Creating markets for recycled resources

To support the development of standards for compost by investigating the benefits and efficacy of compost use in different applications

Literature Report: Organics

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This document forms the main body of the report and the literature review. There is also a set of supplements which contains the Information Packages and Fact Sheets.

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Executive summary

The objectives of the project are to promote the use of composts made from recycled materials in horticulture, landscaping and agriculture by increasing end user awareness of the efficacy of such products and of the potential benefits to their specific businesses. The primary composts included in this project are those made from green waste and kitchen waste feedstocks, plus wood wastes, but recognising that composts may be made from a mixture of feedstocks, including other source separated materials.

This report contains a collation of a literature review of available information and scientific research into the qualities, performance, effective usage and financial benefits of composts made from these recycled materials from a large range of sources in the UK, Europe and internationally. A summary of the findings is given in separately published Information Packages and Fact Sheets on the benefits and efficacy of compost use in different applications based on the scientific evidence. The Information Packages and Fact Sheets are available to download from the WRAP website www.wrap.org.uk.

The end uses for compost included are growing media production, plant propagation, landscaping (including turf), field and protected crop horticulture, and agriculture. An end user consultation group was formed to establish end user needs, factors affecting usage and to establish methods of measuring the qualities of compost products that are relevant to each industry end user sector. These compost characteristics for each sector are provided in this report as well as references to relevant regulations.

This project was carried out concurrently with WRAP projects STA0014, which developed guidelines and specifications for the landscaping sector and STA0013, which carried out research into the use of recycled materials in the production of growing media.

Dissemination activities undertaken included a launch of the information packages and fact sheets at Stockbridge Technology Centre, industry sector newsletters and web sites, the trade press, attendance at conferences and shows and ReMaDe events.

The literature review

The literature review was commissioned to provide scientific data and case studies to demonstrate the benefits of compost use summarised below.

The information sources accessed included existing WRAP reports and translations of guidelines prepared in other European countries, Defra and Environment Agency websites, the ReMaDe programmes, various landfill tax credits scheme project reports, EU project reports and those from other international sources and journals.

The materials under consideration for composting are described before chemical, physical and microbiological properties are detailed and summarised. Composts are able to provide plant nutrients as well as influence soil or growing media properties such as cation exchange capacity. Compost maturity is discussed in relation to nutrient release. A summary of a large number of compost analyses are presented including both chemical and physical properties. The organic matter component of composts will have a large influence on the soil properties, especially when it is applied to soil over a number of years. The bulk density, moisture content and electrical conductivity of composts are important factors that affect the way composts can be used in any given situation. Composts contain a very diverse range of micro organisms which are important in the breakdown of the organic matter in soils, soil structure formation and, potentially, disease suppression.

The benefits of compost use are described ranging from nutrient supply to plants, to the provision of organic matter for soil fertility effects and micro organisms for soil health. Constraints are also investigated such as occasional high levels of soluble salts, potentially toxic elements, compost immaturity and the levels of physical and biological contaminants in composts. However, the introduction of the British Standards Institution's Publicly Available Specification for composted materials (PAS 100) addresses the processing and end product quality parameters leading to improved composted products.

The literature is also summarised for the benefits and constraints found with reference to particular end uses, divided into the agricultural, landscaping and horticultural sectors. In agriculture, compost use is compared to materials currently used, such as inorganic fertilisers and animal manures. Much of the literature information is based on the use of these and other materials, such as biosolids, but the evidence regarding, say, soil aggregation from the addition of organic matter from these sources, is valid when discussing the use of composted materials derived from the municipal waste stream. In landscaping, compost effects on soils are similar to those in agriculture although application rates are usually greater. End users may also require the compost to be screened more finely, for use as a turf topdressing, for instance. There is also the risk of over applying a compost when the plant species being planted is less tolerant of salt levels or high pH, but the guidelines that have been drawn up point out such factors to the end user.

The use of compost in growing media requires a greater knowledge about the properties of the composted material that is to be used. Benefits include nutrient supply and suppression of liverwort, moss and other 'nuisances'. However, the possibility of high pH and salt levels, as well as the potential risk from plant pathogens and the use of an immature product, require that composts are tested more frequently for this end use. Limits on compost characteristics are therefore tighter for use in growing media than in, for instance, general agricultural use.

Summary of the key benefits from using compost

Compost provides organic matter and a supply of nutrients, coupled with a very diverse range of micro organisms that are of benefit to soils and plants when used in agriculture, landscaping and horticulture (including growing media). The key benefits from using compost are:

- the provision of a supply of nutrients leading to a reduced need for fertilisers
- reduced nutrient leaching and improved cation exchange capacity of light soils
- increased yielding potential
- better plant establishment, survival and growth
- improved plant and produce quality
- improved soil structure leading to greater workability of soil and increased traffic tolerance
- reduced soil compaction
- improved root growth
- improved water holding capacity in light soils
- reduced soil erosion risk
- weed control and moisture conservation through mulching
- beneficial micro organisms that can aid soil aggregation, nutrient cycling and plant disease suppression
- reduced pesticide usage and, consequentially,
- financial savings to businesses.

The correct usage of high quality composts in all applications includes the rate and timing of application in accordance with soil and plant needs and with requirements in regulations. By using PAS 100 certified compost that also complies with the specifications for compost, e.g. for landscaping or growing media, then possible constraints sometimes associated with composted materials will be minimised.

The information packages and fact sheets

The information packages and fact sheets developed, which can be downloaded from the WRAP website, include:

- Compost Information Package 1: Using compost in agriculture and field horticulture
- Compost Information Package 2: Using compost in landscaping
- Fact Sheet 01: Compost use for general arable agriculture and grassland
- Fact Sheet 02: Compost use for root crops, field vegetables, salads and fruit
- Fact Sheet 03: Compost use in planting bed establishment
- Fact Sheet 04: Compost use in turf establishment and renovation

- Fact Sheet 05: Compost use in tree and shrub planting
- Fact Sheet 06: Compost use as a mulch
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1. Introduction

This project was carried out by Enviros Consulting Ltd and Stockbridge Technology Centre Ltd. This main report forms part of the whole project report and relates to the literature search, collation of information and scientific data on the benefits and efficacy of compost use in different applications. It includes descriptions of the important characteristics for compost relevant to the main markets for compost and their sub-sectors. The Information Packages and Fact Sheets summarising the main findings of this report for each end application are reproduced separately.

1.1 Objectives and methodology

The objective of this project is to promote the use of composts made from recycled materials in horticulture, landscaping and agriculture by increasing end user awareness of the efficacy of such products and of the potential benefits to their specific businesses.

The primary composts included in this project were those made from green waste and kitchen waste feedstocks, plus wood wastes, although composts may be made from a mixture of feedstocks which may include animal manure, for example. The project was not required to gather information on mixed Municipal Solid Waste (MSW) composts, biosolids composts, agricultural composts made on-farm, spent mushroom compost or composted bark.

The objectives of the literature review were to compile and collate existing information from sources worldwide about the qualities, effective usage and financial and performance benefits of composts made from these recycled materials, with an evaluation of the information gathered. The literature review forms Sections 2 to 4 of this report.

The end uses considered were the production of growing media, plant propagation, landscaping (including turf), field and protected horticulture and agriculture. An end user consultation group was formed to establish end user needs, factors affecting usage and to establish methods of measuring the qualities of compost products that were relevant and accepted by each industry end user sector. These compost characteristics for each sector are reported in Section 5.

All the information gathered was used, in consultation with end users and composters, to produce a set of promotional Information Packages and Fact Sheets, which summarise the main findings of this report. These were launched at an event at Stockbridge Technology Centre in September 2003. These are available as individual documents from www.wrap.org.uk. Other dissemination activities were also undertaken.

1.2 Information sources

Information was gathered from various sources about the qualities, effective usage and financial and performance benefits of composts made from recycled materials. A number of projects and reviews have previously been carried out and can be grouped according to funding sources: WRAP, Government, the Environment Agency, ReMaDes, Landfill Tax Credits, European Union, international, and so on. In addition, information was sought from the international literature, libraries (including the Composting Association's), the Composting Association's compost quality database, the internet and personal contacts. The information sources are briefly described below and a full listing given in the Bibliography.

1.2.1 WRAP projects

WRAP has funded a number of projects which have investigated particular topics in detail and the reader is recommended to read these in conjunction with this report. Where the timing of publication of these reports allowed, the findings have been included in this review, for example:

Project STA0014 on the development of guidelines and specifications for the landscaping sector, which was carried out by Enviros in 2003 and included collation of literature.

Project STA0013 (ongoing) on research into the use of composted recycled materials in the production of growing media, which was conducted by Peatering Out Ltd in 2003/4 and included a literature review.

Project to compare compost standards within the EU, North America and Australasia, which was conducted by Eunomia Research and Consulting Ltd and published in 2002.

Project STA0005 an assessment of options and requirements for stability and maturity testing of composts, which was conducted by ADAS Consulting Ltd and published in 2003.

Project STA0012 (ongoing) included a review of the literature on the occurrence and survival of pathogens of animals, plants and humans in green compost, a review of the literature on eradication of these pathogens and nematodes during composting, on disease suppression and on detection of plant pathogens in compost. This work was carried out by Horticulture Research International and the Institute of Animal Health and was published in 2003.

Through this project, the European Compost Network was funded to translate the German and Belgian compost use guidelines into English. Relevant information from these has been utilized.

Information translated included:

- Compost for landscaping (from Germany)
- Use of compost in landscaping (from Belgium)
- Use of compost in hobby gardening (from Germany)
- Quality compost for agriculture (from Germany, Austria and Belgium)

1.2.2 DEFRA reports

In 2002, a review of the literature entitled: 'Soil microbiology in organic systems – effects on composting manures and other organic wastes on soil processes and pest and disease interactions' was reported in 2003 (OF0313). It is published on the Department for Food and Rural Affairs' (Defra) web site at www.defra.gov.uk/farm/organic/default.htm. The report included:

Section 1 – on standards, regulations and legislation relevant to recycling, compost and manure preparation and application, and a review of common UK practices relating to the preparation and application of un-composted materials, manures, composts and compost extracts.

Section 2 - reviewed current scientific knowledge on the effects of different composting processes on chemical and biological parameters in the finished compost or compost extract.

Section 3 - reviewed the effects of un-composted materials, composts and manures on soil health and quality, soil fertility, crop development and nutrition.

Section 4 - reviewed the effects of un-composted materials, composts, manures and compost extracts on beneficial micro organisms, pest and disease incidence and severity in agricultural and horticultural crops.

1.2.3 The Environment Agency

The Environment Agency has reported on a number of projects including:

'Field trials of compost for agriculture', report CWM 158/9 (Wallace 1996),

'Markets and quality requirements for composts and digestates from the organic fraction of household wastes, report CWM 147/96 (Anon 1996), and

'An assessment of the quality of waste derived composts produced by a range of processes', report P229 (Anon 2000).

1.2.4 The Composting Association

The Composting Association supplied data on the quality of compost within its compost certification scheme. The compost samples were evaluated for conformance with its former 'Standards for Composts' and more recently with the Publicly Available Specification for composted materials (PAS100).

1.2.5 ReMaDe projects

The Recyclables Market Development (ReMaDe) projects have been conducting regional programmes for over five years. The findings from a number of reports, FAQs, case studies and field trials have been incorporated into this report. Contributions have been received from:

- ReMaDe Scotland www.remade.org.uk
- ReMaDe Essex www.remadeessex.org.uk
- London ReMaDe www.londonremade.com
- ReMaDe Kent & Medway www.remade-kentmedway.co.uk

- The Clean Merseyside Centre www.clean-merseyside.com

1.2.6 Landfill tax credits

Market development projects have been conducted including:

- A project 'Compost Use in Agriculture' managed by Enviros Consulting Ltd commenced in 2001 and will be completed in 2004. This comprises seven sites in Eastern England to which compost have been applied at two rates, with and without fertilisers, and compared with untreated and farm standard fertiliser controls. These trials follow on from work conducted by Levington Agriculture in the 1990s reported at www.enventure.co.uk.
- A project evaluating the performance of a range of horticultural crops grown in different types of and blends of composted materials in growing media, including municipal green wastes and chipboard waste, will be completed by Stockbridge Technology Centre in 2004.
- 'The Humberside Project' which started in 1998 was carried out by ADAS. Compost was used as one treatment to aid the formation of topsoils at two sites. Good grass growth was established with no detrimental or toxic effects from the subsoil materials used. The composted green waste treatment added valuable plant nutrients and organic matter to the soil, increasing plant available water supply and topsoil infiltration rates, and decreasing soil bulk density. Soil biomass carbon and nitrogen were increased and greater microbial activity was achieved as shown by increased soil respiration rates (Chambers in press).
- 'Soil Generation at Bootham Lane' was a research project managed by ADAS which commenced in 2000/01. By 2002, it was shown that composted green waste could be successfully incorporated into colliery spoil to create topsoil using standard agricultural machinery. Grass was successfully established (Anon 2002).
- The GROWS project (Green Recycling of Organic Waste from Supermarkets) was managed by the Organic Resource Agency (ORA) and investigated the collection and composting of supermarket waste and the use of the compost in agriculture with reports published in 2002 and 2003.
- The Henry Doubleday Research Association (HDRA) has conducted a number of projects on composting and the use of those composts in various applications.
- Work has been conducted by Liverpool University on 'The potential for the sustainable use of compost in arable crop production' (2002).

1.2.7 EU projects

A review of EU literature was undertaken by the Austrian Government and a seminar was held in November 2001 entitled 'Applying Compost – benefits and needs'. The full review is due to be published in 2003/04 but the findings in the papers presented in the seminar were included in the appraisal of compost in end uses.

A workshop on 'the biological treatment of biodegradable waste – technical aspects' was held in Brussels in April 2002, organised by DG Environment and the JRC. Standards, including measurement of compost stability, were discussed as well as aspects of soil quality and agronomy.

A report was produced by the Swedish Environmental Protection Agency on 'Compost Quality and Potential for Use' in September 1997, which included a literature review.

1.2.8 International projects

In the US, the Composting Council and the Clean Washington Centre established the 'Development of Landscape Architect Specifications for Compost Utilization' (Anon 1997).

A field guide to compost use was prepared in the US (Alexander 1996), as well as a field guide to on-farm composting (Dougherty 1999).

'Compost Utilization in Landscape' was published in 2001 (Alexander 2001)

A review of the use of compost to enhance soil fertility was carried out by the Ohio State University/OARDC. 'Utilization of Compost' is a chapter in the Science of Composting (Epstein 1996) and concludes that considerable literature is available on the use of compost as a soil amendment. Soil response to compost is most readily shown on light and heavy soils. Compost has been shown to be an excellent medium for plant growth, whether in containers (after amendment) or in the field. Factors affecting the response to compost include compost type, particle size, soil type, and physical and chemical characteristics.

1.2.9 Others

Many other researchers have written reports including 'Horticultural Uses of Greenwaste Compost' (Kendle 1994).

1.3 Materials under consideration

1.3.1 Feedstocks

The term compost applies to a considerable number of composted materials produced from a variety of sources. Within this report, in its broadest sense, it includes any organic material that has undergone managed, aerobic microbial degradation at elevated temperatures, resulting in significant microbial, physical and chemical changes to the original material. For the purpose of this report the materials under consideration are those produced from commercial composting operations working to PAS 100. These composts have been produced using source-separated materials derived from green wastes, kitchen wastes and wood wastes and may also include animal manures but are not derived exclusively from them.

- **Green wastes**

Green wastes consist of botanic residues from domestic, amenity, commercial and industrial sources: for example prunings, hedge and lawn clippings, spent bedding and pot plants, roots, tubers, corms and bulb, leaves and other organic debris from gardens, parks, green spaces, driveways and roadsides. It may include ornamental, edible and weed species as well as fungi and any soil that may be attached.

Note: The term 'municipal' is often used in connection with the organic fraction of municipal wastes which are subsequently composted. This term 'includes household waste plus any other wastes collected by a Waste Collection Authority, or its agents, which may include municipal parks and gardens waste, beach cleansing waste, commercial or industrial waste and waste from the clearance of fly-tipped materials.'

- **Kitchen wastes**

Kitchen wastes may be separated into two categories;

- Catering waste
- Catering waste – meat excluded

Catering waste is all waste food including used cooking oil originating in restaurants, catering facilities and kitchens, including central kitchens and household kitchens.

Catering waste – meat excluded requires that there is a system to ensure that meat-excluded kitchen waste is source separated in the kitchen, kept and transported separately and treated separately from kitchen waste that contains meat. Thus, vegetable waste arising in a kitchen is catering waste, meat excluded, and not green waste and must be treated accordingly.

The governing regulations include EU Regulation 1774/2002 on Animal By-products and the Animal By-products Regulations as appropriate to the countries of the UK. The Animal By-products Regulations lay down national rules for the composting or anaerobic digestion of catering waste.

Former foodstuffs such as waste bakery and confectionery goods, food processing or manufacturing wastes not containing meat and foods that need no further cooking before being eaten from shops and supermarkets are not catering wastes (in EU definitions they are Category 3 materials) although they may be treated as catering waste until the 31st December 2005 (former foodstuffs are subject to a transitional measure valid to 31/12/05, this may however become a permanent derogation). Any product that is or contains raw meat or raw fish is not a catering waste or a former foodstuff as it is a category 3 material. Former foodstuffs (after 31st December 2005) and products that are meat or fish, or contain meat or fish, may still be composted but under the conditions appropriate to Category 3 Animal By-products.

- **Wood wastes**

Wood wastes originating either from untreated wood or wood treated with preservatives that will adequately degrade during composting from sources such as joinery, furniture making and packing materials, and including woods that have been re-used in non-laminated chipboards and medium density fibreboard (MDF). Forest residues and products not originally intended for another purpose are excluded from the scope of this report as they would not normally be landfilled.

1.3.2 Benefits and constraints of feedstock materials

During the course of researching this project, it became evident that, as well as offering many benefits, compost made from source-separated wastes still had some potential constraints attached to achieving greater use. Whilst the inherent benefits of the end product are the result of feedstock, method and maturation, the constraints are properties that have been inherited from the feedstock. With the exception of some organic compounds, composting does not reduce physical (e.g. glass, metal etc) or chemical (e.g. potentially toxic element (PTE)) contaminants. However, the majority of biological contaminants are eradicated (Jones and Martin 2003; Noble and Roberts 2003) if the process is well managed. The introduction of the BSI PAS 100, along with complimentary industry specifications for compost developed by WRAP, minimise the presence of contaminants in composts that are certified by carefully controlling the feedstock inspection process and requiring the compost product to meet specific limits for a range of contaminants.

The three principal feedstocks (green wastes, kitchen wastes and wood wastes) differ significantly in their composition and the rate of inclusion will influence both the rate of decomposition and the properties of the final product. The following benefits and constraints are not exhaustive and as such are presented as an overview only.

- **Green wastes**

Green waste may contain easily composted materials such as grass mowings, hedge clippings, annual weeds, spent plants and leaves, plus soil or more resistant, mature woody material. Each of these materials contributes different chemical and physical properties, both to the process and to the end product.

Although green waste can contain the greatest variety of plant materials, it is primarily from private garden, and other horticultural sources such as green amenity spaces and grounds for outdoors sports and leisure. It may therefore contain diseased or chemically treated material or stones and other physical contaminants. The potential for plant pathogen survival has been reviewed (Noble and Roberts 2003). The potential for herbicide and other agro-chemicals to persist has not been reviewed in this report but, even though most are rapidly degraded in the environment, there is evidence that some can persist and affect the end product quality. For example, the herbicide active ingredient 'clopyralid' became a major issue in American composting (Pittenger and Downer 2002). In the unlikely event that herbicide residues might persist at plant-toxic concentrations in compost produced in the UK, the bioassay methods in PAS100 and under further development are designed to detect any such phytotoxins.

- **Kitchen wastes**

Kitchen wastes are predominantly composed of materials of higher water and nitrogen content than green wastes that decompose readily. Such products are easy to compost and provide material readily accessible for microbial decomposition, thus aiding the composting process, and furnishing the end product with more readily available plant nutrients.

Kitchen wastes may contain diseases in the form of plant, human or animal pathogens. Defra commissioned a risk assessment on the transmission of animal diseases through the composting of catering wastes, published in 2002, available from www.defra.gov.uk/animalh/by-prods/publicat/report5.pdf. The likely inclusion, survival and risk of infection from compost use has been reviewed by Jones and Martin (2003) and Noble and Roberts (2003). Physical contaminants (e.g. glass and metal fragments) from kitchen wastes are also perceived to be a constraint by end users. The report for Defra led to the specification for minimum biological processing conditions in the Animal By-Products Regulations 2003, which can be achieved by 'good practice' composting. Further advances in knowledge on pathogen kill in current work will be reflected in future processing conditions and product quality specifications.

- **Wood wastes**

Of all the materials under consideration, wood wastes are potentially the most consistent in that they are principally composed of carbon in the form of resistant lignin compounds. Such compounds are more resistant to biodegradation than cellulose and hemi-cellulose, which are in higher proportion in softer, sappier plant materials. The lignin contribution may be useful when mixing with materials of high nitrogen but provides few nutrients to the final product and may immobilize nitrogen both during the composting process and in subsequent use. Wood wastes do however provide bulk and can be manipulated to provide a specific particle size to achieve void spaces within a pile that allow aeration during the composting process.

Wood from packing materials such as pallets or crates and woods that have been reused in chipboards and MDF may appear untreated but many are in fact treated with preservatives such as pentachlorophenol. Others, especially those originating from overseas, may have been subject to phyto-sanitation, in which case they may have been further chemically treated to prevent the introduction of non-native pests (e.g. Asian longhorn beetle, pine wood nematode). Of particular concern are those wastes originally intended for outside use that may have been treated with copper, chromium and arsenate (CCA) or lead compounds. Composite wood products, sometimes of unknown origin, may contain methylene urea or polyurethane (binding agents) that may be partly resistant to decomposition. Wood wastes may also contain metal in the form of old nails, staples and other fixings.

2. Properties of composted materials

2.1 Compost

2.1.1 The composting process

Composting can be defined as the biological decomposition and stabilisation of organic substrates, under conditions that allow thermophilic temperatures as a result of biologically produced heat, to produce a final product that is stable, free of pathogens and plant seeds, and can be beneficially applied to land (Haug 1993). The predominantly aerobic process is characterized by a period of rapid decomposition and self-heating followed by a cooler, slower decay of remaining organic substrates. Regulating the kinds of organic substrates and controlling the physical and chemical attributes of the decomposition environment in the compost pile facilitates the process (Sylvia, Fuhrmann et al. 1999).

2.1.2 The compost product

Within the literature reviewed there was little description of what constituted compost. Therefore, in relation to the material used in the various studies within this review, compost is taken as meaning "a product produced using one, or a combination, of 'feedstocks', that have been processed by composting to produce an adequately biodegraded material that conforms to the specification (PAS100) and is fit for purpose". Within this definition and the literature reviewed large variations in the physical, chemical and biological components exist. The product can be described by its individual components (chemical, physical, biological), which can then be classified in more detail. However, it is the combination and interaction of the various properties, rather than the value of a single property, that defines a compost.

2.2 Chemical properties of compost

2.2.1 Carbon:nitrogen ratio

The carbon:nitrogen (C:N) ratio and the mineralisation/immobilisation of nitrogen (N) is influenced by the C:N ratio of the compost, the respective forms and total quantity of carbon(C) and nitrogen (N) (reflecting the amount and pattern of compost application), the C:N ratio of the soil, soil type, hydrology and other site specific factors such as climate and use (Amlinger, Bettina et al. 2002). It is important to emphasise that the level of total N in the applied compost or amended soil is not a guide to nitrogen availability to plants. Guidance on the use of fertilizing materials such as manures and slurries in agriculture provides estimates of available nutrients but those who plan and oversee their use are encouraged to tailor applications that take account of test results for the fertilizing material.

