones in the compost sample.

- **Variability Amongst Other Quality Parameters**

A lot of variability was also found in the compost samples within sites and between sites on analysing other parameters, apart from heavy metals. Variability will limit the use of compost in growing media as it can cause significant problems in horticulture if it affects growth rates, nutrition, or plant aesthetics, as successful container production of crops and plants rely on growing media to produce consistent quality plants. Poor quality compost will inhibit the widespread use of compost and the development of future markets for the product.

- **Overall Quality of The Biowaste and Green Waste Compost**

In biowaste compost samples, one sample was classified as Class I compost, four as Class II compost, twelve as stabilised biowaste and three as non-conforming samples.

Three of the green waste samples were classified as Class I compost, three as Class II compost, one as stabilised biowaste and one as a non-conforming sample. The green waste was of a higher quality mainly due to low concentrations of impurities and gravel and stones, and greater levels of maturity. It is important to recognise and acknowledge that poor quality compost will inhibit the widespread use of compost and the development of future markets for the product.

- **Laboratory Units for Reporting Results**

Units of reporting test results need to be more standardised to ensure that facility operators are able to fully interpret and have a good understanding of the results. Laboratories should adopt the specific units specified in the EU Biowaste Directive when reporting compost quality results for the parameters therein.

RECOMMENDATIONS

- Improved source segregation, pre- processing and post-processing of the biowaste are highly recommended to decrease the amount of impurities and gravel and stones in compost.

- It is recommended that every load of feedstock undergo a visual entrance inspection and the contaminants be removed by adequate screening, or the load be rejected if it contains too much contamination.

- Consistent loads of contaminated biowaste should be traced back to the specific area where it came from and residents and suppliers from these areas be made more aware of the importance of source segregation and how to actually carry out proper source segregation of biowaste.

- The lack of consistency in producing a product of uniform quality and content at individual sites is important to address in the future if these facilities are to fully succeed in marketing its product. This could be done by greater control over the physical and biological processing and by allowing the compost to fully mature over time.

- Feedstock intended for composting should be chosen with the end use in mind, whilst adjusting processing procedures accordingly, and producing a pre-determined quality compost product.

- It is strongly recommended to ensure adequate storage areas in new and existing facilities, and to ensure that the product is stored in a manner where it is protected from excess moisture, and there is no possibility of the re-introduction of pathogens to the compost.

- Laboratories should start to report heavy metals in mg/kg of dry weight for an organic matter content of 30%. This will allow an easier comparison of data of different composts as it eliminates the effect of compost maturity and compost with low organic matter content will not be subjected to stricter statutory limits.

- Laboratories should adopt the specific units specified in the EU Biowaste Directive when reporting compost quality results for the parameters therein.

- Composting must be seen as an environmentally safe and sustainable process in which a high quality product with many beneficial attributes and uses is produced instead of a means of waste management. Otherwise, there is a risk of producing great amounts of compost with no added market value.

- The introduction of a national compost standard and a quality assurance scheme is crucial to ensure the quality of compost and to assistant in the development of viable and sustainable markets and outlets for the product.

Further Research

- More research is required into physical and biological processing technologies so that optimum configurations and effective and efficient systems can be designed with a particular emphasis on contaminant screening systems recommended.

- To confirm correlations between heavy metals, more detailed research on a larger scale is required. This should take into account the time of year and the season in which the feedstock is composted.

- Growing trials should be undertaken with a variety of biowaste and green waste composts, over a period of 3-5 years to determine the long-term benefits to the soil physical environment and its nutrient availability to plants. This would instil confidence in farmers to utilise compost to a greater degree and promote the use of compost as an organic fertiliser.

- More research should be carried out the quality of industrial sludge compost especially concerning the presence of substances such as antibiotics and hormones and more detailed study on the quality of commercial organic compost should take place, as the composting of both of these waste streams is growing in Ireland at the present.

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APPENDIX 1

ANNEX III

Environmental quality classes for compost and stabilised biowaste

Parameter	Compost/digestate (*)		Stabilised biowaste (*)
	Class 1	Class 2	
Cd (mg/kg dm)	0.7	1.5	5
Cr (mg/kg dm)	100	150	600
Cu (mg/kg dm)	100	150	600
Hg (mg/kg dm)	0.5	1	5
Ni (mg/kg dm)	50	75	150
Pb (mg/kg dm)	100	150	500
Zn (mg/kg dm)	200	400	1 500
PCBs (mg/kg dm) (**)	-	-	0.4
PAHs (mg/kg dm) (**)	-	-	3
Impurities >2 mm	<0.5%	<0.5%	<3%
Gravel and stones > 5 mm	<5%	<5%	-

(*): Normalised to an organic matter content of 30%.
(**): Threshold values for these organic pollutants to be set in consistence with the Sewage Sludge Directive.

Compost, digestate and stabilised biowaste shall be assumed to belong to a specified class or type if, for each relevant parameter considered individually, samples show that compost, digestate and stabilised biowaste comply with the relevant parameter as in the following table:

Series of samples taken in any twelve-month period	Maximum permitted number of samples which fail to conform to any given parameter	Allowed deviation from statutory limit of samples which fail to conform to any given parameter
2	1	20%
4	1	20%
12	3	20%

The limits apply to the compost just after the composting phase and prior to any mixing with other materials.

ANNEX IV

Sampling frequency and methods for analysis and sampling
[this Annex would have to be brought in line with the updated Sewage Sludge Directive]

(1) In order to inform the end user about the characteristics of compost and stabilised biowaste, the following parameters shall be analysed:

	Parameter	Unit	Reference method (*)	
X	Dry matter	% fresh weight	EN 13039	Soil improvers and growing media – determination of organic matter and ash
X	Organic matter	% dm	EN 13039	Soil improvers and growing media – determination of organic matter and ash
X	Bulk density	kg/l fresh weight	EN 12580	Soil improvers and growing media – Determination of a quantity
X	Electrical conductivity	mS/m	EN 13038	Soil improvers and growing media – determination of electrical conductivity
X	pH(H_2O)	pH-unit	EN 13037	Soil improvers and growing media – determination of pH
X	Nitrogen (as total N and NH_4-N)	mg/kg dm	prEN 13654 parts 1 and 2	Soil improvers and growing media – total N – modified Kjeldahl/Dumas
X	Phosphorus (as P_2O_5)	mg/kg dm	prEN 13650	Soil improvers and growing media – extraction of *aqua regia* soluble elements
X	Potassium (as K_2O)	mg/kg dm	prEN 13650	Soil improvers and growing media – extraction of *aqua regia* soluble elements
X	Calcium (as CaO), magnesium (as MgO), boron (B), molybdenum (Mo)	mg/kg dm	prEN 13650	Soil improvers and growing media – extraction of *aqua regia* soluble elements
X	C/N	-		
	Total impurities	% dm		
	Dynamic Respiration Index	mg O_2/kg VS/h	[ASTM D 5975-96]	Standard test method for determining the stability of compost by measuring oxygen consumption
	Respiration Activity after four days (AT_4)	mg O_2/g dm		
	Salmonella spp	number/50 g dm		
	Clostridium perfringens	number/1 g dm		
	Germinating weed seeds	number/l	[ÖNORM S 2023]	
	Heavy metals: cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), zinc (Zn)	mg/kg dm	prEN 13650	Soil improvers and growing media – extraction of *aqua regia* soluble elements
	Heavy metal: mercury (Hg)	mg/kg dm		
	PAHs	mg/kg dm	[ISO 13877]	
	PCBs	mg/kg dm	[CD 10382]	

(*) Latest available edition.

APPENDIX 2

Appendix 2 Various Types of Composting Technology

(a) a typical windrow

(b) an aerated static pile

(c) In-vessel composting

A VAR Aerated Static Pile at Sandy Road Composting Facility, Galway, Ireland

APPENDIX 3

Appendix 3 Pre-Processing and Separation techniques for sorting feedstock prior to biological

Below is an outline of separation techniques used in the composting of MSW.

- **Screens**

Trommels are often used for the separation of non – compostable materials in feedstock, as outlined in body of text.

A Trommel as seen at Sandy Road Composting Facility

- **Manual Separation**

When feedstock materials have been reduced to similar sizes it becomes practical to sort out the remaining contaminants as the feedstock moves along a conveyor belt Richard, 1991).

