Biodegradable municipal waste composts: analysis and application to agriculture

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SUMMARY

The composting of organic wastes in the UK is driven by the need to reduce the quantity of waste entering landfill. Current UK production of compost is 2 million tonnes (Mt) per annum, which may need to increase to 15 Mt by 2020 in order for the UK to comply with the EU Landfill Directive. The majority of compost in the UK is produced using green waste. However, other forms of biodegradable municipal waste (BMW), including food waste, paper and card, must also be considered for composting, in order to meet the stringent targets of the Landfill Directive.

Compost is used in gardening, horticulture, landscaping, and land restoration. As compost production increases, these markets will become saturated. The addition of green waste composts to agricultural land as a soil conditioner has been emerging as a potential end use for composts. The overall aim of the project is both to demonstrate agricultural benefit of spreading composted BMW to land, and to highlight potential problems.

This study compared and contrasted 12 composts produced from components of BMW. Ten composts contained 100% source segregated BMW and were produced from a variety of wastes including green, fruit, vegetable and kitchen waste, paper and cardboard. One compost was 72% mixed municipal solid waste (MSW) plus 18% source segregated BMW, and one compost was 100% mixed MSW. Composts were analysed for pH, electrical conductivity, carbohydrates, nutrients and contaminants. In general, compost pH was above neutral. Composts containing kitchen or meat wastes had higher nitrogen contents than composts produced from purely green and vegetable wastes. The two MSW composts contained high levels of physical contaminants (glass, plastic and metal) compared to the 10 source segregated BMW composts. The 100% MSW compost had significantly higher levels of potentially toxic elements (PTEs or heavy metals) than the other composts.

In order to ascertain the efficacy of composts as agricultural soil conditioners, a fully replicated field trial was established at Warwick HRI. Four source segregated BMW composts and one mixed MSW compost were incorporated into agricultural soil to examine the effect, either beneficial or harmful, on a response crop of spring barley. The composts were applied according to their nitrogen content at two rates of 250 and 500 kg N ha^{-1}. The third treatment was 250 kg N ha^{-1} compost plus 125 kg N ha^{-1} inorganic nitrogen fertiliser. The control was no compost or fertiliser. The nutrient supply, organic matter and PTE content of the soils were assessed before and after compost application. The harvested grain was analysed to investigate any effect of the composts on yield, nutrients or PTEs.

In general, yields were lowest in the 250 kg N ha^{-1} treatment and highest in the 250 kg N ha^{-1} compost + 125 kg N ha^{-1} treatment. Three of the source segregated BMW composts increased yield compared to the control in all three treatments, and could be recommended for use in agriculture as a soil conditioner. The mixed waste compost reduced barley yield by up to 33% compared to the control. This reduced growth could be attributed to the mixed MSW compost having higher PTEs and sodium contents than the four source segregated composts. Levels of copper and zinc were highest in grain from the mixed MSW compost treatment. In all treatments, levels of lead and cadmium in the barley grains were below European Commission limits for PTEs in cereal grains (CEC 2001). Soil PTEs were not significantly increased on application of the source segregated composts. The mixed MSW compost increased soil lead concentration. However, if these composts were applied annually for 10 years, soil PTE levels would still be well below the recommended UK limits.

ABBREVIATIONS

ABPR	Animal By-Products Regulations
BMW	Biodegradable municipal waste
BS	British Standard
BSI	British Standards Institution
cfu	Colony forming unit
CGAP	Code of Good Agricultural Practice
DEFRA	Department for Environment, Food and Rural Affairs
EC	Electrical conductivity
EfW	Energy from waste
EN	European Standard
EU	European Union
LOI	Loss on ignition
MAFF	Ministry of Agriculture, Fisheries and Food
MBT	Mechanical biological treatment
$\mathbf{mS\ cm^{-1}}$	Milli-Siemens per centimetre (electrical conductivity units)
MSW	Municipal solid waste
Mt	Million tonnes
NCE	Non-compostable element
NVZ	Nitrate vulnerable zone
OM	Organic matter
PAS	Publicly available specification
PTE	Potentially toxic element
RRF	Resource recovery facility
SOM	Soil organic matter
VCU	Vertical composting unit
WIP	Waste Implementation Programme
WRAP	Waste and Resources Action Programme
WSC	Water soluble carbohydrate

1 INTRODUCTION

The total municipal waste produced in the UK in 2003/04 was estimated to be 29.1 million tonnes per year (Defra 2005). Approximately 60% of MSW is organic in origin and can be termed biodegradable municipal waste (BMW). In order to comply with the EU Landfill Directive, levels of BMW going to landfill must be reduced. Composting of BMW is one option. To date, the majority of composting in the UK has used green waste. However, in order to meet recycling targets, other forms of BMW disposal and recycling must be considered. Increasing the quantity and capacity of composting facilities will result in an increased quantity of compost being produced, which will require a disposal route.

This section summarises BMW composting in the UK, and both EU and UK legislation which influences the UK composting industry. Following this, compost characteristics and effects on plants and soil are discussed.

1.1 Composting of biodegradable municipal waste in the UK

BMW contains a wide variety of materials which vary substantially in particle size, moisture, chemical and nutrient content. BMW includes food, green waste, paper and cardboard. Green waste can be defined as post-consumer waste material of botanical origin from gardens, parks and other horticultural activities.

In 2003/04 in the UK, 325 composting facilities were in operation; with 84% of the waste composted being green waste and less than 3% kitchen waste (The Composting Association 2005). Uses for compost in 2003/04 included horticulture, gardening and land maintenance (36%), and land restoration, landfill cover and landfill engineering (24%). In recent years, there has been a rise in compost use by the agricultural sector, with 0.29Mt compost used in 2001/02, increasing to 0.48Mt in 2003/04. Indeed, agriculture accounted for 40% of compost used in 2003/04 (The Composting Association 2005). Returning composted material to agricultural land is the government's preferred option.

1.2 Legislation

The European Commission Directive on the Landfill of Waste (1999/31/EC), (commonly referred to as the Landfill Directive), requires that the volume of BMW sent to landfill in the UK is reduced to:

- 75% of the amount produced in 1995 by 2010
- 50% of the amount produced in 1995 by 2013
- 35% of the amount produced in 1995 by 2020

In order to meet these requirements, up to one-third of the UK's BMW must be diverted away from landfill (Strategy Unit 2002). Although this diversion will be gradual as facilities become available, by 2010 the UK may need to compost and find alternative methods of disposal for between 4.9 and 7.7Mt of BMW per annum, increasing to between 10.6 and 15.5Mt by 2020 (The Composting Association 2003).

This huge amount of composted BMW may swamp the future compost market. Moreover, high quality soil conditioners and composts are principally produced from source separated green waste only. The other major components of BMW including kitchen waste, paper and cardboard must also be diverted from landfill, preferably via composting.

A number of UK composting companies are using source segregated kitchen waste, fruit and vegetable waste and cardboard. Source segregated BMW which does not contain animal wastes can be composted outside (e.g. in open air windrows or aerated piles).

In contrast, some companies utilise mixed MSW. The BMW fraction is separated out mechanically from the other materials either before or after composting. This process is known as mechanical biological treatment (MBT).

The handling, processing and disposal of animal wastes are regulated under the EC Animal By-Products Regulation 1774/2002 and implemented in the four home countries under the following regulations: Animal By-Products Regulations (England) 2003, (Scotland) 2003, (Northern Ireland) 2002 and (Wales) 2003. Current regulations require that the composting of food wastes which contain or may have been in contact with meat or fish must include a period of time in-vessel at a minimum temperature: either a period of one hour at 70^{o}C or two days at 60^{o}C (barrier one). This must then be repeated in a second vessel (barrier two).

The Code of Agricultural Practice for the Protection of Soil (MAFF 1998) states that the spreading of specific wastes onto agricultural land does not require a licence subject to certain conditions. These materials include compost, waste plant matter, waste food and paper. A principal condition is that no more than 250 tonnes/ha waste are spread on the land in any 12 month period.

The EC Nitrates Directive (91/676/EEC) has led to the introduction of nitrate vulnerable zones (NVZs); areas where there is a risk that the nitrate (NO_3) content of surface freshwater and groundwater may exceed 50mg l^{-1}. In 2002 NVZ status was applied to 55% of arable land in the UK.

In NVZs, the maximum amount of fertiliser applied in any 12 month period to grassland is 250 kg N ha^{-1}, and to non-grassland 170 kg N ha^{-1} (http://www.defra.gov.uk). As the N content of compost varies so too will the total volume that can be spread.

1.3 The UK compost market

There are a number of established outlets for composts. Lower quality composts are used for landfill engineering and restoration. Higher quality composts with low levels of contaminants and PTEs are sold for the amateur gardening, grounds maintenance, horticulture and land restoration markets (The Composting Association 2003). The total amount of composted products in 2001/02 in the UK was only 1.0Mt, increasing to 1.2Mt in 2003/04, which is small compared to the several million tonnes of compost, albeit of lower quality, which will be produced to meet the requirements of the Landfill Directive over the next few decades.

There are a number of standards in the UK for composts produced from green waste and used as growing media. These include the BSI PAS 100, produced by the Composting Association and the Waste Resources Action Programme (WRAP 2005), which sets upper limits for concentrations of physical, chemical and microbial contaminants. The APEX specification (www.Apexcompost.co.uk/standards.asp) has guidelines for a number of physical and chemical characteristics, in addition to contaminants. APEX was formed by three large waste management companies in the UK (Cleanaway, Onyx and SITA).

Although the composts in this study are being investigated to ascertain their suitability for application to agricultural land, the PAS 100 and APEX standards will be referred to as they are a good bench mark for quality compost.

1.4 Compost characteristics

A number of parameters can significantly affect compost properties. They include the source and nature of the raw materials or feedstock, pre-treatment (particularly source separation), and the composting method (He et al. 1992). Moreover, the chemical composition of composted BMW will vary widely with seasonal variation in raw input (Ward et al. 2005). For example, green waste will contain a greater proportion of dead leaves and woody material in the winter months, and more grass cuttings and other green plant matter in the summer months.

1.4.1 Compost pH and use as a fertiliser

Compost has been found to have a substantial buffering capacity, and generally has a pH above neutral. Thus compost application could reduce liming costs in agriculture. Inorganic fertilisers can reduce soil quality in a number of ways if applied for a number of years. For example, continued application of NH_4 fertiliser tends to reduce soil pH.

The application of MSW compost to sodic soils has been found to have a number of benefits. Sodic soils are highly alkaline and have high concentrations of sodium which adversely affect crop production and soil structure. Compost application increases the concentration of other salts which displace the sodium (Kochba et al. 2004). This, combined with the enhancement of soil structure by compost could result in the reclamation of sodic and saline soils.

Organic matter has been used as a soil improver and fertiliser for centuries. Although the application of inorganic fertiliser to agriculture is now common practice, using composts derived from green wastes in agriculture is slowly making a come back. Compost contains variable amounts of N, P and K, and is a valuable source of plant nutrients.

Composts have been used successfully as a fertiliser in variety of field crops ranging from grass to maize, grains and broccoli (Rodrigues 2000; Szmidt 1997). The fertilising effect of compost is due to its capacity to release N and other plant nutrients. The application of compost to agricultural soil increases soil organic matter (SOM). As SOM undergoes mineralization, N is released and becomes available to the crop. In many cases, around 25% of available N in compost is released in the first year, with a release of 10% each year thereafter (Sikora and Szmidt 2001). However, this is not a consistent figure, with N release rates varying according to a number of factors including SOM, temperature, moisture and texture. One study of four vineyard soils in Germany showed a 4-33% N release rate in the first year of compost application (Nendel et al. 2005).

1.4.2 Compost chemical characteristics

As mentioned above, BMW consists of a number of organic wastes including food and green waste, paper and cardboard. The type of feedstock will greatly influence the response of crops to the applied compost. The C:N ratio of the compost is one of the principal factors. For example, C:N ratios of MSW compost used in studies on different crops varies from 16:1 (Hadas and Portnoy 1997) to 27:1 (Brito 2001) and 30:1 (Crecchio et al. 2001) to 40:1 (Eriksen et al. 1999). The C:N ratio controls residue breakdown and mineralization of the N contained in the compost. C:N ratios tend to be lower in vegetable wastes and higher in straw, paper and cardboard.

The Soil Association suggest a C:N ratio in the range of 20:1 to 40:1 in mature composts. Above this threshold N becomes immobilised i.e. the N is no longer available to the crop. Compost with a C:N ratio greater than 30:1 applied to soil can actually immobilise available N, causing N deficiency.

Trace elements occur in the environment, soils and plants. Plants acquire the minerals that they need from the soil solution. Six macronutrients (N, K, P, S, Mg, Ca) and eight micronutrients (B, Cl, Cu, Fe, Mn, Mo, Ni, Zn) are essential for plant growth. However, other trace elements, termed potentially toxic elements (PTEs) or heavy metals can also be taken up by plants. The presence of PTEs above a certain concentration can have detrimental effects on plant growth and development. Fertilisers, pesticides and sewage sludge added to soils often contain traces of PTEs. For example, Cd, Cu, Pb, Ni and Zn are all found in inorganic fertilisers (Epstein et al. 1992). PTEs can be toxic to plants, contaminate water and affect human health.

Composts derived from MSW contain PTEs, often due to the presence of solder and lead acid batteries in the waste stream (Mamo et al. 2002). The principal PTEs in MSW compost are Cd, Cr, Cu, Hg, Ni, Pb and Zn. According to the United Nations Environment Programme, the most significant potential environmental problem arising from compost use is its potential to convey PTEs to the soil (UNEP 1996).

The physical appearance of composts can be significantly influenced by the volume of non-compostable elements (NCEs) present. These NCEs are predominantly glass, plastic, stones and metal. Generally composts produced from mixed waste contain a greater proportion of NCEs than source segregated waste composts.

1.5 Project rationale

There are significant drivers to enhance the collection and management of organic waste materials in the UK. These drivers include the EU Landfill Directive and Waste Strategy 2000 (DETR 2000). In order for these objectives to be met increasing amounts of BMW will need to be composted. Indeed, by 2010 the UK may need to compost and find alternative methods of disposal for up to 15.5Mt BMW by 2020. In 2003/04 2.0Mt BMW was composted to produce 1.2Mt of compost (The Composting Association 2005). Thus an eight fold increase in composting is necessary to meet the 2010 target.

To date, research in the UK regarding the use of compost has focused on green waste composts as a peat substitute or soil conditioner (for example: Peatering Out Ltd 2005). This is due to the majority of operations composting green waste only. Results from the few UK field trials investigating green waste composts (Parkinson et al. 1999, HDRA Consultants 2000, Ward et al. 2005) have revealed a number of benefits to both the crop and soil. These findings may not be directly transferable to mixed BMW composts. The feedstock materials and the final product in BMW composts may differ in terms of both physical and chemical properties to those of green waste composts.

Agricultural land covers over 70% of the land area of England and Wales (www.defra.gov.uk). Thus, the potential area for spreading composted BMW is substantial. If long term and repeated applications of composted BMW to land is to become the solution to the UK's current waste problem, then both short and long term field trials will be required to assess its impact. It should be highlighted that the Animal By-Products Order, the Water Directives and the Nitrates Directive must be complied with when compost is applied to land, as for any agrochemical, manure or sewage application. Moreover, the compost should be of agricultural benefit to both the soil and the crop. Thus the compost can be regarded as a positive input into the agricultural system.

Assuming an average compost N content of 1-1.5%, and a maximum permissible application rate of 250 kg N ha^{-1} year^{-1} in Nitrate Vulnerable Zones (NVZs), an area of 375,000-500,000ha would be required to spread 15Mt compost. Cereal production is the largest agricultural sector in the UK, producing 22.3Mt cereals in 2003, including 14.8Mt wheat and 6.6Mt barley. The land area used for cereal production in the UK is approximately 3,100,000ha (www.defra.gov.uk). This large area could easily absorb the increasing volumes of compost which will be produced, and even benefit from the applications of compost.

In order to assure farmers that BMW composts are safe to use, and do indeed have an agricultural benefit, field trials demonstrating this are imperative. Field trials should be supported by articles in the popular farmer’s press and with agreement of the major retailers, whose support is necessary to make it work.

1.6 Project aims

The overall aim of the work described in this report is to improve our understanding of the effects of applying BMW composts to agricultural land. This project will investigate the application of composted BMW to cereals, using BMW compost sourced from a variety of UK companies using a range of organic feedstocks. Such work is necessary to demonstrate to farmers whether compost produced from BMW can be safely used in agriculture without causing detrimental damage to the crop, soil or the environment.

The objectives of the study were to assess:

1. the physical and chemical characteristics of composts produced from BMW
2. the effects of applying BMW composts to agricultural land on both the crop and soil

2. MATERIALS AND METHODS

2.1 Compost acquisition

Two batches of compost were acquired. Batch 1 was an initial screening exercise and was performed on 12 composts from 11 companies. Following screening, five composts were chosen for the field experiment. These are referred to as batch 2.

Table 2.1. The feedstock, composting system, screen size and end use of batch 1 composts
MBT = Mechanical Biological Treatment, RRF= Resource Recovery Facility
VCU = Vertical Composting Unit (in-vessel system)

Compost	Feedstock	System	Screen size (mm)	End use
A	Green & kitchen waste, paper, cardboard	In-vessel / windrow	10	Agricultural soil improver, reclamation, landfill cover
B	50% green waste, 50% fruit & vegetable waste	VCU / windrow	20	Sold as soil conditioner
C	90% green waste, 10% milk	windrow	40	Agricultural soil improver
D	Green waste, vegetable waste	In-vessel	16	Sold as soil conditioner
E	75-80% straw, 20-25% green waste, fruit & vegetable waste, cardboard	Windrow	15	Agricultural soil improver, sold as soil conditioner
F	30-40% green waste, 60-70% fruit & vegetable waste, cardboard	Windrow	15	Agricultural soil improver, sold as soil conditioner
G	Mixed municipal solid waste	In-vessel (MBT)	6	Landfill cover
H	82% green waste, 15% potato waste, 3% manure	Windrow	50	Agricultural soil improver
I	Green waste, cardboard	In-vessel	10	Sold as soil conditioner
J	Green & kitchen waste, paper, cardboard, catering waste	In-vessel / windrow	10	Agricultural soil improver, sold as soil conditioner
K	40% pet food waste, 40% shredded wood waste, 19% green waste, 1% lime	VCU/ static pile	30	Agricultural soil improver and fertilizer
L	72% rejects from RRF, 17% kitchen waste, 11% commercial waste	In-vessel	No screen used	Landfill cover

The majority of the compost feedstocks were 100% source segregated, with the exception of composts G (100% MSW) and L (72% MSW from a Resource Recovery Facility). A variety of composting methods were used including open windrow and in-vessel systems. Composts A, B and J were first composted for up to two weeks in-vessel, followed by maturation in open windrows.

Batch 1 composts were stored at 4^{o}C prior to analysis. The composts were analysed as detailed in section 2.2.

Five composts were selected for use in the field trial: A, B, F, G, J. They represented a range of feedstocks, from mixed MSW to source segregated green waste mixed with vegetable waste, and contained a range of N values, C:N ratios and proximate characteristics. For details please refer to section 3.

Batch 2 composts were obtained in bulk at the end of February 2005 for the field trial. Sub-samples were taken for analysis in accordance with BS EN 12579, and were stored at 4^{o}C. The composts were analysed as detailed in section 2.2. The remainder of the compost for the field trial was stored undercover until required (section 2.3).

2.2 Compost analysis

The composts were analysed according to the British Standards (BS) for soil improvers and growing media, which are used by the Publicly Available Specification (PAS) 100 compost accreditation scheme (WRAP 2005), as detailed in table 2.2. For comparison, the composts were also compared with the APEX compost standards (APEX 2004).

Table 2.2. Compost analysis methods for batch 1 and batch 2

Analysis	**Test method**	**Batch**	
		1	**2**
pH	BS EN 13037	✓	✓
Electrical conductivity	BS EN 13038	✓	✓
Bulk density	BS EN 13040	✓	✓
Moisture content	BS EN 13040	✓	✓
Water holding capacity	See section 2.2.1		✓
Particle size distribution	PAS 100 Annex E	✓	✓
Physical contaminants	PAS 100 Annex E	✓	✓
Organic matter content	BS EN 13039	✓	✓
Carbohydrates	See section 2.2.2	✓	✓
% carbon & % nitrogen	LECO® CN-2000	✓	✓
Nutrients (water soluble): NO_3^-, NH_4^+, K, Ca, Mg, P, Fe, Zn, Mn, Cu, B, Na, Cl^-, S	BS EN 13652	✓	✓
Potentially toxic elements (aqua regia extractable): Cd, Cr, Cu, Pb, Ni, Zn	BS EN 13650	✓	✓
Potentially toxic elements (aqua regia extractable): Hg	ISO/DIS 16772	✓	✓
Salmonella	ABPR Section 2, Part 2	✓	✓
E. coli	BS ISO 11822-3	✓	✓
Total coliforms	BS 5763 Part 2	✓	✓
Bioassay	See section 2.2.3		✓

Prior to analysis, the composts were prepared according to British Standards (BS 2000). Five replicates per compost type were used for % carbon, % nitrogen and carbohydrate analysis. For all other methods three replicates were used.

2.2.1 Water holding capacity

The water holding capacity was only measured on batch 2 composts. Fresh compost samples were sieved to 11mm.

Method to measure field capacity
Galvanised metal cylinders with a volume of 195cm^3 were used. The base of each cylinder was covered with fine nylon fabric (3 threads/mm) and secured with a rubber band. The cylinders were filled with compost and placed in a cold water bath lined with capillary matting for 24h, by which time the samples were saturated. The cylinders were then placed on the sand surface in a sand tower for 24h. Then, still on the sand surface, a pressure of 50cm suction (equivalent to field capacity) was applied for 72h. Samples were weighed, dried at 103^{o}C for 48h and then re-weighed.

Method to measure wilting point
The method and apparatus are as described by Heining (1963). A known volume of fresh compost, 23cm^3, was weighed, soaked in distilled water overnight, then placed in the apparatus and 220lb/in^2 pressure was applied for 14 days. The compost was weighed, dried at 103^{o}C for 48h and re-weighed.

Calculation for available water content
Available water content; the difference between field capacity and wilting point (as % water on a dry weight basis) was calculated from the above measurements.