2.2.2 Nitrogen availability

Factors which affect the rate of availability of nitrogen from organic materials include soil moisture, temperature and microbial activity. As a general rule, in a stable compost, with a C:N ratio of between 15 and 20, 12 - 15 % of the total N, and a potential of 16 - 20 % of the total N, will be readily available within six months (Iglesias-Jimenez and Alvarez 1993). Composts with a C:N ratio above 25 are likely to lead to N immobilisation and those with C:N below 10 are more likely to contribute to nutrient leaching from the amended soil in warm, wet weather if the compost was not highly degraded. On this basis, compost with a C:N ratio of 15 could reasonably be expected to have up to 15 % of its total nitrogen available to a following crop through microbial mineralisation of the organic matter. In the following years, 5 %, 3 % and then 2 % would be available. Such a compost, having a total N of 12.5 g N kg^{-1} and applied at a rate to supply a total N loading of 250 kg N ha^{-1} (20 tonnes dry matter (DM) basis), would have 37.5 kg N (15 %) available in the first year, 10 kg in the 2nd, 6 kg in the 3rd, and 4 kg in the 4th and subsequent years.

2.2.3 Phosphorus

In addition to N, compost may also contain significant amounts of phosphorus (P). However, this can be chemically combined in forms that are not readily available to a plant (often affected by pH). Following mineralisation, P is quickly absorbed onto the surface of negatively charged particles; its availability in solution is therefore typically low even when the total content is high. The acquisition of phosphate for plant nutrition, with its low solubility, has always been an agronomic problem. The literature reviewed showed that plant accessibility to organic P in compost is poorly understood, and with different methods of extracting P and relating this to availability, it has not been possible to determine availability as a consequence of repeated compost applications. The situation is further complicated by plant species' P acquisition strategies. These involve symbiotic associations (Harley and Smith 1983) and enzymes, such as phosphotase

(Read 2000), which can increase the availability of P that would not otherwise have dissolved into the soil water solution. However, CAT extraction has provided a more realistic picture of P availability to the plant where compost has been used as an ingredient in growing media (WRAP project STA0013).

2.2.4 Potassium

As with phosphorus, the total level of potassium (K) in compost varies between sources with concentrations as low 0.71 mg kg^{-1} (Hue and Sobieszczyk 1999) to as high as 7.55 g kg^{-1} . Rodd, Warman et al (2001) also found that compost sourced from the same manufacturer contained 3.23 and 7.55 g K kg^{-1} in two successive years but that K concentrations remained below the maximum tolerable limit for livestock feed compared to the highest mineral fertilisation addition, in which it was exceeded. Similar variations were found by Mamo, Rosen et al. (1999) for two composts which ranged from 2.4 to 3.8 g kg^{-1} and 1.8 to 3.8 g kg^{-1} of K within samples from the same batch. In two separate studies utilising compost sourced from the same manufacturer, K concentrations were 444 and 45 g kg^{-1} respectively (Klock-Moore 1997; Klock-Moore 1999). Composts analysed in two studies by the Composting Association (Table 2) and the ReMaDe project (Table 3) identified K concentrations in excess of 8 g kg^{-1} (Table 1 being an average of data in Tables 2 and 3).

2.2.5 Sulphur, calcium, magnesium and sodium

Although sulphur (S), calcium (Ca) magnesium (Mg) and sodium (Na) have all been found in compost at variable concentrations they rarely reach concentrations that exceed plant needs. In the Composting Association and ReMaDe project the approximate concentrations of calcium and magnesium were 20 g and 3 g kg^{-1} respectively whilst that of sulphur was 1.7 g kg^{-1} and sodium 0.6 g kg^{-1} (Table 4).

2.2.6 Chloride

Chloride (Cl) is an essential plant nutrient. Its concentration in soils and growing media can become excessive because Cl, an anion, typically remains in solution and it is thus easily accessed by the plant. Accordingly, its effects are readily observed. Concentrations in excess of 20 mM in solution (equivalent to 710 mg per litre of solution) can lead to toxicities in 'salt-sensitive' plant species (Marschner 1998) but high Cl levels can be reduced through leaching out of composts prior to use.

2.2.7 Micronutrients

Composts have been found to contain many of the plant micro-nutrients. Copper (Cu), zinc (Zn), nickel (Ni), iron (Fe) and boron (B) are all essential plant nutrients but at high concentrations can become toxic. pH affects the solubility/availability of many micronutrients. PAS100 specifies maximum allowable concentrations of Cu, Zn, and Ni in their 'total' forms (extracted from compost using aqua regia). Composts (see data in tables 6 – 9) have occasionally exceeded the limits. Although this specification does not include a limit for B, phytotoxic concentrations of this micronutrient have not been found. The micronutrients manganese (Mn) and molybdenum (Mo) have also been detected in composts.

2.2.8 Nutrient levels in composts

Using the data from two studies, the average nutrient content for UK compost is shown in Table 1. It has also been possible to determine the skew of the distribution and, in all but K concentrations, the trend is for nutrient concentrations to be positively skewed (Table 4). In other words, with the exception of K, more of the composts tested have nutrient concentrations higher than average than those with nutrient concentrations lower than average. 'Total' nutrients are those extracted from compost using aqua regia as instructed in the relevant British Standard method and specified in Annex F of PAS 100.

Table 1: Total nutrients (averages of Tables 2 and 3)

Parameter	P	K	Mg	Na	Ca	S	Fe	Mn	B
Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Average	2131	8264	2870	592	20194	1726	13775	323	25

Notes to tables

P = phosphorus; **K** = potassium; **Mg** = magnesium; **Na** = sodium; **Ca** = calcium; **S** = sulphur; **Fe** = iron; **Mn** = manganese; **B** = boron; all figures expressed as mg/kg dry matter = parts per million (ppm). P x 2.29 =phosphate as P_2O_5 and K x 1.2 = potash as K_2O

Table 2: Total nutrients (The Composting Association; samples dated up to mid 2003)

Parameter	P	K	Mg	Na	Ca	S	Fe	Mn	B
Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Maximum	4330	10110	6350	588	24500	1770	37600	2718	24
Minimum	960	4150	2310	328	12400	1014	8731	260	1
Median	1920	7195	3270	435	15330	1450	11500	338	19
Mean	2053	6889	3512	451	17160	1428	15710	576	18
90th percentile	2375	8975	5092	545	23376	1740	23652	574	23
No. of samples	16	16	15	12	12	11	12	12	12

Table 3: Total nutrients (ReMaDe project analyses; samples dated from 2001 to mid 2003)

Parameter	P	K	Mg	Na	Ca	S	Fe	Mn	B
Maximum	10240	19800	4780	1625	40200	4390	34800	593	102
Minimum	1290	2790	1550	354	10900	1000	5570	186	11
Median	2252	8875	2655	660	22278	1834	14750	317	27
Mean	2517	8508	2786	781	23333	1970	15206	320	37
90th percentile	2739	11260	3973	1238	30893	2556	18779	426	81
No. of samples	28	28	28	28	28	28	28	28	28

Table 4: Approximate nutrient concentrations and distribution skew of data used

Parameter	P mg/kg	K mg/kg	Mg mg/kg	Na mg/kg	Ca mg/kg	S mg/kg	Fe mg/kg	Mn mg/kg	B mg/kg
Approx conc	2000	8000	3000	600	20,000	1700	14000	300	25
Skew	+	-	+	+	+	+	+	+	+

2.2.9 pH

Out of a total of 189 samples taken in four studies (the Composting Association, Environment Agency, ReMaDe projects, HDRA) (Tables 11 – 14) the pH of UK composts ranged from 5.7 to 9.4 and had a median (within limits of calculation method) of 8.7 (Table 5). These differences between the median and the mean suggest that the pH distribution was negatively skewed in all reports. A pH above 8.0 is not normally a result of Ca concentrations but more likely as a consequence of high sodium (Na) levels (Rowell 2001). Although compost has been shown to have a neutralising effect on an un-buffered acidic solution equivalent to 10 % of a lime addition (Boon 1999), the approximate Ca concentration of 20 g kg^{-1} is insufficient to be the principal basic ion responsible. It is likely therefore that the concentrations of the basic cations K, Mg, Na and ammonium (NH_4) are also important in the development of high pH. Compost pH tends to drop as it matures largely due to nitrification of ammonium forms of N and consequently the availability of some nutrients may be improved.

Table 5: pH levels of composts in four separate studies

source	Min pH	Max pH	Median	90th %	No. samples	Sample X med	Average pH for all samples	
Composting Association	5.7	9.4	8.4	9.0	52	436.8	Total	1848
Environment Agency	7.0	9.1	8.7	8.9	60	522	No. samples	213
ReMaDe	6.3	9.0	8.2	8.7	33	270.6		
HDRA	6.2	9.4	8.7	X	69	591.6	Ave pH	8.68

2.2.10 Cation exchange capacity

The cation exchange capacity (CEC) defines the quantity of negative charge sites in a substrate (e.g. soil, growing medium or compost) that can hold positively charged ions (cations). The principal basic cations (associated with alkaline pH) are calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na), and the acidic cations are hydrogen (H) and aluminium (Al). The higher the CEC, the greater the capacity to hold nutrients and the more buffered is a substrate against nutrient changes (Saharinen 1998). Compost is principally composed of organic matter and humus products that typically have a high CEC capacity (Rowell 1997). Changes in the CEC during composting have been identified as important in determining compost maturity (Harada and Inoko 1980; Estrada, Sana et al. 1987; Chen and Inbar 1993; Bernal, Navarro et al. 1996; Saharinen 1998). An average CEC of 23.67 $cmol_c L^{-1}$, compared to 14.81 for peat, was recorded by Corti, Crippa et al. (1998), whilst Klock-Moore (2001) reported a CEC in compost of nearly five times that of the control media. Joiner (1981) suggested a typical CEC in composts of between 10 - 100 meq 100 cm^{-3}. As compost matures, CEC increases, so that when used as a component of growing media, or as a soil improver, the ability of the substrate to retain cations (nutrients) is improved. As such, the CEC can also be visualised as the ability of a substrate to retain nutrients and maintain concentrations as they are removed by the growing plant or leached into drainage water. A high CEC when combined with other measures of soil fertility, is a good indicator of soil quality and productivity (Ross 2003).

2.2.11 Potentially toxic elements

Although Cu, Ni and Zn are regarded as potentially toxic elements (PTEs), sufficient available levels of these elements are required for plant growth. However, the same is not true for cadmium (Cd), chromium (Cr), lead (Pb), or mercury (Hg), and consequently PAS100 also specifies maximum allowable concentrations for these PTEs in composts. In Tables 6 – 9 a total of 189 samples taken from four different studies showed Cd levels ranging from 0.1 to 15.5 mg kg^{-1} giving an average concentration (within the limitations of the method of calculation) of 1.59 mg kg^{-1} (Table 10). However, omission of the early Environment Agency data (Table 7) reduces the average concentration to 0.6 mg kg^{-1}. Cr levels are much lower, typically at 20 % of the PAS100 limit, as is also the case with Zn and Ni with all the medians and the 90th percentile concentrations being at 50 to 75 % of the PAS100 limits. Hg levels were generally well below the PAS100 limit with the exception of the ReMaDe project that recorded at least one sample with a level as high as 13.3 mg kg^{-1} way exceeding the limit of 1 mg kg^{-1}. All the studies recorded some samples that exceeded the PAS100 limit for Pb.

PAS100 sets upper limits for the 'total' levels of all of these PTEs in their total forms (extracted in 'aqua regia', a concentrated acid). However, much of the total Cd, Cr, Pb and Hg content remain in the compost under normal conditions of use.

Table 6: PTE content (The Composting Association; samples date up to mid 2003)

Parameter	Cd	Cr	Cu	Pb	Hg	Ni	Zn
Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Maximum	1.3	82.7	281.0	943.0	0.5	49.2	397.0
Minimum	0.1	3.2	12.4	8.6	0.0	3.6	1.3
Median	0.6	16.9	51.0	105.0	0.2	14.8	188.0
90th %	0.8	21.0	69.8	128.0	0.3	20.8	247.0
No. of samples	49	49	49	49	49	49	49
PAS100 upper limit	1.5	100	200	200	1.0	50	400

Table 7: PTE content (Environment Agency Report P229; samples: 1995-96)

Parameter	Cd	Cr	Cu	Pb	Hg	Ni	Zn
Maximum	15.5	49.0	72.0	233.0	0.5	64.0	220.0
Minimum	0.6	5.4	19.0	19.0	0.5	4.0	43.0
Median	4.4	28.0	40.5	63.0	0.5	28.0	147.0
90th %	8.1	37.2	58.0	152.0	0.5	39.0	184.4
No. of samples	51	49	52	51	50	51	52
PAS100 upper limit	1.5	100	200	200	1.0	50	400

Table 8: PTE content (ReMaDe project analyses; samples date: 2001 to mid 2003)

Parameter	Cd	Cr	Cu	Pb	Hg	Ni	Zn
Maximum	2.5	83.2	1160.0	301.0	13.3	44.3	572.0
Minimum	0.4	8.0	18.0	32.5	0.1	7.6	75.0
Median	0.6	22.0	58.0	92.0	0.2	15.2	187.5
90th %	1.3	50.0	186.6	206.0	0.5	30.0	315.9
No. of samples	21	21	28	21	19	21	28
PAS100 upper limit	1.5	100	200	200	1.0	50	400

Table 9: PTE content (HDRA Report WWSC09; samples date up to 1999)

Parameter	Cd	Cr	Cu	Pb	Hg	Ni	Zn
Maximum	2.90	157.0	288.0	216.0	1.6	67.0	656.0
Minimum	0.10	5.9	12.0	12.0	0.01	7.0	75.0
Median	0.49	19.0	44.0	107.0	0.2	18.0	185.0
No. of samples	68	68	68	68	68	68	68
PAS 100 upper limit	1.5	100	200	200	1.0	50	400

under normal conditions of use.

Table 10: Cd average content mg kg^{-1} (based on tables 6 - 9)

Study	Number samples	median	90th %	Sample median
Composting Association	49	0.6	0.8	29.4
Environment Agency	51	4.4	8.1	224.4
ReMaDe	21	0.6	1.3	12.6
HDRA	68	0.49	X	33.32
Total	189	N/A	N/A	299.72

Statistical average	
Total cont	299.72
samples	189
Ave cont	1.59

Note

Cd = cadmium; Cr = chromium; Cu = copper; Pb = lead; Hg = mercury; Ni = nickel; Zn = zinc; and all figures expressed as mg/kg dry matter = parts per million (ppm).

2.2.12 Summary of Chemical properties

Depending on the feedstock, composting process and degree of maturity, composts can provide a proportion of the nutrients required for plant growth. The availability of these nutrients depends on the quantity and form that the respective nutrient pools take and the relationship that these nutrient pools have with each other and with other properties of the compost and matrix to which it is added (e.g. soil or growing medium). It is not simply the relative quantity of a given element but also the quality of the feedstock that determines the rate of decomposition and subsequent nutrient and PTE bioavailability. For example, cellulose and lignin have similar percentages of carbon, and contain only carbon, hydrogen and oxygen, but the structures of the molecules that contain the carbon differ radically. Lignin decomposes far more slowly than cellulose, so the quality of lignin as a carbon source is much lower than that of cellulose (Sylvia, Fuhrmann et al. 1999).

The incorporation of other materials (e.g. soil, peat, mineral fertilisers or other components) with the compost will further influence these properties and, consequently, the availability of elements. It is important to realise that compost test results stating concentrations of 'total' elements (nutrients and PTEs) are an established and standardised way of characterising composts but that their mineralisation and loss from the matrix (leaching) or uptake by plants is influenced by the inter-related variables discussed in this report. Elemental concentrations determined by using the CAT method seem to better indicate their availability to plants.

Factors such as pH, temperature and maturity are also crucial in determining the agronomic value and availability of an element. Such variability in the concentration and forms of the chemical components, the interdependency of these and the influence of external factors on the availability combine to make composts, made from varied feed stocks and by different systems, into individual products that require specific analysis in relation to final use. In order to determine the fate and availability of the elements, a compost must be treated as a unique product dependent on the influence of all these factors.

Maturity is also a crucial consideration in determining the availability of the elements. Although different compostable feedstocks often begin with widely divergent nutrient contents, the quantity and quality of the nutrients converge as the composting process proceeds (Sylvia, Fuhrmann et al. 1999).

Test results should always be treated with caution, and the rate and frequency of use of compost should be modified in the light of experience.

2.3 Physical properties of compost

2.3.1 Physical property relationships

In reviewing these properties it has become apparent that there is a need to comment on the interdependency of physical properties. The 'dry bulk density' (DBD) of a substrate is the mass of an oven-dried volume of moist substrate (Bunt 1988) and it is a measure of the volume occupied by a substrate in a 'usable' state. This volume is composed of two components, solid and void, which together form the matrix of particles and pores that provide the rooting environment. The solid component is composed of particles and can be calculated by determining the Particle Density (PD) (Rowell 1997), whilst the void component constitutes the arrangement of pores. The dry BD and PD can be used to calculate the pore volume (PV) and, if the water holding capacity (WHC) is known, then the air filled porosity (AFP) of the compost can be calculated. It is important that these measurements are made according to prescribed methods.

2.3.2 Bulk density (BD)

Bulk density is usually measured on a fresh weight basis (as received) to obtain a mass per volume of a moist sample (Tables 11 - 14) and not as the oven-dried mass of the sample (Bunt 1988). The fresh weight bulk density usually lies between 500 and 600 g/litre. The typical dry BD of a mineral soil is approximately 1.5 g cm^{-3} (Rowell 1997), that of a peat 0.1 g cm^{-3} (Bunt 1988) and that of a compost, based on the literature reviewed, 0.3 g cm^{-3}. If the BD measurements are used in conjunction with the moisture content values (Tables 11 – 14) then the mean dry BD ranges from 298 – 317 g / litre (final column Tables 11 – 14). Within the literature, compost generally has a dry BD of below 0.4 g cm^{-3} and of five composts studied at Reading University, DBD between 0.18 – 0.4 g cm^{-3} was obtained, compared to a reference commercial peat-based growing medium of 0.21 g cm^{-3} (McEwen 2001).

2.3.3 Pore Volume (PV)

The PV is the void within the compost that is not occupied by particles. The particle volume = DBD/PD, therefore the PV = 1 - particle volume and represents the percentage of the compost that is occupied by voids. This PV is the volume within a compost that can be occupied by either water or air. If the water holding capacity is known, then the air filled porosity can be calculated.

Table 11: Physical properties, organic matter, and nitrogen content (The Composting Association; samples date up to mid 2003)

Parameter	BD	M	DM	LOI	OC	Total N		C:N	pH	EC	Dry BD
Units	g/l	%	%	%	%	mg/kg	%	X:1		µS/cm	g/l
Maximum	980	76	92	82	45	16600	6.4	50	9.4	1530	235
Minimum	139	8	24	9	8	6013	0.6	5	5.7	10	117
Median	522	37	63	26	17	13005	1.3	13	8.4	688	329
Mean	529	40	60	31	20	12014	1.4	15	8.2	671	317
90^{th} percentile	670	64	76	50	34	13835	1.6	21	9.0	1090	
No. of samples	52	52	52	50	51	16	49	48	52	52	52

Note

BD = bulk density of wet sample; **M** = moisture content; **DM** = dry matter content; **LOI** = loss on ignition at 450-550°C; **OC** = organic carbon; **Total N** = total nitrogen of dried sample; **C:N** – dried sample; **pH** = standard units; **EC** = electrical conductivity.

Table 12: Physical properties, organic matter, and nitrogen content (Environment Agency Report P229; samples date from 1995 to 96)

Parameter	BD	M	DM	LOI	OC	Total N		C:N	pH	EC	Dry BD
Maximum	758	59	84	80	41	-	1.6	47	9.1	2200	311
Minimum	148	16	42	22	9	-	0.8	7	7.0	235	124
Median	557	48	52	36	15	-	1.2	13	8.7	680	290
Mean	541	45	55	42	18	-	1.2	17	8.5	765	298
90th percentile	744	54	70	72	31	-	1.4	31	8.9	1142	
No. samples	60	60	60	60	60	-	60	60	60	60	60

Table 13: Physical properties, organic matter, and nitrogen content (ReMaDe project analyses; samples date from 2001 to 03)

Parameter	BD	M	DM	LOI	OC	Total N		C:N	pH	EC	Dry BD
Maximum	720	67	80	72	32	27993	2.8	25	9.0	1800	238
Minimum	260	20	33	17	7	6966	0.7	8	6.3	340	208
Median	483	36	64	35	14	11963	1.2	12	8.2	980	309
Mean	492	37	63	40	17	12492	1.3	14	8.1	958	310
90th percentile	611	51	78	57	28	14493	1.5	23	8.7	1390	
No. samples	33	33	33	33	33	33	33	33	33	33	33

Table 14: Physical properties, organic matter, and nitrogen content (HDRA Report WWSC09; samples date up to 1999)

Parameter	BD	M	DM	LOI	OC	Total N		C:N	pH	EC	Dry BD
Maximum	840	61	81	82	37	-	7.6	52	9.4	2290	328
Minimum	310	19	39	10	6	-	0.6	6	6.2	80	251
Median	580	34	66	19	13	-	1.1	12.	8.7	773	383
No. samples	68	68	68	68	68	16	68	68	68	52	68

2.3.4 Water holding capacity (WHC)

The WHC is the maximum amount of water that a compost can hold following saturation and then drainage. It is usually expressed as a v/v relationship, or as a percentage of the total substrate volume.

2.3.5 Organic matter content

As with the nutrient content, the organic matter content of compost can vary considerably depending on feedstocks. On average the physical content of compost made from source separated materials contains 30 % organic matter (m/m in the dry matter, as measured by loss on ignition) (Wallace 2003).

2.3.6 The air filled porosity (AFP)

The AFP is the part of a compost that is filled with air following saturation and drainage. The physical measure of AFP can be made by e.g. the Wolverhampton Method (Bragg and Chambers 1998). However the AFP can also be calculated by subtracting the percentage WHC from the percentage PV.

2.3.7 Hydrological properties

Within the literature, compost generally has a PV and WHC that exceed that of a mineral soil and, whilst generally lower than a peat-based medium, it is comparable to such material and makes little difference when used as a component of a blended growing medium. However, it is important to remember that the hydrological properties are an expression of the pore size and distribution of a complete substrate, rather than the inherent property of a single component.

2.3.8 Other physical properties

Particle size and shape are also important factors in determining how a substrate will behave under a given use. Fully matured compost should consist of particles of various sizes and shapes that naturally aggregate into larger fractions. Screening can be used to remove larger particles and further mechanical processing can be undertaken to produce substrate of a specific size range. Particle size and shape influence the packing of the compost and so exert a strong influence on the pore distribution, PV and consequently the BD. The relationships are complex and poorly understood in relation to composts.

2.3.9 Summary of physical properties

As with chemical properties, physical properties are interdependent. Although it is possible to make a measurement of individual properties, this will not necessarily provide information that assists in determining how the compost will behave when combined with other materials. It is likely that the real value of the measure of parameters such as BD, PD or WHC is in using such information to calculate other factors (e.g. AFP, saturated BD) and that it is the combined influence of these factors that is the true measure of the physical value of the growing medium.

2.4 Biological properties of compost

2.4.1 Biological component

Most organic substrates carry an indigenous population of microbes from the environment. For open-air composting processes, further natural colonisation of compost material occurs during heap construction and turning of windrows. Microbial degradation takes place in three principle stages (mesophilic, thermophilic and the stabilisation or curing stages) and is characterized by population changes throughout the process (Table 15). The thermophilic stage is characterised by relatively few genera and species (Table 16). After the thermophilic stage, mesophiles proliferate again, having been redistributed from cooler parts, or re-introduced during turning (Sylvia, Fuhrmann et al. 1999).