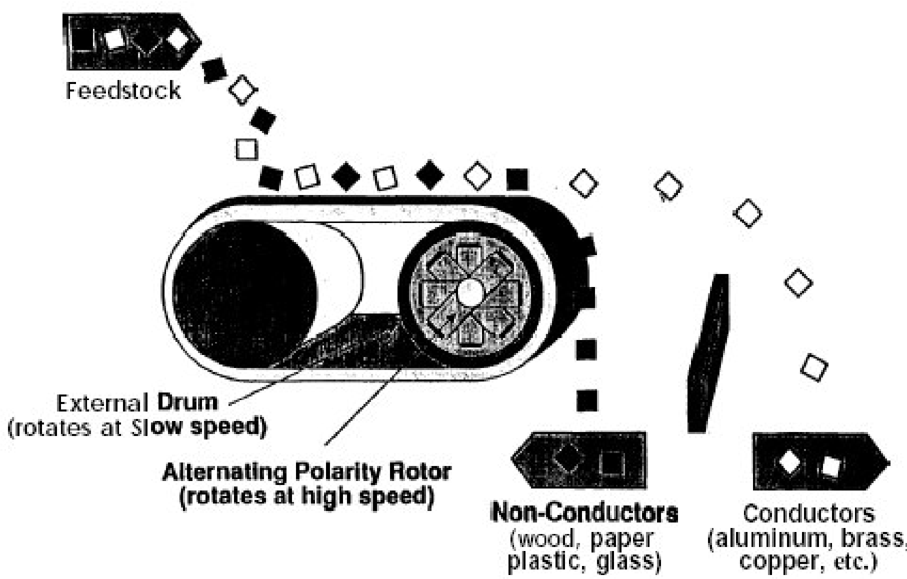
- **Magnetic Based Separators**

Magnetic separators are used to remove ferrous material from feedstock as it moves along a conveyor belt. Because they are inexpensive and effective they can be used at various points throughout the composting facility. Two magnetic separators usually work in-series to increase ferrous removal. Magnetic separation is effective for iron and steel but not for aluminum, copper and other non-ferrous metals.

- **Eddy Current Separators**

Eddy current separators are used to separate non- ferrous materials from the feedstock (Fig???). High-energy electromagnetic fields that induce an electrical charge in non-ferrous metals and other materials that conduct electricity are generated. These materials are then repelled by the non-charged materials in the feedstock and subsequently removed. Eddy current separation should follow magnetic separation to minimise contamination by ferrous materials (EPA, 1994).

AN EDDY CURRENT SEPARATOR

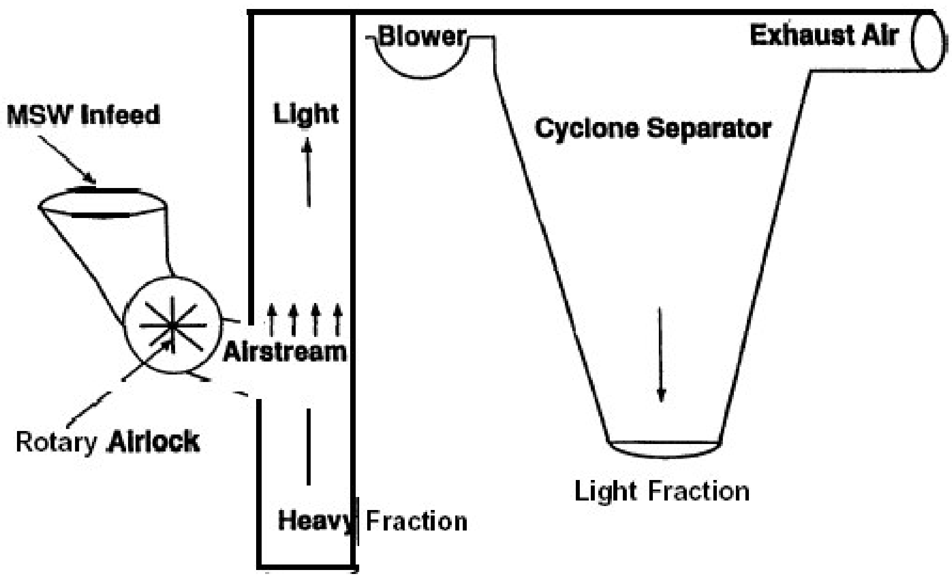


Source: EPA, 1994

- **Air Classifiers**

Air classifiers are additional separation techniques used in some composting facilities. They are used to separate feedstock on the basis of weight differences. Heavier fractions such as glass and metals are removed from lighter materials such as paper and plastic. The main part of the air classifier is the 'throat' where material is fed. An air blower then sucks the lighter material up thorough the throat. They then enter a cyclone separator where they looses velocity and settle out. Heavier materials fall directly out of the throat. Some of this material may also consist of compostbale material as food material. Plastics and sometimes paper are then removed from the lighter phase with the remainder composted (Richard, 1991).

Air Classifiers



- **Wet Separation Techniques**

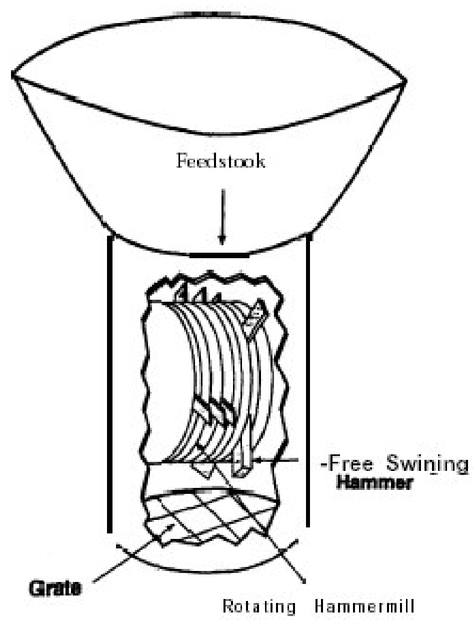
Wet separation techniques are work on a similar principle as air classifiers in that it is based on density differences. Instead of an air medium there is a water medium in which the heavy material drops into a sloped tank where it moves to a removal zone. The lighter organic material floats where it is removed form the reticulating water using separation techniques similar to that used in wastewater treatment plants. This type of separation technique is particularly useful in removing heavy objects such as glass and other sharp objects.

- **Balstic Separators**

Balsitic separators work on the differences in densities and elasticity between inert and organic materials.

Size Reduction Technologies for Reducing Particle Size Prior to Biological Processing

HAMMERMILL



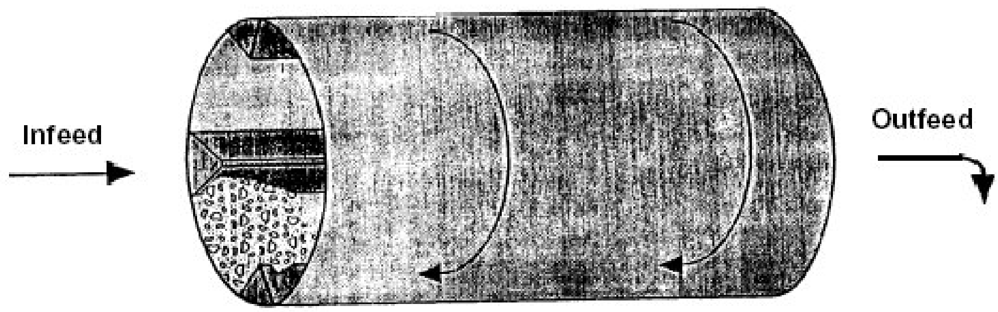
Source: US EPA 530-R-94-003, 1994

Hammermills consist of swinging rotating hammers, which pound the feedstock and reduce it into smaller particles. They are energy intensive with the hammers needing replacement on a regular basis.

Shear Shredders consist of a pair of rotating knives or hooks, which rotate at a low speed with high torque. The shearing action tears or cuts up material, which also opens up the internal structure of the particles, increasing the surface area and the rate of decomposition.

Rotating drums rely on gravity to tumble mix and homogenise materials in rotating drums. These drums may also act as biological reactors with typical residencies times of 36 hours, therefore it is important to ensure adequate aeration at all times.