2.2.2 Carbohydrate analysis

Analysis of water soluble carbohydrate (WSC), cellulose and lignin concentrations were performed on oven dried (80^{o}C) compost. Samples were milled using a rotary mill to pass through a 2mm sieve.

WSC
20ml H_2O was added to 0.2g compost and incubated for 2h in a boiling water bath. The water-soluble fraction was separated by centrifugation at 5,000rpm for 20min then made up to a known volume. WSC was determined using the phenol-H_2SO_4 assay (Dubois et al. 1956).

Cellulose and lignin
The solid residue remaining after centrifugation was dried for 16h at 100^{o}C. Lignin was determined using a method based on Ritter et al. (1932). The compost residue was treated with 4ml 72% H_2SO_4 in an iced water bath for 2h. The acid was diluted to 0.6M strength and reluxed for 2h on a hot plate. Following cooling the solution was filtered through a Whatman GF/A filter. Cellulose was determined by measuring sugars in the filtrate using the phenol-H_2SO_4 assay (Dubois et al. 1956). Material remaining on the filter was dried for 24h at 100^{o}C to determine the acid-insoluble material. The filter was placed in a furnace at 400^{o}C for 16h to determine ash content. Lignin was determined by subtracting the weight of ash from the weight of acid-insoluble material.

2.2.3 Bioassay

A bioassay was performed on the batch 2 composts, using a modified version of the PAS 100 standard protocol the “Method to assess contamination by weed propagules and phytotoxins in composted materials” (WRAP 2005).

The composts were combined with a peat mix consisting of 10 litres sphagnum peat, medium grade, 60g limestone and 40g fertilizer (17:17:17), to give five different treatments:

	Treatment
1	0 % compost: 100% peat
2	25% compost: 75% peat
3	50% compost: 50% peat
4	75% compost: 25% peat
5	100% compost: 0% peat

Growth conditions

The experiment was carried out in July 2005 at Warwick HRI. Trays (210x150x50mm) were filled with the compost mixtures and wetted thoroughly. Ten tomato seeds (variety Moneymaker) per tray were sown, and lightly covered with compost. The trays were situated in a temperature controlled glasshouse (20-25°C) on moist capillary matting, and were also watered from above when required. A fully randomised and blocked experiment was established. Each treatment was replicated five times.

Once a week for four weeks, the number of tomato plants in each tray was recorded. After four weeks the above ground part of the tomato plants were harvested. Fresh weights were recorded, and after oven drying for 48h dry weights were recorded.

2.3 Field trials

2.3.1. Location and design

The field trial was located at Warwick HRI, Wellesbourne (Lat: 52:12:11 N, Lon: 1:36:07 W). The soil was a sandy loam of the Wick series (Whitfield 1974). In 2003 winter wheat (Hareward) was grown, followed by winter barley (Pearl) in 2004. In autumn 2004 a base dressing of 250 kg ha^{-1} P and 240 kg ha^{-1} K was applied.

A randomised and blocked experiment was established in spring 2005. There were three replicates of each treatment; 63 plots of 18m * 4 m wide, 4536 m^2 in total. The design incorporated three compost treatments: (1) the amount of compost required to supply 250 kg ha^{-1} N, (2) the amount of compost required to supply 500 kg ha^{-1} N and (3) the amount of compost required to supply 250 kg ha^{-1} N plus mineral fertiliser to supply an additional 125 kg ha^{-1} N as ammonium nitrate (NH_4NO_3). The actual amounts of compost applied is detailed in table 2.3. Incorporated within the design was a nitrogen fertiliser response trial with six levels of ammonium nitrate: 0, 42, 84, 125, 167 and 209 kg ha^{-1} N: No compost were applied to these plots. The plots which received no compost and no nitrogen fertiliser are referred to as the control plots. Mineral fertiliser was applied on 11th May 2005.

Table 2.3. The rate of compost used in the field trial

	Compost rate (t ha^{-1})	
Compost	**@ 250 kg N ha^{-1}**	**@ 500 kg N ha^{-1}**
A	27.56	55.12
B	43.66	87.33
F	32.43	64.86
G	43.67	87.34
J	28.35	56.71

The composts were distributed evenly over each plot (10th March) and then incorporated (14th March) to a depth of 15-20 cm using a spading machine in a north-south direction. This was followed by a light spring tine used east-west to assist seedbed preparation. Barley (variety Optic) was drilled at a rate of 200 kg ha^{-1} in an east-west direction on 15th March 2005.

Herbicide (Duplosan KV 2.0 litres ha^{-1} and Alpha Briotril plus 19/19 0.5 litres ha^{-1}) was applied at the end of April 2005.

2.3.2. Soil sampling

Soil samples were taken on three occasions and analysed, as detailed in table 2.4. In each instance, cores to two depths (0-30 and 30-60cm) were taken, and samples were bulked together to provide one 0-30cm sample, and one 30-60cm sample per plot.

Pre-drilling nine samples per depth were taken from each block. Pre-top dressing and post-harvest three samples per depth were taken from each plot.

Soil pH, moisture content, conductivity, mineral nitrogen, water soluble nutrients were determined from both the 0-30 and 30-60cm depths, using methods based on MAFF/ADAS (1986). Total carbon and nitrogen were analysed using a LECO® CN-2000. PTEs (aqua regia extractable) were analysed using the PAS 100 methods (BS EN 13650 and ISO/DIS 16772) in the top 0-30cm fraction only, in soils from all compost treatments, plus the zero fertilizer control treatment.

Table 2.4. Soil sample analyses undertaken

Soil sampling date	**Analysis**
Pre-drilling 9th March 2005	pH, conductivity, total C & N, mineral N water soluble nutrients, PTEs
Pre-top dressing 5th May 2005	pH, moisture content, total C & N, mineral N, PTEs
Post-harvest 8th August 2005	pH, conductivity, moisture content, total C & N, mineral N, water soluble nutrients, PTEs

2.3.3 Plant sampling

Plant samples were taken prior to top dressing and at harvest.

Pre-top dressing
The first sampling (9-11th May 2005) was undertaken using a 0.5m^2 quadrat. Two samples were taken from 11 plots per block, representing one plot of each of the compost treatments. All above ground biomass within the quadrat was harvested, fresh weight recorded. Following oven drying at 80^{o}C to constant weight (5 days), the dry weight was recorded. The dried samples were analysed for total C and N using a LECO® CN-2000.

Harvest
The barley was harvested on 4th August 2005. An area of 30m^2 was taken from the centre of each plot. Total grain yield was measured, and sub-samples taken for chemical analysis. Samples were oven dried at 70^{o}C for 48h to measure moisture content. 1000 grain weight was measured. Grain was analysed for minerals (organic N, P, K, Ca, Mg, Na, Mn) using methods based on MAFF/ADAS (1986). In addition, PTEs were analysed in grain from all compost treatments, plus the zero fertilizer control treatment using PAS 100 methods (BS EN 13650 and ISO/DIS 16772).

Samples of straw were oven dried (80^{o}C for 5 days) and minerals (organic N, P, K, Ca, Mg, Na, Mn) were analysed using methods based on MAFF/ADAS (1986).

2.3.4 Statistical analysis

Two way ANOVA was used to compare treatments. Genstat® was used for all statistical analyses. Significant differences are expressed as probability (P) values, where a P value of <0.05 represents a significant difference.

3. RESULTS AND DISCUSSION OF COMPOST ANALYSIS

The results of the batch 1 composts are presented and discussed in section 3.1. The results of the batch 2 composts are presented in section 3.2. In each section, the results and discussion of the physical and chemical analyses are divided into nine sections, as summarised below:

1. pH and conductivity
2. Bulk density and moisture content
3. Particle size distribution
4. Physical contaminants
5. Water soluble carbohydrates, cellulose, lignin, organic matter and ash
6. Carbon and nitrogen content and the C:N ratio
7. Nutrients: NO_3^-, NH_4^+, K, Ca, Mg, P, Fe, Zn, Mn, Cu, B, Na, Cl^-, S
8. Potentially toxic elements: Cd, Cr, Cu, Pb, Ni, Zn, Hg
9. Pathogens

The results are discussed in relation to the BSI PAS 100 (WRAP 2005) and Apex standards (http://www.apexcompost.co.uk/standards.asp). More information regarding UK compost standards can be found in section 1.3.

3.1 Physical and chemical characterisation of batch 1 composts

General observations

The composts were black or brown in colour, with the exception of compost G, which was grey – light brown (Figure 3.1). Composts A to J had either no smell, or a faint, woody smell. Compost K had a strong woody smell. Compost L had a very strong odour similar to silage.

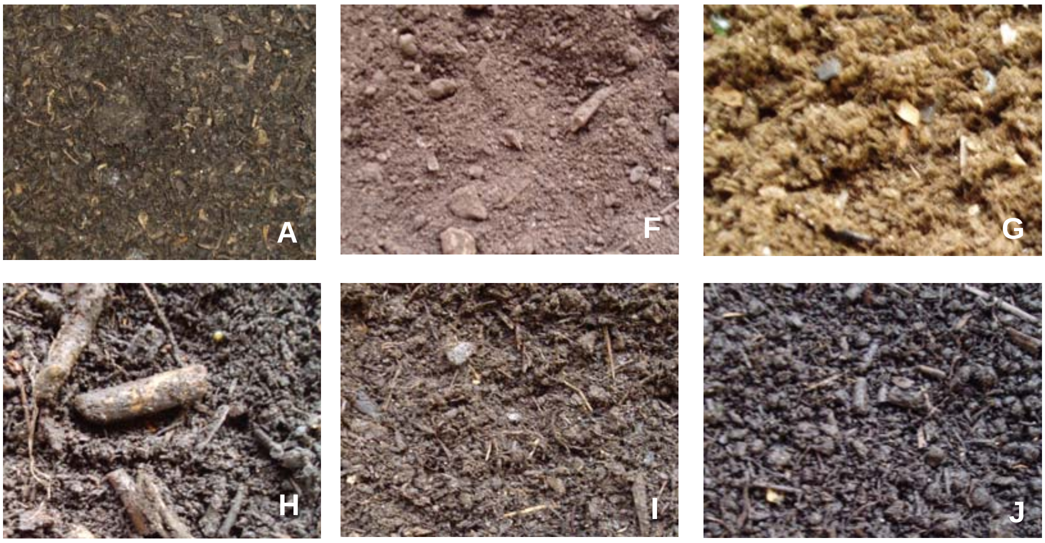

Figure 3.1 Composts A, F, G, H, I and J

3.1.1 pH and conductivity

The pH of the composts varied between 5.1 and 8.7 (Table 3.1), with 11 out of 12 within the PAS 100 pH range of 7.0-8.7. pH influences the availability of nutrients to plants, and plants vary in their tolerance to pH. For cereals, the optimum soil pH is between 6.5 and 7.5 (Wibberley 1989). Using these composts as soil improvers would aid in neutralising acidic soils, and could reduce liming costs. Compost L was very acidic, with a pH of 5.07, which is an indication that this compost was not mature.

Electrical conductivity (EC) is a measure of soluble salt content. EC varies according to the number and type of ions in the solution. In this study, EC varied from 0.67 mS cm^{-1} (compost C) to 3.32 mS cm^{-1} (compost L). The EC of composts G, K and L exceeded the Apex EC limit of 2 mS cm^{-1}, potentially due to the high concentration of some water soluble salts, which could be from the food waste in the feedstock of these composts.

Table 3.1. pH and electrical conductivity (mean ± standard error), with PAS 100 and Apex standards

Compost	**pH**		**Conductivity (mS cm^{-1})**	
A	8.26	± 0.30	1.03	± 0.02
B	8.23	± 0.26	0.83	± 0.02
C	7.25	± 0.17	0.67	± 0.02
D	8.68	± 0.02	0.71	± 0.01
E	8.28	± 0.05	1.66	± 0.01
F	8.45	± 0.01	1.81	± 0.07
G	7.15	± 0.03	2.20	± 0.03
H	8.00	± 0.05	0.68	± 0.04
I	8.38	± 0.03	1.23	± 0.01
J	8.74	± 0.02	1.42	± 0.01
K	8.48	± 0.02	2.20	± 0.11
L	5.07	± 0.04	3.32	± 0.04
	PAS 100	7.0-8.7	Apex	0.75-2.00

In systems where compost is used alone (as a growing medium) high EC can cause reductions in germination and growth. For example, high EC in mixed MSW compost (5.3 mS cm^{-1}) caused growth inhibition in lettuce and cabbage (Brito 2001). EC levels above 9 mS cm^{-1} were found to be detrimental to tomato seedling emergence and development (Castillo et al. 2004). Thus it is important for composts to have an EC below the recommended limit when used as a growing medium. However, when composts are used as a soil conditioner in agriculture, they will be incorporated into the soil and thus diluted. Therefore, the EC of the soil will have a much greater effect on the crop than the EC of the compost. Indeed, in some saline and sodic soils, the soil EC could be higher than that of the compost.

3.1.2 Bulk density and moisture content

The bulk density of the composts ranged from 410 g/l (compost A) to 812g/l (compost F; Table 3.2). The Apex guidelines specify the range of bulk density to be 450-550g/l. Composts E and F exceeded this limit (779 and 812 g/l respectively). This can be explained by low moisture content and 75% of particles being smaller than 4mm. Composts which have only been screened down to 30 or 40mm, such as composts C and K, have bulk densities below the Apex range. This could be due to the distribution of large and small particles creating air spaces in the compost.

The moisture content of the composts varied considerably, from 20% (compost F) to 62% (compost B). This range is much greater than the Apex specification of 35-45%, and PAS 100 35-55%. Very wet compost can cause odour problems, while dry compost can be dusty and may require wetting before use. Moisture content will vary according to the feedstock, time of year, composting and storage conditions. Interestingly, composts B and F both contained fruit and vegetable waste (50% and 60-70%) and green waste (50% and 30-40%), which shows that although the feedstock can be similar, moisture content can still vary.

Table 3.2. Bulk density, dry matter and moisture content (mean ± standard error)

Compost	**Bulk density (g/l)**		**Dry matter (%)**		**Moisture content (%)**	
A	410	± 0.88	55.02	± 0.088	44.98	± 0.088
B	513	± 13.82	37.96	± 0.056	62.04	± 0.056
C	346	± 3.84	60.48	± 0.763	39.52	± 0.763
D	486	± 1.00	53.30	± 0.257	46.70	± 0.257
E	779	± 12.00	63.62	± 0.071	36.38	± 0.071
F	812	± 5.17	79.80	± 0.449	20.20	± 0.449
G	356	± 4.62	68.53	± 0.343	31.47	± 0.343
H	533	± 9.81	54.06	± 1.664	45.94	± 1.664
I	504	± 13.83	70.20	± 0.255	29.80	± 0.255
J	567	± 10.08	46.58	± 0.083	53.42	± 0.083
K	420	± 14.64	68.35	± 0.910	31.65	± 0.910
L	488	± 7.95	52.20	± 0.979	47.80	± 0.979
Apex	450-550				35-45	

Composts with low bulk density and high dry matter content could be difficult to land spread since windy conditions would dissipate the material before incorporation.

3.1.3 Particle size distribution

Particle size grading is an important aspect of compost specification, and will depend on the final use of the product. Coarse particles in composts designated as growing media may be unacceptable to growers. WRAP recommends a maximum screen size of 40mm for general use in arable agriculture, although where a fine seedbed is required, 25mm or 15mm is suggested (WRAP 2004).

The particle size distribution of the composts varied considerably (Figure 3.2), since the composts were screened to different sizes by the composters (Table 1.1). The finer composts (D, E, G, I, and J) had no particles greater than 15mm diameter. For horticulture and gardening, where small volumes of compost are used, consistent and small particle sizes are essential. Composts D, I and J are currently produced for use as a soil conditioner. They are used by landscapers and gardeners as well as for application to agricultural land.

In contrast, composts B, H and K had some particles greater than 30mm in diameter, generally woody material. Compost B is sold as a soil conditioner to landscapers and gardeners. Composts H and K are applied to agricultural land only. Whether the compost is purchased by landscapers and gardeners, or used by farmers, an even-sized and consistent product is more desirable to the end user.

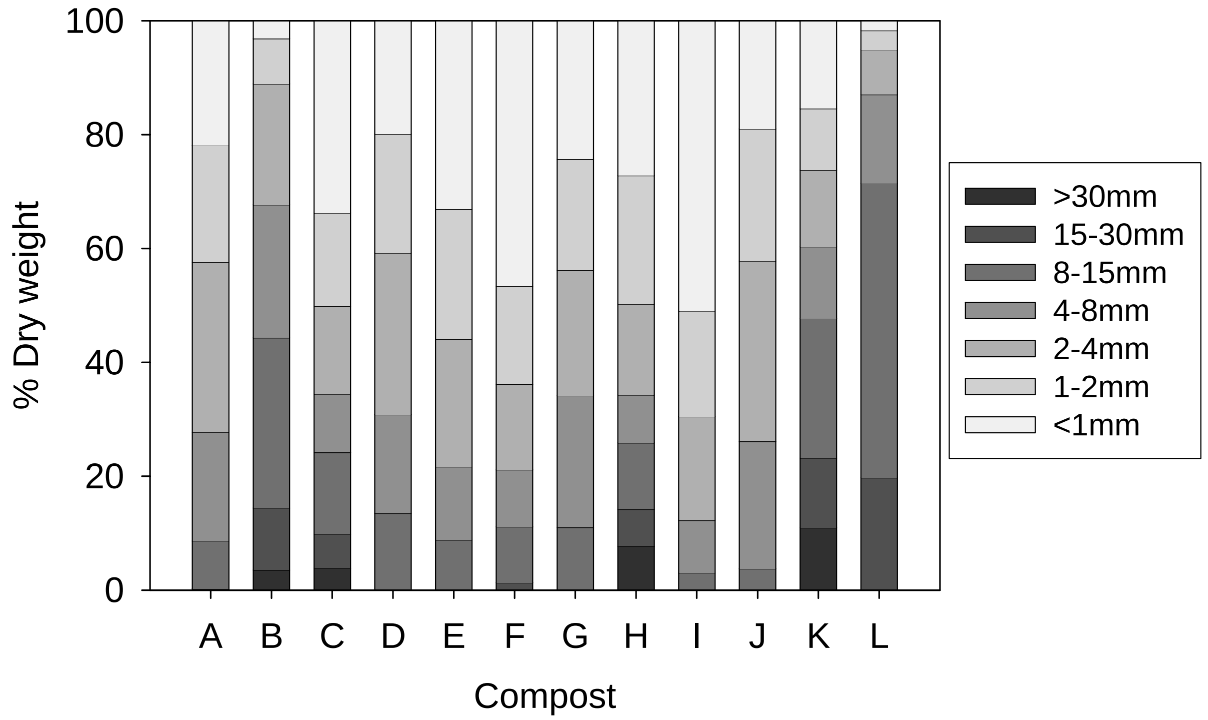

Figure 3.2 Particle size distribution (including contaminants; % dry weight)

3.1.4 Physical contaminants

Physical contaminants are normally removed from composts prior to use. Indeed, most compost suppliers employ screening techniques to remove contaminants. However, despite this, all composts tested contained some physical contaminants or non-compostable elements (NCEs).

The presence and type of NCEs was diverse (Figure 3.3), and was greatly influenced by the type of feedstock. The composts produced from 100% and 72% MSW (G and L respectively) contained greater amounts of glass, metal and plastic than the source segregated composts. Compost L consisted of over 22% contaminants, including 16% glass.

The 10 source segregated composts (A, B, C, D, E, F, H, I, J, K) contained a small proportion of stones ranging from 1.8% (compost A) to 7.3% (compost H). Glass was less than 0.2% and plastic less than 0.9% in all source segregated composts. No metal was found in the source segregated composts.

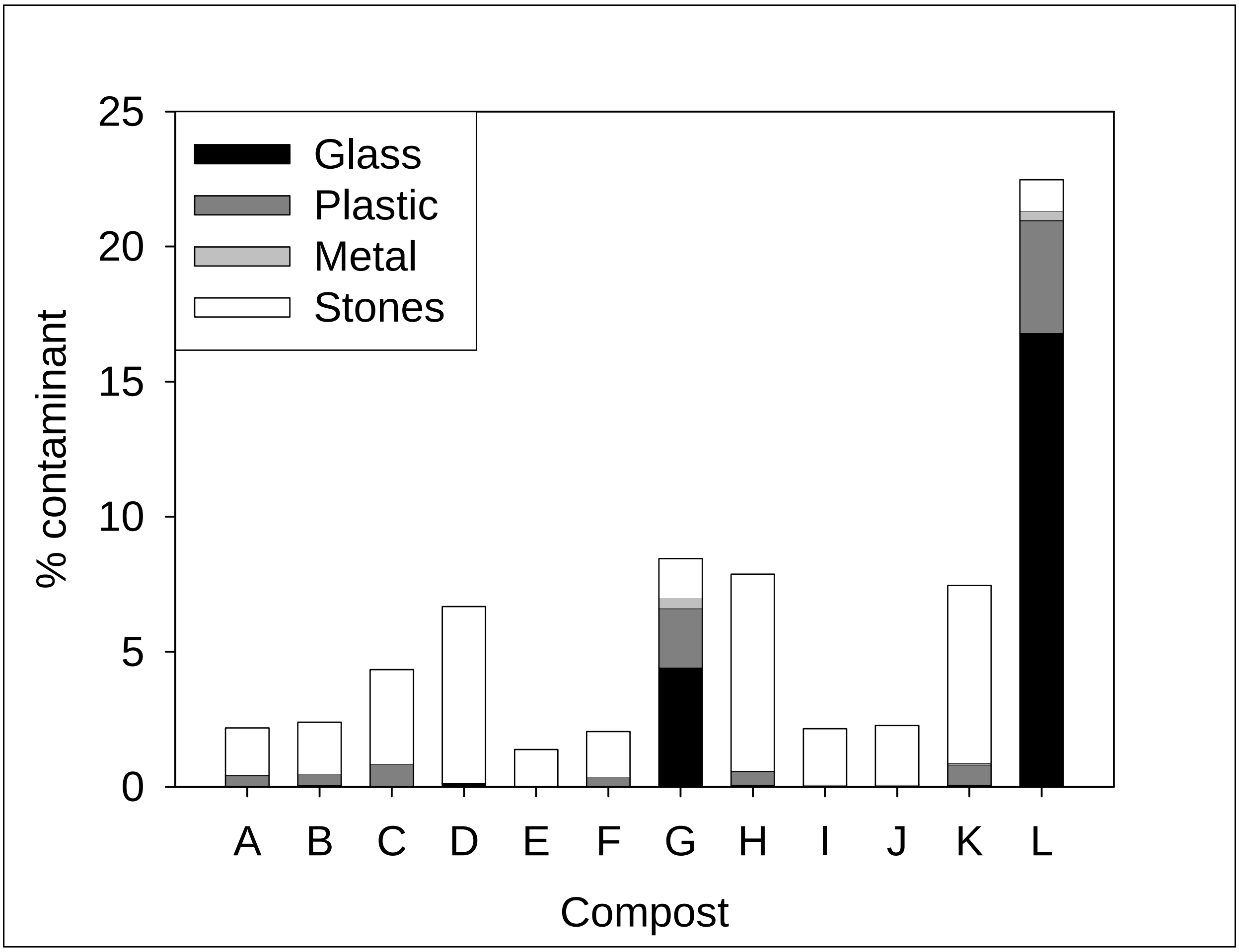

Figure 3.3 Proportion of physical contaminants in composts

Physical contaminants, specifically glass and sharps are a major problem in compost quality. Concerns over public health will severely reduce the use of mixed MSW composts. Moreover, where over 10% of the compost is contaminants, it is a waste of energy and resources to transport and apply. Many consider that it is not possible to obtain good quality compost from mixed MSW (Schauner 1998). However, progress in the mechanical sorting of mixed MSW to extract the non-organic fraction is constantly improving. A study in France has indicated that composts of a similar quality can be produced from either source segregated BMW or mixed MSW (Morvan 2004).