2.4.2 Disease suppression

It has been widely reported in the scientific literature that composts can suppress root diseases (Mandelbaum and Hadar 1997; Lievens, Vaes et al. 2001; Cotxarrera, Trillas-Gay et al. 2002) and that this effect is attributed to one or a combination of four factors. These are competition, antibiosis (the death of an organism as a result of the antibiotic action of another organism), parasitism(the use of an organism by another to obtain nutrients and other services at the expense of the host organism, thus restricting the proliferation or eliminating the host) and induced systemic resistance (the induction of a host defence mechanism by a non parasitic organism in the absence, or in advance of, a specific attack from a parasitic organism) (Lievens, Vaes et al. 2001). These studies have focused on a wide variety of pathogenic organisms. It would appear that no single mechanism is responsible for the control of all pathogens. Rather it is likely that the specific mechanisms are dependent on the type of pathogen and dominance of respective control mechanisms, or a combination of these factors.

Table 15: Microbial population changes during composting

Organism	Mesophilic Stage	Thermophilic Stage	Stabilisation/ Curing Stage	No. Species Present
	(CFU g^{-1} dry mass)			
Bacteria				
Mesophilic	10^{8}	10^{6}	10^{11}	6
Thermophilic	10^{4}	10^{9}	10^{7}	1
Actinomycetes				
Thermophilic	10^{4}	10^{8}	10^{5}	14
Fungi				
Mesophilic	10^{6}	10^{3}	10^{5}	18
Thermophilic	10^{3}	10^{7}	10^{6}	16

From Sylvia et al (1999)

Table 16: Micro organisms commonly associated with compost piles

	Bacteria	Fungi
Mesophiles	*Psudomonas* spp. *Achromobacter* spp *Bacillus* spp. *Flavobacterium* spp. *Clostridium* spp. *Streptomyces* spp.	*Alternaria* spp. *Cladosporium* spp. *Aspergillus* spp. *Mucor* spp. *Humicola* spp. *Penicillium* spp.
Thermophiles	*Bacillus* spp. *Streptomyces* spp. *Thermoactinomyces* spp. *Thermus* spp. *Thermomomospora* spp. *Micropolyspora* spp.	*Aspergillus fumigatus* *Mucor pusillus* *Chaetomium thermophile* *Humicola lanuginosa* *Absidia ramosa* *Sporotrichum thermophile* *Torula thermophile* (yeast) *Thermoascus aurantiacus*

From Sylvia et al (1999)

2.4.3 Summary of biological properties

Although there are relatively few organisms involved in the process of composting, their action provides a substrate that can be colonized and beneficially utilized by plants and vast numbers of the soil flora and fauna. The organisms that are responsible for the processes are naturally present in the wider environment in which the compost is intended for use and so, in themselves, do not add to the general diversity. In general, the application of compost to a specific environment will increase the populations of soil organisms that have proliferated within the compost during its production. However, this is likely to be a transient effect with such populations decreasing as the available substrates on which they depend are consumed. The existing flora and fauna within a receiving environment are also likely to be stimulated, utilising and proliferating on the available substrate and competing with any introduced, or increased, populations inherent within the compost. Within the literature, it is generally accepted that the existing micro-biotica of a receiving environment are sufficiently robust to out-compete any introduced organism for available resources, this being particularly so for fungi (Donnelly 2002).

3. The efficacy and benefits of composted materials

3.1 Benefits of composted materials

3.1.1 Chemical benefits

Compost provides a supply of nutrients in significant quantities to the benefit of soils and plants, some in slow release forms, reducing the need for future fertiliser applications:

- approximately 15 % of the total nitrogen (N) is available from compost in the first year,
- the release of nitrogen may be at a lower rate in subsequent years,
- nitrogen efficiency increases through organic N accumulation when compost is regularly applied,
- phosphorus, magnesium, iron and other nutrients are also slowly released,
- potassium in compost is in more readily available forms compared with organic N and P,
- sulphur tends to be readily available to plants, and
- compost has a high cation exchange capacity (CEC) that can improve the CEC of light soils and growing media and that will reduce leaching of nutrients

Essential plant nutrients

The composition and availability of the plant nutrient components of compost can vary considerably and depends greatly on the feedstocks, the composting process, the maturity, the storage conditions and the compost quality (Amlinger, Bettina et al. 2002). Whilst many compost products contain significant levels of certain plant nutrients, they rarely contain sufficient in available forms to provide the plant's entire requirements (Wootton, Gouin et al. 1981; Fitzpatrick, Edwin et al. 1998)

Immediate nitrogen (N) availability

The dynamics of N mineralisation and immobilisation are primarily dependent on the C/N ratio and the forms and degradability of the N and C components (Hadas and Portnoy 1997; Amlinger, Bettina et al. 2002). Other factors which affect the rate of availability of nitrogen from organic materials include soil moisture, temperature and microbial activity. Whilst composts can contain significant amounts of N, much of this is in an organic form and so much of it is not easily available to plants (Mays, Turman et al. 1973; de Haan 1981; Giusquiani, Marucchini et al. 1988). On average, composts may contain 7 – 18 g N kg^{-1} of substrate (Mamo, Halbach et al. 1998) and between 5 and 36 % of the total N content is available to plants within the first year (Schlegel 1992; Jakobsen 1996; Diez and Krauss 1997; Hadas and Portnoy 1997; Amlinger, Bettina et al. 2002). In contrast to commercial fertiliser, compost was found to have 16 % of its N bio-available (Terman, Soileau et al. 1972) and Iglsias-Jimenez and Alvarez (1993) reported that mature compost would supply 16 - 21 % of the applied N in the first six months. This is broadly consistent with the findings of other workers, who reported that, on average, 15 % of total compost N is immediately or readily available to plants (Hortenstine and Rothwell 1973; Diener, Collins et al. 1993; Amlinger, Bettina et al. 2002)

Long term nitrogen benefits

Compost has a considerable reserve of organic N that is released over time through mineralisation as the soil biotica utilises the carbon substrate. Whilst in the first year approximately 15 % of the compost N is immediately available for plant use, in the second and subsequent years between 2 and 8 % of the organic N is mineralised (Amlinger, Bettina et al. 2002). In field and lysimeter experiments, Gutser (1996) found that approximately 3.5 % of the compost N is made available per annum in subsequent years. Nitrogen efficiency increases through organic N accumulation when compost is continuously applied. With continuous compost amendments and crop rotations with high nutrient demand the efficiency may increase (Amlinger, Bettina et al. 2002). Gutser and Claassen (1994) estimated that continuous compost application at 100 kg N ha^{-1} an^{-1} of total compost, N input will balance with plant uptake within 40 to 80 years. Computations, based on field trials, estimated that total N application by compost would balance the yearly mineralisation potential after 100 years (Aichberger and Wimmer 1999; Aichberger, Wimmer et al. 2000)

Regular additions of compost would potentially raise the long-term availability of N by as much as 4 kg ha^{-1} an^{-1}. Estimates within the literature conclude that over a 25 - 100 year period such additions could result in a net N mineralisation rate that balances plant requirements. However, these are estimates based on modelling data from short-term studies using 10 – 100 tonnes of compost ha^{-1}. In the UK, composts are not normally applied to agricultural soils at rates above 50 t ha^{-1} an^{-1}. Rules for Nitrate Vulnerable Zones (NVZs) and government guidance of bulky amendment material (such as compost) to agricultural soils restrict compost use through limiting the total organic N application during a specified period.

It is likely that a compost as described above would supply 1.75 - 2.5 kg N per 10 tonne (fresh weight) ha^{-1} in the first year, 0.5 kg N ha^{-1} in the second, 0.3 kg N ha^{-1} in the third, and 0.2 kg in following years. Successive applications, either yearly or bulked every third year, would result, after a 10 year period, in a net increase of available mineral N equivalent to 0.25 - 0.3 kg fertiliser N $tonne^{-1}$ ha^{-1} an^{-1}. An application of 10 tonnes of compost ha^{-1} an^{-1}, applied in three yearly loads (30 tonnes every third year), would result, after 10 years, in the net equivalent, in increased annual mineralisation, of 3 kg fertiliser N ha^{-1} an^{-1} in addition to the long-term increase in N availability of 0.2 kg ha^{-1} an^{-1}. Over a 50 year period, an application of 10 tonnes compost ha^{-1} an^{-1} would result in a net increase in mineral N of 13 kg N ha^{-1} an^{-1}.

Phosphorus (P)

Wide variations exist in the literature on the effectiveness of composts to sustain the phosphorus nutrition of crops (Cabrera, Murillo et al. 1991; Murillo, Cabrera et al. 1997), with the amount of P taken up by a plant from compost in soil/compost mixtures varying from 10 to 264 % of the amount of P taken up from a water soluble mineral fertiliser (Pommel 1982; Bezzola, Lopez et al. 1994; Frei, Candinas et al. 1997). Organic amendments can increase P availability by a) direct contribution through mineralisation, b) reduced soil P sorption, and c) organic complexation of cations (e.g. Al and Ca) that limit P solubility (Hue 1990). Rodd, Warman et al. (2001) found that P concentrations in compost sourced from the same manufacturer in two successive years had 2.23 and 4.15 g P kg^{-1} respectively, although in analysis of plant tissue of barley grown in compost amended soils, P concentrations were in the mid-agronomic ranges for all treatments. Pot experiments by Sinaj, Traore et al. (2002) suggested that white clover initially used a fraction of the rapidly exchangeable compost-phosphate, while at a latter stage, plant roots enhanced the mineralisation of compost organic P. However, the coefficient of utilisation of P by white clover is not only related to the forms of P present but also to its effects on N nutrition and it was not clear as to whether this improved N nutrition was due to compost mineralisation, or to an indirect compost effect on N_2 biological fixation. Similarly, mature compost, when applied at 10 t ha^{-1}, increased total P, water soluble P and citrate soluble P and gave plant growth dry matter accumulation, seed yield and P uptake by soybean equivalent to single-superphosphate (SSP) at 26.2 kg P ha^{-1} (Manna, Ghosh et al. 2001).

Potassium (K)

Of all the beneficial macro-nutrients, K concentrations, relative to all the other nutrients, are generally highest in compost (Table 4). In terms of quantity, K is the second most important nutrient for plant growth and low (rather than high) levels are more likely to be detrimental to plant development. However, excessive quantities can lead to “luxury consumption”, which can interfere with the uptake and physiological availability of the other essential basic cations, magnesium and calcium (Marschner 1998). Adequate levels of K in plants are often associated with hardiness and resistance to disease, and also to improved flowering and fruiting.

Magnesium (Mg)

Compost contains Mg, with levels in UK composts commonly in the order of 3 g kg^{-1}. As with many of the nutrients in compost, availability to the plant is dependent on the concentration in solution, which in turn is influenced by factors explained in earlier sections of this report.

Calcium (Ca)

Compost typically contains about 20 g Ca kg^{-1} and the application of 10 tonnes ha^{-1} of compost would potentially supply 200 kg Ca. With such a low Ca level, any changes in soil (or growing medium) pH bought about by the addition of compost is more likely to be as a result of the effects of adding other basic ions such as K, Na or $NH_{4.}$

Sulphur (S)

The high S levels in compost (1700 mg kg^{-1}) are likely to be beneficial in most agricultural situations, as reduced air pollution has led to S levels in many soils becoming low. However, high S levels may limit the inclusion of compost in growing media intended for the production of the more sensitive plant species.

Chloride (Cl)

Where concentrations are low it has been shown that Cl fertilisation can have beneficial effects on wheat and other cereals leading to increased grain yields (Marschner 1998). Furthermore, Timm, Goos et al. (1986) identified Cl as having a beneficial effect in the suppression of root rot diseases, whilst Fixen, Gelderman et al. (1986) identified Cl as having an influence on improved water retention. In combination, these properties contributed to improved plant growth. Other workers have reported that Cl can improve potassium (K) uptake, with work by Buwalda and Smith (1991) showing increased assimilation in Kiwi fruit.

Sodium (Na)

Of all the beneficial nutrients, Na is perhaps the best understood and, whilst high concentrations are associated with saline soils and physiological drought, the absence of Na for many plant species, in particular those that use the C4 photosynthesis pathways, can be detrimental. The use of Na and its benefits in agriculture and horticulture for non-halophytes is well known (Marschner 1998). It is an essential nutrient for the production of sugar beet, as for many other species, including members of the Amarenthacea, Chenopodiacea and Cyperaceae families (Brownell 1979). Whilst some members of these families are common weeds, there are many more that are grown for ornamental and agricultural purposes. The role of Na in plant nutrition is largely though substitution of K, its presence enhancing the water balance and having a beneficial effect on stomatal operation. Additionally, it increases atmospheric CO_2 utilisation and enhances nitrate uptake by roots and assimilation in leaves, resulting in higher dry matter yields in certain species. Pasture and forage crops can benefit from Na through both increased plant growth and nutrient assimilation. Additionally, further benefits for lactating cows occur as they require higher Na than is naturally present, whilst the K that is substituted still exceeds that required for animal nutrition. The acceptability of the forage and the daily intake is also enhanced (Zehler 1981).

Na has also been associated with the stimulation of root production and the increase in leaf area and stomata numbers (Lawlor and Milford 1973). These earlier observations have since been demonstrated in plant production with compost-amended media, as follows. Gajdos (1997) reported that root dry matter in radish (*Raphanus sativus var. radicula* cv. 'Saxa') increased with increases of compost addition in the growth media. Similarly Ozores-Hampton, Vavrina et al. (1999) reported that media amended with composts increased root, shoot and leaf area in tomato (*Lycopersicon esculentum* 'Agriset 761'). However, the benefits of Na, in particular in tomato production, is cultivar dependent and differences can be quite substantial (Figdore , Gabelman et al. 1987; Figdore , Gerloff et al. 1989).

High Na levels in composts are likely to only have adverse effects when the compost is incorporated into growing media mixes at high rates. At lower media incorporation rates, or when added to soil, Na can be beneficial - encouraging root growth (Ozores-Hampton, Vavrina et al. 1999) and increasing water efficiency (Marschner 1998). However, Na is a basic cation and has a strong influence on substrate pH, potentially raising it to above optimum levels.

Other beneficial nutrients

Knowledge about the nutrients and other beneficial substances in compost increases with advances in analytical techniques. Elements such as silicon, cobalt, selenium and aluminium have all been shown to improve or stimulate plant growth and many others are under consideration (Marschner 1998). Composts made from mixed green wastes are likely to contain some or all of these elements.

Cation exchange capacity (CEC)

The CEC of organic matter and composts is generally much higher than that of soils and peats. Consequently, regular additions of compost to soil, or inclusion of compost in growing media, can improve nutrient holding capacity, thus leading to greater fertiliser efficiency and lower leaching potential.

3.1.2 Physical benefits

Compost provides bulky organic matter to soils and, if sufficient is incorporated according to good soil management techniques, leads to:

- improved soil drainage, and
- improved soil aeration, particularly where soils are 'heavy' or compacted.

Compost organic matter is broken down by micro organisms and such activity leads to:

- improved soil particle aggregation, and
- increased water holding capacity, particularly in 'light' soils.

The improved soil structure leads to:

- greater workability of soil,

- improved resistance to compaction by settlement and trafficking, and
- reduced soil erosion and surface capping.

The improved soil conditions for the plants lead to:

- Better and more rapid rooting into the soil
- Improved water uptake
- Better growth
- Fewer replacements

As a bulky addition to the soil, compost will usually improve many of the physical properties of the soil. Repeated applications will continue to improve the soil. Of greatest benefit is the open and bulky nature of compost that will positively influence soil porosity, thus improving both oxygen diffusion and drainage properties. Both the inherent hydrological properties, which combine and interact with the existing soil properties, and the influence of microbial enzyme and exudate production, which enhance aggregation, can improve water retention. Enhanced diffusion and drainage properties can further improve these physical characteristics. As the physical benefits of compost vary according to end-use, such as in soil improvement or in growing media, more information is supplied within those sections of this report.

3.1.3 Microbiological benefits

Soil health and fertility is largely a qualitative rather than a quantitative parameter. However, it is generally accepted that soil microbial activity and diversity are indicative of soil quality and fertility (Wood 2001). The addition of compost to soil inevitably provides a substrate for microbial growth and, as this improves, so does the fertility and health of the soil.

The use of compost can

- aid plant disease suppression

Plant disease suppression

The role of composts in reducing plant disease incidence has been consistently observed for over 50 years (Howard 1940) and has often been attributed to the activities of antagonistic micro-organisms (Tilston, Pitt et al. 2002). However, in any given situation, there may be difficulty in identifying the specific mechanisms responsible, because chemical, physical and biological mechanisms are interlinked (Darrah 1993).

With composts, most of the work has focused on the biological agents that act to displace pathogenic organisms by "out competing" the disease organisms in the rhizosphere (the plant root zone in the soil) through antibiosis and direct parasitism, and mechanisms that induce systemic resistance to disease in the host plant.

Concentrations of chemicals in the soil or growing medium water solution, as reported with Na, are also important in plant disease reduction (Marschner 1998). Extractable carbon content, nitrate-N content and pH have all been shown to contribute to the suppressive capacity of recycled organic matter composts (Hoitink, Stone et al. 1996; Tilston, Pitt et al. 2002).

Biological control of plant pathogens

Some researchers have identified two principle mechanisms of biological control of plant pathogens, i.e. "general suppression" (competition / antibiosis) where the presence of high microbial activity can inhibit the growth of pathogens (e.g. *Phytophthora* and *Pythium spp.*) or "specific suppression" (antibiosis / parasitism) where a specific organism or group of organisms are responsible for the suppression (eg. *R. solani* , *Fusarium spp*) (Hoitink 1986; Hoitink, Inbar et al. 1991). Similarly, De Brito Alvarez, Gagne et al. (1995) found that the addition of some composts to soil increased the incidence in the tomato rhizosphere of bacteria exhibiting antagonism towards *Fusarium oxysporum* f. sp. *radicis-lycopersici, Pyrenochaeta lycopersici*, *Pythium ultimum*, and *Rhizoctonia solani*.

There is a lack of knowledge in this field with regard to compost and no general relationship is valid for all plant diseases. Only a few diseases have been intensively studied and, as with suppression exerted by healthy soils, important properties, such as clay type or content, ion concentrations and the quality of organic matter are often neglected (Hoper and Alabouvette 1996). The importance of compost, both as a substrate to sustain existing soil microbial communities and as means to reinforce suppressiveness, has been identified by several workers (Jensen 1997; McEwen 1997; Hoitink and Boehm 1999). However, the biological control of plant diseases using compost is only possible if all factors involved in its production and utilisation are defined and kept constant (Hoitink, Stone et al. 1996; Tilston, Pitt et al. 2002).

3.1.4 Environmental benefits

Compost use can benefit the wider environment through

- reducing nutrient leaching

Reduction of N leaching

Compost contains significant amounts of N in organic form that, whilst not easily available to plants, are also less leachable (Mays, Turman et al. 1973; de Haan 1981; Giusquiani, Marucchini et al. 1988; Mamo, Rosen et al. 1999). In studies by Insam and Merschak (1997), compost materials were shown to afford considerably lower risk of ground water contamination in forest soils when compared to unstabilised materials or mineral fertilisers. In a three year experiment, compost materials were found not to affect the nitrate content in the sub soil, whereas mineral fertilisers led to an elevated nitrate content (Schlegel 1992). At an application rate of 100 tonnes ha^{-1}, groundwater contamination did not exceed 10 mg l^{-1} (Maynard 1994) and in a three year trial of compost use, combined with efficient irrigation, positive effects in controlling nitrate discharges in comparison to other fertilisers were demonstrated (Diez and Krauss 1997). In a five year rotation in a sandy soil lysimeter, compost was demonstrated to have high efficiency and reduce nitrate leaching, compared to mineral fertilisers, having a leaching : supply ratio of 8.5 % compared to 47 % for mineral fertilisers (Leclerc, Georges et al. 1995).

Reduction in P leaching

Phosphate losses from agricultural land into watercourses can cause serious eutrophication problems. This has become a particular problem with manure P originating from slurry application. Generally, the P losses are linked with particulate losses from the soil (soil erosion) or slurry run off (incidental losses), which can account for 80`% of the P found in water courses (Jarvis 2000). There is little in the literature on the fate of compost P. However, it is likely that the use of a solid P source, as in compost, will reduce incidental P losses.

3.1.5 Synergistic effects

Through supplying nutrients in combination with organic matter and micro organisms, compost application to soils:

- improves the efficiency of nitrogen fertilisers, and
- increases nitrogen turnover.

Interactions of N with mineral fertiliser

Although laboratory experiments have studied the effects of compost as a component in growing media, both with and without mineral fertilisation (Gajdos 1997; Klock-Moore 1997; Klock-Moore and Fitzpatrick 1997; Raymond, Chong et al. 1998; Ozores-Hampton, Vavrina et al. 1999; Klock-Moore 2001; Chen, McConnell et al. 2002), and many have reported enhanced plant performance, few studies have looked at the effects of mineral N efficiency in relation to compost additions within media mixes. Mamo, Rosen et al. (1999) found that, in field experiments, compost improved the efficiency of added mineral fertilisers with only 125 kg N ha^{-1} being sufficient to obtain optimum yields, whilst N fertiliser alone required 250 kg N ha^{-1} to achieve maximum yields. Similarly, Maynard (1989) and Stoppler-Zimmer, Gerke et al. (1999) found compost additions reduced N losses, and the need to fertilise to the recommended level over a five year crop rotation combining compost and mineral fertilisation N availability ranged from 14 % (cereal dominated, pasture) to 32 % (maize dominated) (Buchgraber 2000).

In a 21 year experiment, compost application led to 16 % of the compost N being utilised by the crop in the first year and rising to a cumulative total of 40 % in the final year. This was attributed to enhanced mineralisation as a consequence of compost use. The calculated mineralisation rate was 5 - 8 % in the first year, 3 - 5 % in the second and 1.5 - 2 % in subsequent years (Diez and Krauss 1997). Similarly, compost application rates of 17.8 t ha^{-1} an^{-1} led to 13 % of the compost N being taken up by the following crop of sorghum and it was calculated that from compost / mineral fertiliser applications, that mineralisation rates from compost amendments ranged from 30 - 36 %. (Schlegel 1992). (Maynard 1989) reported that 56 tonnes of compost ha^{-1}, plus the addition of 73 or 146 kg ha-1 of N fertiliser, resulted in no differences in cauliflower yield, supporting the use of composts in reducing fertiliser use and resulting leaching losses of N.

N mobilisation and immobilisation

The mineralisation-immobilisation turnover (MIT) in every soil and under various conditions results in a net mineralisation rate, or a net immobilisation rate. The knowledge of this rate may be useful for using more efficiently organic and inorganic fertilisers and products added to the soil, minimizing the losses of N, with resulting reductions in groundwater contamination, and improving crop N use efficiency (Madrid, Lopez et al. 2001). Mineralisation is affected by ammonia concentration in soil, the C:N ratio of the soil and of added products, pH, moisture, temperature, other nutrients and aeration (Foncht and Verstroete 1977; Schmidt 1982). Furthermore, N load and mobilisation is strongly linked to the levels of soil organic matter (SOM) and the relative magnitude of the active fraction of the total SOM or to the more passive pool currently undergoing alteration (Nortcliff 1999).

The N mineralisation dynamics are predominantly determined by the soil properties C_{tot} and N_{tot}, C:N ratio, soil texture and hydrological properties (Amlinger, Bettina et al. 2002). Although Hadas and Portnoy (1997) agreed that inorganic N release depended on the availability of C and N and the C:N ratio, they found that mineralisation was independent of the soil type/texture and the compost application rate. Mamo, Rosen et al. (1999) found that net N mineralisation was not enhanced by the addition of N fertiliser to the compost amended soil. One plausible explanation was that the added N fertiliser was recycled / incorporated into the SOM. Such short-term immobilisation may not be undesirable, because it can reduce nitrate leaching and contamination of waters (Hue and Sobieszczyk 1999).