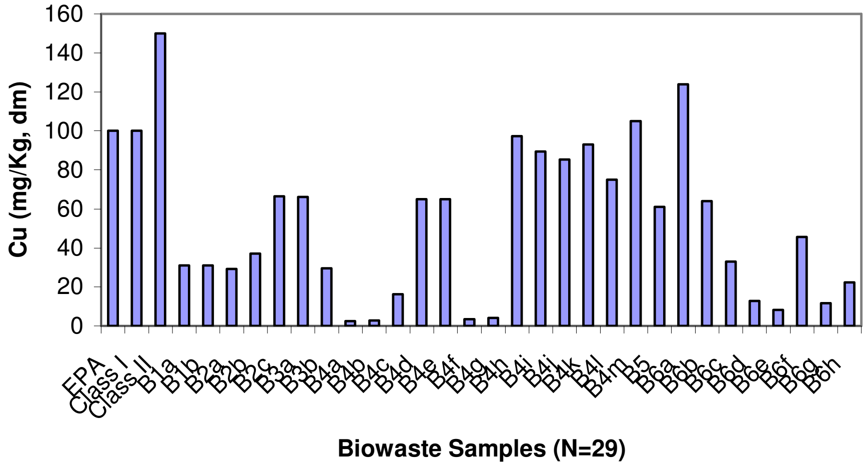
Rotating Drum

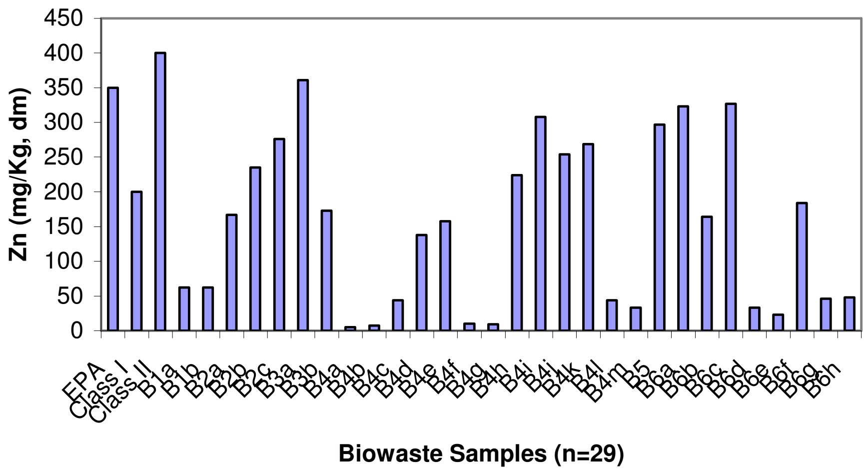


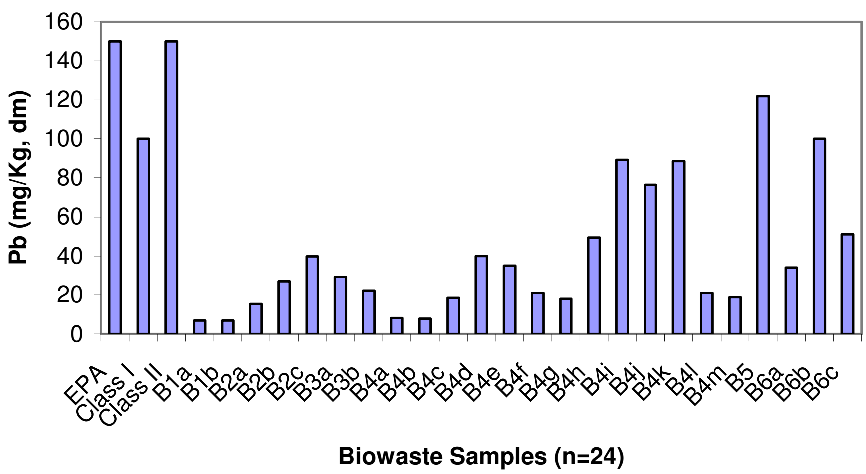
Source: US EPA 530-R-94-003, 1994

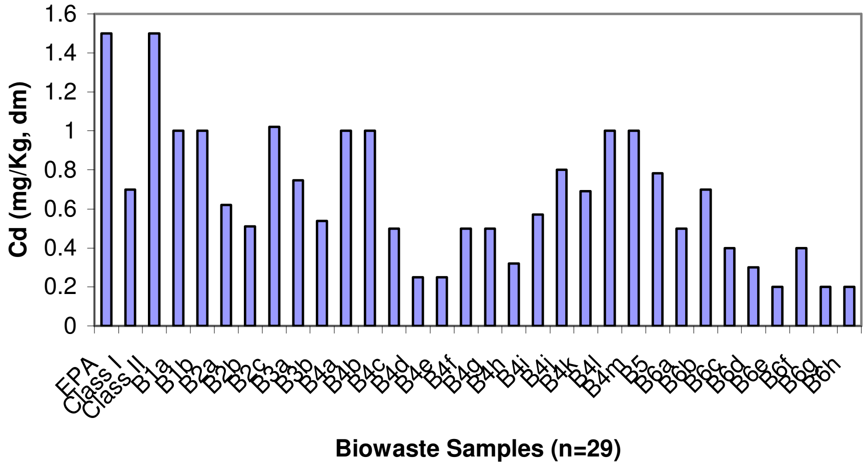
APPENDIX 4

Appendix 5 Graphs of Heavy metal Concentration in Individual Compost Samples

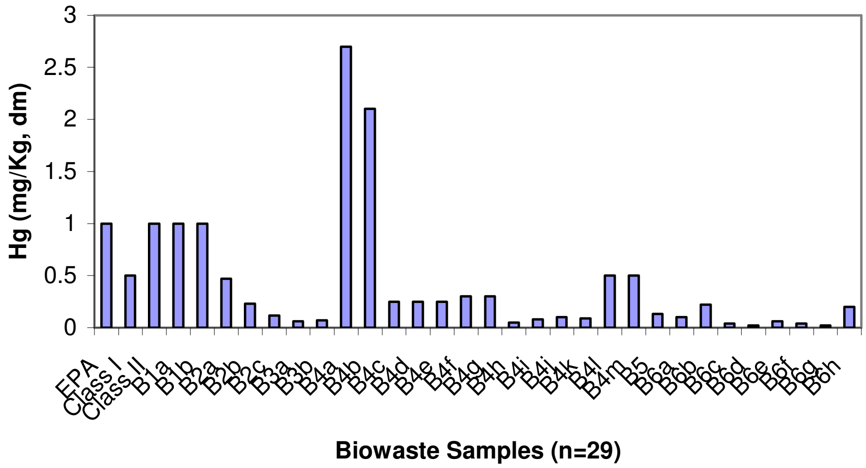




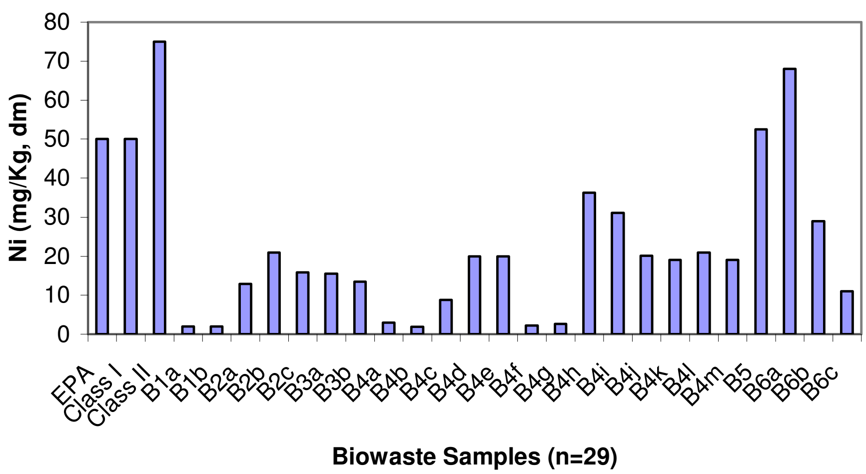




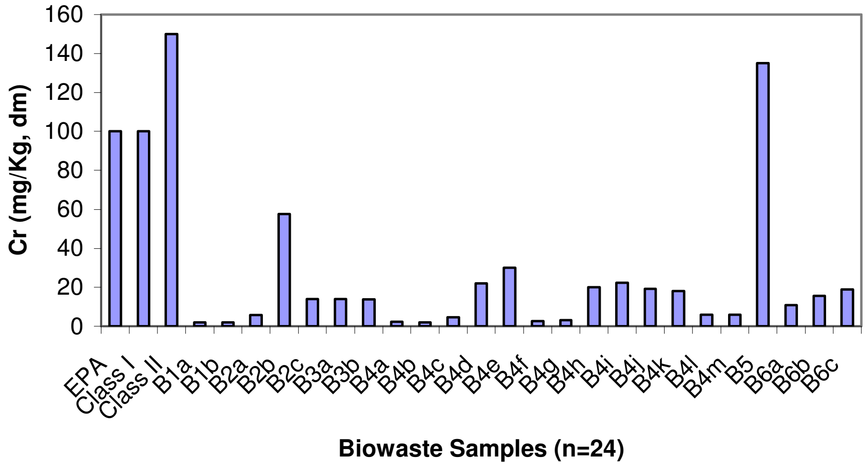
Cd (mg/Kg, dm)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
EPA
Class I
Class II
B1a
B1b
B2a
B2b
B2c
B3a
B3b
B4a
B4b
B4c
B4d
B4e
B4f
B4g
B4h
B4i
B4j
B4k
B4l
B4m
B5
B6a
B6b
B6c
B6d
B6e
B6f
B6g
B6h
Biowaste Samples (n=29)

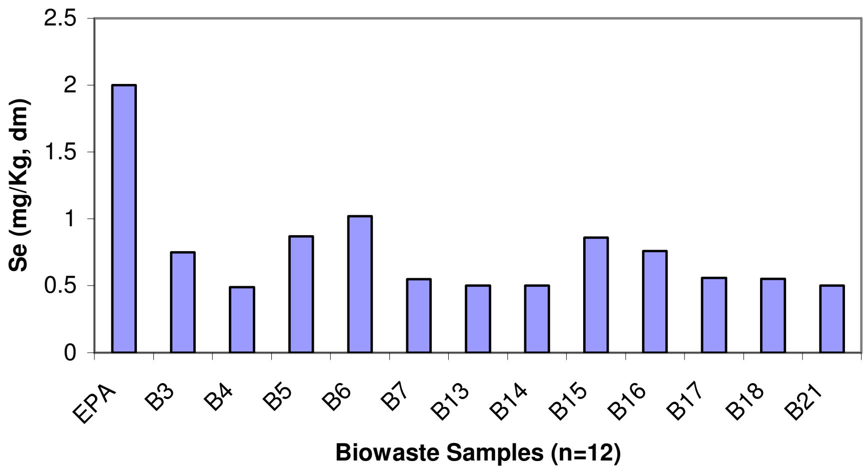