3.1.5 Water soluble carbohydrates, cellulose, lignin, organic matter and ash

During composting, the biodegradable carbon sources (simple sugars and starch) are broken down by microorganisms; with water, carbon dioxide and heat being produced. Thus, water soluble carbohydrates (WSCs) decrease during the composting process as they are utilised by the microbial flora (Sánchez-Mondero et al. 1999). WSCs are more readily broken down than cellulose and lignin. Therefore, in mature compost, only small amounts of WSCs should be present, with higher concentrations of lignin and cellulose. This trend was apparent for the composts investigated in this study (Table 3.3).

Water soluble carbohydrates

In general, WSC concentrations were relatively low, ranging from 0.09% (compost F) to 0.49% (compost H), with the exception of compost L, with a WSC content of 2.45% (Table 3.3). Garcia et al. (1992) compared the WSC concentration of six composts at different stages during composting. They found after 210 days WSC levels were reduced at least eight-fold. As the WSC concentration of compost L was over five-fold higher than the other 11 composts, it is likely that this compost is not mature.

Table 3.3. Water soluble carbohydrates (WSC), cellulose, lignin, loss on ignition (LOI) and ash (contaminants removed; mean ± standard error)

Compost	**WSC (% dry weight)**	**Cellulose (% dry weight)**	**Lignin (% dry weight)**	**LOI (%)**	**Ash (%)**
A	0.40 ± 0.03	11.67 ± 1.59	25.13 ± 1.06	44.7 ± 1.0	55.3 ± 1.0
B	0.43 ± 0.02	17.41 ± 1.98	30.87 ± 1.57	56.4 ± 2.9	43.6 ± 2.9
C	0.29 ± 0.05	11.44 ± 1.20	22.96 ± 1.22	44.8 ± 1.8	55.2 ± 1.8
D	0.21 ± 0.02	9.42 ± 0.77	20.63 ± 0.94	34.9 ± 2.1	65.1 ± 2.1
E	0.10 ± 0.03	4.27 ± 0.40	12.74 ± 0.69	20.2 ± 0.3	79.8 ± 0.3
F	0.09 ± 0.03	2.98 ± 5.01	11.71 ± 0.40	20.4 ± 0.4	79.6 ± 0.4
G	0.37 ± 0.07	40.60 ± 2.25	19.16 ± 0.65	60.3 ± 0.4	39.7 ± 0.4
H	0.49 ± 0.05	10.76 ± 0.93	23.06 ± 1.29	43.0 ± 4.2	57.0 ± 4.2
I	0.34 ± 0.03	7.80 ± 2.29	16.78 ± 0.76	27.0 ± 0.1	73.0 ± 0.1
J	0.45 ± 0.05	13.89 ± 7.53	30.96 ± 3.23	49.0 ± 0.5	51.0 ± 0.5
K	0.39 ± 0.04	31.11 ± 1.57	23.54 ± 1.00	59.4 ± 2.9	40.6 ± 2.9
L	2.45 ± 0.29	34.42 ± 5.01	19.35 ± 1.20	68.8 ± 2.1	31.2 ± 2.1

Cellulose and lignin

The cellulose content was highest in the two mixed waste composts (G and L), which could be due to the high content of paper and cardboard in MSW. Lignin was highest in composts B and J (31% lignin), potentially due to wood in the green waste fraction of the feedstock. The low cellulose and lignin content in composts E and F (Table 3.3) could be due to the high content of fruit and vegetable waste in the feedstock.

Fruit and vegetables contain lower levels of cellulose and lignin than wood. A study comparing ten different vegetables found cellulose concentrations to be 9-23% and lignin concentrations 10-17% (Rahn and Lillywhite 2001). In contrast wood contains 40-50% cellulose and 20-35% lignin (www.paperonweb.com). Thus the proportions of vegetable waste and green waste (containing woody material) in the initial feedstock will influence the cellulose and lignin concentrations in the mature compost.

A UK study (Ward et al. 2005) showed that green waste compost composition varies with time of year. In addition, a study on source segregated composted BMW in the Netherlands found that the composition of BMW containing leaves, branches and grass varied greatly with time, and also location (Veeken & Hamelers 2002). Thus, the time of year that the BMW was collected may have influenced the cellulose and lignin content of the composts in the current study.

Organic matter

The organic matter (loss on ignition) of the composts tested varied from 20% (compost E) to 69% (compost L; Table 3.3). Since intensive agriculture can reduce soil organic matter (SOM), so the addition of composts can enhance SOM. The low cellulose and lignin content in composts E and F is reflected by the low organic matter content. In the other composts, more woody green waste present could result in higher cellulose and lignin concentrations and thus a higher organic matter content.

The high cellulose concentrations in the MSW compost (compost G) could be due to the high paper and cardboard content. This is reflected in the high organic matter content of this compost.

Results so far have indicated that compost L, which was composted for two weeks in-vessel, is not mature. Thus the high organic matter content and high cellulose content of compost L could be due to incomplete degradation, as mixed MSW can take up to six months to reach maturity (Francou et al. 2005).

Ash

Ash in compost is due to the presence of minerals, soil and sand. A study comparing six composts found that the ash content varied considerably 31-67% (Garcia et al. 1992). These results compare well with results from this study, where ash contents ranged from 31% (compost L) to 80% (compost E). Composts E and F had a high ash content of nearly 80%. These two composts had a high bulk density and low moisture content.

3.1.6 Carbon and nitrogen content and the C:N ratio

The carbon content ranged between 12% (compost F) and 37% (compost L). In general terms, composts containing source materials low in cellulose and lignin should have low carbon contents with the opposite also being true, so composts containing wood waste and cardboard as feedstocks should have high carbon contents. Our results do not always support this view. The three composts (E, F, I) with the lowest carbon contents (< 20%) contained cardboard. In contrast, compost B had a high carbon content (> 30%) possibly due to over 12% wood, present in the >15 mm particle size fraction.

The nitrogen content ranged from 1.0% (compost F) to 2.2% (compost K). The nitrogen content of composts is dependent on the quantity of protein in the original feedstock, and the organic nitrogen, nitrate and ammonium in plant materials. High protein and therefore high nitrogen materials, e.g. kitchen and pet food waste, should lead to higher nitrogen content while low nitrogen materials, e.g. straw, cardboard and wood, should result in composts with lower nitrogen content. This view is supported by the results.

The C:N ratio of the composts ranged between 12:1 (composts E & F) and 32:1 (compost G). The C:N ratio can be used as an indicator of the speed of compost decomposition in the soil. Composts with low ratios will break down relatively quickly whilst those with high ratios will take longer. If composts are to have a fertilising value then the nitrogen content and C:N ratio are important.

There will be a C:N ratio above which the composts will use soil nitrogen to aid compost decomposition and will therefore immobilise soil nitrogen. At low C:N ratios of 10 or less, nitrogen will be released from composts. C:N ratios tend to be higher in “brown” BMW such as paper, card, bark and wood, and lower in “green” BMW such as green waste, vegetable waste and grass cuttings. The mixed waste composts had a higher proportion of “browns” (paper and cardboard) than the source segregated composts. With the exception of compost G, all C:N ratios are below the 20:1 level recommended by PAS 100 and Apex.

Table 3.4. %N, %C and C:N ratio (mean ± standard error)

Compost	N (% dry weight)	C (% dry weight)	C:N ratio (:1)
A	1.73 ± 0.03	25.50 ± 1.01	14.74
B	1.61 ± 0.01	30.86 ± 1.28	19.19
C	1.33 ± 0.03	24.30 ± 0.69	18.23
D	1.18 ± 0.07	20.04 ± 1.55	16.99
E	1.03 ± 0.02	12.06 ± 0.22	11.67
F	1.01 ± 0.02	11.75 ± 0.24	11.62
G	1.08 ± 0.02	34.25 ± 0.43	31.65
H	1.45 ± 0.05	24.29 ± 1.40	16.75
I	1.28 ± 0.05	17.27 ± 1.02	13.44
J	2.16 ± 0.04	27.32 ± 0.39	12.66
K	2.18 ± 0.06	32.79 ± 1.58	15.03
L	1.90 ± 0.01	37.32 ± 0.75	19.68
PAS 100	0.7-1.0		15-20

3.1.7 Nutrients

Essential macronutrients

Nitrate (NO_3 -N) concentrations ranged between 0.4 mg kg^{-1} (compost G) and 518 mg kg^{-1} (compost F). Composts E, F and H had levels greater than 299 mg kg^{-1} which we attribute to the original feedstocks containing vegetable wastes, which themselves contain high levels of nitrate. There is one exception, compost K, where the inclusion of pet food waste may have resulted in the high nitrate concentration.

Ammonium (NH_4 –N) concentrations ranged from 15 mg kg^{-1} (compost E) to 1510 mg kg^{-1} (compost K). However, this wide range is misleading since ten out of the twelve composts showed levels below 200 mg kg^{-1} with just two composts (K and L) having concentrations greater than 1300 mg kg^{-1}. As was the case for nitrate we think the inclusion of pet food waste accounts for the high level in compost K while compost L was immature.

After nitrogen, phosphorus (P) is the second most limiting element in soils, followed by potassium (Salisbury & Ross 1992). P concentrations ranged from 23 mg kg^{-1} (compost F) to 247 mg kg^{-1} (compost J). In general, concentrations of potassium (K) in the composts were higher than for all other nutrients, and varied three-fold from 1852 mg kg^{-1} (compost H) to 6615 mg kg^{-1} (compost J).

Table 3.5. Essential macronutrients (mg kg^{-1} dry matter; mean ± standard error)

Compost	**NO_3-N**		**NH_4-N**		**P**		**K**	
A	6.0	± 2.6	42.4	± 6.7	194.9	± 8.9	5329	± 56
B	33.7	± 7.4	53.7	± 11.6	104.4	± 8.4	4971	± 148
C	19.0	± 3.8	41.0	± 3.4	176.8	± 5.7	4010	± 122
D	8.2	± 2.1	141.7	± 15.5	183.0	± 8.0	3315	± 41
E	498.6	± 17.5	15.0	± 2.5	61.2	± 5.0	3783	± 100
F	518.2	± 23.5	170.8	± 1.8	23.0	± 4.9	2664	± 38
G	0.4	± 0.5	27.6	± 3.2	43.1	± 3.2	2165	± 45
H	299.3	± 18.0	88.0	± 19.2	47.4	± 2.2	1852	± 76
I	129.4	± 2.9	192.8	± 12.7	177.7	± 18.4	3683	± 122
J	35.9	± 3.1	65.7	± 1.3	246.9	± 10.1	6615	± 168
K	377.8	± 23.9	1508.9	± 74.6	202.8	± 14.1	3714	± 217
L	0.6	± 0.4	1337.3	± 24.6	137.9	± 6.6	3107	± 34

Secondary macronutrients

Calcium (Ca) and Magnesium (Mg) concentrations were considerably higher in the two mixed waste composts (G and L) compared to the 10 source segregated composts. Ca ranged between 219 mg kg^{-1} (compost I) and 10082 mg kg^{-1} (compost L), with all source segregated composts below 535 mg kg^{-1}. Mg content varied from 54 mg kg^{-1} (compost B) to 890 mg kg^{-1} (compost L). Again, MSW composts were at the higher end of the range (above 330 mg kg^{-1}), with source segregated composts all containing Mg contents below 130 mg kg^{-1}.

Sulphur (S) concentration ranged from 175 mg kg^{-1} (compost B) to 3327 mg kg^{-1} (compost G). Sodium (Na) concentration ranged between 239 mg kg^{-1} (compost D) and 3176 mg kg^{-1} (compost G). In all secondary nutrients, compost G had either the highest or second highest concentration of the 12 composts.

Table 3.6. Secondary macronutrients (mg kg^{-1} dry matter; mean ± standard error)

Compost	Ca	Mg	S	Na
A	406.1 ± 45.5	76.5 ± 7.9	246.6 ± 7.6	631.5 ± 9.0
B	313.5 ± 25.7	54.0 ± 4.2	174.5 ± 9.5	512.0 ± 17.0
C	324.2 ± 22.4	74.5 ± 3.7	351.7 ± 10.7	292.9 ± 9.4
D	345.4 ± 27.5	84.9 ± 5.0	206.1 ± 5.3	239.3 ± 1.2
E	338.6 ± 18.9	103.0 ± 8.6	566.8 ± 18.9	509.7 ± 9.0
F	236.7 ± 24.4	75.9 ± 10.5	420.6 ± 4.4	431.7 ± 10.6
G	3239.3 ± 108.5	336.8 ± 12.4	3327.2 ± 63.2	3176.1 ± 11.4
H	302.3 ± 19.5	116.1 ± 8.9	219.6 ± 17.0	486.9 ± 25.7
I	218.8 ± 30.2	69.0 ± 8.3	264.5 ± 11.3	365.0 ± 12.2
J	533.0 ± 33.9	128.6 ± 8.7	337.6 ± 8.2	569.8 ± 12.2
K	440.4 ± 36.5	91.5 ± 8.9	1167.0 ± 94.6	2525.7 ± 159.1
L	10082.0 ± 295.7	889.9 ± 19.6	737.5 ± 7.4	2511.7 ± 11.8

Micronutrients

Iron (Fe) content ranged from 32 (compost H) to 366 mg kg^{-1} (compost E). Manganese (Mn) and copper (Cu) concentrations were highest in the two mixed waste composts (G and L). Zinc (Zn) concentration varied from 0.64 (compost H) to 39.19 mg kg^{-1} (compost L). Compost G had the second highest Zn concentration of 8.5 mg kg^{-1}. The 10 source segregated composts had Zn levels of <5.3 mg kg^{-1}. Concentration of boron (B) ranged between 0.59 mg kg^{-1} (compost H) and 6.14 mg kg^{-1} (compost A). The concentration of chloride (Cl) ranged four-fold from 1.0 g kg^{-1} (compost H) to 4.7 g kg^{-1} (compost K).

Table 3.7. Micronutrients Fe, Mn and Cu (mg kg^{-1} dry matter; mean ± standard error)

Compost	Fe	Mn	Cu
A	157.08 ± 17.32	2.75 ± 0.30	1.20 ± 0.06
B	105.38 ± 9.49	2.62 ± 0.29	1.31 ± 0.14
C	159.02 ± 23.64	5.35 ± 0.45	0.72 ± 0.05
D	299.92 ± 20.20	5.12 ± 0.28	1.18 ± 0.47
E	366.12 ± 42.63	5.66 ± 0.71	0.62 ± 0.06
F	107.81 ± 38.24	1.51 ± 0.54	0.32 ± 0.06
G	88.30 ± 13.29	12.21 ± 0.57	11.19 ± 0.39
H	32.27 ± 1.38	1.34 ± 0.03	0.47 ± 0.03
I	96.36 ± 15.29	4.26 ± 0.64	0.97 ± 0.12
J	250.11 ± 21.03	5.59 ± 0.39	1.32 ± 0.05
K	126.61 ± 14.16	2.64 ± 0.26	2.73 ± 0.13
L	69.68 ± 2.73	40.74 ± 0.15	12.46 ± 3.99

In summary, all composts contained all of the plant nutrients. The 100% source segregated composts contained higher levels of NO_3 and Fe than the composts containing mixed MSW. The two MSW composts contained levels of some plant nutrients which were considerably higher than the source segregated composts, including Ca, Mg, Mn, S and Na, in addition to the PTEs Cu and Zn. These elements are required by plants in small amounts, although high concentrations can be toxic.

Table 3.8. Micronutrients Zn, B and Cl (mg kg^{-1} dry matter; mean ± standard error)

Compost	Zn		B		Cl	
A	2.85	± 0.24	5.94	± 0.27	2113	± 105
B	2.29	± 0.26	6.14	± 0.38	1372	± 130
C	2.77	± 0.28	2.88	± 0.14	1824	± 75
D	3.91	± 0.19	2.51	± 0.05	1276	± 49
E	1.92	± 0.30	2.64	± 0.15	1367	± 151
F	0.65	± 0.09	1.40	± 0.17	1267	± 132
G	8.50	± 0.47	4.52	± 0.13	2934	± 225
H	0.64	± 0.02	0.59	± 0.03	1015	± 184
I	2.68	± 0.34	2.39	± 0.16	2212	± 111
J	5.26	± 0.28	4.40	± 0.17	4040	± 363
K	3.73	± 0.23	2.23	± 0.13	4724	± 366
L	39.19	± 1.02	4.86	± 0.08	3693	± 271

Total nutrients

The composts containing meat either from kitchen waste (A, G, J, L) or pet food waste (K) contained over 9 g kg^{-1} nutrients (Table 3.9). These composts had the highest EC levels (Table 3.1). Of these, the two mixed waste composts (G and L) had in excess of 15 g kg^{-1} nutrients. The addition of composts with high soluble salts can be harmful to seed germination and plant growth, by causing water stress and ion toxicities (Recycled Organics Unit 2003).

In contrast, compost H contained less than a third of this (4.5 g kg^{-1} nutrients), and had low EC. Low levels of nutrients in composts may indicate low amount of nutrients in the original feedstock. This could be due to the potato waste in the feedstock in compost H, which is relatively nutrient poor.

Table 3.9 Total nutrients and PTEs

Compost	Total nutrients (g kg^{-1})	Total PTEs (g kg^{-1})
A	9.2	0.3
B	7.7	0.4
C	7.3	0.3
D	6.1	0.3
E	7.6	0.2
F	5.9	0.2
G	15.4	1.5
H	4.5	0.4
I	7.4	0.3
J	12.8	0.5
K	14.9	0.5
L	22.7	0.4

Large variations in nutrients have been observed in a number of studies. A study of over 200 composts in USA revealed between 5-fold and 100-fold differences in nutrient levels (Mamo et al. 2002), such as NO_3-N ranging from 2 to 1419 mg kg^{-1} and NH_4-N ranging from 1 to 3220 mg kg^{-1}.

Essential plant nutrients were present in all the composts. However, high nutrient levels do not necessarily infer that the compost will be suitable for application to agriculture. Indeed, it is not just the total nutrient level that must be considered, but the concentration of individual nutrients. For example, high levels of nitrate will be beneficial to the crop, whereas high levels of sodium or boron may reduce germination and growth.

Timing of compost application is important, as is the case with inorganic fertilisers and organic manures. Incorporating the compost into the soil (Mamo et al. 2002) and delaying of planting (O'Brien & Barker 1996) will allow ammonium and soluble salts to dissipate, thus reducing effects of salts on germination. However, to minimise leaching of valuable nutrients, application should be restricted just before sowing. WRAP (2004) advises a two week time gap between incorporating the compost into the soil and sowing.

3.1.8 Potentially toxic elements

PTEs (potentially toxic elements) in MSW can be due to a number of components including batteries, solder, wine bottle caps, old circuit boards and fishing weights. In addition, pigments and stabilisers in plastics may contain PTEs (Richard & Woodbury 1992). As source segregated composts should not contain these waste materials, PTEs should be considerably lower than in mixed MSW composts.

This is borne out by the results, which show that the concentrations of all PTEs in the 10 source segregated composts, plus compost L were lower than the upper limits specified by PAS 100. The PTE concentrations of 100% MSW compost G were generally much higher than for the other 11 composts, with Cu, Ni, Pb and Zn concentrations exceeding the PAS 100 upper limits (Tables 3.10 and 3.11).

Table 3.10. Cu, Ni, Pb and Zn concentration and permissible levels in accordance with BSI PAS 100 (mg kg^{-1} dry weight; mean ± standard error)

Compost	**Cu**		**Ni**		**Pb**		**Zn**	
A	45.97	± 0.78	11.33	± 0.47	71.53	± 10.08	155.00	± 5.34
B	76.27	± 2.23	18.60	± 3.40	110.33	± 1.78	218.67	± 8.29
C	45.40	± 4.38	20.07	± 5.96	94.93	± 7.41	159.67	± 7.79
D	34.33	± 2.09	14.20	± 2.20	89.17	± 5.10	173.00	± 12.75
E	32.20	± 1.72	17.97	± 0.22	55.90	± 7.77	111.00	± 3.08
F	31.60	± 1.16	18.20	± 0.37	47.97	± 3.78	100.07	± 5.19
G	223.67	± 65.46	197.33	± 20.18	414.00	± 14.12	563.33	± 12.46
H	48.03	± 2.74	18.00	± 1.42	113.00	± 1.87	200.33	± 2.48
I	35.33	± 2.71	11.67	± 0.48	84.30	± 3.11	182.33	± 8.95
J	53.57	± 3.19	14.60	± 0.55	127.33	± 6.01	266.33	± 17.68
K	91.63	± 4.18	12.53	± 0.71	161.67	± 4.71	249.00	± 1.22
L	77.97	± 21.53	13.93	± 1.98	107.60	± 28.74	148.33	± 33.48
PAS 100	≤200		≤50		≤200		≤400	

Table 3.11. Cd, Cr and Hg concentration and permissible levels in accordance with BSI PAS 100 (mg kg^{-1} dry weight; mean ± standard error)

Compost	**Cd**		**Cr**		**Hg**	
A	0.473	± 0.035	17.867	± 2.661	0.193	± 0.023
B	0.780	± 0.012	21.567	± 0.820	0.250	± 0.028
C	0.627	± 0.064	18.667	± 1.680	0.210	± 0.019
D	0.637	± 0.080	17.833	± 0.942	0.197	± 0.058
E	0.497	± 0.051	25.733	± 0.942	0.117	± 0.004
F	0.470	± 0.035	26.433	± 0.531	0.130	± 0.025
G	1.163	± 0.099	72.800	± 2.475	0.373	± 0.059
H	0.697	± 0.041	19.400	± 2.514	0.333	± 0.029
I	0.577	± 0.025	14.067	± 0.934	0.193	± 0.022
J	0.873	± 0.062	26.633	± 9.903	0.243	± 0.004
K	0.683	± 0.054	33.033	± 2.866	0.343	± 0.022
L	0.780	± 0.184	10.690	± 2.698	0.180	± 0.093
PAS 100	≤1.5		≤100		≤1	

PTE concentrations have been shown to be higher in mixed MSW composts compared to source segregated BMW composts (Richard & Woodbury 1992, Ciavatta et al. 1993). In a Europe-wide study, PTE concentrations were 2 to 10 times higher in mixed MSW compost as compared to compost from source segregated household waste (Amlinger et al. 2004). This compares well with the results from this study, where total PTEs were 1.5 g kg^{-1} in mixed MSW compost G, compared to 0.5 g kg^{-1} or less for the 10 source segregated composts (Table 3.9).