It was calculated (Castellanos and Pratt 1981; van Faassen and van Dijk 1987) that N immobilisation would occur if the compost C:N ratio exceeds that of 15 to 20. Hue and Sobieszczyk (1999) calculated that N immobilisation would be minimal if the C:N ratio of the soil is also maintained between the ranges of 15 to 20. In general, when stabilised organic products are added to the soil, and with an adequate C:N ratio (<20), the mineralisation process is enhanced (Nogales, Gallardo-Lara et al. 1982). Scarsbrook (1965) indicated that, when a C:N ratio <15 exists, then N mineralisation exceeds N immobilisation. However, he further qualifies that C:N ratio is a simplistic tool for determining net mineralisation / immobilisation of N from organic inputs.

Apart from site (e.g. soil moisture effects) and cultivation-specific factors, the availability of nitrogen is predominantly dependent on the following parameters (Amlinger, Bettina et al. 2002):

- C:N ratio of raw material, composting conditions and the maturity of compost (e.g. microbial effects)
- Post treatments e.g. screening and compost quality
- Time of application (e.g. temperature effects)

3.2 Potential constraints of materials

3.2.1 Elemental contaminants

The use of source-separated feedstocks coupled with compliance with PAS100 and complimentary specifications for different end uses for composts will lead to the production of good quality composts that are fit for purpose. The European Commission is addressing many concerns through the introduction of a soil protection strategy and is developing proposals for a directive on biowastes, expected in 2004/05.

Elements, such as chloride (Cl) and sodium (Na), which are naturally occurring in composted products, can have detrimental as well as beneficial effects on plant growth if present in excessive amounts. Consistent and uniform germination is dependent on seeds having easy access to water for imbibition. Water that contains high concentrations of Na ions is not as easily absorbed and germination rates have been demonstrated to be adversely influenced, although subsequent growth was not affected (Gajdos 1997; Raymond, Chong et al. 1998).

Electrical conductivity (EC) is the measure of the total soluble salt concentration in a solution. Where the salt concentrations are high, but the relative ratios of the soluble nutrients are balanced, the effects are lessened compared to a situation, as is often the case with compost, where the EC is a consequence of a high concentration of a single chemical component such as K, NH_4 or Na. In general, EC values below 1000 microSiemens/cm (100 mS/m) are regarded as acceptable for most horticultural substrates. Levels of potentially toxic elements in composts are generally at low levels and forms of the elements Cu, Ni and Zn are also part of the range of nutrients required by plants.

Nutrient availability is partly pH dependent, with many mineral elements (e.g. P and Mn) becoming more insoluble with rising pH. Whilst high pH can often be mediated by dilution with acidic substrates, changes in availability will be dependent on thorough homogenisation. Equally, this effect extends to the PTE content of compost, with high pH locking elements out of solution, whilst the lowering of pH may result in PTEs entering into solution and becoming more available to plants, or migrating into the ground water.

3.2.2 Physical contaminants

Concern over the presence of physical contaminants (e.g. glass, metals, ceramics, plastics or stones) in the finished product has been addressed by the introduction of PAS 100, in conjunction with compost specifications for the landscape and growing media industries.

3.2.3 Biological contaminants

Concerns about the presence of potentially harmful organisms (plant, animal and human pathogens) have been extensively reviewed by Jones and Martin (2003) and Noble and Roberts (2003). The risk of introducing plant diseases through insufficiently composted feedstocks is being addressed by a WRAP-funded project in 2003/04 carried out by Horticultural Research International (HRI). An unstabilised compost may also provide a plant pathogen with an opportunity to re-establish in soil and methods to assess compost stability have been investigated by WRAP. Use of composts that comply with PAS 100 and meet the complimentary industry specifications for different end use markets is unlikely to be constrained by the incidence of biological or other contaminants.

3.3 The use of compost in agriculture

The use of compost in agriculture is likely to rise significantly as composting increases in the UK. The benefits of compost to agriculture are that:

- it provides a source of nutrients that are present in significant quantity and are balanced for crop needs
- it improves the utilisation of applied nitrogen fertiliser
- it provides organic matter that can improve soil structure, C.E.C., water infiltration and water holding capacity
- the added micro organisms are able to recycle nutrients and aid in plant disease suppression
- it saves on the costs of fertilisers, pesticides, cultivations and irrigation, and
- it improves crop yields

Repeated applications of compost over time may be necessary to maximise these effects.

3.3.1 Plant nutrition effects

Organic manures from cattle, pigs and poultry that are used in agriculture include farmyard manures (FYM), litters, sludges and slurries. Biosolids (sewage sludges) are also applied to land. Compost derived from source-separated municipal wastes, which has to compete with these materials, has different properties. Compost may have been made with the addition of some of these alternative materials, leading to uncertainty about how, when and the quantity to apply to soil. However, if the proportion is relatively small then the compost will not be significantly different from compost made solely from plant residues. Therefore, it is always advisable to know the feedstocks that were used to produce the compost and to have an analysis of the compost, or manure, prior to application.

It is the nutrient content of the organic manures, sludges or composts that will be of primary interest to a farmer, as this has the greatest effects on farm costs and is easiest to quantify. Nutrient management information for manures used by farmers is given in RB207 Fertiliser Recommendations for Agricultural and Horticultural Crops (Anon 2000) and Managing Livestock manures (Chambers 2001).

Typically, 60 % of the phosphate (P_2O_5) and 90 % of the potash (K_2O) contained in these manures is available to the next crop. Because the nitrogen (N) present in these materials is relatively available (Chambers 1992), the timing of application plays an important role in the usage of the N by the next crop. Slurries and poultry manures are 'high' in the proportion of readily available N (40 - 60 % of total N) compared with FYM, which is 'low' in available N (10 - 25 % of total N). However, the availability of the N in compost is usually below 10 % (and often between 1 - 5 %) so the timing of application is less critical. Autumn application, therefore, does not lead to environmental problems of groundwater contamination and spring application does not lead to odour problems from ammonia volatilisation. The application of organic materials should be made with reference to the Soil Code and NVZ regulations.

Carbon to nitrogen ratio (C:N) is often used as an indicator for the rate of N release. Nitrogen release from plant tissues was shown to be related to the C:N ratio with N being released when the ratio was below 20:1 (Swift 1979). For manures, the C:organic N ratio (with ammonium-N stripped) was found to be a good indicator of N release over the first 4 - 6 weeks plant growth (Chadwick, 2000). For C:N ratios between 12 and 15, the proportion of organic N mineralised was below 18 % and, above a ratio of 15, the organic N mineralised was less than 10 %. However, it was also found that the N mineralised was related to the initial mineral N content prior to stripping. As compost feedstocks contain little mineral N compared with manures, the N release is likely to be much lower from compost. This may be related to the types of organic matter containing the N and their rates of breakdown in soil.

From recent projects conducted in the UK, the Tables 17 and 18 below give some chemical properties of various composts and manures.

Table 17: Physical properties, organic matter, and nitrogen content

Parameter	BD	M	DM	LOI	OC	Total N	C:N	pH	EC	w/s NH_4-N	w/s NO_3-N
Units	g/l	%	%	%	%	%	X:1		µS/cm	mg/l	mg/l
Compost [1]	503	36.5	63.5	30.5	15.5	1.25	12.5	8.3	834	35	31
Compost [2]	480	43.3	56.7	44.4	25.8	1.24	20.8	8.8	700	64	8
GROWS [3]	n/a	34.5	65.5	40.6	n/a	1.78	23.0	8.7	2300	243	696
HDRA [4]	n/a	n/a	n/a	19.4	12.6	1.08	11.6	8.4	880	4	112
Cattle FYM [5]	n/a	n/a	n/a	31.2	23.5	2.17	11.0	8.9	3152	48	183
Poultry manure [5]	n/a	n/a	n/a	29.5	19.9	2.41	8.4	7.4	4358	332	739

Notes

BD = bulk density of wet sample; **M** = moisture content; **DM** = dry matter content (100% - water content); **LOI** = loss on ignition at 450-550°C; **OC** = organic carbon; **Total N** = total nitrogen of dried sample; **C:N** – carbon to nitrogen ratio of dried sample; **pH** = standard units (<7 is acidic, >7 is alkali); **EC** = electrical conductivity (an indicator of total water soluble salts); **w/s** = water soluble; **NH_4-N** = ammonium-N; **NO_3-N** = nitrate-N

Table 18: Total nutrients

Parameter	P	K	Mg	Na	Ca	S	Fe	Mn	B
Units	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Compost [1]	2086	8035	2963	608	18804	1642	13125	327	23
Compost [2]	2455	7970	1825	566	26300	1655	9670	262	21
GROWS [3]	8800	27100	5000	n/a	49600	n/a	n/a	n/a	n/a
HDRA [4]	2350	8475	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Cattle FYM [5]	5600	32575	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Poultry manure [5]	12950	22150	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Notes

P = phosphorus; **K** = potassium; **Mg** = magnesium; **Na** = sodium; **Ca** = calcium; **S** = sulphur (now sulphur);**Fe** = iron; **Mn** = manganese; **B** = boron; all figures expressed as mg/kg dry matter = parts per million (ppm). **Note** P x 2.29 =phosphate and K x 1.2 = potash

Sources:
[1] WRAP landscape specifications project based on Composting Association and ReMaDe data
[2] Compost use in Agriculture, Enviros Consulting 2002
[3] Open windrow GROWS Project compost – vegetable waste and manure
[4] Wyvern compost 1997-2000 HDRA Report
[5] 1997-2000 HDRA Report

Compost and nutrient application rates

Based on Tables 17, 20 tonnes of compost in dry matter form equates to 31.5 tonnes of fresh compost. If applied to one hectare of land, this would provide the soil with the amounts of nutrients as shown in Table 19 below.

Table 19: Nutrients applied at 20 tonnes dry matter ha^{-1}

Nutrients	Total amount (kg/ha)	Available year 1 (kg/ha)	Available year 2 (kg/ha)
Nitrogen as N	250	25 (10 %)	12 (5 %)
Phosphate as P_2O_5	100	60 (60 %)	20 (20 %)
Potash as K_2O	200	100 (50 %)	50 (25 %)
Magnesium as Mg	60	18 (30 %)	18 (30 %)
Sulphur as S	30	15 (50 %)	7 (25 %)

Note: S x 2.5 = SO_3 ; Mg x 1.66 = MgO

The figures for the available nutrients are examples only based on the percentages in brackets. Availability may vary from these figures depending on the feedstocks and the characteristics of the composts.

The nutrients calculated from the actual application rates, nutrient contents and availabilities should therefore be taken into account in the nutrient management of the rotation. Compost may be applied annually, according to the rules for nitrate vulnerable zones (NVZs), with up to 250 kg/ha total N from compost in selected, individual fields and according to crop available-N requirements. Note that compost and other N-source fertilizing materials applied to selected fields must not exceed 'whole farm' limits for total N addition per year. Readers should refer to the NVZ regulations and an advisor for further information and advice. For land not within an NVZ, 500 kg/ha total N from compost may be applied once every two years. Crops such as potatoes, which respond to high potash applications, may therefore be targeted for the compost application within the rotation.

More than 95 % of the N in the soil is organically bound. It therefore has to be mineralised by the micro organisms before it can be taken up by the plants as ammonium or nitrate. Organic fertilisers, such as farmyard manures or composts made from plant materials, contain different ratios and forms of organically bound N, influencing the rate of nitrate release from them. In slurry, for example, only up to 30 - 50 % of the N is organically bound. The rest is readily available to the plant in the form of ammonium-N. In composts, more than 90 % of the N is organically bound. The release of plant-available N is slow and long-lasting. The process and rate of mineralisation is related to temperature, soil moisture and microbial activity.

Beneficial use of compost depends on identifying a management strategy that supports crop production and protects water quality. (Mamo, Rosen et al. 1999) found that annual compost application, with reduced supplemental fertilisation, was the best management strategy to reach optimum crop yield while minimising nitrate-N leaching losses. The estimated N mineralisation in their research ranged from 0 to 12 % and 3 to 6 % in the annual and single compost addition, respectively and was influenced by the C:N ratio of the composts. The nitrogen and carbon mineralisation dynamics of composts was compared with manures (Hartz, Mitchell et al. 2000) and indicated that 5 %, or less, of the total nitrogen in compost was mineralised.

Available potassium levels in soils under potatoes are of concern (Skinner 1998). Index 2 is generally satisfactory for most crops but, for potatoes, high index 2 or 3 is preferred. Thirty five percent of soils samples under potatoes were found to be index 1 or below. Compost can supply significant amounts of potassium, as shown above, and can raise soil indices. Green waste compost was applied to soils in South-West England and forage maize grown (Parkinson, Fuller et al. 1999). Crop yield showed a positive response to fertiliser, with an additional response to compost. Annual applications of compost at 50 t/ha significantly increased soil organic matter, and extractable potassium and magnesium.

Nutrients such as sulphur are becoming more deficient in UK soils as atmospheric deposition declines due to reduced air pollution (Anon 2000). Compost can contribute to the sulphur supply to crops, especially on light soils. Sodium is also often applied to beet crops and compost can maintain a supply of this secondary nutrient to the soil.

Many reviews of the use of composts have been conducted and, generally, conclude that compost has a positive influence on soils and plants (Gallardolara and Nogales 1987). It improves physical properties such as porosity, water holding capacity and bulk density. It also promotes the buffering capacity of soil and increases the organic matter content and cation exchange capacity. Appropriate application of high quality composts should ensure that neither levels of organic pollutants, or potentially toxic elements, in the soil build up to toxic concentrations.

Soil incorporation of composts usually results in a positive effect on the growth and yield of a wide variety of crops and the restoration of ecological and economic functions of land. Agricultural uses of compost have shown promise for a variety of field crops but specific responses are crop and site dependent (Shiralipour, Mcconnell et al. 1992). In most cases, yields are highest when composts are applied in conjunction with fertilisers.

Effects on soil pH and electrical conductivity (EC)

The pH of soil is reduced when acidifying inorganic fertilisers are applied. Compost has a small neutralising value (NV) of 5 % CaO equivalent in the dry matter (3% in fresh compost), compared with 50 % for ground limestone or chalk (Boon 1999). The NV of 30 tonnes of fresh compost is therefore equivalent to 2 tonnes of limestone. This rate is able to maintain soil pH, with repeated applications raising pH slowly.

Due to high salinity (as indicated by EC) of some composts, salt sensitive seed should not be sown within two weeks of compost application, a precaution that is routine for many fertilisers and other manures. Manures may have a much greater EC than compost, so compost is generally safer in this respect (see Table 17 above). Soil EC, soil nitrate levels and pH were found to be largely unaffected by compost addition compared with inorganic fertiliser (ammonium nitrate) which acidified the soil, and increased the soil EC and nitrate levels (Stamatiadis, Werner et al. 1999). A positive interaction between compost and inorganic fertiliser was seen with increased broccoli yields from the combination.

3.3.2 Physical effects

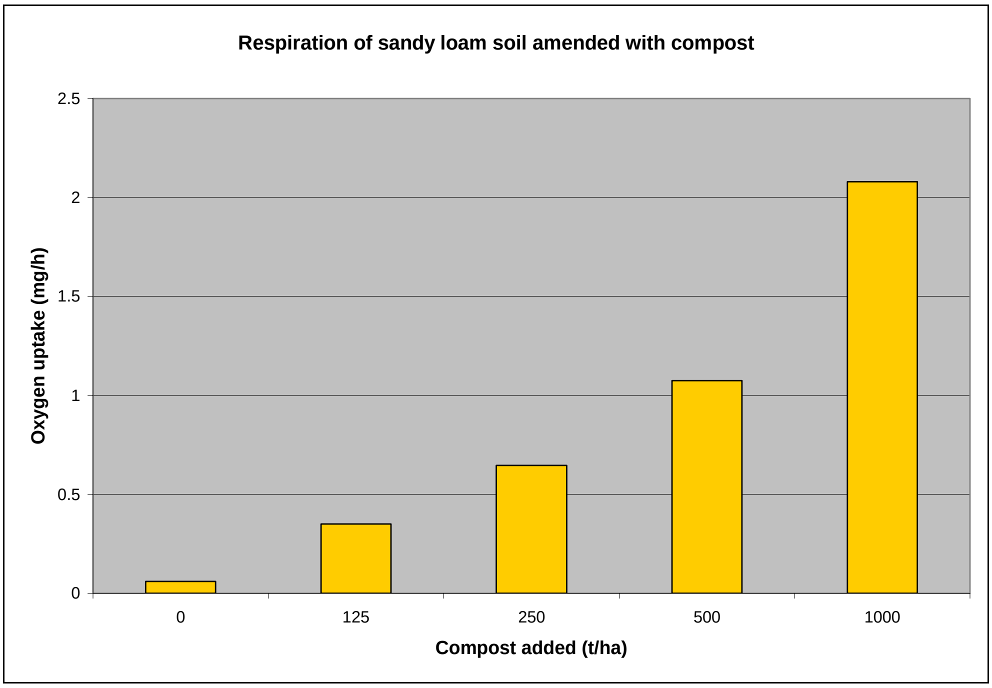
In England & Wales, soil organic matter levels declined from 1980 to 1995 from 3.4 % to 2.8 % in arable / ley cultivation, mainly due to ploughing out of grassland and on lowland organic and peaty soils in tillage (Webb 2001). The threat from soil erosion to crop productivity will be greatest on shallow soils (less than approximately 30 cm depth) - mostly over chalk and sandstone - as further removal of soil will lead to increased drought stress. The textures of soils most at risk from erosion are sandy or loamy soils with less than 30 % clay or, alternatively, fine sandy soils with less than 3.4 % organic matter. 20,500 km^2 was calculated to be at risk in arable areas in England and Wales (Morgan 1985).

Fifty tonnes of compost/ha can apply 10 tonnes of organic matter/ha and raise the soil organic matter (SOM) level by 0.25 %. If applied annually, this would lead to a gradual rise in SOM, albeit counteracted by mineralisation (based on 3,000 t soil/ha in the top 30 cm with a soil organic matter content of 2 % in the dry matter). The average soil organic matter content of arable soils in England and Wales is 4.1 % but a significant proportion is low in organic matter (<2 %) (Skinner 1998).

Compost contains organic matter, which, in conjunction with biological activity, aids the formation of soil structure. A literature review was conducted for the Enviros project 'Compost use in Agriculture' (Blake 2002). In summary, compost has the potential to significantly improve the structure aggregation of soils. It contains the chemical building blocks, which are the precursors of soil humic substances and polysaccharides which, in turn, bind soil particles into aggregates.

Soils and composts naturally contain the micro organisms required for biodegradation and synthesis. The application of compost as a source of organic carbon and micro organisms has a priming action on soil microbial fauna and flora, both adding to, and stimulating the activity of the soil microbial biomass. Work carried out by Reading University (Wallace 2003 unpublished data) in laboratory studies demonstrate this effect as shown in Figure 1.

Figure 1: Respiration of sandy loam amended with compost



Long-term experimental trials are required to fully demonstrate the effects of organic matter on soil structure. Such experiments have been conducted on the soils at Broadbalk, in one of the 'Rothamsted Classical Experiments' (Anon 1991). Here, FYM application resulted in soil containing more than twice the organic matter content (4.6 %) than plots receiving mineral fertiliser only (2.1 %). Also at Rothamsted, the changes in organic matter status of a soil were demonstrated where, under arable cultivation, the SOM was 2.2 after 7 years, compared with 3.4 % under a grass ley for 7 years (Clement 1964). In a silt loam in Lincolnshire, soil under grassland for 100 years had a SOM of 7.6 %, compared with the same soil, which had been ploughed up into arable for the last 25 years, which had a SOM of 2.2 %. The aggregate strength of the grassland soil was much greater than that of the arable soil (Low 1972).

Water movement into and through a soil, plus aggregate stability, was measured in a soil with 88 % sand and 7 % clay (Benbi, Biswas et al. 1998). The saturated hydraulic conductivity of the soil and infiltration rate were improved where farmyard manure was applied. Organic carbon was increased and the percentage of water stable aggregates raised, as shown in Table 20.

Table 20: Water stable aggregates

	Saturated conductivity cm/hr		Infiltration rate cm/hr	% water stable aggregates	% organic carbon
	0 - 15 cm depth	15 - 30 cm depth			
Control	3.5	1.80	1.1	16.8	0.26
NPK fertilisers	3.67	1.74	1.1	19.6	0.30
FYM + NPK	4.43	2.17	1.6	29.2	0.42
LSD (0.05)	0.58	0.31	0.5	0.4	0.02

In Australia, changes in particulate organic carbon (POC) relative to total organic carbon (TOC) were measured in soils with a wide range of different land uses. POC tended to make up a greater proportion of TOC under pasture and more conservative management than traditional cropping regimes. POC was the form of carbon preferentially lost when soils under long-term pasture were cultivated (Chan 2001).

Various soil properties were measured following the amendment of two soils by compost applied at various rates (Aggelides and Londra 2000). In the loamy soil, organic matter was increased from 1.1 % to 2.5 %, pH raised from 6.8 to 7.1 and the cation exchange capacity (CEC) increased from 14.4 to 20.1 meq/100g following compost application at 35 t/ha. Greater increases were associated with higher compost application rates. For the clay soil, effects were less marked. Organic matter increased from 3.2 to 4.4 %, pH was raised from 7.6 to 7.7 and CEC increased from 54.2 to 55.8 meq/100g. This shows that greater benefits can be conferred on lighter textured soils. Compost addition also increased hydraulic conductivity and total porosity, and decreased bulk density, in both soils. Compost increased the soil water retention capacity and improved soil aggregate stability.

Soil available water capacity was found to increase from 15.1 % to 17.1 % with incorporation of compost (Naeini and Cook 2000). Maize yields were increased in trials in South East England and were attributed to the additional potassium input from the compost. A lower ratio of calcium plus magnesium to potassium was seen in the plants but this was found to be due to increased potassium uptake and not decreased calcium or magnesium uptake.

3.3.3 Biological effects

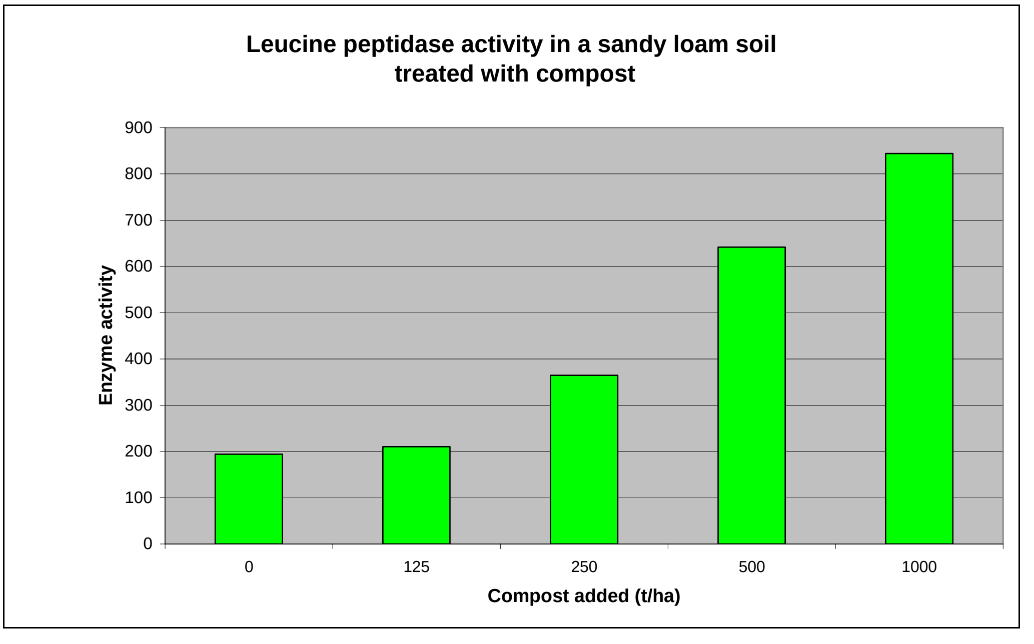
The process of soil aggregation was shown to be mediated by microbial action in an experiment on a Rothamsted soil (Watts 2001). It was also shown that a soil with a greater respiration rate (and a greater microbial activity) had a greater amount of soil aggregation.