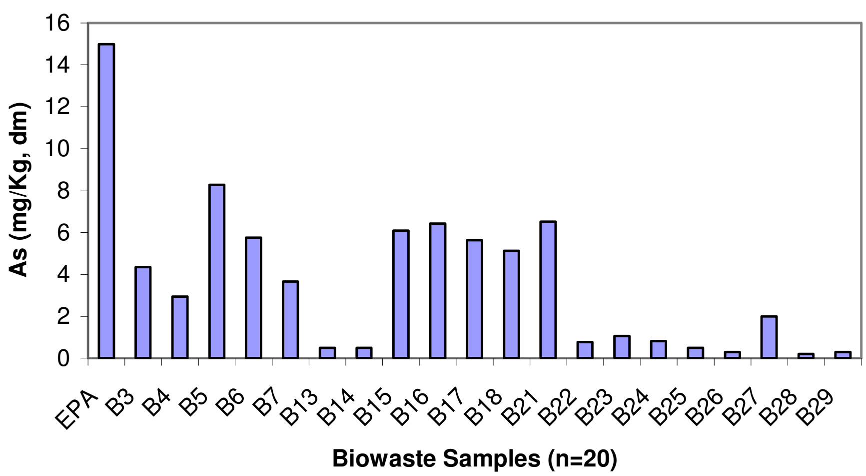
Hg (mg/Kg, dm)
3
2.5
2
1.5
1
0.5
0
EPA
Class I
Class II
B1a
B1b
B2a
B2b
B2c
B3a
B3b
B4a
B4b
B4c
B4d
B4e
B4f
B4g
B4h
B4i
B4j
B4k
B4l
B4m
B5
B6a
B6b
B6c
B6d
B6e
B6f
B6g
B6h
Biowaste Samples (n=29)

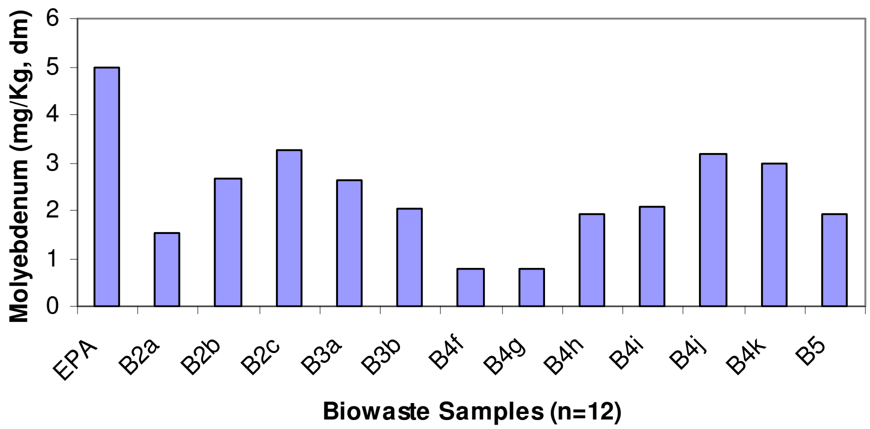


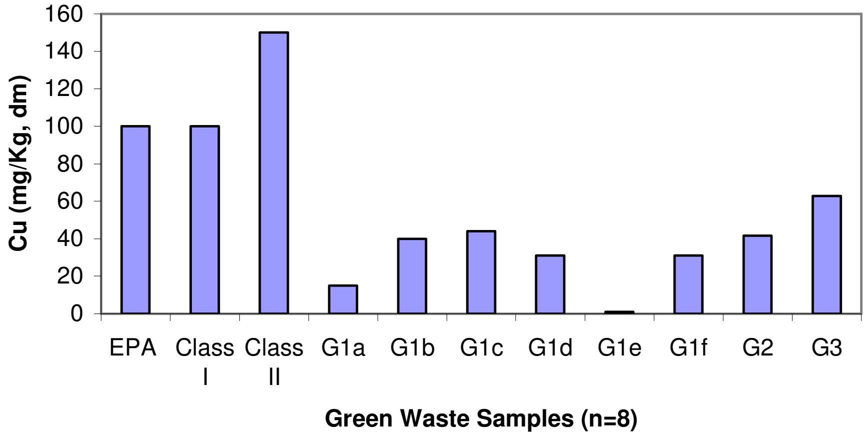
Ni (mg/Kg, dm)
80
70
60
50
40
30
20
10
0
EPA
Class I
Class II
B1a
B1b
B2a
B2b
B2c
B3a
B3b
B4a
B4b
B4c
B4d
B4e
B4f
B4g
B4h
B4i
B4j
B4k
B4l
B4m
B5
B6a
B6b
B6c
Biowaste Samples (n=29)

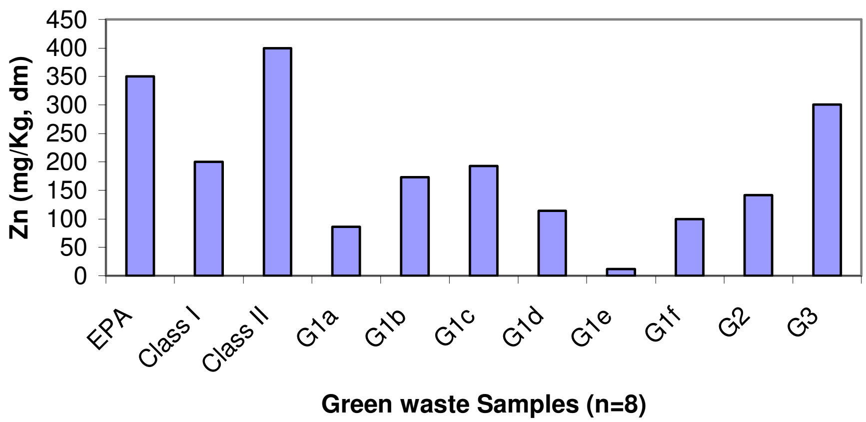

160
140
120
100
80
60
40
20
0
Cr (mg/Kg, dm)
EPA
Class I
Class II
B1a
B1b
B2a
B2b
B2c
B3a
B3b
B4a
B4b
B4c
B4d
B4e
B4f
B4g
B4h
B4i
B4j
B4k
B4l
B4m
B5
B6a
B6b
B6c
Biowaste Samples (n=24)