Interestingly, compost L, which contained 72% MSW also had a low total PTE concentration of 0.4 g kg^{-1}. The high level of physical contaminants (>22%) including metal, plastic and glass, could imply that PTEs would be higher in compost L. However, as previously discussed (section 3.1.5), compost L was not mature. As composts undergo degradation and maturation WSCs and cellulose are broken down. During this process PTEs become more concentrated as organic matter decreases. In addition, organic acids which are produced during composting cause leaching of metals from waste (Petruzzelli 1996). We suggest that if compost L was matured, PTE concentration would increase.

The behaviour of PTEs in the soil is influenced by a number of interactive biotic and abiotic processes, which determine chemical speciation and bioavailability. Soil pH, cation-exchange-capacity and redox potential drive the biogeochemical processes in soils. Thus it is not merely the concentration of the PTEs in the compost which must be considered, but also any changes the compost may exert on the soil properties. High pH and high organic matter content of MSW composts minimise the availability of PTEs to plants. Indeed, a study in USA found the levels of PTEs in compost derived from MSW to be much lower than the Environmental Protection Agency maximum levels and safe for crop production (Shelton 1991).

3.1.9 Pathogens

Microbial contamination of MSW is mainly of faecal origin (Deportes et al. 1998). Sources of micro-organisms in MSW include nappies, pet litter and food. As many microbes are heat sensitive, they are normally killed during the first stage of composting, where temperatures in excess of 60°C are achieved.

In this study none of the composts contained Salmonella. However, coliforms and *E. coli* were present in all 12 composts (Table 3.13), with levels of *E. coli* below the PAS 100 limit of ≤1000 in seven composts (B, C, E, F, G, K and L). Compost H contained the highest levels of coliforms and *E. coli*. This is probably due to the feedstock containing 3% manure.

Table 3.12. Pathogen contents

Compost	**Coliforms 30°C (cfu/g)**	***E. coli* 44°C (cfu/g)**	***Salmonella* 37°C (/25g)**
A	26667	<1340	absent
B	380	<10	absent
C	3728333	< 673	absent
D	205000	38333	absent
E	173	140	absent
F	170	<67	absent
G	<273	27	absent
H	5733333	1347333	absent
I	468333	43567	absent
J	31667	22000	absent
K	<33	<10	absent
L	120	<10	absent
PAS 100		<1000	absent

3.2 Physical and chemical characterisation of batch 2 composts

Compost G was light brown and had a slight smell of silage. The other four composts were dark brown/black in colour, having a slight woody smell.

3.2.1 pH & conductivity

Compost pH ranged between 7.67 (compost F) and 8.68 (compost A). Electrical conductivity ranged between 0.85 (compost B) and 2.25 mS cm^{-1} (compost F; Table 3.20).

Table 3.20. pH and electrical conductivity (mean ± standard error)

Compost	**pH**		**Conductivity (mS cm^{-1})**	
A	8.68	± 0.01	1.08	± 0.02
B	8.43	± 0.07	0.85	± 0.04
F	7.67	± 0.07	2.25	± 0.03
G	7.88	± 0.05	1.56	± 0.02
J	8.31	± 0.03	1.24	± 0.01

3.2.2 Bulk density and moisture content

Compost G had the lowest bulk density and the lowest moisture content. Compost F had the highest bulk density. Compost B had the highest moisture content and available water content (Table 3.21).

Table 3.21. Bulk density, dry matter, moisture content and available water content (mean ± standard error)

Compost	**Bulk density (g/l)**		**Dry matter (%)**		**Moisture content (%)**		**Available water content (%)**	
A	431	± 4.51	60.88	± 0.44	39.12	± 0.44	58.54	± 6.89
B	530	± 1.55	38.95	± 0.21	61.05	± 0.21	106.47	± 6.26
F	730	± 17.74	57.10	± 1.21	42.90	± 1.21	41.24	± 2.73
G	419	± 4.85	60.90	± 0.38	39.10	± 0.38	46.75	± 7.12
J	549	± 5.31	43.22	± 0.55	56.78	± 0.55	52.02	± 4.88

3.2.3 Particle size distribution

No compost had particles greater than 30mm in size (Table 3.23). Compost A had the most small particles, with 38% less than 1mm in diameter.

Table 3.23. Particle size distribution (including contaminants; % dry weight)

Compost	>30mm	<30mm	<15mm	<8mm	<4mm	<2mm	<1mm
A	0.00	0.00	4.96	11.32	24.03	21.30	38.39
B	0.00	8.50	38.94	24.69	19.47	5.91	2.48
F	0.00	0.00	22.16	15.28	20.10	18.33	24.12
G	0.00	2.87	30.06	21.87	21.83	12.94	10.44
J	0.00	0.00	3.31	17.29	31.77	26.78	20.86

3.2.4 Physical contaminants

Compost G, the only compost from mixed MSW, had a greater proportion of physical contaminants than the four source segregated composts. PAS 100 standards state that total glass, metal and plastic should not exceed 0.5%, as is the case with composts A, F and J. The PAS 100 upper limit for stones is less than 8%, as it is for all five composts.

Table 3.24. Physical contaminants (% dry weight)

Compost	Glass	Plastic	Metal	Stones	Other
A	0.138	0.163	0.001	3.271	0.000
B	0.079	0.475	0.004	3.237	0.000
F	0.036	0.081	0.000	1.253	0.000
G	5.546	4.423	1.894	2.939	0.022
J	0.028	0.035	0.000	1.407	0.000

3.2.5 Water soluble carbohydrates, cellulose, lignin, organic matter and ash

Compost G had the highest concentration of WSC and cellulose, with compost F having the lowest. Lignin content was highest in composts B and J, and lowest in compost F (Table 3.25). Organic matter was lowest, and ash highest in compost F

Table 3.25. WSC, cellulose, lignin, organic matter and ash
(mg g^{-1} dry weight; mean ± standard error)

Compost	WSC (% dry weight)		Cellulose (% dry weight)		Lignin (% dry weight)		LOI (%)		Ash (%)	
A	0.51	± 0.04	9.95	± 0.90	23.00	± 1.02	41.2	± 0.6	58.8	± 0.6
B	0.55	± 0.03	18.71	± 0.67	29.67	± 0.99	57.5	± 1.4	42.5	± 1.4
F	0.32	± 0.03	3.59	± 0.30	16.52	± 1.59	24.8	± 0. 5	75.2	± 0.5
G	0.76	± 0.06	26.80	± 1.52	21.31	± 1.83	59.4	± 1.2	40.6	± 1.2
J	0.44	± 0.03	6.99	± 0.24	29.38	± 1.02	45.6	± 0.8	54.4	± 0.8

3.2.6 Carbon and nitrogen content and the C:N ratio

Nitrogen was lowest in the mixed MSW compost G and highest in compost J, the compost containing both kitchen and catering waste (Table 3.26). Carbon concentration ranged between 14% and 30%. The C:N ratio was higher in compost G than the other composts.

Table 3.26. N and C content, and C:N ratio (mean ± standard error)

Compost	N (% dry weight)		C (% dry weight)		C:N ratio (:1)
A	1.49	± 0.03	24.50	± 0.41	16.43
B	1.47	± 0.03	29.54	± 0.74	20.05
F	1.35	± 0.03	14.43	± 0.42	10.73
G	0.94	± 0.02	29.64	± 1.29	31.59
J	2.04	± 0.04	26.60	± 0.51	13.03

3.2.7 Nutrients

Compost F had the highest NO_3–N content, and the lowest NH_4–N content. In contrast, G had the lowest NO_3–N content and the highest NH_4–N content (Table 3.27). Mixed waste compost G had the highest concentration of all secondary nutrients (Table 3.28). With the exception of Fe and B, micronutrient concentrations were highest in mixed waste compost G (Tables 3.29 and 3.30).

Table 3.27. Essential macronutrients (mg kg^{-1} dry matter; mean ± standard error)

Compost	NO_3–N		NH_4–N		P		K	
A	88.2	± 21.7	236.5	± 35.6	103.8	± 4.0	4022.3	± 69.8
B	10.5	± 6.4	76.5	± 18.8	117.8	± 5.8	4738.8	± 183.5
F	1188.3	± 24.6	17.1	± 1.2	46.2	± 0.9	5657.9	± 48.3
G	1.8	± 2.2	656.6	± 15.6	27.3	± 2.2	1569.3	± 83.9
J	297.4	± 4.8	29.7	± 4.4	121.0	± 4.9	5447.1	± 25.2

Table 3.28. Secondary macronutrients (mg kg^{-1} dry matter; mean ± standard error)

Compost	Ca		Mg		S		Na	
A	306.3	± 29.2	55.9	± 4.3	450.8	± 25.2	871.9	± 20.3
B	348.3	± 30.4	62.8	± 5.6	166.5	± 11.6	582.9	± 19.3
F	445.7	± 5.6	106.1	± 0.8	657.5	± 16.3	564.4	± 16.7
G	1811.1	± 85.9	235.6	± 6.9	2418.7	± 117.0	2584.1	± 73.1
J	305.8	± 8.7	75.8	± 2.7	185.6	± 3.4	938.4	± 25.1

Table 3.29. Micronutrients Fe, Mn and Cu (mg kg^{-1} dry matter; mean ± standard error)

Compost	Fe		Mn		Cu	
A	93.42	± 11.80	2.15	± 0.28	1.41	± 0.63
B	107.02	± 15.75	3.10	± 0.42	2.37	± 0.41
F	114.42	± 3.70	2.73	± 0.08	0.76	± 0.24
G	72.20	± 4.37	3.62	± 0.24	7.17	± 0.78
J	83.92	± 7.08	1.73	± 0.24	1.11	± 0.36

Table 3.30. Micronutrients Zn, B and Cl (mg kg^{-1} dry matter; mean ± standard error)

Compost	Zn		B		Cl	
A	3.89	± 0.98	6.59	± 0.30	1464.89	± 32.58
B	3.49	± 0.23	7.87	± 0.37	1135.16	± 40.88
F	1.50	± 0.08	3.40	± 0.07	1633.57	± 72.25
G	5.30	± 0.56	4.96	± 0.19	1808.58	± 212.73
J	2.07	± 0.04	6.16	± 0.03	3762.26	± 310.80

3.2.8 Potentially toxic elements

Compost G had the highest concentration of all PTEs exceeding PAS 100 limits in Cu, Ni, Pb and Zn (Tables 3.31 and 3.32). Concentrations of Pb, Zn, Cr and Hg in compost G are lower in batch 2 than in batch 1 (see Tables 3.10 and 3.11 for batch 1 results).

Table 3.31. Cu, Ni, Pb and Zn concentration and permissible levels in accordance with BSI PAS 100 (mg kg^{-1} dry weight; ± standard error)

Compost	**Cu**		**Ni**		**Pb**		**Zn**	
A	45.50	± 1.26	12.10	± 0.39	76.53	± 5.91	154.67	± 13.14
B	78.87	± 7.80	21.40	± 6.26	218.50	± 160.51	267.67	± 75.61
F	41.50	± 1.44	14.97	± 0.98	55.47	± 1.17	138.00	± 4.30
G	240.67	± 128.81	227.67	± 25.12	293.67	± 59.04	455.00	± 24.40
J	51.77	± 2.54	12.33	± 0.08	152.67	± 42.67	259.33	± 9.63
PAS 100	≤200		≤50		≤200		≤400	

Table 3.32. Cd, Cr and Hg concentration and permissible levels in accordance with BSI PAS 100 (mg kg^{-1} dry weight; ± standard error)

Compost	**Cd**		**Cr**		**Hg**	
A	0.563	± 0.029	15.000	± 0.283	0.147	± 0.015
B	1.117	± 0.183	21.533	± 1.628	0.150	± 0.019
F	0.683	± 0.008	21.267	± 1.724	0.077	± 0.004
G	1.197	± 0.128	58.933	± 1.543	0.177	± 0.020
J	0.930	± 0.031	18.133	± 1.712	0.177	± 0.033
PAS 100	≤1.5		≤100		≤1	

3.2.9 Pathogens

Total coliforms varied from 20,267 (compost J) to 13,133,333 cfu/g (compost G). The coliform levels were higher in all five composts than for batch 1 (see Table 3.12).

Composts F, G and J contained concentrations of *E. coli* below the PAS 100 limit of ≤1000. None of the composts contained *Salmonella*.

Table 3.33. Pathogen contents

Compost	**Coliforms 30°C (cfu/g)**	***E. coli* 44°C (cfu/g)**	***Salmonella* 37°C (/25g)**
A	1,489,000	18667	not detected
B	1,461,333	16000	not detected
F	30,873	<10	not detected
G	13,133,333	<10	not detected
J	20,267	<10	not detected

3.3 Bioassay

Germination

The germination rate of the tomatoes grown in different concentrations of compost varied considerably with the compost concentration and time (Figure 3.4). In the 0% compost treatment (peat control), a germination rate of 88% was observed after four weeks. Higher levels of germination were observed in the 25% compost treatment in composts A (98% germination), B (88% germination) and J (86% germination). The 100% compost J treatment produced the lowest germination rate of 26% after four weeks.

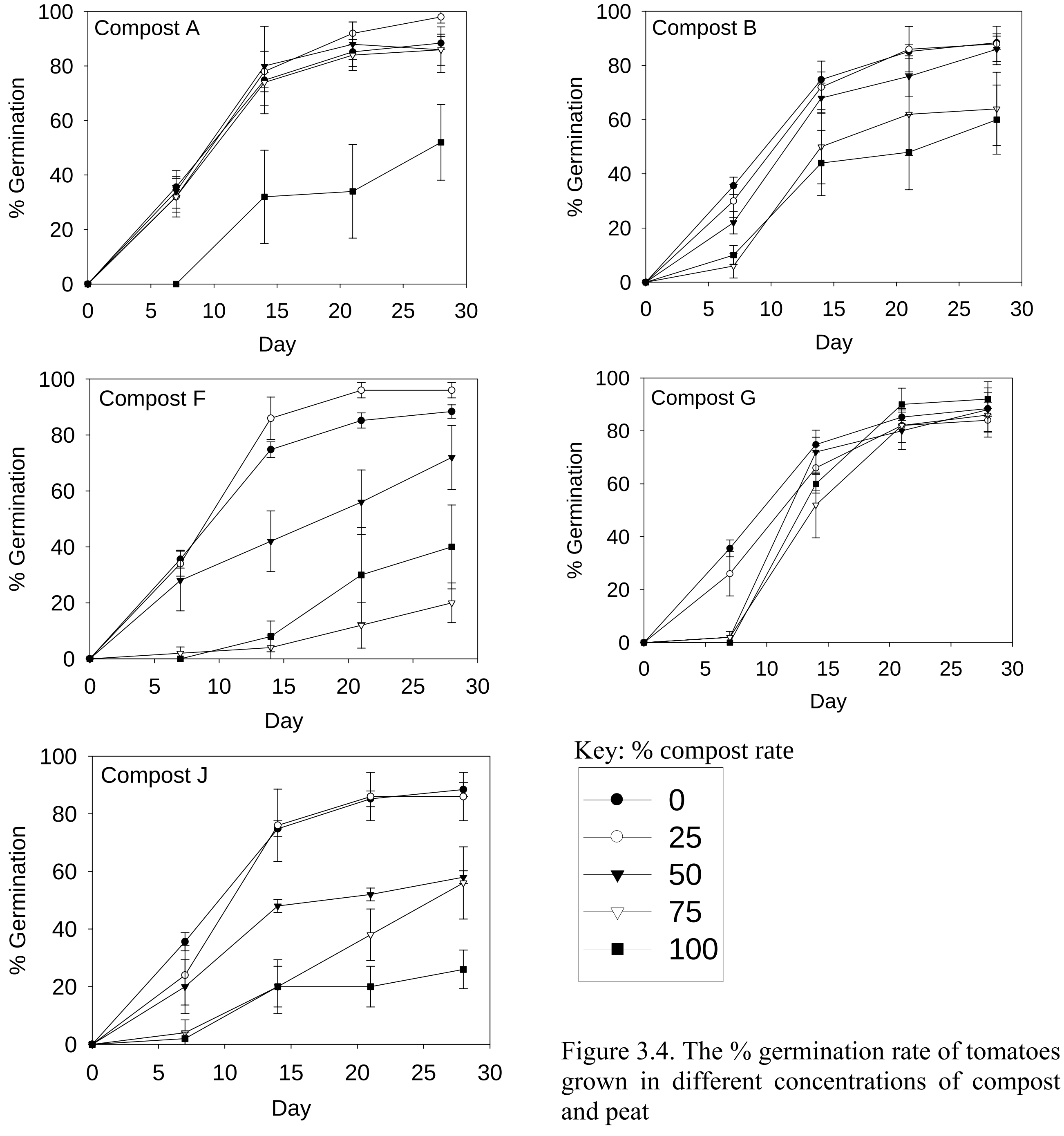

Figure 3.4. The % germination rate of tomatoes grown in different concentrations of compost and peat

In all composts, the higher compost concentrations (75% and 100% compost) inhibited germination, as shown in figure 3.5. For example, after seven days the higher compost concentrations showed a germination rate of less than 20%, compared to 36% in the control. Marchiol et al. (1999) noted that delayed germination occurred in a number of grass species grown in MSW compost.

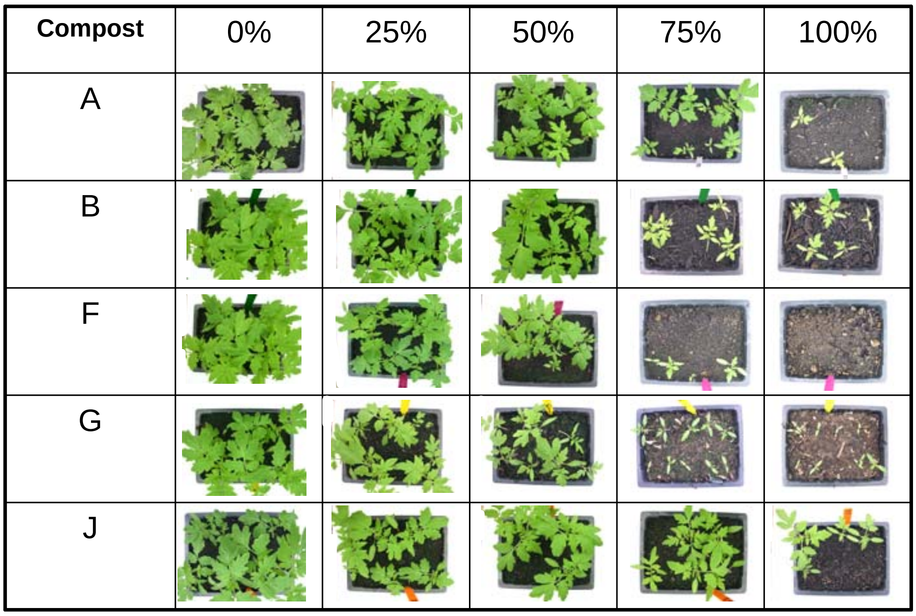

Figure 3.5. Tomato plants grown in different concentrations of compost; 21 days after sowing

Growth

In general, dry weight was greatest in the 25% compost treatment and lowest in 100% compost (Figure 3.6). At 25%, compost resulted in a yield increase of over 10% in all five composts. Differences between composts were also observed, with increases in tomato plant dry weight at 25% compost, from 11% (compost G), 27% (A), 34% (F), 41% (J) to 53% (B).

A study comparing three green waste composts found 25% compost to produce the greatest yield in barley plants, with an increase at 50% compost in one of the composts only (HDRA Consultants 2000). In this study, the 50% compost treatment reduced yield in composts A, F and G, but increased yield by over 25% in composts B and J. The 75% compost treatment resulted in a reduction in yield of at least 45% in all five composts, being over 80% in composts F and G. A reduction in yield of over 70% was observed in the 100% compost treatment in A, B, F and G, with a 41% reduction in compost J.

The fresh:dry weight ratio of the tomato plants varied from 10 to 14 (Figure 3.7).