Compost consisting of highly biodegraded organic materials is needed in plant growing media. However, when compost is applied to land, its effect is through the initiation and acceleration of microbial processes, leading to the production of soil stabilising agents (Sela, Goldrat et al. 1998). These researchers found that optimal activity was obtained in compost sampled following 7 - 14 days of windrow composting. Polysaccharide concentrations in soil also followed a similar optimum curve, peaking with application of 14 - 30 days-old compost. From the environmental point of view, the composting of any organic waste is a process that should preferably eliminate, or at least acceptably reduce, the environmental damages inflicted by the waste. Composting should also reduce the volume of the waste and improve its handling properties.

Stability and maturity are terms that have become established for how biodegraded composted material has become. Compost should have reached a degree of stability that will not result in environmental nuisances when handled and applied to soils, or at least minimise them. The management and duration of a composting process should be set with compost end-uses in mind. For example, compost applied to soils should be sufficiently biodegraded that it does not induce oxygen depletion in the soil, lock up soil nitrogen, or contain phytotoxic concentrations of natural, chemical by-products of biodegradation, such as ammonium-N and organic acids. Thus, where the key benefit sought from compost is an improvement of soil structure and it is possible to maintain a period of approximately 14 days between compost incorporation and plant seeding/establishment, the batches used for this purpose may be composted over a shorter duration than is necessary for other end-uses. Such practice also reduces costs of production for the relevant compost batches.

Where compost is added to soil, it has been shown, in work carried out by Reading University, that enzyme activity in the soil is increased in proportion to the amount added, see Figure 2, (Wallace 2003 unpublished data). There may also be a cumulative effect from smaller, annual additions. Annual application of adequate amounts of compost (Albiach, Canet et al. 2000) led to a significant increase of soil enzymes activities. The activity of the enzymes was related to nitrogen, phosphorus and sulphur nutrient turnover cycles.

Figure 2: Effects on enzyme activity from compost applied to soil.



3.3.4 Plant diseases

The value of the organic matter and microbial life in the compost has not been fully quantified in the UK, although extensive work has been carried out in the USA. The risk of introducing plant diseases through feedstocks is currently being examined in a WRAP-funded project in 2003/4 by Horticultural Research International (HRI). An unstabilised compost may also provide plant pathogens in soil with an opportunity to re-establish after application. Methods to assess compost stability have been investigated by WRAP (2003).

Many crop diseases are soil-borne. Some attack a wide range of crops but, without a host, they are short-lived, e.g. 'Take-all' of cereals and grass. Others have a narrower host range, coupled with long-term survival in the soil, e.g. onion white rot *Sclerotium cepivorum* and pea wilt *Phoma medicaginis*. Club root of brassicas *Plasmodiophora brassicae* is a particularly difficult disease as it has a wide host range and is very persistent.

'Take-all' in wheat, *Gaeumannomyces graminis*, is favoured by light alkaline soils and above average rainfall in winter and spring. It is common in intensively produced cereal crops. Work by Exeter University (Pitt 1998) indicated that 50 t/ha of green compost may be effective at reducing the effects of this disease by up to 80 % under controlled conditions. Similar control was found for pea wilt and onion white rot in glasshouse trials. Field trials managed by Exeter University found that only 20 - 30 % suppression of take-all was achieved, although a 40 % increase in yield was obtained.

All brassica crops may be affected by club root. Cultural controls include liming and improved drainage. Compost has both a small liming effect and can improve the drainage of heavy soils. It would therefore seem to be a promising control agent. This was indeed found to be the case in glasshouse trials conducted by Exeter University. In field trials, club root was controlled in the season of application only, at 100t compost/ha. These researchers also investigated black scurf of potatoes, caused by *Rhizoctonia solani*, which may also be reduced by compost application. This disease affects the quality of the skins and hence the market value of the potatoes.

More research on these diseases is required in the UK in order to prove that compost can be effective, and to establish the limiting factors that need to be managed to optimise the control of soil-borne plant pathogens. The end result should be an enhanced value for compost in agriculture when targeted at these diseases.

3.3.5 Results from practical trials

The following projects were largely funded through the Landfill Tax Credits Scheme. They showed that compost could:

- increase crop yields,
- increase soil organic matter content,
- improve soil structure, aeration and drainage,
- improve water infiltration rates and increase water holding capacity,
- increase the availability of primary and secondary nutrients,
- interact with inorganic fertilisers raising the efficiency of their use,
- increase the diversity, population and activity of soil organisms and the natural suppression of soil-borne plant pathogens, and
- maintain or raise soil pH levels.

Note that the rate at which, and extent to which, these beneficial effects occur depend, in part, on the rate and frequency of compost application. Improvements to soil organic matter, structure, aeration, drainage and pH tend to take longer that the other effects listed above.

ReMaDe projects

The Recyclables, Market Development (ReMaDe) programmes in the UK have generated some information on the use of compost in agriculture and horticulture. ReMaDe Essex conducted a project on a very heavy clay soil using a range of rates of compost (up to 400 t/ha) in conjunction with inorganic nitrogen, with oil seed rape as the test crop. This resulted in yield increases of almost one tonne of seed per hectare. ReMaDe Kent and Medway conducted a trial on onions in 2002. This showed increased plant establishment and crop yield from the use of compost.

The 'Grows' project

Compost was manufactured from supermarket store waste and farm organic manures using three composting systems: open windrow, the Gore cover system and the BioSal in-vessel system. In the open windrow, the crushed store waste was mixed with spent stable bedding (1 - 2 parts bedding: 1 part crushed store waste by volume).

These materials were then tested in a field trial (Pickering 2003) during the 2001/02 growing season. The composts produced from the different systems did not differ in their effects on the yield of triticale, but raising the application rate from 0, 28 or 41 tonnes/ha to the highest rate of 81 tonnes/ha did increase yield. This was ascribed to increased availability of nutrients. However, the soil at the site had a relatively high organic matter content (approximately 6 %) making significant nitrogen responses hard to detect.

There were positive effects from the compost applied on available phosphate, potash, magnesium and organic matter levels immediately after application and on phosphate and potash after harvest. No effects were seen on soil pH, soil potentially toxic element levels or weed growth following compost application. No adverse effects were seen on seed germination. This work supports the findings of others, who concluded that repeated compost applications are likely to be beneficial through the gradual improvement of soil fertility.

HDRA reports

HDRA Consultants' booklet 'Using compost in agriculture' (Edwards) was a guide based on research carried out by the HDRA organisation 'Researching the use of compost in agriculture – report of field trials 1997-2000' (Anon 2000). Three trials were conducted, two on-farm trials and a further replicated trial at HDRA's research grounds. The fully replicated trial was a four-year study of compost use within an organic field vegetable cropping sequence. Various rates of compost were applied and compared with manures and an untreated control. Generally, there was a steady increase in yield, relative to un-amended plots, when compost was applied annually. However, at the beginning of the rotation, a grass clover ley was ploughed in and the soil had a relatively high background level of organic matter and so treatment effects were difficult to detect. Subsequently, no significant treatment differences were found in the potato crop yields or quality in 1997, nor the onions in 1998. In 1999, cabbages showed a significant increase in marketable yield in plots receiving repeated amendments but in the next year onions did not.

Nitrate leaching was assessed by utilising ceramic cups installed after the harvest of the potato crop. There were no significant differences in losses between treatments, suggesting that there is no increased leaching risk as a result of applying compost, even at a high rate. The proportion of plant-available nitrogen from compost and farmyard manure was found to be relatively low compared with that from poultry manure and slurry. Mineral nitrogen in the top 30 cm of soil was measured regularly. This showed that mineralisation of compost N was less than 10 % from the compost.

Soil pH rose only slightly from pH 6.5 in response to compost additions over four years. No measurable changes in total organic matter were found. Improvements in soil bulk density, particle density and aggregate stability due to compost addition to the soil were statistically non-significant. It was concluded that the level of original soil organic matter (3.5 %) masked effects of the treatments and that trials over a longer period of time, with repeated applications, would be required to detect differences on this site.

Soil available phosphorus (index 2) remained steady in the un-amended plots and a slight rise was seen from compost or FYM addition. In comparison, the effects of poultry manure raised the soil P index to 3 by 1999. Potassium declined from index 2 to index 1 in the un-amended plots, whereas the annual addition of compost maintained the soil K status. Magnesium levels did not change from index 3. Small increases in soil potentially toxic element (PTE) levels were detected due to the addition of compost, showing that repeated applications over a long period could result in changes to the soil.

Levington Agriculture reports

A series of trials with green compost were conducted by Levington Agriculture Ltd in the late 1990s and early 2000s, starting with two trials on oilseed rape (Wallace 1996). In a heavy soil, plant populations were significantly increased in the autumn after planting by compost application rates of 25 t/ha and above. By November, plant vigour was increased by 12.5 t/ha and above but, by spring, only applications above 25t/ha showed effects on vigour. In the light textured soil, final populations were not affected by the addition of compost, but plant vigour was improved in the autumn. By the spring, only the highest rate of compost, 100 t/ha, showed significant effects on plant vigour relative to untreated soil.

From the analysis of crop samples in the spring, the phosphorus content of the oilseed rape plants was increased at the site with low P index (heavier soil), and potassium content was significantly increased at both sites by the application of 100 t/ha compost. The addition of compost to the soil, in addition to the farm standard nitrogen topdressing, did not result in any significant increase in seed or soil yield.

A project was commenced in 1999, through Enventure Research, on a farm with light textured soils in East Anglia with low organic matter (Boon 1999). On two adjacent sites, potatoes and sugar beet were grown to compare compost applied at two rates (50 and 100 t/ha fresh compost) in conjunction with full, reduced or nil nitrogen against untreated and farm standard fertilisers in replicated trials. The trials demonstrated that compost alone could not provide adequate available nitrogen for potato or sugar beet crop growth equal to inorganic fertilisers, but that, in combination with reduced N inputs, compost could replace base dressings, especially in terms of potassium addition. Soil-available nitrogen after harvest, where compost had been applied, was not significantly different from untreated plots, indicating that there was no increased risk of nitrate leaching into ground waters.

The project was continued in 2000 at the sugar beet site, where winter wheat was grown to test the residual effects on the compost applied in 1999 (Wallace 2000). The soil pH had been maintained by the application of compost, whereas the inorganic fertilisers had resulted in a slight fall in pH from 7.8 to 7.5. Soil-available potassium had been raised by compost addition, from 103 mg/l to 121 and 159 mg/l for the 50 and 100 t/ha of compost respectively, when applied with nitrogen.

This site had a low available sulphur level and it appears that the winter wheat responded to the residual S applied in the 100 t/ha compost applied the previous year in conjunction with the full rate of inorganic fertiliser N. A small amount of nitrogen was released from the compost which, at the 100 t/ha compost rate, resulted in a yield response of 1 t/ha of grain above untreated. Where N inputs were reduced by 80 kg N/ha, but compost had been applied at 100 t/ha the previous year, yields were not significantly different from the full N rate alone. The greatest yields were achieved from full N plus 100 t/ha compost in 1999, due to the interactions with the other nutrients applied.

Spring barley was sown in 2001, with the treatments as in 1999 but with the inorganic fertilisers adjusted to allow for the 2001 crop (Turner 2001). Again a positive interaction was found. Compost plus high nitrogen input from inorganic fertilisers giving the best yields. However, yields were low overall due to late planting following a wet winter. This site was incorporated into subsequent Enviros trials using the same treatments on the same plots.

Enviros Consulting trials

A project commenced in autumn 2001, through funding by EB Nationwide, on seven sites over three years in Eastern England, with one site continuing on from the Levington Agriculture project. The results for year one are, as yet, unpublished but good yield responses have been demonstrated, with interactions between compost and inorganic fertilisers.

The soils were analysed post 2002 harvest. Soil pH has been maintained between 7.5 and 7.6 by compost addition, compared with 7.6 in untreated and a lower pH of 7.4 where only inorganic fertiliser was applied. Soil-available phosphate has been maintained or increased by compost depending on crop offtake (dependent on N applied and subsequent yields) and the rate of compost applied. Soil-available potassium has been raised by the application of compost, from 140 mg/l in untreated plots (index 2-), to over 200 mg/l in high compost application plots (index 2+), with low crop offtake. Application of compost has increased soil organic matter (SOM). Untreated plots have an average of 3.23 % SOM, rising to 3.57 where 100 t/ha of compost had been applied (Wallace 2003 unpublished data).

Liverpool University reports

The University of Liverpool reported on the 'The potential for the sustainable use of compost in arable crop production' in February 2002 (Whyatt 2002). They found that compost has a liming effect on soils and that it is a good source of potassium, which is rapidly available from the compost following application and incorporation. The report confirmed that mineralisation of the organic–N was slow and that compost does not cause nitrate leaching. No increase in the total concentrations of each PTE tested in the receiving soil were recorded as a result of compost addition.

The 2003 report gives results of further work, especially on the changes in soil microbiology.

Other Entrust reports

Reading University are conducting a project on compost use in agriculture through the Berkshire Trust.

'Applying compost – benefits and needs'

The proceedings of this EU-funded review are published on the http://europa.eu.int/comm/environment/waste/compost/index.htm web site. The following items are extracted from a number of the papers presented in the conference held in November 2001.

Highest yields are attained in an environmentally acceptable way by a combination of organic and inorganic fertilisation. Compost is a suitable material to increase the carbon content of soils due to its stability, which gives lasting improvements to soil physical characteristics (Korschens 2001). An increase in the carbon by 0.1 % results in:

- an increase in hydroscopicity of 0.06 to 0.08 %
- an increase in water holding capacity of 0.4 to 0.6 %
- a decrease in dry matter density of 0.004 to 0.005 g/cm3
- a decrease in bulk density of 0.006 to 0.008 g/cm3

Work by Ghent University (Nevens 2001) concluded that repeated applications of composts, in conjunction with animal manures, enabled the reliance on additional inorganic fertiliser to be progressively reduced each year.

Nutrient efficiency was discussed in work by the Technical University of Munich (Ebertseder 2001). They found that the nitrogen and sulphur present in composts were only very slightly soluble in water but, in contrast, 35 % of the phosphorus and over 75 % of the potassium was dissolved in CAL (Calcium-Acetate-Lactate solution). N utilisation by the crop in the year of application accounts for not more than 5 % of the total N applied, but this varies according to the quality of the compost, its feedstock materials, application date, etc. The immediately plant available N is related to the water extractable N in stable composts but, in less stable composts, the carbon forms into which nitrogen is bound and the rate at which they are broken down govern N release. A review of the fertilising effects of compost (Weinfurtner 2001) summarised that the utilisation of nutrients differs and depends on the type of compost and site-specific conditions. For example, in moderately acid soil, phosphorus was 70 % as effective as inorganic P fertiliser, whereas in slightly basic soil, it was only 20 % as effective. The application of compost increases yield and, in part, the quality of plants but compost is not an equivalent to mineral fertilisers. Combined with mineral N supplementation, repeated application of composts to soils can lead to the same yield as a mineral NPK fertiliser regime. This is because compost is primarily a substitute for P and K fertilisation.

The phosphorus (P) forms comprise soluble forms and organic compounds, plus relatively insoluble inorganic compounds which tend to increase as a proportion with compost maturity. The P in compost should be viewed as available to plants 'long-term', similar to the transformation products from soil-applied mineral P fertilisers. The potassium (K) in compost is more easily soluble and its plant availability can be equated with that of inorganic fertiliser. The sulphur in compost comprises a readily soluble portion as well as organically bound S, which is slowly released as with nitrogen.

Disease suppression was demonstrated by the University of Kassel (Bruns 2001). Horticultural crops were tested and significant reductions in *Pythium spp*. root rot was observed for cucumber as well as other plant / pathogen interactions such as cucumber / *Rhizoctonia solani* and tomato / *Phytophthora nicotianae*.

Compost was found to increase the numbers and mass of earthworms over four years, especially when applied at 22.5 t/ha annually, rather than twice this amount every two years (Christiaens 2001).

The effect of compost on physical soil properties was presented (Weinfurtner 2001). It was concluded that effects were sometimes difficult to show with statistical significance but that effects should be expected on the soil structure of sandy or clayey soils. Annual application of small amounts of compost was said to be more effective than the single application of a large amount. Several years of experiments in Austria (Kluge 2001) have shown that soil-improving effects of compost application develop gradually over time and that long term experiments are required to demonstrate them. Susceptibility of soils to erosion was shown to be decreased by the application of compost in loamy soils, by increasing their water infiltration rate and the stability of aggregates (Ebertseder 2001).

3.4 The use of compost in landscaping

Most landscape projects are associated with the development of greenfield sites or previously developed land (brownfield sites). Landscape specifications are based on a layer of 'topsoil' over 'subsoil' that may be the locally occurring subsoil or imported fill. The topsoil may be a naturally occurring material or it may be manufactured from subsoil and organic matter. The topsoil is the rooting zone for newly planted trees, shrubs, herbaceous plants and grass. It will support shrubs, herbaceous plants and grass throughout their life. Trees will establish in the topsoil but must be able to root out into the surrounding subsoil if they are to develop to maturity. Topsoils need to contain organic matter for the proper establishment and growth of all landscape plants. The correct organic matter content of naturally occurring and manufactured topsoils will ensure effective and sustainable planting schemes.

The considerable beneficial properties of compost mean that it can be used effectively in landscaping (Alexander 1991; Logsdon 1992; Alexander 1996; Landschoot 1996; Gouin 1997; Anon 1998; Alexander 1999; Block 2001; Alexander 2002; Kendle 2002; Lawson 2002). The relationships between the landscape and plants are explained in the Plant User Handbook (Hitchmough and Fieldhouse 2004). This book details plant selection and management, as well as soils and their amelioration, from a landscape architect's viewpoint.

Compost can be used as a soil conditioner in plant bed establishment, as a component of backfill mixes for trees and shrubs, in the manufacture of topsoil, for the establishment and renovation of turf, and as a mulch.

Compost applied to soils in landscaping leads to:

- raised organic matter levels
- increased soil nutrient levels for plant growth
- improved soil cation exchange capacity leading to reduced nutrient losses caused by leaching
- better plant survival, growth and quality
- reduced soil compaction
- improved soil water holding capacity and moisture conservation

- improved soil structure and drainage
- increased soil microbial activity
- increased soil temperatures
- reduced erosion by better plant establishment and mulching

3.4.1 Plant nutrition effects

Nutrients

Composts contain plant nutrients in an ideal form in association with the organic matter. They are naturally 'slow-release' over a prolonged period. Nitrogen may be locked up in immature composts but this is easily compensated for by the application of a nitrogen fertiliser.

The composition and availability of nutrients in composted materials can vary and depends upon the composition and quality of the original feedstock, the composting process, maturity and subsequent storage. It is advisable to obtain a chemical analysis of the compost material and the site soil when planning landscape works.

The nutrient requirements for planting schemes can largely be supplied by composted materials, although additional nitrogen fertiliser may be required in some cases (Sikora and Szmidt 2001).

Effects on soil pH and soil electrical conductivity

The pH of finished compost tends to be alkaline. Applications of compost are unlikely, however, to raise soil pH to undesirable levels. This has implications for planting schemes that contain ericaceous subjects, e.g. rhododendrons and camellias. Soils above pH 6.5 may adversely affect growth rates, and low rates of compost incorporation should be used when planting these subjects. The existing soils on a site should always be considered when choosing plant material.

Electrical conductivity (EC) is a measure of the salinity of compost. The EC of green waste composts is rarely excessive for landscape uses such as backfill mixes, soil amendment, topsoil manufacture and topdressings. Some other soil ameliorants, such as manure or mushroom compost, can have a high EC.

3.4.2 Physical effects

Compost grades and application rates

The selection of different particle size grades of compost is necessary for the range of landscaping operations to which it can be applied. For example, coarser, woodier fractions are required for a stable, effective and long-lasting mulch, while compost applied to turf must be finely screened to facilitate dispersal of the particles down through the sward and into the soil (refer to the compost characteristics section for details). Soil ameliorants and compost for topsoil manufacture are generally a wide range of particle sizes.

In 2003, The Waste Resources Action Programme (WRAP) worked with landscape architects experienced in compost use and with the Composting Association to provide UK landscapers with reliable compost specifications for a range of applications through project STA0014. The specifications are available from the WRAP web site. Detailed practical information on the successful use of compost can be found in the 'Field Guide to Compost Use' (Alexander 1996), 'Compost Use on State Highway Applications' produced by the Composting Council Research and Education Foundation (CCREF) and the United States Composting Council (USCC) (Table 21). However, these are publications intended for the US industry and specifications for compost quality and application may not be appropriate in the UK.

WRAP's 'Compost specifications for the landscape industry' document includes tables such as the conversion of compost depth to a volume per 100m^2 (Table 21). Tables are also provided to aid the calculation of the amount of compost required to raise soil organic matter levels from a low to an adequate status.

Table 21: Volume of compost addition calculator

Cubic metres of compost required to cover 100m^2	
0.5 cm layer	0.5 m^3
1.0 cm layer	1.0 m^3

Cubic metres of compost required to cover 100m^2	
2.5 cm layer	2.5 m^3
5.0 cm layer	5.0 m^3
7.5 cm layer	7.5 m^3
10.0 cm layer	10.0 m^3

Organic matter

Humus content plays a central role in soil structural stability and particle aggregation. The addition of organic matter will encourage the formation of stable soil crumbs. This process increases the number and size of the pore spaces in the soil, enhancing the rate at which water can enter the soil, and also increasing the volume of air and water that the soil can hold. The application of organic matter as composted materials will therefore improve soil structure and drainage, reduce bulk density and provide a more suitable rooting environment for plant growth (Pagliai, Guidi et al. 1981; Fortun, A et al. 1989; Hernando, Lobo et al. 1989; Pinamonti 1998). In addition, the dark colour of compost can raise the soil temperature and will assist germination and improve growth rates in cool conditions.

Mulches

Compost mulches act as a physical protective barrier to the soil surface. They can provide enormous benefits to gardens and landscape plantings through weed control, moisture conservation, water drainage and erosion control. Their mode of action is on several fronts.

Deep mulching with composts has been shown to retard weed growth, both through the physical smothering effect, and through the use of immature, active composts (Pinamonti 1998; Stratton, Barker et al. 2000; Ozores-Hampton, Obreza et al. 2001; Ozores-Hampton, Obreza et al. 2002). Chemical herbicides can be expensive and damaging to the environment, and herbicide resistance is increasingly commonplace. Compost mulches provide a cheap, environmentally-safe means of weed control which reduce costs and labour inputs and provide an attractive finish around young plants.

Moisture conservation is improved through the reduction of evaporation rates of water from the soil surface. An increase in moisture retention will reduce the requirement for irrigation.

Soil erosion is a risk during the formation of banks in construction projects and of road and motorway verges and the rapid establishment and maintenance of vegetation cover is important for minimising erosion. Mulches will prevent the removal of soil particles by saltation by reducing the impact of rain splash on the soil surface. By providing a layer of coarser surface material, mulches also slow down surface water run-off and increase the total water that percolates into the soil from each rainfall event. An interesting development in the control of erosion is the use of filter berms to retain dislodged particles of soil from sloping banks, or from particularly vulnerable soils (Washington Centre and Inc 1997; Tyler 2001). In addition to their direct benefits, mulches act as soil improvers over time, as they gradually degrade and become incorporated into the site soil.