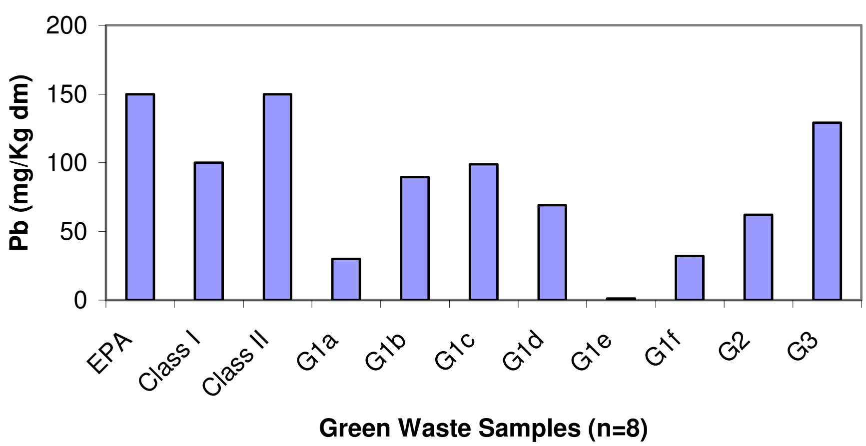

2.5
2
1.5
1
0.5
0
Se (mg/Kg, dm)
EPA
B3
B4
B5
B6
B7
B13
B14
B15
B16
B17
B18
B21
Biowaste Samples (n=12)

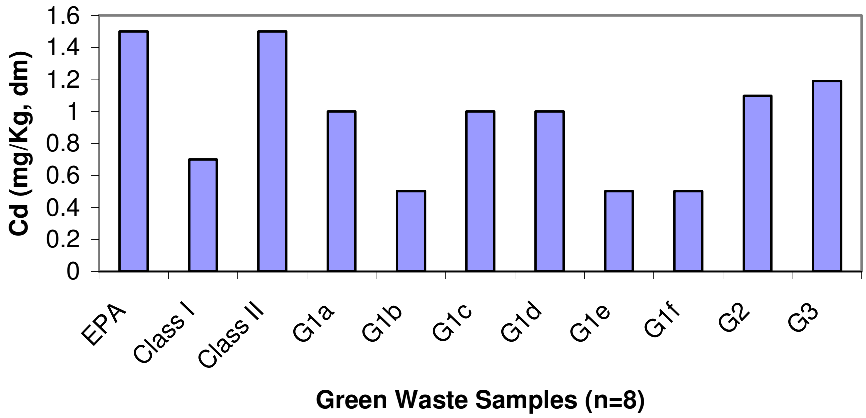

16
14
12
10
8
6
4
2
0
As (mg/Kg, dm)
EPA
B3
B4
B5
B6
B7
B13
B14
B15
B16
B17
B18
B21
B22
B23
B24
B25
B26
B27
B28
B29
Biowaste Samples (n=20)

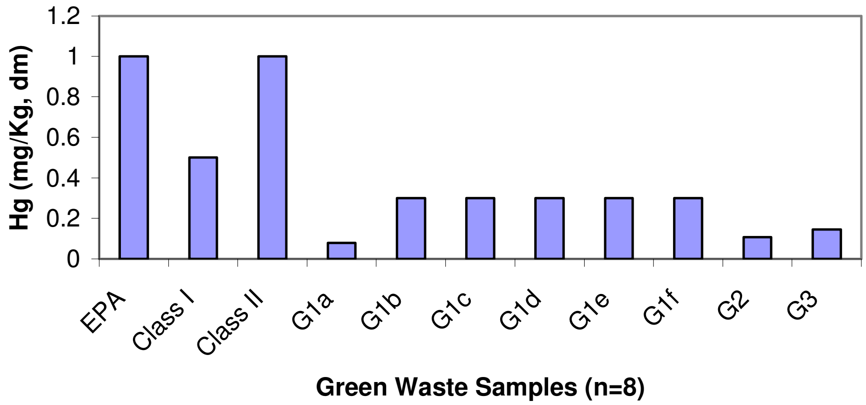

Molyebdenum (mg/Kg, dm)
6
5
4
3
2
1
0
EPA
B2a
B2b
B2c
B3a
B3b
B4f
B4g
B4h
B4i
B4j
B4k
B5
Biowaste Samples (n=12)

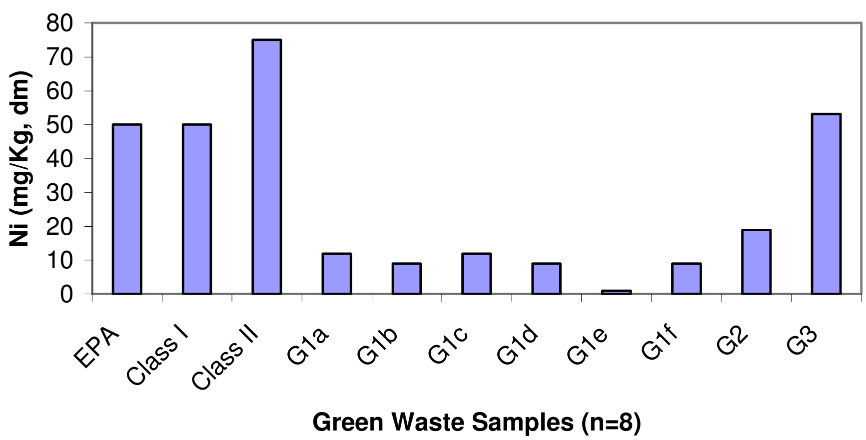

160
140
120
100
80
60
40
20
0
Cu (mg/Kg, dm)
EPA
Class I
Class II
G1a
G1b
G1c
G1d
G1e
G1f
G2
G3
Green Waste Samples (n=8)

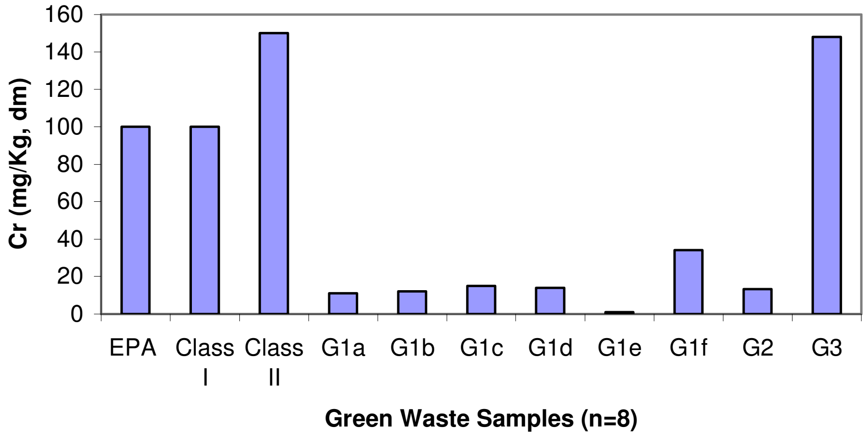

450
400
350
300
250
200
150
100
50
0
Zn (mg/Kg, dm)
EPA
Class I
Class II
G1a
G1b
G1c
G1d
G1e
G1f
G2
G3
Green waste Samples (n=8)

