COMPOSTED GREEN MATERIAL AND ITS USE IN GROWING MEDIA

VICTORIA SURRAGE

A thesis submitted in partial fulfilment of the requirements of the Nottingham Trent University for the degree of Doctor of Philosophy

March 2007

ABSTRACT

The initial focus of this research was to establish various trends in green waste production for example variation in source and treatment of green waste. A comprehensive overview of the current green waste cycle was undertaken *via* a questionnaire titled ‘Management of Green Waste’.

From the producers of composted green material identified in the survey, fifteen sources agreed to participate within a study reviewing best practise leading to the production of material suitable for inclusion in growing media.

Due to increasing external pressures, the use of composted green waste as a potential alternative or diluent in growing media is being considered. If composted green material was to be used in the retail and professional markets, storage is of paramount importance. However very little information is available on the effects of storage on composted green material. Therefore the next step in this research was to conduct growth/storage trials using varying percentages of composted green material mixed with peat. The mixtures used in the trial were split, half of the material was stored in a 10˚C constant temperature room, and the other half was stored in green house conditions.

From the results gained in the peat-reduced growth and storage trials it was evident that some composted green materials could be a good diluent materials for peat based growing media if the feed stock and production method were monitored. Parameters such as the bulk density and conductivity may be an issue if this material was to be used as the sole component, however by the addition of other material for example bark, these materials could act as a diluents for these parameters enabling a higher inclusion rate of composted green material.

In view of demand for peat free growing media, allied to the production of composted green material, the next step in this research was to conduct a peat free growth and storage trial, using material such as bark that could eliminate some of the issues such as bulk density associated with the use of composted green material. From the twelve month growth/storage trial, one sample was identified and used in a peat-free trial. Mixtures were prepared at 0, 10, 20, 25, 30, 40, and 50% by volume other alternative materials to peat i.e. composted pine bark, composted bark, and wood waste i.e. chipboard soaked in urea formaldehyde.

By comparing the peat-reduced and the peat-free mixtures containing composted green material, the peat-free mixtures appear to be a superior product compared to the peat-reduced mixtures. By the addition of composted bark, composted pine bark and wood waste in varying quantity combined with the composted green material, the average values taken from the six month trial indicated that; the bulk density was reduced which would have a large implication on transportation cost, the organic matter content was increased with the corresponding decrease in ash content, improving the structure of the material and the cation-exchange capacity. The concentrations of nitrate-nitrogen, phosphorus and potassium, all increased which in turn increased the electrical conductivity: this could reduce the need for the addition of fertilisers, reducing production costs.

Acknowledgements

There are just so many thank yous.

Firstly, I thank Dr W.R Carlile for his truly amazing support especially with my awful spelling and grammar. I definitely owe him a few beers; well the Irish beer is not that good apparently.

I think we are solely responsible for any increases in BT's profit this year!

I would also like to thank Dr G.R Ball for all his support and advice especially with my stats.

I then must thank Debbie Baker for all her help and incredible organisational skills and for being a second pair of eyes, to find all those little inaccuracies i.e. tuning windrows and storage of producers. She is a star.

Thanks must also go to Jim for his general support, by just leaving me to it, and then being there when I needed him.

Charlie and Jenny, I probably would have starved without you. Thank you for just listening to me, I may have moaned a little!

And then we come to my family; Mum, Dad and my 'Little Bro' who are always there for me through thick and thin. A heartfelt thank you goes to them for all their support.

CONTENTS **PAGE**

List of Figures

List of Tables

Chapter 1.0 Waste Production

The background to this theses is wide ranging, varying from data collection on regional waste to the finer points of compost utilisation in growing media; therefore the introduction is initially wide ranging but ultimately focuses on specific aspects of composting. An overview of waste disposal in the United Kingdom is in this chapter and is followed by a second chapter that considers growing media and their constituents.

1.1 Waste Production in the United Kingdom – A brief overview

Municipal Waste includes household wastes and other waste collected by a Waste Collection Authority, or its agents, such as municipal parks and garden waste, beach cleansing waste, commercial or industrial waste and waste resulting from the clearance of fly-tipped materials (Defra, 2005).

Within the United Kingdom, approximately 29.7 million tonnes of municipal waste was produced in 2004/05. Household sources accounted for 86% of the total amount of municipal waste, 25.7 million tonnes, which equates to approximately 513kg of household waste per person per annum (Defra, 2006).

Household waste in the United Kingdom typically consists of 20% green waste (Defra, 2003); consequently the annual production of green waste at present is estimated to be around 5 million tonnes per year, which equates to 10–12 million m^3 based on a bulk density of 400-500g/L. Green waste includes vegetation and plant matter from household gardens, local authority parks and gardens and commercial landscaped gardens (Defra, 2000).

Waste management is of major concern within the United Kingdom, compared to other European Union member states. In 2004/05 the United Kingdom disposed of 67% (19.9 million tonnes) of its municipal waste produced *via* landfill (Defra, 2006) This may be compared to The Netherlands and Denmark, where almost no municipal waste was disposed of in landfill, with Sweden, Germany and Luxembourg all land filling less than a quarter of their municipal waste (Defra, 2006a) (Figure 1.1.1).

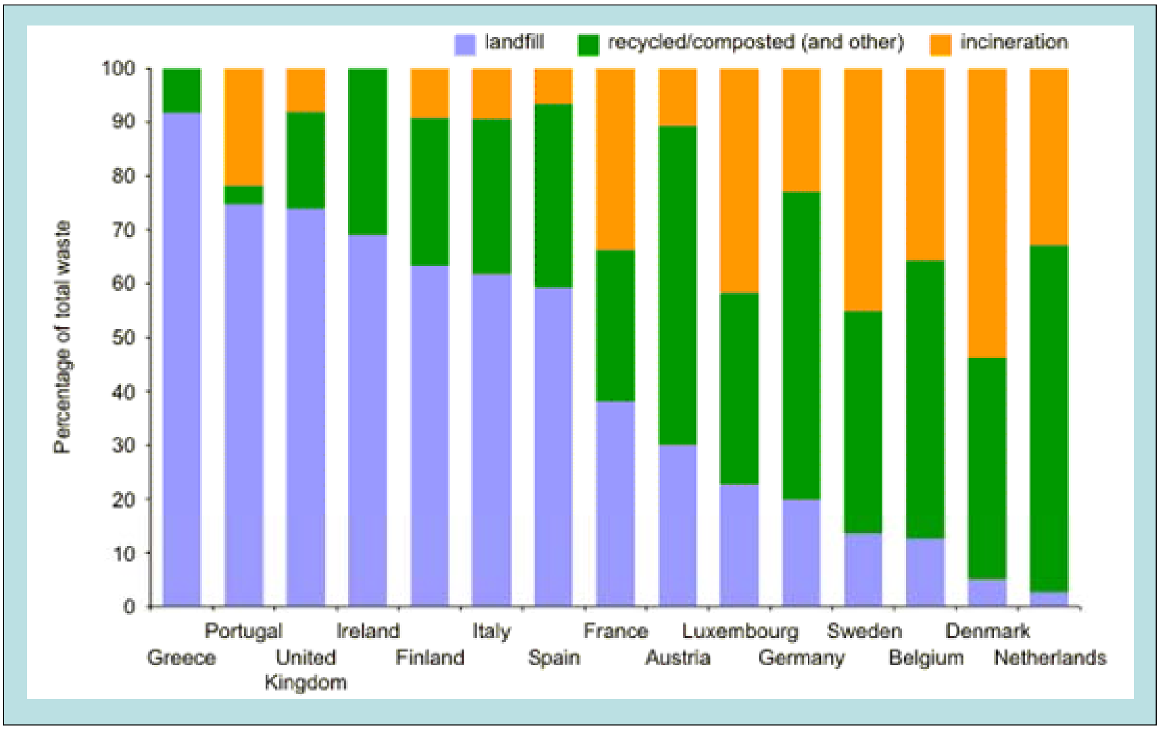


Figure 1.1.1: Municipal waste management in the European Union (Defra, 2006a)

Source separation of organic residues from households, gardens and parks, termed Biowaste, is the primary waste management method used in Germany. In 1991 a voluntary, quality standard, quality label and RAL (Reichs - Ausschuss fur Lieferbedingungen) (Committee of the German Reich for Terms and Conditions of sale) quality monitoring system for the composting of source separated organic residues from households and gardens was established. There is now a legal framework for the organic waste stream and compost production – the Biowaste Ordinance - which came into force in 1998. Similarly in The Netherlands, the national policy is to treat collected organic components of household waste separately as far as possible and otherwise utilise these components for direct conversion to energy, *via* composting and anaerobic digestion. Recycling in the United Kingdom has improved substantially over the past 20 years. In 1983/84 3kg per person per year of household waste was recycled in England, compared to 2004/05 where 115kg per person per year was recycled (Defra, 2006).

Within the United Kingdom most green waste has historically been disposed of in landfill sites. Since this current study is focused on regional development, this has significant reference to the East Midlands, for example 'At current rates of filling, landfill capacity is set to run out in less than 8 years time.' in Nottinghamshire (EMRLGA, 2002). Within the East Midlands 66% (1,684 thousand tonnes) of municipal waste was disposed of in landfill in comparison to 685 thousand tonnes (27%) of municipal waste being recycled/composted in 2004/05 (Defra, 2006).

To combat the problem of increased landfill the Government produced the Waste Strategy 2000, which sets national guidelines for waste management to which all local authorities must adhere. Through the Waste Strategy 2000 statutory targets have been made to increase the recycling or composting of municipal household waste:

- To recycle or compost at least 25% of household waste by 2005
- To recycle or compost at least 30% of household waste by 2010
- To recycle or compost at least 33% of household waste by 2015

The target for 2005/06 was achieved in the United Kingdom, as a household recycling rate of 26.7% was achieved in 2005/06 (Defra, 2006 b). Waste Strategy 2000 has since been updated, with information on these updates published by Defra, (2005). The United Kingdom government is now proposing to increase the statutory targets to 40% by 2010, 45% by 2015 and 50% by 2020; this decision has been aided by the EU Landfill Directive (Defra, 2006c).

The EC Landfill Directive (99/31/EC) requires the United Kingdom to reduce the volumes of biodegradable municipal waste (BMW) which is sent to landfill and promote alternatives such as recycling, composting and energy recovery from waste. The waste hierarchy was originally described in the Waste Framework Directive (75/442/EEC), and states that waste prevention should be prioritised above waste recycling and recovery, with waste disposal being used as the last option (Defra, 2000a).

The Landfill (England and Wales) Regulations 2002 implements the requirements of the Landfill Directive by producing national targets for reducing the amount of BMW disposed of *via* landfill. By 2010, the amount of BMW being land filled must be 75% of that produced in 1995, by 2013 it must be 50% and by 2020 it must be just 35% of that produced in 1995 (Defra, 2000a). It also aims to reduce the amount of methane, a powerful green house gas, emitted from landfill.

To facilitate England in meeting the national targets set out in the Landfill Regulation 2002 under the Waste and Emissions Trading (WET) Act 2003, the Landfill Allowances and Trading Scheme (LATS) were implemented. LATS was the world’s first allowance trading scheme for municipal waste and was launched in April 2005. The aim of this scheme is to give local authorities flexibility in meeting the Landfill Directive targets. Each local authority has allowances for the amount of BMW they can landfill for every year of the scheme until 2020. They are able to trade allowances with other local authorities, sell allowances if they have diverted more waste from landfill (*via* recycling) or buy more if they are likely to exceed their allowance. They can also bank unused allowances or borrow from their future allowances (Jennings, 2006).

The United Kingdom also has a wider legally binding target, agreed to within the Kyoto Protocol in December 1997 viz to cut the emissions of green house gases by 12.5% below 1990 levels by 2008-2012 (Defra, 2000b).

With this action in place, it is still not certain whether local authorities will meet their targets. The National Audit Office (NAO) warned there is significant risk that local authorities in England will fail to meet the EU Landfill Directive targets. The amount of BMW sent to landfill must be cut by 3.5million tonnes by 2010 and by a further 3.7 million tonnes by 2013 to meet the Landfill Directives. Failure to meet the Landfill Directive targets could risk the government being fined up to £180million a year from the EU. The NAO also estimates that local authorities could incur penalties under the Landfill Allowances and Trading Scheme of some £40 million a year, rising to £205million a year in 2013 (ENDS, 2006).

1.2 Methods of Waste Disposal

As noted, landfill is the primary method of waste disposal (Figure 1.2.1). The majority of landfills are operated on a phased cell system whereby, as one cell is being filled, another is being prepared and another is being completed/restored. Waste is tipped by incoming transfer/collection vehicles at a designated ‘working face’ on the cell where active disposal is taking place. The waste is then spread out and compacted by a purpose built compactor in a series of layers, or ‘lifts’, such that the void is minimised. At the end of the working day the final lift is often covered by ‘daily cover’ usually consisting of soil, or another inert material, to reduce odour, litter spread and access to waste by birds and vermin (Enviros Consulting Ltd, 2004).

Modern landfill requires a significant degree of engineering, for example lining and abstraction systems, in order to contain the waste, control emissions and minimise potential environmental effects. The primary by-products of landfill, where biodegradable materials have been disposed of, are; landfill gas (a combination of methane, CH_4, carbon dioxide

CO_2, and trace organics) and leachate (a liquor resulting from water passing through the waste mass) (Enviros Consulting Ltd, 2004).

Figure 1.2.1: Aerial view of a landfill site (Horsham District Council, 2003)

Other methods of waste disposal include incineration, anaerobic digestion and composting

1.2.1 Incineration

Incineration operates by feeding municipal solid waste into a moving grate where it is then burnt. The heat generated produces steam, driving turbines to generate electricity. The burning of the municipal solid waste produces two end-products; solid incinerator bottom ash (up to 25% of the weight of the municipal solid waste) which falls to the bottom of the grate for collection, and a much finer fly ash which is in the flue gases (air and gaseous combustion products) (POST, 2000).

There are many advantages and disadvantages for the process of incineration. Incineration reduces the amount of landfill space needed and has a longer life expectancy compared to a landfill site. Incineration also produces beneficial by-products such as the generation of electricity and heat. Emissions such as dioxins, furans and metals from incineration have decreased substantially in recent years driven by increasingly stringent limits on emissions set in European directives. The Waste Incineration Directive (WID) 2000/76/EC was agreed by the European Parliament and the Council of the European Union in December

2000. It should have been transposed into each Member State's national legislation by 28 December 2002. The aim of the Directive is to prevent or limit, as far as practical, negative effects on the environment, in particular pollution by emissions into air, soil, surface and ground water, and the resulting risk to human health from the incineration and co-incineration of waste. The Directive seeks to achieve this high level of environmental and human health protection by the setting and maintaining of stringent operational conditions, technical requirements and emission limits values for plant incinerating and co-incinerating waste throughout the European Community. The WID regulations precede the requirements set by the Municipal Waste Incineration (MWI) Directives (89/429/EEC) and (89/369/EEC). The WID applied to all new waste incineration installations from the 28 December 2002 and all existing installation from 28 December 2005. For installations which also come under the Integrated Pollution, Prevention and Control (IPPC) Directive (96/61/EC) compliance with WID is not essential as the requirement set for the IPPC are more broadly based and involve more stringent emission limits values and conditions (Defra, 2006d).

Combustion of municipal solid waste is now estimated to account for around 0.5% of the total United Kingdom emissions. (Defra *et al.* 2006e). The ash residue remaining after combustion has been shown to be non-hazardous solid waste that can be safely land filled or reused, for example in road building or path building. There is also the ability to reclaim metals e.g. Aluminium.

Disadvantages include the fact that a large number of the population would prefer not to live within the vicinity of an incineration plant. Even with stringent limits on emissions, there are still concerns over the production of by-products such as dioxins and furans which could escape into the atmosphere. Incineration generates relatively high emissions of oxides of nitrogen, hydrogen, chloride and sulphur dioxide, which therefore require abatement using flue gas cleaning systems, although emissions, VOC's and odours which do escape are generally low (Defra *et al.*. 2006e). By-products from incineration such as fly-ash from the filters could contain poisonous compounds such as heavy metals. If this material is reused, compounds may be leached into water courses (Envocare, 2006).

1.2.2 Composting

Composting is a biological process in which micro-organisms convert biodegradable organic matter into a stabilised residue known as compost. The process uses oxygen drawn from the air and produces carbon dioxide and water vapour as by-products (Enviros Consulting Ltd, 2004).

$$\text{Organic Matter} + O_2 \longrightarrow \text{Stabilised product} + CO_2 + H_2O$$

(Groenhof, 1998)

The process of aerobic biodegradation is very complex and is a balance between the levels of organic waste, micro-organisms, oxygen and moisture content. These parameters need to be carefully controlled if the process is to proceed satisfactorily. Groenhof (1998) stated the ideal feedstock has a carbon to nitrogen ratio of 30:1 for effective microbial activity, thus preventing unnecessary recycling of carbon and excessive loss of nitrogen.

There are a variety of composting techniques, the simplest process being open air windrow composting (Figure 1.2.2.1). The biodegradable waste feedstock is placed into elongated piles (windrows) approximately 1.5 to 3 metres high in material.

Figure 1.2.2.1: Windrows composting site (By the permission of Bord na Mona.)

Throughout the composting process, it is essential that oxygen is in plentiful supply, with 15% inclusion as an optimum value. Oxygen ensures that optimum aerobic microbial activity is sustained and that it prevents the composting process from becoming anaerobic and subsequently producing unpleasant odours for example hydrogen sulphide, volatile sulphur and nitrogen compounds and volatile fatty acids can be produced. The latter having been associated with phytotoxic reactions (Joshua *et al.* 1998). This is achieved by mechanically turning the piles or by having air forced into the piles, until the oxygen demand of the process can be met through the natural diffusion of fresh air into the pile. This is the curing or maturation stage of the pile.

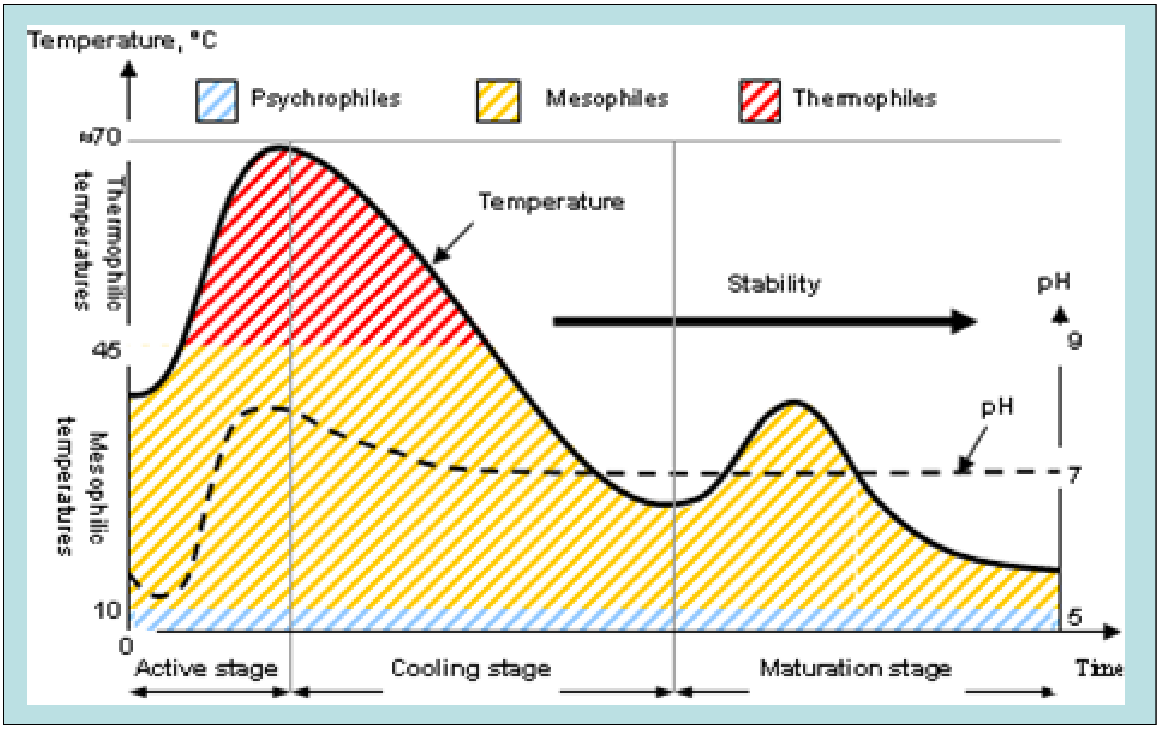


Figure 1.2.2.2: Temperature and pH profiles during composting (Teg Environmental PLC, 2005)

The frequency of turning is governed by the temperature of the compost piles and usually takes place when the pile approaches 60˚C. Moisture is also an essential component of the composting process. Too much moisture in the material will displace the oxygen within the interstitial spaces, leading to anaerobiosis. This in turn will prevent any significant rise in temperature, the microbial activity may be reduced and the pile may not mature (Groenhof, 1998). On the other hand the addition of water is needed if the pile becomes too dry.

During the composting process high temperatures, usually in the region of 60-70˚C, will be achieved by the composting pile, indicated by Figure 1.2.2.2. Temperature in excess of 55˚C have been implicated in the elimination of potential pathogenic micro-organisms from the compost substrate and this observation forms the basis of the sanitisation phase of composting known as pasteurisation (Joshua *et al.* 1998). Individual composting facilities have slightly varying methods. Some may shred the biodegradable waste before composting to speed up the process; other facilities may screen the material after it has been composted. The final particle size will depend upon the desired usage of the end product. If the material is to be spread on agricultural land it may only need to be shredded to a particle size of 40mm. If composted material was to be included in growing media, the material would need to be finer and therefore a smaller grade would be needed, commonly 10mm (Prasad, pers comm). Composted materials are also screened to remove any waste contamination, such as plastic, metal and glass. The process of composting can take from eight to sixteen weeks to produce a stable end-product.

The microbiology of composting involves a succession of bacteria, actinomycetes and fungi, dictated in part by the availability of specific nutrients within the composting material. Initially carbohydrates and proteins may be degraded at the beginning of the process, followed by more complex molecules such as lignin towards the end of the process. Microbial activity is also governed by temperature. In the early (mesophilic) stages of a pile mesophilic organisms, usually bacteria and fungi predominate, with the subsequent (thermophilic) phase characterised by actinomycetes plus bacteria, and the final curing stage (again mesophilic) may involve the reappearance of fungi (Groenhof, 1998).

In-vessel composting is as the name implies, carried out in a closed container (Figure 1.2.2.3). This allows a higher degree of process control than is possible with windrow composting. In-vessel systems can be broadly categorised into five types: containers, silos, agitated bays, tunnels and enclosed halls. This composting process typically takes between 7 and 21 days, with a maturation time commonly between 4-10 weeks. Many in-vessel systems involve the forced aeration of the feedstock. As this process is undertaken in an enclosed area, there is the ability to control the undesirable side effects such as odour and noise (Enviros Consulting Ltd, 2004).

Figure 1.2.2.3: A fully enclosed 10,000 tonnes per year composting facility. (By the permission of Transform Compost Systems.)

1.2.3 Anaerobic Digestion

Anaerobic digestion is the biological treatment of biodegradable organic waste in the absence of oxygen, utilising microbial activity to break down the waste in a controlled environment (Figure 1.2.3.1). Anaerobic digestion produces three by-products; biogas which is rich in methane and can be used to generate heat and/or electricity, fibre (or digestate) which is nutrient rich and has the potential to be used as a soil improver, and liquor which is also nutrient rich and has the potential to be used as a liquid fertiliser. In the United Kingdom, anaerobic digestion has so far been limited to small on-farm digesters, treating agricultural, household/industrial waste and sewage sludge. There are a limited number of trial facilities investigating the anaerobic digestion of different feed stocks, such as household kitchen waste and green waste. Larger anaerobic digestion plants have been developed in Europe and North America using feedstock from a number of sources (Enviros Consulting Ltd, 2004).

Figure 1.2.3.1: Anaerobic digester (By the permission of Onsite Power Systems.)

There are three main steps in the digestion process; pre-treatment, anaerobic digestion and post treatment.

Pre-treatment involves the separation of the biodegradable organic waste from the mixed waste stream. The particle size of the organic waste is then reduced to aid digestion.

Anaerobic digestion occurs within the digester, a warmed, sealed, airless container. Upon introduction of the feedstock, bacteria within the digester ferment the organic fraction and convert it into biogas, a mixture of carbon dioxide, methane and small amounts of other gases. There are two types of anaerobic digestion; mesophilic and thermophylic.

Mesophilic digestion, is where the feedstock remains in the digester for 15-30 days at approximately 30-35˚C. Thermophilic digestion is where the feedstock stays in the digester for 12-14 days at 55˚C. Mesophilic digestion tends to be more tolerant and robust than the thermophilic digestion, reducing the need for expensive technology, energy input and the degree of expertise needed for the operation of the equipment. However the mesophilic method does require a larger digestion tank. Thermophilic digestion produces larger quantities of methane, with a faster throughput of feedstock and gives a higher degree of control of pathogen.

During the anaerobic digestion process between 30-60% of the initial feedstock is converted into biogas. This gas may be burned, and can then be used for heat and power generation. As more feedstock is introduced into the system, the digestate is pumped into a storage tank. Biogas is still produced in this tank and collected. The residual digestate can then be separated to produce fibre and liquor.

If the end-product is to be used in horticulture or agriculture, the digestate is usually refined in the post treatment phase. The material can be spread directly onto farmland as a slurry or divided into a liquid and solid fraction. The solid fraction can be made into dry and fully stabilised compost by maturing it for 2-4 weeks, and the liquid fraction can be mixed with the incoming waste to inoculate and moisten it, be sent to a wastewater treatment plant or applied to farmland as a liquid fertiliser (Enviros Consulting Ltd, 2004).

The United Kingdom's current government policy towards composting waste treatment is summarised in the following statement taken from the Defra web page (Defra, 2006c). 'The government strongly supports the composting of waste, as a vital component towards meeting the Waste Strategy targets for recycling and composting and targets under the Landfill Directive to reduce the land filling of biodegradable municipal waste. The Waste Strategy made clear that the government sees a need for a significant expansion in capacity for the composting of waste over the next decade. It is a key objective of the government to increase the amount of the organic waste stream which is composted.'

1.3 Compost in Growing Media

One of the end uses of composted material is as a constituent of growing media. Growing media is seen as a high value destination for composted materials. Often composted materials need to be disposed of at a cost. Their use in growing medium may attract income for the compost producer. Additionally compost of a suitable quality may be used to replace peat, now considered a finite resource (non-sustainable), in growing media (Carlile, 1997). However compost for use in growing media must be of sufficient quality to sustain good plant growth. Chapter 2 gives a review of growing media with particular reference to the influences of environmental and other lobby groups on patterns of use in the United Kingdom from 1990 to date, as well as considerations of organic alternatives to peat: the latter still being the principal constituent of growing media worldwide.

Chapter 2.0 Growing Media

Statistics on the use of growing media in the United Kingdom have been collected by the Peat Working Group (PWG) established in 1992, which has now been superseded by the Horticultural Growing Media Forum (HGMF). PWG initiated the first data collection on growing media substrates in 1993 continuing through 1996-1999, with the ODPM (Office of the Deputy Prime Minister) conducting the penultimate study in 2001. The most comprehensive recent analysis on growing media substrates is published in 'Monitoring of peat and alternatives products for growing media and soil improvers in the United Kingdom 2005' by Defra in November 2006.

Within this document, the data produced has been divided into two categories, Growing Media and Soil Improvers (including mulches). To clarify the difference between them, growing media, also referred to as 'compost' in the United Kingdom, is a material in which plants are grown isolated from open ground. Soil improvers are materials which are added to the soil, i.e. open ground, mainly to improve the physical condition such as water holding capacity and nutrient content. Mulches have a similar role to soil improvers. They are layered on to the soil surface to improve physical conditions and visual appearance, for example to induce the suppression of weeds and minimise erosion.

The PWG and HGMF have identified within the United Kingdom horticultural market for soil improvers and growing media, four main consumer groups:

Amateur gardeners; this is a wide spectrum of consumers containing all social groupings and age classes. The main products brought by amateur gardeners are multi-purpose composts used for raising plants, filling tubs and baskets etc and growing bags used for growing tomatoes and other vegetables. To improve soil quality, amateur gardeners also buy bagged soil improvers and mulching materials. All these materials are general brought from a retailer. The standard of growing media for amateur use is not generally held to be as high as that held for professional use and indeed considerable variations in plant performance have been seen in media for the amateur market (Gardening from Which, 2007).

Professional growers; there are 3,000 glasshouse ornamental nurseries and 5,500 nursery stock growers in the United Kingdom who use large quantities of growing media (Wallace *et al.* 2006). The materials used by the professional grower are often from the same sources as the material used by the amateur market. However the professional grower will have more specialised mixes according to the crop that is grown in the substrate and as noted above requires a high quality, consistent product throughout the growing year.

Private sector landscapers; there are approximately 8,000 landscape contractors operating in the United Kingdom. This sector mostly uses soil improver products such as planting composts and mulches, generally purchased in bulk loads,

Local authority grounds maintenance; there are almost four hundred local authorities in the United Kingdom which have statutory responsibilities for grounds maintenance, focusing on the up-keep of open space amenities such as parks, gardens and playing fields. The majority of materials used within this sector are soil improvers (Wallace *et al.* 2006).

The market for growing media materials has expanded substantially since the 1990s, in particular within the amateur (retail) sector. Due to the increasing demand for materials such as composts, soil improvers, mulches etc, there has been a 20% increase in the horticultural market from 1999 to 2005. This represents a general increase of 0.2 million m^3 of material used per year (Wallace *et al.* 2006). As shown in Figure 2.01.

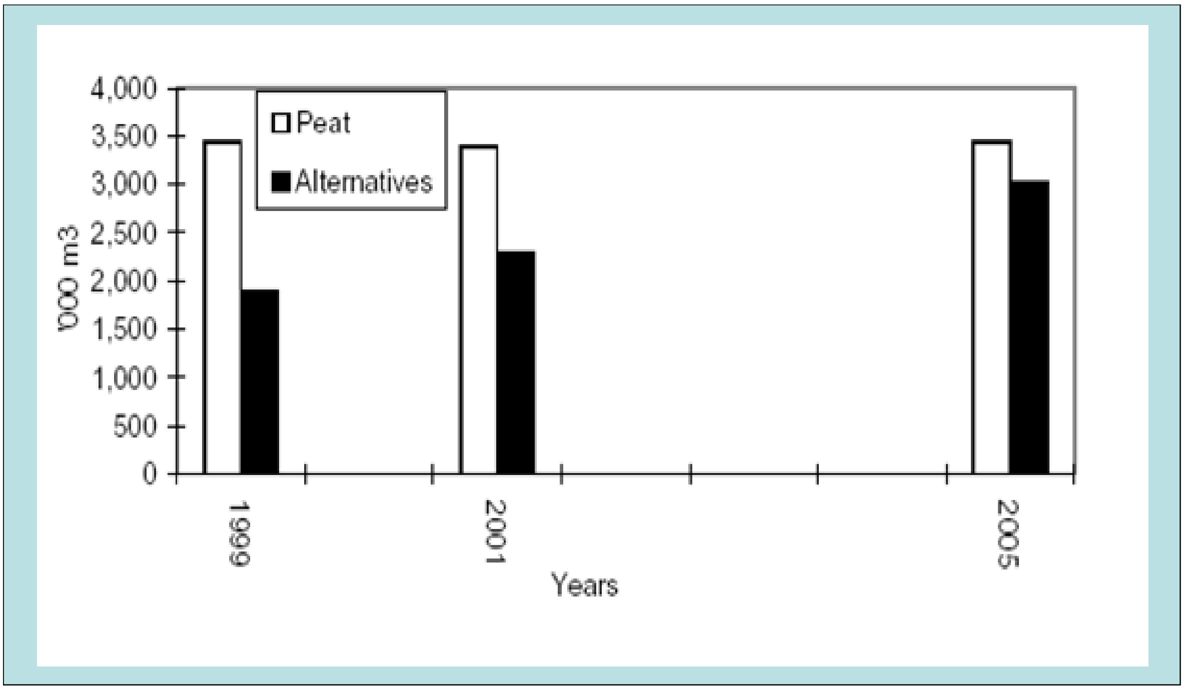


Figure 2.0.1: Combined use of peat and alternatives by amateur gardening, local authorities, private sector landscaping market and professional growers 1999-2005 ('000m^3) (Wallace *et al.* 2006).

In 2005, the total consumption of peat and alternative materials used in all four sectors was 6.46 million m^3 of which 3.44 million m^3 (53%) was peat and 3.02 million m m^3 (47%) was alternatives to peat (Figure 2.0.1). These materials were then processed to produce two main end-products, soil improvers and growing media. From the original 6.46 million m^3 of material, 4.00 million m^3 was used to produce growing media and 2.46 million m^3 was used to produce soil improvers. From the original 3.44 million m^3 of peat used, 96% (3.29 million m^3) was used in growing media, with 4% (0.15 million m^3) being used in soil improvers.

Amateur gardeners were the major users of growing media in 2005 (59% of the total material used) followed by professional growers (22%) and landscape contractors (17%). Local authorities used a small proportion in comparison to the other sectors (2%) (Figure 2.0.2).

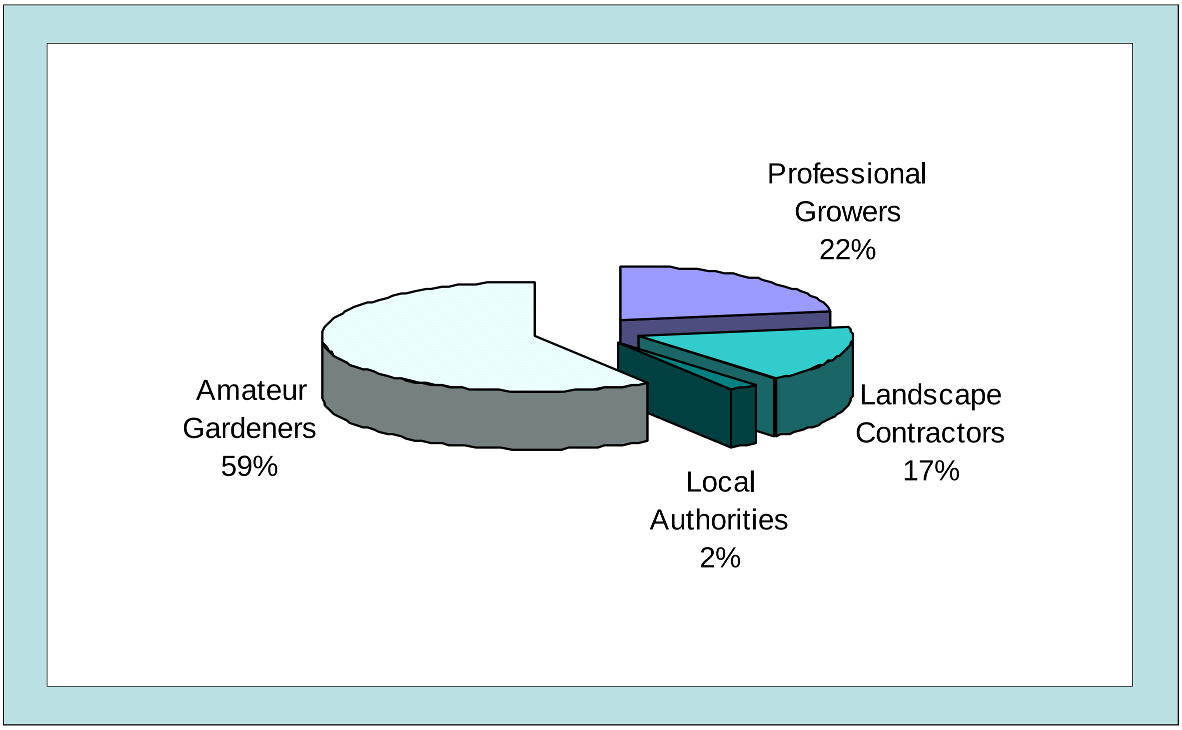


Figure 2.0.2: Consumption of materials by main user groups (Wallace *et al.* 2006).

Amateur gardeners accounted for 66% of the total volume of peat used across the four market sectors, 2,148,800 m^3 (Figure 2.0.3).

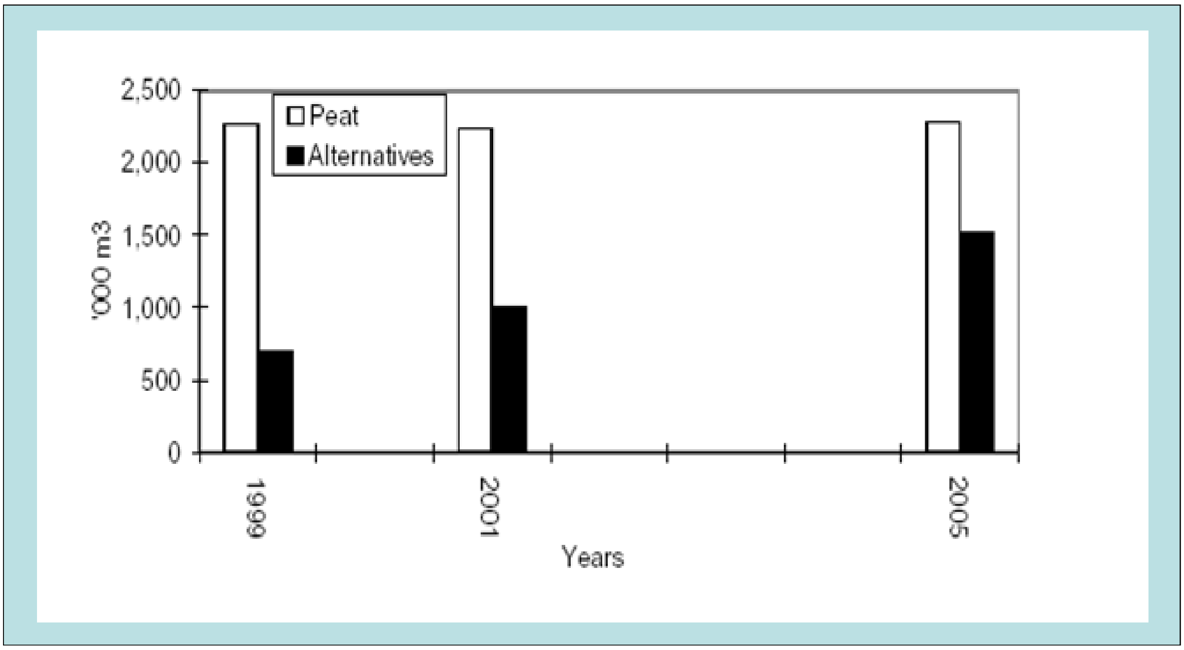


Figure 2.0.3: Use of peat and alternatives by the amateur gardening market 1999-2005 (‘000m^3) (Wallace *et al.* 2006).

The professional growers used 1,133,000 m^3 of peat which equates to approximately half of the total used by amateur gardeners in 2005. Amateur gardeners also consumed 50% of the total of alternatives materials produced in 2005. With landscape contractors using 35% of the total of alternatives produced. Within the professional growers markets, the move from peat to alternatives is slow, with only 9.2% of alternatives used in the growing media for the professional market.

Approximately half the peat used in the United Kingdom in 2005 was from the Republic of Ireland (56%). Northern Europe supplied 6% which was sourced mainly from the Baltic States and used in the professional market. The volume of peat produced in the United Kingdom has fallen since 2001, which reflects reduced extraction of some United Kingdom sites and increased extraction from sites in other countries. In 2001 producers based in the United Kingdom extracted 45% of the total peat supplied to the horticultural market; and this had fallen to 38% by 2005.

From 1999 to 2005 the volume of peat used has remained fairly consistent at approximately 3.4 million m^3. However the proportions of peat used within the four horticultural sectors has fallen from 60% to 53%. This is due to the increased use of alternatives to peat in growing media.

From the original 3.02 million m^3 of materials other than peat used in 2005, 2.31 million m^3 (76%) was incorporated in soil improvers with 0.71 million m^3 (24%) used in the production of growing media.

2.1 Constituents of Growing Medium

2.1.1 Peat

Peat is formed by the partial decomposition of sphagnum, other mosses and sedges. Under acid, water logged conditions, and in the absence of nutrients, the micro-organisms, which would normally break down or decompose the plants, are excluded and only partial decomposition (humification) of the dead tissue occurs. The differences between peat are related to variations in local climate, the species of plant from which the peat is formed and their degree of decomposition in the bog (Bunt, 1988).

There are three basic types of peat bog that exist and there are mires of intermediate status. Blanket Bogs are formed in upland areas. The rainfall and associated high levels of humidity coupled with cooler temperatures encourage the growth of hardy grass species and mosses initially in shallow basin areas. These then spread out over the poorly utilised surrounding ground and unite into a shallow 'blanket' over large areas of upland plateaux.

Figure 2.1.1.1: Blanket bog

Sedge peat arises in lowland estuarine areas where annual flooding can lead to marshes and mires forming. These in turn gave rise to reed-swamps and resulted, eventually, in the formation of the sedge peat. The predominant species are sedges (*Carex spp*) and reeds (*Phragmites spp*). Large volumes of reeds peat has been extracted for use in horticultural products, but most has disappeared through utilisation of sedge peat areas for example in the English Fenlands, for agriculture.

The final type of peat bog is the raised mire. These are formed initially in lowland areas of poor drainage, sphagnum mosses develop and over many millennia rise above the landscape in a 'dome' format. These bogs can be several meters deep and this combined with their easy accessibility has led to their widespread exploitation for horticultural purposes in the United Kingdom. Indeed raised mires are now considered rare habitats in the United Kingdom.

Peat classification is undertaken using the 'Von Post' scale, developed by Von Post in the early 1920s, as shown below in Table 2.1.1.1. The Von Post Scale, grades the peat, giving it a value from 1-10.

Degree of Humification	Von Post Scale	Description of Peat
Very Little	H1	White Peat
	H2	Baltic Peat
(Fibric)	H3	Light peat
Slightly	H4	E.g. Irish Sphagnum
	H5	
(Mesic)	H6	Dark Peat
Moderate	H7	
	H8	E.g. Lowland sedges
(Sapric)	H9	Black Peat
Highly (Sapric)	H10	

Table 2.1.1.1: A simplified version of the Von Post Scale (Bragg, 1998; Bunt, 1988)

There are other classification methods, which are in use. The International Peat Society proposed a simplified classification system based on botanical composition, degree of decomposition and nutrient status (Bunt, 1988).

Peatlands are unique habitats that support a variety of birds, invertebrates and plants; carnivorous plants such as the Sundew (*Drosera spp*) thrive in these low nutrient ecosystems as well as rare insects such as the unique 'Thorne Moors beetle', *Bembidion humerale* which occurs on Thorne Moor near Yorkshire. From an archaeological perspective, water logged peat preserves artefacts and bodies such as Lindow Man in Cheshire as well as pollen. These are able to provide information on past land use and other plant remains related to human practice, in turn providing information of past climate change. Services provided by peat bogs are that they smooth water flow by holding and releasing excessive precipitation. They are a source of fossil fuel energy, a source of atmospheric carbon by anaerobic decay and perhaps most importantly they are atmospheric carbon sinks (Meade, 2006). 'The northern hemisphere peatlands, of which blanket peat is a part, contains 50% of the total global soil carbon, 1,400 billion tonnes. The United Kingdom as a whole holds 15% of the total global area of peatlands and blanket peat contains the bulk of the nation's soil carbon' (Stern, 2007).

From a horticultural perspective the physical properties of peat are that it is a stable material with high lignin content. It has a low bulk density compared to many other materials, and thus relatively low transport costs. Depending on the degree of humification all types of peat will have inherent water holding properties and associated air capacity, for example a peat identified as a H1-3 will show high air capacity whilst retaining the ability to absorb water easily, compared to a H7-9 where the peat inherently has poor air capacity but is highly retentive of water. Peat has a high organic matter content and it can be prepared in a range of particle sizes to enable specific growing requirements to be met (Bunt, 1988). Peat has a low pH, 3.5-4.0, and low nutrient content, with a moderate cation exchange capacity. Biologically, peat is generally free from contaminants and pathogens. Nitrogen immobilisation is slower in peat compared to other materials, for example bark. The pH and nutrient status of peat can be easily amended for specific horticultural purposes.

Peat can be sourced in large quantities at a commercially viable cost. It is also known to be reliable and consistent in use and is an excellent diluent for other materials in growing media, due to its physical and chemical properties (Growing Media Association (GMA), 2004).

In the United Kingdom the extraction of peat for horticultural use has attracted much debate. Much indigenous peat has been extracted from Sites of Special Scientific Interest

(SSSI). Findings from 'Minerals Planning Guidance (MPG) Document 13' indicated in 1994, that just over 70% of the areas of peatlands with planning permission (over 4,100 ha) were also designated as SSSI's, with 2,500 hectares continuing to be worked upon (DoE, 1995). In 1996 the National Peatlands Resource Inventory (NPRI) was published representing the most comprehensive assessment of the lowland raised bog resources in Great Britain to date. Of the original 69,700 ha, only 3,836 (5.5%) ha could be described as 'near natural', which means only six percent of this habitat type have survived relatively undamaged (Lindsay & Immirzi, 1996).

Peat is still the main constituent used within the horticultural market in the United Kingdom. 3.44 million m^3 was used in 2005. However the United Kingdom government recognises that peat is ultimately a finite resource and that its extraction can have a significant environmental impact and is therefore committed to the reduction in peat use. Within the MPG the initial target of 40% peat replacement for the total requirements of soil conditioners and growing media by 2005, was set (DoE, 1995). This target was achieved (Wallace *et al.* 2006). The United Kingdom government then set a further target for soil conditioners and growing media to be 90% peat-free by 2010 (Wallace *et al.* 2006). Many feel this is an unachievable target (Robinson, 2006).

Carlile, (1997) gives a comprehensive review of the conflict between environmental groups and commercial peat producers and consumers during the 1990s. This conflict still continues, for example in 1998 Friends of the Earth attended the Chelsea flower show to urge gardeners to avoid using peat. The campaigning flower pot men 'Bill and Ben' highlighted the destructive nature of the commercial peat industry and recommended the use of peat alternatives (Friends of the Earth, 1998). The battle to save peat bogs continued when in 2002 the government saved three of Britain's most important peat bogs by paying £17.3 million to purchase the peat bogs. The purchase was the accumulation of a twelve-year campaign by conservation groups and local people to save the remaining 6% of United Kingdom peat bogs. The three bogs, Thorne and Hatfield Moors as well as Wedholme Flow, were all designated SSSI's and Special Areas of Conservation (SAC's) under the European Habitat Directive; however extraction continued from these sites due to planning permissions which pre-dated the law. Scotts, the owner of Thorne and Hatfield Moors would have been able to extract the sites for another 20 years (Brown, 2002). In 2004 the Royal Society for the Protection of Birds (RSPB) and Friends of the Earth backed a survey undertaken by the Deputy Mayor of London. The survey focused upon peat reduction policies within the horticultural retail sector. According to the survey, it was found that many of the major retailers of peat products were not making significant progress towards the removal of peat from its products; the survey findings were then published (ENDS, 2004). In 2005 the RSPB and National Trust produced one hundred different types of plant plug grown entirely in peat-free growing media, to demonstrate that alternatives can be as good as their peat equivalents. These plants were made available for purchase from the RSPB and the National Trust (RSPB, 2005) and in 2006 the RSPB endorsed a range of peat-free products from Terra Ecosystems (RSBP, 2006).