Mortality rates in landscape plantings can be reduced using compost. In a three year study, the effects of compost applied as a mulch, or as a soil amendment, in the production of nursery stock species significantly reduced mortality rates in sycamore species (*Acer rubrum*; *A.saccharum*) in the first year, and increased subsequent growth in sycamores and in pin oak (*Quercus palustris*) (Maynard 1998).

However, site conditions will influence the results. Experiments established by Hodge in 1991 investigated the effects of seven organic amendments (including products from composted green waste) on *Q. robur* performance in a chalk, a silt, and a clay site (Hodge 1995). Survival rates after three years were improved in amended clay topsoil, but not in the chalk or silt topsoils. Similarly, growth rates increased in amended soils on the chalk site, but not in silt or clay soils.

3.4.3 Biological effects

Control of plant diseases

Plant losses due to soil borne diseases can be substantial, expensive and visually unattractive. Landscapers have been encouraged to use pesticides in the past, but attitudes are changing to these management practices. Alternative, non-chemical methods are increasingly being sought. Composts are biologically active and contain a complex mix of fungi, bacteria, protozoa and arthropods. Mature composts contain a range of microbes which have been shown to suppress a range of plant pathogen species (Hoitink, Stone et al. 1996; de Ceuster and Hoitink 1999).

Antagonists of turf grass diseases are present in almost all soils and are associated with all plant species. However, intensively managed soils which receive large quantities of chemical fertilisers, pesticides and herbicides can have reduced numbers of microbes. For example, the persistent use of broad-spectrum fungicides suppresses the beneficial microbes as well as the plant pathogens. A reduction in the level of these antagonists will increase the opportunities for pathogens to become established in plant tissues. In addition, newly constructed turf areas may lack organic matter and therefore cannot support a large, diverse microbial population.

A considerable amount of research has been carried out on golf courses and sports pitches in the USA and Canada which has done much to further understanding of the potential for using compost as a disease control measure. Studies have demonstrated a reduction in severity and incidence of a wide range of turf grass diseases, particularly when compost was applied as a topdressing, a winter cover, a root zone amendment, or as a compost tea (Nelson and M. J. Boehm 2002). Known bio controls of turf grass diseases are shown in Table 22 (Nelson 1992).

Antagonists can be isolated from a wide variety of different environments. However, composts provide some of the best means of introducing a complex microbial community, with a range of antagonistic species, to the soil.

The control of nematode pests using soil-borne fungi has also been demonstrated (Siddiqui and Mahmood 1996; Noble and Roberts 2003). In some cases populations of several thousand root-knot nematodes have been reduced to near undetectable levels within 6 months. In other experiments, the effects of compost on nematode populations has taken up to three years to manifest themselves (McScorley and Gallaher 1996).

The use of bio controls is often more complicated than the immediate effects of using chemical pesticides, although in the longer term they lead to a more stable soil environment. In order to use these control agents successfully it is important to understand a little of their biology. Firstly, it is necessary to consider their use in conjunction with the existing chemical management programme. Modifications to the programme may be required to ensure the establishment and proliferation of antagonists. Secondly, sufficient levels of organic matter must be available to support microbial life and, thirdly, soil conditions will affect their ability to thrive, particularly temperature, moisture, nutrients and pH.

Table 22: Known biological controls of turf grass disease

Pathogen	Antagonists	Trial location
Brown patch (*Rhizoctonia solani*)	*Rhizoctonia* spp	Ontario, Canada
	Laetisaria spp Microbial complexes	North Carolina New York Maryland
Dollar spot (*Sclerotinia homeocarpa*)	*Enterobacter* spp. *Fusarium* spp. *Gliocladium* spp. Microbial complexes	New York Ontario, Canada South Carolina New York
Grey snow mold (*Typhula* spp.)	*Typhula* spp. *Trichoderma* spp. Microbial complexes	Ontario, Canada Massachusetts New York
Pythium blight (*Pythium aphanidermatum*)	*Enterobacter* spp. *Pseudomonas* spp. Various bacteria Microbial complexes *Trichoderma* spp.	New York Ohio Illinois New York New York Ohio
Pythium root rot (*Pythium graminicola*)	Microbial complexes	
Red thread (*Laetisaria fuciformis*)	Microbial complexes	New York

Pathogen	Antagonists	Trial location
Southern blight (*Sclerotium rolfsii*)	*Trichoderma* spp.	North Carolina
Take-all patch (*Gaeumannomyces graminis* var. *avenae*)	*Pseudomonas* spp.	Colorado
	Gaeumannomyces spp.	Australia
	Phialophora spp.	
	Microbial complexes	

Soil remediation

The reclamation of 'brownfield' (formerly developed and used) sites and contaminated land can be enhanced by the use of compost as a soil ameliorant (Cole, Zhang et al. 1995; Alexander 1999; ADAS 2002). Composted materials contain micro organisms, which can degrade many of the toxic organic compounds such as herbicides and hydrocarbons. An example of its application is its use in the bioremediation of petroleum contaminated soils. Compost also has the chemical ability to bind heavy metals and other contaminants, modifying the soil environment, such that their uptake into plant tissues is reduced.

3.4.4 Results of practical applications in the UK

Golf course topdressing

In order to encourage Essex-based sports turf managers and groundsmen to use compost, ReMaDe Essex conducted a trial to investigate how well compost topdressing compares with a standard topdressing mix used on many golf courses.

The trial was carried out in 2002 at Lexden Wood Golf Club located just outside Colchester. Four different topdressing treatments were evaluated within the trial and assessments demonstrated that the compost treatments out-performed the standard sand-based topdressing in terms of turfgrass density, vigour and foliage colour. A weed count and observations on disease presence suggested no increase in incidence above the untreated control or standard treatment.

Manufacture of topsoil

Compost is the ideal form of organic matter to add to subsoils to provide a growing medium for landscape plantings. A number of projects carried out by Tom La Dell Landscape Architects are detailed below.

At the Imperial Business and Retail Park, Gravesend, topsoils were created from selected subsoils and imported organic matter some fifteen years ago. The site is an old chalk pit adjacent to the Thames, close to the centre of Gravesend. Two large papermills were built in it 100 years ago and these were demolished in the late 1980's. An area of about a hectare was topsoiled and planted. A suitable subsoil, with a fairly low silt and clay content, was found in some settlement lagoons. The first topsoil was made with the subsoil and compost made from segregated green waste. The second phase used peat excavated from a nearby riverside construction site. The subsoil and organic matter were mixed on a hard standing using a 360 degree excavator. The resultant topsoil was 5 – 6 % organic matter by dry weight. The compost-based topsoil needed no further additives and has supported good tree and shrub growth since planting. The peat-based topsoil required the addition of nutrients, added as Growmore. In the second season, as the soil is alkaline, a magnesium deficiency showed up as yellowing leaf veins. This was cured by an Epsom salts application.

Tilmanstone Colliery, Deal, is a Kent Coalfield regeneration site, developed by the South East England Development Agency. It is entirely coal shale. Topsoil was manufactured from the coal shale and green waste compost. It was made by the contractor to a performance specification of particle size distribution and organic matter by dry weight. The contractor used a barrel screen for the mixing and this removed larger pieces of shale. Chalk was added to reduce the effects of long-term acidification. The organic matter was specified at 7 % dry weight so that no further compost was added when planting. Watering after planting was not needed even on this exposed site. Post-manufacture testing showed an excellent topsoil for trees, shrubs, herbaceous plants and grass. A single nitrogen addition was needed in the grass areas as the carbon/nitrogen ratio was rather high. Woody plants are more tolerant of this. Some 38,000 cubic metres of topsoil were manufactured and used on level areas and 1 in 2 slopes. Growth has been excellent even in hot and dry summers.

The entrance to Redlands Industrial Estate, Coulsdon, Surrey, was overgrown with sycamores and self seeded cotoneaster. The topsoil was thin over compacted chalk and most was removed with site clearance. Topsoil was created in situ by mixing green waste compost with the chalk with a mini excavator. The chalk was broken up 1 metre deep and the compost incorporated half a metre deep. The dry-weight organic matter content was 5 – 6 %. This approach meant that no subsoil (chalk) was removed from site and no imported topsoil was needed. A mixture of trees, shrubs and perennials were planted in February 2002.

At Lakeside Retail Park, Thurrock, the car park was planted in 1980 but the tree growth was poor due to inadequate topsoil depth and compacted subsoil. This led to stunted growth and broad, bushy crowns that obscured views within the car park. The decision was made by Land Securities to replace the trees and prepare the soil properly for vigorous growth and high crowns. The planting pits were prepared by mixing the subsoil and remaining topsoil up to 1 metre deep. This gave a good particle size distribution and a small amount of organic matter. Compost was added in situ to raise the organic matter levels to 6 – 7 % and the site was ready for re-planting.

3.4.5 Results of practical applications in the USA

States in the USA have been actively expanding their use of compost for many years and it is now the material of choice in many landscaping operations, including major works. This expansion has been based on research work and demonstration trials.

The Connecticut Departments of Environment and Transport carried out a two year study in the late 1990s which demonstrated that compost was effective in controlling soil erosion, in establishing turf, and as a planting backfill mix for trees and shrubs.

Soil erosion control

During the reconstruction of the intersection on Routes 98 and 6 in Chaplin, Connecticut, eight study cells were set up on a 2:1 slope of silty sand and treatments of compost mulch, wood mulch, hay and straw mulch, filter berm and a bare soil control were applied. Some cells were seeded and others were not.

All of the treated cells reduced erosion rates compared with the untreated bare soil control, and the compost treatments performed as well as, or better than, the standard erosion control methods employed by the State Departments. Levels of soluble salts in the run-off were very low and all PTEs and nutrients were within pollution leaching limits and Connecticut drinking water standards. The filter berm was dissected at the end of the experiment and it was demonstrated that little or no sediment had penetrated the berm beyond two inches.

Turf establishment

Three sites were chosen to examine the use of compost in turf establishment. Compost was applied to existing backfilled soil at varying rates and compared to a control section containing no compost. The treatments were seeded with a standard grass mix and monitored for plant growth.

Results showed that amending backfilled soils with moderate amounts of compost significantly improves turf establishment, with the sward in these plots growing much better than in the untreated control. Differences between rates of compost were more difficult to identify, suggesting that even a low rate of application can provide considerable benefits. Soil analyses also revealed that compost addition increased the soil moisture holding capacity, and improved the pH of the soil such that lime applications could be significantly reduced or even eliminated.

Planting schemes

The Interstate 91/Route 3 was chosen as the site for the field test for compost-amended backfill mixes in tree and shrub plantings. The applications consisted of a 1:2 compost to soil mix ratio and an untreated control. All plots were mulched with wood chips after planting with a range of standard landscape species, e.g. Berberis and Euonymous.

An inventory conducted the following spring revealed that none of the plants in the compost-amended plots needed replacing (i.e. a 100 % survival rate), compared to a survival rate of only 60 % in the standard control plots. A further inspection in the following autumn demonstrated that survival was still 100 %, 12 months after planting.

3.4.6 Swedish recommendations for landscape application

Sweden has a large area of heavy clay soils and, for these soils, it is recommended to apply compost little and often. The compost should be coarsely screened (0 - 25 mm) and incorporated up to 150 - 200 mm deep only. For mixing with soil, compost should be applied at up to 30 % v/v, unless it is nutrient rich, in which case, lower amounts should be applied. Mixing should not be to a depth greater than 200 mm for heavy soils and 400 mm for sandy soils.

The nitrogen released and utilised from compost depends on the soil moisture content, whether the compost is mixed in well or used as a mulch, and the length of the plant growing season. Short-term agricultural crops will only benefit from up to 10 % of the total N applied, whereas landscaped plants may utilise up to 20 %. Only up to 40 % of the total N may be utilised in the first 5 years.

For planting trees, compost used as a mulch, rather than mixed into the disturbed planting pit soil, may be as, or more, beneficial.

For establishing lawn and sports turf areas, apply up to 20 % v/v compost with the soil, well mixed to 150 mm depth. The compost should be very stable material and supplementary fertiliser may be applied to obtain a close sward as rapidly as possible.

In outdoor containers, compost may be added at up to 30 % v/v unless it is very nutrient rich, in which case 20 % or less should be used (adjusted according to nutrient concentrations in the analysis report). The screen size should be 10 mm for this end use. The compost should be mature and additional nitrogen fertiliser is usually required.

As a mulch for suppressing weed growth, compost should be applied in a 80 - 100 mm thick layer. The compost should have the <10mm particles removed so that weed seeds do not readily become established.

In a turf top dressing, a mix of 33 % compost and 67 % washed sand is recommended. For pitches, the product should be screened to <10mm and up to 5 - 7 mm depth applied. For golf greens, the product should be screened to <4 mm and only 1 - 3 mm depth applied. The grass should be growing vigorously at the time of application, and water added if conditions are dry.

The report suggests that compost should not be used in conjunction with plant species such as *Rhododendron* or blueberry which prefer acidic soil conditions. Food wastes, if included in the compost feedstocks, may raise the salt (EC) content of the end product. Chloride will be raised and therefore should not be applied in large amounts to salt sensitive plant species such as redcurrants, blackcurrants and strawberries. *Ribes alpinum* is also sensitive to chloride.

3.5 The use of compost in growing media and retail soil improvers

There are many benefits from the use of composted materials in the production and use of growing media and retail soil improvers. However, it is to be recognised that the demands by the industry on the quality of the composts are high. Compost specifications for the use of compost in growing media are being developed by WRAP in 2004 (ORG0012).

For growing media and retail products compost provides

- nutrients for plant growth, many in slow release form,
- enhanced nitrification,
- a liming effect,
- increased cation exchange capacity in growing media, and
- organic matter with associated beneficial micro organisms that may aid plant disease suppression, and
- suppression of liverwort, algae and moss.

3.5.1 Plant nutrition effects

Interim results from WRAP Project STA0013 show that, in a wide range of crop types, green compost can provide all the base nutrients in a growing medium except N. Furthermore, addition of liming material was reduced and often eliminated.

Although composts can contain significant amounts of N, much of this is in an organic form and so is not easily available to plants (Mays, Turman et al. 1973; de Haan 1981; Giusquiani, Marucchini et al. 1988). On average composts may contain 7 – 18 g N kg-1 of substrate (Mamo, Halbach et al. 1998) but compared to commercial mineral fertiliser only 16 % of the compost N is bio available (Terman, Soileau et al. 1972) and (Iglesias-Jimenez and Alvarez 1993). This is also supported by other workers with, on average, 15 % of total compost N being available to plants (Hortenstine and Rothwell 1973; Diener, Collins et al. 1993; Amlinger, Bettina et al. 2002).

Although laboratory experiments have studied the effects of compost as a component in potting media, both with and without mineral fertilisation (Gajdos 1997; Klock-Moore 1997; Klock-Moore and Fitzpatrick 1997; Raymond, Chong et al. 1998; Ozores-Hampton, Vavrina et al. 1999; Klock-Moore 2001; Chen, McConnell et al. 2002), and many have reported enhanced plant performance, few studies have looked at the effects of mineral N efficiency where compost is included in growing media.

For the horticulturist, the inclusion of high quality green compost in a growing medium formulation could result in the contribution of N as nitrate (NO_3), or ammonia (NH_4), equivalent to 15 % of the total compost N. A compost, with fresh BD of 0.5 kg l^{-1} and a total N content of 12.5 g kg^{-1} incorporated into a growing medium at 50 % v/v, could potentially contribute 300 mg N per litre of growing medium over the following six months.

Unpublished research by Rainbow and Wilson showed that inclusion of green compost in a peat-based growing medium could accelerate nitrification (conversion of ammonium-N to nitrate-N).

The availability of compost P, particularly over the short-term, is poorly understood and can vary from 10 to 264 % of the amount of P available in a mineral fertiliser (Pommel 1982; Bezzola, Lopez et al. 1994; Frei, Candinas et al. 1997). Considerable data gaps exist in knowledge of the fate of many compost components including the role of organic P in plant nutrition (Hue 1990). However, organic P amendments can increase P availability with as much as 2.62 g P Kg-1 compost being available (Manna, Ghosh et al. 2001).

Potassium concentrations in UK composts are generally high and exceed the immediate requirements of most plants (Marschner 1998). Except in the case of sensitive plants these high concentrations should not prove detrimental to the inclusion of compost in growing media formulations.

Whilst Mg levels in compost are generally low, compost could supply sufficient Mg for most plants. However, as with the other basic cations, Mg becomes increasingly less available with rising pH and is similarly dependent on the percentage of the cation exchange capacity occupied by Mg ions.

The percentage base saturation (PBS) is the percentage of the CEC that is occupied by basic cations (Ca, Mg, K and Na), with the remainder of the capacity occupied by acidic ions. The cations K, Mg, Ca and Na are normally dominant and it is the respective ratios that determine the soluble concentrations.

Research on micronutrient concentrations in compost have focused on the possible toxicity of high levels. In particular, Cu, Zn, Ni and B have been investigated. The PAS 100 specification limits the concentration of Cu, Zn and Ni and collated data on the types of compost covered in this report confirms that these limits are unlikely to be exceeded. Although levels of B five times that found in manure have been recorded in compost (Rodd, Warman et al. 2001), these did not have any adverse effects on plant growth.

The availability of nutrients is affected by the pH dependency of nutrient availability (P, Mg, Fe) and interactions with other components. These interactions can be detrimental, as in N immobilisation, directly beneficial, as in encouraging symbiotic associations (*Rhizobium* and mycorhizae), or indirectly beneficial through continuation of microbial degradation releasing additional nutrients into solution.

Although an essential plant nutrient, chloride (Cl) remains in solution where it is easily accessed by plants. Timm, Goos et al. (1986) identified Cl as having a beneficial effect in the suppression of root rot diseases. Fixen, Gelderman et al. (1986) identified Cl as having an influence on improved water retention, which in combination with the disease suppression properties, contributed to improved plant growth. In excess, Cl can be detrimental but it is removed via drainage water and it can also be flushed out prior to use.

Sodium (Na) in plant nutrition can enhance stomatal operation, increase CO_2 efficiency and enhance nitrate uptake. Na has also been associated with the stimulation of root production and the increase in leaf area and stomata numbers (Lawlor and Milford 1973). In radish production with compost amended media, Gajdos (1997) reported that root dry matter increased with compost additions. Similarly, Ozores-Hampton, Vavrina et al. (1999) reported increased root, shoot and leaf area in tomato gown in compost-amended media. However, the benefits of Na are invariably cultivar-dependent and there can be quite substantial differences between cultivars (Figdore , Gabelman et al. 1987; Figdore , Gerloff et al. 1989). Most work has concentrated on aerial growth rather than root growth, although this lack of information is reflected generally and not restricted to composts (Gregory and Hinsinger 1999).

3.5.2 Physical effects

The principal properties of a growing medium are to provide a stable environment that can supply water, oxygen and anchorage for the plant (Carlile 1997). Hoitink and Poole (1980) reported that the success of plant growth in container substrates amended with compost largely depends on the physical properties of the substrate. Due to the limited volume within a container the roots must have the opportunity to develop and fully exploit the medium. The medium must therefore facilitate optimum root development and be capable of providing a constant supply of water, oxygen and nutrients to sustain plant growth.

Hydrological

The water holding capacity (WHC) is often the only hydrological property of compost that is reported. However, water in composts, as in soils, is held within pores of different sizes, with water more easily lost from larger pores. The distribution of the pores has a strong influence on the fate, direction and ease of movement of the water held within them (Rowell 1997). Whilst the total WHC of a substrate is a useful measure, it does not necessarily mean that a substrate with a high WHC can supply a plant with more water, or for a longer period, than one with a lower WHC. An important requirement of a good growing medium is a high capacity for moisture retention and drainage of excess water (Corti, Crippa et al. 1998), with the quantity of water held in the mid ranges (released between –0 and –100cm of suction), the easily available water (EAW) and less easily available water (LEAW), or water buffering capacity (WBC), being of most practical importance. Water held below –100cm, is the unavailable water (UAW) and although this is above the permanent wilting point, it is difficult for containerised plants to extract water at this suction without stress resulting in poor growth.

- **Water holding capacity (WHC)**

The WHC of a medium is the total amount of water held within a substrate that is potentially available to the plant and is defined as that being held at tensions between the permanent wilting point and container capacity (Bunt 1988). The WHC of the particle size grades of green waste composts tested and reported here is generally far lower than existing media mixes ranging from 22 to 40.3 % (Klock-Moore 1997; Maynard 1998; Klock-Moore 1999; Klock-Moore 2001). However, when used as a constituent in media mixes, this percentage rises considerably with values ranging between 43.5 (Klock-Moore and Fitzpatrick 1997) to 92 % (Chen, McConnell et al. 2002) for mixes containing 60 and 80 % compost additions respectively. Joiner (1981) recommended a WHC of 20 – 60 % for a growing medium.

- **Easily Available water (EAW)**

The EAW capacity of a growing medium is the measure of the quantity of water released by the substrate under a suction of a water column of between –0 and –50cm and represents that portion that can be readily absorbed by the roots (Corti, Crippa et al. 1998). Corti, Crippa et al. (1998) found that composts made from source-separated municipal solid waste (SSMSW) and yard green waste (GWC) compared favourably with two growers' mixes and a peat substrate having an EAW of 78 and 83 % of the EAW of the growers' mixes and 58.5 and 62.5 % of the EAW of the peat respectively. It is noted that, unlike many of the other parameters important in determining the value of a substrate to a grower, measurement of EAW is time consuming and, as a consequence, is rarely measured by researchers.

- **Water buffering capacity (WBC)**

The WBC, or less easily available water, is the quantity of water released by the substrate under a suction of a water column between –50 and –100cm and represents that portion of water that is less readily available to the roots (Corti, Crippa et al. 1998). As with EAW, the measurement of WBC is a time consuming process and, as a consequence, is rarely measured by researchers. In the work carried out by (Corti, Crippa et al. 1998), compost made from the source-segregated organic fraction of municipal solid waste (SSMSW) had the highest WBC, whilst green waste compost compared favourably with professional grower media mixes, exhibiting 93 % of the WBC of the latter.

- **Hydraulic conductivity (HC)**

The hydraulic conductivity is the ease at which water can move through a substrate and it influences the rate at which a substrate can drain (Brady 1990). A growing medium needs to have good drainage to prevent water logging and promote adequate gaseous exchange. The hydraulic conductivity is therefore related to a growing medium's ability to provide sufficient aeration.

- **Wettability**

The hydrophobic properties that are exhibited by peat are not normally shown in mature composts. It is therefore likely that inclusion of composts into peat based growing media will aid wetting and may reduce the need to use a surfactant.

Gaseous exchange

As well as access to water, a medium must provide adequate opportunity for both the diffusion of oxygen and the release of CO_2 from the respiration of roots and microbial components. The determination of the ability of a substrate to fulfil this function is commonly expressed as the percentage of air filled pores (AFP). Prasad and Maher (2002) found that whilst there was little data available from experimental work on desirable AFP, there is a considerable amount of information derived from grower experience and that air space of between 20 – 40 % air-filled pores was generally desirable, but for slower growing deciduous shrubs 15 – 30 % was adequate.

- **Air filled porosity (AFP)**

In comparing SSMSW and green composts against growers mixes and peat substrates, Corti, Crippa et al. (1998) found that both the SSMSW and the GWC had higher or equal AFP, having 24 and 12 % more AFP than peat and 5 % +/- than the growers' mix. Klock-Moore (2001) found that compost AFP was 89 % of that of a non-amended medium and, in compost-included media, there was little change in the AFP. Similar results were reported by Raymond, Chong et al. (1998). Joiner (1981) suggested that as a general rule AFP should be 5 – 30 % of pore space.