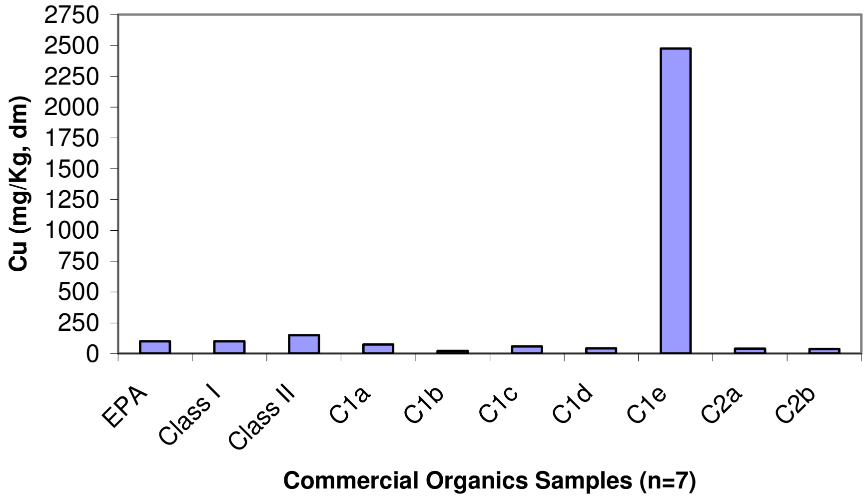

200
150
100
50
0
Pb (mg/Kg dm)
EPA
Class I
Class II
G1a
G1b
G1c
G1d
G1e
G1f
G2
G3
Green Waste Samples (n=8)


1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Cd (mg/Kg, dm)
EPA
Class I
Class II
G1a
G1b
G1c
G1d
G1e
G1f
G2
G3
Green Waste Samples (n=8)

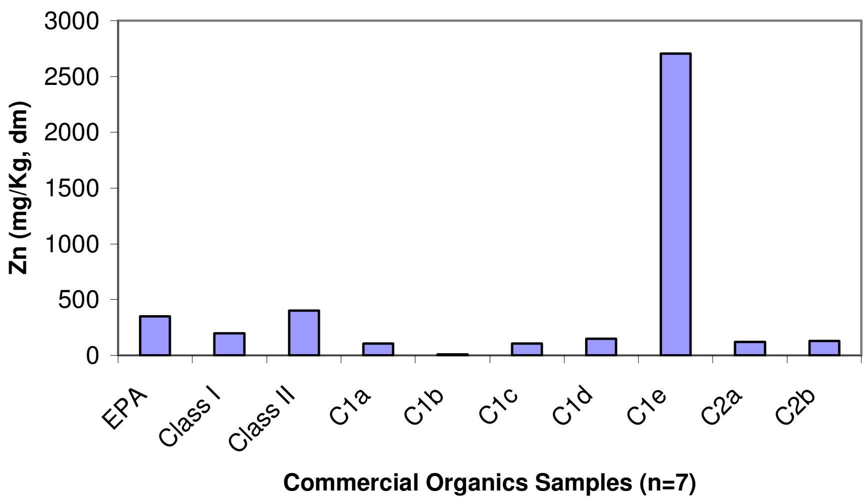

1.2
1
0.8
0.6
0.4
0.2
0
Hg (mg/Kg, dm)
EPA
Class I
Class II
G1a
G1b
G1c
G1d
G1e
G1f
G2
G3
Green Waste Samples (n=8)


80
70
60
50
40
30
20
10
0
Ni (mg/Kg, dm)
EPA
Class I
Class II
G1a
G1b
G1c
G1d
G1e
G1f
G2
G3
Green Waste Samples (n=8)

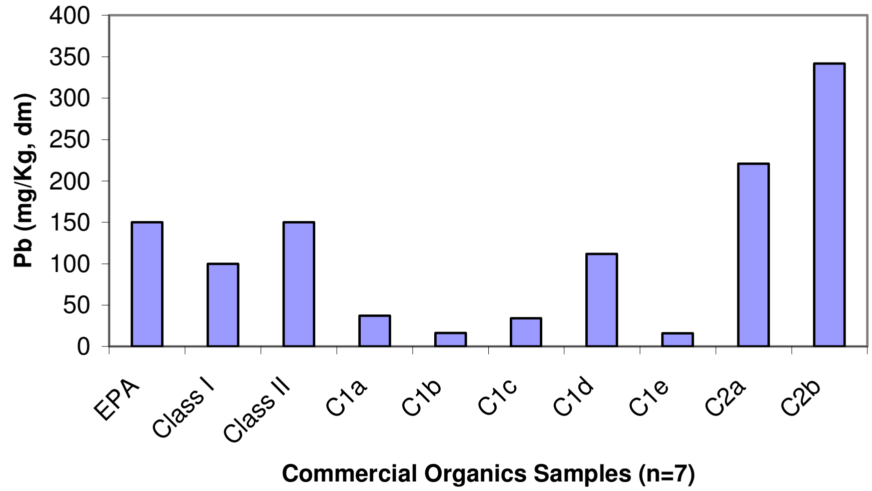

160
140
120
100
80
60
40
20
0
Cr (mg/Kg, dm)
EPA
Class I
Class II
G1a
G1b
G1c
G1d
G1e
G1f
G2
G3
Green Waste Samples (n=8)

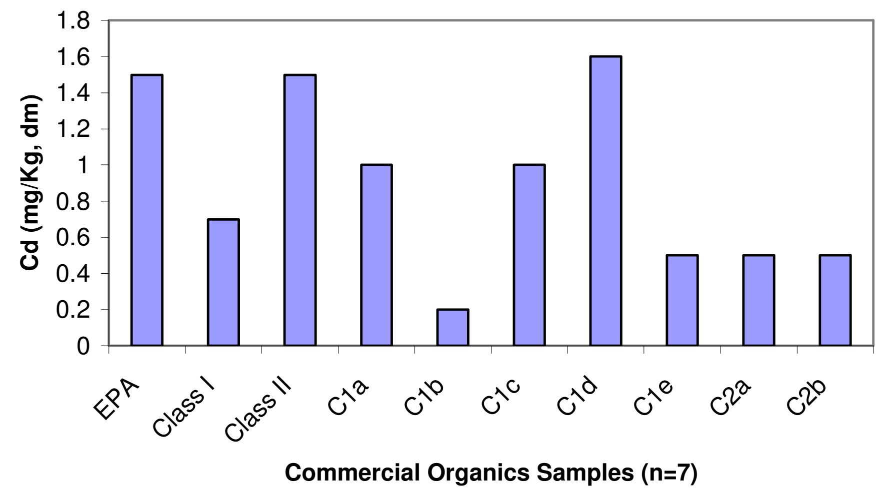


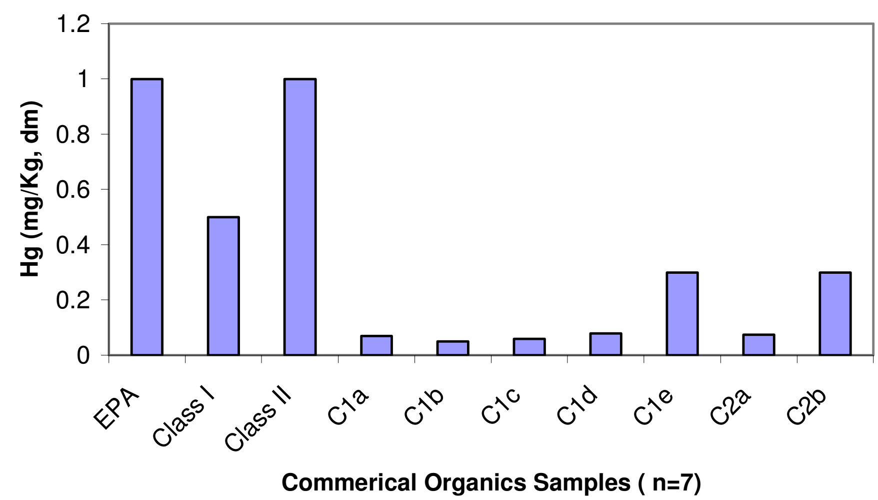
Cu (mg/Kg, dm)
2750
2500
2250
2000
1750
1500
1250
1000
750
500
250
0
EPA
Class I
Class II
C1a
C1b
C1c
C1d
C1e
C2a
C2b
Commercial Organics Samples (n=7)