If a replacement for peat within the professional market was to be produced, there are five key areas that would need to be addressed; the physical, chemical, biological, ethical and aesthetic requirements.

The general functions of a growing medium are to provide; anchorage for plant root system, retention of adequate air spaces to allow root respiration, retention of available water, depending upon the irrigation system. The volume of medium occupied by the root system in a container is usually far less than for a soil-grown plant. The requirements of growing media have commonly been listed from an agronomic viewpoint, but environmental and other pressure now suggest that media must be examined from a broader perspective. The features of growing media that may need to be taken into account in the new millennium may be summarised as follows (Gilchrist, 2003; Holmes, 2003).

Physical Requirements

- The air/water ratio
- The flow of the medium
- Bulk density of >500g/L may be disadvantageous – handling & transport costs
- Stability of the structure over time is particularly important for long term crops and storage of growing media
- Freedom from contaminates

Chemical Requirements

- Control of pH
- Control of salinity (Electrical conductivity)
- Supply of nutrients

Biological Requirements

- Microbial populations
- Peat & inorganic-based media are less biologically active than material with less stable organic compounds (e.g. bark, composted green material)
- Biologically active mixes may offer control of root pathogens

Ethical Requirements

- Multiple retailers want to demonstrate social and environmental responsibility
- The 'sustainability' of raw materials
- Indigenous products may be preferred to imported
- Ethical Trading Initiative (ETI) issues for production process

Consumer/Aesthetic Requirements

- A growing medium may be part of an end product
- For amateur gardening products the medium is handled so must look/feel and smell nice!
- Consumers think of a growing medium as a 'soil' so the colour is important

2.1.2 Inorganic and Organic Alternatives to Peat in Growing Media within the United Kingdom

The Defra review of 2005 identified bark as the most commonly used peat alternative, accounting for 56% of the total of alternative materials used in 2005 (Wallace *et al.* 2006). The total volume of bark used by the four horticultural sectors in 2005 was 1.67 million m^3. The majority of bark was used in soil improver products, predominantly surface mulches (1.3 million m^3) but the proportions used in growing media doubled from 0.13 million m^3 in 1999 to 0.37 million m^3 in 2005. The total volume of bark supplied increased by 25% from 2001 to 2005. The United Kingdom provided 50% of the bark used, with 34% imported from the Southern European countries and 16% from several Northern European countries.

In 2005 composted green material was the second largest peat alternative in the United Kingdom, with 543,000 m^3 (81%) of composted green material produced being incorporated into soil improvers and 130,000 m^3 (19%) used in growing media. This was an increase of 41% from the volumes of composted green material used in 2001 at 92,000 m^3. Green compost now accounts for 22% of the total of alternatives used, as shown in Table 2.1.2.1. All composted green material was produced in the United Kingdom.

Spent Mushroom Compost (SMC) accounted for 12% of the total of alternative materials used in 2005; this was a decline from 28% in 2001. Availability of SMC has become an issue due to the significant reduction in mushroom production in the United Kingdom in the last five years (Wallace *et al.* 2006). This has led to an increased uptake of green compost.

Timber industry by-products (wood waste and wood fibre) materials are becoming increasingly important as raw materials in the horticultural industry. These materials currently account for 4% of alternatives used. Wood fibre is mainly manufactured in Germany, France and by a United Kingdom growing media manufacturer in Northern Ireland. Brash is mainly produced in the Thetford Forest area in Norfolk. Wood waste supply is inconsistent as it is influenced by changes in the industries producing the waste for example improved processes may produce less waste. Loam accounted for 3% of the total of alternatives. Currently the Defra report of 2005 indicates that coir occupied only 0.7% of the peat alternatives market; this is likely to be a gross underestimate (Carlile, pers comme). Other material for example cocoa shell, brash and inorganic materials such as perlite and vermiculite account for to 2.5% of the total of alternative materials used in 2005 (Wallace *et al.* 2006).

Alternative Material	Total Volume of Material ('000 m^3)	Percentage of Material (%).	Growth Since 2001 (%)
Bark	1,678.5	56	25
Green Compost (Composted Green Material)	672.7	22	108
Spent Mushroom Compost	351.2	12	-6
Wood Fibre	57.9	1.9	744
Brash	10.6	0.4	
Wood Waste	61.9	2	-13
Loam	97.6	3	-15
Coir	22.5	0.7	65
Cocoa Shell	13.5	0.4	-28
Others	53.6	1.77	139
Total	3,020	100.17 (Due to rounding)	

Table 2.1.2.1: Percentage totals of alternative materials consumed within the United Kingdom horticultural market in 2005 ('000 m^3) (Data was taken from Wallace *et al.* 2006).

2.1.3 Inorganic Alternatives to Peat

There are many inorganic peat alternatives such as; perlite and vermiculite both being produced from alumino silicates of volcanic origin and are used in relatively low volumes compared to peat in growing media (Bragg, 1998). Mineral wool is produced by melting diabase rock such as basalt and then spinning the resulting molten material into fibres. These materials are expensive, consume large amounts of energy in production and may be difficult to dispose of (White, 2004).

Other inorganic materials include pumice, sand, gravel, loam and expanded clay which are largely used in niche markets (Bragg, 1998).

2.1.4 Coir

Coir is the outside layer of husk that surrounds the shell of the coconut. Between these fibres is the corky substance called coir pith or coir dust. When the husk is processed, industrially valuable long fibres are removed leaving a considerable amount of both pith tissue and short to medium length fibres. These materials remain available as a waste product (Abad *et al.* 2002). Initially coir was used in the tropics as a locally available material for preparing soilless growing media in containerised crop production. In the last few years, the beneficial properties of coir have been recognised and it is now being used in many different parts of the world (Abad *et al.* 2002). However transportation costs for this material are expensive, since production in mainly situated in Sri Lanka and India. Coir is a lightweight material and able to maintain excellent air porosity even when saturated and has good water retention properties. Coir had a high lignin content of approximately 45%, which means this material degrades slower than other peat alternatives and is able to maintain its water/air ratio. Coir is generally held to promote a good root system. This material is able to do this because of the optimal balance between the fibres (aeration) and the finer fractions for water retention. Coir has a naturally high potassium level which would reduce the need for additional K-based fertilisers. Research has shown very promising results, (Mazuela *et al.* 2004) however there are issues associated with variation between samples (Noguera *et al.* 2000).

2.1.5 Bark

Bark is an organic material from the outside layer of trees. Bark was regarded as a waste product, but is now widely used in growing medium mixes (Wallace *et al.* 2006). Bark is a naturally variable material. Variability can be due to the type of wood from which it is obtained, the species of tree and its age, and the soil type and region where is it grown. Two types of bark are used in horticultural growing media; softwood bark (SWB) (conifer such as pine barks) and hard wood bark (HWB) (deciduous trees). The main differences between the two groups are that HWB’s contain up to 40% cellulose, which degrades quickly causing nitrogen deficiency, whereas SWB has only 5% cellulose and therefore the biological requirement for nitrogen is less. Most HWB are phytotoxic if used in the fresh state. Therefore these must be composted, whereas some, but not all SWB can be used without composting. HWB is more suppressive of several root-infecting fungi and nematodes than SWB (Bunt, 1988).

There are various treatments for bark, which produce varying end-products. Leaching together with microbial activity reduces the content of easily decomposable compounds (Figure 2.1.5.1). Potassium in particular, but also to some extent other elements, could be leached by water during or after the debarking. The rate of loss is dependant upon the water temperature, the size of the particles and the length of exposure time.

Bark Quality	Weight - % of dry bark				
	N	P	K	Ca	Mg
Fresh	0.37	0.06	0.28	1.02	0.09
Fresh, leached	0.33	0.03	0.11	0.91	0.06

Table 2.1.5.1: Relative amounts of different elements in fresh and leached spruce bark (Solbraa, 1979).

Storage or ageing is another treatment of bark, where a slow decomposition and leaching of bark components takes place during storage in aerobic conditions. During a storage trial conducted by Solbraa (1979), the initial nitrogen demand was reduced in bark which had been stored aerobically, mainly because of a reduction in the content of decompostable compounds by micro-organisms. Solbraa (1979) also found after some years of aerobic storage, the structure of the bark was similar to composted bark.

Composting is another treatment for bark. A composted bark is defined as a bark with fertilisers added, which is composted in aerobic conditions with sufficient water content and at temperatures high enough to permit microbial activity. In his classic treatise Solbraa (1979) stated that 'the content of easily decomposable compounds was reduced during composting, and a great part of the added nitrogen was tied up in organic compounds. Based on the initial and added content of plant nutrients, the compost will act like a slow release fertiliser, because of the continuing decomposition and tie-up of nitrogen'.

There are various end uses for bark in plant production, depending on the treatments of the bark and the final product parameters; mulches (Figure 2.1.5.1), landscaping, soil conditioners and growing media.

Figure 2.1.5.1: Bark being used as a mulch

A major use of bark is the inclusion in growing media. There are two major sources of bark available, which are used in growing medium; pine bark and mixed conifer bark (Bragg, 1998). Pine Barks are chipped from the tree. They are then matured in heaps to allow natural heating cycles to occur. This is a slow process requiring the heaps to be turned and moistened to ensure uniformity. After a suitable ageing time, the material is then screened and may be hammer milled to produce a more uniform particle size range. The ageing or maturing phase reduces the volatile and sometimes phytotoxic compounds such as terpenes. Aged or matured pine bark requires some extra nitrogen in the final mix to compensate for the barks immobilisation of nitrogen by the microbes (Bragg, 1998).

Mixed conifer bark's are from a variety of sources, generally waste products from the timber and fencing industry. The production process is undertaken by machine which effectively peels the bark off the tree with the addition of white wood from the raw timber. Most samples of conifer bark are composted after the addition of supplementary nitrogen to ensure a more even end product in terms of nitrogen immobilisation. This is particularly necessary because of the high levels of white wood found in the mix, which is less desirable to the end user and also has a far higher demand for nitrogen. This material is mainly used for mulching by the landscape industry (Bragg, 1998). In the United Kingdom very little attention has been paid to hardwood barks.

In fresh, untreated bark growth-regulating compounds such as phenols and phenolic compounds, terpenes, steroids, alkaloids, cyanides and organic acids, can reduce or inhibit plant growth. Leached or stored bark will reduce or eliminate the growth regulating compounds. Ageing or storage of bark may require several months or even years before the material can be considered for use in growing medium. Composting is the best method of eliminating inorganic and organic growth inhibitors in bark because of the penetrating ability of the fungal hyphes and enzymes, the growth-regulating compounds are decomposed inside the particles as well as the outside layers (Solbraa, 1979). Manganese can be found in high levels in fresh and stored barks, these levels are reduced after leaching.

2.1.6 Wood Fibre/Wood Waste

Wood fibre is a manufactured product made by subjecting wood chip to steam under pressure, which blows the fibres apart. The wood chips used are waste wood from the timber industry from coniferous plantations. It has only recently been incorporated into United Kingdom growing media market, mostly using imported German wood fibres under the brand name ‘Toresa’. It has a low bulk density, low nutrient levels and a relatively low pH (Wallace *et al.* 2006). The initial pH is often close to neutral. However wood fibres have little buffering capacity and thus have little influence on the resultant pH of the mix. The addition of wood fibres will initially increase the air-filled porosity (Bragg, 1998). Forestry brash is sometimes known as wood fibre in the United Kingdom, however this is incorrect. Brash is produced from lop and top tree waste and is a by-product from the timber industry. It has similar characteristics to fine bark and must be composted or matured before use to stabilise the material.

Wood waste is a generic term for the by-products produced from the timber/wood manufacturing industry for example chipboard or furniture manufacturers (Wallace *et al.* 2006). Care must be taken to ensure there are no contamination issues from phytotoxic paint, preservative or varnish.

2.1.7 Spent Mushroom Compost (SMC)

Spent Mushroom Compost is a by-product of mushroom production. This compost contains chopped straw, horse/pig or poultry manure, gypsum and added nutrients. The compost is then topped with a casing of peat, mixed with chalk or sugar beet waste and lime. Once the mushrooms have been harvested the compost is discarded. The SMC contains 10-15% peat by volume (so cannot be classified as a peat-free alternative); it has a high nutrient level, and usually has a high pH because of the lime in the casing. It is used by many landscapers as a soil improver but it is unsuitable for use as a growing media component because of the high pH and nutrient status (Bunt, 1988).

2.1.8 Green Waste

Green waste is material derived from plants such as trees, shrubs, grass, vegetables, fruit and other plant types; it does not include kitchen, human and animal by-products or catering waste and wastes that contain non-biodegradable fractions. Green waste is produced by a number of sources such as domestic gardens, green spaces that are publicly, privately or communally owned, highways, nurseries, field-based plant production and processors of vegetable or salad crops. The main feedstock used for additions to growing media is green waste from landscapers and gardeners.

Green waste is composted *via* a variety of methods to produce composted green material (Figure 2.1.8.2), which is also known as household green waste compost, yard waste compost, green compost and biowaste compost. There are large quantities of this material available, often at minimal cost; however transportation costs are high due to the high bulk density and this has limited the use of the material. It also has a high electrical conductivity, often associated with the high potassium levels found in this material. The pH is often high, but this can vary with source.

Composted green material is beneficial and has a number of uses; as land coverage such as landfill sites after appropriate sites have been decommissioned; as a mulch; as a soil conditioner as it improves the nutrient status and organic matter level of the soil and in growing media. Research and development into the use of composted green material as a component in growing media has encouraged greater use of this material. There has been a 41% increase in the use of green compost in growing media since 2001. In 2005, 130,000m^3 of composted green material was used compared to 92,000m^3 in 2001 (Wallace *et al.* 2006). For inclusion in growing media, composted green material has often been blended with material with a low bulk density and nutrient content.

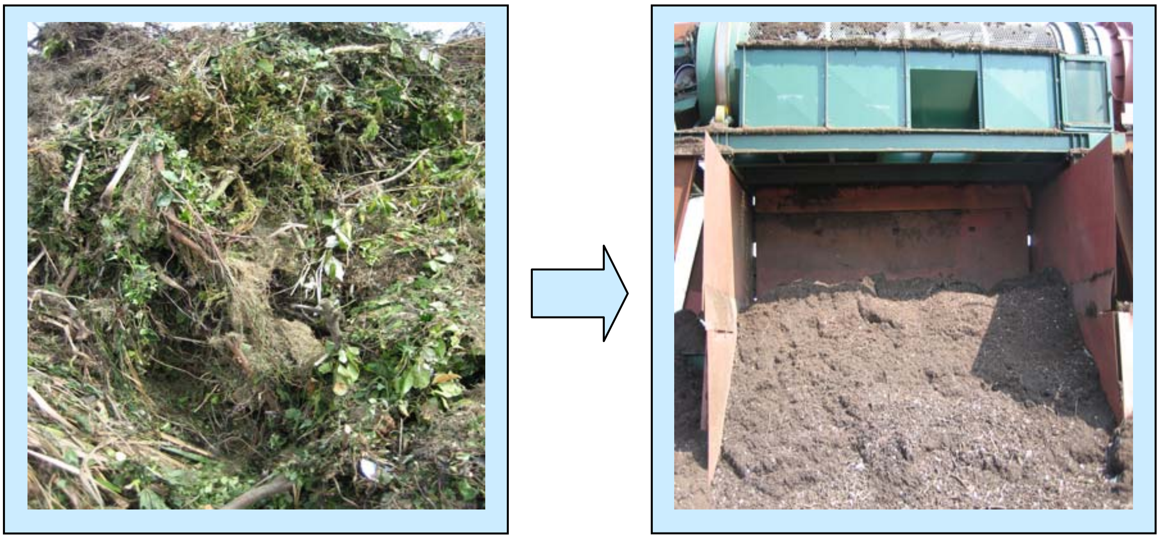


Figure 2.1.8.1: Landscape/domestic green waste converted to composted green material

This thesis focuses on composted green material and many trials have been conducted using composted green material. Many investigations have focused on the agricultural use of composted green material, since this is seen as the major route of disposal, such as Parkinson *et al.* (1999); Hartl *et al.* (2003) and Wolkowski, (2003).

However pressure from the government and environmental groups already noted in 2.1.1 have led to the use of composted green material as an alternative to peat within the horticultural industry and in turn has meant an increase in the number of trials conducted on green materials as alternatives to peat. Pronk (1995) conducted one of the first published studies in green material. She found that it was possible to substitute 15% aerobically composted domestic waste or 15/30% anaerobically composted domestic waste for peat, with fertiliser adjustment in accordance with frequent analysis of the mixture. The results from the study conducted by Pronk (1995) can be seen in Figure 2.1.8.1. No problems were found with the loss of physical quality of the mixtures; however Pronk concluded that nutrient availability and pH would need to be monitored closely. The initial physical quality could even be slightly improved by amendments of composted domestic waste. As the proportions of composted domestic waste increased, the yields were reduced due to the high EC and pH. Pronk stated plants that are more tolerant of high EC and pH grew more successfully in compost-peat potting mixture.

Media	Perlite (%)	Compost (%)	Fresh weight (g/plant)	R^2
Standard	15	0	64.1	91
Compost 1	12.5	15	53.4	76
Compost 1	25	15	70.0	66
Compost 1	12.5	30	42.4	92
Compost 1	25	30	32.8	86
Compost 2	12.5	15	61.0	94
Compost 2	25	15	58.8	95
Compost 2	12.5	30	54.8	94
Compost 2	25	30	48.0	87
Compost 3	12.5	15	64.5	96
Compost 3	25	15	60.1	95
Compost 3	12.5	30	54.6	93
Compost 3	25	30	50.8	85
Compost 4	12.5	15	67.8	91
Compost 4	25	15	62.1	92
Compost 4	12.5	30	63.7	97
Compost 4	25	30	60.2	86
Compost 4	25	45	51.5	84
Compost 4	35	45	39.9	87

Table 2.1.8.1: The fresh weight production (g/plant) at harvest and the correlation coefficient (R^2) from the model. (Composts 1, 2 and 3 were aerobically composted products. 1 and 2 had a small sieve fraction, 0-10mm, and 3 a large sieve fraction, 10-20 mm. Compost 4 was an anaerobically composted product) (Pronk, 1995).

Ribeiro *et al.* (2000) found that the geranium species *Pelargonium x hortorum* Bailey cv Meridonna could be grown in a peat- based substrate with 15-20% of MSWC (municipal solid waste compost). Indeed 20% MSWC provided an adequate supply of potassium, magnesium, calcium and some micronutrients for plant growth. However, additional phosphorus and nitrogen would be required. Application rates of MSWC greater than 20% reduced plant growth as a consequence of the high level of salts and rates greater than or equal to 40% resulted in high copper levels in plants.

Similar results were found by Prasad & Maher, (2001) using tomatoes. Their experiments found that composted green material could be incorporated with peat for a growing medium at a rate of 20% by volume without adversely affecting plant performance. They also found that the composted green material had a high salt content, especially potassium and that the availability of nitrogen was reduced with the addition of composted green material. This can be seen in Table 2.1.8.2 below.

Source	Rate of Green Material (% volume)				Mean
	0	10	20	50	
Early growth (g/plant) of Tomato seedlings					
Dublin	13.4	13.2	13.4	9.9	12.4
Thorpe	11.9	11.8	12.8	8.5	11.3
Dunbrik	11.4	13.7	11.1	5.9	10.5
Mean	12.2.	12.9	12.4	8.1	
Final weight (g/plant) of tomato seedlings.					
Dublin	27.3	30.1	30.1	18.1	26.4
Thorpe	26.5	29.4	25.9	18.3	25.0
Dunbrik	27.1	31.3	30.3	26.6	28.8
Mean	27.0	30.2	28.8	21.0	

Table 2.1.8.2: Effects of source and proportion of composted green material on plant growth of tomato seedlings (Prasad & Maher, 2001).

At the first harvest (early growth data) there was no effect of the composted green material on growth up to the 20% level. At the 50% rate, plants grown in the Dunbrik material were severely reduced in weight while those in Dublin and Thorpe materials were much less so. This is probably due to the high electrical conductivity and potassium level in the Dunbrik material, indicated in Table 2.1.8.3. At the final harvest, growth was again little effected by inclusion of composted green material up to a proportion of 20%. At the 50% inclusion rate growth was severely reduced in the Dublin and Thorpe material while the reduction was much less in the Dunbrik sample, producing satisfactory results.

Source	% CGM	pH	EC	P	K	NH_4-N	NO_3-N
Dublin	0	4.8	161	112	165	56	67
	20	5.8	204	94	280	60	74
	50	6.4	178	48	340	30	51
Thorpe	0	4.9	190	125	200	55	70
	20	5.5	177	88	300	41	59
	50	6.7	199	37	460	31	64
Dunbrik	0	5.0	197	120	230	58	70
	20	5.9	232	75	420	45	85
	50	6.6	289	34	680	32	97

Table 2.1.8.3: Nutrient levels in composted green material/peat mixes with three sources of composted green material (mg/L of a 1:1.5 volume water extract, Electrical Conductivity (EC) as mS/m) (Prasad & Maher, 2001).

Table 2.1.8.3 contains information on the nutrient status of a range of composted green material/peat mixes used in the growth trial. As the proportions of composted green material increased in the growing media so did the pH and the K levels. Variations between the samples were observed. Within the Dublin and Thorpe material the N level tended to decrease at the high rate of composted green material but with the Dunbrik sample the N level was maintained.

Trials funded by Waste Resource Action Programme (WRAP) concluded that a variety of vegetables (Cabbage, Courgette, Leeks and lettuce) could be propagated successfully in peat-reduced and peat-free growing media containing 25% by volume of composted green material, with the addition of a base dressing of ammonium nitrate (Peatering Out Ltd, 2005). A trial conducted by Clean Merseyside Centre in conjunction with Porters Horticulture Ltd (unpublished data), stated that a 50/50 composted green material and peat was the best all round performer of the reduced peat mixes, performing almost as well as the standard mix in many aspects of the trial. In a study conducted by Veeken *et al.* (2005) incorporation of 60% v/v compost wetsieved biowaste as a peat replacement did not reduce cucumber growth. Other growth trials conducted using peat alternatives which produced positive results were Guérin *et al.* (2001) and Keeling *et al.* (1994).

There are issues associated with the use of composted green waste, such as stability, storage, variability between sources, which will be addressed in the research programme reported in this thesis.

2.1.9 Stability of Composted Green Material

Compost stability is important for the product quality assessment (Lasaridi & Stentiford, 1998). Keeling *et al.* (2005) stated that compost stability could considerably influence plant development. Stability needs to be addressed in these substrates: in composting piles of material, and within the growing medium containing composted green material.

The first issue to be addressed is the use of immature compost. If a composting pile has not fully matured there are problems associated with the usage of this material; such as a high pH which changes nutrient availability (Prasad & Maher, 2001). Another major problem is the high carbon to nitrogen ratio in immature material, which can result in nitrogen immobilisation (Wolkowski, 2003). Phytotoxicity is another issue associated with immature material due to the presence of organic acids as the intermediate by-products of continued decomposition. Acetic acid and phenolic compounds, in particular, may suppress seed germination, inhibit root growth, or suppress yields (Butler *et al.* 2001). However workers have indicated the beneficial properties of using unstable composts for example Keeling *et al*. (1994) found that extended growth trials showed the slow-nutrient releasing properties of RDC (Refuse-derived compost).

Although there are many methods and opinions on how to assess the stability/maturity of growing media as yet no standard methods have been accepted (Reinikainen & Herranen, 2001; Lasaridi & Stentiford, 1998; Boulter-Bitzer *et a*l. 2006; Mondini *et al*. 2003). Bernal *et al.* (1998) stated 'both stability and maturity usually go hand in hand, since phytotoxic compounds are produced by the micro-organisms in unstable compost', when stability is related to the microbial activity of the material and maturity is associated with the plant growth potential or phytotoxicity. Where as Butler *et al.* (2001) states 'compost maturity' and 'compost stability' are not synonymous. Butler *et al*. (2001) then further states compost maturity refers to the degree of humification of the material and compost stability refers to the level of activity of the microbial biomass.

There are many research papers stating different techniques which could be used to assess the stability and maturity of materials for use in growing media. Physical tests such as pile temperature, odour, colour, aeration demand, can give a general observation on the stability/maturity of the material. To gain information on the degree of maturity, chemical analyses can be used such as C/N ratios (Bernal *et al.*., 1998), humic substances (Albiach *et al.* 2001; Bernal *et al.* 1998), cation exchange capacity (Bernal *et al.* 1998; Butler *et al.* 2001), stabilisation of organic matter (Francou *et al*. 2005; Albiach *et al.* 2001). There are also biological assays which are used to assess stability and maturity, for example phytotoxicity *via* seed germination (Wu & Ma, 2001), plant growth (Reinikainen & Herranen, 2001; Keeling *et al*. 1994; Zmora-Nahum *et al.* 2005). Microbial biomass and activity are also useful indicators of maturity and quality and applications of these methods have been shown to provide valuable information on the dynamics of composting and evaluation of end-product quality (Boulter-Bitzer *et al.* 2006). These tests include fluorescein diacetate (FDA), microbial respiration measurements either as oxygen consumption or carbon dioxide production (Reinikainen & Herranen, 2001; Lasaridi & Stentiford, 1998; Butler *et al.* 2001; Wu & Ma, 2001) and enzymatic activity (Boulter-Bitzer *et al*. 2006; Mondini *et al*. 2004).

Other tests for compost maturity are, for example using gas chromatography and mass spectrometry as methods to identify extractable organic constituents. The findings proposed that the absence of extractable organic compounds is indicative of compost stabilisation (Keeling *et al*. 1994a) Another example of a method used for compost stability/maturity is a respirometric technique, the SOUR test (Specific Oxygen Uptake Rate) that utilises a dissolved oxygen probe to measure changes in the oxygen concentration of an aqueous compost suspension. Lasaridi & Stentiford, (1998) concluded that respiration was a suitable indicator for compost stability and that using an aqueous compost suspension (SOUR test), instead of a solid matrix, as in most traditional respiration test, offers certain advantages (Lasaridi & Stentiford, 1998).

Phospholipid Fatty Acid (PLFA) analysis is a technique used to indicate the microbial community composition without culturing the micro-organisms. It is based on the fact that different subsets of a microbial community differ in their fatty acid composition. It has been used to study changes in the microbial community in compost and provide an indication of stability (Boulter-Bitzer *et al.* 2006). The Dewar self-heating test is another method used to assess stability/maturity. After adjusting to the optimum moisture content the growing medium is placed in a Dewar flask (vacuum flask) at an ambient 20˚C temperature. Any microbial activity causing the temperature to rise stabilises after 2 to 5 days. The higher the temperature achieved the less stable the substrate is. Butler *et al.*

(2001) stated that the Dewar test was an effective maturity indicator. Richardson & Rainbow, (2005) stated that the Dewar stability test proved to be the most reliable tool for predictions of marked N immobilisation within their research; however it was not totally reliable, due to values being highly erratic and should be used in conjunction with an N-immobilisation test. Richardson & Rainbow, (2005) concluded it is most likely that a Dewar result of less than 27˚C, combined with a Nitrogen Drawdown Index (NDI) of more than 0.7, is the best indicator of mixes likely to retain water-soluble N in storage.

Overall among the numerous chemical and biological parameters used to evaluate compost stability and maturity, the most widely accepted are the microbial respiration test based on O_2 uptake and CO_2 evolution and the seed germination test for phytotoxicity (Wu & Ma, 2001; Lasaridi & Stentiford, 1998). However, as stated by Reinikainen & Herranen, (2001) there is no sole method for the assessment of compost stability or maturity. Often a combination of methods is employed and these in turn depend on the intended compost use.

Variation in compost quality may arise as a result of the feedstock material or through differences in the composting process parameters (Ward & Litterick, 2004). This was also found by Reinikainen & Herranen (2001) and Veeken *et al.* (2005).

Feedstock variation may occur due to socio-economic characteristics. The area from which the waste is collected may affect feedstock quality, for example waste collected from rural areas may differ significantly from that collected from urban areas. Seasonal variation is also another factor to be considered, with soft, high nitrogen materials being collected in spring and summer, and woodier materials being collected in winter months. (Ward & Litterick, 2004). However, Ward *et al*. (2004) investigated the potential for site and seasonal variation of composted green waste across the United Kingdom and their findings suggested that variations in feedstock characteristics may not be as pronounced as it often thought (Ward *et al*. 2005). Overall there was evidence of seasonal variation, but no evidence of geographical variation in feedstock characteristics. However there was no statistical evidence given to substantiate their findings.

The composting process/manufacturer may also produce variations in the final end-product (Butler *et al.* 2001). This could be associated with varying technology. For example composting windrows that are covered will lose less soluble nutrients through leaching than windrows receiving high rainfall. If the initial material is screened, this may produce a different composition of the end-product.

Variability of composted green material is a key issue in the use of this material within horticulture. Many research papers have observed this variation between samples, and stated the need for further investigation including Prasad & Maher (2001) and Eriksen *et al*. (1999). Veeken *et al.* (2004) stated that the variations in biowaste composition may lead to large fluctuations in the quality of the composted green material. For example in heavy metal content, organic matter content, electrical conductivity and stability of the material. Prasad & Maher (2001) found that there were considerable differences between three composted green waste materials in terms of analysis and also plant performance, and that this variability underlined the need for good evaluation procedures to establish the suitability of composted green waste for use in growing media.

There is thus a clear need for standardisation in the approach to producing composted green material especially to gain the confidence of manufacturers of growing media who may wish to incorporate this material into their end-products (Duckworth, 2005). To increase confidence in the composted green material produced within the United Kingdom the British Standards Institute (BSI) Publicly Available Specification for Composted Material (PAS) 100 was launched in November 2002 (Table 2.1.9.1). The specification covers the entire process by which compost is produced: from raw materials and production methods, through to quality control and lab testing. This ensures the composts certified by The Composting Association are quality assured, traceable, safe and reliable. The Composting Association certification scheme is the only United Kingdom scheme providing third party assessment of conformity with BSI PAS 100 (TCA, 2005). This ensures the compost is apt for its intended purpose.

Key Element	Summary Description
Process Control	• A process control system supported by accurate record keeping and document control procedures must be in operation throughout the composting process. • The process control system must use composting and product batch codes to ensure identification of composting material through the process. • Compost producers must undertake Hazard Analysis and Critical Control Points (HACCP) analysis. • Compost producers must have clearly defined Standard Operating Procedures (SOP's) covering quality management aspects of the composting process. • All staff must be appropriately trained and supervised. • The process control system must be regularly reviewed and updated as appropriate.
Input Material	• Criteria must be established for the acceptance or rejection of input materials arriving at the site for composting. • Activities for the storage and preparation of input material must be recorded.
Compost activity – sanitisation	• All input material must be sanitised in a defined and identifiable phase. • Temperature checks must take place every working day during the sanitisation phase. • Moisture checks must take place at the start of the sanitisation phase.
Compost activity – stabilisation	• Procedures to achieve stabilisation of all material composted must be followed.
Compost quality requirements	• Limits for human pathogens (indicator species), potentially toxic elements, physical contaminants, stability (CO_2 evolution) and weed propagules must not be exceeded. • Plant response when grown in compost is required to be at least 80% compared with those grown in peat controls and not show any abnormalities.
Product preparation	• Product preparation must be described in the SOP's document, including: criteria for compost material unsuitable for product preparation; the options for distribution, treatment or disposal; and how such decisions will be recorded when the product is unsuitable.
Compost maturation	• SOP's must describe any maturation phase applicable to any compost grade produced.
Compost sampling and analysis	• Compost must be sampled and tested when the batch has completed the composting process, after screening and before any blending with other materials. • Detailed records of sampling must be kept.
Final product storage	• Provision must be made for final product storage including storage location, conditions and product batch identification.
Classification of compost	• Compost produced must be classified as one of the following products: • soil improver • mulch • growing medium • turf dressing • topsoil (manufactured) • other (as specified by producer)
Labelling and marketing	• The compost recipient must receive the following information: • Product type • Nominal particle size grade

	• Quantity • Moisture content • Input material types to the composting process • PAS 100 conformity declaration • Information that enables traceability checks • Instructions for storage and use • Advice on risk and appropriate precautions for safe handling and use • Contact details of producer/supplier
Monitoring and traceability	• Process for monitoring, composting – and product – batch identification, and control of non-conforming composting materials must be in place.

Table 2.1.9.1: BSI PAS 100 specifications

Within the specification above, there are further requirements and detection limits for example pathogen numbers and potentially toxic element concentrations (TCA, 2005). The Composting Association have also recently produced ‘The Composting Industry Code of Practice’ to enable operators to identify good practice for their own individual sites (Duckworth, 2005). The usage of composted green material has doubled since 2001 to 0.67 million m^3 due to increased availability and improved composting standards (Wallace *et al.* 2006).

2.1.10 Storage, Stability and Nitrogen Dynamics in Growing Media

One consequence of the use of unstable materials in growing media is nitrogen immobilisation. This primarily results from microbial activity in the medium. Peat is stable in storage due to its high lignin content, which is resistant to microbial degradation.
Growing media based upon peat are usually fertilised with straight inorganic nutrients therefore the only changes that may occur in storage are from the dissolution of calcium and magnesium from the added chalk or dolomitic limestone (Carlile, 2004; Bunt, 1988). However there is the possibility that peat-free media may develop problems from storage. Alternative materials to peat such as bark, timber waste, wood waste have a high cellulose and hemicellulose content (polysaccharides), which are readily degradable by micro organisms (Carlile, 2005). This gives considerable opportunities for the development of micro organisms. This can lead to; structural breakdown and microbial growth which may lead to the utilisation of nutrients in particular nitrogen. From an aesthetic opinion, microbial growth in growing medium that is bagged may look unsightly and deter customers (Carlile, 2004).

Prasad and Maher (2001) found that the reduction in available N occurred despite the fact that both peat and composted green material were given similar dressings of Calcium Ammonium Nitrate (CAN) (0.75 kg/m3). The implication of this is that microbial activity was still existent in the composted green material and that the microbial population was still absorbing N. N retention is highlighted as a problem when using composted green material.

The effects of micro organisms in locking up nitrogen in growing media often become apparent after storage (Carlile, 2004).

Dickinson (1995) conducted measurements of urease activity on varying growing media mixes. As shown in Table 2.1.10.1 there was no urea in either of the peat based mixtures. This was expected as there were no known source of urea in the peat based mixtures and only very low concentrations were recorded in Mix 6 (50% Pine Bark/50% Spruce Bark and Paper Waste), in the freshly prepared mix. Both Mix 5 (50%Spruce bark and paper waste/50% Chipboard waste) and Mix 7 (50% Pine Bark/ 50% Chipboard waste) contained chipboard waste that contained higher concentration of urea-N in the freshly prepared samples, these values were reduced significantly after 18 month storage. This was found to be due to microbial transformation of urea liberated from ureaformaldehyde (UF).

	18 Month old substrate Urea-N (μg ml $^{-1}$)	Freshly prepared substrate Urea-N (μg ml $^{-1}$)
Peat	0.0	0.0
Mix 5	6.2 +/- 1.2	40.3 +/- 1.9
Mix 6	0.0	0.8 +/- 0.5
Mix 7	8.6 +/- 0.9	35.2 +/- 1.6

Table 2.1.10.1: Mean urea-N concentrations in 18 month old and freshly prepared peat and wood-based media (+/- 95% CL) (Dickinson, 1995).

Nitrogen lock up within horticultural medium is of a clear importance as plants are grown in limited containers. Many research papers have stated the need for further research into nitrogen availability in composted green material Peatering Out Ltd, (2005a); Prasad & Maher, (2001) and Wolkowski, (2003).

There is very little information available on the effects of storage on composted green material. The storage of media containing composted green material is an important issue for many growing media manufacturers (Wallace *et al.* 2006). As stated previously, the demands of the amateur gardener have increased substantially, which means growing media manufacturers are having to produce bagged growing media well in advance of the maximum sale period. Bagged growing media is currently being stored by the retailers, for periods of up to a year (Carlile, 2005).

WRAP has funded trials using composted green material. Richardson & Rainbow (2005) conducted a twelve month storage trial for WRAP using retail growing media products containing composted green materials. The storage trial compared peat-free, peat-reduced and all peat mixes; using two types of peat and four alternatives substrates, brash, bark fines and two composted green material, 20 and 33% v/v. Although the storage conditions were a little vague, the pallets were left outside on a concrete base at an exposed site. Richardson & Rainbow (2005) concluded that bulk density, moisture content, dry matter, total N and organic matter were consistent during twelve months storage. However there was a marked variation shown between the treatments for the immobilisation of water soluble N, as seen by the reduction of NH_4-N and NO_3-N. The highest loss of N was in the green compost mixes, especially in the peat-free formulations where both brash and bark fines were used. There was virtually no nitrogen immobilisation within the pure Irish peat based growing medium used in their studies. Richardson & Rainbow (2005) also found the presence of green compost increased nitrification. There was no final evaluation in relation to the storage conditions, since the material was only left in one storage situation (Richardson & Rainbow, (2005).

Another very similar trial funded by WRAP (Peatering Out Ltd, 2005a) and carried out at the same time as the studies reported in this thesis, was to assess the storage stability of a wide range of green compost formulations using two sources of green compost at higher input rates of 33% and 66%v/v combined with sphagnum peat, bark and two types of composted brash. The study was carried out over nine months under varying storage conditions including ambient storage (in an unheated barn), ambient storage under load (simulating stacked pallets) and warm storage (in a polythene tunnel). The results were similar to the trial above; instability was greatest when the proportion of green compost was 67% v/v rather than 33% v/v and/or where composted brash and bark fines were used. Again there was a reduction in readily available nitrogen in the mixes containing green compost. The greatest stability was seen with the mixes containing the higher proportions of peat.

However within this trial they were able to compare storage conditions; storage under warm conditions or under load had no major or consistent effect on the level of NH_4-N, NO_3-N or other key indicators monitored over the twelve months (Peatering Out Ltd, 2005 a).

2.2 Aims and Summary of Research

The initial focus in this research was to gain an overview of the situation regarding green waste within the East Midlands region of England. This was done by the production of a questionnaire titled 'Management of Green Waste' which was sent to local authorities and waste manufacturing plants.

The next step in this research was to establish a database of analyses of the composted green material produced by the local authorities and waste manufacturing plants within the East Midlands. From the questionnaire responses, sources which produced composted green material were invited to supply a sample of their end-product. From this baseline analysis, any variation in the end-products produced could be established. Twelve sources agreed to participate in the baseline analysis. From the sources used in the baseline analysis, four were identified for inclusion in further trials.

Recently, composted green material has been considered as a potential alternative or as a diluent for peat. Therefore the next step in this research was to conduct growth trials using varying percentages of composted green material mixed with peat. A storage trial was also conducted. The mixes used in the trial were split, half of the material was stored in a 10˚C constant temperature room, and the other half was stored in a glasshouse. Comparisons were made between the two storage conditions.

To assess the growth and storage trials, analysis was conducted monthly for the first six months and bimonthly for the next six months. This trial was conducted over a one year time frame. From the twelve month growth and storage trial, one sample was identified and used in an attempt to develop a peat-free medium containing composted green material. This was conducted on a six month time frame. As the initial growth/storage trial had focused on peat-reduced growing medium, the natural progression was to conduct a peat-free trial.

Chapter 3.0 Survey of Waste Management in the East Midlands

3.1 Introduction

To establish various trends in green waste production for example variation in source and treatment of green waste, a comprehensive overview of the current green waste cycle was undertaken. A review of current practice in production and handling of composted green material from domestic and other sources was undertaken *via* a carefully designed questionnaire to establish unique features of management systems for green waste in the United Kingdom. Questionnaire design was an important factor within this part of the research, as specific information needed to be obtained from local authorities. A questionnaire based on the methodology of Aaker *et al.* (2001) and Churchill (1995), titled 'Management of Green Waste' was produced.

The information required from the local authorities focused on management of green waste streams, the life cycle of their green waste from production to disposal and the volumes encountered within these processes. This survey obtained, the key trends in green waste disposal, variation in handling and composted green material production. The questionnaire took approximately six months to complete, dating from January 2003 until June 2003 and was sent to 272 local authorities within England. Ell (2007) stated that relevant literature suggests that a response rate to questionnaire surveys of around 20-25% is good.

3.2 Review of Questionnaire Design and Procedures

From contacts established *via* the questionnaire, sources of composted green material were identified for use in laboratory and glasshouse studies based on that developed by Aaker *et al*. (2001). Other such methodologies have been produced for example Churchill (1995) (Figure 3.2.1). A brief review of design and desirable features of questionnaires follows, with the methodologies selected for use in the survey of green material

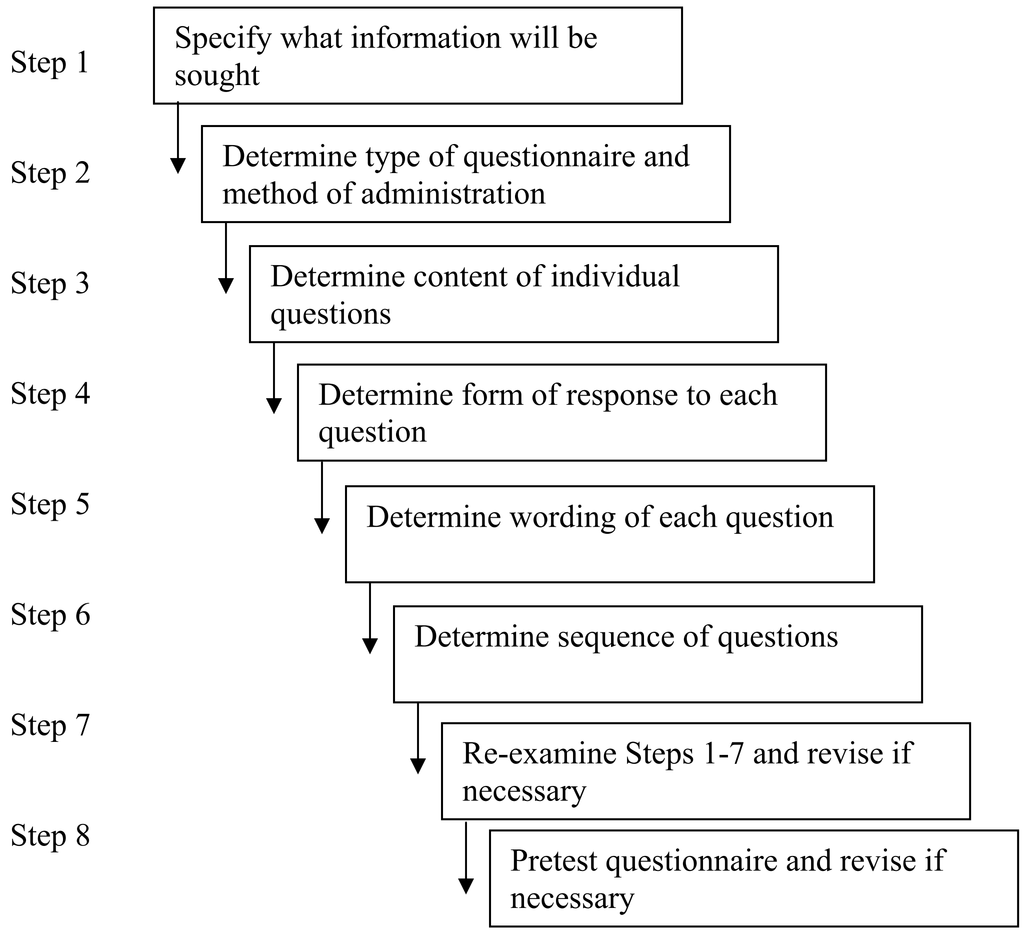


Figure 3.2.1: Procedures for developing a questionnaire (Churchill, 1995)

The first stage in questionnaire design is good prior knowledge and research into the topic. This allows the framing of some specific hypotheses for investigation, which can then guide the research. The hypothesis can also guide the questionnaire, the initial stage is called 'planning what to measure' (Aaker *et al*. 2001).

The second stage within the questionnaire design was formatting the questionnaire; this determined the format for each question and what information would be obtained. There are many types of question, which can be used to obtain the desired information.

An open-ended question, known also as 'free answer' or 'free response', leaves the respondent free to reply to open-ended questions in their own words rather than being limited to choosing from a set of alternatives (Aaker *et al*. 2001).

Closed questions are where the response is strictly limited. There are two types of closed question; the simple alternative questions (also referred to as dichotomous questions) where the respondent has only two choices of response or the multichotomous questions, which is a fixed alternative question; respondents are asked to choose the alternative that most clearly corresponds to their position on the subject. This type of question may not capture the respondent's true feelings, or the respondents may have a more complex opinion, but in the case of many questions the answer may be based on fact, therefore there is no opinion needed. If this type of question is used, there is a need to research the list of alternatives to provide sufficient scope for respondents to give a valid answer (Chisnall, 2001).

For information on green waste streams, the two most commonly used question designs were dichotomous and multichotomous closed questions. Boxes were provided for the answers to ensure the answers given were clear and for the correct option. There were two open-ended questions, which were given a much larger box for the respondents' opinion. This was to enable the respondent to provide as much information as they felt necessary. Due to this being a mail orientated questionnaire, open-ended questions were limited. The questions needed to be self contained and structured.

The third stage is question wording. This is a very important stage, as it can increase the response rates of the questionnaire. Poor phrasing of a question can cause incorrect or vague answers to be given because of misunderstanding. Vocabulary can be a major problem with questionnaire design. The person who is producing the questionnaire will be more knowledgeable of the questionnaire topic than the respondent, and can be prone to using words which are not familiar to the respondent. The questionnaire, when sent, was directed towards personnel within the specific area of waste management (Aaker *et al*. 2001).

Sequencing and layout decisions were the fourth stage within the design of the questionnaire. This stage looked in detail at the layout, to ensure logical progression throughout the questionnaire.

A frequently used approach is the funnel approach. This type of questioning will start with the most general questions gradually focusing down to more specific questions. This method was used for the 'Management of Green Waste' questionnaire, starting with open questions about waste management and filtering down to composting activities and finally to the cost of the end-product. The first questions were simple and easy to answer, to put the respondents at ease.

There is an opposite technique called the 'inverted funnel' technique. Here the initial questions are specific and then move towards the more general questions. This technique is rarely used, but is occasionally deployed where the topic surveyed does not evoke strong feelings (Aaker *et al.* 2001). Chisnall (2001) stated that the advantages of the funnel technique is that moving from general to more specific questioning builds up a good relationship between the interviewing parties.

The final stage was pretesting and correcting problems. 'Before a data collection instrument is finalised, it should be pretested or used on a small sub-sample of the population in a pilot study' (Bourque & Clark, 1992). The purpose of the pretest was to ensure the questionnaire would obtain the information wanted.

The questionnaire was sent to 20 local authorities *via* email attachment to see if they were able to complete the questionnaire and provide the data needed. There was a limiting factor of time involved in the testing of the questionnaire, and therefore it proved difficult to test the questionnaire in a more personal manner. The responses were returned with feedback on the completion of the questionnaire. Some of the respondents could not use the text boxes and some of the boxes needed to be enlarged. The responses produced the data which was requested. The questionnaire 'Management of Green Waste' is shown in Figure 3.3.1.

3.3 Administration of Questionnaire

The questionnaire produced was called 'Management of Green waste' and was contained within two sides of A4. The questionnaire was sent by email attachment to the personnel responsible for green waste. The local authorities without a direct email address were sent the questionnaire by post and this was directed towards the waste management section.