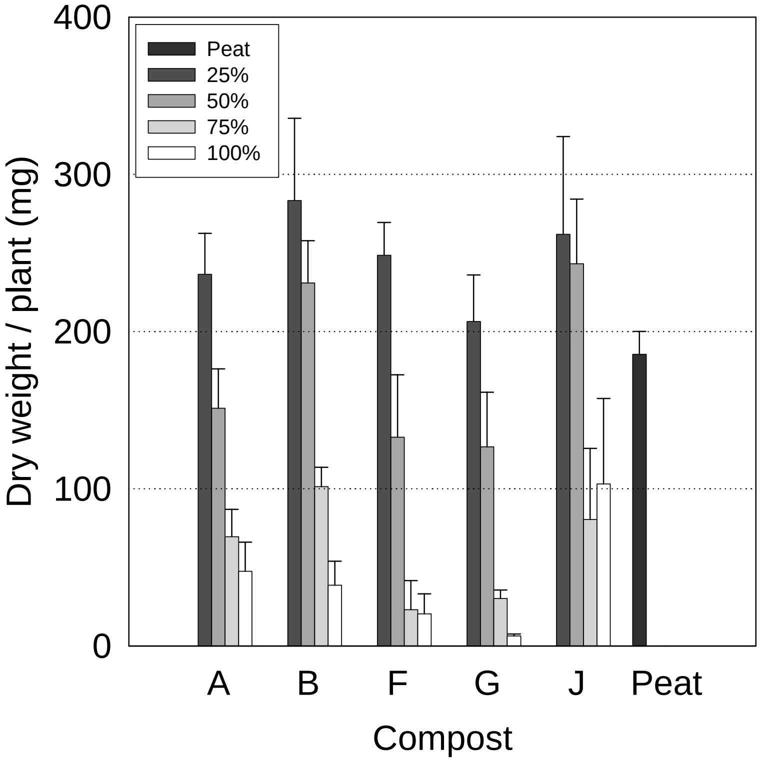

Figure 3.6. Dry weight of tomato plants grown in peat or different concentrations of compost (25%, 50%, 75% or 100%)

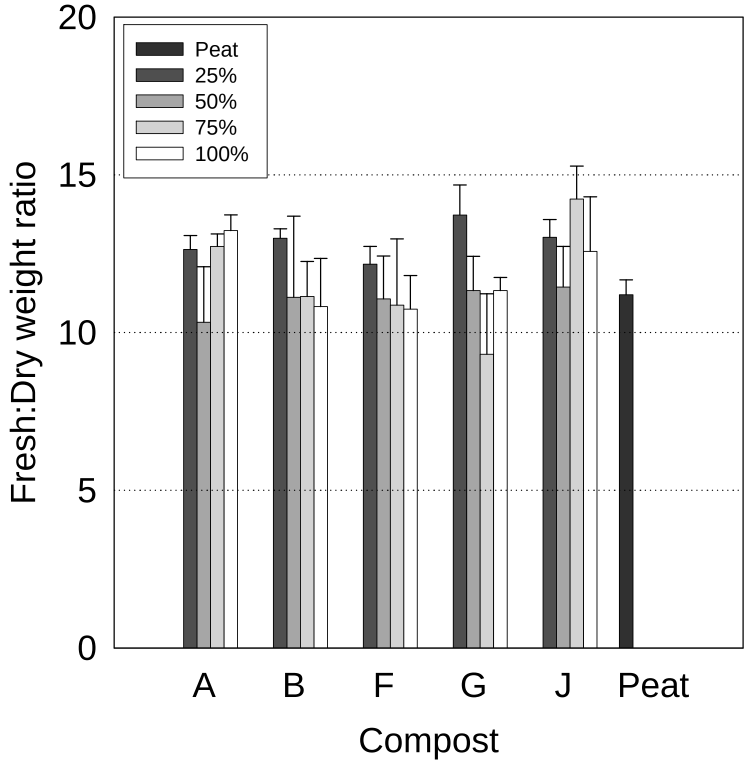

Figure 3.7. The fresh:dry weight ratio of tomato plants grown in peat or different concentrations of composts (25%, 50%, 75% or 100%)

When compost is used in agriculture it is generally incorporated into the soil, and so a concentration of 25% compost or less is expected. This study has shown that the 25% compost treatment did not suppress germination of tomatoes, and growth was slightly greater than when no compost was used.

3.3.1 Comparison of composts

In general, results of batch 1 composts were similar to batch 2, but not identical. For example, pH, electrical conductivity and C:N ratio were comparable in both batches (table 3.34). In addition, the C:N ratio in the mixed MSW compost G was considerably higher than the four source segregated composts in both batches, probably due to the higher proportion of paper and card waste in the MSW.

Table 3.34. pH, electrical conductivity and C:N ratio of batch 1 and batch 2 composts

	pH		**Conductivity (mS/cm)**		**C:N (:1)**	
Compost	**Batch 1**	**Batch 2**	**Batch 1**	**Batch 2**	**Batch 1**	**Batch 2**
A	8.26	8.68	1.03	1.08	14.74	16.43
B	8.23	8.43	0.83	0.85	19.19	20.05
F	8.45	7.67	1.81	2.25	11.62	10.73
G	7.15	7.88	2.20	1.56	31.65	31.59
J	8.74	8.31	1.42	1.24	12.66	13.03

Interestingly, there were differences in the pathogen levels between the two batches, as illustrated in table 3.35. In all five composts, coliforms were lower in batch 1.

Table 3.35. Microbiology results of batch 1 and batch 2 composts

	Coliforms 30°C (cfu/g)		***E. coli* 44°C (cfu/g)**	
Compost	**Batch 1**	**Batch 2**	**Batch 1**	**Batch 2**
A	26667	1489000	<1340	18667
B	380	1461333	<10	16000
F	170	30873	<67	<10
G	<273	13133333	27	<10
J	31667	1489000	22000	18667

These results indicate that, in general, compost properties are similar for each compost, but that there are variations between batches. With the exception of the microbial analyses, variations between batches are generally lower than variations between the different types of compost.

WRAP recommends regular testing of compost to ensure that the nutrient and contaminant levels are known before compost use. Indeed, prior to compost application it is necessary to ascertain the N concentration, so that application rates can be adjusted, in order to comply with the nitrates directive, if applicable.

3.4 Compost analysis summary

Analysis was performed on 12 composts supplied from UK commercial composting plants. Ten composts were produced from 100% source segregated BMW which included paper, cardboard and green, fruit, vegetable, meat and kitchen wastes. One compost was 72% mixed MSW plus 18% source segregated BMW and the other compost was 100% mixed MSW. Composts were analysed for a number of parameters including pH, electrical conductivity, carbohydrates, nutrients and contaminants.

Chemical compost characteristics

In general, compost pH was greater than 7. Nitrogen content varied between 1.0 to 2.2% with the higher levels found in composts containing source segregated kitchen or meat wastes. Phosphorus concentration ranged from 23 to 247 mg kg^{-1} and potassium between 1851 and 6615 mg kg^{-1}. Total salts were higher in mixed waste composts (15-23 g kg^{-1}), predominantly due to high concentrations of Ca, S and Na. Levels of PTEs in the 10 source segregated BMW composts were much lower than the limits for composts in the UK (PAS 100). However, the 100% mixed MSW compost exceeded the PAS 100 levels in four of the seven heavy metals tested (Cu, Ni, Pb and Zn).

Physical compost characteristics

The MSW composts contained higher levels of physical contaminants (glass, plastic and metal) than the source segregated BMW composts.

Compost as a growing medium

The composts tested can be used as a growing medium for plants such as tomatoes, without deleterious affects on plant growth at a rate of 25% compost to 75% peat. Concentrations of compost above 50% were found to reduce the growth of tomato plants.

4 RESULTS AND DISCUSSION OF THE FIELD TRIAL

4.1 Soil analysis

Soil samples were taken on three occasions: prior to compost application, pre-fertiliser treatment and post-harvest. Samples were taken to two depths: 0-30 cm and 30-60 cm. Further details are available in section 2.3.2.

4.1.1 Prior to compost application (9th March 2005)

Soil samples were taken from the three blocks prior to compost application. Soil pH ranged from 6.67 to 7.05 which was lower than the pH of the composts (7.67-8.68). Soil conductivity ranged from 1.72 to 2.18 mS cm^{-1}. Total soil carbon was <0.8%, and total soil nitrogen <0.05% (Table 4.1).

Table 4.1. Soil pH, conductivity, %C, %N, C:N ratio and loss on ignition (LOI)

Block	**pH**		**Conductivity (mS cm^{-1})**		**%C (dry weight)**		**%N (dry weight)**		**C:N**		**LOI (%)**	
	0-30	30-60	0-30	30-60	0-30	30-60	0-30	30-60	0-30	30-60	0-30	30-60
1	6.67	6.93	1.89	1.81	0.77	0.56	0.04	0.03	17.50	19.14	2.36	2.08
2	7.00	6.83	2.18	1.71	0.75	0.52	0.04	0.02	20.75	22.74	2.44	2.22
3	6.95	6.81	2.16	1.72	0.74	0.47	0.04	0.02	21.20	19.71	2.56	2.23
Mean	6.87	6.86	2.08	1.75	0.75	0.52	0.04	0.02	19.82	20.53	2.45	2.18

Soils contained higher levels of NO_3–N compared to NH_4–N (Table 4.2). Mineral N ranged from 20 to 30 kg ha^{-1} in each layer, equating to around 50 kg ha^{-1} in the 0-60 cm soil layer. Phosphorus (P) and potassium (K) were highest in the top soil layer (0-30 cm).

Table 4.2. Soil plant nutrients

Block	**NO_3–N (mg kg^{-1})**		**NH_4–N (mg kg^{-1})**		**Mineral N (kg ha^{-1})**		**K (mg kg^{-1})**		**Mg (mg kg^{-1})**		**P (mg kg^{-1})**	
	0-30	30-60	0-30	30-60	0-30	30-60	0-30	30-60	0-30	30-60	0-30	30-60
1	4.0	4.3	1.7	0.8	26.0	22.9	141.4	97.3	115.0	114.2	55.0	33.6
2	5.1	4.6	1.7	0.9	30.2	24.9	124.1	64.2	124.0	133.6	59.9	25.3
3	3.8	3.7	0.9	0.8	20.8	20.1	94.1	43.8	110.6	116.1	55.4	19.1
Mean	4.3	4.2	1.4	0.8	25.7	22.6	119.9	68.4	116.5	121.3	56.8	26.0

4.1.2 Prior to top dressing (5th May 2005)

The incorporation of composts increased the amounts of total carbon and nitrogen in the 0-30 cm layer (Table 4.3). In the period between compost incorporation (9th March) and pre top dressing (5th May) the percentage of carbon and nitrogen increased in all compost treatments compared to the control although the increases were not significant. The incorporation of composts made little or no differences to the percentage of carbon and nitrogen in the 30-60 cm soil layer.

Table 4.3. Total carbon and nitrogen in field soils on 5th May 2005 (mean ± standard error)

Treatment		% C		%N	
Compost	N rate (kg N ha^{-1})	0 - 30	30 - 60	0 - 30	30 - 60
A	250	0.818 ± 0.006	0.437 ± 0.054	0.057 ± 0.004	0.027 ± 0.002
A	500	1.184 ± 0.127	0.483 ± 0.049	0.077 ± 0.005	0.033 ± 0.002
A	250+125N	0.893 ± 0.012	0.462 ± 0.009	0.062 ± 0.004	0.031 ± 0.000
B	250	0.962 ± 0.124	0.541 ± 0.110	0.060 ± 0.011	0.040 ± 0.014
B	500	0.981 ± 0.150	0.511 ± 0.061	0.063 ± 0.009	0.040 ± 0.013
B	250+125N	0.838 ± 0.052	0.507 ± 0.040	0.055 ± 0.008	0.031 ± 0.003
F	250	0.804 ± 0.035	0.448 ± 0.079	0.055 ± 0.001	0.031 ± 0.006
F	500	0.837 ± 0.194	0.474 ± 0.039	0.056 ± 0.014	0.030 ± 0.006
F	250+125N	0.803 ± 0.081	0.493 ± 0.077	0.052 ± 0.003	0.031 ± 0.010
G	250	0.968 ± 0.081	0.546 ± 0.053	0.062 ± 0.009	0.035 ± 0.005
G	500	0.905 ± 0.134	0.486 ± 0.035	0.059 ± 0.006	0.030 ± 0.002
G	250+125N	0.872 ± 0.102	0.595 ± 0.130	0.057 ± 0.008	0.040 ± 0.011
J	250	0.803 ± 0.029	0.549 ± 0.095	0.056 ± 0.002	0.036 ± 0.008
J	500	1.075 ± 0.238	0.484 ± 0.031	0.072 ± 0.019	0.031 ± 0.003
J	250+125N	0.916 ± 0.016	0.510 ± 0.015	0.067 ± 0.008	0.037 ± 0.004
Control	0	0.770 ± 0.084	0.483 ± 0.048	0.049 ± 0.008	0.031 ± 0.005
P value		No Fert	No Fert	No Fert	No Fert
Compost		0.230	0.417	0.139	0.551
N rate		0.131	0.962	0.331	0.887
Compost x N rate		0.209	0.830	0.500	0.755

The 0-30 cm soil layer contained slightly more moisture than the 30-60 cm soil layer (Table 4.4). Moisture in the 0-30 cm layer ranged from 12.8 to 14.9% and 11.1 to 12.9% in the 30-60 cm layer. There were significant differences in both layers. In the 0-30 cm layer the incorporation of composts resulted in a significant increase in moisture content whereas in the 30-60 cm layer the same treatment resulted in a significant decrease. However the absolute values are small so we would not expect to see any effects on growing conditions.

Soil pH ranged from 6.7 to 7.3 in the 0-30 cm layer and from 6.6 to 6.8 in the 30-60 cm layer (Table 4.4). The range of values spans a maximum of 0.53 and there were no significant differences so we would not expect soil pH to have an effect on growing conditions.

Table 4.4. Soil % moisture and pH on 5th May 2005 (mean ± standard error)

Treatment		% moisture		pH	
Compost	N rate (kg N ha^{-1})	0 - 30	30 - 60	0 - 30	30 - 60
A	250	13.30 ± 0.26	11.28 ± 0.11	6.85 ± 0.20	6.71 ± 0.15
A	500	13.38 ± 0.35	11.09 ± 0.43	7.27 ± 0.12	6.74 ± 0.09
A	250+125N	13.53 ± 0.30	11.30 ± 0.19	6.87 ± 0.16	6.63 ± 0.17
B	250	13.11 ± 0.10	12.52 ± 0.32	6.76 ± 0.23	6.65 ± 0.16
B	500	14.86 ± 0.77	12.47 ± 0.15	7.09 ± 0.08	6.68 ± 0.07
B	250+125N	13.22 ± 0.35	12.70 ± 0.79	6.74 ± 0.14	6.66 ± 0.11
F	250	13.30 ± 0.37	11.72 ± 0.44	6.86 ± 0.32	6.71 ± 0.17
F	500	12.80 ± 0.19	11.46 ± 0.48	6.92 ± 0.28	6.70 ± 0.18
F	250+125N	12.94 ± 0.31	11.57 ± 0.28	6.81 ± 0.14	6.73 ± 0.11
G	250	13.61 ± 0.52	12.85 ± 1.22	6.97 ± 0.01	6.72 ± 0.02
G	500	14.68 ± 0.52	12.91 ± 0.85	7.08 ± 0.13	6.79 ± 0.20
G	250+125N	14.83 ± 0.19	11.81 ± 0.22	7.03 ± 0.03	6.79 ± 0.10
J	250	13.03 ± 0.26	12.01 ± 1.10	6.81 ± 0.10	6.82 ± 0.20
J	500	13.57 ± 0.51	11.49 ± 0.50	6.91 ± 0.14	6.75 ± 0.09
J	250+125N	13.34 ± 0.37	12.18 ± 0.98	6.75 ± 0.10	6.61 ± 0.07
Control	0	12.91 ± 0.35	12.59 ± 0.21	6.90 ± 0.20	6.64 ± 0.12
P value		No Fert	No Fert	No Fert	No Fert
Compost		<.001	0.008	0.379	0.839
N rate		0.057	0.925	0.067	0.914
Compost x N rate		0.014	0.727	0.779	0.929

Table 4.5. Soil mineral N on 5th May 2005 (mean ± standard error)

Treatment		Mineral N kg ha^{-1}		
Compost	N rate (kg N ha^{-1})	0-30	30-60	0-60
A	250	81.5 ± 1.3	75.5 ± 2.7	157.0 ± 3.5
A	500	86.7 ± 2.9	75.7 ± 1.6	162.4 ± 4.4
A	250+125N	80.2 ± 0.8	76.2 ± 1.1	156.4 ± 1.6
B	250	80.3 ± 4.8	76.8 ± 2.7	157.1 ± 7.5
B	500	84.5 ± 2.4	78.4 ± 0.3	162.9 ± 2.7
B	250+125N	77.1 ± 2.3	75.6 ± 2.5	152.7 ± 4.8
F	250	79.0 ± 4.1	75.6 ± 2.4	154.6 ± 6.4
F	500	82.3 ± 2.9	76.3 ± 4.1	158.6 ± 7.0
F	250+125N	77.2 ± 2.1	76.5 ± 2.3	153.7 ± 4.4
G	250	80.4 ± 2.1	77.7 ± 2.1	158.2 ± 3.8
G	500	83.0 ± 2.7	78.1 ± 4.1	161.1 ± 6.7
G	250+125N	82.3 ± 0.8	76.6 ± 0.7	158.9 ± 1.4
J	250	78.0 ± 1.5	76.6 ± 3.5	154.6 ± 2.7
J	500	88.5 ± 11.8	76.3 ± 1.8	164.8 ± 13.3
J	250+125N	79.1 ± 4.6	74.9 ± 3.8	154.0 ± 8.3
Control	0	78.9 ± 1.6	76.3 ± 1.3	155.2 ± 2.8
P value		No Fert	No Fert	No Fert
Compost		0.658	0.758	0.738
N rate		0.012	0.501	0.046
Compost x N rate		0.746	0.795	0.282

Mineral nitrogen levels in the 0–30 cm layer (Table 4.5) showed some variation suggesting that mineralisation did occur from some of the composts. In treatments where 250 kg N ha^{-1} was applied in the composts, levels of mineral N did not differ significantly from the control. However, where 500 kg N ha^{-1} N was applied in the composts, levels of mineral nitrogen were significantly higher than the control. The increase ranged from 3.3 kg N ha^{-1} (compost F) to 9.6 kg N ha^{-1} (compost J). Levels of mineral nitrogen in the 30-60 cm layer showed no significant effect resulting from the incorporation of composts.

Although not significant, where 250 kg N ha^{-1} was applied in the composts, there is some evidence of soil nitrogen immobilisation when compared to the control plots. Any immobilisation where 500 kg N ha^{-1} N was applied is masked by the extra nitrogen mineralised from the composts.

It is also possible that the effects of incorporating the composts could have been more pronounced, since high levels of spring mineralisation may have masked the effects. Between drilling and top-dressing, a period of only 57 days, the mineral nitrogen levels in the control plots increased from 50 kg/ha to 150 kg/ha. This amount of nitrogen mineralisation is unusual on the sandy loam soils at Wellesbourne.

4.1.3 Post-harvest soil samples (8th August 2005)

Table 4.6. Total carbon and nitrogen in field soils on 8th August (mean ± standard error)

Treatment		% C				% N			
Compost	N rate (kg N ha^{-1})	0 - 30		30 - 60		0 - 30		30 - 60	
A	250	0.87 ± 0.03		0.49 ± 0.04		0.054 ± 0.01		0.033 ± 0.00	
A	500	0.89 ± 0.03		0.51 ± 0.04		0.056 ± 0.00		0.033 ± 0.00	
A	250+125N	0.87 ± 0.02		0.55 ± 0.03		0.054 ± 0.00		0.033 ± 0.00	
B	250	0.95 ± 0.05		0.57 ± 0.06		0.059 ± 0.01		0.039 ± 0.00	
B	500	0.97 ± 0.07		0.54 ± 0.09		0.056 ± 0.00		0.033 ± 0.00	
B	250+125N	0.92 ± 0.05		0.53 ± 0.06		0.056 ± 0.00		0.036 ± 0.00	
F	250	0.86 ± 0.06		0.52 ± 0.03		0.054 ± 0.00		0.035 ± 0.00	
F	500	0.94 ± 0.07		0.54 ± 0.07		0.069 ± 0.00		0.037 ± 0.00	
F	250+125N	0.99 ± 0.12		0.55 ± 0.10		0.068 ± 0.01		0.035 ± 0.01	
G	250	0.93 ± 0.08		0.56 ± 0.09		0.056 ± 0.00		0.037 ± 0.01	
G	500	0.86 ± 0.03		0.49 ± 0.04		0.051 ± 0.00		0.032 ± 0.00	
G	250+125N	0.94 ± 0.07		0.57 ± 0.02		0.060 ± 0.01		0.038 ± 0.00	
J	250	0.88 ± 0.06		0.48 ± 0.05		0.057 ± 0.00		0.030 ± 0.00	
J	500	0.89 ± 0.09		0.52 ± 0.01		0.055 ± 0.01		0.034 ± 0.00	
J	250+125N	0.83 ± 0.04		0.56 ± 0.03		0.051 ± 0.00		0.040 ± 0.00	
Control	0	0.79 ± 0.02		0.52 ± 0.03		0.049 ± 0.00		0.035 ± 0.00	
FERT	42	0.77 ± 0.02		0.52 ± 0.07		0.049 ± 0.00		0.034 ± 0.00	
FERT	84	0.84 ± 0.04		0.51 ± 0.08		0.052 ± 0.01		0.035 ± 0.01	
FERT	125	0.82 ± 0.03		0.52 ± 0.07		0.050 ± 0.00		0.032 ± 0.00	
FERT	167	0.84 ± 0.08		0.45 ± 0.05		0.053 ± 0.00		0.030 ± 0.00	
FERT	209	0.83 ± 0.05		0.53 ± 0.05		0.056 ± 0.01		0.036 ± 0.00	
P value		All	No Fert	All	No Fert	All	No Fert	All	No Fert
Compost		<.001	0.024	0.592	0.902	<.001	0.011	0.656	0.831
N rate		0.926	0.954	0.508	0.457	0.887	0.893	0.561	0.454
Compost x N rate		0.213	0.349	0.477	0.530	0.031	0.079	0.093	0.130

Incorporation of composts increased the carbon content in the 0-30 cm soil layer in comparison to the control. Levels of carbon were highest using composts G and J and lowest in the control (Table 4.6). There were no significant differences in the 30-60 cm soil layer.

Levels of total nitrogen in the 0-30 cm soil layer were highest where compost J was incorporated with 0.07% (250 and 500 treatments), compared to 0.05 or 0.06% for the other treatments. There were no significant differences in the 30-60 cm soil layer.