Shrinkage

For a substrate to be of use, it must remain sufficiently stable to support a growing plant throughout its life. That is to say, the medium should finish its useful life in the same, or near the same, physical state as it started. There should be no appreciable shrinkage or other physical, chemical or biological changes that negatively impact on plant growth while the substrate is in use. When evaluating 12 compost formulations for production of three foliar plants, Chen, McConnell et al. (2002) found that media shrinkage of up to 15 % had no impact on plant production, or quality, and that shrinkage occurred only during the production. Furthermore, shrinkage was also exhibited by the peat-based media.

3.5.3 Biological effects

Plant disease suppression

Within the literature there is evidence that compost may stimulate the proliferation of microbial antagonists to plant pathogens in the rhizosphere and so control some plant diseases. In growing tomato in suppressive compost media, De Brito Alvarez, Gagne et al. (1995) confirmed previous reports indicating that the use of composts in container media has the potential to protect plants from soil-borne root pathogens. Such results have been further substantiated by other workers (Mandelbaum and Hadar 1997; Lievens, Vaes et al. 2001; Cotxarrera, Trillas-Gay et al. 2002). It is now believed that this property can be attributed to one, or a combination of factors, including competition, antibiosis, parasitism and induced systemic resistance (ISR) and that the mechanism of control is dependent on the disease organism and the specific properties of the compost (Lievens, Vaes et al. 2001).

- **Pythium spp. (damping-off)**

Damping-off caused by *P. irregulare* was successfully suppressed using compost and leaf compost achieving 85 % and 60 % suppression respectively (Ben-Yephet and Nelson 1999). However, Bettiol, Migheli et al. (1997) found the suppressiveness of compost-amended media against *P. ultimum* in cucumber (*Cucumis sativus L.*) production was variable with some composts being conducive rather than suppressive and that manure compost was the most suppressive. Ringer, Millner et al. (1997) found that manure compost-amended potting mixes were suppressive to damping-off caused by *Pythium* spp. but that the type of manure in the compost had a greater influence on control. There was evidence that low levels of NO_2 or NO_3 were associated with suppression. Similarly, Erhart, Burian et al. (1999), using seventeen composts from separately collected organic household waste, plus one bark compost, found that a significant number of samples were slightly phytotoxic and that only bark compost could be used to exert an economically relevant control of *P. ultimum* in horticultural media. van Os and van Ginkel (2001) found that suppression of *Pythium* root rot in bulbous iris revealed that microbial parameters were negatively associated with *Pythium* growth rates, indicating that high microbial biomass and activity were associated with induced suppression of *Pythium*.

- **Fusarium spp (wilts)**

The effects of compost amended media on the incidence of *Fusarium* crown and root rot in tomato (Pharand, Carisse et al. 2002) and *Fusarium* wilt of tomato caused by *F. oxysporum* (Cotxarrera, Trillas-Gay et al. 2002) showed substantial reduction in the disease-associated symptoms compared with controls grown in peat media. Lievens, Vaes et al. (2001) found root rot of plants germinated in suppressive mix and then transplanted into conducive mix was significantly less severe than that of plants germinated in the conducive mix. Furthermore, Zhang, Han et al. (1998) found that growing media inoculated with *Pantoea agglomerans* 278A (extracted from compost) induced systemic acquired resistance (SAR) in cucumber against anthracnose caused by *Colletotrichum orbiculare*. This suggested that compost-induced disease suppression involved the development of plants' resistance responses rather than antagonistic properties of the control agent.

- **Phytophthora spp**

Kim, Nemec et al. (1997), in evaluating ten composts and soil amendments for control of *Phytophthora* root and crown rot of bell pepper caused by *Phytophthora capsici*, found that none of the treatments which did not include chitosan, crab shell waste, and citrus pulp with molasses were effective in reducing root and crown rot of bell pepper. Kannangara, Utkhede et al. (2000) identified contrasting effectiveness in disease suppression of composts made from the same waste, suggesting that composting method strongly influences the disease-suppression properties of the finished compost.

- **Plasmodiophora brassicae (clubroot)**

Plasmodiophora brassicae (clubroot) is one of the major diseases that occur in crucifers. It has become established practice to control clubroot by chemical methods through the use of Ca and raising soil pH. Control of this disease has shown to be largely influenced by soil pH and exchangeable calcium (Murakami, Tsushima et al. 2002).

Compost has been identified as a potential source of the pathogen. However, evidence within the literature suggests that compost may well possess and confer suppressive properties to the soil or growing medium or induce systemic resistance in potential host plant species. Isolates of microbe *Streptomyces* spp. from soil have been shown to have excellent suppressive effects on *Plasmodiophora brassicae* (Kim, Choi et al. 2002). Researchers Murakami, Tsushima et al. (2000) suggested that biotic factors are responsible for disease suppression in soil. With strains of *Streptomyces* spp. playing a significant role in biodegradation during aerobic composting processes, those resulting from well managed processes are likely to exert suppressive effects on *Plasmodiophora brassicae*. Suppressive effects using vermicompost (soft organic wastes biodegraded by selected species of worm) against *Plasmodiophora brassicae, Phytophthora nicotianae and Fusarium oxysporum* have been demonstrated to be dose dependent (Szczech, Rondomanski et al. 1993). Therefore this may also be the case with green composts.

Levels of boron, which can be high in compost, have been shown to reduce the maturation rate of *Plasmodiophora brassicae* (Webster and Dixon 1991).

- **Liverwort, moss and algae**

Infestation of the growing medium surface by these organisms is often a serious problem, especially where overhead irrigation is used. Interim results from the WRAP Project STA0013 show that growing media based on a green compost and bark or brash benefit from reduced infestation.

Influence of residual enzyme activity

Composting is essentially a microbial process involving three principle groups of micro-organisms (bacteria, actinomycetes and fungi) from the natural environment that are present on the substrate (feedstocks) when the composting process begins. The process is characterized by a mesophilic stage (20 – 40 ^{0}C) followed by a thermophilic stage (40 – 80 ^{0}C) and then into a gradual cooling and curing stage (Sylvia, Fuhrmann et al. 1999). Microbes produce hydrolytic extra-cellular enzymes in order to depolymerise the substrate into water-soluble components that can then be metabolised. The activities of enzymes such as cellulase, lipase, protease and amylase rise and fall during the composting process.

3.5.4 Results of plant growth trials

The use of composts as components in growing media has received considerable attention world-wide. Researchers have, in recent years, conducted a considerable number of growth experiments to evaluate the value of such products for the production of plants using composted components in growing media formulations. However, this research has not followed a consistent pattern and whilst the work has been of value, collating and comparing results has proved difficult, due to the adoption of a variety of methods, formulations and analysis techniques and even terms for composts made from the same types of feedstock.

Composted products derived from bio-solids (sewage sludge), the source separated organic fraction of municipal solid waste (SSMSW), the organic fines from centrally sorted MSW, yard trimmings, wood wastes, waxed corrugated cardboard, spent mushroom compost and paper have been used in research, singularly or in combination, either alone or mixed with other substrates such as peat, pine bark, shredded wood, top soil, vermiculite, perlite or Styrofoam. Formulations containing from 0 % compost (controls) to 100 % compost have been used to assess growth responses by a variety of plant species.

Similarly, composts have also differed in the method of manufacture, degree of composting and maturation prior to use. The duration of the experiments has also differed, depending on plant species and researcher preference, as has the use of fertilisation, with experiments being conducted with or without fertiliser additions.

Consequently, making comparisons between experimental results has proved a difficult task which, in order to make sense and use of the data available, has required a certain amount of inference. Media components have therefore been categorised into four main groups; composts (any product that has been derived from a waste that has received treatment by aerobic composting), peats, barks and inerts (perlite, vermiculite and Styrofoam). Plant growth trials that included high proportions of compost types excluded from the scope of this study have been omitted. However, because many researchers have achieved significant results with media that have contained a proportion of these other compost types, where they have not been the main ingredient(s) in the growing media, the results have been included.

Germination experiments

Germination experiments using compost-based media have consistently produced poor results when compared with existing formulations. Raymond, Chong et al. (1998) reported that germination of lettuce (*Lactuca sativa* L.var. *longifolia* Lam. Cv Paris Island) and radish (*Raphanus sativus* L.cv Red Boy) were both delayed when grown in media containing immature composts, although the same media gave excellent results when used with cuttings. Similarly, Gajdos (1997) reported that lettuce (*Lactuca sativa L: va.capitata* cv.'Nanda'), garden cress (*Lepidium sativum),* ryegrass (*Lolium Perenne* cv. 'Majestic'), radish (*Raphanus sativus var. radicula* cv. 'Saxa') and African marigolds (*Tagetes tenuifolia* cv. 'Daily Marietta') all experienced germination delays when grown in immature composts. Tomato (*Lycopersicon esculentum* cv. 'Agriset 761') grown in compost-amended media with high salt concentration led to delayed germination in some treatments, with germination decreasing in response to compost additions. However, there were no differences in growth 30 days after sowing (Ozores-Hampton, Vavrina et al. 1999).

The influence of high salinities on the imbibition of seeds is well known and documented in the literature. Whilst solute concentration is not the only factor, and seed / media contact also plays a role, it is likely that growing media that contain high salt concentrations will have a significant negative effect on imbibition and subsequent germination.

Trials using plug plants

The use of compost-amended media for the transplanting of plugs of annual bedding plants has been shown to produce equal or superior results to existing formulations. In Florida, experiments using plugs of the salt-sensitive plant species, Impatiens (*Impatiens wallerana* Hook.f), snap-dragon (*Antirrhinum majus* L.) and Salvia (*Salvia farinacea* Benth. 'Blue Rhea') have all demonstrated the benefits of compost inclusion in growing media (Klock-Moore and Fitzpatrick 1997; Klock-Moore 1999; Klock-Moore 2001).

Trials using hardy nursery stock

Growth trials carried out in Canada over two seasons using four hardy nursery plants Deutzia (*Duetzia gracilis* L.), silverleaf dogwood (*Cornus alba* 'Eligantissima'), red-osier dogwood (*Cornus sericea* L.), and ninebark (*Physocarpus opulifolius* L.) by Raymond, Chong et al. (1998) using 12 different immature composts, gave excellent results compared to two standard nursery mixes. Only Deutzia failed to achieve marketable size in a single growing season. However, all compost formulations produced plant quality that exceeded that achieved in the commercial mixes.

Long-term trials using cuttings of interior foliage plants *Cordyline terminalis* 'Baby Doll', *Dieffenbachia maculata* 'Camille', and *Dracaena fragans* 'Massangeana' cane, demonstrated that media formulations containing as much as 60 % compost produced marketable plants equal to, or of higher quality, than those produced using un-amended media. All formulations, including those containing 80 % compost, produced marketable plants during the production period. Although media shrinkage occurred during production, formulations containing less than 60 % compost shrank the same, or less than, the control media. No further shrinkages were observed in subsequent interior evaluation.

Outdoor nursery trials

Studies into the benefits of compost in greenhouse, field vegetable and outdoor nursery horticulture have shown benefits in soil conservation, pest control, weed control and fertility. In ball and burlap operation, where woody plants are grown on field scale for several years before removal, compost applied as a mulch, improved plant growth indices, suppressed weeds and helped to mitigate soil losses thus extending the usefulness of the land used (Maynard 1998). Earlier workers had previously demonstrated that compost mulches improved growth and canopy mass in deciduous seedlings (Gouin and Walker 1977; Kotze 1989). Similarly, in citrus production in Florida, compost mulches reduced the incidence of greasy spot disease (*Mycosphaerella citri*) which causes premature leaf drop. Compost was effective both in aiding the decomposition of infected leaves and acting as a physical barrier to re-infection, thus reducing the need to control chemically (Litvany and Ozores-Hampton 2002).

In assessing effects of compost on efficiency of water use in irrigated vegetable production, field matured compost (applied previously as immature) produced significant increases in tomato size and yield and, in general, it was found that amending a sandy soil with compost significantly improved plant growth and yield in drip irrigated vegetable production (Clark, Stanley et al. 2000). In field trials with outdoor peppers, the use of compost produced improved harvests with lower mineral fertiliser use (Hartz, Costa et al. 1996). Similarly, compost improved the growth of both white and red clover and cucumbers grown in soil (Sainz, Taboada et al. 1998; Sinaj, Traore et al. 2002).

4. Compost characteristics

The following compost characteristics were agreed with the End User Consultation Group and compost manufacturers to form the basis for the Information Packages and Fact Sheets produced. The text leading up to subsection 7 on compost characteristics was provided as background to the End User Consultation Group.

4.1 Introduction

Technical definitions for compost and composting are provided in the Publicly Available Specification for Composted Materials (PAS 100) (see sub-section 3 below). In simplified terms, compost is the material that is formed during the composting process. Composting is a managed process of biological decay of organic materials. Conditions within the composting heaps are controlled by various means to ensure there is sufficient air, moisture and high temperatures within each heap to lead to compost that will have beneficial effects when added to soil or container-mixes that support plants. Composting using worms can also produce high quality 'vermicomposts'.

Compost is produced from organic materials that may come from a range of sources. The characteristics given in this section are for compost produced from source-separated kitchen and garden wastes, including wood wastes, and may include animal manures as a minor ingredient of the composting feedstock. They do not include municipal solid waste (MSW), sewage sludge, or agricultural waste derived composts; nor spent mushroom compost or composted bark.

As these composts are made from wastes it is important that there are regulations governing their production and use, and voluntary industry standards and specifications covering any market-related aspects unspecified in the regulations. Specifications are also needed to indicate which properties of composts are important to take into consideration when an end-user wishes to obtain compost products, and as an aid to the manufacturer to meet end-user requirements.

4.2 Regulations

Most composting is carried out on a sufficiently large scale to require planning permission from the planning authority and a waste management licence from the regulator. The composting of catering wastes, including domestic kitchen wastes, is regulated in England by the Animal By-Products Regulation 2003 and 'plant approval' by the State Veterinary Service is necessary. Similar legislation is in force in Wales, Scotland and Northern Ireland. The new regulations supersede the Animal By-Products Order 1999 and the amendments to it. Guidance notes for compliance with the Statutory Instrument 2003 No. 1482 The Animal By-Products Regulations 2003 are available from:

http://www.defra.gov.uk/animalh/byprods/publicat/compost_guidance.pdf

The Animal By-Products Regulation 2003 and those relating to Nitrate Vulnerable Zones affect how compost may be used. For compost that contains catering waste and is subject to the ABPR, the compost producer must provide certain information to the end user and there are restrictions on its use with regards to livestock grazing or cropping for feeding to livestock.

Total nitrogen inputs to agricultural land within Nitrate Vulnerable Zones (NVZs) are restricted. Statutory limits apply for all 'organic manures', including composts, applied within NVZs. Composted materials can only be used as per the rules for 'organic manures' below.

For the whole farm, calculate the maximum application of total nitrogen loading permitted from organic manures for the year ahead:

(x ha grass land * 250) +

(x ha non-grass land designated NVZ within last 4 years * 210) +

(x ha non-grass land designated NVZ 4 or more years ago * 170)

where x = number of hectares, * = multiply

Decide how best to share out the permitted compost applications amongst individual fields, taking into account the following:

- composts can be applied at rates that supply a maximum of 250 kg total nitrogen/ha/yr/individual field, provided available nitrogen does not exceed crop requirements; and

- nitrogen from artificial fertilisers may be used in addition to compost to provide an adequate amount of available nitrogen for the crop.

In landscaping, it is important that the base soil characteristics are taken into consideration especially where land is being restored from industrial use. The Contaminated Land Exposure Assessment (CLEA) model and Soil Guideline Values (SGVs) should be taken into consideration (see www.defra.gov.uk/environment/landliability/index.htm and www.environment-agency.gov.uk/subjects/landquality for details). As an example, soil may be contaminated with arsenic and care should be taken when mixing or cultivating in compost due to risks of dust inhalation. For further information, contact the Health and Safety Executive. Reference may also need to be made to BS3882:1994 Specification for topsoil.

4.3 Industry standards and specifications

Compliance with industry standards and specifications is voluntary unless stipulated in legislation. The Composting Association provided the industry with Standards for Composts in May 2000 and these formed the basis of the Publicly Available Specification for Composted Materials published by the British Standards Institution (PAS100:2002). Composting operators are being urged to become certified compliant with this PAS by the Composting Association.

End-users purchasing certified composts will be assured that minimum safety–related requirements are being met, and that relevant characteristics will be monitored on an on-going basis. Additionally, input materials into the process will have traceability, the composting process will be monitored and process data recorded. The compost products are tested for human pathogen indicator species, potentially toxic elements, physical contaminants and weed propagules. The compost must also perform well in plant germination and growth bioassays. Standardised test methods are also specified in order to assure reproducibility of data and true comparison between products.

Specifications for compost are related to fitness-for-purpose. The end-user must be in agreement with the producer that the compost will perform as required. Specifications aid the purchaser to agree on the quality of the compost with the producer.

The PAS 100 sets upper limits for safety-related characteristics listed in the tables below. PAS100 recommends that 'those involved in compost production, specification, supply and use may need to know product characteristics associated with further technical parameters and/or require a product of a quality higher than the minimum specified in this PAS'. Accordingly, this document sets out other parameters that describe product processing, i.e. screening, and recommends which additional characteristics should be measured in relation to end-use, such as pH and electrical conductivity, which may affect plant growth.

Building on PAS100, the 'compost characteristics for various end uses' in sub-section 7 recommend minimum and maximum values for some parameters and list other characteristics that should be determined and declared in labelling.

4.4 Principal end uses

The end uses for which the compost has been evaluated in agriculture and field horticulture are:

A. soil improvement for general field horticultural and agricultural use e.g. cereals, brassicas, etc

B. soil improvement for root crops and certain vegetable crops where a finer tilth is required

The end uses for which the compost has been evaluated in landscaping are:

C. garden bed establishment

D. manufactured topsoil

E. tree/shrub planting

F. turf establishment/renovation

G. turf top dressing

H. mulching

The end uses for which the compost has been evaluated in growing media and retail products are:

I. growing media production

J. soil improver – bagged product

4.5 PAS100 parameters and limits

PAS100 sets out limits for parameters to ensure that the compost does not cause harm to human health or the environment.

Parameter	PAS 100 limits
Input materials	Source-separated biodegradable materials
Human pathogens	*Salmonella* spp. absent in 25 g sample *E. coli* less than 1000 cfu g^{-1}
Potentially toxic elements	Cadmium ≤ 1.5 ppm Chromium ≤ 100 ppm Copper ≤ 200 ppm Lead ≤ 200 ppm Mercury ≤ 1 ppm Nickel ≤ 50 ppm Zinc ≤ 400 ppm
Physical contaminants	Total glass, metal and plastic > 2 mm to be ≤ 0.5 % m/m of air-dried sample of which ≤ 0.25 % is to be plastic Stones > 2 mm to be ≤ 7 % m/m of air-dried sample
Phytotoxins	Germination and growth not less than 80 % of the performance achieved by the controls
Weed propagules	Viable weed seeds ≤ 5 per litre

Notes and comments

Input materials

Plant materials that carry diseases could be included and composted. The composting process will kill the vast majority of plant diseases as temperatures reach over 55 °C for extended periods, and the materials are regularly mixed and turned unless in a static batch system with uniform heating. Composting temperatures are monitored and recorded. Research on plant pathogen destruction through composting is currently being conducted by Horticulture Research International under WRAP project STA0012.

PAS100 requires that records are kept of input materials and these are traceable through to the end product.

End product testing against the agreed limits will verify that the input materials are not contaminated by other environmental hazards such as potentially toxic elements from soil or plant material.

Human pathogens

If the levels of the indicator organisms are within the limits then this indicates that the composting process has been well managed and the product suitably stored.

Potentially toxic elements (PTEs)

These limits give a good margin of safety to humans and the environment.

Physical contaminants

Physical contaminants within these limits do not have a visual impact on end-use, and provide a minimum for safe use of composts. Some end-users, such as growing media manufacturers, may specify more stringent limits for physical contaminants.

Phytotoxins

The plant germination and growth bioassays have been included to indicate to the end user whether the compost tested contains substances that have toxic effects on plants.

Weed propagules

These maximum levels must be considered in relation to the influx of wind-blown weed seeds into, e.g. a landscaping situation, and weed seeds already present in soils.

4.6 Additional parameters for consideration by industry

PAS100 lists a range of additional determinations and declarations recommended for compost parameters according to end use. Not all parameters are relevant to each end-use. The parameters that are *recommended* to be shown on product label or documentation in PAS100 are indicated in the tables below as *labelling only*. It is important to note that inclusion of certain parameters in labelling/ product information sheets may be useful to end-users, but the values are not required to fall within a specific range, i.e. are not specified in PAS100.

Further parameters to be measured that are useful to end users are indicated in the notes for each section.

4.7 Compost characteristics for various end uses

These characteristics for compost are to aid the composting industry to manufacture products that are suitable for different end uses. The characteristics also aid end users by providing guideline values for the parameters that are relevant to them. Note that specific end users, such as organic growers, have additional requirements and may also not be allowed to use composts derived from kitchen wastes because of concerns about the potential inclusion of genetically modified organisms (GMOs) or their derivatives in these feedstocks.

Parameters that are marked for labelling only may be declared voluntarily by the compost manufacturer to aid the end user utilise the product more effectively.

Soils are commonly assessed for available nutrients and values expressed as indices for phosphate (P_2O_5), potash (K_2O) and magnesium (Mg). Analysis of soil samples before and after compost addition can be compared with agricultural and horticultural values in the 'Fertiliser Recommendations for Agricultural and Horticultural Crops 2000' (RB209) available from DEFRA and for landscaping in BS3882:1994 'Specification for topsoil'.

In agriculture the total nitrogen in organic soil amendments must be taken into account in nitrate vulnerable zones (NVZs) see www.defra.gov.uk/environment/water/quality/nitrate, and in other areas the Soil Code (MAFF 1998 available from Defra) should be followed (see regulations above).

4.7.1 Agriculture and field horticulture

A. Soil improvement for general field horticulture and agriculture

Parameter	Specification/ labelling
Bulk density (g/l)	Labelling only
Maximum screen size (mm)	**40 mm**
Particle size distribution	Labelling only
Moisture content (% m/m)	**Minimum 35 %** **Maximum 55 %**
Organic matter content (% m/m)	**Minimum 25 %**
Total nitrogen (% dry weight)	Labelling only
Total phosphorus (% dry weight)	Labelling only
Total potassium (% dry weight)	Labelling only
pH	Labelling only
Electrical conductivity (μS/cm or mS/m)	Labelling only

Additional information

Growers and farmers may also wish to know the neutralising value of compost and this can be measured to give a liming value for compost when compared with their soil pH and texture.

From the total nitrogen and organic matter content of the compost, the carbon to nitrogen ratio (C:N) of the compost can be estimated. This can indicate the availability of the nitrogen contained in the compost although analysis of the carbon forms (lignin and cellulose for example) and nitrogen forms (N-containing molecules and ammonium:nitrate ratios) may give more detailed information leading to a closer estimate of availability but at greater cost.

Use of compost on grassland where livestock will graze will be subject to the Animal By-Products Regulations 2003 restrictions relating to catering wastes, if included in the composting feedstocks. Generally, the larger the screen size the greater the chance of physical contaminants being present, which may make the material unsuitable for use where animals graze.