The sample population, which the questionnaire was sent to, were employees of local authorities working within a waste management section - an environment in which they would understand about green waste processes and should have access to appropriate data.
Due to the questionnaire being sent by mail and email attachment, the physical appearance of the questionnaire was crucial. Identifying logos, of the university were situated on both the cover letter and the questionnaire.

A cover letter was also included. ‘The letter should outline the objectives of the survey and invite informants to respond by completing and returning the enclosed questionnaire’ (Chisnall, 2001). The cover letter enabled the informant to realise the importance of this study and the value of their contribution. A cover letter was sent with both the mail and email version.

Incentives to try and increase the response rates were included in both the mail and email questionnaires. For example the inclusion of a self-addressed pre-paid envelope within the mail-sent questionnaires and a copy of the results were provided to the respondents, in both the mail and email-sent questionnaires.

No time restriction was given to the local authorities on how quickly the questionnaire had to be returned, but a date was used as a cut off point for the return of the questionnaire to enable the data analysis to be initiated.

3.3.1 Final version of Questionnaire

WREN

Management of Green waste

The Nottingham Trent University

Please put your answers in the boxes provided

1. List the main sources of green waste within your Borough/District, from their origin.

   1. [ ] 4. [ ]
   2. [ ] 5. [ ]
   3. [ ]

2. How is the green waste collected?

   i. Pre-paid plastic sacs. [ ]

   If so, how much do they cost to purchase? [ ]

   ii. Pre-paid compost-able bags. [ ]

   If so, how much do they cost to purchase? [ ]

   iii. Wheelie bins/ Twin bin scheme [ ]

   iv. Bulky Household waste collection. [ ]

   Is there a fee for this service? [ ]

   v. Free freighter service. [ ]

   If so, how often is this service provided? [ ]

   vi. Household waste centres [ ]

   vii. Other.

   Please write your answer here:

3. What is the frequency of collection? [ ]

4. Do you keep a record of the weights of green waste handled? Y [ ] N [ ]

4a. If so, what are the weights of green waste produced within the sections below, over a timescale of the past year?

   i. Commercial [ ] ii. Domestic [ ]

   iii. Municipal [ ]

Y N

5. Have you surveyed the components of green waste?
5a. If so, what are they?

Please write your answer here:

6. Please rank in order of volume, the methods used to dispose of green waste?

i. Landfill
ii. Incineration
iii. Compost Production
iv. Other

6a. If green waste is composted, who undertakes this process?

i. A local company (Name of company)
ii. The District/Borough
iii. Other

6b. What method is used for the compost production?

i. Windrows
ii. In-vessel system
iii. Other (Please Specify)

6c. Is the end-product sold? Y N

6d. How much does it cost to purchase?

7. Within the district/borough are there any green initiatives being undertaken, that has not already been mentioned?

Please write your answer here:

If you would like a summary of the results, please tick the preferred method of correspondence.

via email *via* preferred postal address

Postal/Email Address:

My Contact Details are:
The Nottingham Trent University
Faculty of Science
Clifton Campus
Clifton Lane
Nottingham
NG11 8NS
Victoria.surrage@ntu.ac.United Kingdom
Thank you for your co-operation in completing this questionnaire.

3.4 Main findings from survey, 'Management of Green Waste'

A Microsoft Word document titled 'Results of Survey' was produced with the addition of a Microsoft Excel document 'Green Waste Data'. All the participants of the survey which requested the results were forwarded both documents. Survey results are given in Appendix 1. As stated previously 272 local authorities within England were sent the questionnaire, 138 replied, producing a response rate of 51%. This was double the expected return rate.

Each local authority included within the questionnaire was asked to identify their main sources of green waste. Figure 3.4.1 identifies the principal sources of green waste production within a local authorities remit. The main source of green waste produced in the largest quantities by the surveyed local authorities was Domestic waste (D), which has not been classified as either garden or kitchen waste. Domestic Garden waste (DG) was the second major source of green waste production. Grounds Maintenance (GM) was the third principal source of green waste production, but was produced by fewer local authorities than the previous two methods.

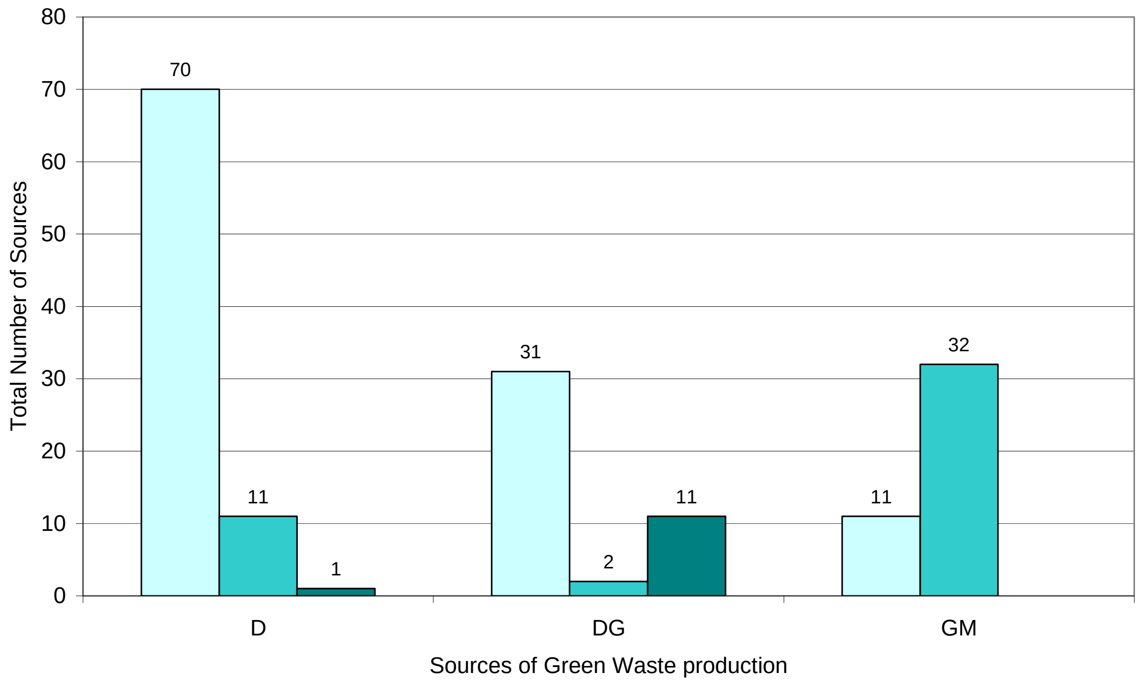


Figure 3.4.1: Principal Sources of green waste. ■ Indicates the primary method. ■ Indicates the secondary method. ■ Indicates the tertiary method.

The second issue to be addressed within the questionnaire was how green waste was collected. This is shown in Figure 3.4.2. Household Waste Centres (HWC) was the primary method used for the collection of green waste. These sites were operated by the County Council; the green waste was taken to the sites by the public. 21% of green waste collections were undertaken using Pre-Paid sacks (PP). 14% of local authorities collected their green waste *via* Bulky Household Waste (BHW) collections, with only 13% of the local authorities using Wheelie bins/Twin Bins (WB/TB) as their green waste collection method. Pre-Paid Compostable (PC) bags were the least favoured method for green waste collections, with only 3% of local authorities using this method.

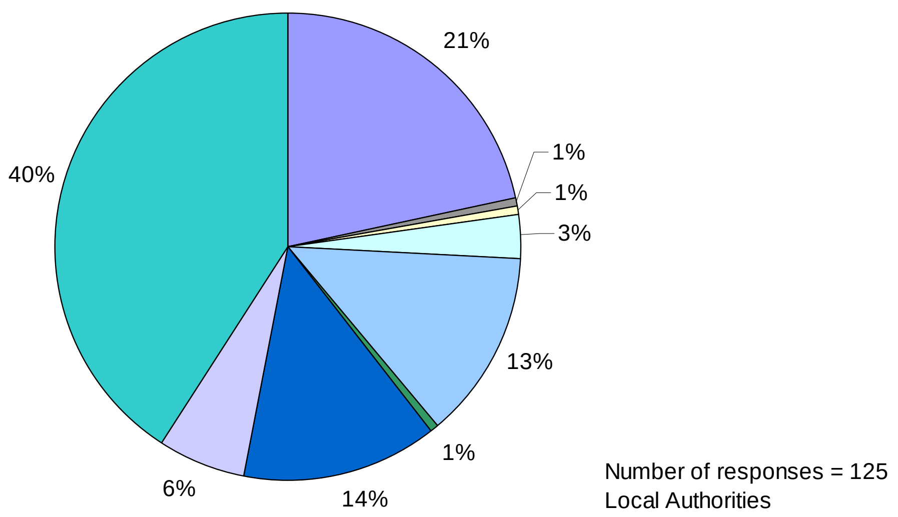


Figure 3.4.2: Green waste collection methods. ■ Indicates Pre-Paid sacks (PP). ■ Indicates PP taken by household member to Household Waste Centre (HWC). ■ Indicates PP including all waste types. ■ Indicates Pre-paid Compostable (PC). ■ Indicates Wheelie bins/Twin Bins (WB/TB). ■ Indicates waste not separated in Twin Bins (TB). ■ Indicates Bulky Household Waste (BHW). ■ Indicates free freighter service. ■ Indicates HWC.

From 138 local authorities surveyed, 15% had surveyed the components of green waste on a very basic level, 77% of local authorities may produce a composted green material, but had not surveyed the components of their green waste and 8% have no green waste management infrastructure implemented within the local authority, all their green waste was land filled, therefore key information obtained from the survey was that 85% of local authorities surveyed had undertaken no green waste analysis or had no green waste management as shown over page in Figure 3.4.3. The components of green waste, from the survey results are shown Figure 3.4.4. Garden waste, which included grass, hedge cuttings etc accounted for 38% of the components of green waste, with other components such as wood chipping, straw and cardboard achieving 3 – 8% of the percentage. 13% of the green waste surveyed was kitchen waste. This shows a large variation in the feedstock materials of composted green material, especially if this material is to be incorporated into growing media for the professional market where higher degrees of specification are required, and if the manufacturer wishes to gain a BSI PAS 100 certification.

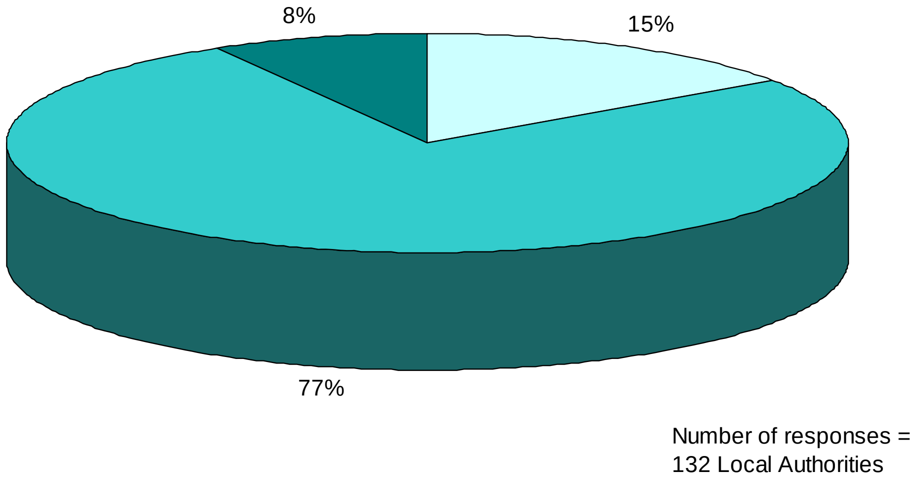


Figure 3.4.3: Surveying components of green waste. ■ Indicates yes. ■ Indicates no. ■ Indicates no management of green waste.

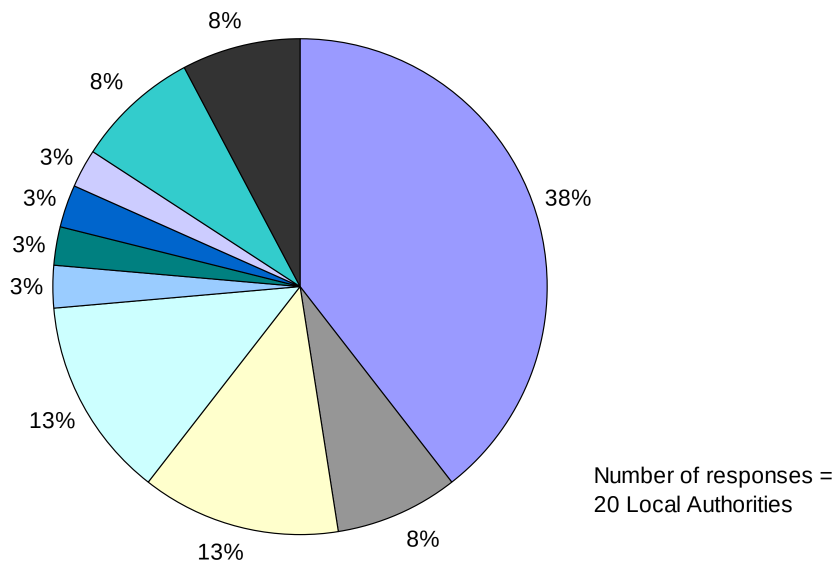


Figure 3.4.4: Components of green waste. ■ Indicates garden waste. ■ Indicates cardboard. ■ Indicates kitchen waste. ■ Indicates uncooked vegetable peelings.

■ Indicates wood chippings. ■ Indicates pet straw. ■ Indicates wood. ■ Indicates cooked and uncooked meat. ■ Indicates contaminants. ■ Indicates monitored by contractors.

Within the questionnaire the local authorities were asked to rank in order of greatest volumes their methods of green waste disposal. The primary method was the method the local authorities used to dispose of their largest volumes of green waste. Figure 3.4.5 indicates landfill as the primary method for green waste disposal for 56% of the local authorities surveyed. Compost production contributes to 41% of the primary waste disposal method for green waste. Within the secondary waste disposal methods, composting was attributed to 68% of the total, with landfill contributing only 29%. Incineration and other methods such as on-farm composting dominated the tertiary and quaternary methods of waste disposal.

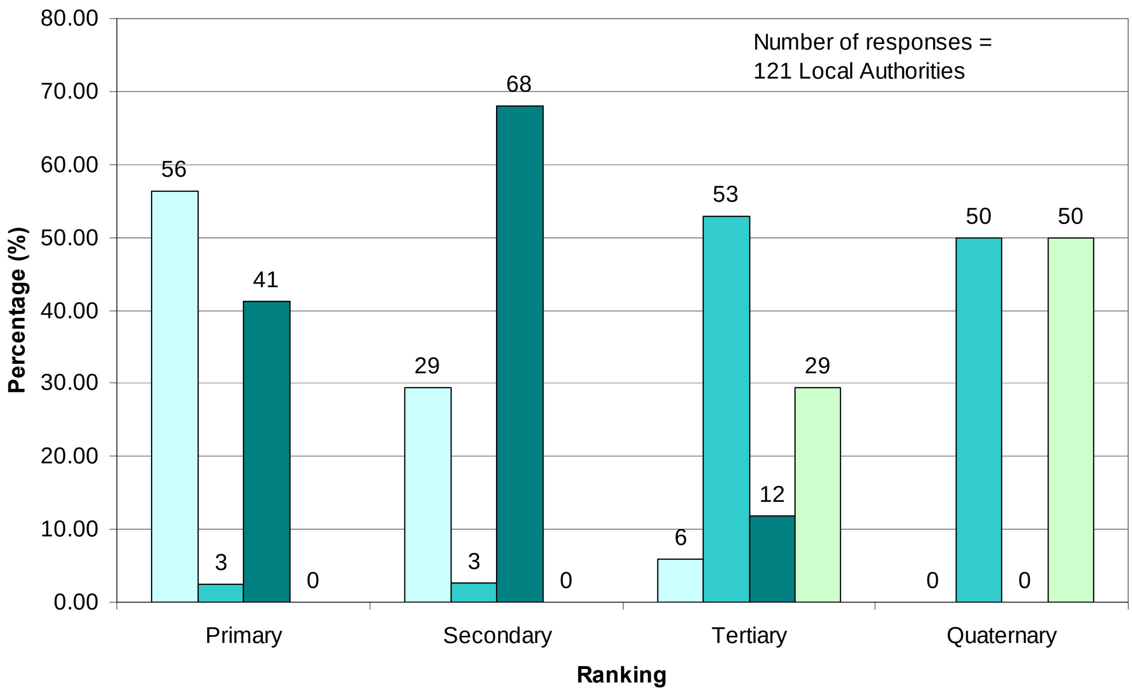


Figure 3.4.5: Disposal methods for green waste. ■ Indicates landfill. ■ Indicates incineration. ■ Indicates compost production. ■ Indicates other alternative method.

The majority of the manufacturing process of compost is undertaken by local companies and private contractors, 51% and 16% respectively, with only 14% undertaken by local authorities themselves e.g. County Councils and District/Borough Councils. Other methods of compost production such as on-farm composting and community composting schemes are undertaken on a much smaller scale, as indicated in Figure 3.4.6.

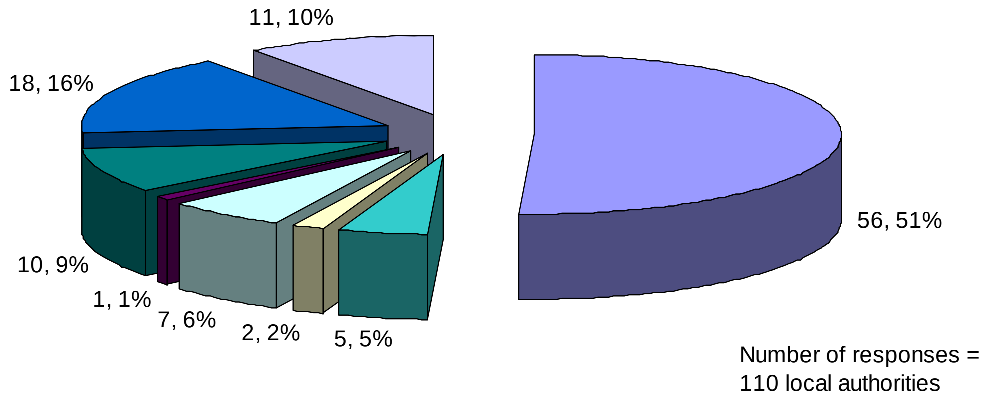


Figure 3.4.6: Who undertakes the process of composting? ■ Indicates a local company (ALC). ■ Indicates District/Borough Council. ■ Indicates Community/Resident. ■ Indicates On-Farm. ■ Indicates Landfill Operator. ■ Indicates County Council. ■ Indicates Private Contractor. ■ Indicates other.

Another issue associated with green waste is the method of compost production, as shown in Figure 3.4.7. Windrow composting is used by 78% of the local authorities surveyed as the main composting process method. In-vessel composting methods only contributed to 8%. There were other methods used but these processes were only undertaken by a single or small number of manufacturing plants.

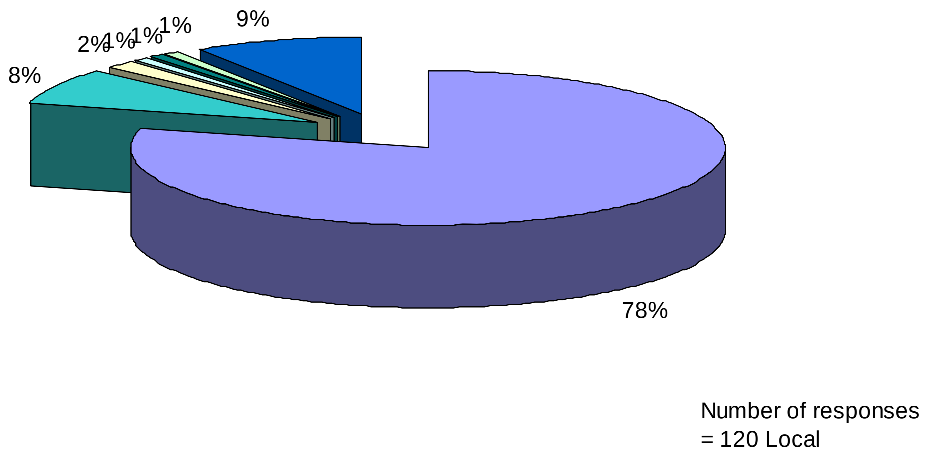


Figure 3.4.7: Methods of compost production. ■ Indicates windrow. ■ Indicates in-vessel. ■ Indicates basic pile. ■ Indicates aerated static pile. ■ Indicates home composting. ■ Indicates other. ■ Indicates no green waste management.

Within the local authorities who actually produced a composted green material, there are a number of local authorities which sold the material, (Figure 3.4.8). There was a large variation in the cost of the composted green material sold.

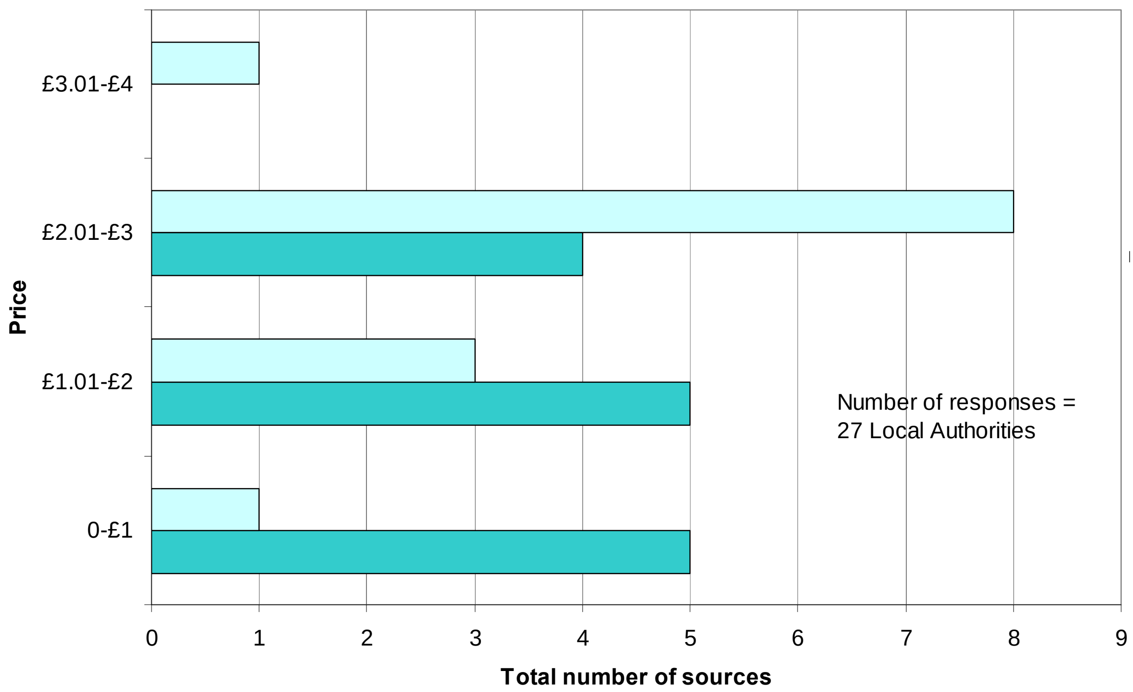


Figure 3.4.8: Cost of end-product, composted green material. ■ Indicates bags. ■ Indicates 25Kg/40L.

Within the questionnaire local authorities were asked if they were undertaking any other recycling initiatives which were not previously mentioned in the questionnaire. The most common tangible recycling initiative was subsidised compost bins followed by Community Compost Schemes. The most common intangible recycling process was the promotion of home composting with 25% of local authorities undertaking this process. A few, 6%, of local authorities had no green waste management strategies and 25% of local authorities had no recycling initiatives.

3.5 Discussion

It is important to note that data gained from the questionnaire may not be entirely reliable. The questionnaire was directed towards the personnel within the local authorities who deal with green waste, but the person who completed the questionnaire may not have known the answers to some of the questions within the questionnaire, for example if the composition has been investigated and may not have taken the trouble to enquire if any research had been undertaken.

From the survey, there is no consistency of approach for the management of green waste within local authorities waste management strategies, with 6% of the local authorities surveyed having no green waste management and 25% having no recycling initiatives. The Composting Industry Code of practice stated the need for overarching waste strategy within the United Kingdom (Duckworth, 2005).

The survey 'Management of Green Waste' was carried out during the latter part of 2002. When this survey was conducted the primary method of green waste disposal was by Household Waste Centres where the green waste was taken to the site by the public. This method accounted for 40% of the green waste collections, with various methods used for the collection of composted green material at lower percentages. This variation in collection could influence the quality of composted green material produced. Due to legislation, and the imposed increases in recycling targets, the findings produced from this survey may have changed as many local authorities are now providing collection services for green waste. Defra (2005) stated that the proportions of households served by 'kerbside' recycling collections schemes has increased from 2 households out of 3 in 2002/03 to nearly 4 households out of 5 in 2003/04, with the main material for collection for recycling being composting material.

From 138 local authorities who replied to the survey there had been no in-depth studies of the composition of the green waste that is entering the composting process. 85% of the local authorities had undertaken no green waste analysis or had no green waste management. From the 15% of local authorities which had surveyed the components of the green waste, the surveys were conducted on a very basic level. The results of this basic analysis are contained within Figure 3.4.4. A disturbing finding was that 13% of the surveyed components of green waste were kitchen waste which is unwanted in growing media. Due to the Foot & Mouth outbreak and BSE scares within recent years, the composting of catering waste or green waste that may have been in contact with raw meat has been restricted. As stated previously, green waste refers to garden or park waste such as grass or flower cuttings, or branches. Green waste is composted under regulations that may comprise of a Waste Management License, an Exemption from Waste Management Licensing, or in some instances a Pollution Prevention and Control permit from the Environment Agency/SEPA (Environment Agency, 2001). However, if green waste is mixed with catering waste, this waste must be considered as catering waste and treated accordingly, i.e. in-vessel composting where the are process is stringently monitored. The definition of catering waste, as defined under the new EU rules is ‘all waste food including used cooking oil originating in restaurants, catering facilities and kitchens, including central kitchens and household kitchens.’

Figure 3.4.5 indicated landfill as the primary method for green waste disposal for 56% of the local authorities surveyed. This was expected as indicated in Chapter 1.1. A positive finding was that the manufacture of compost contributed to 41% of the primary waste disposal method for green waste.

Over half of local authorities surveyed did not produce the compost themselves, 66% as shown in Figure 3.4.6. Local companies were used by 51% of the local authorities, limiting the environmental impact and cost from transportation. A proportion of the composting is undertaken by larger companies (16%), where the end-product has been assessed for example Waste Recycling Group undertake Kent County Councils composting and have been accredited with the BSI PAS 100 standard or the composting is undertaken by farmers therefore the product is not sold and is used on site.

Compost production was mainly undertaken using the windrow technique. This was expected as this process is a relatively simple method with lower maintenance costs compared to other techniques such as in-vessel composting. Other methods indicated from the survey were; aerated static pile and basic pile, which suggest the material is left to decompose. These techniques would probably have a very varied quality end-product.

From 118 local authorities who responded, 52% sell the composted green material compared to 48% which had no sales of the end-product (Appendix 1, Figure 10). Figure 3.4.8 contains information on the varied costs as either a weight or volume basis e.g. 25Kg or 40L of composted green material. As stated previously, there was a large variation in the cost of the composted green material produced. The majority of the manufacturing process of compost was undertaken by local companies and private contractors with some being certified as BSI PAS 100 standard and are therefore able to market the material as a growing medium, which is viewed as the premium market for composted green material. Veeken *et al.* (2005) states that there is a need to produce higher quality composted green material, that could then be included in the higher price market, i.e. the professional market. Gajdos (1998) found that the majority of waste disposal facilities are primarily focused on the increase in turnover rate of waste streams and are therefore paying less attention to the quality of the end-product produced.

Where the composted green material has a certified standard (e.g. BSI PAS 100) this has increased the retail value of this material. The composted green material that is being sold at the lower end of the price range is probably marketed as a mulch or soil improvers. In order to consider composted green material for use on growing media, the parameters that require focus are the quality and consistency of the material. As indicated by this research, there were variations in feedstock materials, variations in the manufacturing process and therefore variations were indicated in the final end-product, composted green material.

Chapter 4.0 Establishment of the variation in quality of green materials

4.1 Introduction

Following the survey reported in Chapter 3, the local authorities which produced a composted green material were sent a follow up email asking if they would wish to participate in a study reviewing best practise leading to the production of material suitable for inclusion in growing media. This involved a comprehensive evaluation of their end-product. From the initial producers identified, twelve sources agreed to participate within the trial (Table & Figure 4.1.1). Samples of their final end-products were sent or collected. The samples which were collected were taken from a pile of matured compost by digging into the pile and taking the sample from a number of places within the pile. When asking for samples to be sent, a representative sample was asked for, as stated in the BSI PAS 100 protocol. For confidential reasons the samples were given a number from which they are referred to throughout. The samples obtained varied in their use/quality from soil improvers to actual peat-free composts.

Sample Number	Location	Method of Production	Differentiation
1	Arnold, Nottingham	Basic Pile	Shredded
2	Arnold, Nottingham	Basic Pile	Matured for 3-4 Weeks
3	Arnold, Nottingham	Basic Pile	Matured for 6 Weeks
4	Caythorpe, Lincolnshire	Windrow	
5	South Anston, Sheffield	Windrow	Matured for 6 Months
6	South Anston, Sheffield	Windrow	Matured for 2 Months
7	Dorset	Not available	
8	Shropshire	Windrow	
9	Chester	Windrow	
10	Cheshire	Windrow	
11	Nottingham	Windrow	
12	Suffolk	In-vessel	
13	Worksop, Nottingham	Windrow	
14	Kent	Windrow	PAS 100
15	Lancashire	Windrow	

Table 4.1.1: Location of composted green material sources

Figure 4.1.1: Location of composted green material sources.
(● = Source)

The aim of this part of the research was to assess the quality of the end-products being produced with a view to in-depth investigations into their suitability for inclusion in growing media and subsequent long term studies that may occur in stored media

4.2 Methods & Materials

The analytical procedures used to determine the properties of the media were derived from the following; International Society for Horticultural Science (ISHS) – Laboratory Manual from Commité Européen de Normalisation (CEN) – Standards for Chemical and Physical Analysis of Growing Media in combination with the techniques used by Turner & Carlile (1982), and Dickinson (1995) within their research at Nottingham Trent University.

The physical parameters determined were; bulk density, organic matter and ash content and soil moisture content. The chemical parameters included; pH, electrical conductivity, nitrogen, potassium and phosphorus concentrations.

Methods for Physical Analyses

4.2.1 Determination of Bulk Density (BD)

The material used for this analysis was in its “received state”.
Apparatus was used as described in the CEN manual (ISHS, 2003).

- Sieve with perforated edge, of 200mm diameter, with 20mm square apertures, independently supported above the funnel *via* a tripod, and not connected to the cylinder.

- Test Cylinder: A rigid test cylinder, having a capacity of 1000ml +/- 30ml. Made from a pipe of 100mm +/- 1mm diameter, and 127mm +/- 1mm in height. The test cylinder had a known volume and weight.

- Removable collar, 50mm high and of the same internal diameter as the cylinder.

- 60˚ funnel, with an upper diameter of 170mm and a lower diameter to fit the collar.

- Plunger, having a diameter 5mm less than both the cylinder and the collar, with a mass of 650g.

This apparatus is shown in Figure 4.2.1.1

Figure 4.2.1.1: Equipment used for the determination of bulk density

The removable collar was placed upon the test cylinder. The funnel was then placed on top of the removable collar. The sieve was then placed over the top of the apparatus and supported *via* a tripod. Using a scoop, a homogenised sample was passed through the screen, with gentle agitation if needed. Once the apparatus was overfilled, the screen and funnel were then removed. The excess material was then removed using a straight edge. The plunger was placed on top of the material for three minutes. The plunger and collar were then carefully removed. The material was then levelled off using a straight edge. The test cylinder was then weighed and the weight was recorded.

This procedure was repeated in triplicate for each of the three individual samples, giving nine replicates in total. All error values referred to in this research are 95% confidence limits (ISHS, 2003).

Figure 4.2.1.2: Demonstration of equipment

4.2.2 Determination of Organic Matter (OM) /Ash (ASH) Contents

The samples were dried in a ventilated oven at 75˚C +/- 5˚C. To ensure the samples were dry, a touch test was used. When touched, if the samples crumbled they were dry. The samples were then ground up, using a pestle and mortar and passed through a 2mm sieve, samples were labelled as ‘<2mm’ samples. Some of the samples contained larger pieces of materials that could not be broken down, this section of the sample was still used but was labelled as ‘>2mm’.

The weight of a crucible was recorded (m_0). Approximately 5g of (**<2mm**) or (**>2mm**) sample was then weighed into the crucible. The crucible was then placed in a drying oven at 103˚C +/- 2˚C for four hours. The weight of the crucible to the nearest 0.001g was recorded. The crucible was then placed back in the oven for a further 1hour. The weight was again recorded to the nearest 0.001g. This process was repeated until the difference between two successive weightings was less than 0.01 (m_1).

The crucible was then placed in a cool muffle furnace; the temperature was then brought up to 450˚C +/- 10˚C over approximately 1 hour. The crucible was then left in the muffle furnace for a further six hours, and then placed into a desiccator to enable the crucible/sample to cool down to room temperature. The crucible was then weighed to the nearest 0.001g. The crucible was then placed back into the muffle furnace for a further one hour and then placed once more into the desiccator. When cooled, the weight of the crucible to the nearest 0.001g was again recorded. This was continued until the difference between two successive weightings was less than 0.01g (m_2). This process was repeated in triplicate for each sample.

The following calculations were then used to achieve the organic matter and ash contents as a percentage. Organic matter expressed as a percentage by mass of the dried sample, is given by the following equation:

$$W_{om} = \frac{m_1 - m_2}{m_1 - m_0} * 100$$

Ash content, expressed as a percentage by mass of the dried sample, is given by the following equation:

$$W_{ash} = \frac{m_2 - m_0}{m_1 - m_0} * 100$$

This procedure was repeated in triplicate for each of the three individual samples, giving nine replicates in total. All error values referred to in this research are 95% confidence limits (ISHS, 2003).

4.2.3 Determination of Moisture

The material used for this analysis was in its "received state". A glass petri dish was weighed (3dp), this value was recorded. Approximately 10g of material was then weighed out into the petri dish, which was then placed into a ventilated oven at 105˚C for 48 hours. The sample was then removed from the oven and weighed. The sample was then placed back in the oven for a further 1hour and weighed. This process was repeated until the difference between the two successive weighings was 0.1g. To calculate the moisture content, the following equation was used:

$$= \left(\frac{x - y}{y} \right) * 100$$

x = initial weight of sample
y = weight of dried sample

This procedure was repeated in triplicate for each of the three individual samples, giving nine replicates in total. All error values referred to in this research are 95% confidence limits (ISHS, 2003).

4.2.4 Determination of pH

Using the BD values, the equivalent weight to 60ml of the sample was transferred to a 500ml flask. The material used for this analysis was in its "received state". 300ml of distilled water was then added to the flask and shaken for 60 minutes on a mechanical shaker, giving a dilution ratio of 1:5. The pH was then taken, using the Corning pH meter model 7. After the pH of the sample had been recorded, the solution was then filtered and collected in a beaker. This procedure was repeated in triplicate for each of the three individual samples, giving nine replicates in total. All error values referred to in this research are 95% confidence limits (ISHS, 2003).

4.2.5 Determination of Electrical Conductivity

The electrical conductivity was measured using an electrical conductivity Portland Electronics Ltd, model P335. The meter was set to the temperature of the filtrate (20˚C) (Filtrate was gained from the method 4.2.4 Determination of pH). The probe was inserted into the filtrate and the electrical conductivity was recorded. The probe was rinsed thoroughly between each use to eliminate contamination. Distilled water was used to set the probe, (to an electrical conductivity of 0µmhos). This procedure was repeated in triplicate for each of the three individual samples, giving nine replicates in total. All error values referred to in this research are 95% confidence limits (ISHS, 2003).

4.2.6 Determination of Nitrate Nitrogen

Nitrate Nitrogen values were analysed on the same day as extraction, due to possible deterioration in storage.

To analyse the Nitrate Nitrogen concentrations, an Orion nitrate probe, model 93-07 was used. By using 0.1631g per 100ml of Potassium Nitrate, a stock solution of 1000mg/L NO_3 was produced. From the stock solution, standards of 100 and 10mg/L were produced. All samples (filtrate) and standards had 0.4ml of Ionic Strength Adjuster (ISA); 2M ammonium sulphate solution was added to them. The 100mg/L and 10mg/L standards were used to calibrate the probe. After ten samples the probe was recalibrated to ensure accuracy. When recording the nitrate concentrations, each sample was placed on a magnetic stirrer, with a stirring bean added to the sample. By placing a heat proof mat underneath each sample on the magnetic stirrer, the fluctuation in results due to temperature change was minimised (Carlile, 2004a).

This procedure was repeated in triplicate for each of the three individual samples, giving nine replicates in total. All error values referred to in this research are 95% confidence limits.

4.2.7 Determination of Potassium

Potassium was analysed using the Corning 410 flame photometer. Before the samples could be analysed, a calibration curve was plotted using a stock solution of 100mg/L (0.0259g per 100ml Potassium nitrate) to produce standards of 10, 5, 4, 3, 2, and 1mg/L. The filtrates (Gained from the method 4.2.4 Determination of pH) were diluted before analysis (Carlile, 2004). This procedure was repeated in triplicate for each of the three individual samples, giving nine replicates in total. All error values referred to in this research are 95% confidence limits.

4.2.8 Determination of Phosphorus

The initial method used to test the extraction of ‘available’ phosphorus was the Schofield method (Schofield, 1955). However this method proved unsatisfactory and inconsistent, probably due to the contamination from washing detergents used to clean the test tubes. Experiments were conducted using new solutions, different batches of test tubes, acid washed test tubes and eventually brand new test tubes. This did increase the accuracy of the calibration curve but not to a satisfactory level. There was also another problem identified with this method, as testing large numbers of samples with a progressive colour development is difficult. This data was going to be used on a comparative basis; therefore a method that produced accurate consistent results was needed.

Colorimetric tests with microplates were used to develop the method for determination of urea and its use in studies of nitrogen mineralisation in growing media (Carlile & Dickinson, 1997). This method was initially evaluated and subsequently adopted for the phosphorus analysis, overcoming the problem with contamination and allowing large numbers of samples to be measured simultaneously (96 samples per plate).

Therefore the phosphorus assay was conducted using the Titertek Multiskan mcc/340 and a 96 sample size microplate. Within the phosphorus analysis a calibration curve was produced using standards of 0, 5, 10, 15, 20 and 25mg/L of phosphorus. The standards were produced using a stock solution of 25mg/L (0.011g potassium dihydrogen orthophosphate per 100ml) and distilled water. In each well, 12.5µl sample/standards were added, 12.5µl of 1.5M sulphuric acid, 62.5µl of 1.5% ammonium molybdate. When all of the components had been added to the microplate, 62.5µl of 1.5% ascorbic acid was then be added to both the samples and the standards. The solutions were then left to stand for 20 minutes to allow the colour to develop. The absorbance readings were then taken *via* the Titertek Multiskan mcc/340. A calibration curve was produced and the concentration of the samples was then calculated.

This procedure was repeated five times for each of the three individual samples, giving fifteen replicates in total. All error values referred to in this research are 95% confidence limits.

4.3 Results

A huge variation was evident in the samples of composted green material, both structurally and in terms of physical and chemical analysis.

The variation in structure can be observed in the photograph below.

Figure 4.3.1: Visual assessment of composted green material.

The samples above had a large variation in bulk density, which was expected after visual observations. For example Sample 3 had a bulk density of 243g/L (+/- 9.2g/L), compared to Sample 15 which had a bulk density of 837g/L (+/- 2.8g/L), as shown in Figure 4.3.2. This would have huge implications on the transportation costs of this growing medium.

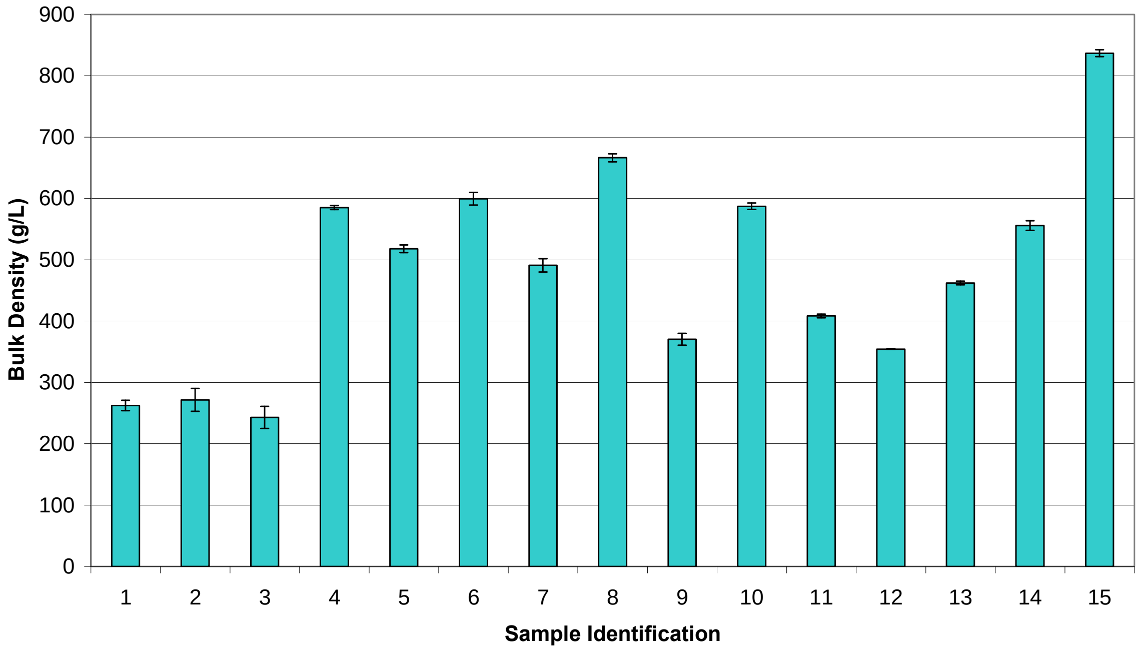


Figure 4.3.2: Bulk Density values of composted green material samples. The 95% confidence limits are indicated by error bars.

Figure 4.3.3 indicates a wide range of green material moisture contents, ranging from 46.04% +/- (1.43%) in Sample 7 to 71.6% +/- (1.05%) for Sample 15.

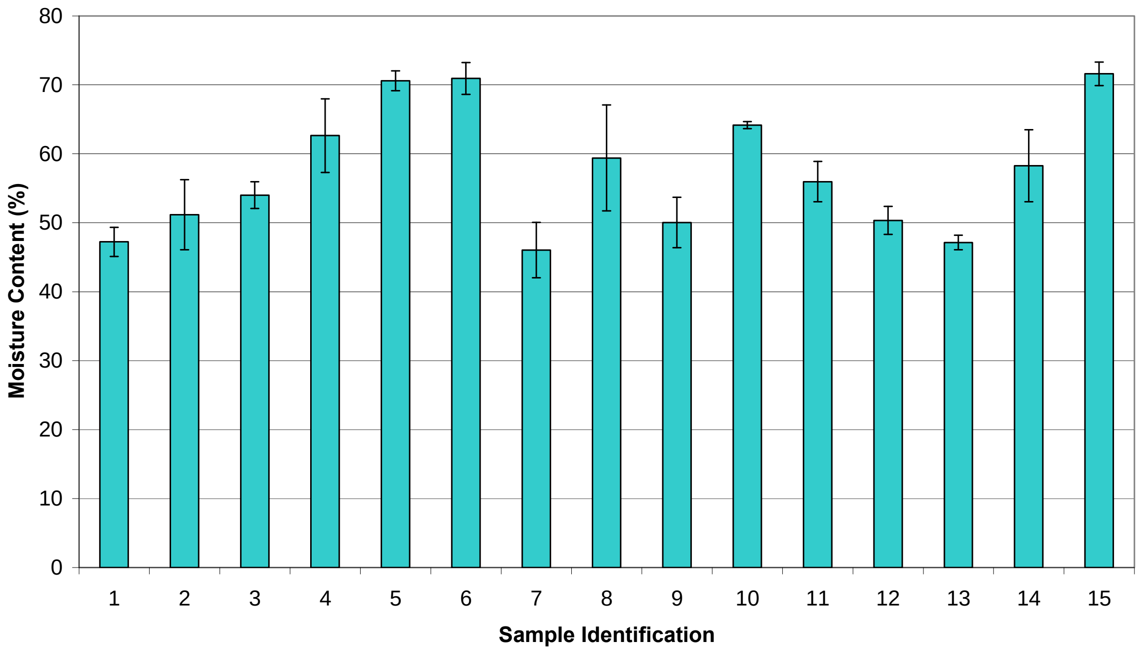


Figure 4.3.3: Moisture contents of composted green material samples. The 95% confidence limits are indicated by error bars.

This variation within the data was further reinforced by the varying organic matter and ash contents. Sample 8 had the lowest organic matter content, 13% (+/- 1.7%), compared to Sample 1 with 76% (+/- 4.6%) organic matter (Figure 4.3.4 (a) and 4.3.4 (b)).

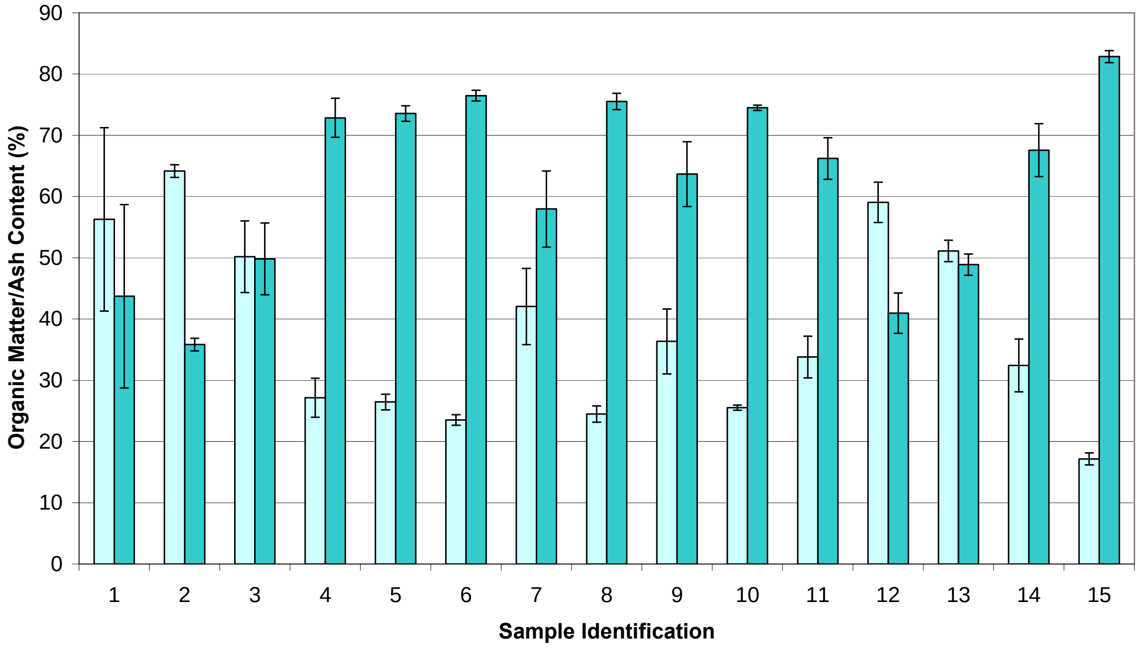


Figure 4.3.4 (a): Composition of organic matter/ash **(<2mm)** in composted green material samples. Indicates organic matter content. Indicates ash content. The 95% confidence limits are indicated by error bars.