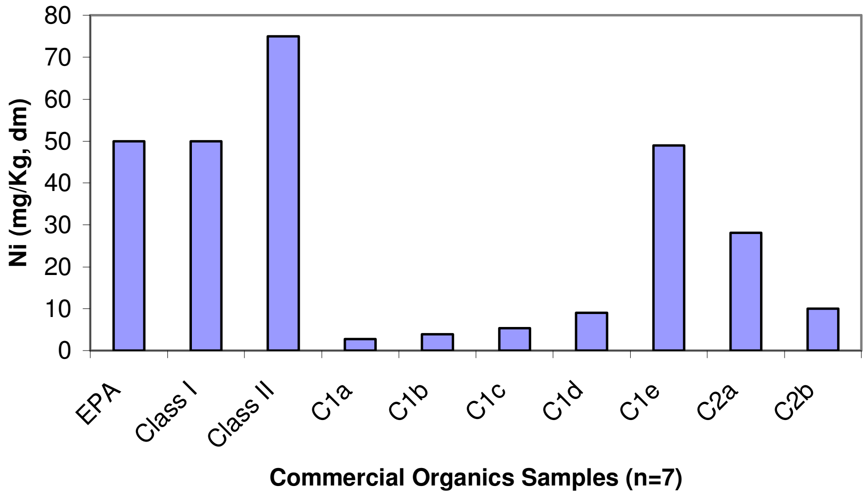


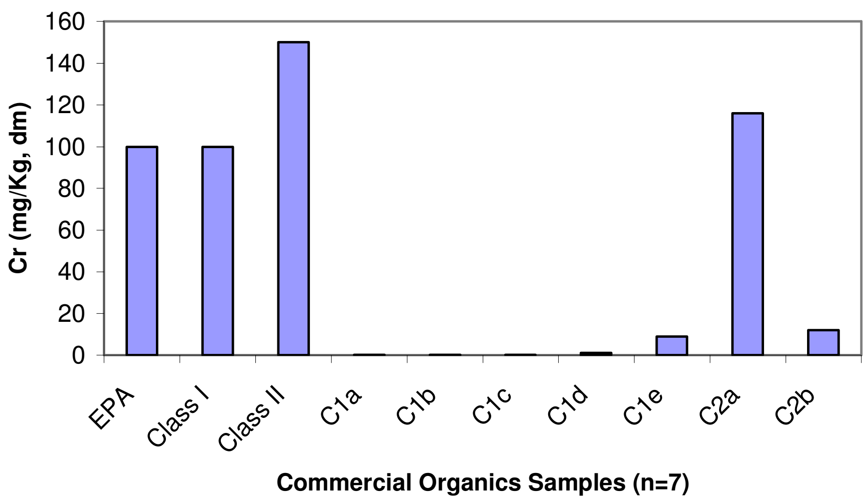
Zn (mg/Kg, dm)
3000
2500
2000
1500
1000
500
0
EPA
Class I
Class II
C1a
C1b
C1c
C1d
C1e
C2a
C2b
Commercial Organics Samples (n=7)

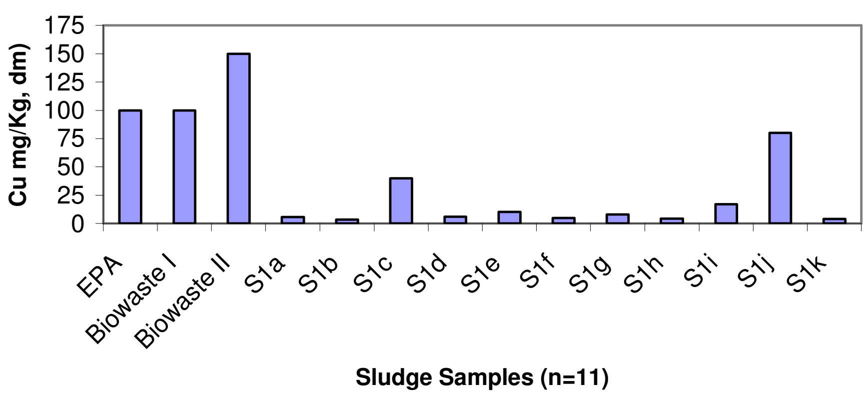

400
350
300
250
200
150
100
50
0
Pb (mg/Kg, dm)
EPA
Class I
Class II
C1a
C1b
C1c
C1d
C1e
C2a
C2b
Commercial Organics Samples (n=7)

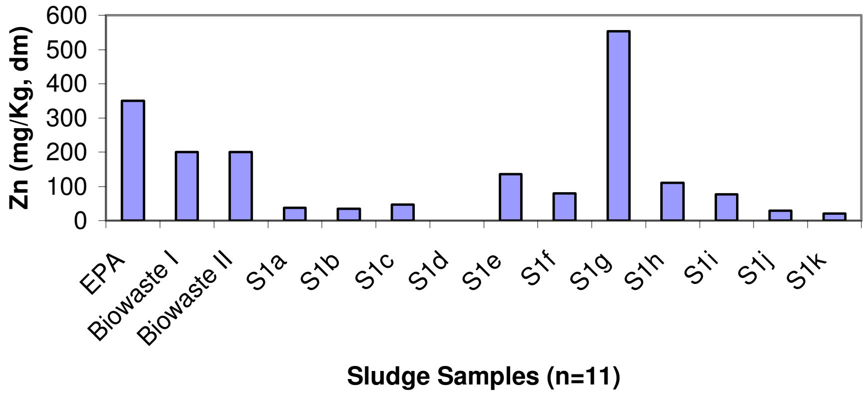

1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Cd (mg/Kg, dm)
EPA
Class I
Class II
C1a
C1b
C1c
C1d
C1e
C2a
C2b
Commercial Organics Samples (n=7)


1.2
1
0.8
0.6
0.4
0.2
0
Hg (mg/Kg, dm)
EPA
Class I
Class II
C1a
C1b
C1c
C1d
C1e
C2a
C2b
Commerical Organics Samples (n=7)

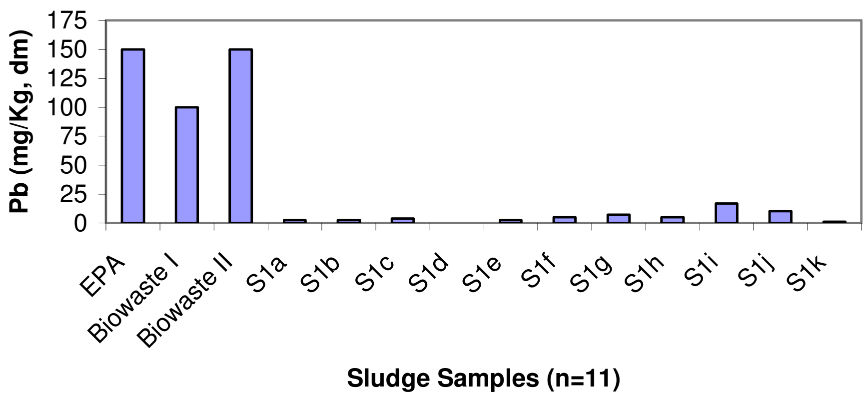

Ni (mg/Kg, dm)
80
70
60
50
40
30
20
10
0
EPA
Class I
Class II
C1a
C1b
C1c
C1d
C1e
C2a
C2b
Commercial Organics Samples (n=7)


Cr (mg/Kg, dm)
160
140
120
100
80
60
40
20
0
EPA
Class I
Class II
C1a
C1b
C1c
C1d
C1e
C2a
C2b
Commercial Organics Samples (n=7)

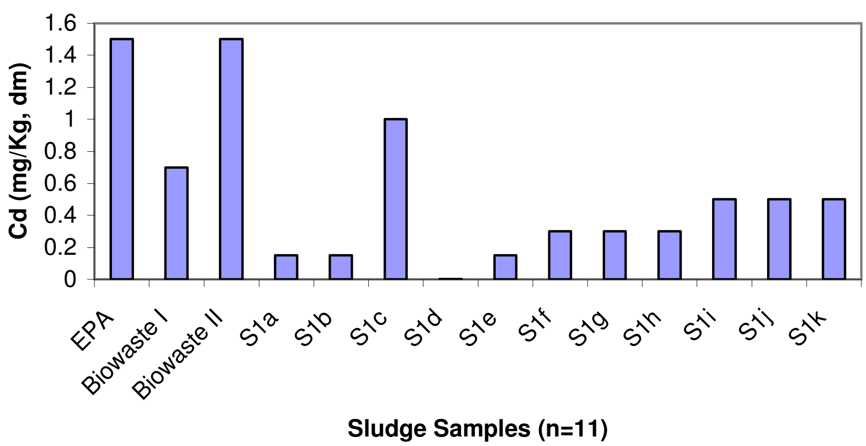

Cu mg/Kg, dm)
175
150
125
100
75
50
25
0
EPA
Biowaste I
Biowaste II
S1a
S1b
S1c
S1d
S1e
S1f
S1g
S1h
S1i
S1j
S1k
Sludge Samples (n=11)