B. Soil improvement for root crops and certain vegetable crops

Parameter	Specification / labelling
Bulk density (g/l)	Labelling only
Maximum screen size (mm)	**25 mm – most crops** **15 mm - seedbed**
Particle size distribution	Labelling only
Moisture content (% m/m)	**Minimum 35 %** **Maximum 55 %**
Organic matter content (% m/m)	**Minimum 25 %**
Total nitrogen (% dry weight)	Labelling only
Total phosphorus (% dry weight)	Labelling only
Total potassium (% dry weight)	Labelling only
Water extractable Nitrate (NO_3-N)	Labelling only
Water extractable Ammonium (NH_4-N)	Labelling only
pH	Labelling only
Electrical conductivity (µS/cm or mS/m)	Labelling only

Notes

For most crops 25 mm screened compost products will be suitable but where a fine seed bed is required a maximum 15 mm screen size is recommended.

Water extractable nitrate and ammonium-nitrogen may be requested by some end users if their seedlings are sensitive to ammonium-N.

Additional information

Growers and farmers may also wish to know the neutralising value of compost and this can be measured to give a liming value for compost when compared with their soil pH and texture.

From the total nitrogen and organic matter content of the compost, the carbon to nitrogen ratio (C:N) of the compost can be estimated. This can indicate the availability of the nitrogen contained in the compost although analysis of the carbon forms (lignin and cellulose for example) and nitrogen forms (N-containing molecules and ammonium:nitrate ratios) may give more detailed information leading to a closer estimate of availability but at greater cost.

Use of compost on grassland where livestock will graze will be subject to the Animal By-Products Regulations 2003 restrictions relating to catering wastes, if included in the composting feedstocks. Generally, the larger the screen size the greater the chance of physical contaminants being present, which may make the material unsuitable for use where animals graze.

4.7.2 Landscaping

It is important that the base soil characteristics are taken into consideration especially where land is being restored from industrial use. The Contaminated Land Exposure Assessment (CLEA) model and Soil Guideline Values (SGVs) should be taken into consideration (see www.defra.gov.uk/environment/landliability/index.htm and www.environment-agency.gov.uk/subjects/landquality for details). As an example, soil may be contaminated with arsenic and care should be taken when mixing or cultivating in compost due to risks of dust inhalation. For further information, contact the Health and Safety Executive.

Reference may also need to be made to BS3882:1994 Specification for topsoil.

C. Garden bed establishment

Parameter	Specification/ labelling
Bulk density (g/l)	Labelling only
Maximum screen size (mm)	**25 mm**
Particle size distribution	Labelling only
Moisture content (% m/m)	**Minimum 35 %** **Maximum 55 %**
Organic matter content (% m/m)	**Minimum 25 %**
Total nitrogen (% dry weight)	Labelling only
Total phosphorus (% dry weight)	Labelling only
Total potassium (% dry weight)	Labelling only
CAT-extractable nutrients	Labelling only
Water extractable Nitrate (NO_3-N)	Labelling only
Water extractable Ammonium (NH_4-N)	Labelling only
pH	**Maximum 8.7**
Electrical conductivity (μS/cm or mS/m)	**Maximum 2000**

Note

For plants requiring a low pH (acid soil) a maximum pH of 8.0 could be specified but compost has only a low neutralising value and maintains rather than significantly increases soil pH. The starting soil pH also needs to be considered as to whether these plants should be used.

D. Manufactured topsoil

Parameter	Specification / labelling
Bulk density (g/l)	Labelling only
Maximum screen size (mm)	**25 mm**
Particle size distribution	Labelling only
Moisture content (% m/m)	**Minimum 35 %** **Maximum 60 %**
Organic matter content (% m/m)	**Minimum 25 %**
Total nitrogen (% dry weight)	Labelling only
Total phosphorus (% dry weight)	Labelling only
Total potassium (% dry weight)	Labelling only
Water extractable Nitrate (NO_3-N)	Labelling only
Water extractable Ammonium (NH_4-N)	Labelling only
pH	**Maximum 8.7**
Electrical conductivity (μS/cm or mS/m)	**3000**

Note

For plants requiring a low pH (acid soil) a maximum pH of 8.0 could be specified but compost has only a low neutralising value and maintains rather than significantly increases soil pH. The starting soil pH also needs to be considered as to whether these plants should be used.

E. Tree/shrub planting

Parameter	Specification/ labelling
Bulk density (g/l)	Labelling only
Maximum screen size (mm)	**25 mm**
Particle size distribution	Labelling only
Moisture content (% m/m)	**Minimum 35 %** **Maximum 55 %**
Organic matter content (% m/m)	**Minimum 25 %**
Total nitrogen (% dry weight)	Labelling only
Total phosphorus (% dry weight)	Labelling only
Total potassium (% dry weight)	Labelling only
CAT-extractable nutrients	Labelling only
Water extractable Nitrate (NO_3-N)	Labelling only
Water extractable Ammonium (NH_4-N)	Labelling only
pH	**Maximum 8.7**
Electrical conductivity (µS/cm or mS/m)	**Maximum 2000**

Note

For plants requiring a low pH (acid soil) a maximum pH of 8.0 could be specified but compost has only a low neutralising value and maintains rather than significantly increases soil pH. The starting soil pH also needs to be considered as to whether these plants should be used.

F. Turf establishment/renovation

Parameter	Specification/ labelling
Bulk density (g/l)	Labelling only
Maximum screen size (mm)	**25 mm (15 mm for seedbeds)**
Particle size distribution	Labelling only
Moisture content (% m/m)	**Minimum 35 % Maximum 55 %**
Organic matter content (% m/m)	**Minimum 25 %**
Total nitrogen (% dry weight)	Labelling only
Total phosphorus (% dry weight)	Labelling only
Total potassium (% dry weight)	Labelling only
CAT-extractable nutrients	Labelling only
Water extractable Nitrate (NO_3-N)	Labelling only
Water extractable Ammonium (NH_4-N)	Labelling only
pH	**Maximum 8.7**
Electrical conductivity (μS/cm or mS/m)	**Maximum 2000**

Note

For sports pitches and where grass seed is being sown the finer maximum screen size of 15 mm could be specified, with 10 mm for root zones, e.g. golf greens.

G. Turf top-dressing

Parameter	**Specification / labelling**
Bulk density (g/l)	Labelling only
Maximum screen size (mm)	**10 mm**
Particle size distribution	**95 % < 8 mm** **Fine turf 95 % < 5 mm**
Moisture content (% m/m)	**Minimum 35 %** **Maximum 55 %**
Organic matter content (% m/m)	**Minimum 25 %**
Total nitrogen (% dry weight)	Labelling only
Total phosphorus (% dry weight)	Labelling only
Total potassium (% dry weight)	Labelling only
CAT-extractable Nutrients	Labelling only
Water extractable Nitrate (NO3-N)	Labelling only
Water extractable Ammonium (NH4-N)	Labelling only
Water extractable Chloride (Total Chloride)	Labelling only
pH	**Maximum 8.7**
Electrical conductivity (μS/cm or mS/m)	**Maximum 2500**

Note

Compost may be used mixed with sand, or alone. Where grass seed is sown along with top dressing, the chloride content of the compost may optionally be specified at a maximum of 800 mg/l to help avoid germination delays.

For fine turf where an alkaline pH may be associated with fungal disease, a sand:compost mix should ideally not be alkaline i.e. the pH less than 7.0. The sand and compost should be tested for neutralising value (lime content equivalent) to avoid raising the root zone pH.

For the top dressing of sports pitches, the compost should be free of any sharp materials e.g. glass.

H. Mulching

Parameter	Specification / labelling
Bulk density (g/l)	Labelling only
Maximum screen size (mm)	**75 mm**
Particle size distribution	Labelling only
Moisture content (% m/m)	**Minimum 25 %** **Maximum 55 %**
pH	Labelling only

Note

The maximum screen size specified will depend on the visual appearance required at the landscape site. Use a 75 mm screen for a coarse roadside mulch or a 50 mm screen for a medium grade mulch.

The removal of fine particles can reduce the bulk density of the mulch to aid transport and spreading. It also reduces the germination of wind-blown weed seeds as the mulch remains drier. The fine particles can be removed by passing the material over e.g. a 5 mm or 10 mm screen with the screened 'fines' used for other markets. The resultant mulch may have a fines content with particles less than 2 mm of less than 10 %, for example. On clay soils the use of a mulch with a low fines content is advisable as otherwise anaerobic conditions may develop when the soil is wet.

4.7.3 Growing media and retail soil improvers

I. Growing media production

Parameter	Specification / labelling
Bulk density (g/l)	**< 600**
Maximum screen size (mm)	**10 mm**
Particle size distribution	Labelling only
Moisture content (% m/m)	**Minimum 35 %** **Maximum 55 %**
Organic matter content (% m/m)	**Minimum 25 %**
Total nitrogen (% dry weight)	Labelling only
Total phosphorus (% dry weight)	Labelling only
Total potassium (% dry weight)	Labelling only
CAT-extractable Nutrients	Labelling only
Water extractable Nitrate (NO3-N)	Labelling only
Water extractable Ammonium (NH4-N)	Labelling only
Water extractable Chloride (Total Chloride)	Labelling only
pH	**Maximum 8.5**
Electrical conductivity (µS/cm or mS/m)	**Maximum 1000**

Note

Compost bulk density is reported on a fresh weight basis. On a dry weight basis compost has a greater bulk density than say peat, which may affect the transport costs of bulk materials. However, plants grown in growing media based on compost show less weight difference than those based on peat alone at the point of dispatch as plants are normally well watered prior to loading which minimises the differences.

The screen size specified is for general inclusion in growing media. Specific end uses may require a different range of particle sizes, e.g. seeding/modules, bedding, pot plants and Hardy Ornamental Nursery Stock. 'Longs' (particles with one dimension, i.e. length, greater than the screen size) tend to be broken up during the mixing process but could be specified to be less than an amount of the compost by weight greater or equal to 8 mm.

Air-filled porosity (AFP) of a growing media mix is dependent on the sizes and relative amounts of all the particles from all of the materials used. The ideal level of fine particles varies with cultivar, container size, irrigation system and other circumstances.

The compost products must be able to flow freely for blending and bagging operations. This is a function of particle size and shape, as well as moisture content.

J. Soil improver – bagged product

Parameter	Specification / labelling
Bulk density (g/l)	Labelling only
Maximum screen size (mm)	**15 mm**
Particle size distribution	Labelling only
Moisture content (% m/m)	**Minimum 35 %** **Maximum 55 %**
Organic matter content (% m/m)	**Minimum 25 %**
Total nitrogen (% dry weight)	Labelling only
Total phosphorus (% dry weight)	Labelling only
Total potassium (% dry weight)	Labelling only
CAT-extractable nutrients	Labelling only
Water extractable Nitrate (NO_3-N)	Labelling only
Water extractable Ammonium (NH_4-N)	Labelling only
pH	**Maximum 8.5**
Electrical conductivity (µS/cm or mS/m)	**Maximum 1500**

Note

For plants requiring a low pH (acid soil) a maximum pH of 8.0 could be specified but compost has only a low neutralising value and maintains rather than significantly increases soil pH. The starting soil pH also needs to be considered as to whether these plants should be used.

The compost products must be able to flow freely for blending and bagging operations. This is a function of particle size and shape, as well as moisture content.

5. Test methods

5.1 Project Horizontal

Within Europe, the qualities and existing or required methods for assessing selected quality parameters for sludges, biowastes and soils are under review.

The overall objective of the European project "Horizontal" is to develop horizontal and harmonised European standards in the fields of sludge, soil and treated biowaste and to facilitate regulation of these major streams in the multiple decisions related to different uses and disposal governed by EU Directives. The revision of the Sewage Sludge Directive 86/278/EEC, the upcoming Directive on the Biological Treatment of Biodegradable Waste and the Soil Monitoring Directive calls for standards on sampling, on hygienic and biological parameters and on methods of test for inorganic and organic contaminants and for mechanical properties of these materials. The work for developing horizontal and harmonised European standards is split up in coherent Work Packages (WPs), each of which addresses a main aspect of all relevant standards required, or likely to be required, in EU regulations regarding sludge, biowaste and soil.

More information is available at http://www.ecn.nl/library/horizontal/DaviWB/Pagina1.html.

For information with regards potentially toxic elements (PTEs) see desk study 18. This report in hand deals with a desk study under WP 6: Inorganic Parameters: Assessment of the feasibility of draft horizontal standards for:

- the digestion of samples prior to the determination of trace elements
- covering sludge, soil, treated biowaste and neighbouring fields

Existing standards and/or draft standards are assessed and key points where possible differences exist are identified and the differences evaluated in order to prepare draft horizontal standards. In addition, assessments of ongoing activities in the relevant CEN/TC workgroups are included in the project:

- CEN/TC 292/WG 3 Waste
- CEN/TC 308/WG 1, Sludge
- CEN/TC 345, Soil (the TC is newly established)
- CEN /TC 223, Soil improvers and growing media

In many European countries, digestion methods used for solid environmental samples such as waste, sludge and soil are based on the use of aqua regia in accordance with the relevant European and International standards for the different areas. However, in some European countries, e.g. the Nordic countries, the digestion methods are primarily based on the use of nitric acid.

The report in hand covers an evaluation of both principles with a view to the development of horizontal standards.

5.2 Overview of current test methods

Parameter		Method	
Pathogens - plant		If necessary the sample is diluted with peat with the addition of essential plant nutrients for satisfactory plant growth. Seeds are planted and the growth observed and compared with a peat based growing media over a 4-week period.	For satisfactory growth the test sample should not be less than 80 % w/w of the control. All abnormalities in plant growth to be recorded.
Potentially toxic elements (Cd, Cr, Cu, Pb Mg, Ni, Zn)		The dried ground sample is extracted with aqua regia. The dissolved elements are determined by AA, ICP or similar techniques.	
Physical contaminants		The dried sample is sieved and any physical contaminants (glass, metal, plastics, stones, brick, rubble etc. are removed by hand and weighed. The individual and total mass of contaminant is expressed as a % of the whole sample.	
Phytotoxins		See plant pathogens	
Weed propogules		The sample is prepared in a similar manner to plant pathogens and any except that no seed are planed. Any plant growth over a 4 week period is noted	It is assumed that any plant growth is from weeds.
Organic matter		The weighed dried sample is incinerated at 450^{o}C The loss in weight is assumed to be due to loss of organic matter.	Plastic will also be volatilised at this temperature – it is assumed that carbonates are not decomposed.
Total nitrogen (N)		The sample is either digested in acid (Kjeldahl) or burnt in an oxygen stream (Dumas)	Both methods have some limitations. Kjeldahl can be determined on a wet sample but is known to give low results on some cyclic organic compounds and that not all nitrates are converted to NH_4N Dumas can only be carried out on dry samples therefore any volatile nitrogen is lost during the drying process.
Total potassium (K)		A dried finely ground sample is extracted with aqua regia. The K in the extract can be determined by flame spectroscopy, AA, ICP etc.	
Total chloride (Cl)		The method BS EN 13652 describes water-soluble chloride not total chloride that requires ashing under alkaline conditions.	

Parameter		**Method**	
Nutrients Calcium chloride extractable		A fresh sieved sample passing a 20 mm sieve or a 40 mm sieve is extracted 1:5 v/v with 0,01 mol/l calcium chloride and 0,002 mol/l DTPA for 1 hr. The extracted nutrients are determined on the filtered extract by for example, AA, ICP, flame, ion chromatographic and colorimetric procedures.	
Water soluble chloride, ammonium and nitrate		A freshly sieved un-dried sample passing a 20 mm sieve or a 40 mm sieve is extracted 1:5 v/v with water for 1 hr. The extracted nutrients are determined on the filtered extract by for example, ion chromatographic, distillation and colorimetric	
Electrical conductivity		A fresh sieved sample passing a 20 mm sieve or a 40 mm sieve is extracted 1:5 v/v with water for 1 hr. The electrical conductivity is determined on the filtered extract.	
pH		A fresh sieved sample passing a 20 mm sieve or a 40 mm sieve is extracted 1:5 with water for 1 hr. The pH is determined on the suspension.	
Bulk density	The bulk density (laboratory compacted bulk density) is required to enable the laboratory to take a weight equivalent to a specified volume for some of the tests outlined above.	The sample is gently homogenised to break up any agglomerations. The sample is passed through a sieve into a specially constructed 1-litre cylinder. A mass of 650 g is placed on the sample and the excess sample is stuck off. The mass of 1 litre compressed sample is determined to give the density of the material under test.	
Moisture or dry matter		The sample is gently homogenised to break up any agglomerations and a weighed portion is dried at 103 ^{o}C to constant weight. The loss in mass is deemed to be the moisture content.	
Particle size distribution		A dried portion of sample is passed through a series of sieves taking care not to break down the sample during sieving. The mass on each sieve is determined and expressed as a % of the whole sample.	
Air filled porosity	This is a specialised technique requiring a sand bath to provide water tension.	The sample is saturated in water and then equilibrated on a sand box at minus 50 cm water pressure head. The sample is then transferred into double ring sample cylinders, re-wetted and equilibrated at minus 10 cm water pressure head. After equilibration the physical properties are calculated from the wet and dry weights of the sample in the lower ring. It is necessary to also determine the organic matter content.	
Water holding capacity		See Air filled porosity	

6. Glossary and abbreviations

6.1 Glossary

Air Filled Porosity (AFP)

The AFP is the part of a compost that is filled with air following saturation and drainage.

Bulk Density (BD)

Composts and growing media are often sold with a measurement of bulk density being on the basis of 'fresh' or 'as received' weight per litre or cubic metre of material.

Cation Exchange Capacity (CEC)

CEC refers to the ability of a substrate to hold positively charged cations on its exchange sites.

Compost

Solid particulate material that is the result of composting, that has been sanitised and stabilised and that confers beneficial effects when added to soil and/or used in conjunction with plants.

Composting

Process of controlled microbiological decomposition of biodegradable materials under managed conditions that are predominantly aerobic and that allow the development of thermophilic temperatures as a result of biologically produced heat, in order to achieve compost that is sanitised and stable.

Dry Bulk Density (DBD)

The dry bulk density of a soil, compost or growing medium is the weight of oven dried material per unit volume where the volume is that of the material in its natural state. Soils may be dried and ground to pass 2 mm and e.g. nutrient contents expressed as mg per litre of soil where the volume is that of the 2 mm sieved soil.

Easily Available Water (EAW)

The EAW capacity of a growing medium is the measure of the quantity of water released by the substrate under a suction of a water column of between –0 and –50cm and represents that portion that can be readily absorbed by the roots.

Electrical Conductivity (EC)

Electrical Conductivity is a measure of total soluble salt concentration in a solution.

Feedstocks

The components of a compost defined by their origin.

Green Wastes

Arboreal and other botanical residues such as grass clippings and other plant residues derived from parks, gardens, nurseries and amenity areas and sometimes waste from vegetable or fruit processing activities.

Growing Media

Growing media are specially prepared formulations designed to grow plants in containers. They provide support for plant growth by delivering water, nutrients and oxygen to the root system. Containers include pots, trays, troughs, tubs, hanging baskets or growing bags. Soil improvers and conditioners are not considered as growing media for the purposes of this work as they are applied to soil *in situ*

Hydraulic Conductivity (HC)

The hydraulic conductivity is the ease at which water can move through a substrate and influences the rate at which a substrate can drain.

Kitchen Wastes

Kitchen Wastes are the food wastes originally intended for human consumption. They may be raw or cooked and have originated as a consequence of preparation, have been surplus to consumption, or spoiled.

Mature/Maturity

The degree of biodegradation at which composted material is not phytotoxic or exerts negligible phytotoxicity in any plant growing situation when used as directed.

Pore Volume (PV)

The PV is the volume within the compost that is not occupied by particles and that can be occupied by either water or air.

Soil Improver (Conditioner)

A material added to soil *in situ* to enhance its physical, chemical and/or biological properties

Water Buffering Capacity (WBC)

The WBC or less easily available water (LEAW) is the quantity of water released by the substrate under a suction of a water column between –50 and –100cm and represents that portion of water that is less readily available to the roots.

Water Holding Capacity (WHC)

The WHC of a medium is the total amount of water held within a substrate and which is potentially available to the plant. It is defined as water held at tensions between the permanent wilting point and container capacity

Wettability

The wettability of a substrate is the ease with which it can absorb water.

Wood Wastes

Originate from untreated or biodegradable preservative treated woods from joinery, furniture making and packing materials including woods that have been reused in chipboards and MDF.

Yardwaste

American term for green waste.

6.2 Abbreviations

6.2.1 Terms

ADAS	Agricultural Development and Advisory Service
AFP	Air Filled Porosity
Avg, Ave	Average
BD	Bulk Density
BSI	British Standards Institute
CAT	Aqueous solution of aqueous $CaCl_2$ + DTPA (chelating agent). CAT-extraction helps to reveal the levels of nutrients that are available to plants.
CCME	Canadian council of ministers of the environment
CCREF	Composting Council Research and Education Foundation
CEC	Cation Exchange Capacity
CFU	Colony forming units
CLEA	Contaminated Land Exposure Assessment
Ctot	Total Carbon
DAS	Days after sowing
DBD	Dry Bulk Density
DEFRA	Department of Environment Food and Rural Affairs
DG Environment	Directorate General Environment
DM	Dry Matter
EAW	Easily Available Water
EC	Electrical Conductivity
FAQs	Frequently asked questions
FYM	Farmyard Manure
GMO	Genetically modified organisms
GROWS	Green Recycling of Organic Waste from Supermarkets
GWC	Green waste compost (or composted green waste, green compost)
HC	Hydraulic Conductivity
HDRA	Henry Doubleday Research Association
HRI	Horticultural Research International
ISR	Induced Systemic Resistance
JRC	Joint Research Centre (a Directorate General of the European Commission)
LEAW	Less Easily Available Water
LOI	Loss on Ignition

LSD	Least significant difference
MC	Moisture Content
MDF	Medium density fibreboard
MIT	Mineralisation Immobilisation Turnover
mM	milli Molar
m/m	mass for mass
MSW (compost)	Municipal Solid Waste
NPK (fertiliser)	Nitrogen, Phosphorus, Potassium
Ntot	Total Nitrogen
NVZ	Nitrate Vulnerable Zone
OARDC	Ohio Agricultural Research & Development Center
OC	Organic Carbon
ORA	Organic Resource Agency
PAS	Publicly Available Specification
PBS	Percentage Base Saturation
PD	Particle Density
POC	Particulate Organic Carbon
ppm	Parts per million
PTE	Potentially Toxic Element
PV	Pore Volume
ReMaDe	Recyclables Market Development
SGV	Soil Guideline Value
SOM	Soil Organic Matter
SSMSW	Source Separated Municipal Source Waste
TMV	Tobacco Mosaic Virus
TOC	Total Organic Carbon
UAW	Unavailable Water
USCC	United States Composting Council
v/v	Volume for Volume
w/s	Water Soluble
WBC	Water Buffering Capacity
WHC	Water Holding Capacity
WRAP	The Waste and Resources Action Programme

6.2.2 Elements, compounds, cations and anions

Al (Al^{3+})	Aluminium (ion)
B	Boron
C	Carbon
C:N	Carbon to Nitrogen ratio
Ca (Ca^{2+})	Calcium
CAL	Calcium Acetate Lactate Solution
CaO	Calcium Oxide
Cd	Cadmium
Cl (Cl^{-})	Chlorine (chloride)
CO_2	Carbon Dioxide
Cr	Chromium
Cu	Copper
Fe	Iron
H (H^{+})	Hydrogen
K (K^{+})	Potassium
K_2O	Potash
Mg (Mg^{2+})	Magnesium
Mn	Manganese
Mo	Molybdenum
N, N_2	Nitrogen
Na (Na^{+})	Sodium
NaCl	Sodium Chloride
NH_4	Ammonium
NH_4-N	Ammonium-N
Ni	Nickel
NO_2	Nitrogen Dioxide
NO_3	Nitrate
NO_3-N	Nitrate-N
P	Phosphorus
P_2O_5	Phosphate
Pb (Pb^{2+})	Lead
S	Sulphur
SO_3	Sulphur trioxide
Zn	Zinc

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