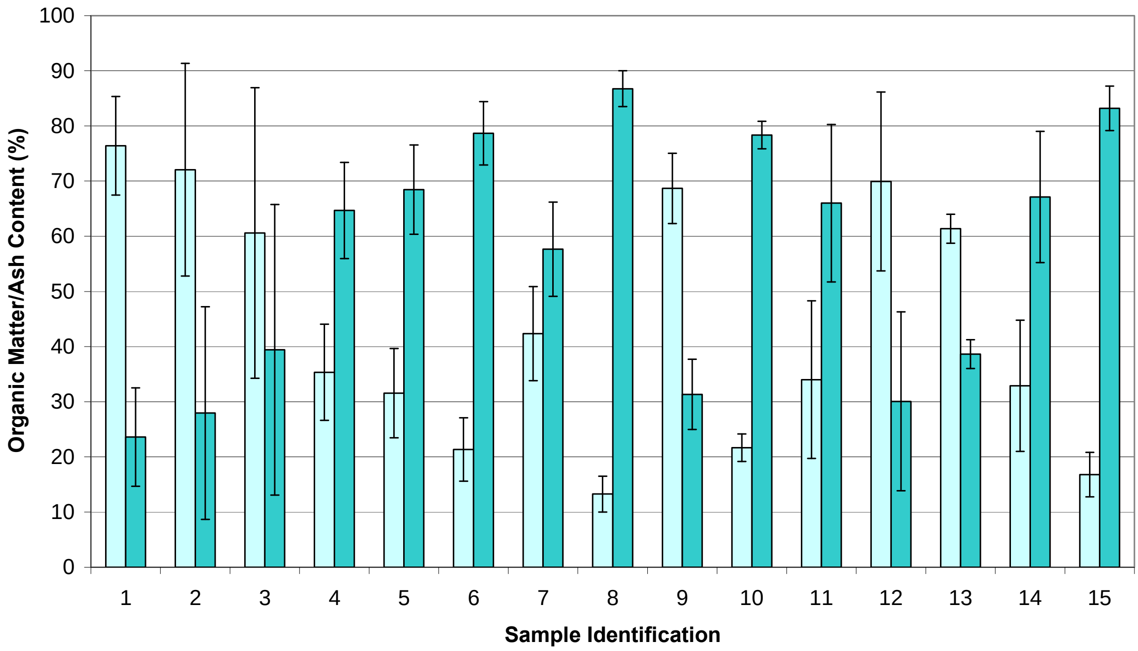


Figure 4.3.4 (b): Composition of organic matter/ash **(>2mm)** in composted green material samples. Indicates organic matter content. Indicates ash content. The 95% confidence limits are indicated by error bars.

All pH values were well above that associated with growing media (pH 5-6) and there was a considerable variation in the pH values obtained for the twelve samples ranging from pH 6.9 (+/- 6.3*10-16) to 8.65 (+/- 0). There was also a huge variation in the electrical conductivity values obtained, sample 9 having the lowest electrical conductivity reading of 466.67µmhos (+/- 38.94µmhos), with sample 15 having a electrical conductivity reading nearly treble that 1292µmhos (+/- 22.05µmhos), as shown in Figure 4.3.5 (a) and (b).

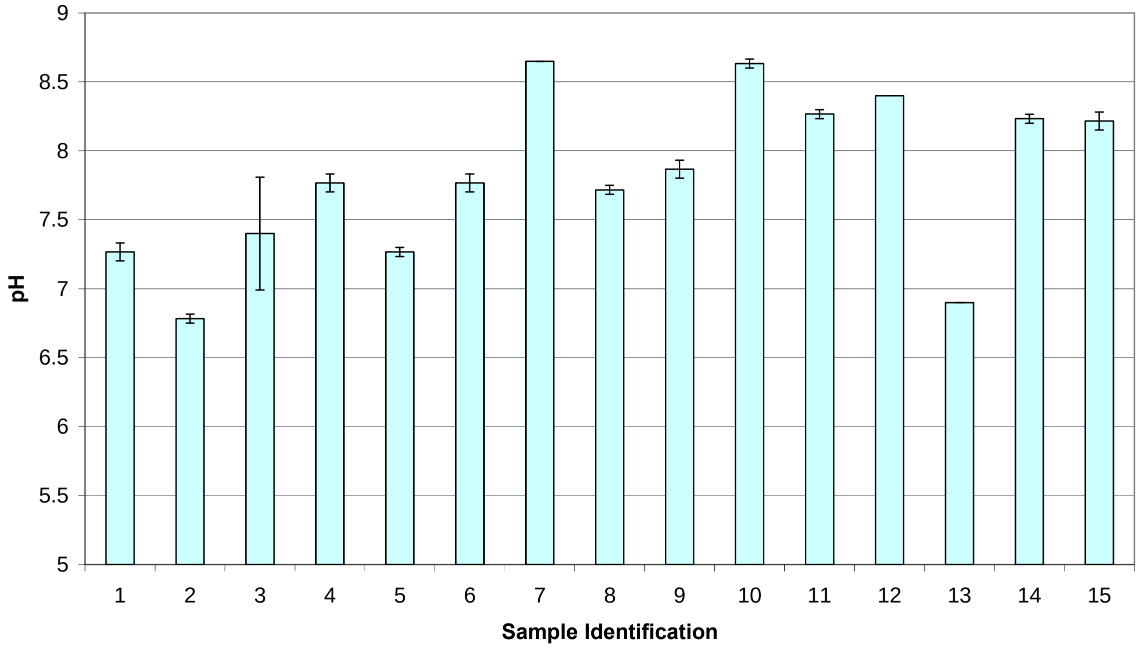


Figure 4.3.5 (a): Variability of pH. Indicates pH values. The 95% confidence limits are indicated by error bars.

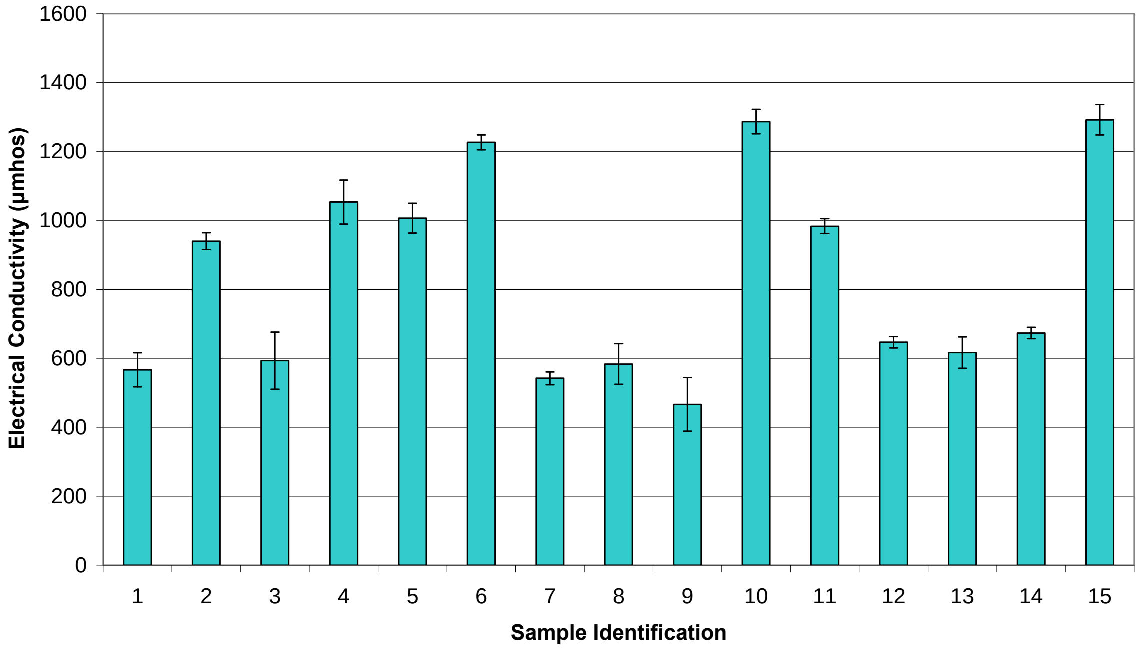


Figure 4.3.5 (b): Variability of electrical conductivity. Indicates electrical conductivity values. The 95% confidence limits are indicated by error bars.

A number of macro nutrients were also investigated (Figure 4.3.6). Phosphorus was present in low concentrations throughout the samples. Potassium was present in high concentrations, but with large variations between samples. The levels of nitrate in the samples varied considerably from 469mg/L (+/- 2.7 mg/L) in Sample 8 to negligible amounts in several other samples.

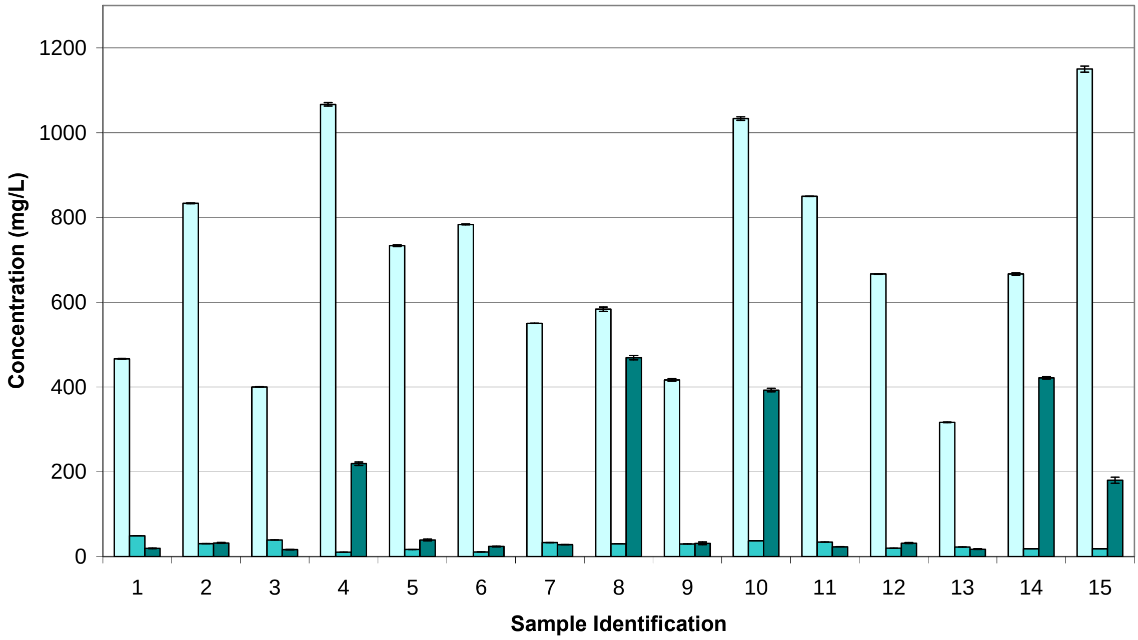


Figure 4.3.6: Macro nutrient concentrations from twelve samples of composted green material. ■ Indicates potassium concentrations. ■ Indicates phosphorus concentrations. ■ Indicates nitrate concentrations. The 95% confidence limits are shown by error bars.

4.4 Discussion

This part of the research investigated the variability of composted green material and its potential for use in growing media. The parameters investigated showed clearly how variable this material is.

Figure 4.3.2 illustrates the variability within the bulk density. This would have great implications on transportation costs for the manufacturers as well as possibly deterring the public from buying the end-product. If composted green material is to be included within growing media, the weight of the end-product needs to be consistent, and preferably as low as possible. Indeed for retail sales, the public must be able to lift the product and transport it. As stated in Chapter 2, a bulk density of less than 500g/L is favourable; seven out of the original twelve samples had a bulk density greater than 500g/L. The composted green material would be mixed with other lighter material, reducing the bulk density. However the inherent initial high starting weight of the composted green material could be problematic.

Growing media is sold in volume. However, with the exception of the lightest of substrates, transport costs are paid by weight. ‘Transport in’ costs are therefore a function of density and distance from source to growing media manufacturing site. ‘Transport out’ costs are somewhat more complex due to the geographical distribution of customers and the demands set by the retailers and growers. They may often require a delivery at short notice or in part, or small load sizes and manufacturers often have a nationwide distribution. Consequently, the effects of the density of a substrate on the overall end-to-end logistics cost is very significant indeed (Waller & Temple-Heald, 2003).

As stated by Groenhof (1998) the end-product would ideally have 40% moisture content. Increasing the moisture content increases the bulk density, which again would have implications on the transportation costs. Figure 4.3.3 indicates the lowest moisture content within the studies was 46.04% +/- 1.43% with many of the samples containing higher amounts of moisture. The handling of the material is also very important. The consumer wants a material that has a similar consistency to growing media, if the moisture content was too high this could affect the air-water ration by decreasing aeration. The material may loose its cohesion and therefore appear unsuitable as a growing media.

As stated previously the main constituent of growing media at present is peat, which had a high organic matter, approximately 90% (Ribeiro *et al*. 2000). Organic matter improves the structure of the medium increasing the water holding capacity and also provides a supply of plant nutrients *via* its cation exchange capacity, principally nitrogen. With some samples of composted green material, there was a relatively high ash content; therefore a high mineral content which could indicated high transportation cost for this material.

Pronk (1995) was one of the first researchers to identify that high pH might be a problem in growing media and thus the pH of such media needs to be considered in the light of nutrient availability. Composted green material has high pH values compared to the traditional growing medium, pH 5-6 (Bunt, 1988). Within this study the pH values ranged from 6-8 – 8.65, with a majority of samples within the range of pH 7-8. Growing media with a high pH i.e. pH 7 and above can increase the availability of some macro and micro nutrients, for example magnesium and calcium. However a high pH can also reduce nutrient availability, for example potassium, phosphorus, iron, manganese, boron (Bunt, 1988).

Electrical conductivity is also an important factor as high rates of growth are often achieved by using high concentration of nutrients as feed. However if the concentration of nutrients is too high, plant growth can be restricted, either by specific ion toxicity or by a general salinity effect (high salinity) by reducing the availability of water. According to Warnecke, (1990) (in Ribeiro *et al*. 2000) the maximum tolerable electrical conductivity for 'high-nutrient requiring plants' is 5mS cm^{-1}, or 5000μmhos, which indicates that all the samples of composted green material would fall below this limit. Bunt, (1988) would consider a electrical conductivity of 150-500μmhos as suitable for seedling growth, however the BSI PAS 100 standard for growing media states the electrical conductivity must be no higher than 1000μmhos. The majority of the samples were below this value; however a high electrical conductivity is not a disadvantage. The high electrical conductivity can be reduced by diluting the composted green material with other material i.e. peat. The electrical conductivity values varied considerably for the twelve samples. A majority of the high electrical conductivity values were probably attributed to the high potassium levels within the sample.

The samples used within the analysis all contained varying concentration of nutrients. They could be a valuable source of fertiliser within a growing media. Trace elements were not included in this analysis; however other researchers have shown the advantage gained form the inclusion of composted green material (Ribeiro *et al.* 2000). Figure 4.3.6 shows a large variation in macronutrient concentrations. Potassium was present in high concentrations, but with a large variation between samples. This high concentration could reduce the need for additional K-based fertilisers, therefore reducing production costs, however excess levels of potassium can cause adverse effects by reducing the uptake of several other nutrients, for example Ca, Mg, Mn, and Zn. Similar conclusions may be drawn for nitrate concentrations where again there was a large variation between samples. Again the addition of nitrates is valuable within a growing medium. Nitrates are of course essential for plant growth, however if there is available nitrates in excess the resulting high salinity conditions could potentially inhibit seedling growth. Within a number of samples, there were negligible amounts of nitrogen. Studies conducted for Waste Resource Action Programme (WRAP) in the United Kingdom have shown nitrogen availability to be a significant problem for growing media containing green material and other recycled material, with the need to supply additional nitrogen (Peatering Out Ltd, 2005a; Richardson & Rainbow, 2005).

Overall variation within the representative parameters is evident. From the analysis of twelve different sources of composted green material considerable variation is apparent. Variability observed in Chapter 3 within the samples could be due to a number of processes within the production of composted green material. Variability was found within the sources of green waste, the collections of green waste and the composting processes.

If this type of study was to be carried out across the United Kingdom, the variation might be very large indeed. There is a clear need for standardisation in the approach to producing composted green material for the inclusion in growing media. These variations reinforce the view that variability of composted green material is an issue which hinders the use of this medium in composts and is of major concern to manufacturers of growing media who may wish to incorporate composted green material into their products. To overcome this problem, The Composting Association has recently produced 'The Composting Industry Code of Practice' to enable operators to identify good practice for their own individual sites (Duckworth, 2005). The document is non statutory. It is intended to aid composters, especially those people and organisations, who are considering establishing and operating a composting facility, of any scale. It provides a route map through the regulatory requirements and sets good operational performance standards for a composting facility. It also dovetails with the requirements of the BSI PAS 100 standard.

The dissemination of such knowledge of good practise will hopefully lead to a better quality composted green material that could be used as a diluent or replacement for peat in growing media.

Variation between samples is apparent; however there are many benefits to be gained from the inclusion of composted green material in growing media. As stated composted green materials contain readily available forms of a wide range of nutrients for example potassium and magnesium and can contain slow release forms of nitrogen which may reduce the need for conventional fertilisers therefore reducing the production costs. The high cation exchange capacity increases the nutrient buffering and therefore may reduce leaching (Holmes, 2006). Due to the high pH of composted green material, the liming value is such that the addition of liming materials could be reduced or even eliminated.

Chapter 5.0 The Storage Characteristics of Peat-Reduced Media containing Composted Green Material

5.1 Introduction

The initial aim of this research was to investigate the potential of composted green material for the inclusion in growing media, by looking at various chemical and physical measurements. An important factor within the use of composted green material as a constituent of growing media is how this material is affected by storage. As stated in Chapter 2, peat is relatively stable in storage compared to alternative material (Prasad & Maher, 2004). Peat is not broken down as readily as other alternative materials for example wood fibres, due to its high lignin content. However there is little information available on how composted green material acts in storage (Butler *et al.* 2001; Wu & Ma, 2001), although two investigations were initiated by WRAP during the period of research in this thesis.

In this section of the thesis comprehensive studies are reported on; germination, plant performance in media containing composted green material, physical properties and nutrient analysis over a storage period of one year. Storage was monitored at two different temperatures in an attempt to reflect storage of media in a commercial situation.

Several factors influenced selection of the four samples of composted green material to be included within the peat-reduced growth /storage trials. As a focus of this project is on composted green material production situated near Nottinghamshire, the samples used in this study needed to be accessible and situated around Nottinghamshire, Figure 5.1.1.

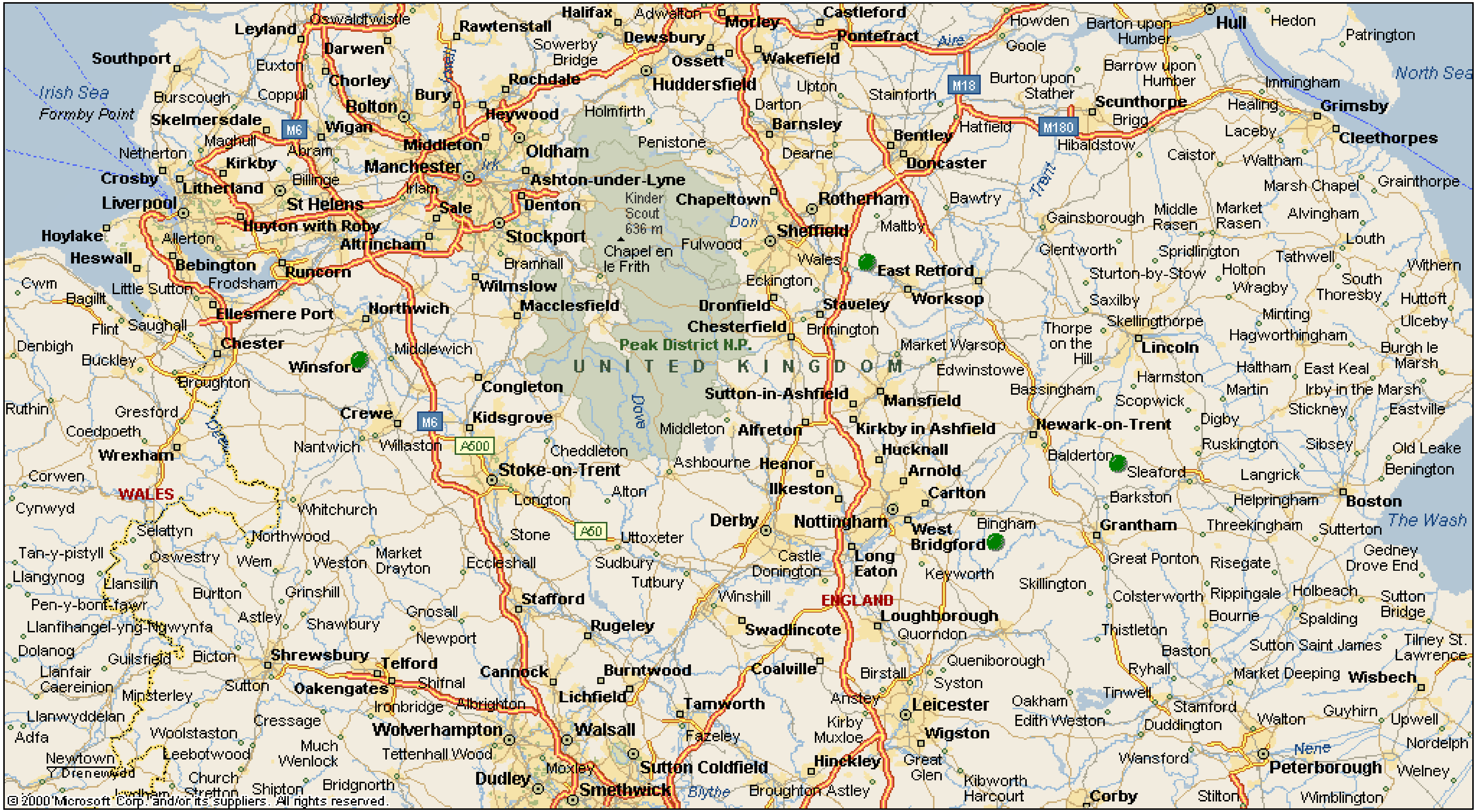


Figure 5.1.1: Location of composted green material sources.
(● = Source)

The second issue was time, as a number of parameters were going to be investigated; only a limited number of samples could be used. Data produced from the analysis conducted on the original twelve samples (Chapter 3) was also considered in the selection of the four samples (Figure 5.1.1).

Parameter	Sample Identification			
	4	5	10	11
Bulk Density (g/L)	585.05 +/- 3.27	517.93 +/- 6.43	587.34 +/- 5.35	408.47 +/- 2.99
Moisture Content (%)	62.63 +/- 5.35	70.6 +/- 1.44	64.17 +/- 0.50	55.97 +/- 2.92
Organic Matter Content **(<2mm)** (%)	27.14 +/- 3.19	26.44 +/- 1.27	25.52 +/- 0.42	33.786 +/- 3.40
Organic Matter Content **(>2mm)** (%)	35.33 +/- 8.71	31.55 +/- 8.10	21.65 +/- 2.51	34.00 +/- 14.29
Ash Content **(<2mm)** (%)	72.86 +/- 3.19	73.86 +/- 1.27	74.48 +/-0.42	66.21 +/- 3.40
Ash Content **(>2mm)** (%)	64.67 +/- 8.71	68.45 +/- 8.10	78.35 +/- 2.51	66.00 +/- 14.29
pH	7.77 +/- 0.07	7.27 +/- 0.03	8.63 +/- 0.03	8.27 +/- 0.03
Electrical conductivity (μmhos)	1053.33 +/- 63.77	1006.67 +/- 43.20	1286.67 +/- 35.59	983.33 +/- 21.60
Nitrate Concentration (mg/L)	219.00 +/- 4.11	39.17 +/- 2.12	392.67 +/- 4.15	23.17 +/- 0.36
Phosphorus Concentration (mg/L)	10.30 +/- 0.003	16.98 +/- 0.007	37.12 +/- 0.004	34.34 +/- 0.002
Potassium Concentration (mg/L)	1066.88 +/- 0.07	733.35 +/- 0.20	1033.35 +/- 0.34	850.02 +/- 0.51

Table 5.1.1: Analyses of Samples 4, 5, 10 and 11. The 95% confidence limits are indicated by +/- limits.

The main selection criteria were based upon material produced in or within close proximity to Nottinghamshire. Other parameters taken into consideration were the nitrate concentrations and pH values, as there were a range of pH and nitrate concentrations, which would affect the nutrient availability and seed germination.

5.2 Methods & Materials

For each of the four samples of composted green material selected for extended analysis, approximately 120L of material was collected. This enabled a total of 50L of each mixture to be produced. Mixtures were prepared at 10, 20, 30, 40, 50, and 70% by volume with sphagnum peat, with the addition of dolomitic limestone to both the samples and the all peat mix, where appropriate, to achieve a pH ranging from 5.5 – 6.5, during the mixing of the composted green material/peat. Preliminary studies were conducted to establish the quantity of lime that needed to be added to mixtures in order to obtain pH levels between 5.5 -6.5. The control was an all peat mix, with a standard commercially produced nutrient mixture also added. As shown in Table 5.2.1 & 5.2.2. The different components were combined using a new cement mixer to eliminate contamination issues.

Mixtures (CGM %)	Composted Green Material (CGM) (L) e.g. Sample 4	Sphagnum Peat (L)	Total (L)
All Peat Mix (0 %)	0	50	50
10%	5	45	50
20%	10	40	50
30%	15	35	50
40%	20	30	50
50%	25	25	50
70%	35	15	50

Table 5.2.1: Composition of mixtures used within the peat-reduced growth and storage study.

Lime Requirements (g per 50L)	Composted Green Material Sample				All Peat Mix	Nutrient Mix
	4	5	10	11		
0%	n/a	n/a	n/a	n/a	500	75
10%	200	400	500	400	n/a	n/a
20%	50	300	300	350	n/a	n/a
30%	n/a	n/a	200	300	n/a	n/a
40%	n/a	n/a	150	200	n/a	n/a
50%	n/a	n/a	n/a	100	n/a	n/a
70%	n/a	n/a	n/a	n/a	n/a	n/a

Table 5.2.2: Lime and nutrient requirements for the individual mixtures.

The mixtures used in this study were split, half of the material was stored in a 10˚C constant temperature room (10˚C), and the other half was stored in a glasshouse (GH). The samples were stored in labelled sealed plastic bags and placed next to one another.

Growth studies were carried out using lettuce (*Lactuca sativa* 'Winter Density') and tomato (*Lycopersicum esculentum* 'Moneymaker'). For each mixture, for example the mixture containing 10% of Sample 4 stored at 10˚C, five 9cm pots were sown with 10 seeds equally spaced. This process was repeated for both the lettuce and tomato growth studies. Germination counts for lettuce were taken after one week. Tomato germination was assessed 10-14 days after sowing. Tomato plants were then chosen at random and potted on into 7.5cm pots, again this was replicated five times. The plants were then left for a further period of time, 14-21 days according to season. The plants were then cut from the bottom of the stem and the fresh weights were taken.

To assess the mixtures used in the peat-reduced growth and storage trials, analysis was conducted monthly for the first six months and bimonthly for the next six months thereafter. This trial was conducted over a one year time frame.

Methods of Physical Analyses

5.2.1 Determination of Bulk Density (BD)

The methodology is in section 4.2.1 Determination of Bulk Density (BD)

5.2.2 Determination of Organic Matter (OM) /Ash (ASH) Contents

The methodology is in section 4.2.2 Determination of Organic Matter (OM) /Ash (ASH) Contents

The determination of moisture contents was omitted from these analyses due to time constraints

Methods for Chemical Analyses

5.2.4 Determination of pH

The methodology is in section 4.2.4 Determination of pH

5.2.5 Determination of Electrical conductivity

The methodology is in section 4.2.5 Determination of Electrical conductivity

5.2.6 Determination of Nitrate Nitrogen

The methodology is in section 4.2.6 Determination of Nitrate Nitrogen

5.2.7 Determination of Potassium

The Inductively Coupled Plasma Optical Emission Spectrometry (ICP- OES) was used to analysis the macro and micro nutrient concentrations. The Corning 410 flame photometer was an accurate method for the analysis of potassium, but was time consuming. As the numbers of samples that needed to be analysed increased, the need for a more time efficient analysis was sought.

5.2.7.1 Determination of Macro/Micro Nutrients

Using the ICP-OES many macro and micro nutrients could be analysed at the same time, and therefore several analyses were conducted concomitantly. Analyses of macronutrients - calcium (Ca), magnesium (Mg), potassium (K) and representative micronutrient zinc (Zn) were analysed. Within the filtrate, the concentration of macro and micro nutrients varied, therefore it was often necessary to prepare two different dilutions, a 1/5 dilution and 1/10 dilution.

The extract was defrosted and placed into a 15ml disposable polystyrene tube. The extract was diluted using distilled water to the appropriate concentration and then placed on to an auto- sampler. This procedure was repeated in triplicate for each of the three individual samples, giving nine replicates in total. All error values referred to in this research are 95% confidence limits.

Standards of 1000mg/L were produced, using 0.259g per 100ml potassium nitrate, 1.0138g per 100ml magnesium sulphate $7H_20$, 0.3676g per 100ml calcium chloride dehydrate, 1.1g per 250ml zinc sulphate with 2ml 36%HCL and 0.2877g per 100ml potassium permanganate with 0.4g per 100ml hydroxyl ammonium sulphate. The standards were then diluted to 50 and 20mg/L and were then used to calibrate the instrument and establish the calibration curves.

A peristaltic pump was used to obtain the extract. This was then aspirated *via* a nebuliser and spray/mixing chamber to form fine droplets. Using argon as a carrier gas, the extract was fed into the plasma. The extract is vaporised and atomised. The excess energy produced from the atoms, is emitted as photons. The photons are of wavelengths characteristic of the atom and proportional to the number of atoms present. Within the extracts, standards were placed for the purpose of quality control. The ICP-OES generates a report, which contains the concentration of the elements and any other specifications that were needed (Boss & Fredeen, 1997; Ceram, 2006).

5.2.8 Determination of Phosphorus

The methodology is in section 4.2.8 Determination of Phosphorus

5.3 Results

Main Findings

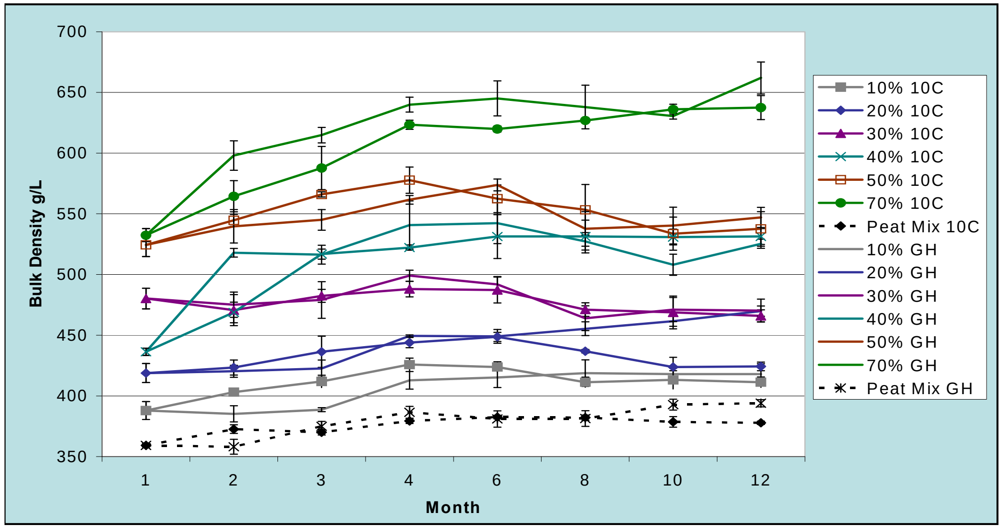
Physical Analyses

From the average bulk density values obtained from the twelve month trial, there is a distinct correlation between the percentage of composted green material and the bulk density. As the percentage of composted green material increase, the bulk density of the mixtures also increases (Figure 5.3.2). This correlation was more prominent in mixtures containing Samples 4 and 10, showing higher R^2 values, Figure 5.3.2 and Table 5.3.1.

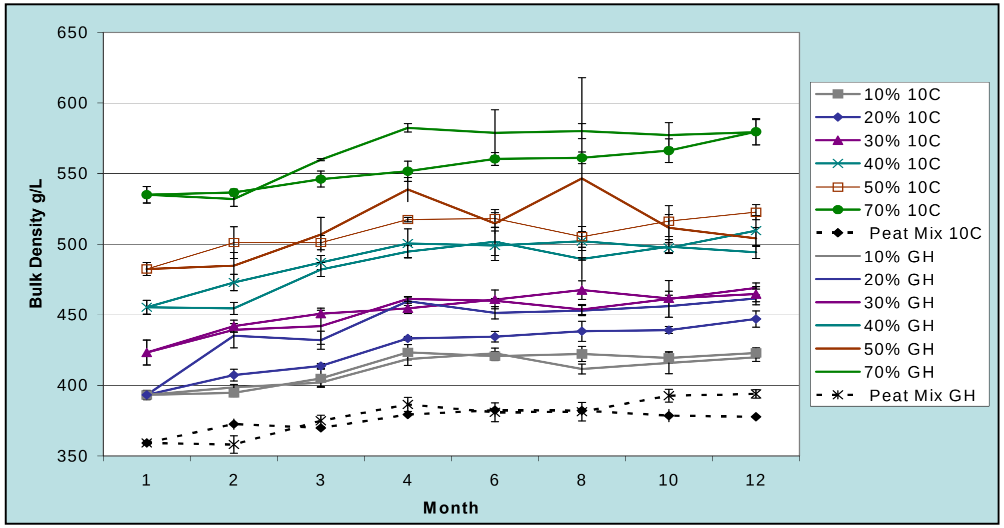
The bulk density of mixture containing Samples 4 and 10 were fairly constant over the twelve month storage trial as shown in Figure 5.3.1. The bulk density values for mixtures containing Sample 5 rose initially and then stabilised at a value of 461.63g/L (+/- 10.68). Compared to mixture containing Sample 11 where the bulk density values continued to rise throughout the duration of the study. The mix containing 50% of Sample 11 stored under glasshouse conditions had an initial bulk density of 356.6g/L (+/- 2.7 g/L), which rose to 460.1 g/L (+/- 1.1 g/L). This indicates that this sample of composted green material may not have fully matured and therefore was not as stable as the other samples.

The all peat mix had the lowest bulk density value and this remained constant throughout the twelve month trial.

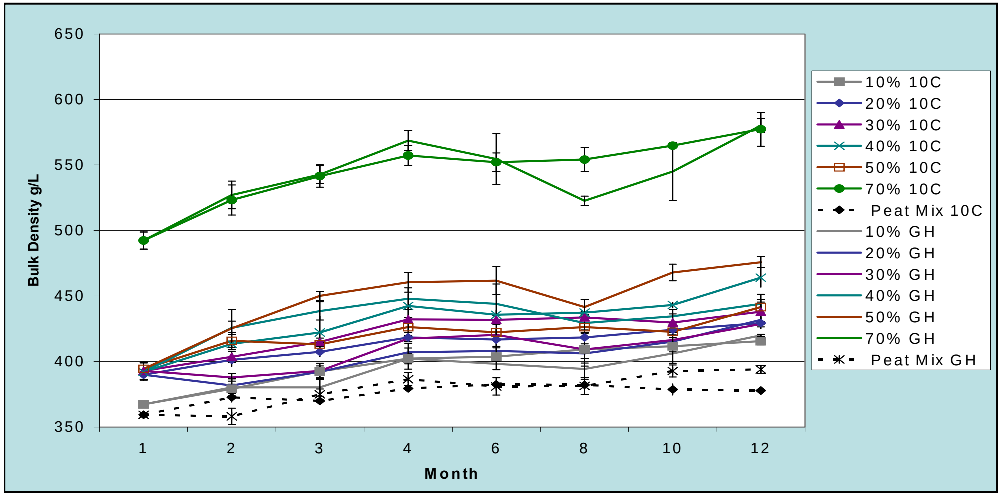
Sample 4



Sample 10



Sample 5



Sample 11

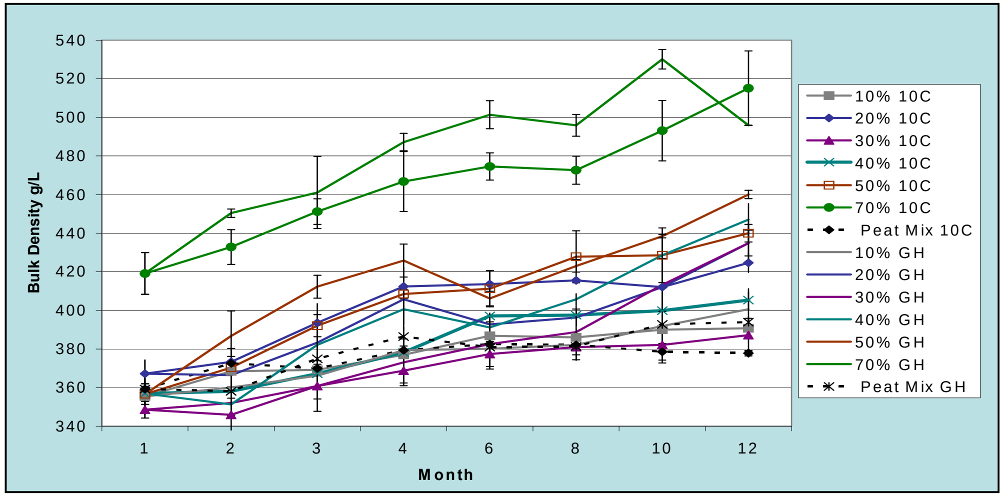


Figure 5.3.1: Bulk density values for the peat reduced growth/storage trial. The 95% confidence limits are indicated by error bars.

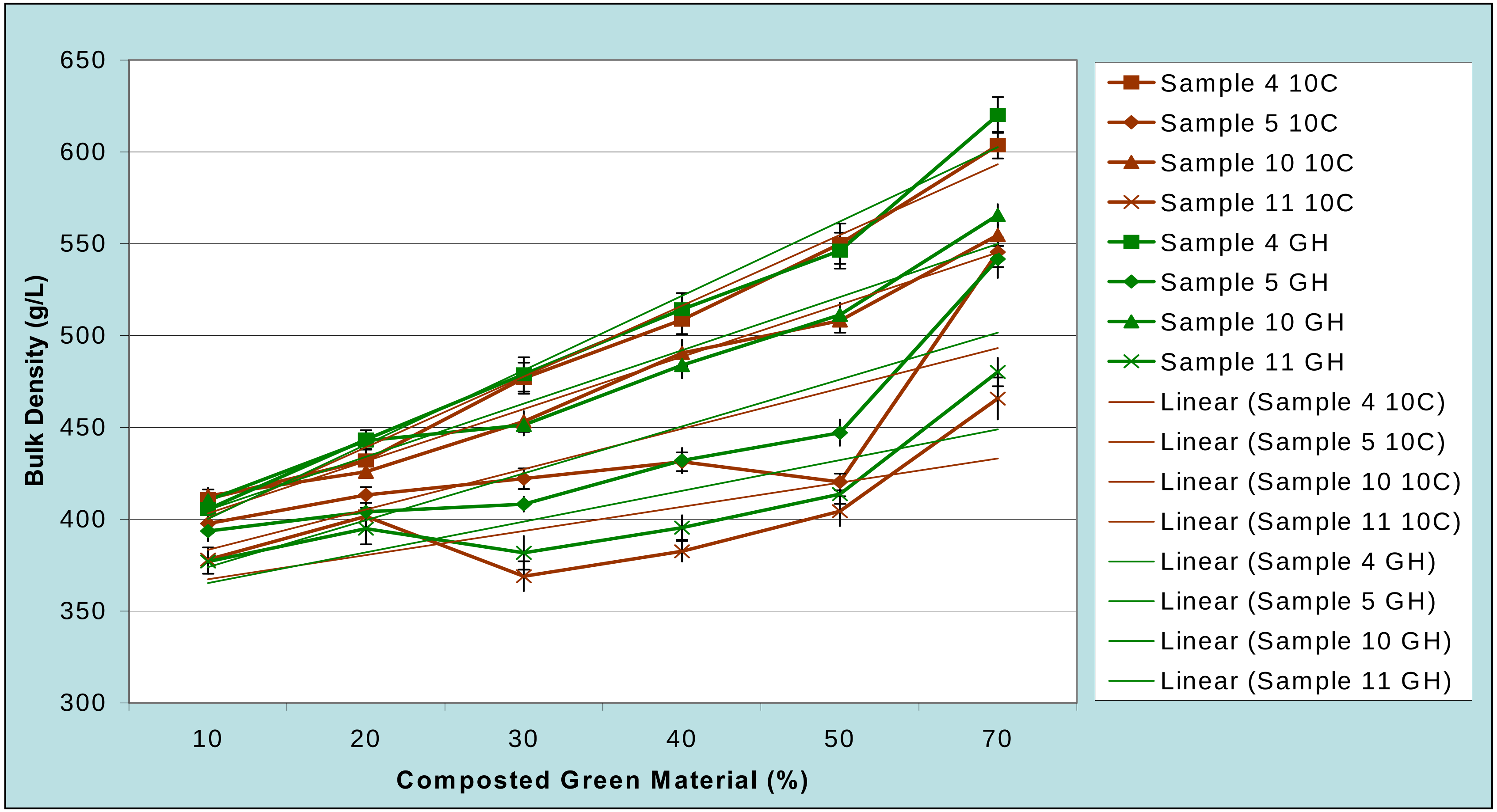


Figure 5.3.2: The relationship between bulk density and the proportions of composted green material. The 95% confidence limits are indicated by error bars.

Organic matter contents (< 2mm) and (>2mm) had very similar negative correlations i.e. as the percentage of composted green material increased, the organic matter content decreased, Figures 5.3.4 and 5.3.6. This trend occurred within all the peat-reduced mixtures. The (>2mm) samples had slightly higher organic contents compared to (<2mm) samples. As the percentage of composted green waste increased, the ash contents increased, Figures 5.3.8 and 5.3.10. Mixtures containing Samples 4, 5 and 10 had similar organic matter and ash contents. Mixtures containing Sample 11 had higher organic matter contents and lower ash contents. The (<2mm) samples had more variation between samples containing lower percentages of composted green material and then converged towards very similar values for higher concentrations of composted green material. For the (>2mm) samples, there was slightly more variation within mixtures, also indicated by the larger 95% confidence limits.

The organic matter and ash contents were fairly constant in both storage conditions throughout the twelve month study, as shown in Figure 5.3.3, 5.3.5, 5.3.7 and 5.3.9.

The all peat mix had similar organic matter contents to the mixtures containing 10% composted green material. The average organic matter content for the all peat mix stored at 10˚C was 82.60% (+/- 1.80%) compared to the 10% mixture of Sample 11 stored at 10˚C having an organic matter content of 77.03% (+/- 1.32%). The all peat mix had lower ash contents compared to the composted green material samples.

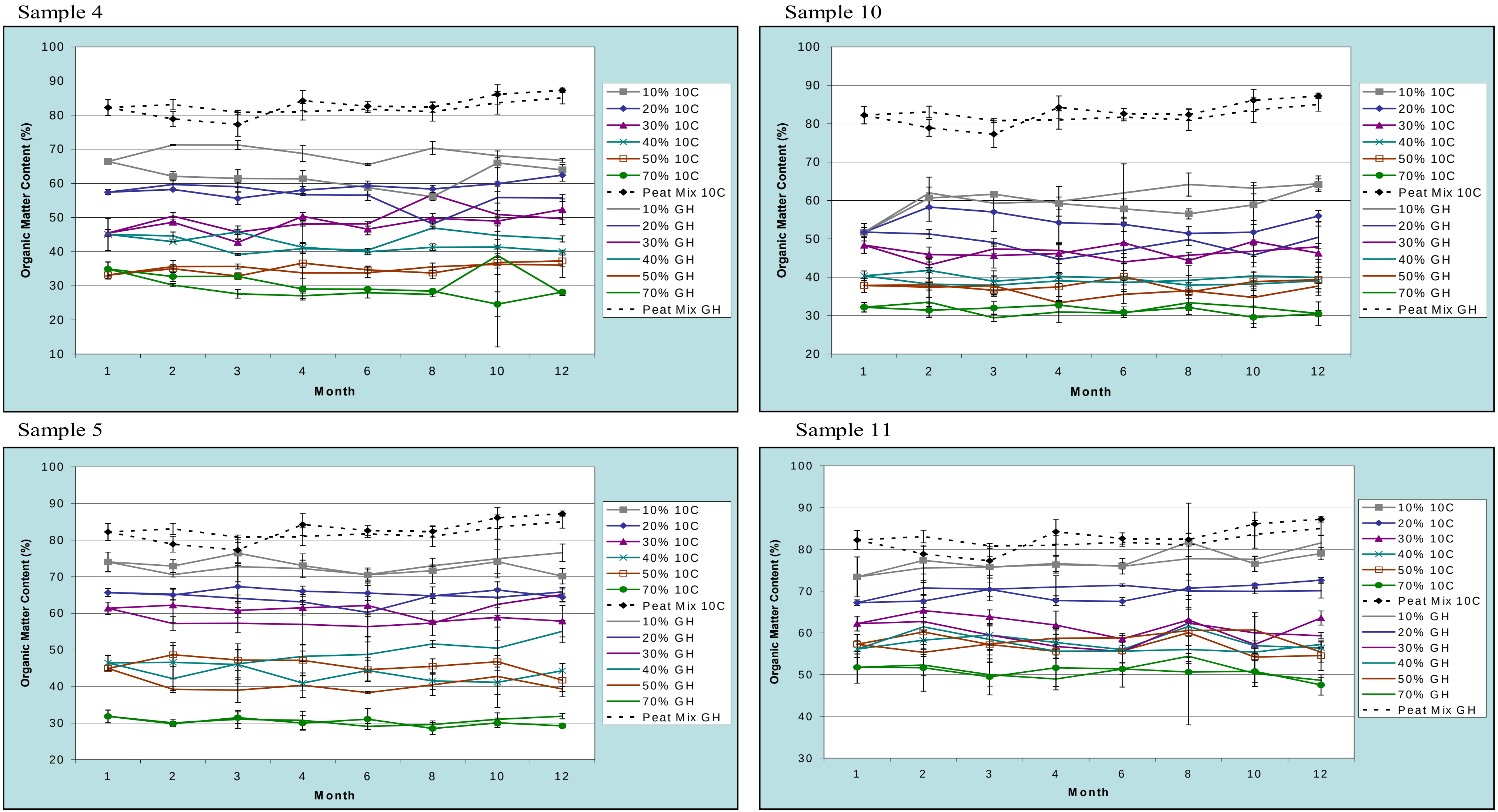


Figure 5.3.3: Organic matter content (<2mm) for the peat reduced growth/storage trial. The 95% confidence limits are indicated by error bars.