Table 4.7. Soil % moisture and pH on 8th August 2005 (mean ± standard error)

Treatment		% moisture				pH			
Compost	N rate (kg N ha^{-1})	0 - 30		30 - 60		0 - 30		30 - 60	
A	250	8.89 ± 0.08		6.15 ± 0.77		6.92 ± 0.05		6.81 ± 0.09	
A	500	8.91 ± 0.71		5.34 ± 0.28		7.02 ± 0.06		6.92 ± 0.31	
A	250+125N	8.10 ± 0.47		5.11 ± 0.35		6.62 ± 0.25		6.71 ± 0.04	
B	250	9.22 ± 0.26		7.80 ± 1.10		6.81 ± 0.10		6.86 ± 0.05	
B	500	8.99 ± 0.27		6.47 ± 0.63		6.87 ± 0.14		6.73 ± 0.10	
B	250+125N	8.53 ± 0.29		5.11 ± 0.20		6.86 ± 0.10		6.80 ± 0.03	
F	250	8.60 ± 0.32		6.10 ± 0.47		6.85 ± 0.15		6.79 ± 0.11	
F	500	8.58 ± 0.23		6.22 ± 0.08		6.99 ± 0.14		6.91 ± 0.18	
F	250+125N	8.59 ± 0.40		5.33 ± 0.06		6.82 ± 0.04		6.85 ± 0.10	
G	250	9.13 ± 0.23		8.20 ± 1.54		6.99 ± 0.06		6.88 ± 0.18	
G	500	9.43 ± 0.30		6.31 ± 1.03		7.07 ± 0.07		6.70 ± 0.15	
G	250+125N	8.52 ± 0.19		6.06 ± 0.09		6.92 ± 0.04		6.79 ± 0.15	
J	250	8.64 ± 0.07		5.93 ± 0.69		6.77 ± 0.09		6.60 ± 0.09	
J	500	8.85 ± 0.58		6.16 ± 0.42		6.86 ± 0.10		6.90 ± 0.07	
J	250+125N	8.17 ± 0.07		6.23 ± 0.89		6.71 ± 0.08		6.75 ± 0.09	
Control	0	8.60 ± 0.07		6.67 ± 0.32		6.89 ± 0.33		6.73 ± 0.11	
FERT	42	8.56 ± 0.12		5.73 ± 1.00		6.72 ± 0.05		6.92 ± 0.15	
FERT	84	8.73 ± 0.14		6.16 ± 0.43		6.89 ± 0.08		6.91 ± 0.11	
FERT	125	8.58 ± 0.51		5.76 ± 0.44		6.80 ± 0.05		6.79 ± 0.08	
FERT	167	8.30 ± 0.35		5.20 ± 0.16		6.58 ± 0.15		6.61 ± 0.04	
FERT	209	8.51 ± 0.39		6.57 ± 1.29		6.52 ± 0.02		6.67 ± 0.09	
P value		All	No Fert	All	No Fert	All	No Fert	All	No Fert
Compost		0.131	0.227	0.100	0.096	0.021	0.294	0.817	0.822
N rate		0.121	0.013	0.052	0.014	0.043	0.140	0.365	0.822
Compost x N rate		0.715	0.703	0.194	0.204	0.718	0.797	0.282	0.366

Where composts were incorporated, soil moisture levels at harvest in the 0-30 cm layer were generally higher than the control (Table 4.7) but not significantly so. There were no differences in the 30-60 cm soil layer.

In this study, soil pH was slightly higher in composts A, B and G compared to the control although this was not statistically significant. The incorporation of composts did lead to significant differences in the pH of the 0-30 cm layer although the narrow spread of the data suggests that pH will not influence the results. There was no effect on the 30-60 cm soil layer. Where compost is incorporated annually, an increase in soil pH would be anticipated, as observed in a number of studies (Mkhabeka & Warman, 2005). A UK field study comparing three composts found a slight increase in soil pH with two years of compost application (HDRA Consultants, 2000). The ability of compost to raise the soil pH is one of the many advantages it has over inorganic fertilisers (Mkhabeka & Warman 2005), although these beneficial effects take time to become apparent.

The incorporation of composts did not result in any significant differences in electrical conductivity (Table 4.8). Even though the buffering effect of the soil is large, over time an increase could be expected with repeated compost applications.

The incorporation of composts should over time lead to an increase in soil organic matter as determined by loss on ignition although it does require multiple applications. However even within the limited duration of this trial we did find some increase in soil organic matter. The increases were not significantly different between the two sampling dates, 9th March (Table 4.1) and 8th August (Table 4.8)) but were quantifiable. Although the differences are small, the incorporation of composts did increase the organic matter when compared to the control and the double application rate resulted in greater organic matter in comparison to the single rate.

Table 4.8. Conductivity (EC) and loss on ignition (LOI) on 8th August 2005

Treatment		EC (mS cm^{-1})				LOI (%)
Compost	N rate (kg N ha^{-1})	0 - 30		30 - 60		0 - 30
A	250	2.55 ± 0.13		2.46 ± 0.10		2.32 ± 0.04
A	500	2.55 ± 0.03		2.44 ± 0.00		2.46 ± 0.04
A	250+125N	2.53 ± 0.02		2.47 ± 0.03		2.43 ± 0.07
B	250	2.53 ± 0.06		2.49 ± 0.07		2.52 ± 0.03
B	500	2.52 ± 0.01		2.43 ± 0.01		2.57 ± 0.15
B	250+125N	2.51 ± 0.05		2.49 ± 0.03		2.45 ± 0.03
F	250	2.50 ± 0.05		2.44 ± 0.03		2.36 ± 0.03
F	500	2.50 ± 0.11		2.49 ± 0.14		2.47 ± 0.15
F	250+125N	2.56 ± 0.14		2.48 ± 0.13		2.49 ± 0.11
G	250	2.55 ± 0.12		2.51 ± 0.14		2.46 ± 0.15
G	500	2.62 ± 0.06		2.55 ± 0.05		2.48 ± 0.14
G	250+125N	2.52 ± 0.07		2.51 ± 0.05		2.55 ± 0.02
J	250	2.48 ± 0.08		2.41 ± 0.16		2.30 ± 0.13
J	500	2.65 ± 0.03		2.56 ± 0.02		2.58 ± 0.27
J	250+125N	2.52 ± 0.12		2.48 ± 0.13		2.46 ± 0.09
Control	0	2.49 ± 0.10		2.45 ± 0.12		2.17 ± 0.04
FERT	42	2.50 ± 0.05		2.47 ± 0.08		n.d.
FERT	84	2.49 ± 0.04		2.42 ± 0.03		n.d.
FERT	125	2.54 ± 0.10		2.50 ± 0.03		n.d.
FERT	167	2.50 ± 0.12		2.40 ± 0.09		n.d.
FERT	209	2.47 ± 0.10		2.51 ± 0.13		n.d.
P value		All	No Fert	All	No Fert	No Fert
Compost		0.548	0.774	0.671	0.754	0.003
N rate		0.902	0.495	0.807	0.826	0.134
Compost x N rate		0.499	0.480	0.696	0.727	0.745

(n.d. not determined; ± standard error)

The mineral N level in the control plots at harvest was 57 kg ha^{-1} (Table 4.9). Comparing the soils that received the two rates (250 & 500 kg N ha^{-1}) of compost application showed minimal differences in mineral N at harvest. Plots where compost, without the additional ammonium-nitrate, had been applied were lower in mineral N than the control. This suggests that incorporation of composts had an immobilising effect on existing soil mineral N. Where an additional 125 kg ha^{-1} of ammonium-nitrate had been applied mineral N levels were higher. Where composts A and F were incorporated this additional fertiliser N may have overcome any immobilising effect and allowed some mineralisation of contained compost nitrogen.

Composts are known to mineralise their nutrients slowly and we would expect that more nitrogen would become available in the next 4-6 years. Moreover, regular applications of compost will ensure that the reported benefits of composts on soil structure, moisture retention and disease suppression will occur. In this study, the maximum permitted quantity of compost was applied (determined according to maximum N application in nitrate vulnerable zones in the UK; 250 kg N ha^{-1}). This amount was equivalent to less than 45 t ha^{-1} compost, a layer of compost less than 1 cm thick before incorporation.

Table 4.9. Mineral N content of field soils on 8th August 2005 (mean ± standard error)

Treatment		Mineral N (kg ha^{-1})		
Compost	N rate (kg N ha^{-1})	0 - 30	30 - 60	0 - 60
A	250	31.9 ± 1.5	15.4 ± 6.0	47.3 ± 12.3
A	500	32.0 ± 1.4	16.5 ± 1.9	48.5 ± 7.0
A	250+125N	58.4 ± 3.7	17.1 ± 2.6	75.5 ± 14.3
B	250	32.9 ± 1.0	18.8 ± 5.0	51.7 ± 8.9
B	500	29.8 ± 4.4	19.3 ± 6.9	49.1 ± 15.7
B	250+125N	46.3 ± 1.4	16.6 ± 2.2	62.9 ± 6.0
F	250	30.0 ± 1.5	15.1 ± 3.3	45.1 ± 9.5
F	500	33.3 ± 1.7	16.2 ± 3.7	49.5 ± 10.9
F	250+125N	68.2 ± 5.2	18.2 ± 5.5	86.4 ± 22.0
G	250	32.0 ± 1.5	15.8 ± 3.6	47.8 ± 9.7
G	500	33.8 ± 2.7	16.1 ± 8.3	49.9 ± 19.4
G	250+125N	53.3 ± 2.1	13.4 ± 6.6	66.7 ± 15.5
J	250	31.7 ± 1.5	15.6 ± 8.4	47.3 ± 15.3
J	500	34.8 ± 1.2	18.0 ± 3.8	52.8 ± 9.3
J	250+125N	43.2 ± 2.1	16.8 ± 3.0	60.0 ± 12.1
Control	0	37.0 ± 1.7	20.2 ± 2.8	57.2 ± 7.2
FERT	42	32.0 ± 1.0	20.0 ± 4.9	52.0 ± 8.2
FERT	84	42.2 ± 0.7	21.4 ± 8.7	63.6 ± 14.0
FERT	125	47.0 ± 2.2	19.2 ± 7.9	66.2 ± 18.9
FERT	167	48.3 ± 1.7	20.9 ± 5.5	69.2 ± 13.3
FERT	209	64.8 ± 6.0	28.3 ± 12.1	93.1 ± 7.6

P value	All	No Fert	All	No Fert	All	No Fert
Compost	0.877	0.624	0.022	0.542	0.640	0.457
N rate	0.092	0.838	0.530	0.803	0.101	0.709
Compost x N rate	0.955	0.608	0.969	0.973	0.936	0.734

The incorporation of composts increased potassium in all treatments in the 0-30 cm layer, except for compost F applied at the 250 kg ha^{-1} N level (Table 4.10). There were no significant differences in potash levels. All composts applied at the 500 kg N ha^{-1} level increased the concentration of magnesium in the 0-30 cm soil layer (Table 4.11).

Table 4.10. Water soluble P and K of soil on 8th August 2005 (mean ± standard error)

Treatment		P (mg kg^{-1})		K (mg kg^{-1})	
Compost	N rate (kg N ha^{-1})	0-30	30-60	0-30	30-60
A	250	81.9 ± 24.4	33.5 ± 9.6	163.2 ± 17.1	69.9 ± 10.3
A	500	69.5 ± 18.2	31.0 ± 7.4	171.3 ± 23.2	68.4 ± 4.6
A	250+125N	80.3 ± 19.7	24.3 ± 5.9	160.1 ± 14.7	57.5 ± 6.7
B	250	70.7 ± 14.8	24.1 ± 5.1	208.5 ± 32.8	73.3 ± 12.6
B	500	64.1 ± 7.3	25.2 ± 4.7	197.8 ± 25.3	78.3 ± 7.3
B	250+125N	80.0 ± 18.1	24.3 ± 2.1	164.9 ± 10.7	58.7 ± 3.0
F	250	69.6 ± 21.3	30.8 ± 7.9	139.4 ± 6.3	69.6 ± 6.8
F	500	79.3 ± 19.9	27.3 ± 11.7	179.3 ± 34.7	68.6 ± 6.8
F	250+125N	75.8 ± 22.6	25.9 ± 8.5	193.3 ± 40.4	67.1 ± 5.5
G	250	83.2 ± 16.1	28.6 ± 8.0	167.1 ± 1.3	75.4 ± 8.6
G	500	73.7 ± 5.4	25.2 ± 0.9	187.2 ± 17.5	67.0 ± 6.9
G	250+125N	89.1 ± 18.0	32.1 ± 8.6	163.5 ± 12.2	72.8 ± 3.2
J	250	76.9 ± 19.9	22.4 ± 4.9	167.3 ± 6.8	65.0 ± 6.8
J	500	61.5 ± 8.2	23.4 ± 2.1	191.1 ± 30.1	66.5 ± 4.2
J	250+125N	60.0 ± 10.2	22.7 ± 0.7	146.4 ± 9.4	85.9 ± 17.4
Control	0	74.8 ± 20.4	26.9 ± 4.6	140.6 ± 15.8	72.2 ± 6.7
FERT	42	64.3 ± 9.7	24.2 ± 4.0	143.7 ± 18.9	65.3 ± 13.6
FERT	84	73.1 ± 10.7	28.2 ± 11.0	144.9 ± 6.2	63.6 ± 8.6
FERT	125	65.5 ± 11.4	25.1 ± 3.7	162.0 ± 25.6	70.9 ± 8.5
FERT	167	69.9 ± 25.1	26.1 ± 5.9	133.4 ± 10.3	60.3 ± 4.8
FERT	209	75.5 ± 20.8	28.3 ± 9.6	145.5 ± 15.4	61.6 ± 9.5

P value	All	No Fert	All	No Fert	All	No Fert	All	No Fert
Compost	0.157	0.239	0.100	0.138	0.011	0.228	0.620	0.739
N rate	0.753	0.421	0.960	0.805	0.674	0.315	0.942	0.953
Compost x N rate	0.464	0.486	0.427	0.489	0.183	0.247	0.112	0.061

Table 4.11. Soil magnesium concentration on 8th August 2005 (mean ± standard error)

Treatment		Mg (mg kg^{-1})			
Compost	N rate (kg N ha^{-1})	0 - 30		30 - 60	
A	250	110.9 ± 17.4		120.0 ± 17.4	
A	500	133.6 ± 3.8		122.8 ± 11.5	
A	250+125N	107.6 ± 2.5		101.2 ± 6.7	
B	250	119.2 ± 16.3		148.8 ± 36.0	
B	500	133.7 ± 6.5		144.3 ± 11.3	
B	250+125N	113.3 ± 4.3		114.6 ± 2.1	
F	250	119.0 ± 6.5		134.2 ± 18.3	
F	500	120.1 ± 26.9		153.1 ± 14.4	
F	250+125N	132.4 ± 16.7		129.3 ± 17.8	
G	250	118.5 ± 18.0		156.2 ± 35.8	
G	500	120.7 ± 14.7		125.7 ± 8.4	
G	250+125N	111.5 ± 2.6		129.4 ± 13.4	
J	250	114.7 ± 9.2		128.7 ± 23.6	
J	500	131.5 ± 14.3		145.1 ± 16.9	
J	250+125N	135.9 ± 11.9		150.7 ± 19.0	
Control	0	113.0 ± 9.5		146.8 ± 10.0	
FERT	42	125.1 ± 8.4		125.1 ± 43.2	
FERT	84	113.0 ± 6.3		137.9 ± 24.2	
FERT	125	167.6 ± 34.5		146.0 ± 24.8	
FERT	167	107.0 ± 4.6		115.2 ± 3.1	
FERT	209	123.0 ± 18.7		128.9 ± 37.5	
P value		All	No Fert	All	No Fert
Compost		0.788	0.437	0.389	0.186
N rate		0.010	0.155	0.740	0.428
Compost x N rate		0.558	0.170	0.555	0.364

4.2 Plant analysis

Plant samples were taken pre-top dressing in May (56 days after drilling) and at harvest in August (142 days after drilling) as detailed in Section 2.2.

Visual assessment of the crop four weeks after sowing revealed a reduction in size and vigour, and a yellowing of the leaves in plants treated with compost G, compared to all other treatments. However, after fertiliser application, plants treated with both compost G and fertiliser showed some recovery, becoming greener and more vigorous.

4.2.1 Plant samples prior to top dressing (10th May 2005)

Table 4.12. Fresh and dry weight yields of barley and nitrogen uptake on 56 days after drilling (mean ± standard error)

Treatment		Fresh weight	Dry weight	N uptake
Compost	N Rate (kg N ha^{-1})	(t ha^{-1})	(t ha^{-1})	(kg ha^{-1})
A	250	3.46 ± 0.29	0.61 ± 0.05	17.41 ± 2.21
A	500	4.51 ± 0.46	0.78 ± 0.05	21.25 ± 1.81
B	250	2.98 ± 0.48	0.51 ± 0.07	15.28 ± 2.46
B	500	2.86 ± 0.54	0.50 ± 0.08	15.40 ± 2.44
F	250	4.27 ± 0.12	0.75 ± 0.00	22.67 ± 1.09
F	500	5.78 ± 0.72	0.94 ± 0.08	29.25 ± 1.55
G	250	1.21 ± 0.51	0.23 ± 0.09	6.78 ± 3.14
G	500	0.79 ± 0.09	0.15 ± 0.02	4.60 ± 0.65
J	250	3.56 ± 0.61	0.63 ± 0.07	18.08 ± 3.93
J	500	4.04 ± 0.22	0.71 ± 0.04	21.27 ± 1.34
Control	0	3.33 ± 0.46	0.61 ± 0.06	16.89 ± 3.18
<u>P value</u>				
Compost		<.001	<.001	<.001
N rate		0.072	0.065	0.119
Compost x N rate		0.019	0.017	0.070

Plant yield on day 50 varied according to compost type and rate. Composts F and J increased yield at both rates, with compost A increasing yield at the 500 kg N ha^{-1} rate only. A 15% reduction in yield was observed in compost B. The mixed waste compost G caused a significant reduction in plant yield at both concentrations; 62% (250 kg ha^{-1}) and 75% (500 kg N ha^{-1}).

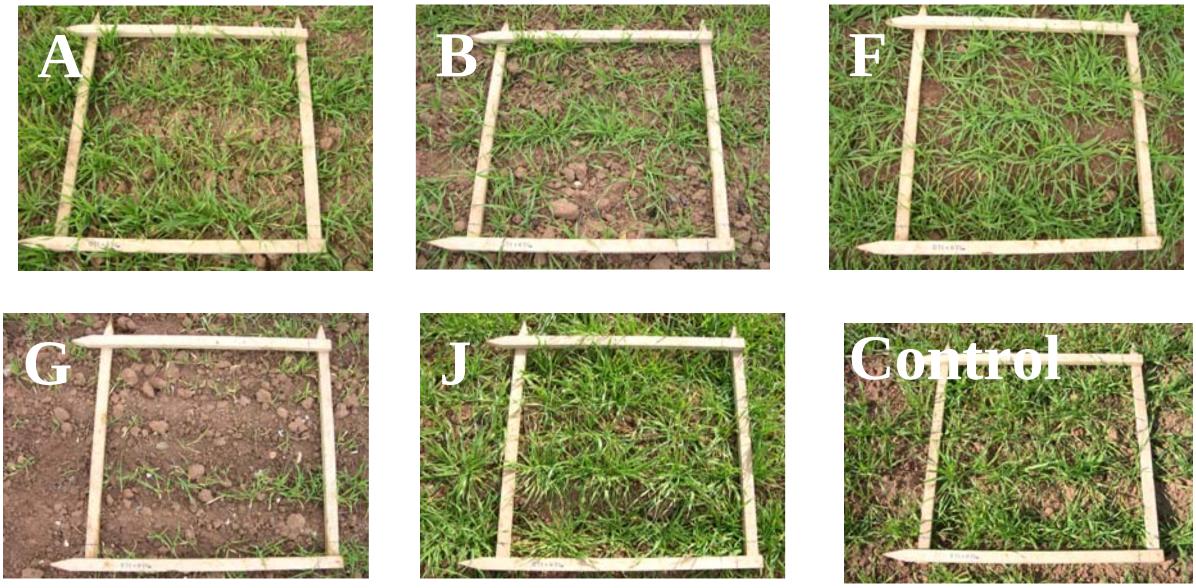

Figure 4.1. The five composts and control on day 50

Table 4.13. %C, %N and C:N ratio of above-ground barley on day 50 (mean ± standard error)

Treatment		%C	%N	C:N (:1)
Compost	N rate (kg N ha^{-1})	(dry weight)	(dry weight)	
A	250	41.1 ± 0.4	2.84 ± 0.11	14.5 ± 0.7
A	500	37.3 ± 0.8	2.67 ± 0.05	14.0 ± 0.6
B	250	40.9 ± 0.4	2.94 ± 0.18	14.0 ± 1.0
B	500	41.3 ± 0.8	3.03 ± 0.01	13.6 ± 0.2
F	250	37.7 ± 2.3	2.98 ± 0.14	12.7 ± 0.6
F	500	39.1 ± 2.6	3.08 ± 0.14	12.7 ± 0.3
G	250	40.5 ± 1.3	2.76 ± 0.41	15.1 ± 2.1
G	500	42.3 ± 0.1	3.01 ± 0.05	14.0 ± 0.3
J	250	39.6 ± 2.4	2.83 ± 0.31	14.1 ± 1.0
J	500	39.2 ± 0.5	2.98 ± 0.07	13.2 ± 0.5
Control	0	38.6 ± 3.6	2.75 ± 0.36	14.2 ± 0.6
P value				
Compost		0.050	0.479	0.195
N rate		0.984	0.704	0.471
Compost x N rate		0.050	0.595	0.864

There are a number of possible explanations for the reduced growth caused by mixed MSW compost G. Firstly the high concentration of NH_4–N in compost G (>2.2 g kg^{-1}); high concentrations of NH_4–N in the region 1.2-2.3 g kg^{-1} have been found to inhibit grass seed germination (O'Brien and Barker 1996). High concentrations of NH_4 have been found to decline 7-10 days after compost application, although initial phytotoxic effects can damage seeds and plants may not recover (O'Brien and Barker 1996). In this study, the barley was sown four days after compost application, and so it is possible that the high levels of NH_4 in compost G caused a reduction in barley germination and performance.

Secondly, compost G generally had higher concentrations of PTEs and sodium than the other four composts, which may have caused the reduced yield observed in the barley. Indeed, as shown in the plant bioassay (Section 3.30), compost G delayed germination and stunted the growth of tomato seedlings.

Thirdly, compost G had a high C:N ratio. When the C:N ratio is less than 20:1 (as was the case with composts A, B, F and J), composts do not lock up nitrogen. However a C:N of >20:1 may reduce nitrogen availability to plants.