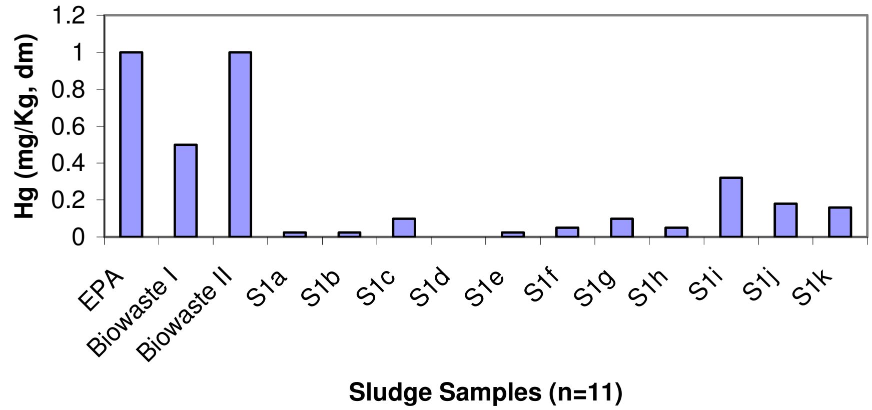
600
500
400
300
200
100
0
Zn (mg/Kg, dm)
EPA
Biowaste I
Biowaste II
S1a
S1b
S1c
S1d
S1e
S1f
S1g
S1h
S1i
S1j
S1k
Sludge Samples (n=11)

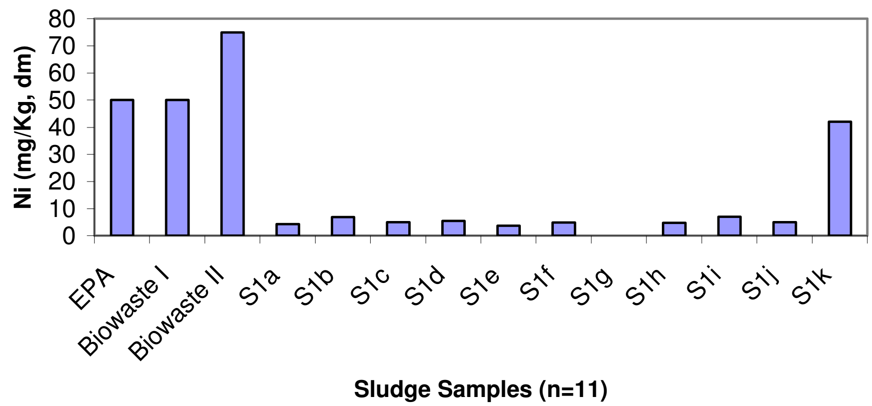


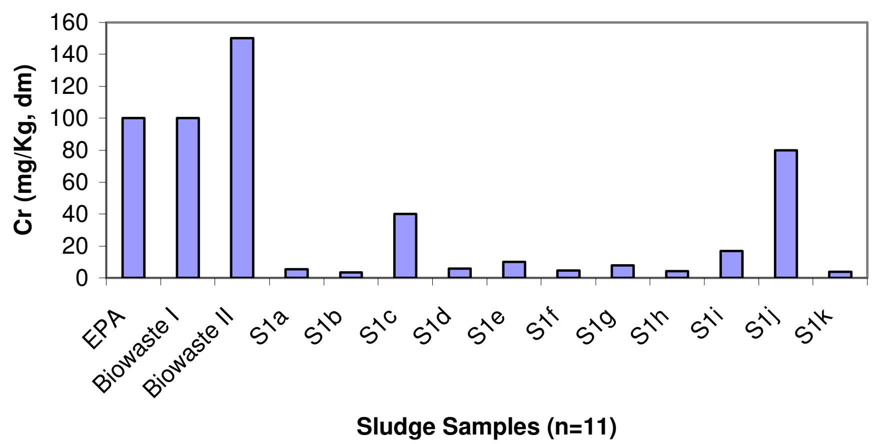
175
150
125
100
75
50
25
0
Pb (mg/Kg, dm)
EPA
Biowaste I
Biowaste II
S1a
S1b
S1c
S1d
S1e
S1f
S1g
S1h
S1i
S1j
S1k
Sludge Samples (n=11)



1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Cd (mg/Kg, dm)
EPA
Biowaste I
Biowaste II
S1a
S1b
S1c
S1d
S1e
S1f
S1g
S1h
S1i
S1j
S1k
Sludge Samples (n=11)


Hg (mg/Kg, dm)
1.2
1
0.8
0.6
0.4
0.2
0
EPA
Biowaste I
Biowaste II
S1a
S1b
S1c
S1d
S1e
S1f
S1g
S1h
S1i
S1j
S1k
Sludge Samples (n=11)

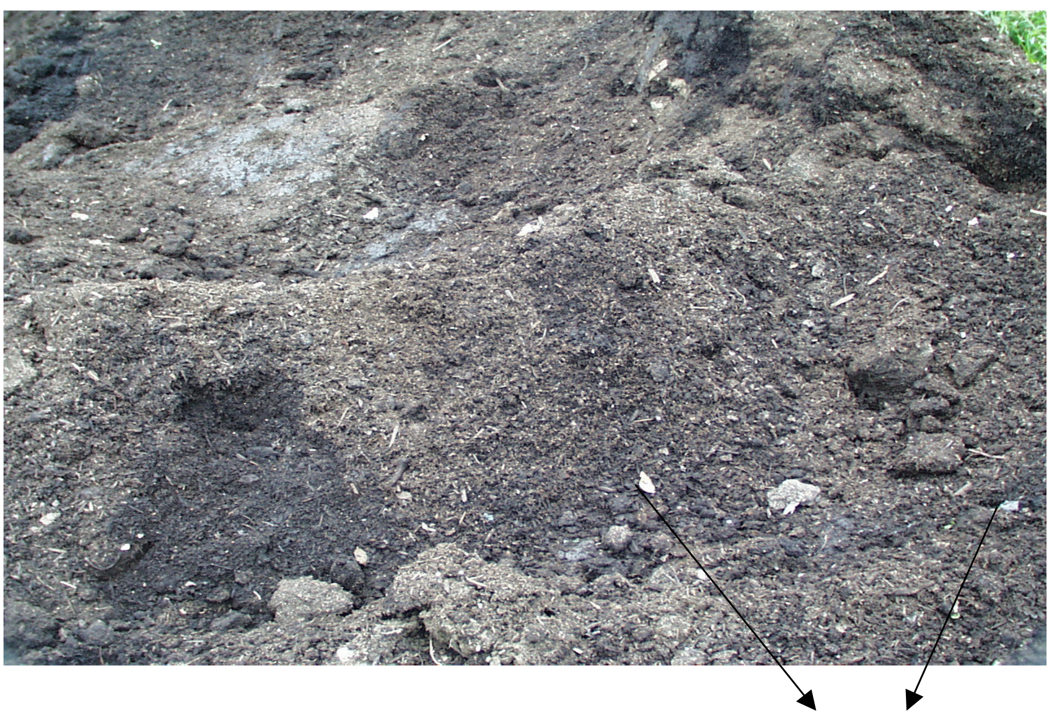

Ni (mg/Kg, dm)
80
70
60
50
40
30
20
10
0
EPA
Biowaste I
Biowaste II
S1a
S1b
S1c
S1d
S1e
S1f
S1g
S1h
S1i
S1j
S1k
Sludge Samples (n=11)


Cr (mg/Kg, dm)
160
140
120
100
80
60
40
20
0
EPA
Biowaste I
Biowaste II
S1a
S1b
S1c
S1d
S1e
S1f
S1g
S1h
S1i
S1j
S1k
Sludge Samples (n=11)

APPENDIX 5

Appendix 5 Photographs taken During Site Visits

Start of biological composting at a Composting Facility



Finished product with evidence of impurities present **Plastic**

Also store improperly on water logged soil