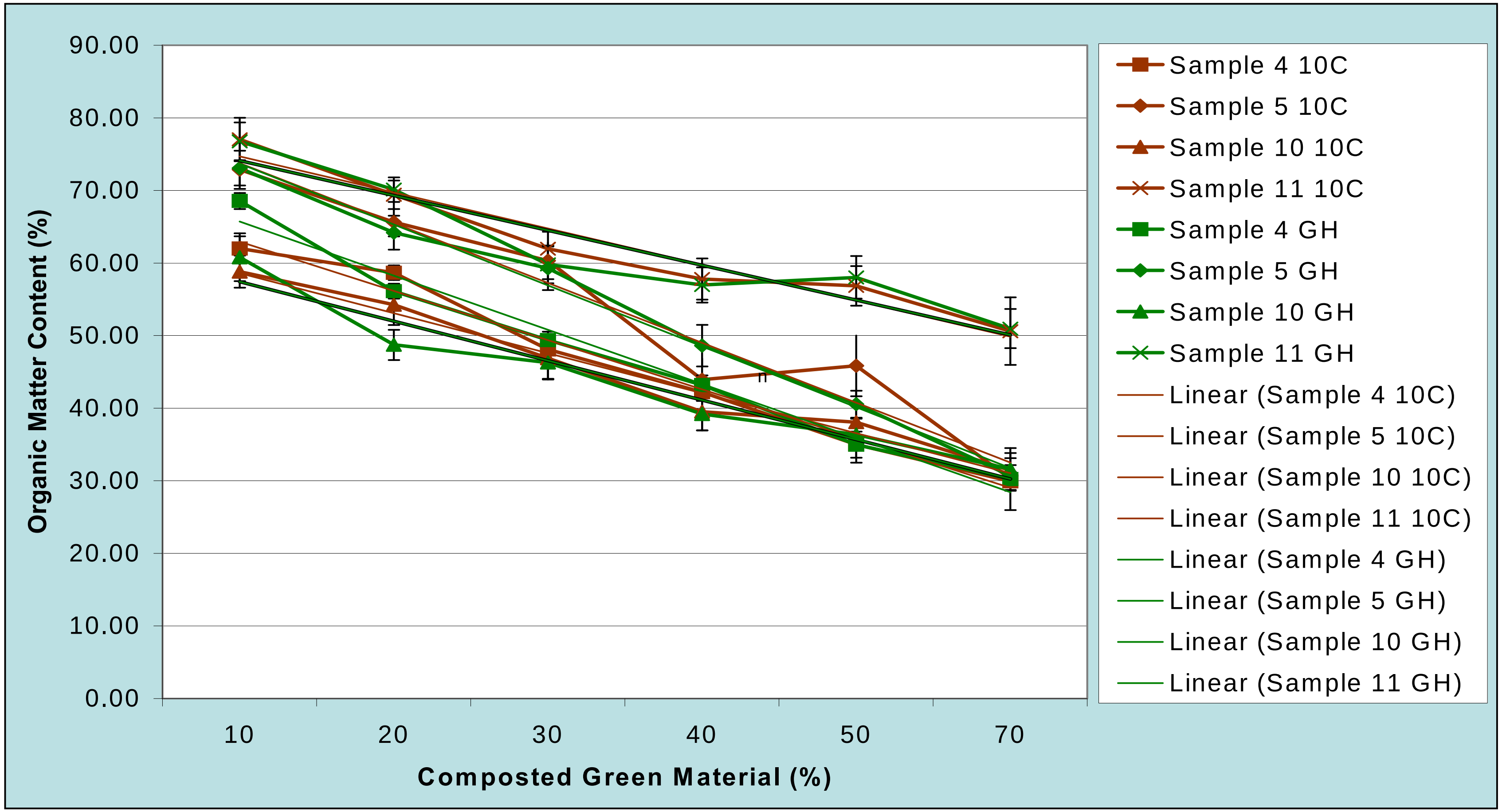


Figure 5.3.4: The relationship between organic matter content (<2mm) and the proportions of composted green material. The 95% confidence limits are indicated by error bars.

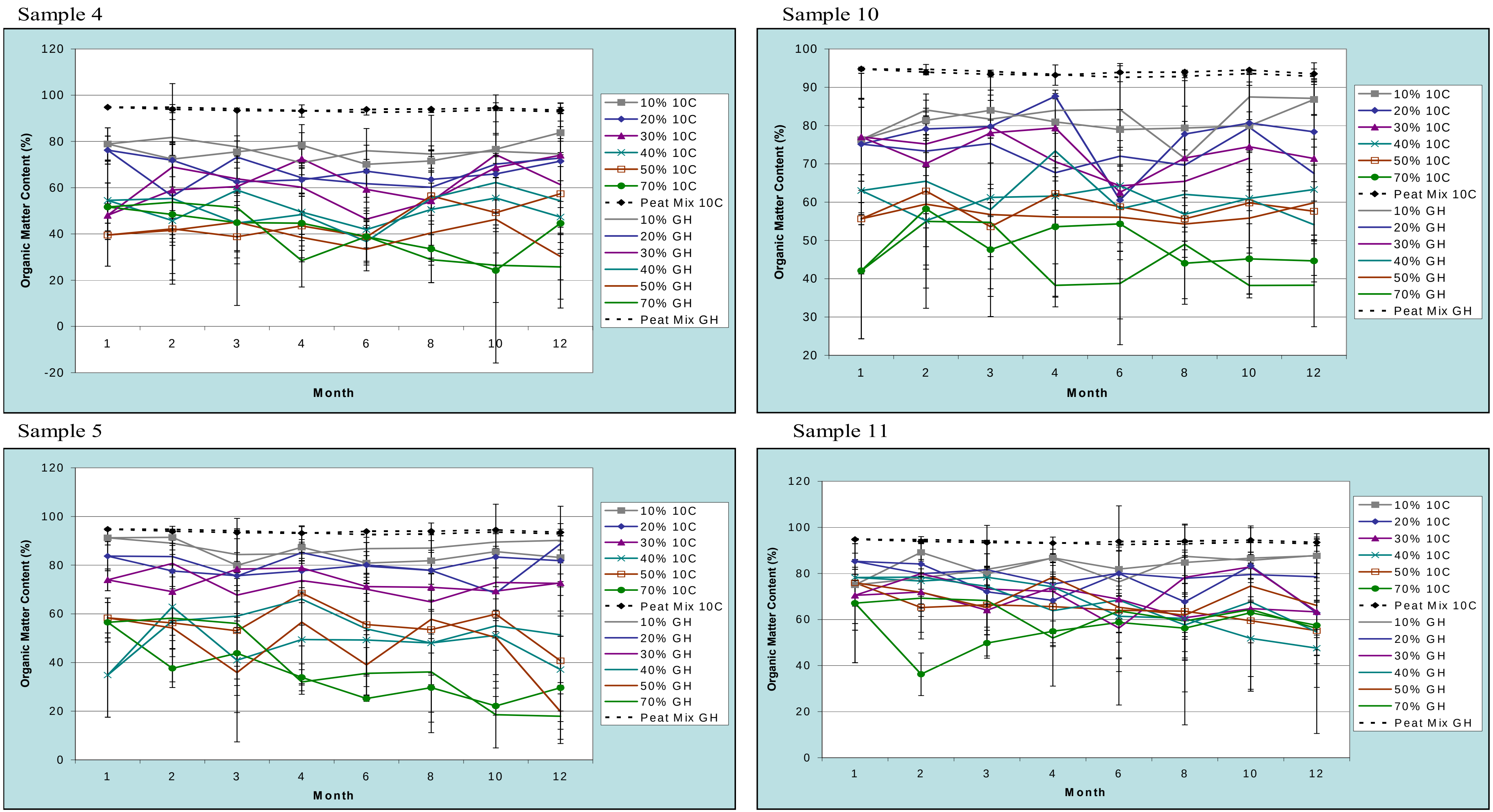


Figure 5.3.5: Organic matter content (>2mm) for the peat reduced growth/storage trial. The 95% confidence limits are indicated by error bars.

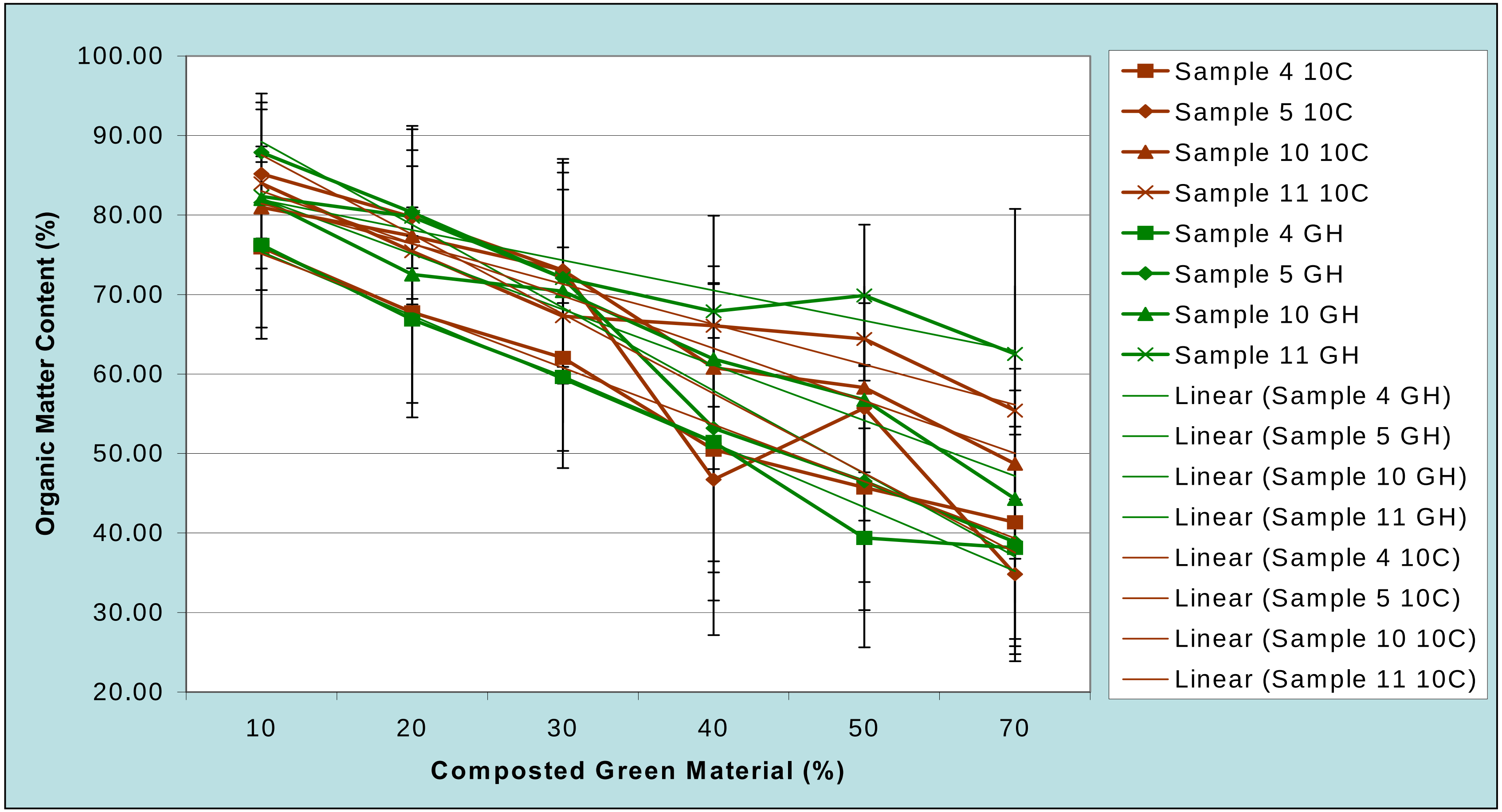
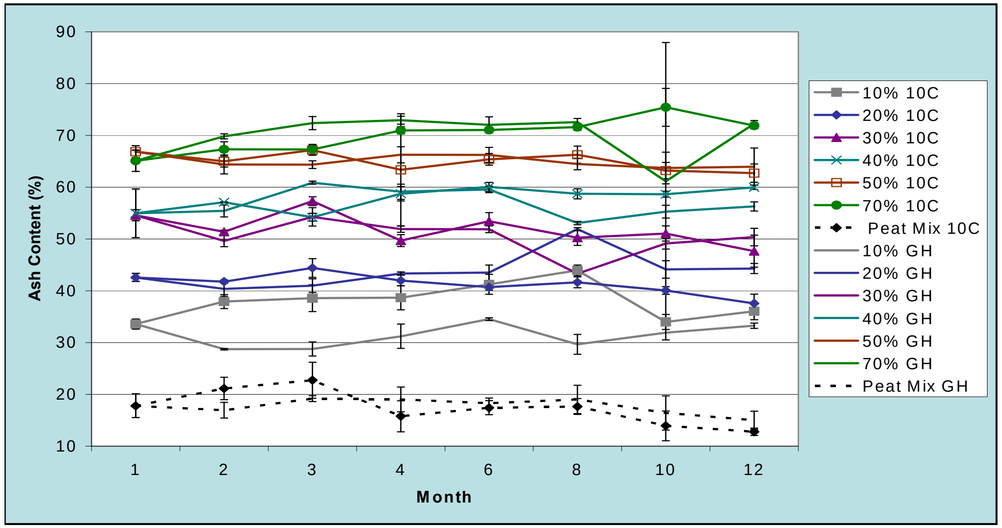
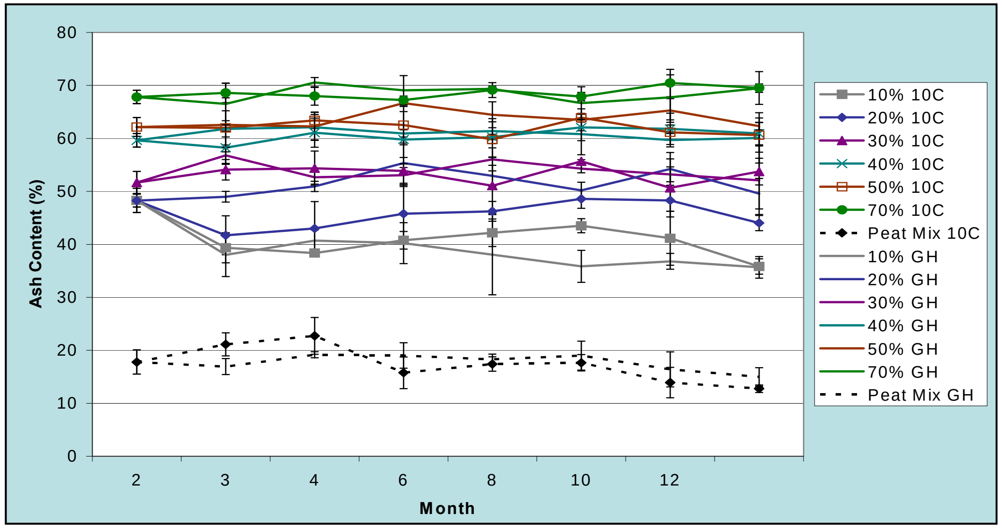


Figure 5.3.6: The relationship between organic matter content (>2mm) and the proportions of composted green material. The 95% confidence limits are indicated by error bars.

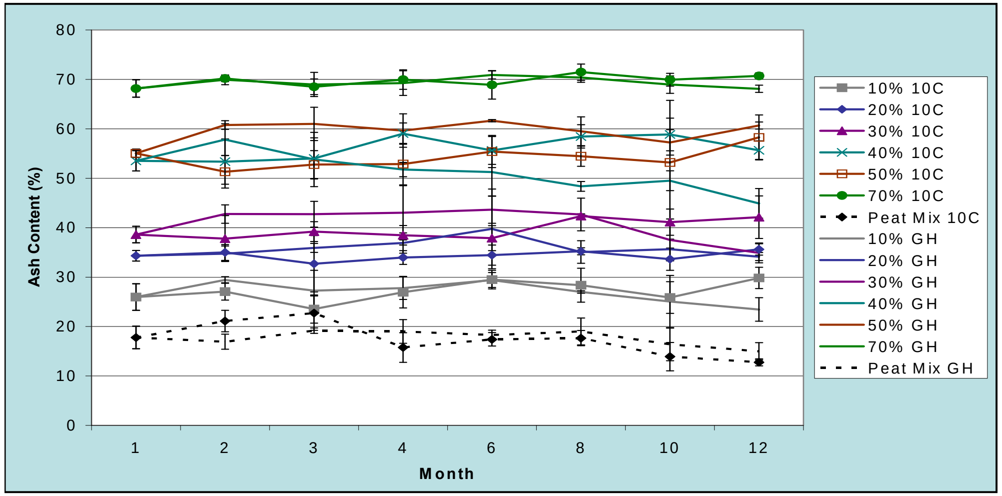
Sample 4



Sample 10



Sample 5



Sample 11

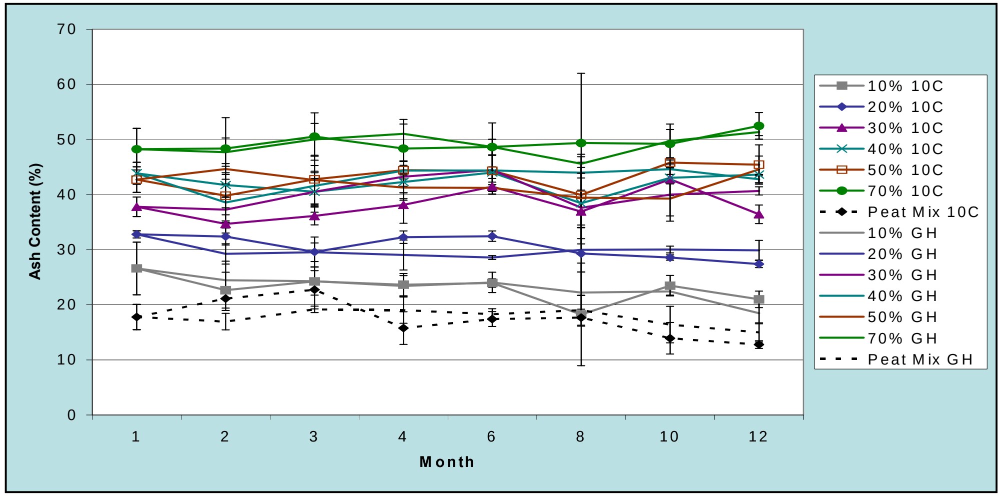


Figure 5.3.7: Ash content (<2mm) for the peat reduced growth/storage trial. The 95% confidence limits are indicated by error bars.

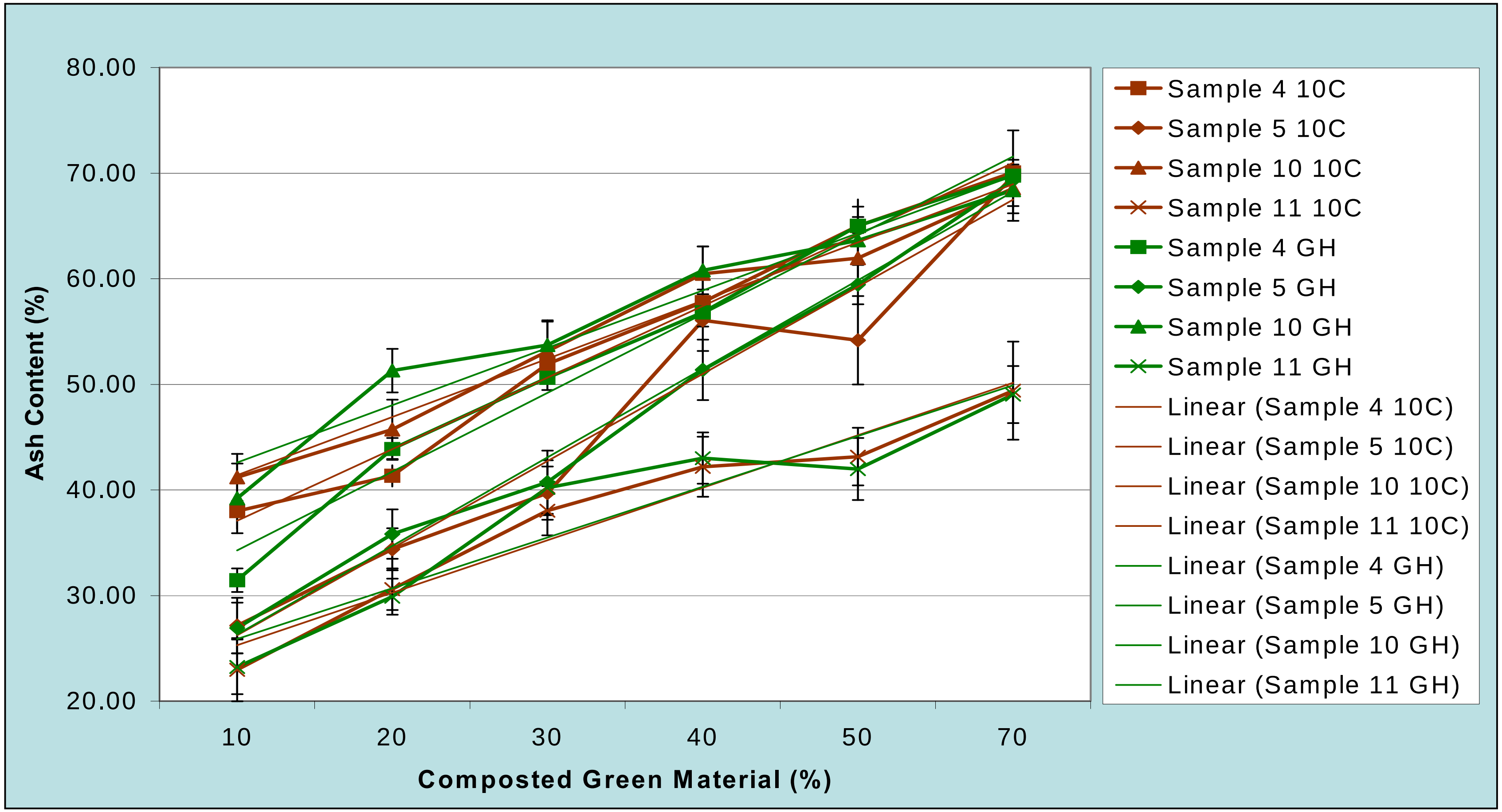
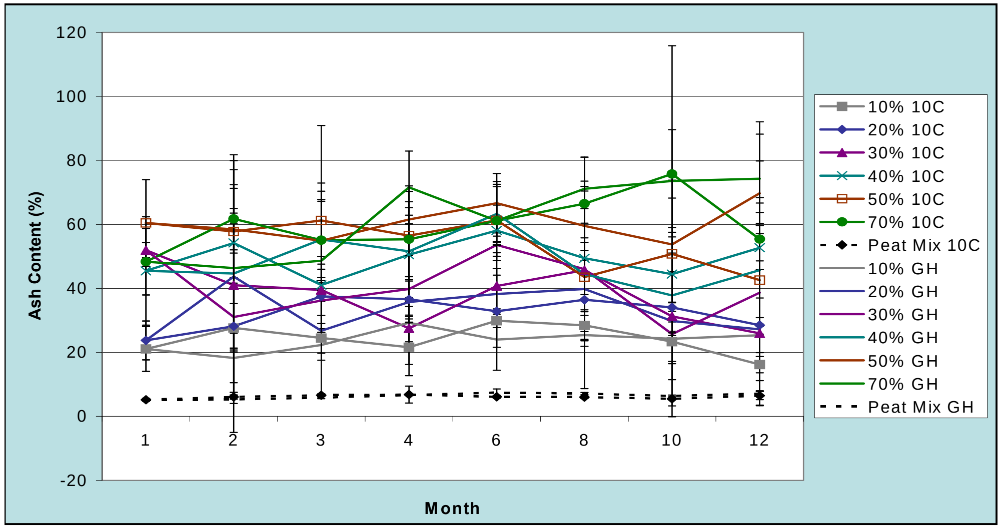
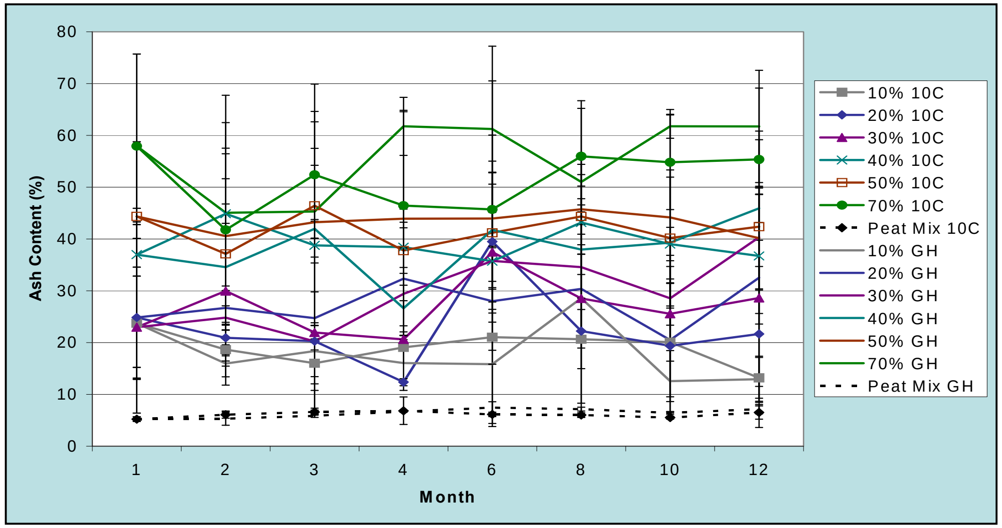


Figure 5.3.8: The relationship between ash content (<2mm) and the proportions of composted green material. The 95% confidence limits are indicated by error bars.

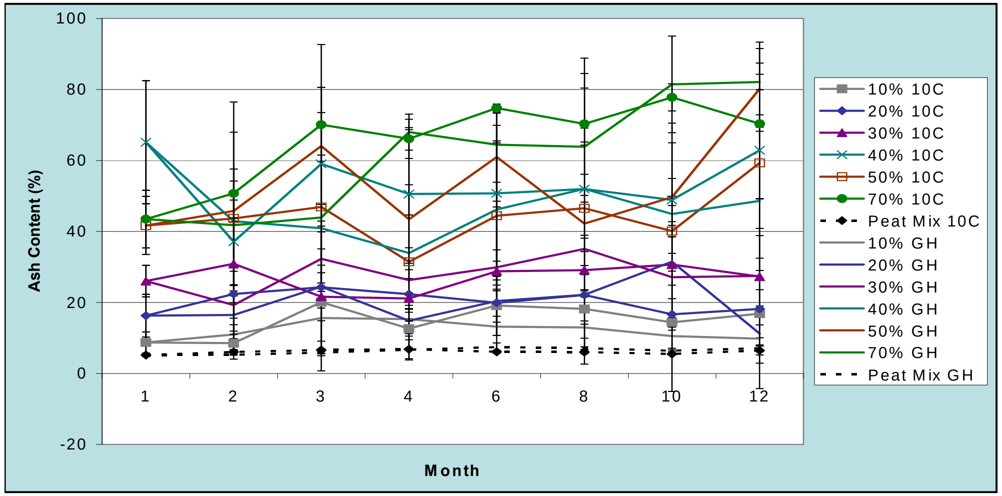
Sample 4



Sample 10



Sample 5



Sample 11

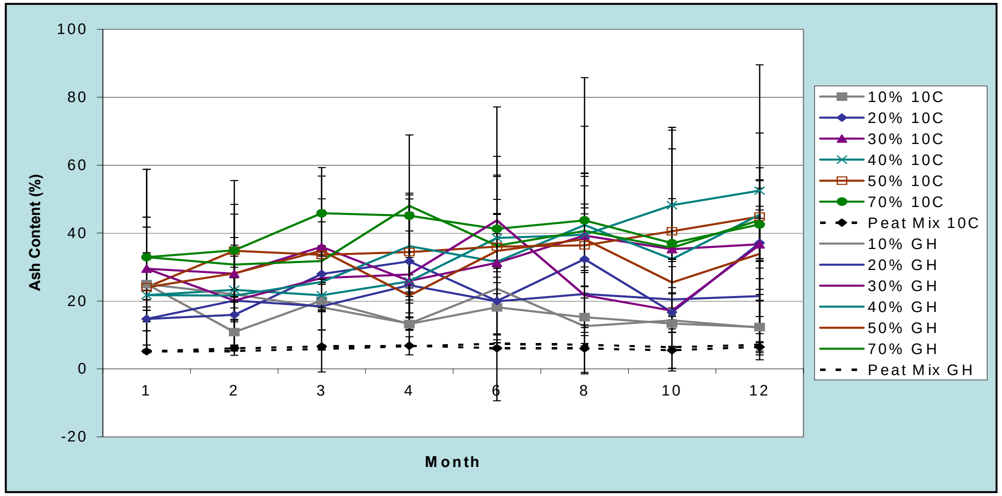


Figure 5.3.9: Ash content (>2mm) for the peat reduced growth/storage trial. The 95% confidence limits are indicated by error bars.

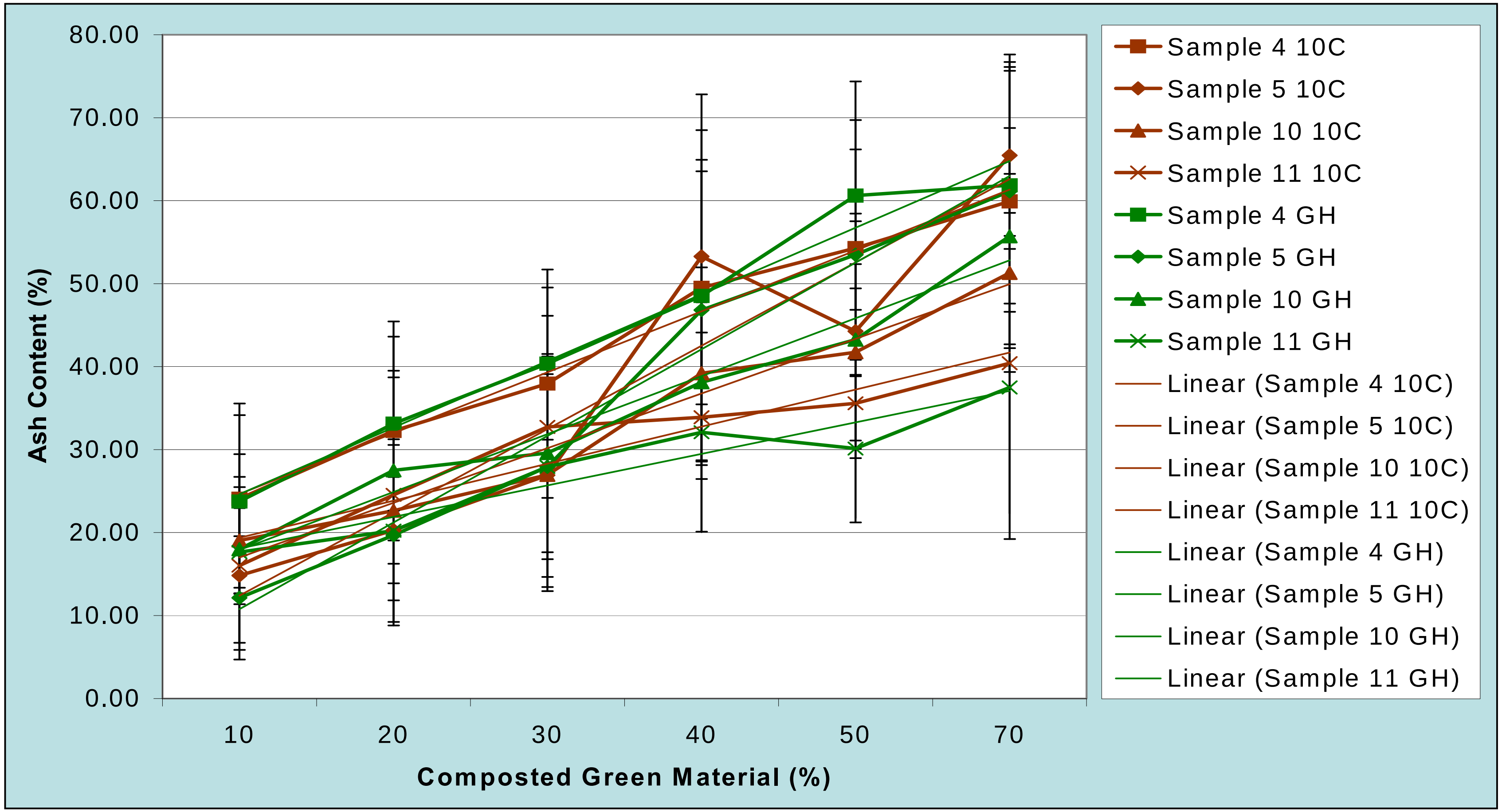
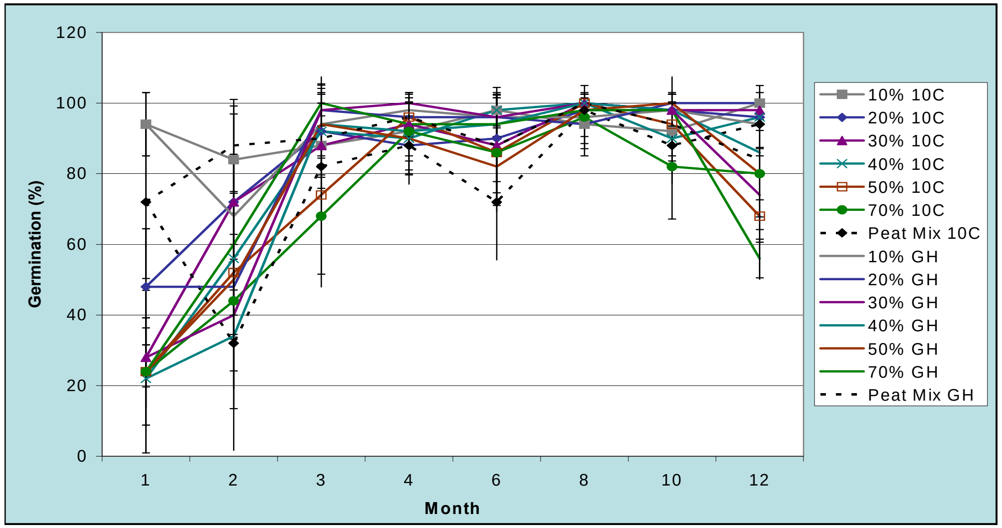


Figure 5.3.10: The relationship between ash content (>2mm) and the proportions of composted green material. The 95% confidence limits are indicated by error bars.

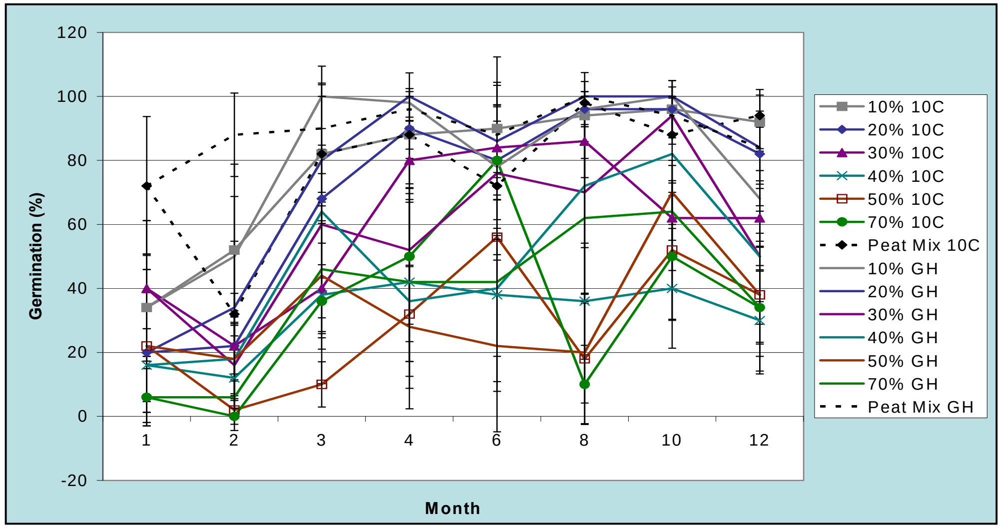
Mixtures containing Samples 4 & 5 had similar high germination counts, with mixture containing Sample 10 having the lowest counts. This pattern was evident in both storage conditions (Figure 5.3.11). Within the mixtures produced using the four samples of composted green material, there was a definite negative correlation: as the percentage of composted green material increased, the germination counts decreased, Figure 5.3.12. Mixtures containing Sample 4, 5 and 11 had variable germination counts for the initial 1-4 Months of the trial, which then stabilised. This pattern occurred within the all peat mix, but not to the same extent. Mixtures containing Sample 10 had variable germination counts throughout.

The all peat mix had variable germination counts between storage conditions. The average germination count for the 10˚C stored mixture was 78.25% (+/- 14.34) compared to 89.00 (+/- 11.39) for the glasshouse. The all peat mix had similar germination counts to the 10-20% mixtures for Samples 4, 5 and11.

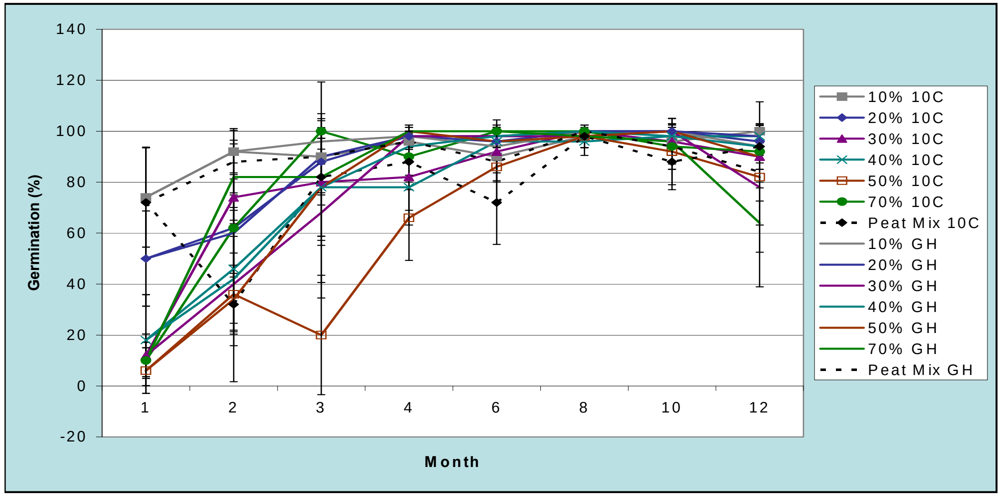
Sample 4



Sample 10



Sample 5



Sample 11

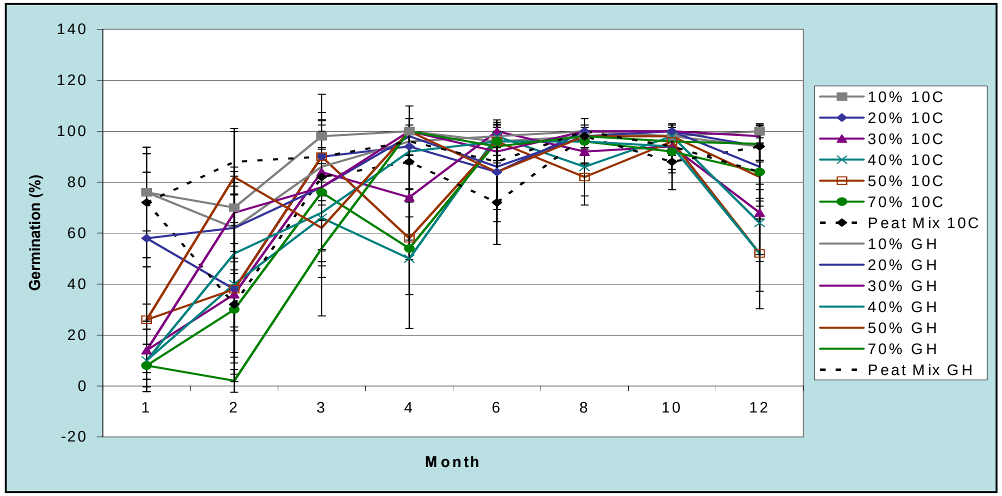


Figure 5.3.11: Lettuce germination values for the peat reduced growth/storage trial. The 95% confidence limits are indicated by error bars.

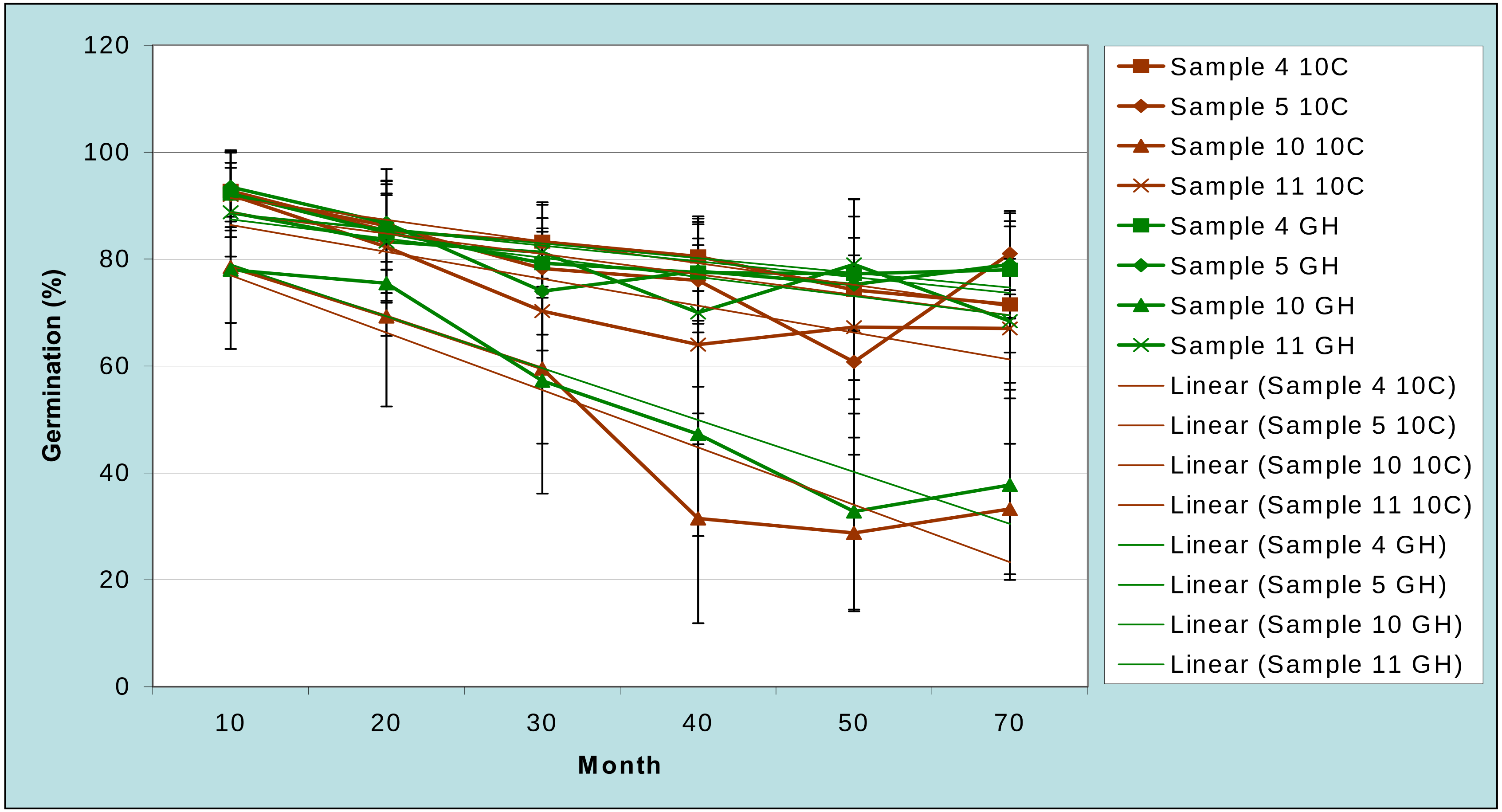


Figure 5.3.12: The relationship between lettuce germination and the proportions of composted green material. The 95% confidence limits are indicated by error bars.

From the analysis in Figure 5.3.13 and 5.3.14, there was no obvious trend in the average mass of tomatoes produced. From Figure 5.3.13, mixtures containing Sample 10 produced the largest mass compared to the other mixtures containing composted green material samples. Mixtures containing Sample 11 had the lowest mass of fresh weights. For all mixtures, there is a dip in Month 4. This is probably due to an external factor; possibly drying out over a hot weekend. The all peat mix (10˚C and glasshouse stored) produced the largest mass ranging from 8.653 g (+/- 0.96g) – 21.482g (+/- 1.25g). As shown there is a large range of results, indicating there may be other parameters affecting the mass of fresh weights produced.

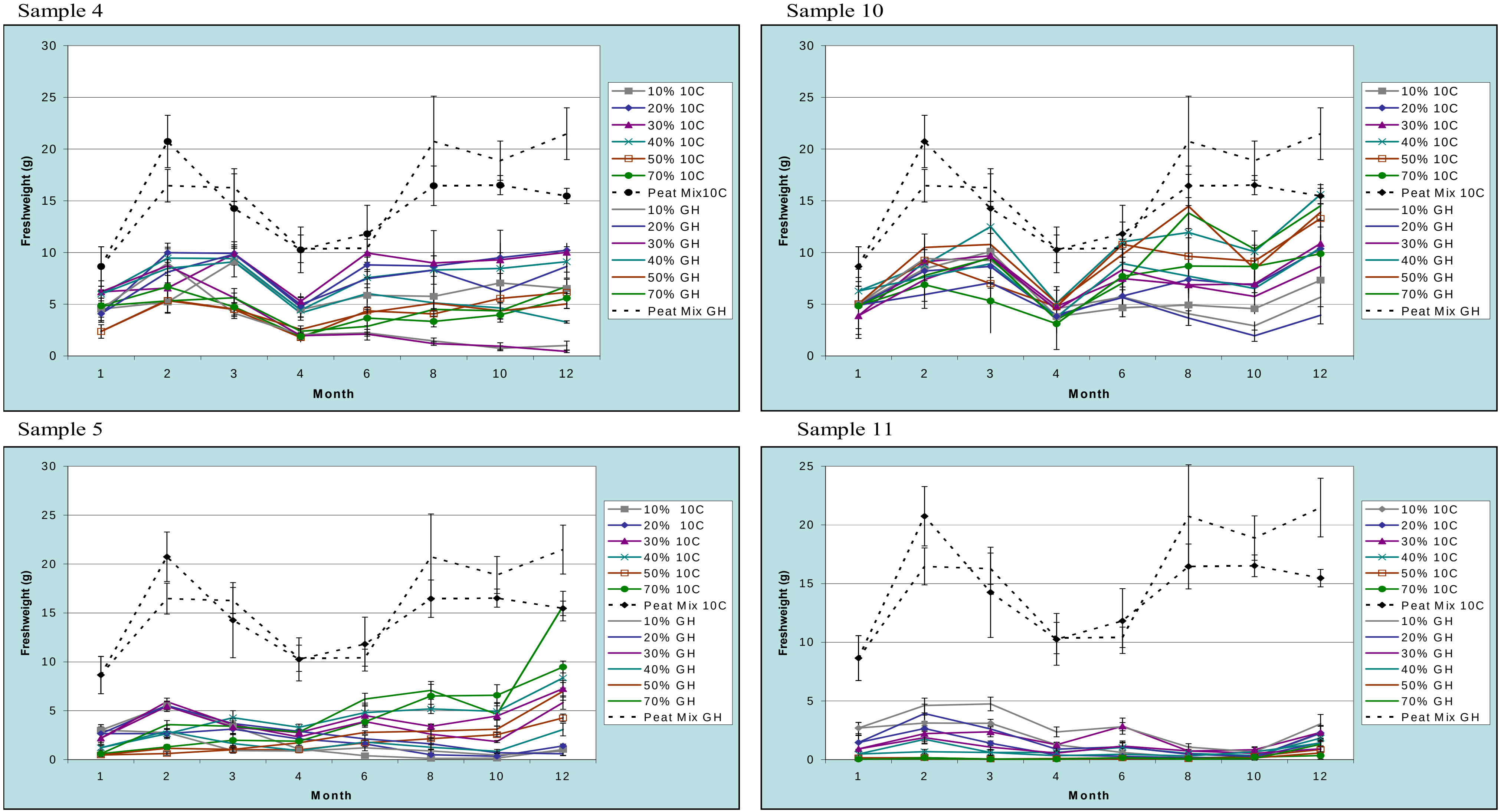


Figure 5.3.13: Fresh weight values (tomatoes) for the peat reduced growth/storage trial. The 95% confidence limits are indicated by error bars.