4.2.2 Plant samples at harvest (4th August 2005)

Yield: Fertiliser response curve

The commercial yield potential for this barley variety (Optic) under optimum growth conditions is 6.5 - 6.9 t ha^{-1} and the results from this trial agree, ranging from 5.41 (Control) to 6.68 t ha^{-1} (FERT 125). However, the response to inorganic fertiliser was minimal with a flat response curve. We attribute this to the high levels of soil mineral nitrogen throughout the growing season. The flat response curve has made interpreting the results from the compost treatments difficult.

Table 4.14. Barley grain yield (85% dry matter), 1000 grain weight, protein and N (mean ± standard error)

Treatment		Yield		1000 grain weight		Grain N	
Compost	N rate (kg N ha^{-1})	(t ha^{-1})		(g)		(% dry matter)	
A	250	5.53 ± 0.46		39.3		1.17 ± 0.03	
A	500	6.45 ± 0.08		39.1		1.28 ± 0.02	
A	250+125N	6.71 ± 0.38		32.3		2.01 ± 0.03	
B	250	4.66 ± 1.04		41.7		1.35 ± 0.13	
B	500	5.05 ± 0.30		41.1		1.23 ± 0.01	
B	250+125N	6.50 ± 0.35		32.9		1.90 ± 0.09	
F	250	6.56 ± 0.19		38.3		1.29 ± 0.04	
F	500	7.09 ± 0.10		36.7		1.38 ± 0.04	
F	250+125N	6.65 ± 0.14		34.7		1.91 ± 0.02	
G	250	3.60 ± 0.34		41.9		1.46 ± 0.11	
G	500	3.89 ± 0.87		44.2		1.46 ± 0.18	
G	250+125N	4.82 ± 0.37		38.7		2.03 ± 0.09	
J	250	5.66 ± 0.45		38.1		1.14 ± 0.09	
J	500	6.16 ± 0.32		38.6		1.19 ± 0.06	
J	250+125N	6.88 ± 0.21		33.4		1.83 ± 0.09	
Control	0	5.41 ± 0.43		38.7		1.20 ± 0.08	
FERT	42	6.56 ± 0.13		38.8		1.42 ± 0.05	
FERT	84	6.71 ± 0.08		36.2		1.71 ± 0.03	
FERT	125	6.78 ± 0.18		34.8		1.92 ± 0.06	
FERT	167	6.35 ± 0.20		33.6		2.11 ± 0.04	
FERT	209	6.38 ± 0.29		35.2		2.16 ± 0.06	
P value		All	No Fert	All	No Fert	All	No Fert
Compost		<.001	<.001	<.001	<.001	<.001	<.001
N rate		<.001	<.001	<.001	<.001	<.001	<.001
Compost x N rate		0.086	0.020	0.055	0.083	0.210	0.286

Yield: Compost treatments

Grain yield was significantly affected by both compost type and rate. In comparison to the control, the incorporation of composts A, F and J increased grain yield and composts B and G reduced it. Grain yield increased on average by 10% where the amount of compost incorporated doubled the nitrogen content from 250 kg N ha^{-1} to 500 kg N ha^{-1}. Applying an additional 125 kg N ha^{-1} ammonium nitrate to the compost treatments was sufficient to overcome any soil mineral nitrogen immobilisation caused by compost incorporation except in compost G. In a field study using MSW compost, maize showed reduced growth and vigour where compost only was applied, however, the addition of mineral fertiliser allowed the plants to recover (Eriksen et al 1999).

In comparison to the control, compost A increased grain yield by 2% and 19% at the 250 and 500 kg N ha^{-1} rates respectively. Compost A had no effect on the 1000 grain weight although the grain nitrogen content was less than the control at both rates of compost application.

In comparison to the control, compost B reduced grain yield by 14% and 7% at the 250 and 500 kg N ha^{-1} rates respectively. In contrast, both 1000 grain weight and grain nitrogen content were greater than the control at both rates of compost application.

In comparison to the control, compost F increased grain yield by 21% and 31% at the 250 and 500 kg N ha^{-1} rates respectively. The 1000 grain weight was lower than the control and the grain nitrogen greater than the control at both rates of compost application. We suggest that these large increases in yield can be attributed to the high levels of nitrate in the compost. Nitrates are easily absorbed by the crop, and so composts with high nitrate levels could promote early growth and development, even before the top dressing is applied.

In comparison to the control, compost G reduced grain yield by 33% and 28% at the 250 and 500 kg N ha^{-1} rates respectively. In contrast, both 1000 grain weight and grain nitrogen content were greater than the control. Although compost G restricted seedling germination and establishment, the plants that did survive were not adversely affected at the later growth stages. Compost from MSW reduced yield in lettuce and garden cress, with composts produced from source segregated BMW having no detrimental effects on germination or growth (Gajdos 1997). This reduction in yield in the mixed MSW compost could be due to the high levels of salts and PTEs (see section 3.2) or high C:N ratio.

In comparison to the control, compost J increased grain yield by 5% and 14% at the 250 and 500 kg N ha^{-1} rates respectively. The 1000 grain weight was lower than the control and the grain nitrogen greater than the control at both rates of compost application.

Table 4.15. Barley grain analysis P, K and C (mean ± standard error)

Treatment		P	K	C
Compost	N rate (kg N ha^{-1})	mg kg^{-1} dry weight	mg kg^{-1} dry weight	% dry weight
A	250	0.37 ± 0.01	0.54 ± 0.01	42.6 ± 0.3
A	500	0.37 ± 0.02	0.56 ± 0.02	42.3 ± 0.3
A	250+125N	0.43 ± 0.02	0.65 ± 0.02	42.7 ± 0.4
B	250	0.41 ± 0.04	0.60 ± 0.04	42.6 ± 0.2
B	500	0.39 ± 0.02	0.58 ± 0.02	42.1 ± 0.6
B	250+125N	0.46 ± 0.01	0.66 ± 0.03	42.7 ± 0.3
F	250	0.37 ± 0.01	0.56 ± 0.01	42.2 ± 0.2
F	500	0.40 ± 0.01	0.58 ± 0.01	42.8 ± 0.3
F	250+125N	0.45 ± 0.01	0.65 ± 0.01	42.9 ± 0.5
G	250	0.45 ± 0.03	0.63 ± 0.02	42.6 ± 0.2
G	500	0.44 ± 0.04	0.64 ± 0.05	42.5 ± 0.2
G	250+125N	0.50 ± 0.04	0.70 ± 0.04	42.4 ± 0.2
J	250	0.38 ± 0.01	0.55 ± 0.02	42.6 ± 0.2
J	500	0.31 ± 0.07	0.53 ± 0.04	41.1 ± 1.3
J	250+125N	0.37 ± 0.08	0.63 ± 0.03	42.5 ± 0.8
Control	0	0.37 ± 0.02	0.55 ± 0.03	42.6 ± 0.2
FERT	42	0.41 ± 0.01	0.60 ± 0.01	42.5 ± 0.4
FERT	84	0.43 ± 0.01	0.63 ± 0.01	42.9 ± 0.3
FERT	125	0.47 ± 0.02	0.66 ± 0.03	43.1 ± 0.1
FERT	167	0.45 ± 0.05	0.68 ± 0.02	43.1 ± 0.5
FERT	209	0.48 ± 0.01	0.68 ± 0.01	43.1 ± 0.4

P value	P All	P No Fert	K All	K No Fert	C All	C No Fert
Compost	<.001	<.001	<.001	<.001	0.081	0.573
N rate	0.002	0.005	<.001	<.001	0.582	0.312
Compost x N rate	0.065	0.663	0.696	0.733	0.252	0.348

Composts A, B, F and J applied at 250 + 125 kg N ha^{-1} produced a higher barley yield than the control. Moreover, with the exception of compost F, yield was greater in the compost + inorganic fertiliser treatment than compost alone; this was also observed for MSW compost in potato and maize (Mkhabeka & Warman 2005). A Swedish study found that applying compost (50 kg N ha^{-1}) in combination with fertiliser (50 kg N ha^{-1}) resulted in a higher grain yield of oats and barley than using compost alone (100 kg N ha^{-1}) (Svensson et al. 2004), as was seen in compost B. They recommended that compost should not be used as the sole fertiliser in intensive grain cropping, rather it should be regarded as a soil conditioner which must be complemented with mineral N.

Grain analysis

The barley grain was analysed for P, K and C (Table 4.15), Ca, Mg and Cu (Table 4.16) and Fe, Mn, Na and Zn (Table 4.17).

The application of all the composts resulted in significant, but numerically slight, increases in the phosphorus, potassium, calcium, magnesium, copper and sodium concentrations in the barley grain. In all cases compost G resulted in the highest levels. However, these results are not significant in the terms of this trial since all the fertiliser treatments also increased concentrations of the same elements. Concentrations of manganese and carbon contents were unaffected by any of the compost treatments.

Table 4.16. Barley grain analysis Ca, Mg and Cu (mean ± standard error)

Treatment		Ca	Mg	Cu
Compost	N rate (kg N ha^{-1})	mg kg^{-1} dry weight	mg kg^{-1} dry weight	mg kg^{-1} dry weight
A	250	0.07 ± 0.00	0.14 ± 0.00	4.37 ± 0.47
A	500	0.08 ± 0.00	0.16 ± 0.01	4.49 ± 0.11
A	250+125N	0.09 ± 0.00	0.19 ± 0.01	5.76 ± 0.41
B	250	0.08 ± 0.00	0.16 ± 0.01	5.39 ± 0.28
B	500	0.08 ± 0.00	0.16 ± 0.01	5.02 ± 0.22
B	250+125N	0.09 ± 0.00	0.18 ± 0.01	5.78 ± 0.42
F	250	0.07 ± 0.00	0.16 ± 0.00	4.59 ± 0.08
F	500	0.08 ± 0.01	0.16 ± 0.01	4.81 ± 0.21
F	250+125N	0.08 ± 0.00	0.18 ± 0.00	5.78 ± 0.25
G	250	0.08 ± 0.00	0.17 ± 0.01	5.38 ± 0.49
G	500	0.08 ± 0.01	0.16 ± 0.01	5.25 ± 0.76
G	250+125N	0.10 ± 0.01	0.19 ± 0.00	6.91 ± 0.52
J	250	0.07 ± 0.01	0.15 ± 0.01	4.39 ± 0.52
J	500	0.07 ± 0.01	0.15 ± 0.00	4.58 ± 0.18
J	250+125N	0.09 ± 0.01	0.18 ± 0.01	5.99 ± 0.39
Control	0	0.07 ± 0.01	0.14 ± 0.01	4.31 ± 0.48
FERT	42	0.07 ± 0.00	0.16 ± 0.00	5.38 ± 0.80
FERT	84	0.08 ± 0.00	0.18 ± 0.00	5.47 ± 0.28
FERT	125	0.09 ± 0.01	0.19 ± 0.01	5.56 ± 0.16
FERT	167	0.09 ± 0.00	0.19 ± 0.00	6.01 ± 0.21
FERT	209	0.09 ± 0.00	0.20 ± 0.00	5.98 ± 0.40

P value	Ca All	Ca No Fert	Mg All	Mg No Fert	Cu All	Cu No Fert
Compost	0.002	<.001	<.001	<.001	<.001	<.001
N rate	<.001	<.001	<.001	<.001	<.001	<.001
Compost x N rate	0.120	0.158	0.424	0.468	0.386	0.333

Figure 4.2. The field trial on 15th April and 1st July 2005

Table 4.17. Barley grain analysis Fe, Mn and Na (mean ± standard error)

Treatment		Fe		Mn		Na	
Compost	N rate (kg N ha^{-1})	mg kg^{-1} dry weight		mg kg^{-1} dry weight		mg kg^{-1} dry weight	
A	250	47.3 ± 3.3		18.2 ± 0.5		47.5 ± 11.1	
A	500	52.3 ± 1.9		20.1 ± 0.4		50.3 ± 1.4	
A	250+125N	71.1 ± 1.6		24.5 ± 3.6		68.9 ± 10.8	
B	250	50.9 ± 5.7		18.9 ± 1.3		56.4 ± 6.7	
B	500	76.6 ± 17.8		21.7 ± 1.9		49.3 ± 2.5	
B	250+125N	72.3 ± 2.9		22.2 ± 0.9		64.2 ± 5.8	
F	250	51.3 ± 3.2		20.7 ± 0.5		44.6 ± 1.2	
F	500	53.5 ± 1.6		20.6 ± 0.7		48.1 ± 6.2	
F	250+125N	71.4 ± 2.5		23.0 ± 0.3		64.2 ± 12.1	
G	250	54.3 ± 3.6		20.7 ± 1.0		62.9 ± 6.0	
G	500	58.9 ± 4.4		19.7 ± 1.0		72.1 ± 19.0	
G	250+125N	84.0 ± 2.0		24.8 ± 0.1		94.2 ± 24.7	
J	250	49.2 ± 0.7		18.2 ± 2.1		43.5 ± 6.5	
J	500	48.4 ± 0.0		21.6 ± 2.6		44.7 ± 3.5	
J	250+125N	67.7 ± 3.6		20.5 ± 1.9		60.8 ± 10.5	
Control	0	47.7 ± 3.6		17.7 ± 1.4		44.4 ± 5.8	
FERT	42	61.7 ± 6.1		19.9 ± 0.5		46.6 ± 3.9	
FERT	84	65.6 ± 2.0		21.9 ± 1.0		54.3 ± 0.9	
FERT	125	67.4 ± 3.1		21.4 ± 0.7		56.6 ± 2.6	
FERT	167	76.2 ± 4.7		26.9 ± 4.1		73.5 ± 23.9	
FERT	209	79.5 ± 8.7		22.8 ± 0.3		70.1 ± 15.5	
P value		All	No Fert	All	No Fert	All	No Fert
Compost		0.263	0.431	0.393	0.540	<.001	<.001
N rate		0.927	0.529	0.732	0.317	<.001	<.001
Compost x N rate		0.214	0.382	0.199	0.366	0.879	0.858

Table 4.18. Barley straw analysis (mean ± standard error)

Treatment		C	N	P	K
Compost	N rate (kg N ha^{-1})	% dry weight	% dry weight	mg kg^{-1} dry weight	mg kg^{-1} dry weight
A	250	43.0 ± 0.8	0.30 ± 0.04	0.07 ± 0.01	1.13 ± 0.10
A	500	43.9 ± 0.7	0.30 ± 0.01	0.07 ± 0.00	1.11 ± 0.10
A	250+125N	42.4 ± 0.8	0.60 ± 0.05	0.09 ± 0.01	1.58 ± 0.09
B	250	42.0 ± 0.5	0.34 ± 0.04	0.08 ± 0.01	1.35 ± 0.09
B	500	43.2 ± 0.1	0.32 ± 0.03	0.08 ± 0.00	1.48 ± 0.13
B	250+125N	42.3 ± 0.4	0.55 ± 0.07	0.09 ± 0.01	1.74 ± 0.10
F	250	44.3 ± 0.3	0.32 ± 0.04	0.06 ± 0.01	1.14 ± 0.10
F	500	43.3 ± 1.1	0.38 ± 0.05	0.05 ± 0.01	1.05 ± 0.09
F	250+125N	44.2 ± 0.8	0.65 ± 0.04	0.07 ± 0.00	1.54 ± 0.05
G	250	41.8 ± 1.4	0.46 ± 0.06	0.13 ± 0.02	1.79 ± 0.15
G	500	42.2 ± 1.3	0.51 ± 0.08	0.14 ± 0.01	1.85 ± 0.10
G	250+125N	43.2 ± 0.2	0.60 ± 0.08	0.10 ± 0.02	2.19 ± 0.08
J	250	41.9 ± 0.1	0.35 ± 0.06	0.07 ± 0.01	1.13 ± 0.21
J	500	44.1 ± 0.4	0.31 ± 0.00	0.07 ± 0.01	1.10 ± 0.05
J	250+125N	42.6 ± 0.9	0.61 ± 0.15	0.09 ± 0.02	1.78 ± 0.30
Control	0	42.6 ± 0.8	0.33 ± 0.04	0.07 ± 0.01	1.29 ± 0.01
FERT	42	43.5 ± 0.4	0.45 ± 0.06	0.08 ± 0.01	1.40 ± 0.16
FERT	84	43.3 ± 0.3	0.45 ± 0.04	0.07 ± 0.00	1.60 ± 0.08
FERT	125	43.1 ± 0.7	0.61 ± 0.06	0.09 ± 0.02	1.76 ± 0.05
FERT	167	41.9 ± 0.7	0.72 ± 0.16	0.10 ± 0.02	1.86 ± 0.11
FERT	209	42.8 ± 0.7	0.71 ± 0.08	0.09 ± 0.02	1.93 ± 0.09

P value	C All	C No Fert	N All	N No Fert	P All	P No Fert	K All	K No Fert
Compost	0.008	0.007	<.001	0.007	<.001	<.001	<.001	<.001
N rate	0.178	0.147	<.001	<.001	0.159	0.159	<.001	<.001
Compost x N rate	0.024	0.232	0.241	0.239	0.012	0.012	0.468	0.529

Straw carbon content was between 41.8% and 44.3% and was not significantly affected by the application of composts. Nitrogen content was between 0.30% and 0.51% and was significantly affected by the application of composts. However there was no clear relationship between application rate and nitrogen content except where compost G was applied, where the nitrogen content was 37% and 53% greater than the control with the 250 and 500 rates, respectively.

Straw phosphorus concentrations were between 0.05 and 0.14 mg kg^{-1} dry weight and were significantly affected by compost application. There was little variation between composts A, B, F and J, however, compost G resulted in high values that were nearly double the control. The application rate was not a significant factor in phosphorus concentration.

Straw potassium concentrations were between 1.05 and 2.19 mg kg^{-1} dry weight. The application of compost G resulted in significantly higher values. The application rate was also a significant factor in potassium concentration however no obvious relationship could be found between rate and concentration.

Table 4.19. Barley straw analysis (mg kg^{-1} dry matter; mean ± standard error)

Treatment		Ca	Mg	Cu
Compost	N rate (kg N ha^{-1})	mg kg^{-1} dry weight	mg kg^{-1} dry weight	mg kg^{-1} dry weight
A	250	0.39 ± 0.01	0.09 ± 0.00	2.04 ± 0.16
A	500	0.36 ± 0.03	0.09 ± 0.00	2.00 ± 0.28
A	250+125N	0.42 ± 0.00	0.08 ± 0.00	3.32 ± 0.75
B	250	0.44 ± 0.06	0.11 ± 0.01	2.33 ± 0.10
B	500	0.40 ± 0.01	0.10 ± 0.00	2.34 ± 0.39
B	250+125N	0.40 ± 0.02	0.08 ± 0.00	2.75 ± 0.20
F	250	0.36 ± 0.03	0.09 ± 0.01	2.07 ± 0.45
F	500	0.36 ± 0.03	0.08 ± 0.00	2.19 ± 0.33
F	250+125N	0.39 ± 0.01	0.08 ± 0.00	2.60 ± 0.24
G	250	0.48 ± 0.02	0.12 ± 0.00	2.65 ± 0.12
G	500	0.51 ± 0.03	0.12 ± 0.00	2.36 ± 0.26
G	250+125N	0.50 ± 0.03	0.11 ± 0.01	2.99 ± 0.26
J	250	0.38 ± 0.02	0.09 ± 0.00	2.15 ± 0.43
J	500	0.40 ± 0.01	0.09 ± 0.00	2.27 ± 0.22
J	250+125N	0.42 ± 0.04	0.08 ± 0.01	3.25 ± 0.66
Control	0	0.43 ± 0.03	0.10 ± 0.00	2.06 ± 0.22
FERT	42	0.46 ± 0.02	0.10 ± 0.01	2.43 ± 0.40
FERT	84	0.39 ± 0.03	0.08 ± 0.00	3.17 ± 0.78
FERT	125	0.43 ± 0.02	0.08 ± 0.00	3.13 ± 1.18
FERT	167	0.43 ± 0.04	0.09 ± 0.01	3.30 ± 0.98
FERT	209	0.42 ± 0.03	0.09 ± 0.00	2.75 ± 0.30

P value	All	No Fert	All	No Fert	All	No Fert
Compost	<.001	<.001	<.001	<.001	0.460	0.376
N rate	0.561	0.538	<.001	<.001	0.021	<.001
Compost x N rate	0.526	0.561	0.018	0.032	0.834	0.485

Calcium concentrations in straw ranged from 0.36 to 0.51 mg kg^{-1} dry weight. Statistically, the application of composts was significant but the application rate was not. Compost G gave the highest readings but no clear pattern was obvious within the other composts. The higher application rate actually resulted in lower concentrations.

Straw magnesium concentrations were between 0.8 and 0.12 mg kg^{-1} dry weight. Both compost type and application rate were statistically significantly different although the spread of the data is small with only compost G appearing higher that the rest.

Straw copper concentrations were between 2.0 and 2.99 mg kg^{-1} dry weight. The application of composts was significant. Compost A concentrations were less than the control while composts B, G, G and J were greater than the control. Concentrations within the compost treatments were comparable for both application rates.

Iron concentrations in straw ranged from 23.1 to 44.0 mg kg^{-1} dry weight. The spread of the data is narrow although the application of composts was significant. Composts A, B and F were comparable to the control but composts G and J gave higher values especially at the higher application rate. The higher application rate gave higher results.

Manganese concentrations in straw ranged from 8.53 to 13.55 mg kg^{-1} dry weight. The application of composts was significant. While composts A, B, F and J were comparable to the control, compost G again gave the highest values. There was no effect from different application rates.

Straw sodium concentrations were between 423 and 989 mg kg^{-1} dry weight. Both compost application and rate significantly affected sodium concentrations. All composts increased sodium in comparison to the control and the higher application rate resulted in higher concentrations. Compost G had the highest result at both application rates.

Zinc concentrations in straw ranged from 3.67 to 12.59 mg kg^{-1} dry weight. Compost application was significant in comparison to the control with all the composts treatments having higher results than the control. The application rate was not significant although the higher rate gave higher concentrations.

This sector of the report has highlighted many examples where the application of compost G has resulted in significantly higher levels of elements in both the grain and straw. We suggest that this is not a response to the compost but that it is luxury uptake due to the reduced biomass accumulation within this treatment. The toxic elements contained within compost G initially reduced seed germination and plant establishment however once the plants were growing they had greater resources to exploit in comparison to other treatments.