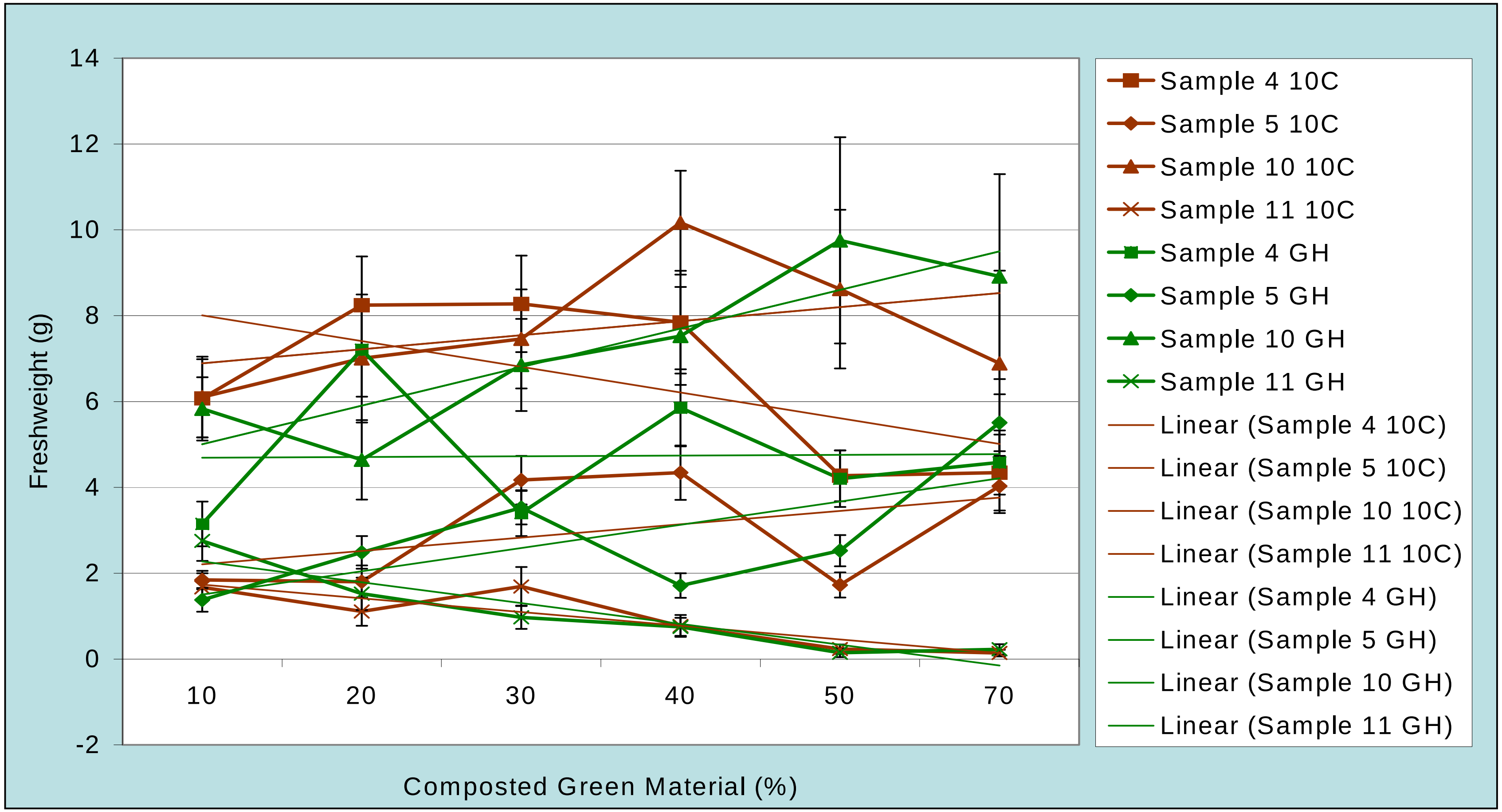


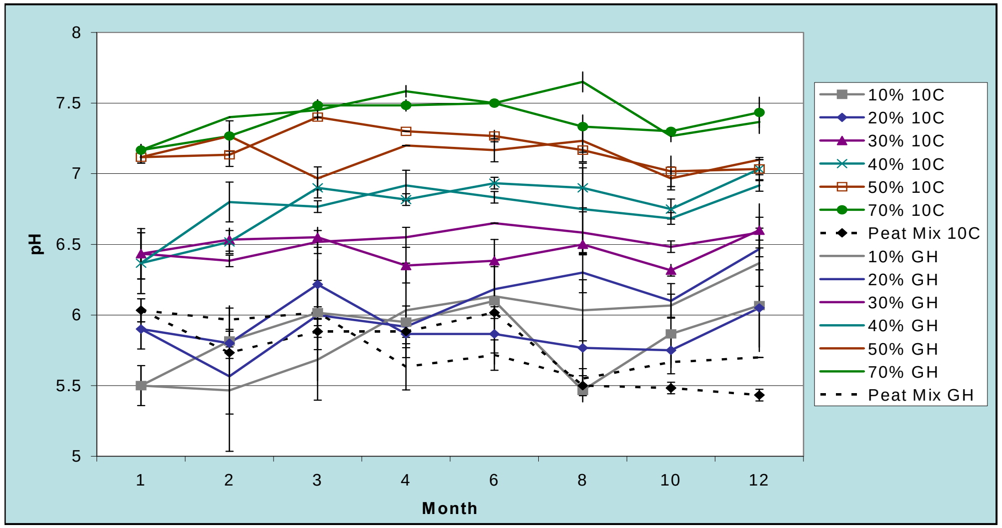
Figure 5.3.14: The relationship between fresh weight (tomatoes) and the proportions of composted green material. The 95% confidence limits are indicated by error bars.

Chemical Analyses

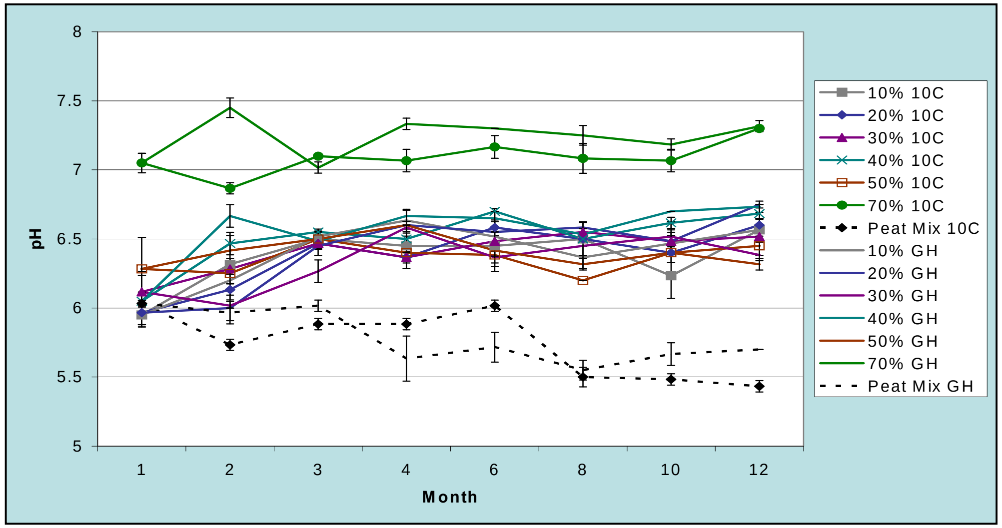
The pH values for each mix were fairly constant over the twelve month storage trial; for example mixtures containing Sample 4 had a range of pH values from 5.50 (+/- 0.07) – 6.10 (+/- 0.07), Figure 5.3.15. There is a correlation between the pH values and the proportions of composted green material. As the percentage of composted green material increased, the pH of the mixtures also increased, Figures 5.3.16. However there were variations between the samples.

The pH values from the all peat mix were constant throughout the storage trial.

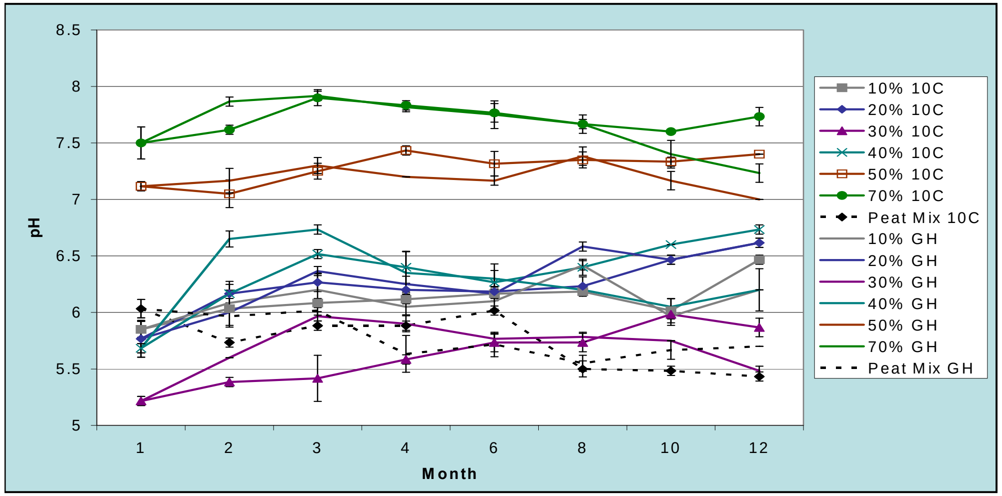
Sample 4



Sample 10



Sample 5



Sample 11

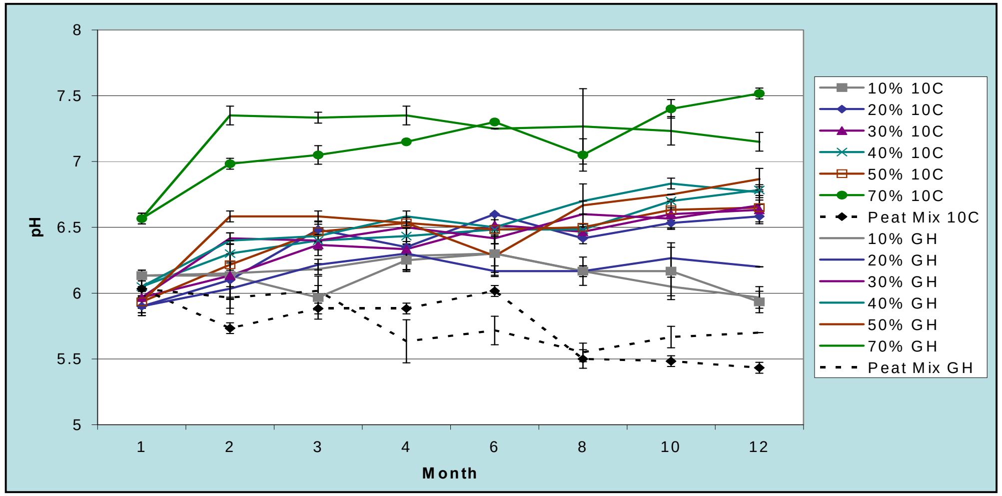


Figure 5.3.15: pH values for the peat reduced growth/storage trial. The 95% confidence limits are indicated by error bars.

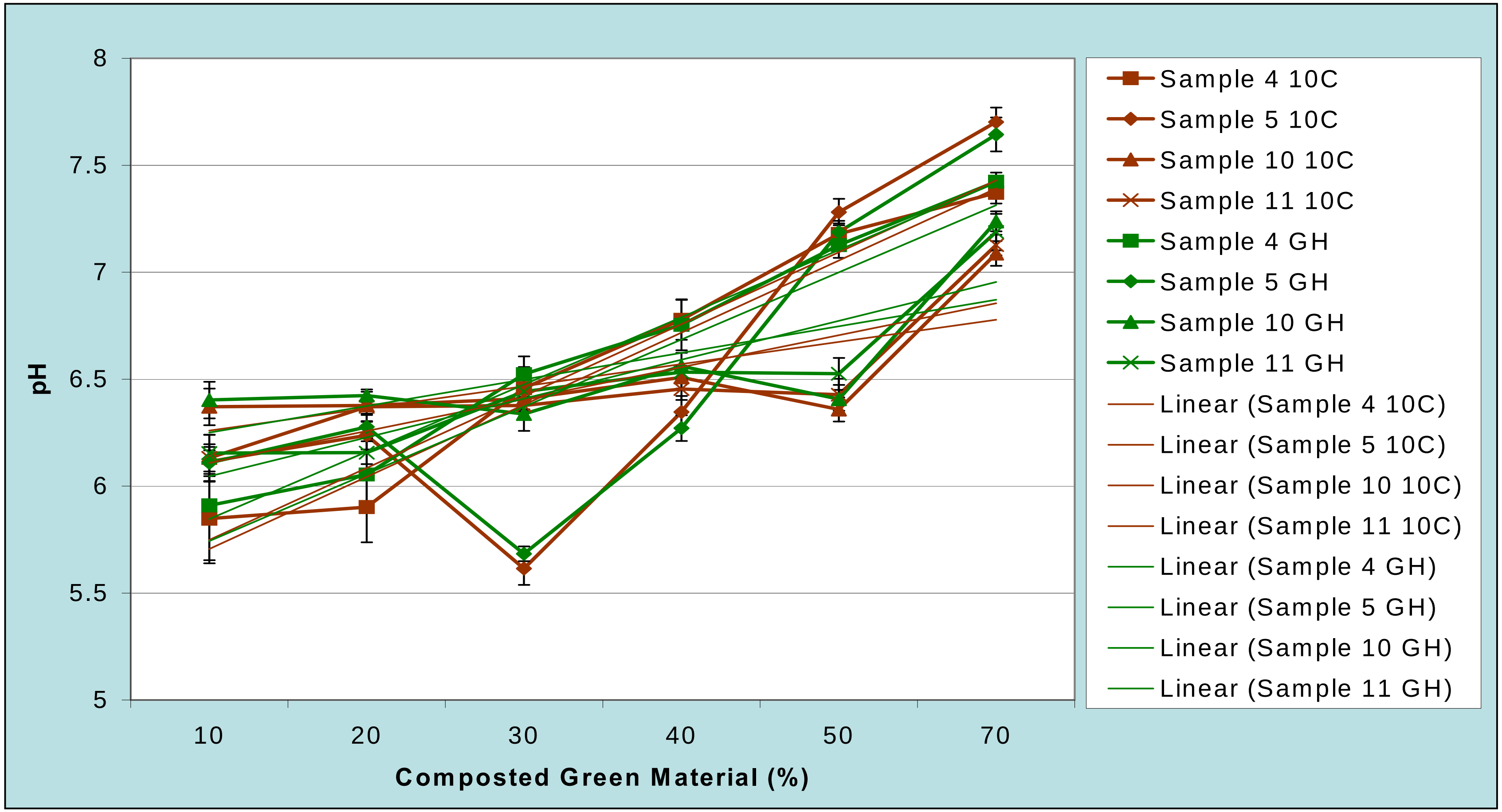


Figure 5.3.16: The relationship between pH and the proportions of composted green material. The 95% confidence limits are indicated by error bars.

Figure 5.3.17 and 5.3.18 contain the trends within the electrical conductivity values. As the percentage of composted green waste increased, the electrical conductivity increased. The trend is the same for mixtures containing Samples 4, 5, 10 and 11. As shown in the mixture containing 10% of Sample 5 stored at 10˚C had an initial electrical conductivity of 230µmhos (+/- 3.1µmhos) which increased to 760µmhos (+/- 25.3µmhos) for the mixture containing 70% of Sample 5. Mixtures containing Sample 11 had the lowest electrical conductivity values recorded as shown on Figure 5.3.17. Mixtures containing Sample 4 and 10 had similar high electrical conductivity values. Within the mixtures containing higher percentages of Sample 4 and 10 i.e. 40-70% mixtures, the electrical conductivity values were equal to and above the all peat mix for both storage conditions.

The electrical conductivity values for the all peat mix stored at 10˚C and glasshouse conditions varied over the twelve month trial. The all peat mix stored at 10˚C had an average of 728.8µmhos (+/- 15.8µmhos) compared to the all peat mix stored under glasshouse conditions having an average electrical conductivity of 942.9µmhos.

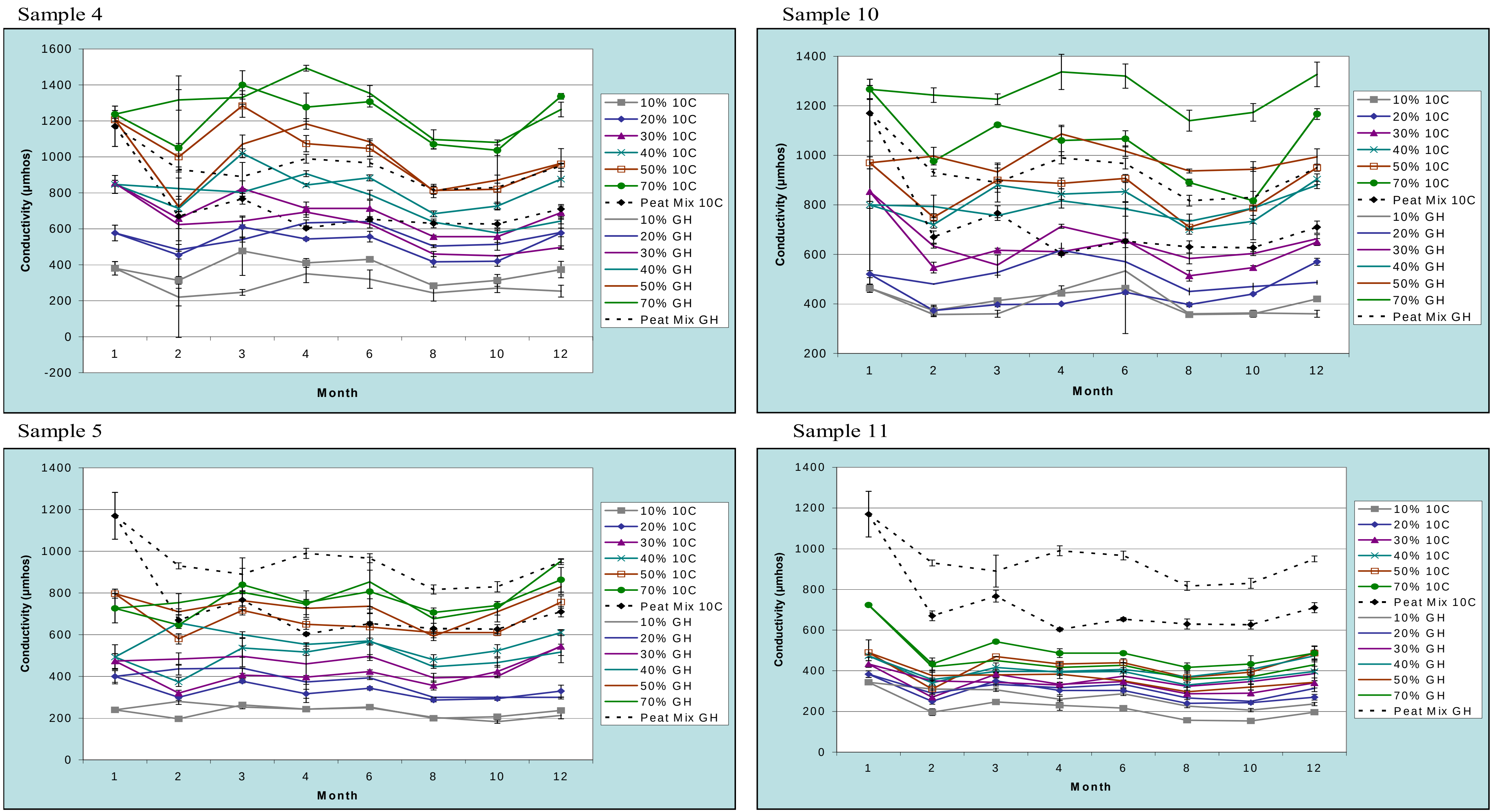


Figure 5.3.17: Electrical conductivity values for the peat reduced growth/storage trial. The 95% confidence limits are indicated by error bars.

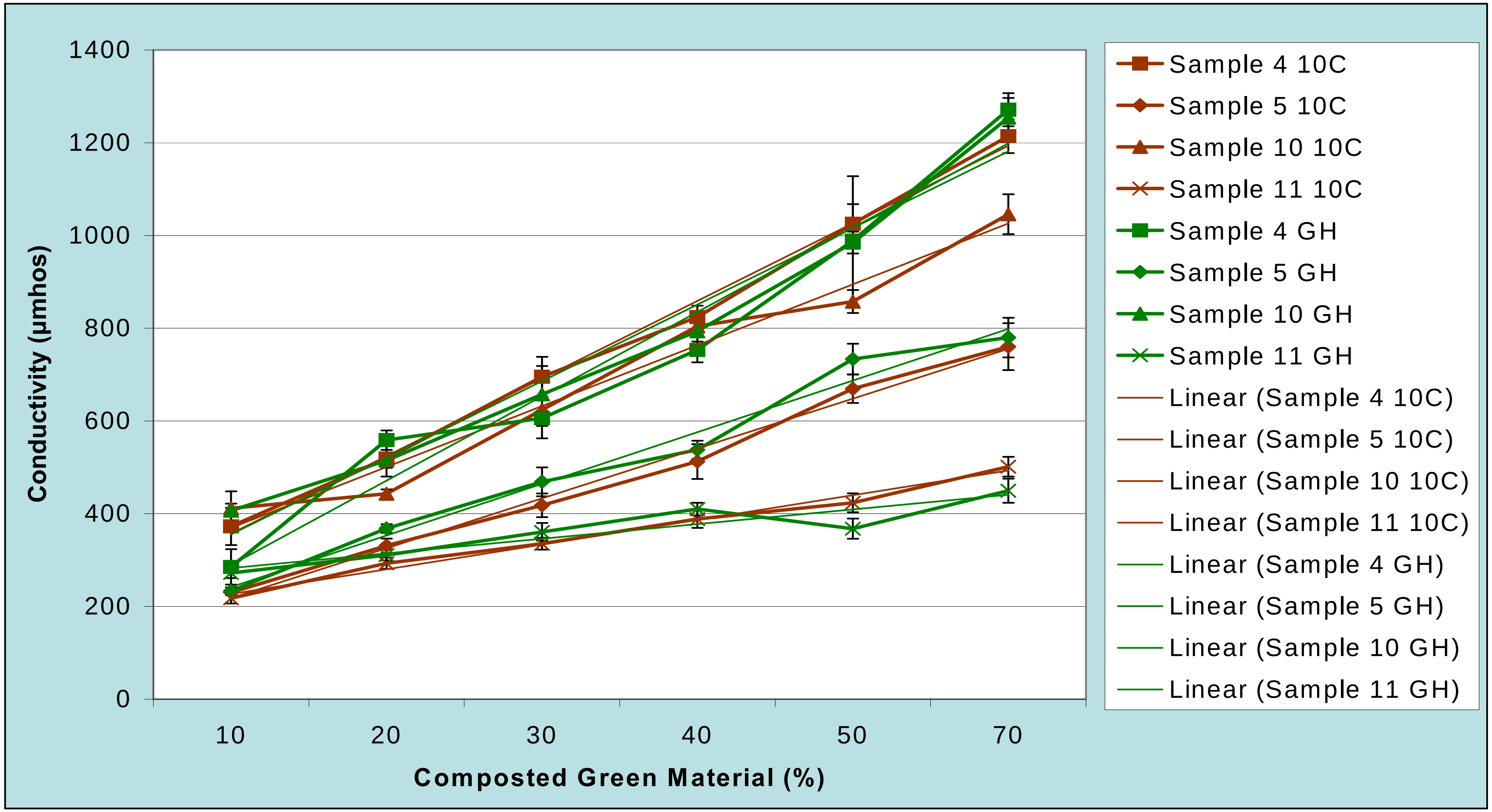


Figure 5.3.18: The relationship between electrical conductivity and the proportions of composted green material. The 95% confidence limits are indicated by error bars.

There was no obvious trend in the nitrate concentration from Figure 5.3.20. There are both negative and positive correlations in the relationship between the proportion of composted green material and nitrate concentration.

By observing Figure 5.3.19, mixtures containing Sample 4 varied over the twelve month storage and growth study; the mixtures stored at 10˚C had fairly constant nitrate concentrations. By contrast the mixtures stored under glasshouse conditions varied. There was no consistency between the mixtures.

Mixtures containing Samples 5 and 10, for both the 10˚C and glasshouse storage conditions showed trends of increasing nitrate concentrations over the twelve month trial, in the mixtures containing larger percentages of composted green waste i.e. 30-70%. For example the mixtures containing 70% of sample 5 stored at 10˚C had an initial nitrate concentration of 29.00mg/L (+/- 2.81mg/L) in month one rising to 930.00mg/L (+/- 24.75mg/L) in the twelfth month.

By contrast, mixtures containing Sample 11 had very low nitrate concentrations throughout; at 10˚C mixtures containing Sample 11 had negligible amounts, within the glasshouse stored mixtures there were slightly higher concentration.

The all peat mix appeared to vary a little in storage. The all peat mix stored at 10˚C had an initial high concentration. This then fell in Month two and then increased gradually. By contrast, the mixtures stored under glasshouse conditions had an initial high concentration and steadily increased throughout the twelve month trial.

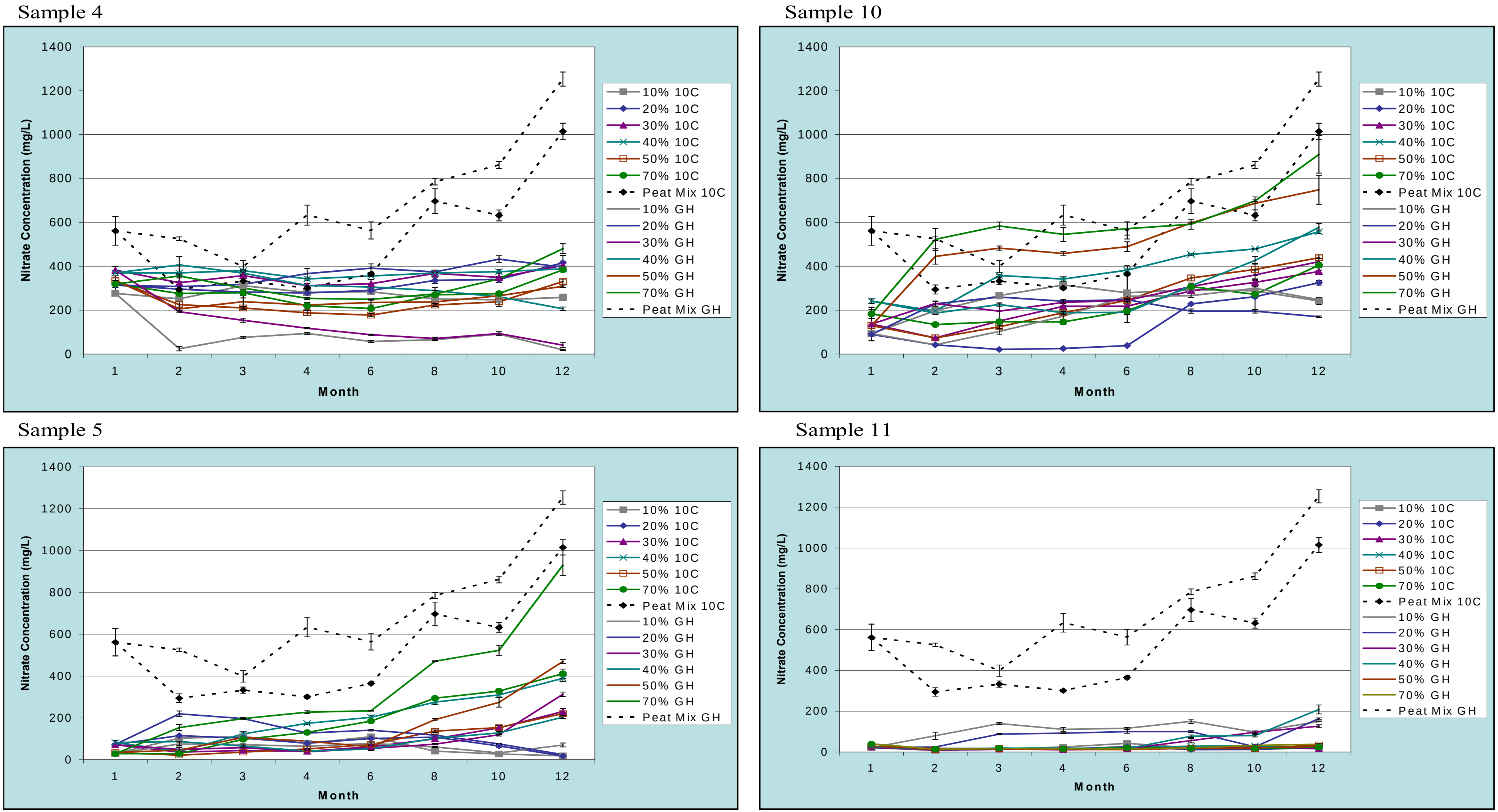


Figure 5.3.19: Nitrate concentration for the peat reduced growth/storage trial. The 95% confidence limits are indicated by error bars.

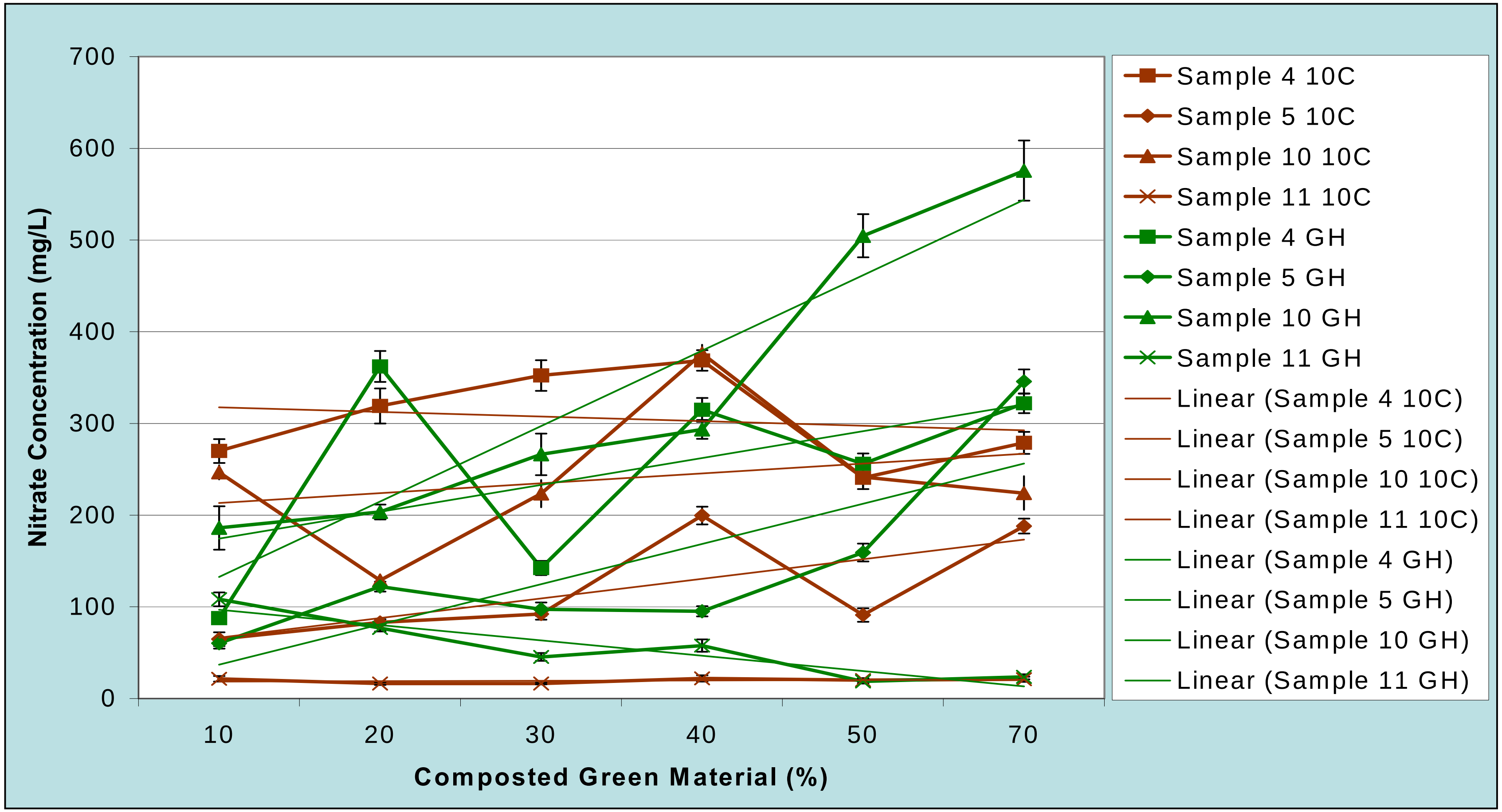
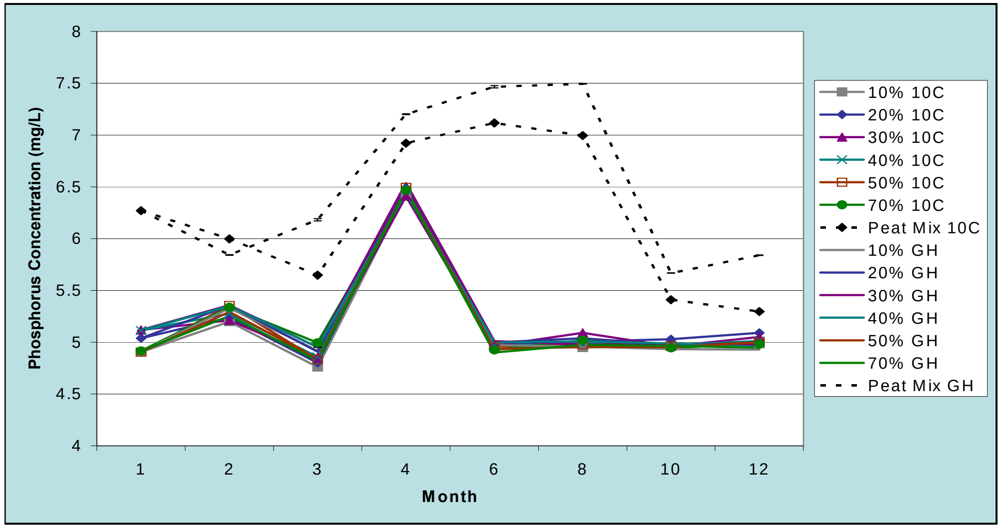


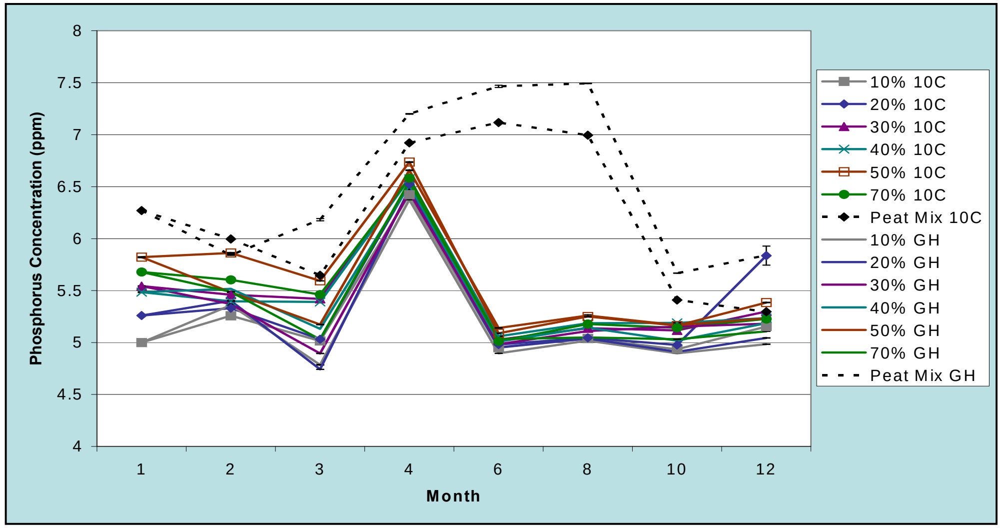
Figure 5.3.20: The relationship between nitrate concentration and the proportions of composted green material. The 95% confidence limits are indicated by error bars.

Figures 5.3.21 and 5.3.22 indicate low concentration of phosphorus within the peat-reduced mixtures; however the values are all very similar. This indicates human error within the analysis. Unfortunately these results cannot be treated as reliable.

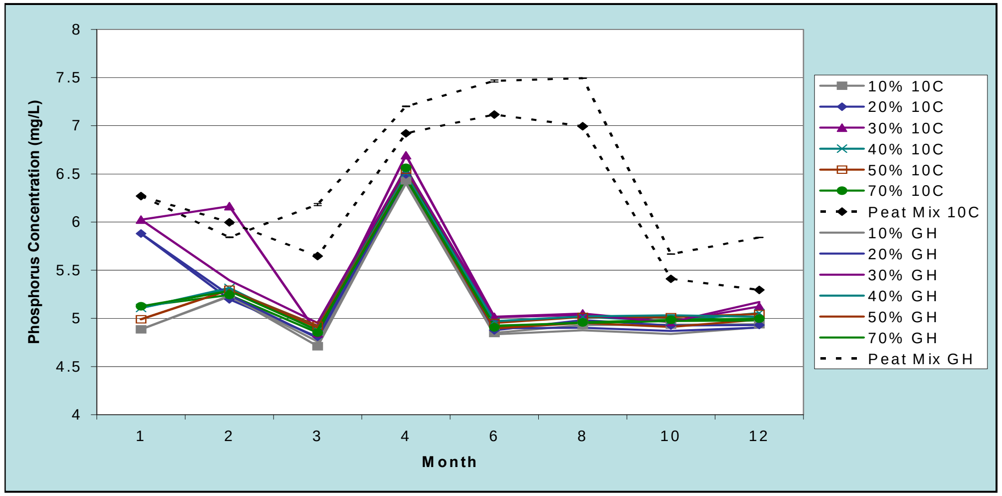
Sample 4



Sample 10



Sample 5



Sample 11

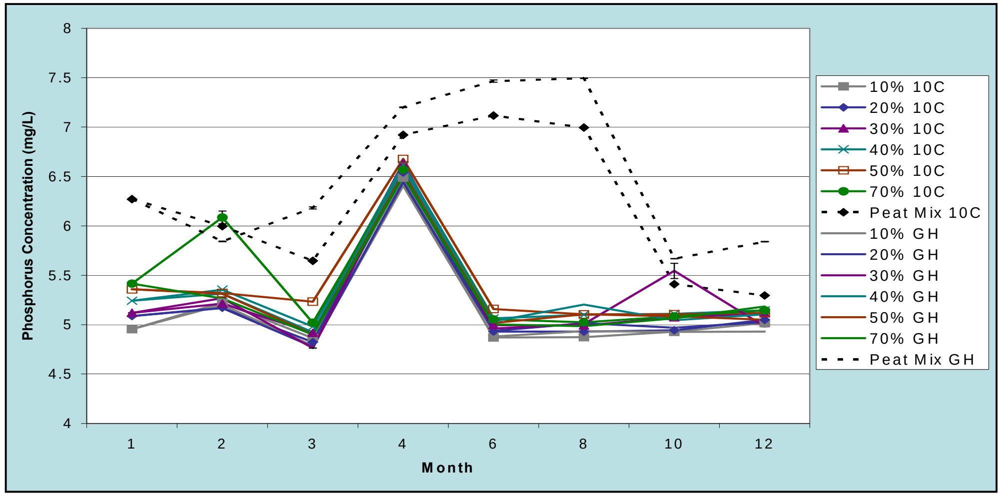


Figure 5.3.21: Phosphorus concentration for the peat reduced growth/storage trial. The 95% confidence limits are indicated by error bars.

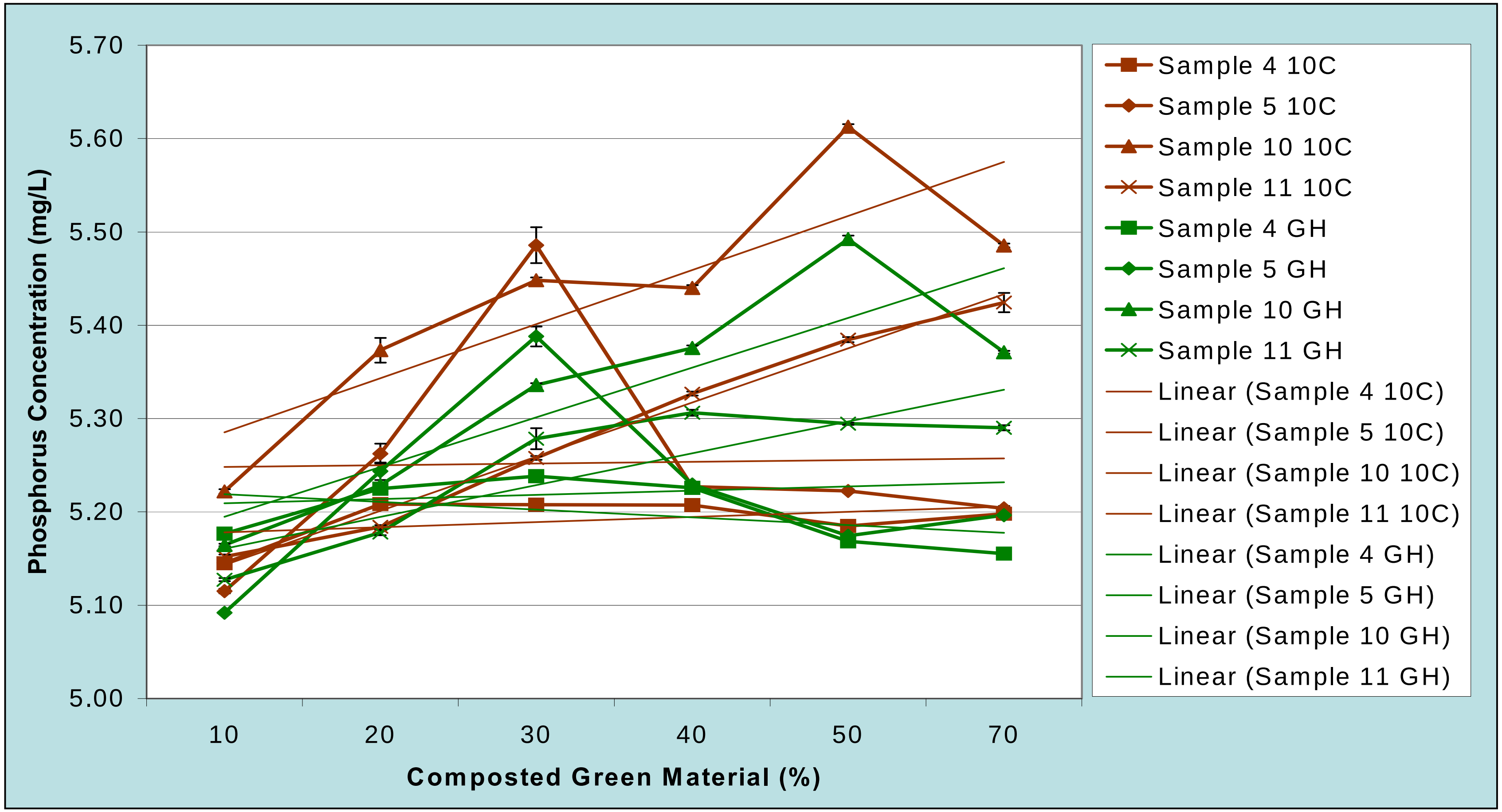


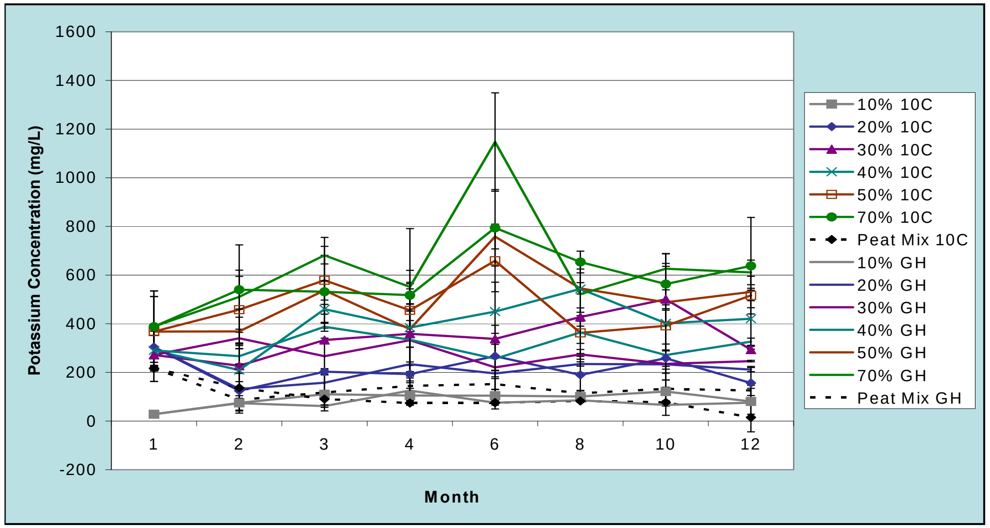
Figure 5.3.22: The relationship between phosphorus concentration and the proportions of composted green material. The 95% confidence limits are indicated by error bars.

As the percentage of composted green material increased, the potassium concentration also increased for the peat-reduced mixtures, Figure 5.3.24. All mixtures contained high levels of potassium.

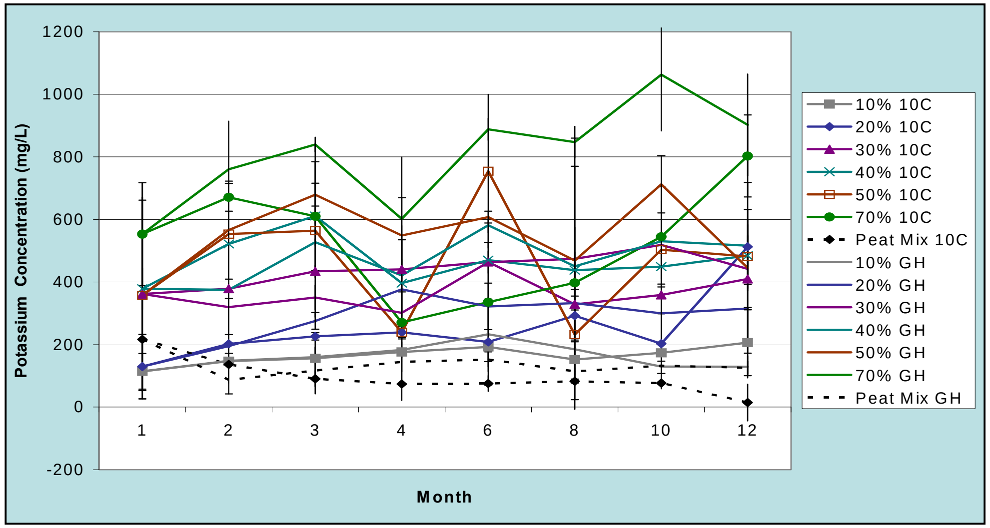
The all peat mix contained similar potassium concentrations to the 10-20% peat-reduced mixtures, for example the all peat mix (GH) average concentration over the twelve month study was 135.27 mg/L (+/- 11.62 mg/L) compared to the mixture containing 20% of Sample 5 (GH) which had a potassium concentration of 147.24 mg/L +/- 14.83 mg/L.

The potassium concentrations in mixtures containing lower percentages of composted green material i.e. 10-30% were fairly constant over the twelve month trial but when the proportions of composted green material were increased i.e. 40-70%, potassium concentration varied throughout the twelve month study. This was evident in the peat-reduced mixtures in both the 10˚C and glasshouse storage conditions, Figure 5.3.23.

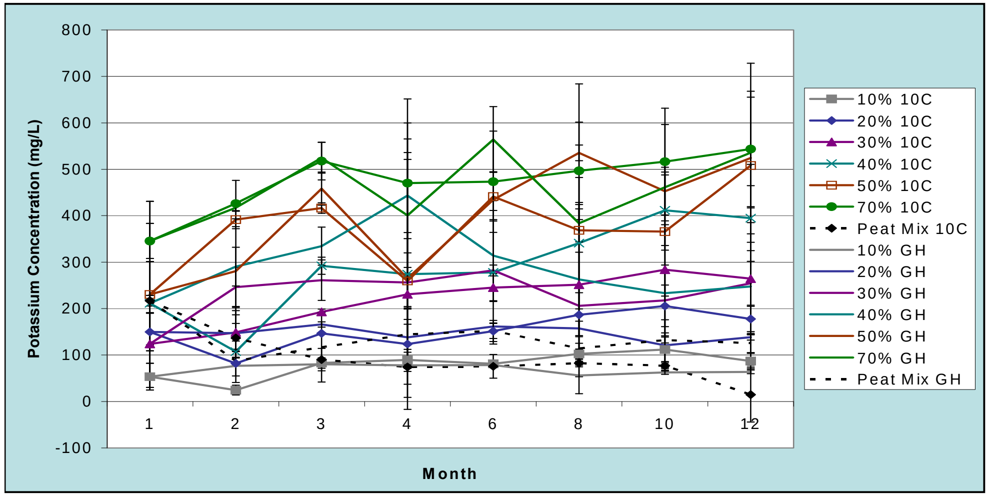
Sample 4



Sample 10



Sample 5



Sample 11

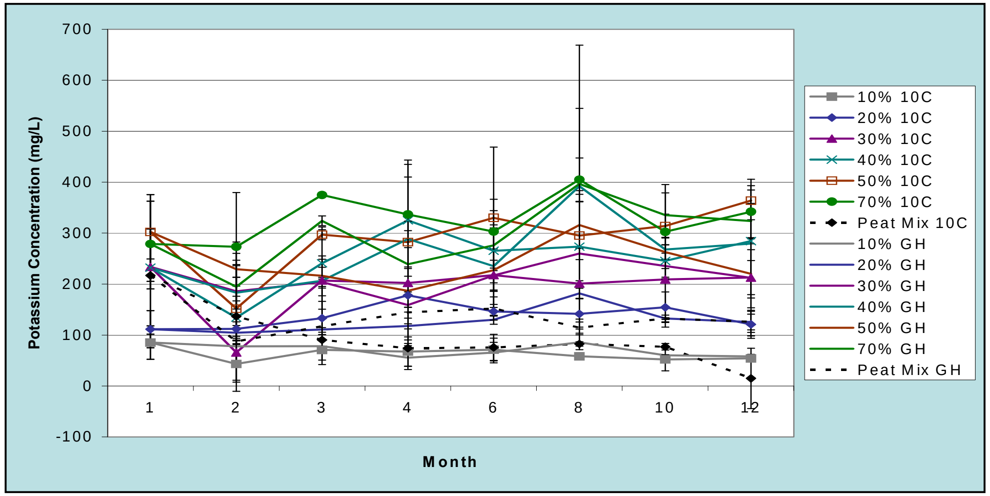


Figure 5.3.23: Potassium concentration for the peat reduced growth/storage trial. The 95% confidence limits are indicated by error bars.

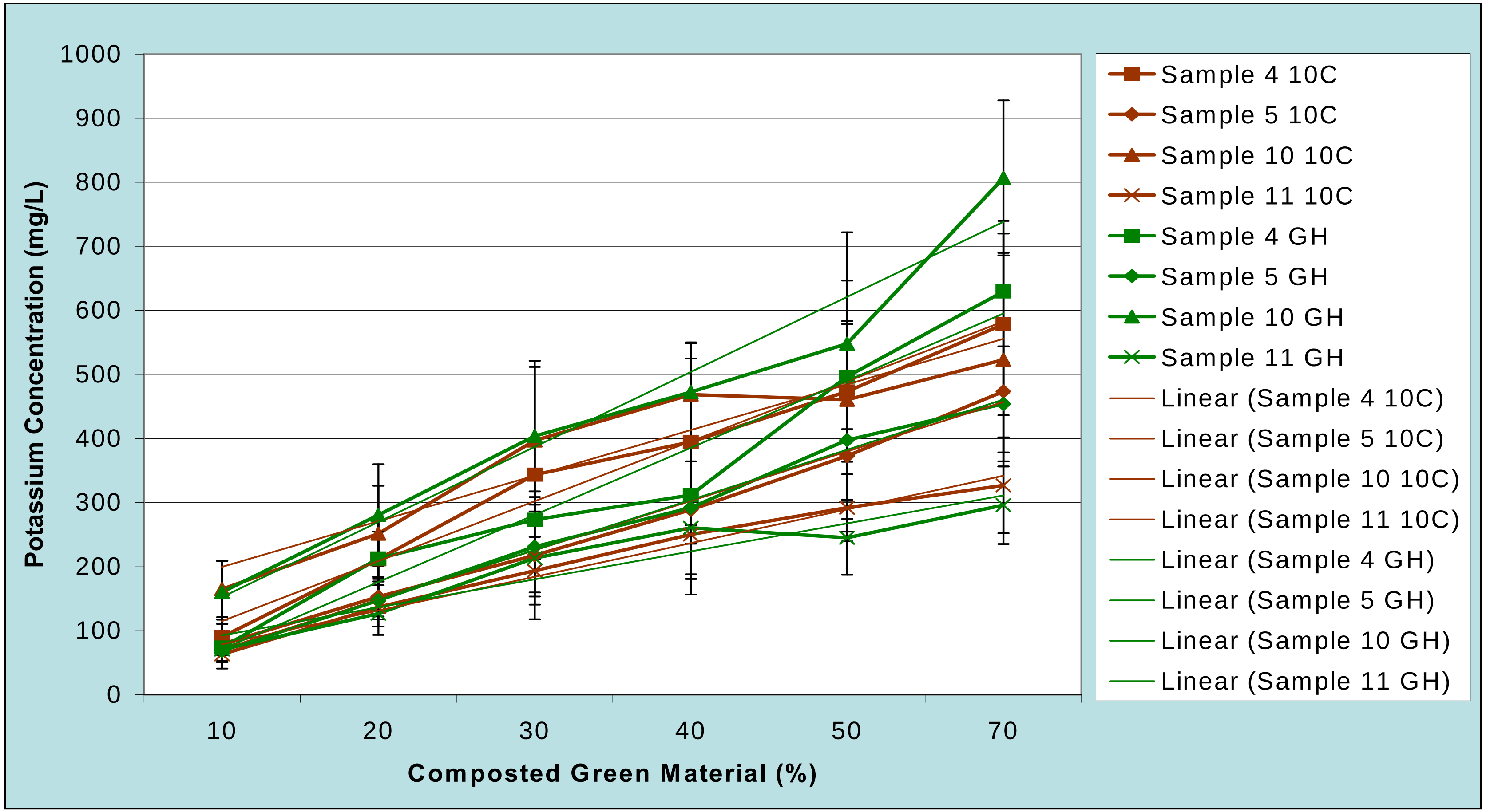


Figure 5.3.24: The relationship between potassium concentration and the proportions of composted green material. The 95% confidence limits are indicated by error bars.

As the percentage of composted green material increased, the concentration of magnesium decreased, Figure 5.3.26. There was little difference in the average concentration of magnesium within the four samples of composted green material used. For the mixtures containing 30% composted green material, there was a range of 9.07mg/L (+/- 1.48 mg/L) – 25.34mg/L (+/-2.79 mg/L) for all four samples. Magnesium concentrations in the individual mixtures were fairly constant over the twelve month trial, Figure 5.3.25.

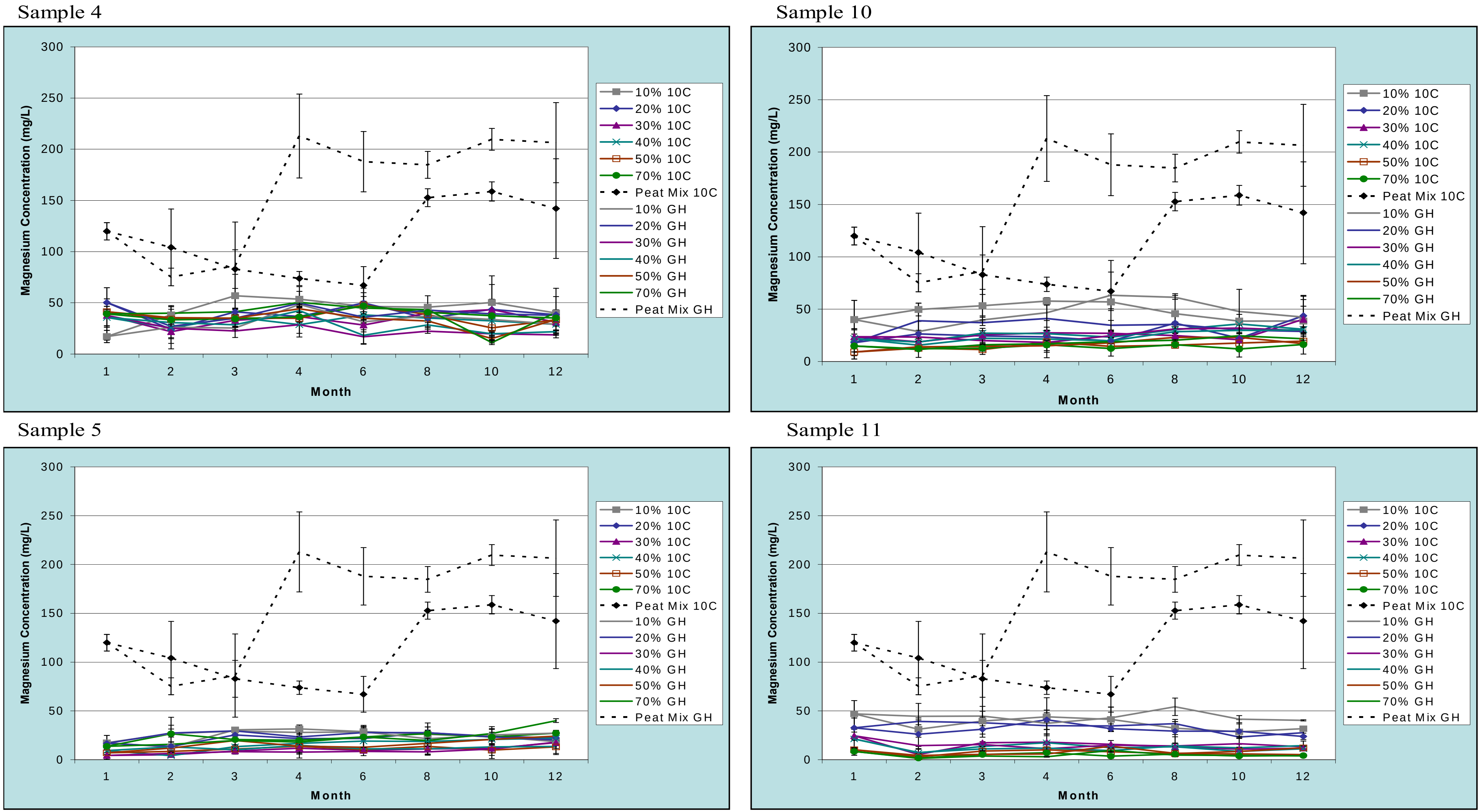


Figure 5.3.25: Magnesium concentration for the peat reduced growth/storage trial. The 95% confidence limits are indicated by error bars.

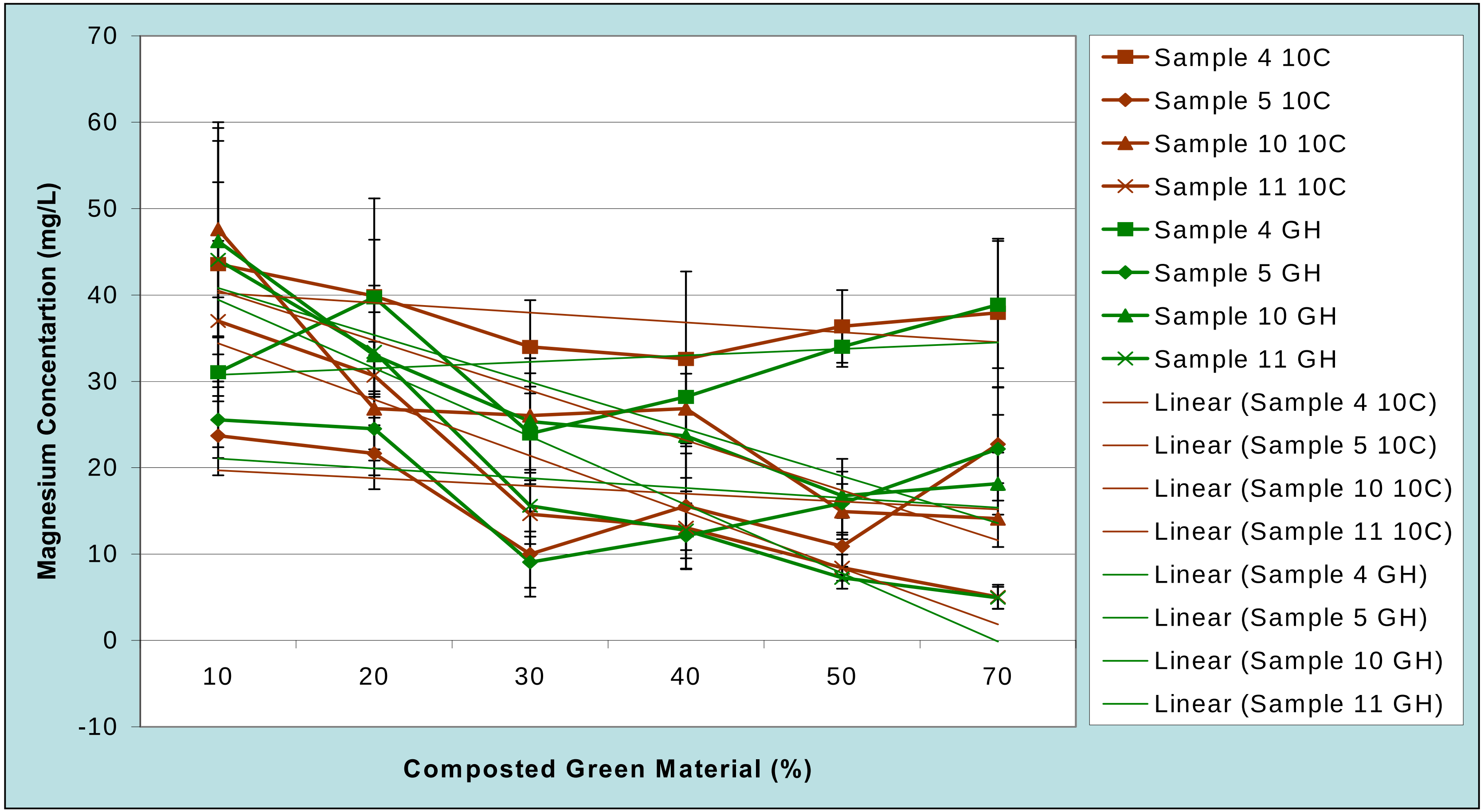
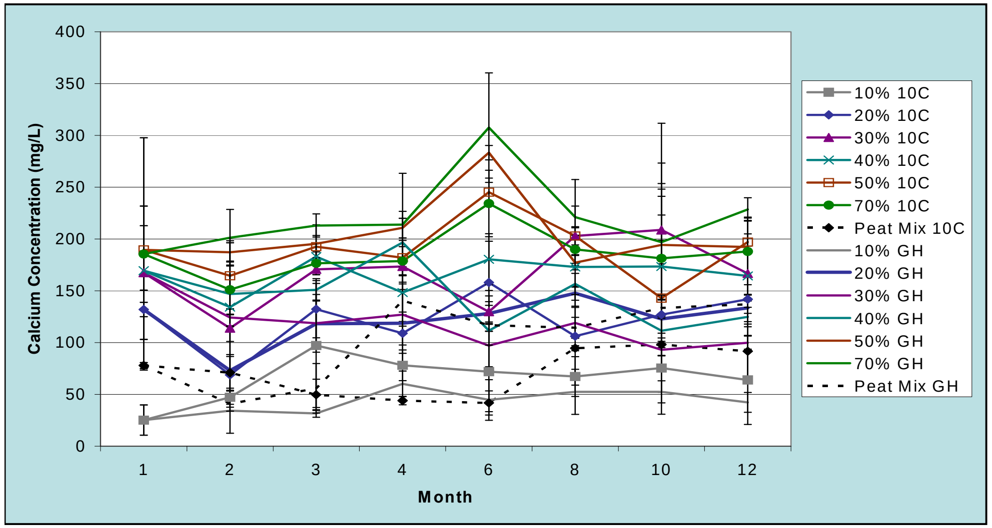


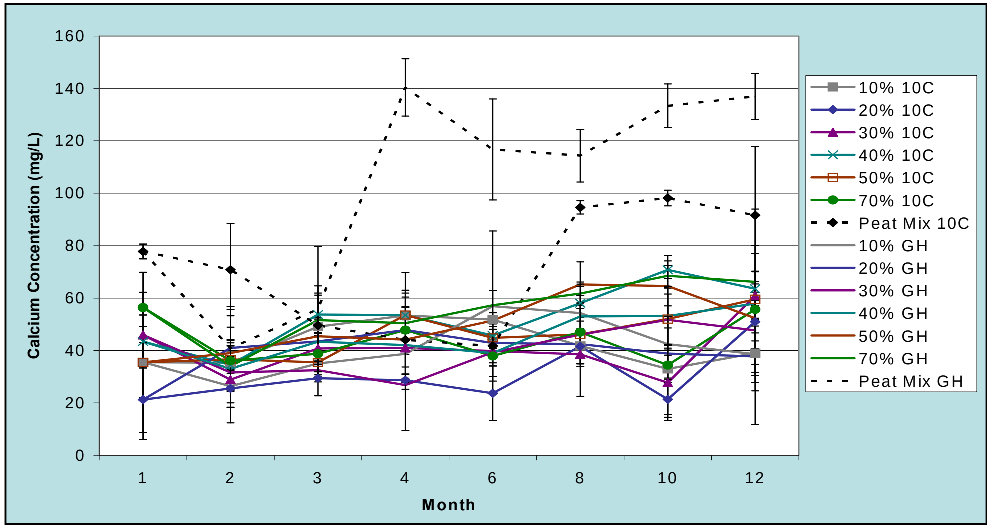
Figure 5.3.26: The relationship between magnesium concentration and the proportions of composted green material. The 95% confidence limits are indicated by error bars.

Mixtures containing Samples 5, 10 and 11 contained similarly low concentrations of calcium, Figure 5.3.27. Calcium levels varied a little in some mixtures during the experimental period. Observations from mixtures containing Sample 11 indicated as the percentage of composted green waste increased, the calcium concentration decreased (Figure 5.2.28). Mixtures containing Sample 4 had a very high concentration of calcium compared to the all peat mix and peat-reduced mixtures for Samples 5, 10 and 11 (Figure 5.2.27). For example the average calcium concentration for a mixture containing 70% of Sample 4 (GH) was 220.94 mg/L (+/- 19.68 mg/L); this can be compared to the all peat mix (GH) 102.01 mg/L (+/- 5.45 mg/L).

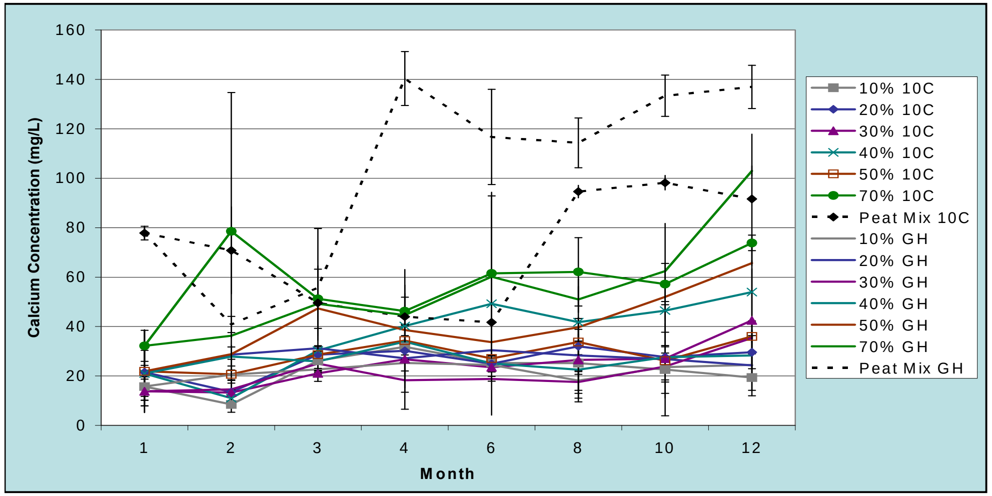
Sample 4



Sample 10



Sample 5



Sample 11

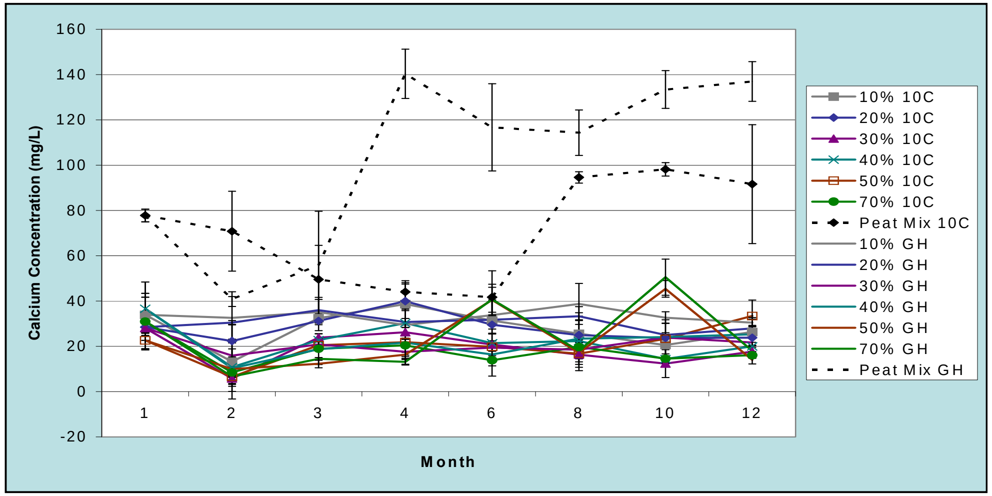


Figure 5.3.27: Calcium concentration for the peat reduced growth/storage trial. The 95% confidence limits are indicated by error bars.

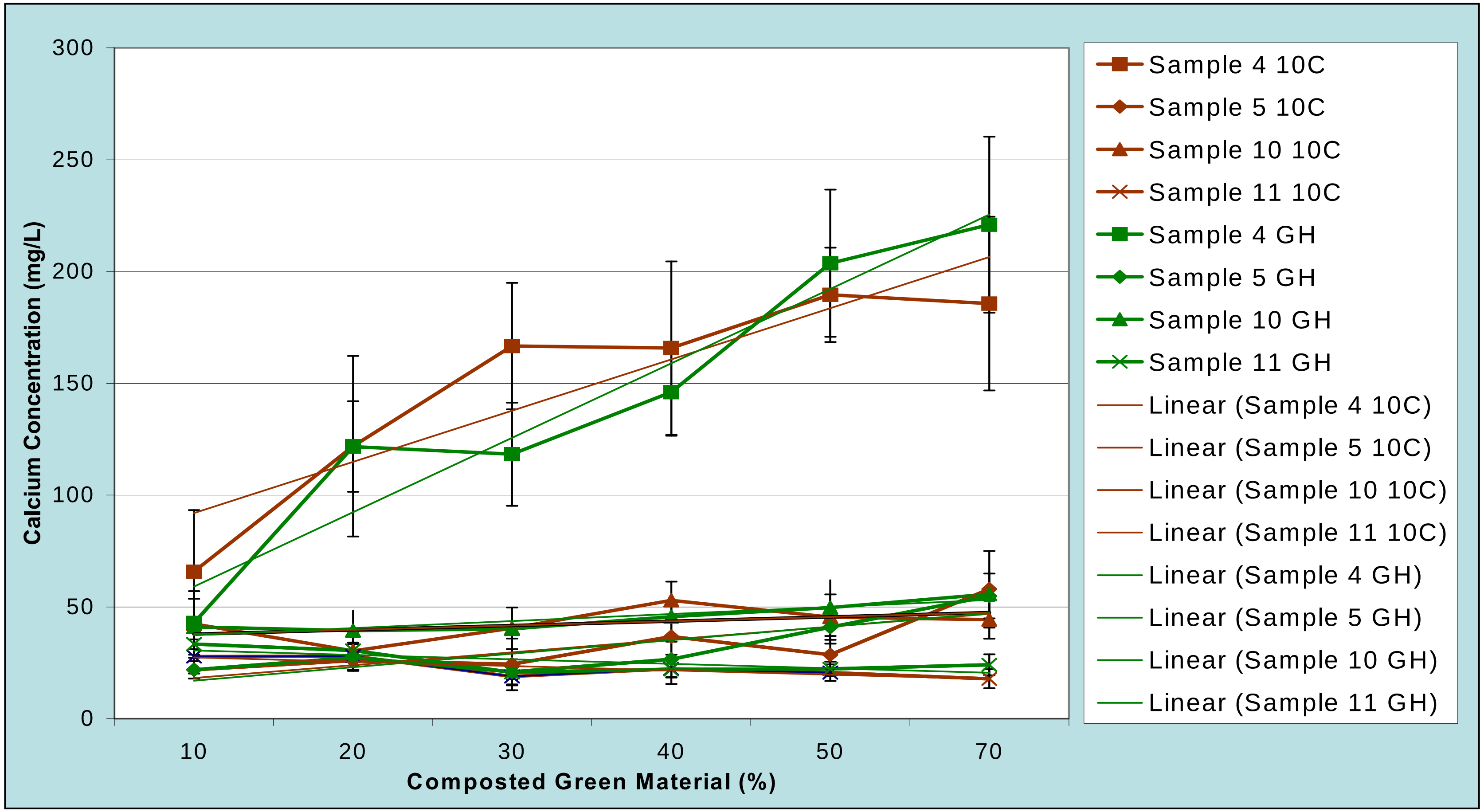


Figure 5.3.28: The relationship between calcium concentration and the proportions of composted green material. The 95% confidence limits are indicated by error bars.

A vast majority of peat-reduced mixtures contained zinc levels undetectable by the ICP with only negligible amounts in some samples.

Sample	10˚C Conditions	+/- Trend Line	Glasshouse Conditions	+/- Trend Line
Sample 4 Bulk Density	.9868	Positive	.9777	Positive
Sample 5 Bulk Density	.5872	Positive	.7666	Positive
Sample 10 Bulk Density	.9765	Positive	.9577	Positive
Sample 11 Bulk Density	.4977	Positive	.6797	Positive
Sample 4 Organic Matter Content (<2mm)	.9872	Negative	.9811	Negative
Sample 5 Organic Matter Content (<2mm)	.947	Negative	.9931	Negative
Sample 10 Organic Matter Content (<2mm)	.9801	Negative	.9484	Negative
Sample 11 Organic Matter Content (<2mm)	.9516	Negative	.8944	Negative
Sample 4 Ash Content (<2mm)	.9872	Positive	.9811	Positive
Sample 5 Ash Content (<2mm)	.947	Positive	.9931	Positive
Sample 10 Ash Content (<2mm)	.9801	Positive	.9484	Positive
Sample 11 Ash Content (<2mm)	.9516	Positive	.8944	Positive
Sample 4 Organic Matter Content (<2mm)	.9816	Negative	.9787	Negative
Sample 5 Organic Matter Content (<2mm)	.8827	Negative	.9771	Negative
Sample 10 Organic Matter Content (<2mm)	.9669	Negative	.9687	Negative
Sample 11 Organic Matter Content (<2mm)	.928	Negative	.9099	Negative
Sample 4 Ash Content (<2mm)	.987	Positive	.9787	Positive
Sample 5 Ash Content (<2mm)	.8828	Positive	.9771	Positive
Sample 10 Ash Content (<2mm)	.9669	Positive	.9687	Positive
Sample 11 Ash Content (<2mm)	.9039	Positive	.9099	Positive
Sample 4 Fresh weights	.3537	Negative	.0004	Positive

Sample 5 Fresh weights	.1958	Positive	.4575	Positive
Sample 10 Fresh weights	.1763	Positive	.7798	Positive
Sample 11 Fresh weights	.7811	Negative	.8749	Negative
Sample 4 Germination Count	.9703	Negative	.7386	Negative
Sample 5 Germination Count	.4498	Negative	.5326	Negative
Sample 10 Germination Count	.8593	Negative	.9114	Negative
Sample 11 Germination Count	.7391	Negative	.7297	Negative
Sample 4 pH	.9725	Positive	.9888	Positive
Sample 5 pH	.6488	Positive	.6401	Positive
Sample 10 pH	.4658	Positive	.4694	Positive
Sample 11 pH	.6887	Positive	.8087	Positive
Sample 4 Electrical conductivity	.9961	Positive	.9624	Positive
Sample 5 Electrical conductivity	.9918	Positive	.9809	Positive
Sample 10 Electrical conductivity	.9722	Positive	.9734	Positive
Sample 11 Electrical conductivity	.9884	Positive	.8448	Positive
Sample 4 Nitrate Concentration	.0347	Negative	.2504	Positive
Sample 5 Nitrate Concentration	.47	Positive	.6367	Positive
Sample 10 Nitrate Concentration	.0646	Positive	.8931	Positive
Sample 11 Nitrate Concentration	.0818	Positive	.8557	Negative
Sample 4 Phosphorus Concentration	.1771	Positive	.1899	Negative
Sample 5 Phosphorus Concentration	.0008	Positive	.0074	Positive
Sample 10 Phosphorus Concentration	.7042	Positive	.732	Positive
Sample 11 Phosphorus Concentration	.9894	Positive	.7321	Positive
Sample 4 Potassium Concentration	.9833	Positive	.9597	Positive
Sample 5 Potassium Concentration	.9937	Positive	.9958	Positive
Sample 10 Potassium Concentration	.905	Positive	.9544	Positive

Sample 11 Potassium Concentration	.9841	Positive	.8986	Positive
Sample 4 Magnesium Concentration	.2852	Negative	.0525	Positive
Sample 5 Magnesium Concentration	.0767	Negative	.0957	Negative
Sample 10 Magnesium Concentration	.7995	Negative	.863	Negative
Sample 11 Magnesium Concentration	.91	Negative	.8981	Negative
Sample 4 Calcium Concentration	.8164	Positive	.9282	Positive
Sample 5 Calcium Concentration	.7263	Positive	.6374	Positive
Sample 10 Calcium Concentration	.8321	Positive	.2385	Positive
Sample 11 Calcium Concentration	.5196	Negative	.6921	Negative

Table 5.3.1: Coefficients of determination (R^2) - represent the individual relationship between each parameter and the proportion of composted green material in the samples (see figures in 5.3).

This type of data representation was achieved by the production of a line graph. A trend line was then calculated for the data contained within the graph. An equation of the line and subsequent R-squared values can then be produced from the trend line. The R-squared value is a number ranging from 0 - 1, that reveals how closely the estimated values for the trend line respond to the actual data. A trend line is most reliable when the R-squared value is at or near 1. Table 5.3.1 contains the R^2 values for each individual parameters studied. The R^2 value is used to assess how closely each individual parameter is related to the percentage composition of composted green material.

5.4 Discussion

Several parameters remained fairly constant over the twelve month storage trial, they included; bulk density, organic matter and ash contents, pH, electrical conductivity, magnesium and calcium concentrations. Parameters which varied during storage were; germination percentage, fresh weight, potassium and nitrate concentration. There were low concentrations of manganese and zinc throughout the duration of the trial.

The bulk density values for mixtures containing Sample 4 and 10 were fairly constant over the twelve month storage trial; however the bulk density of mixtures containing Sample 11 steadily increased through out the duration of the trial, indicating that the material may not have fully matured.

Another indicator suggesting that Sample 11 may not have fully matured is the development of fungal growth found in the samples containing Sample 11. These growths only occurred within the initial two months.

Figure 5.4.1: An example of fungal growth in mixtures containing Sample 11.

As the percentage of composted green material increased, the bulk density also increased. Many workers have found similar trends (Veeken *et al.* 2005; Ribeiro *et al.* 2000). Many research papers have concluded that bulk density and total pore space within a growing medium are inversely related (Kristoffersen & Riley, 2005; Searle & Sorensen, 2004). Prasad & Maher (2001) found that the air content at a tension of 10cm was not affected by the increased bulk density of composted green material, but the water holding capacity was reduced at the 50% inclusion of composted green material. Mohee & Mudhoo (2005) found conflicting results, concluding that free air space (FAS) was negatively correlated to the bulk density of compost.

The organic matter and ash contents were fairly constant during the twelve month trial for all four samples of composted green material. There was greater variation in the 95% confidence limits for the (>2mm) sample; this was due to the sample being heterogeneous and therefore possibly having greater variation. The (>2mm) samples have slightly higher organic matter contents than the (<2mm). This could be due to the inclusion of a larger piece of woody material, that could not be ground down to (<2mm) size (Ward *et al*. 2005).

Both the pH and electrical conductivity were fairly constant over the duration of the trial. In growing media high pH values could reduce the uptake of potassium. However, this was not a problem associated with composted green material, as there were large concentrations of naturally occurring potassium, indicating that the addition of composted green material could reduce the need for K-based fertilisers. The concentrations of potassium were high within all four samples of composted green material.

Magnesium and calcium concentration were relatively constant during the trial. Mixtures containing Samples 5, 10 and 11 had similar, low concentrations of calcium however; mixtures containing Sample 4 had much higher concentrations of calcium indicating a source of calcium within the composted green material. Magnesium concentrations were fairly constant and low in all four samples of composted green material. The concentrations of magnesium are affected by other cations such as potassium and ammonium, as the concentration of these cations increase, the magnesium concentration decreases. This correlation was evident in all four samples stored at 10˚C. Mixtures containing Sample 4 had a weak positive correlation in the mixture stored under glasshouse conditions. This correlation was more prominent in mixtures containing Samples 10, having R^2 values ranging from 0.74- 0.76 and Sample 11 ranging from 0.94 – 0.96 as indicated (This can be seen in Appendix 2).

Unfortunately precise data on the level of phosphorus were not obtained. However deficiency in phosphorus was apparent in some treatments. Low phosphorus concentrations can lead to stunted growth and leaf discoloration along the veins in the form of purpling. This may spread to the lower stem base. Deficiencies in phosphorus were observed, as indicated in Figure 5.4.2.

Figure 5.4.2: Phosphorus deficiency in tomatoes.

Germination counts were used to assess the phytotoxicity of the composted green material samples. Lettuce was used to assess the phytotoxicity as lettuce is renowned for being sensitive to phytotoxins (Keeling *et al.* 1994). Of course phytotoxicity must be distinguished from salinity effects, which is discussed later. Germination percentages varied within the trial. The variability within the composted green material and the all peat mix may be due to a number of parameters, for example temperature, water availability, high salinity and nitrate concentration

The availability of water is a determining factor upon germination (Mayer & Poljakoff-Mayer, 1989). It can be determined by a number of physical properties, i.e. the water holding capacity and air-filled porosity which are governed by the pore size and hence the material from which it is produced. Ribeiro *et al.* (2000) found that the addition of composted green material increased the bulk density and therefore reduced the total porosity, which in turn reduced the water holding capacity. Prasad & Maher (2001) stated that the water holding capacity was reduced at a 50% rate of composted green material, this may have increased the variability of the lettuce germination. A major factor in determining availability of water is the electrical conductivity (Bunt, 1988). The build up of nutrients which is often referred to as 'high salinity' can produce a specific ion toxicity effect for example manganese or boron or as a general salinity effect can reduce the amount of water available to the plant, this can occur if a high level of fertiliser is applied.

This is mainly due to osmotic potential within the plant cells moving water through the plant due to the solute potential.

Germination and initial seedling growth are the stages of development most sensitive to salinity, irrespective of the salt tolerance of the mature plant (Mayer & Poljakoff-Mayer, 1989). The coefficient of determination (R^2) indicated a general negative correlation between lettuce germination and electrical conductivity values (Appendix Three). As the electrical conductivity increased the germination decreased. The high electrical conductivity values within composted green material are primarily due to the high potassium levels. Many researchers have found reduction in germination associated with the high salinity of composted green material (Prasad & Maher, 2001; Ribeiro *et al.* 2000)

The temperature of the glasshouse may be another factor which inhibited the germination. The trial was initiated in June and therefore high temperature may have provided variation within the germination percentages.

Mixtures containing Samples 4, 5 and 11 had variable germination within Months 1-4. The germination then stabilised. This trend has been found by other researchers (Peatering Out, (2005a). This indicates that the samples of composted green material may not have been fully matured when the trial was initiated. Bernal *et al.* (1998) stated that maturity of compost is associated with plant-growth potential or phytotoxicity and that the degree of maturity may be measured by biological methods involving seed germination since immature composts may contain phytotoxic substances such as phenolic acids and volatile fatty acids (Bernal *et al.* 1998).

As indicated in the main findings, there was no direct correlation between the yield (fresh weights) and the percentage of composted green material. Therefore other parameters may have been influencing the yield production, for example the salinity or the pH.

An attempt was made at a stepwise regression analysis, to establish which parameters were having the largest effect upon plant growth. Regression analysis is used to investigate and model the relationship between a response variable and one or more predictors. In this particular case, the response variable was the fresh weight values and the predictors were the other parameters investigated. From the parameters investigated the stepwise model produced a subset of predictors containing a number of parameters which have the most significant effect upon the plant yield for that particular sample. Multiple regression analysis is necessary when there are a large number of parameters to be assessed. The stepwise regression analysis is contained in Appendix 4.

Parameter (P-value <0.05)	Composted Green Material Sample			
	4	5	10	11
Nitrate Concentration	+ve	+ve	+ve	+ve
Storage Conditions	+ve	+ve	+ve	+ve
Electrical conductivity		+ve	+ve	+ve
pH		-ve	-ve	
Ash (>2mm)		-ve	-ve	
Bulk Density	-ve			
Percentage				-ve
Phosphorous			-ve	

Table 5.4.1: Simplified version of the stepwise regression analysis for the determination of fresh weight. Indicating the significant parameters only.

Figure 5.4.3 shows the variation in plant growth produced from the four samples of composted green material

Sample 4

Sample 10

Sample 5

Sample 11

Figure 5.4.3: Peat -reduced growth trial.

As expected, nitrates were the prominent parameter, indicating a positive correlation for all four samples of composted green material. By looking at the P and R-squared values obtained, nitrate concentrations were highly correlated to the fresh weight production with correlation ranging from 44-80%. This was also indicated by the correlation values in Table 5.3.1. This has been found by many researchers (Prasad & Maher, 2001). The nitrate concentration varied in storage and between samples.

The nitrate concentration in mixtures containing Samples 5 and 10 increased during the twelve month storage trial, indicating a slow release form of nitrogen. This has been found by other researchers (Erhart *et al*. 2005). Composted green material may have considerable reserves of organic-N or protein –N which is not readily available to the plant. Microbial mineralisation occurs as the microbes utilise the carbon substrates e.g. organic matter, producing a slow release form of nitrogen, simulating the application of a slow release fertiliser i.e. ureaformaldehyde. As a general rule, in stable composts, with a C/N ratio of between 15:1 and 20:1, there is a potential of 16-20% of the total N being readily available within the first year (Enviros Consulting Ltd, 2004).

From the stepwise regression analysis, storage had a significant effect upon all four samples of composted green material, with p-values ranging from 0 -0.002. The correlations indicated that storage conditions had a positive effect upon the plant yield. This may be due to the material maturing during the trial and therefore becoming more stable. This was indicated by the lettuce germination findings. The germination counts increased, as the storage time increased.

Within this research there were two storage conditions; glasshouse ranging from approximately (4 - 35˚C) and 10˚C storage conditions. Within the statistical analysis, glasshouse storage conditions were given the value 1 and 10˚C storage conditions were given the value 2. As a stepwise regression is an equation of the line, and the relationship between storage and fresh weight was a positive correlation. The storage condition with the higher value within the equation i.e. the 10˚C storage condition, favoured fresh weights production.

Many alternative materials to peat in growing media, for example bark and brash contain high cellulose contents which are readily degraded by micro-organisms resulting in structural breakdown of the material leading to microbial growth which may lead to the utilisation of nutrients, especially nitrogen (Carlile, 2004). The utilisation of nitrogen is called nitrogen immobilisation, making the nitrogen unavailable to the plant. However Butler *et al.* (2001) found that as temperatures declined actinomycetes and fungi become less biologically active in biosolid compost stored at 4˚C than freshly tested samples, indicating that a reduction in temperature and storage decreased the microbial activity therefore making the suggestion that the samples of composted green material could be more stable. The results from the stepwise regression analysis suggested that composted green material stored at 10˚C constant temperature conditions produced higher fresh weight values. The decrease in microbial activity and the subsequent increase in available nutrients could be one reason for the increased growth.

Prasad & Maher (2001) found a decrease in available nitrogen within samples of composted green material, the implication of this being that microbial activity was still existent in the composted green material and that the microbial populations were still absorbing the nitrogen, even though the samples appeared to have stabilised with low C/N ratios. Richardson & Rainbow (2005) found similar findings. The composted green material samples used in their trial had low C/N ratios. However all the NO_3/NH_4 ratio for treatments containing composted green material fell due to loss of NO_3-N.

Many peat-free media, particularly those that have undergone composting, have inherently high microbial populations (Carlile, 2004). Similar trends to the work in this thesis were found by Dickinson (1995).

Sample 11 produced very low fresh weights throughout the duration of the trial, which as stated in the main finding was inversely related to the percentage of composted green waste. As indicated by the stepwise regression analysis, fresh weight production was greatest in the mixtures containing lower percentages of composted green material. This material may not have matured fully, since immature composts may contain phytotoxic substances such as phenolic acids and volatile fatty acids, lowering germinations and fresh weights

From the results gained in the peat-reduced growth and storage trials it was evident that some composted green materials could be a good diluent material for peat based growing media if the feed stock and production methods were monitored. However there was variation between the samples of composted green material.

In view of demand for peat-free growing media (Wallace *et al.* 2006), allied to the production of composted green material, the next step in this research was to conduct a peat-free growth and storage trial, using material such as bark that could eliminate some of the issues such as bulk density associated with the use of composted green material.

Chapter 6.0: Peat-free Growing Media

6.1 Introduction

From the peat-reduced twelve month growth and storage trial, one sample was identified for use in a further growth and storage trial. The initial growth and storage studies had focused upon peat-reduced growing medium, and had identified issues with the use of composted green material including potential considerations of bulk density. Therefore the next step in this research was to conduct a peat-free growth and storage trial, using alternative materials that could eliminate some of the issues associated with the use of composted green material.

6.2 Materials & Methods

Sample 4 was chosen for use in the peat-free growth and storage studies as this sample performed well in the previous peat-reduced growth trial, producing good fresh weight values compared to the other samples of composted green material. A total of 60L of each mixture was produced. Mixtures were prepared at 0, 10, 20, 25, 30, 40, and 50% by volume with other alternative materials to peat i.e. composted pine bark, composted bark, and wood waste i.e. chipboard soaked in ureaformaldehyde (Table 6.2.2). Brief descriptions of the alternative materials used in this study are provided over the page. Table 6.2.1 contains analyses of the initial substrates used in the peat-free trial. The 95% confidence limits are indicated by +/- limits.

The wood waste, composted bark and composted pine bark all had low bulk densities, with high organic matter contents and corresponding low ash contents. The pH value of the wood waste was 8.33 (+/- 0.04). This high pH was due to the high ammonia content, as this material had been soaked in ureaformaldehyde. Due to the high nitrate-nitrogen and ammonia concentrations, the electrical conductivity of this material was high. The composted bark had a pH of 7.20 (+/- 0.00), with a low electrical conductivity indicating little nutrient availability. The composted pine bark had a low pH of 4.27 (+/- 0.00) again with a low electrical conductivity indicating little nutrient availability. This material contained no nitrates or ammonia. The composted pine bark used within this trial was milled to a particle size described as ‘fines’. Wood waste i.e. chipboard is soaked in ureaformaldehyde to facilitate complete biological stabilisation of the material and to reduce nitrogen immobilisation.