Table 4.20. Barley straw analysis (mean ± standard error)

Treatment		Fe		Mn		Na		Zn	
Compost	N rate (kg N ha^{-1})	mg kg^{-1} dry weight		mg kg^{-1} dry weight		mg kg^{-1} dry weight		mg kg^{-1} dry weight	
A	250	30.7 ± 5.8		9.07 ± 0.50		489 ± 220		3.67 ± 0.44	
A	500	29.7 ± 8.6		8.53 ± 1.69		438 ± 77		4.56 ± 1.09	
A	250+125N	39.5 ± 9.9		9.91 ± 1.30		707 ± 171		4.77 ± 0.53	
B	250	40.8 ± 6.3		11.02 ± 2.66		509 ± 120		9.28 ± 4.54	
B	500	29.3 ± 0.8		9.81 ± 1.52		544 ± 135		5.25 ± 1.37	
B	250+125N	29.3 ± 1.3		10.75 ± 2.05		690 ± 110		9.74 ± 6.34	
F	250	23.1 ± 1.5		9.85 ± 2.37		393 ± 57		4.55 ± 1.53	
F	500	29.8 ± 2.6		9.13 ± 1.01		394 ± 35		5.95 ± 0.11	
F	250+125N	31.8 ± 1.4		9.99 ± 1.38		701 ± 314		5.49 ± 0.91	
G	250	41.3 ± 6.9		13.55 ± 0.49		874 ± 89		11.73 ± 0.89	
G	500	44.0 ± 9.7		12.37 ± 1.05		989 ± 94		11.76 ± 2.49	
G	250+125N	69.4 ± 27.1		14.38 ± 1.63		1506 ± 291		9.18 ± 2.38	
J	250	27.0 ± 2.9		8.68 ± 1.82		364 ± 105		5.74 ± 0.64	
J	500	56.2 ± 24.9		10.29 ± 2.21		423 ± 58		12.59 ± 9.54	
J	250+125N	35.7 ± 3.7		10.56 ± 1.61		694 ± 194		4.85 ± 0.88	
Control	0	33.9 ± 3.2		10.04 ± 1.46		413 ± 97		4.37 ± 0.18	
FERT	42	52.9 ± 24.5		11.73 ± 1.68		571 ± 241		3.97 ± 0.64	
FERT	84	25.7 ± 2.8		9.39 ± 1.24		646 ± 95		3.45 ± 0.49	
FERT	125	33.3 ± 4.7		11.96 ± 1.45		623 ± 198		7.94 ± 4.39	
FERT	167	34.8 ± 7.6		11.68 ± 0.87		939 ± 535		5.29 ± 1.67	
FERT	209	33.1 ± 6.3		11.04 ± 1.38		925 ± 461		7.22 ± 0.78	
P value		All	No Fert	All	No Fert	All	No Fert	All	No Fert
Compost		0.036	0.038	<0.001	<.001	<.001	<.001	0.018	0.048
N rate		0.444	0.474	0.414	0.296	0.004	<.001	0.875	0.895
Compost x N rate		0.113	0.116	0.862	0.791	0.814	0.354	0.349	0.451

Nitrogen uptake in compost treatments

With the exception of compost F, the application of composts at the 250 kg N ha^{-1} rate reduced nitrogen uptake in the grain in comparison to the control. This suggests that existing soil mineral nitrogen was immobilised by the application of the composts and that the increase where compost F was applied was the result of higher levels of nitrate. Where composts were applied at the 500 kg N ha^{-1} rate, composts A, F and J increased nitrogen uptake in grain in comparison to the control whereas composts B and G reduced it. It is likely that the higher nitrogen content at the 500 kg N ha^{-1} rate was sufficient to overcome the immobilising effect of the compost itself. The overall nitrogen uptake at the 500 kg N ha^{-1} rate was 13% higher than at 250 kg N ha^{-1}.

The immobilising effect of the composts was highlighted again where an additional 125 kg N ha^{-1} was applied to the composts. With the exception of compost A, even with this additional mineral fertiliser the nitrogen uptake in grain for the compost treatments was reduced in comparison to the control (FERT 125 kg N ha^{-1}). However this result is not unexpected since many workers have found that composts release little or no nitrogen in their first year. The differences in nitrogen uptake in grain and straw due to both compost type and rate were significant and the pattern was the same for nitrogen uptake in straw.

Table 4.21. Barley grain, straw and total nitrogen uptake (mean ± standard error)

<table>
<tr><th colspan="2">Treatment</th><th colspan="2">Grain N uptake</th><th colspan="2">Straw N uptake</th><th colspan="2">Total N uptake</th><th>% N recovery</th></tr>
<tr><th>Compost</th><th>N rate (kg N ha^{-1})</th><th colspan="2">(kg N ha^{-1})</th><th colspan="2">(kg N ha^{-1})</th><th colspan="2">(kg N ha^{-1})</th><th></th></tr>
<tr><td>A</td><td>250</td><td colspan="2">55 ± 4</td><td colspan="2">11 ± 1</td><td colspan="2">66 ± 4</td><td>0</td></tr>
<tr><td>A</td><td>500</td><td colspan="2">70 ± 2</td><td colspan="2">13 ± 1</td><td colspan="2">83 ± 3</td><td>+3</td></tr>
<tr><td>A</td><td>250+125N</td><td colspan="2">115 ± 7</td><td colspan="2">27 ± 4</td><td colspan="2">142 ± 11</td><td>+20</td></tr>
<tr><td>B</td><td>250</td><td colspan="2">52 ± 8</td><td colspan="2">10 ± 3</td><td colspan="2">62 ± 11</td><td>-2</td></tr>
<tr><td>B</td><td>500</td><td colspan="2">53 ± 3</td><td colspan="2">11 ± 2</td><td colspan="2">64 ± 5</td><td>-1</td></tr>
<tr><td>B</td><td>250+125N</td><td colspan="2">105 ± 4</td><td colspan="2">23 ± 2</td><td colspan="2">128 ± 4</td><td>+16</td></tr>
<tr><td>F</td><td>250</td><td colspan="2">72 ± 0</td><td colspan="2">14 ± 1</td><td colspan="2">86 ± 1</td><td>+8</td></tr>
<tr><td>F</td><td>500</td><td colspan="2">83 ± 3</td><td colspan="2">18 ± 2</td><td colspan="2">101 ± 2</td><td>+7</td></tr>
<tr><td>F</td><td>250+125N</td><td colspan="2">108 ± 1</td><td colspan="2">29 ± 2</td><td colspan="2">137 ± 3</td><td>+18</td></tr>
<tr><td>G</td><td>250</td><td colspan="2">45 ± 6</td><td colspan="2">11 ± 1</td><td colspan="2">56 ± 6</td><td>-5</td></tr>
<tr><td>G</td><td>500</td><td colspan="2">47 ± 4</td><td colspan="2">14 ± 5</td><td colspan="2">61 ± 9</td><td>-1</td></tr>
<tr><td>G</td><td>250+125N</td><td colspan="2">83 ± 5</td><td colspan="2">19 ± 1</td><td colspan="2">102 ± 5</td><td>+9</td></tr>
<tr><td>J</td><td>250</td><td colspan="2">55 ± 8</td><td colspan="2">13 ± 1</td><td colspan="2">68 ± 7</td><td>0</td></tr>
<tr><td>J</td><td>500</td><td colspan="2">62 ± 6</td><td colspan="2">12 ± 1</td><td colspan="2">74 ± 7</td><td>+2</td></tr>
<tr><td>J</td><td>250+125N</td><td colspan="2">107 ± 6</td><td colspan="2">27 ± 6</td><td colspan="2">134 ± 8</td><td>+18</td></tr>
<tr><td>Control</td><td>0</td><td colspan="2">56 ± 8</td><td colspan="2">12 ± 1</td><td colspan="2">68 ± 8</td><td></td></tr>
<tr><td>FERT</td><td>42</td><td colspan="2">79 ± 3</td><td colspan="2">19 ± 2</td><td colspan="2">98 ± 2</td><td>+75</td></tr>
<tr><td>FERT</td><td>84</td><td colspan="2">97 ± 2</td><td colspan="2">20 ± 2</td><td colspan="2">117 ± 4</td><td>+60</td></tr>
<tr><td>FERT</td><td>125</td><td colspan="2">110 ± 5</td><td colspan="2">27 ± 2</td><td colspan="2">137 ± 5</td><td>+56</td></tr>
<tr><td>FERT</td><td>167</td><td colspan="2">114 ± 2</td><td colspan="2">30 ± 6</td><td colspan="2">144 ± 5</td><td>+46</td></tr>
<tr><td>FERT</td><td>209</td><td colspan="2">117 ± 8</td><td colspan="2">30 ± 2</td><td colspan="2">147 ± 6</td><td>+38</td></tr>
<tr><td colspan="2">P value</td><td>All</td><td>No Fert</td><td>All</td><td>No Fert</td><td>All</td><td>No Fert</td><td></td></tr>
<tr><td colspan="2">Compost</td><td><.001</td><td><.001</td><td><.001</td><td>0.004</td><td><0.001</td><td><.001</td><td></td></tr>
<tr><td colspan="2">N rate</td><td><.001</td><td><.001</td><td><.001</td><td><.001</td><td><.001</td><td><.001</td><td></td></tr>
<tr><td colspan="2">Compost x N rate</td><td>0.09</td><td>0.016</td><td>0.292</td><td>0.277</td><td>0.024</td><td>0.049</td><td></td></tr>
</table>

Total nitrogen uptake increased with the increasing rate of mineral nitrogen in the FERT treatments. The application of composts had mixed effects on total nitrogen uptake. At the 250 kg N ha^{-1} rate composts B and G reduced total nitrogen uptake in comparison to the control, while composts A and J gave comparable and compost F higher uptakes. At the 500 kg N ha^{-1} rate composts B and G reduced total nitrogen uptake in comparison to the control and A, F and J increased it. The application of compost F at the 500 kg N ha^{-1} rate gave comparable total nitrogen uptake to the 42 kg N ha^{-1} FERT rate.

Nitrogen uptake in the compost + FERT treatments was considerably higher than compost alone. However, only the application of compost A resulted in a higher total nitrogen uptake in comparison to the control (FERT 125 kg N ha^{-1}) demonstrating again that the application of composts is likely to lead to immobilisation of soil mineral nitrogen in the first year of application. Compost G significantly reduced nitrogen uptake suggesting that it reduced establishment rather than nitrogen uptake; this view is supported by the grain nitrogen content which was higher than the control.

Although the composts contained either 250 or 500 kg ha^{-1} nitrogen, the proportion of the nitrogen that was recovered by the growing crop was minimal, only composts F and J showed positive recovery rates. However, in subsequent years as the compost breaks down in the soil, more nitrogen will be released. Under normal field conditions, not more than 10 to 15% of the total nitrogen in the compost is available in the year of application. Nitrogen recovery rates using ammonium-nitrate ranged from 75% at 42 kg ha^{-1} to 38% at the highest rate of 209 kg ha^{-1}.

Table 4.22. Total nutrients and PTEs applied in the 250 kg N ha^{-1} compost treatment (kg ha^{-1})

Compost	**NO_3–N**	**NH_4–N**	**P**	**K**	**Ca**	**Mg**	**S**	**Na**	**Total nutrients**	**Total PTEs**
A	1.48	3.97	1.74	67.49	5.14	0.94	7.56	14.63	129.33	5.11
B	0.18	1.30	2.00	80.59	5.92	1.07	2.83	9.91	125.22	10.36
F	22.01	0.32	0.86	104.78	8.25	1.97	12.18	10.45	193.33	5.04
G	0.05	17.46	0.73	41.74	48.17	6.27	64.33	68.73	298.04	33.98
J	3.64	0.36	1.48	66.75	3.75	0.93	2.27	11.50	137.97	6.07

In addition to available nitrogen, compost application weights and nutrients varied (see Table 4.21). For example, in the 250 kg N treatment 44 t ha^{-1} of composts B and G was applied, compared to 32 t ha^{-1} (compost F), and 28 t ha^{-1} (composts A and J).

Pre planting soil mineral N levels were approximately 50 kg ha^{-1} in the 0-60 cm level. Two months later just before top dressing, levels had risen to 150 kg ha^{-1}. This amount would normally be sufficient for a barley crop, and is indicated by the fairly flat fertiliser nitrogen response curve. This large quantity of available N may have masked any fertilising benefits of the composts.

4.3 Potentially toxic elements in soil and plant

Table 4.23. Concentrations (mg kg^{-1} dry weight) in 0-30 cm soil layer on 9th March 2005 (pre compost incorporation and pre drilling).

Block	**Pb**	**Ni**	**Zn**	**Cd**	**Hg**	**Cr**	***Cu***
1	nd	15.5	49.6	0.31	0.01	18.7	14.1
2	17.9	16.1	43.0	0.13	0.02	19.7	13.2
3	14.0	13.3	37.5	0.38	0.01	18.1	12.0
Mean	16.0	15.0	43.4	0.27	0.02	18.8	13.1
GAP[*]	≤300	≤110	≤300	≤3.0	≤1	≤400	≤200
PAS 100[**]	≤200	≤50	≤400	≤1.5	≤1	≤100	≤200
Compost[***]	55-294	12-228	138-455	0.6-1.2	0.01-0.02	15-59	45-240

[*] Maximum permissible levels in soil from the Code of Good Agricultural Practice (MAFF, 1993)

[**] Recommended levels in compost from BSI PAS 100.

[***] Range of concentrations in composts used in the field trial.

Table 4.24. Concentrations (mg kg^{-1} dry weight) in 0-30 cm soil layer on 5th May 2005. (52 days after compost incorporation).

Compost	**Treatment (kg N ha^{-1})**	**Pb**	**Ni**	**Zn**	**Cd**	**Hg**	**Cr**	**Cu**
A	250	14.7	13.0	42.1	0.32	0.03	16.7	20.1
A	500	15.6	13.8	41.4	0.37	0.03	16.8	15.9
A	250+125N	13.5	12.0	37.2	0.32	0.02	15.0	12.5
B	250	22.7	11.8	43.1	0.42	0.03	15.3	18.3
B	500	16.4	13.2	42.8	0.41	0.03	16.8	16.3
B	250+125N	16.4	13.0	40.3	0.31	0.05	16.3	15.0
F	250	16.5	14.7	42.1	0.37	0.03	17.2	17.0
F	500	14.3	13.3	39.6	0.26	0.02	17.5	12.3
F	250+125N	15.4	15.3	44.0	0.38	0.04	17.7	19.3
G	250	15.6	13.7	40.8	0.14	0.03	17.5	12.7
G	500	16.9	12.0	45.1	0.43	0.03	16.3	17.4
G	250+125N	15.9	13.6	41.0	0.29	0.04	16.6	15.4
J	250	15.2	12.0	37.3	0.27	0.03	15.6	11.9
J	500	17.6	12.9	41.0	0.39	0.02	15.7	18.0
J	250+125N	17.3	13.3	42.7	0.39	0.03	16.4	20.5
Control	0	14.3	13.2	40.2	0.34	0.03	17.4	12.8
	GAP*	≤300	≤110	≤300	≤3.0	≤1	≤400	≤200
	P value	0.252	0.800	0.273	0.23		0.422	0.370

[*] Permissible levels in soil from the Code of Good Agricultural Practice (MAFF 1998)

Table 4.25. Concentrations (mg kg^{-1} dry weight) in 0-30 cm soil layer on 8th August 2005. (147 days after compost incorporation and post harvest).

Compost	**Treatment (kg N ha^{-1})**	**Pb**	**Ni**	**Zn**	**Cd**	**Hg**	**Cr**	**Cu**
A	250	14.0	13.4	41.2	0.24	0.03	17.6	12.3
A	500	15.7	14.4	43.7	0.35	0.04	18.8	13.1
A	250+125N	13.7	13.2	40.4	0.35	0.03	16.9	11.9
B	250	15.9	14.1	42.9	0.34	0.02	18.4	13.0
B	500	15.3	13.9	42.3	0.24	0.04	18.2	12.7
B	250+125N	15.6	13.5	42.6	0.35	0.03	17.8	12.6
F	250	13.8	13.4	40.3	0.33	0.03	17.2	11.8
F	500	14.2	13.8	42.3	0.31	0.03	17.8	12.9
F	250+125N	15.9	14.3	44.9	0.39	0.03	18.8	13.3
G	250	18.0	14.4	42.7	0.20	0.04	17.7	13.1
G	500	17.3	14.7	44.9	0.22	0.03	18.4	13.5
G	250+125N	16.8	15.6	48.2	0.36	0.04	19.1	13.9
J	250	17.6	14.4	44.0	0.29	0.03	18.7	18.4
J	500	15.6	13.9	42.8	0.35	0.03	18.1	12.6
J	250+125N	14.6	13.6	42.9	0.28	0.03	18.0	12.7
Control	0	14.6	14.0	42.2	0.35	0.04	18.4	12.5
	GAP*	≤300	≤110	≤300	≤3.0	≤1	≤400	≤200
	P value	0.070	0.224	0.130	0.881		0.736	0.388

*Permissible levels in soil from the Code of Good Agricultural Practice (MAFF, 1998)

At both pre-compost incorporation and 52 days post compost incorporation, concentrations of PTEs in the field soils were consistently lower than the maximum permissible levels stated in the Code of Good Agricultural Practice (MAFF 1998). There were no significant differences between the levels of PTE in the different compost treatments 57 days after incorporation and there was no significant difference between the two sampling dates. This suggests that no leaching of PTEs from the incorporated composts occurred.

A comparison of the results from the 9th March (day 0) and 8th August (day 157) showed very little difference. Levels of PTEs in the soil remained lower than the permissible levels in soil from the Code of Good Agricultural Practice on both dates. This is further evidence that no leaching of PTEs from the composts had occurred. Pinamonti & Zorzi (1996) did observe an increase in soil PTE content when used as a mulch in orchards and vineyards although their field trials extended for more than five years. We would expect some leaching of PTEs from our composts to occur during the winter months.

A comparison of the treatments post harvest results showed that levels of lead and nickel were higher, but not significantly so where compost G had been incorporated.

In UK agriculture, maximum permissible PTE loading is based on concentrations in the soil. However, when composts are incorporated into the soil it is not always easy to calculate what the final soil concentration will be. Limiting PTE inputs from composted BMW in the UK would be easier to regulate by establishing maximum application rates per dry weight compost, rather than on the concentration of metals in the soil. Even after 10 years of compost application at the current rate, PTE levels in the soil would still be well below the GAP limits.

Table 4.26. PTE content in barley grain (mg kg^{-1} dry weight)

Compost	**Treatment (kg N ha^{-1})**	**Pb**	**Ni**	**Zn**	**Cd**	**Hg**	**Cr**	**Cu**
A	250	0.09	0.30	21.8	0.02	< 0.004	< 0.06	4.99
A	500	0.04	0.17	22.5	0.02	< 0.004	0.22	4.93
A	250+125N	0.06	0.20	23.3	0.02	< 0.004	0.08	5.42
B	250	0.05	0.20	24.3	0.02	< 0.004	< 0.06	5.77
B	500	0.05	0.23	24.0	0.02	< 0.004	< 0.06	4.99
B	250+125N	0.05	0.23	22.4	0.02	< 0.004	< 0.06	5.18
F	250	0.06	0.09	20.6	0.02	< 0.004	0.25	4.85
F	500	0.10	0.30	20.8	0.02	< 0.004	0.07	4.61
F	250+125N	0.08	0.13	22.7	0.03	< 0.004	0.13	5.13
G	250	0.07	0.70	31.8	0.03	< 0.004	< 0.06	5.34
G	500	0.06	0.19	32.1	0.03	< 0.004	< 0.06	5.29
G	250+125N	0.14	0.30	31.6	0.03	< 0.004	< 0.06	5.56
J	250	0.06	0.26	20.8	0.02	< 0.004	0.11	5.09
J	500	0.08	0.30	21.9	0.02	< 0.004	0.10	4.86
J	250+125N	0.09	0.20	24.6	0.03	< 0.004	0.10	5.29
Control	0	0.06	0.26	22.0	0.02	< 0.004	< 0.06	4.52
	P value	0.006	0.093	<0.001	0.881		0.325	0.149

The lead concentration in the barley grain ranged from 0.04 to 0.14 mg kg^{-1}, which is lower than the 0.2 mg kg^{-1} European Commission regulation (EC 466/2001) limit for lead in cereal. The cadmium concentration in the barley grain was consistently low, ranging from 0.02 to 0.03 mg kg^{-1}, as compared to the European Commission regulation EC 466/2001 (CEC 2001) limit for cadmium in cereal grain which is 0.1 mg kg^{-1}.

Copper and zinc levels in the barley grain were highest in the three mixed MSW compost G treatments, with 15% more copper and 30% more zinc in compost G grain than in FERT 0 grain. The application of MSW composts in agriculture has been found to increase the PTE content of a number of plant parts in a number of species. For example, MSW compost increased copper and zinc content in corn above ground tissues (Paino et al 1996). Moreover, vines grown in soil amended with mixed MSW compost for six years accumulated cadmium, chromium, lead and nickel in tissues and musts (Pinamonti et al 1999). Apple leaves and fruits were found to accumulate cadmium, chromium, lead and nickel when trees were treated with mixed MSW compost (Pinamonti et al 1997). These data show that when compost containing high levels of PTEs is applied to the soil, the PTEs are taken up by the crop.

4.4 Field trial summary

Effect of compost treatment on plant establishment
Plant establishment was as good as or better than the control with composts A, F and J. In contrast, composts B and G reduced plant establishment and early growth in comparison to the control.

Effect of compost treatment on yield
Three composts, A, F and J, increased barley yield when compared to the control by 2%, 21% and 5% respectively. These composts can be recommended for use in agriculture as a soil conditioners. Two composts, B and G, reduced barley yield when compared to the control by 14% and 33% respectively. In the case of compost G, we suggest that the reduced yield can be attributed to the composts containing higher sodium and PTE levels than the other four source segregated composts.

Incorporating the composts immobilised soil mineral nitrogen. However, except for compost G, this could be overcome by applying 125 kg N ha^{-1} as ammonia nitrate.

Effect of compost treatment on grain
There was little or no effect on PTEs in the barley grain from the composts. Levels of lead and cadmium were below the European Commission limits for PTEs in cereal grains. Levels of copper and zinc were highest in grain from compost treatment G.

Effect of compost treatment on soil
The application of compost increased nitrogen, carbon, and organic matter in the soil. Application of the source segregated composts did not significantly increase soil PTEs. The mixed MSW compost increased soil lead concentration. Even if these composts were applied annually for 10 years at the rates used in this study, soil PTE levels would still be well below the recommended UK limits.

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