Parameter	Wood waste - DIY	Composted Bark	Composted Pine Bark	Composted Green Material
Bulk Density (g/L)	309.92 +/- 6.16	393.74 +/- 7.26	301.06 +/- 4.32	665.29 +/- 8.83
Organic Matter Content (<2mm) (%)	98.12 +/- 0.07	85.61 +/- 1.63	85.69 +/- 2.58	27.43 +/- 2.31
Organic Matter Content (>2mm) (%)	98.68 +/-0.07	83.44 +/- 18.68	95.73 +/- 0.63	18.45 +/- 4.10
Ash Content (<2mm) (%)	1.88 +/- 0.06	14.39 +/- 1.33	14.31 +/- 2.10	72.57 +/- 1.89
Ash Content (>2mm) (%)	1.32 +/- 0.07	16.56 +/- 15.25	4.27 +/- 0.51	81.55 +/- 3.35
pH	8.33 +/- 0.04	7.20 +/- 0.00	4.90 +/- 0.00	7.72 +/- 0.04
Electrical conductivity (μmhos)	733.33 +/- 29.44	220.00 +/- 24.49	156.67 +/- 8.16	2733.33 +/- 40.82
Nitrate Concentration (mg/L)	558.33 +/- 40.21	25.83 +/- 6.68	7.67 +/- 1.08	1660.00 +/- 62.85
Phosphorus Concentration (mg/L)	3.88 +/- 1.78	18.73 +/- 2.81	12.72 +/- 0.79	10.91 +/- 1.92
Potassium Concentration (mg/L)	7.83 +/- 0.46	18.00 +/- 0.87	29.77 +/- 0.44	2088.83 +/- 33.36
Ammonia Concentration (mg/L)	128.43 +/- 0.03	17.12 +/- 0.04	0.10 +/- 0.30	14.07 +/- 0.39
Magnesium Concentration (mg/L)	0.43 +/- 0.04	0.58 +/- 0.04	2.95 +/- 0.20	17.56 +/- 0.84
Calcium Concentration (mg/L)	1.77 +/- 0.35	7.69 +/- 0.10	6.76 +/- 0.24	78.12 +/- 2.92
Zinc Concentration (mg/L)	2.10 +/- 0.15	2.04 +/- 0.01	2.09 +/- 0.01	2.09 +/- 0.06
Manganese Concentration (mg/L)	2.33 +/- 0.01	2.31 +/- 0.00	2.93 +/- 0.04	2.43 +/- 0.03
Dehydrogenase Assay (μg of TPF)	96.06 +/- 11.19	571.13 +/- 19.39	266.67 +/- 45.24	831.85 +/- 257.02

Table 6.2.1: Analyses of initial substrates used in peat-free growth/storage trial. Three individual samples were used with analyses replicated in triplicate. The 95% confidence limits are indicated by +/- limits.

The control was a ‘peat-free mix’, which was commercially available. The different components were combined using a new cement mixer to eliminate contamination issues.

Mixture (CGM %)	Composted Green Material (CGM) (L)	DIY (L)	Composted Pine Bark (L)	Composted Bark (L)	Total (L)
0 %	0	6	24	30	60
10%	6	6	24	24	60
20%	12	6	24	18	60
25%	15	6	24	15	60
30%	18	6	24	12	60
40%	24	6	24	6	60
50%	30	6	24	0	60
Peat-free Mix	n/a	n/a	n/a	n/a	60

Table 6.2.2: Composition of mixtures used within the peat-free growth/storage trial.

The mixes were again split, half of the material was stored in a 10˚C constant temperature room (10˚C), and the other half was stored in a glasshouse (GH). The trial was initiated on the 28 November 2005 and was completed at the end of May 2006. Changes in temperature under glasshouse conditions were recorded throughout the duration of the study and can be observed in Figure 6.2.1.

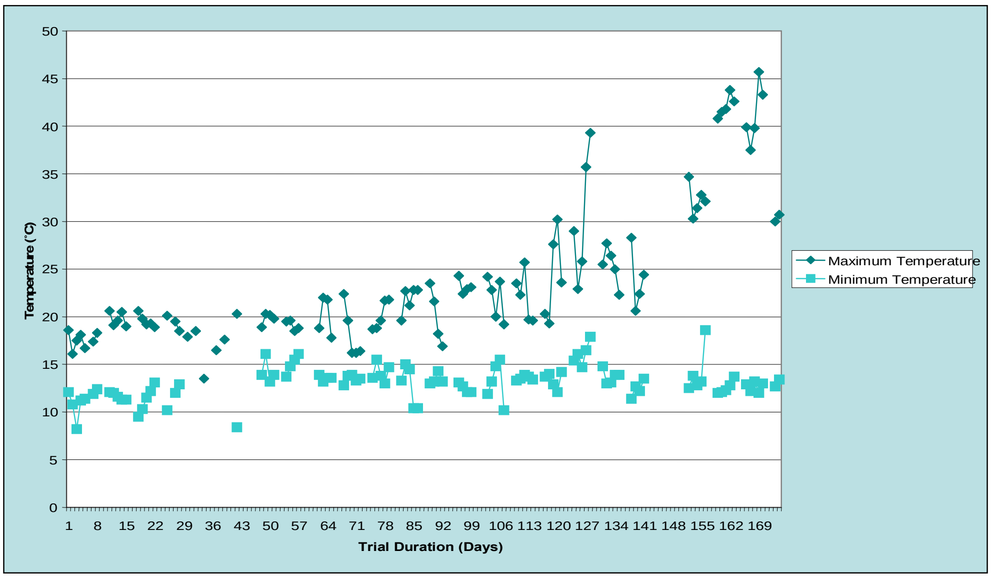


Figure 6.2.1: Glass house temperature readings taken during the peat free growth/storage trial.

Growth studies were again carried out using lettuce (*Lactuca sativa* ‘Winter Density’) and tomato (*Lycopersicum esculentum* ‘Moneymaker’). For the germination tests, seedling trays were sown with 20 lettuce/tomato seeds for each mixture (Figure 6.2.2), this was replicated five times. Germination counts for lettuce were taken after one week.

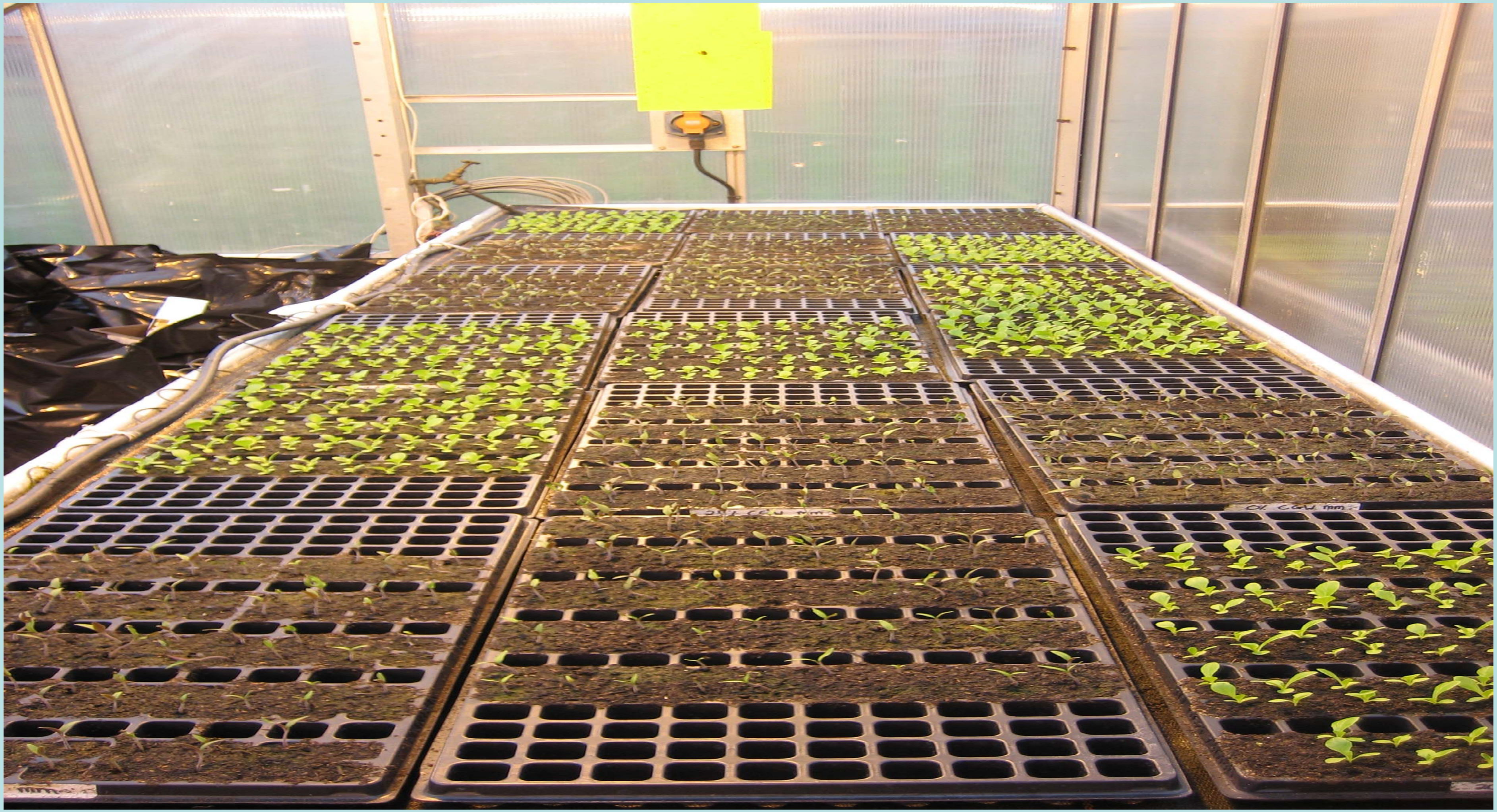


Figure 6.2.2: Germination of lettuce and tomato seeds

Germination counts for tomatoes were taken after approximately 14 days, and then five plants were then chosen at random and potted on into 7.5cm pots. The plants were then left for a further period of time, 14-21 days according to season. The plants were then cut from the bottom of the stem and the fresh/dry weights were recorded.

To assess the mixtures used in the peat-free growth and storage studies, analysis was conducted monthly for the duration of the trial. The trial was six months in duration.

Methods of Physical Analyses

6.2.1 Determination of Bulk Density (BD)

The methodology is in section 4.2.1 Determination of Bulk Density

6.2.2 Determination of Organic Matter (OM)/ Ash (ASH) Contents

The methodology is in section 4.2.2 Determination of Organic Matter & Ash Contents

6.2.3 Determination of Dry Weight

When the fresh weights had been taken, the material was the placed into a foil tray and then into a drying oven at 105˚C +/- (5˚C). The material was left for 48 hours. The trays were then weighed and placed back into the oven for a further 1 hour. The dry weights were recorded again. This process was repeated until the difference between two successive weightings was less than 0.01.

The determination of moisture contents was omitted from these analyses due to time constraints

Methods for Chemical Analyses

6.2.5 Determination of pH

The methodology is in section 4.2.4 Determination of pH

6.2.6 Determination of Electrical Conductivity

The methodology is in section 4.2.5 Determination of Electrical conductivity

6.2.7 Determination of Nitrate Nitrogen

The methodology is in section 4.2.6 Determination of Nitrate Nitrogen

6.2.8 Determination of Macro/Micro Nutrients

The methodology is in section 5.2.7.1 Determination Macro/Micro Nutrients

With the addition of Manganese

6.2.8.1 Determination of Manganese

Manganese concentrations were determined using the ICP-OES. Methodology is in section 5.2.7.1 Determination of macro/micro nutrients. To produce a stock solution of 1000mg/L, 0.2877g of potassium permanganate was used, 50ml of distilled water, and approximately 0.4g of hydroxyl ammonium sulphate was added to decolourise the solution. The solution was then made up to 100ml with distilled water. The stock standard was left overnight.

6.2.9 Determination of Phosphorus

The methodology is in section 4.2.8 Determination of Phosphorus

6.2.10 Determination of Ammonium Nitrogen

This analysis was conducted immediately after extraction. If the sample is left for a period of time in warm (laboratory conditions) ammonium-N may be converted to nitrate-N.

A stock solution of 1000mg/L ammonium (0.382g per 100ml ammonium chloride) was produced. From this, 100, 10, 1 and 0.1 mg/L ammonium standards were produced and used to achieve a calibration curve. 20ml of standard/sample (filtrate) was used for the analysis. 0.2ml of 10M NaOH was added to all standards/samples, which were then stirred for 2 minutes. The addition of strong NaOH converts ammonium to ammonia, which may be detected by the ion selective electrode (ISE). The Ammonia ISE (Orion 951000) was used to record the pH values of the samples and standards. This procedure was repeated in triplicate for each of three individual samples, giving nine replicates in total. All error values referred to in this research are 95% confidence limits.

6.2.11 Determination of Dehydrogenase Activity

The dehydrogenase activity assay was used to gain an assessment of the stability of the composted green material *via* the measurement of microbial activity. The method was taken from Dickinson, (1995).

Redox dyes such as Triphenyl Tetrazolium Chloride (TTC) are used to detect increased respiration associated with substrate oxidation or utilisation. When bacteria oxidise carbon substrates, NADH is formed with a resultant flow of electrons. Triphenyl tetrazolium chloride will capture these electrons to form Triphenyl Tetrazolium Formazan, a bright red precipitate, which can be assayed spectrophotometrically (Weaver *et al*. (1994). The resultant red precipitate is an indication of the microbial activity, the higher the absorbance reading the larger the amounts of microbial activity.

All equipment and solutions used in this assay were sterilised before use. 3g of composted green material was weighed into a sterile conical flask. 0.5ml of sterile calcium carbonate suspension was added, produced by suspending 1g of $CaCO_3$ in distilled water and autoclaving. 3ml of sterile 1% 2, 3, 5 triphenyltetrazolium chloride (TTC) was also added. This was produced by adding 3g of TTC to 100ml distilled water and filter sterilising through a 0.2µm acrodisc. The conical flask was then covered in foil to eliminate any light source and shaken by hand to ensure the solution and media had mixed. The conical flask was then incubated at 30˚C for 24 hours. The sample was then extracted using 96.5ml methanol and 3.5ml distilled water. The conical flask was then placed on a mechanical shaker and shaken for 3 minutes in every 20 minutes for 3 hours. 2mls of solution was then extracted and spun in a MSE Micro centaur at maximum speed for 5 minutes. The absorbance of the red supernatant was measured at 485nm against the methanol blank using a Cecil Spectrophotometer 1000 Model. A calibration curve was produced by using a stock solution of triphenyl formazan (TPF) to produce 500, 1000, 1500, 2000 and 2500 µg per 100ml. The stock solution was produced dissolving 100mg of TPF in 100ml of methanol.

6.3 Results

Main Findings

Physical Analyses

Similar trends to Chapter 5 were observed within the work reported in this chapter. The bulk density values were constant over the six month storage trial. A similar correlation to the peat-reduced trials was found, with high R^2 values, Figure 6.3.2. As the percentage of composted green material increased, the bulk density increased. However the overall bulk density values were lower for the peat-free mixtures. This was due to the diluting factor of the other material with lower bulk densities. For example the peat-reduced mixture containing 50% of Sample 4 stored under glasshouse conditions had an average bulk density of 546.18g/L (+/- 9.74g/L) compared to the peat-free mixture which had a bulk density of 503.94g/L (+/- 6.56g/L). As stated in Chapter 2, a bulk density of less than 500g/L is preferable. The majority of the peat-free mixtures are below this value, with the mixture containing 50% of composted green material being slightly over this value. The 'commercial peat-free standard' had bulk density value similar to the 10% mixtures, as shown on Figure 6.3.1.

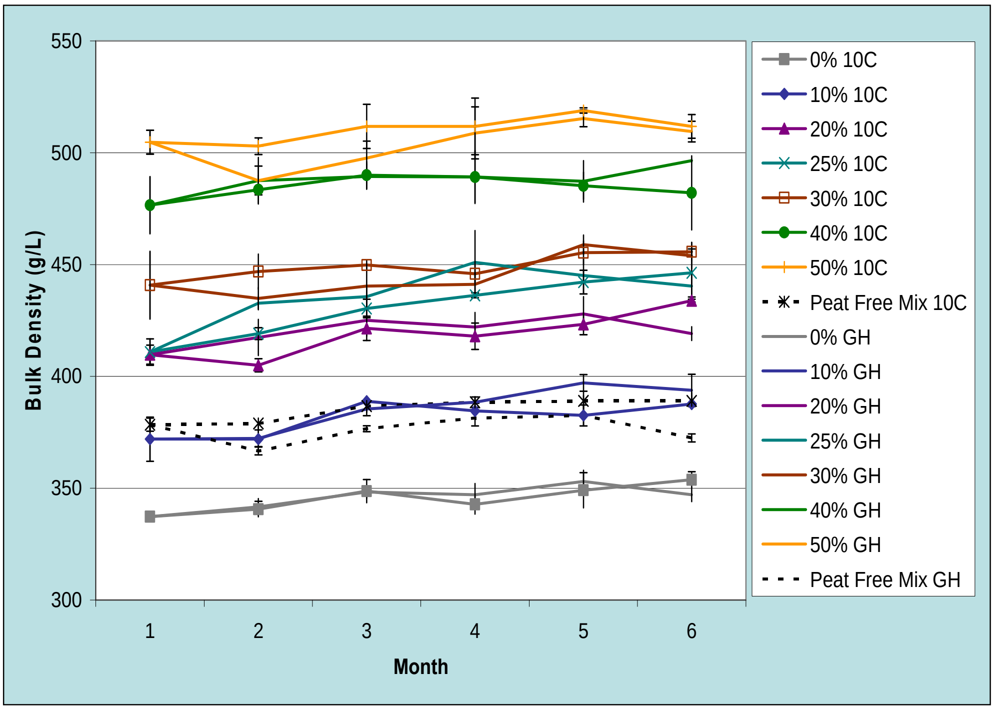


Figure 6.3.1. Bulk density values for the peat free growth/storage trial. The 95% confidence limits are indicated by error bars.

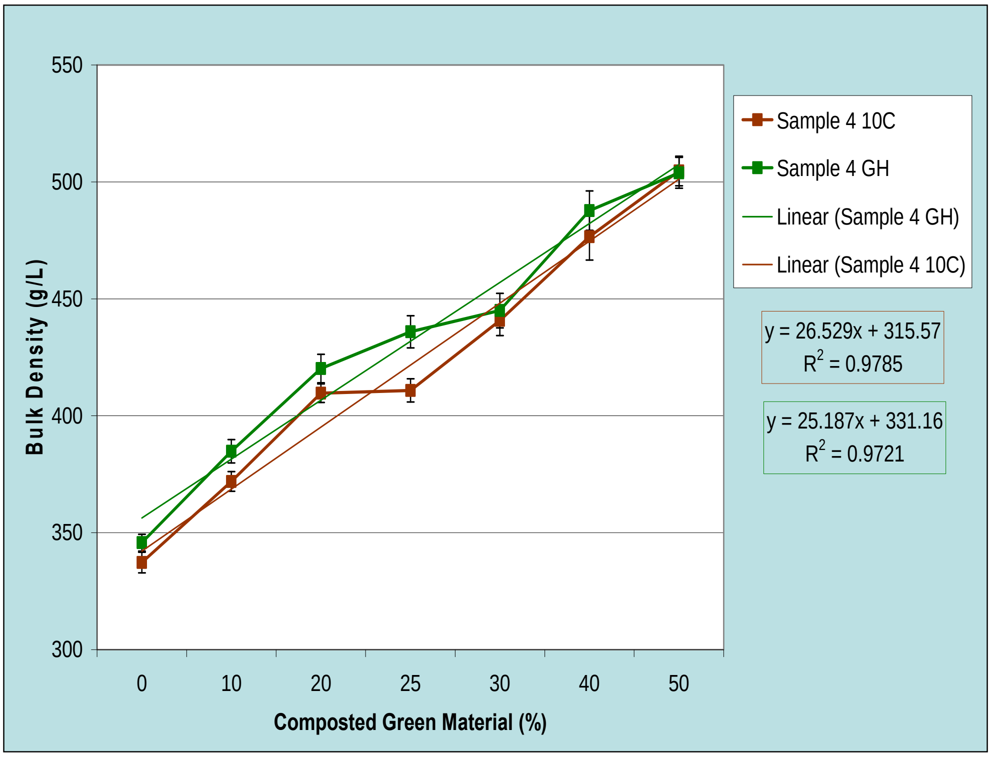


Figure 6.3.2. The relationship between bulk density and the proportions of composted green material. The 95% confidence limits are indicated by error bars.

With respect to organic matter and ash contents, similar correlations found with the peat-reduced mixes were also seen in the peat-free mixes. As the percentage of composted green material increased the organic matter content decreased and the ash content increased, with high correlations, Figures 6.3.4, 6.3.6, 6.3.8, 6.3.10. Both the organic matter (<2mm) and the ash (<2mm) samples showed little variation over the six month storage trial. The samples (>2mm) were still fairly constant, but with larger variations compared to the (<2mm) samples. This is indicated by the variation in 95% confidence limits between Figures 6.3.6, 6.3.10 and 6.3.4, 6.3.8.

The 50% peat-free mixtures contained approximately 50% organic matter in both the (<2mm) and (>2mm) samples, Figure 6.3.3 & 6.3.5, which was higher than the peat-reduced mixtures.

Ash contents; (< 2mm) and (>2mm) were lower in the peat-free mixtures compared to the peat-reduced mixture in both storage conditions. For example the peat-reduced mixture containing 50% of Sample 4 stored under glasshouse conditions, had an average ash content of 58.12% (+/- 2.28%) compared to the peat-free mixture containing 50% of Sample 4 stored under glasshouse conditions, which had an ash content of 48.52% (+/- 7.88%).

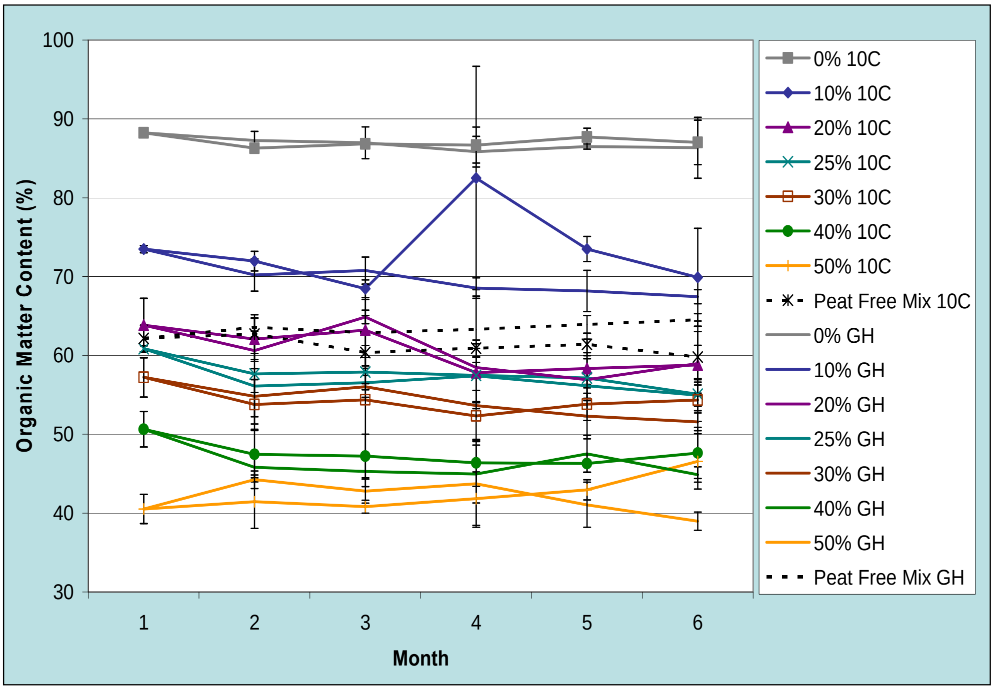


Figure 6.3.3. Organic matter contents (<2mm) for the peat free growth/storage trial. The 95% confidence limits are indicated by error bars.

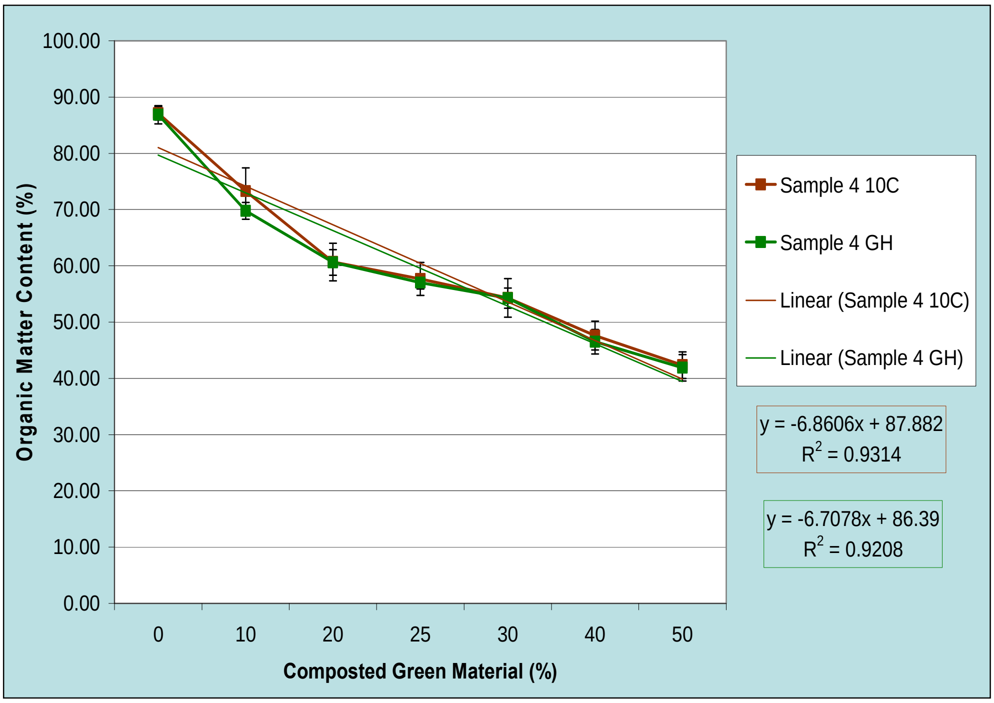


Figure 6.3.4. The relationship between organic matter content (<2mm) and the proportions of composted green material. The 95% confidence limits are indicated by error bars.

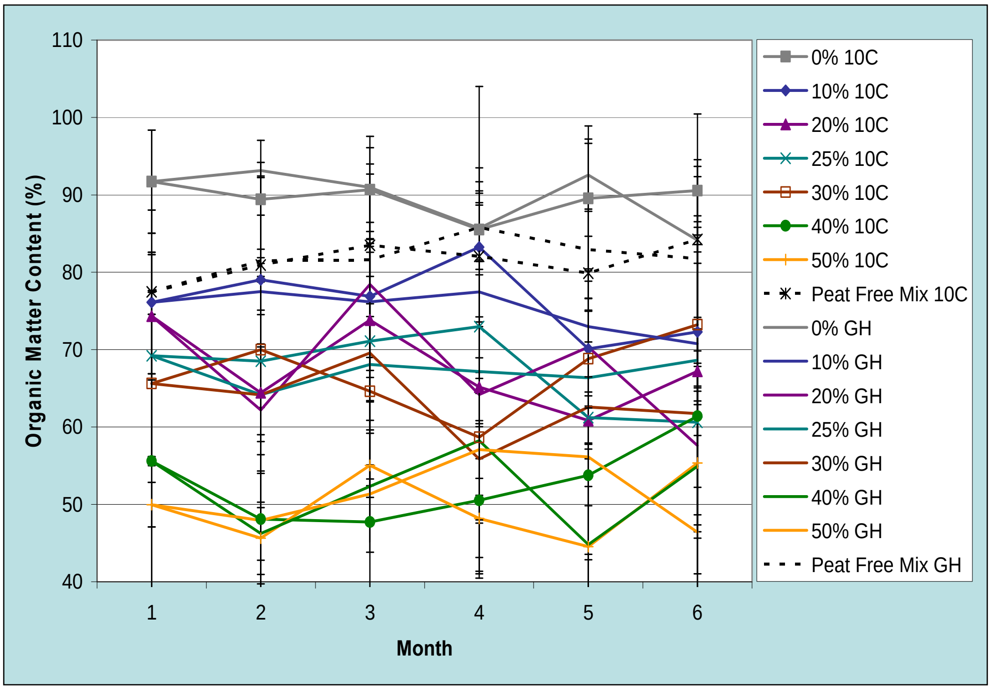


Figure 6.3.5. Organic matter content (>2mm) for the peat free growth/storage trial. The 95% confidence limits are indicated by error bars.

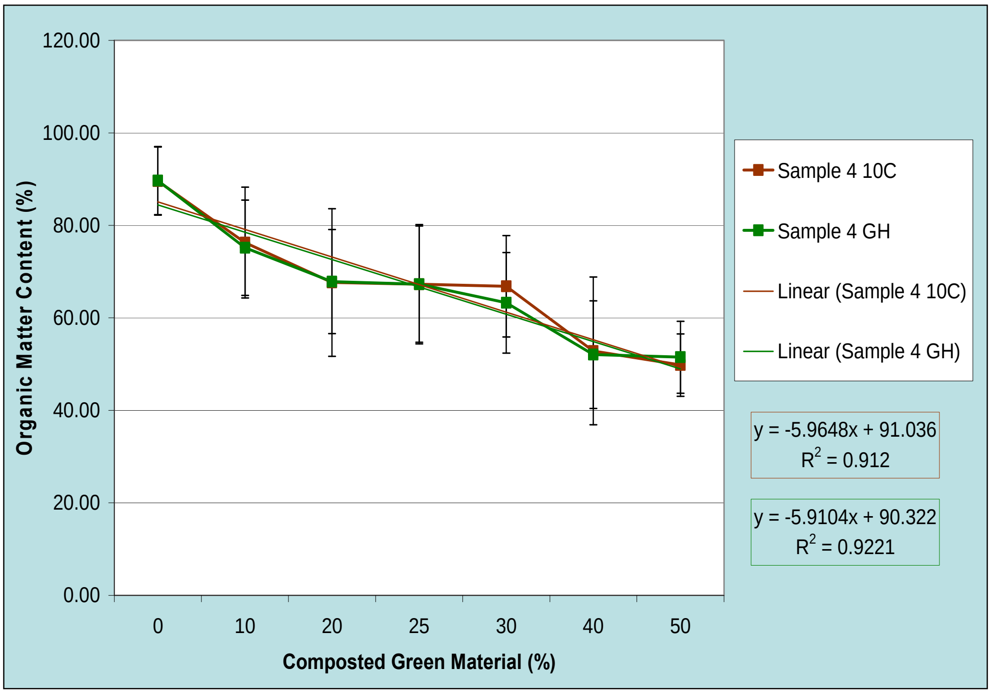


Figure 6.3.6. The relationship between organic matter content (>2mm) and the proportions of composted green material. The 95% confidence limits are indicated by error bars.

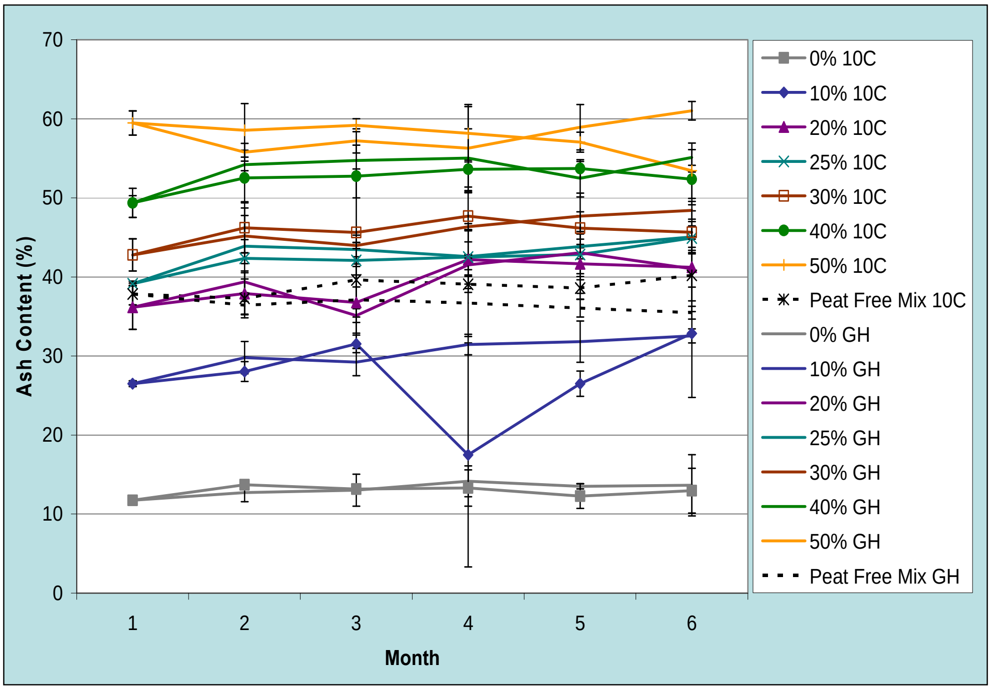


Figure 6.3.7. Ash content (<2mm) for the peat free growth/storage trial. The 95% confidence limits are indicated by error bars.

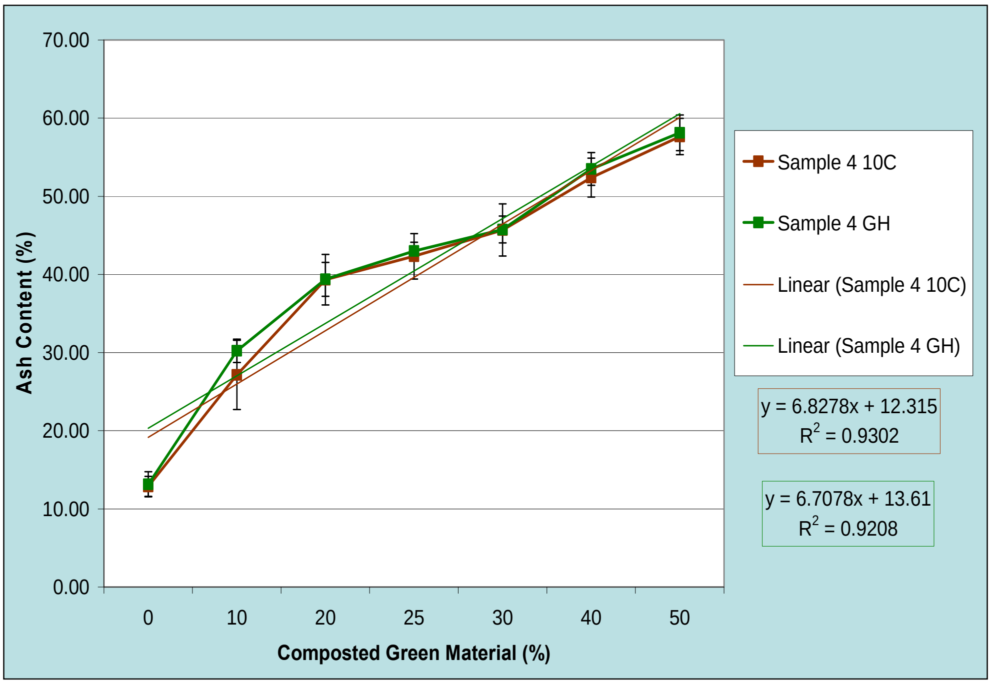


Figure 6.3.8. The relationship between ash content (<2mm) and the proportions of composted green material. The 95% confidence limits are indicated by error bars.

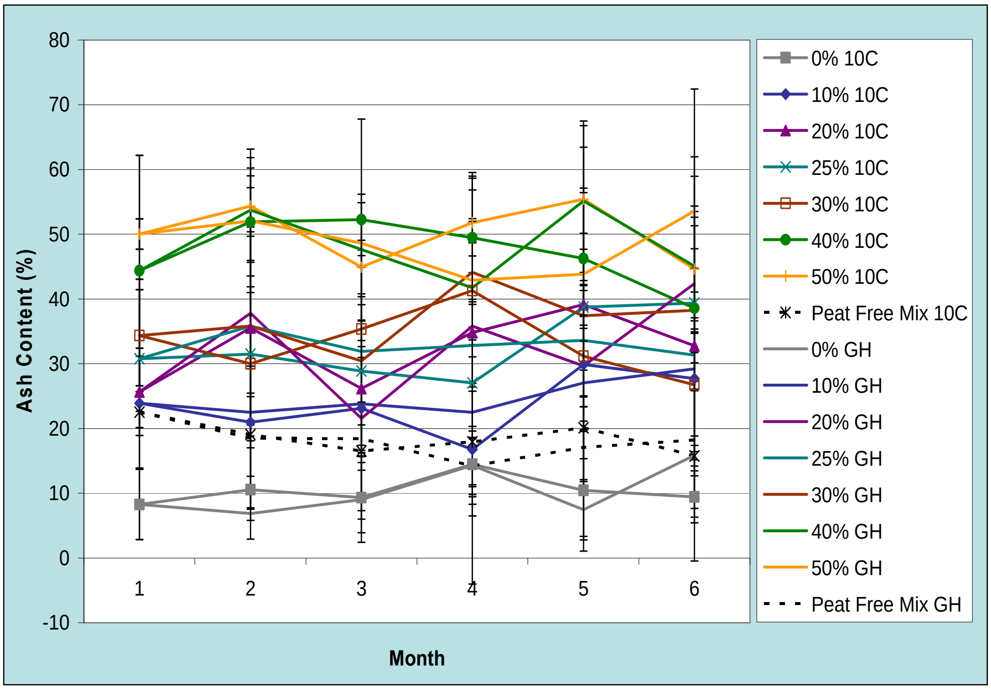


Figure 6.3.9. Ash content (>2mm) for the peat free growth/storage trial. The 95% confidence limits are indicated by error bars.

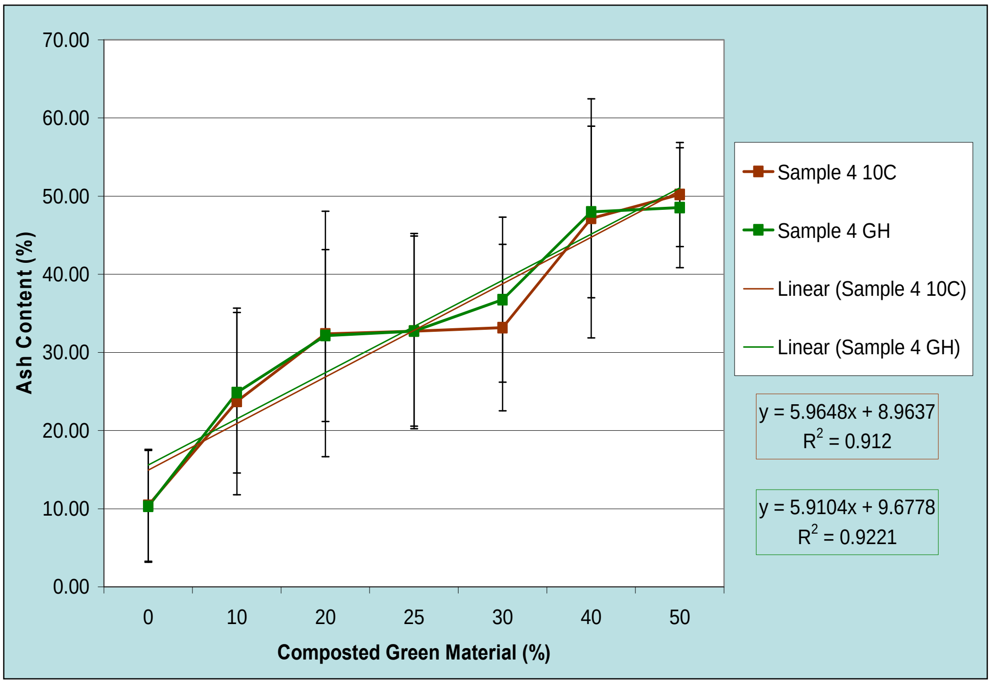


Figure 6.3.10. The relationship between ash content (>2mm) and the proportions of composted green material. The 95% confidence limits are indicated by error bars.

With the average lettuce germination percentages, there was a correlation between the percentage germination and the proportions of composted green material. As the percentage of composted green material increased, the germination percentage decreased, with R^2 values ranging from 0.84 – 0.97 (Figure 6.3.12). For both storage conditions, germinations were similar and fairly constant in the mixtures containing lower percentages of composted green material. As the percentage increased, variability within the germination percentages increased, (Figure 6.3.11). The ‘commercial peat-free standard’ had a similar germination to the 0-20% composted green material mixtures.

By comparing the peat-reduced and the peat-free average germination percentages, Figures 5.3.12 and 6.3.12, it would appear that the mixtures had very similar germination percentages. For example the peat-reduced mixture containing 10% of Sample 4 had a germination percentage of 92.25% +/- 8.13%, compared to the peat-free mixture containing 10% of Sample 4 having a germination percentage of 94.33% +/- 5.85%, a similar pattern was observed in the higher concentrations of composted green material. The peat-reduced mixture containing 50% composted green material had a germination percentage of 74.25% +/- 16.93%, compared to the peat-free mixture having a germination percentage of 69.33% +/- 13.77%.

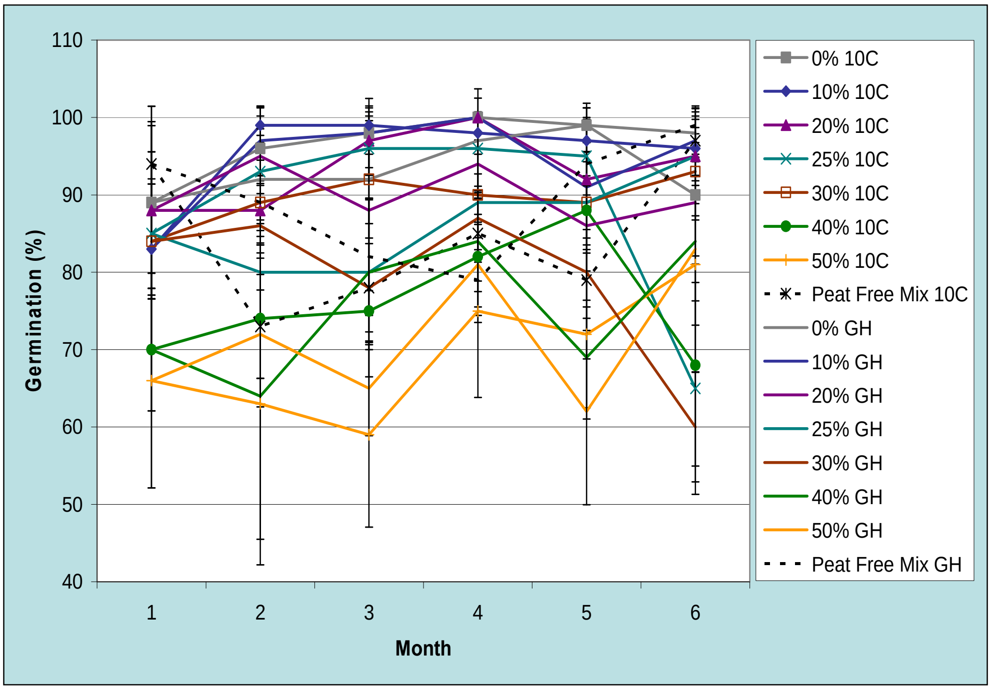


Figure 6.3.11. Lettuce germination values for the peat free growth/storage trial. The 95% confidence limits are indicated by error bars.

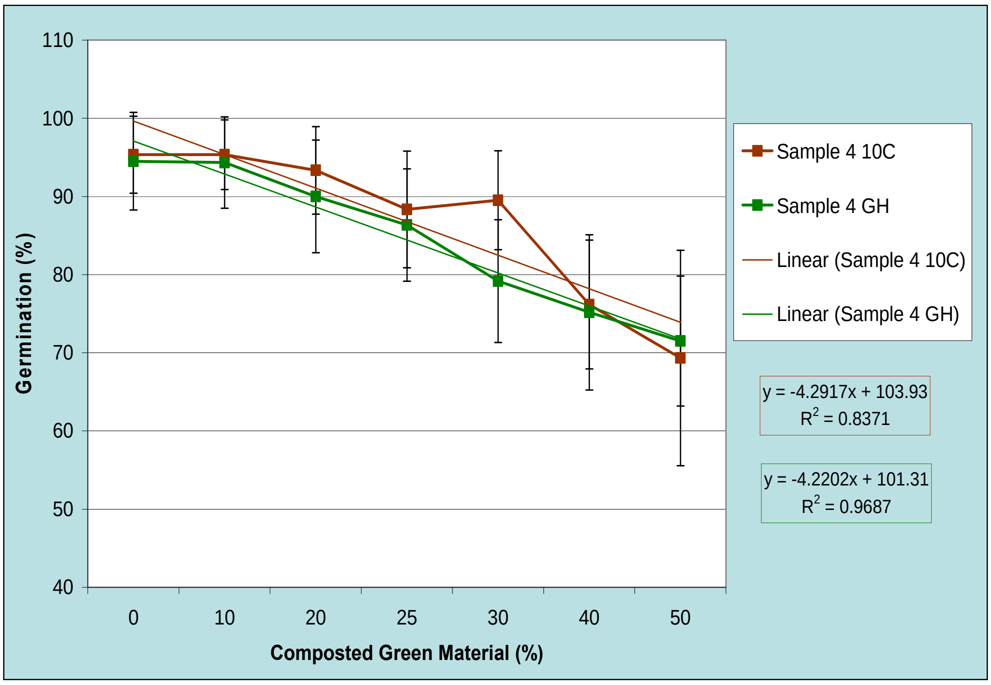


Figure 6.3.12. The relationship between lettuce germination and the proportions of composted green material. The 95% confidence limits are indicated by error bars.

The tomato germination was also correlated with the proportions of composted green material in the growing media, similar to the peat-free mixtures for lettuce germinations, Figures 6.3.14, with R^2 values ranging from 0.84- 0.98. For both storage conditions, germinations were similar and fairly constant in the mixtures containing lower percentages of composted green material. As the percentage increased, variability within the germination percentages increased, (Figure 6.3.13). In both storage conditions, the peat-free mixtures containing composted green material achieved higher germination percentages than the 'commercial peat-free standard' for the 0-30% mixtures.

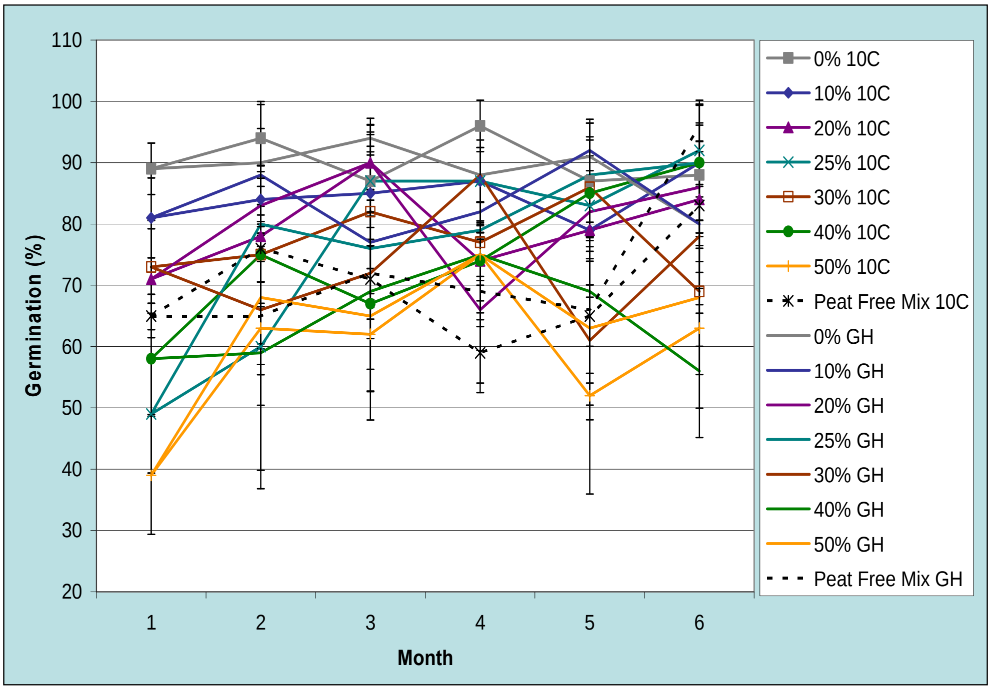


Figure 6.3.13. Tomato germination values for the peat free growth/storage trial. The 95% confidence limits are indicated by error bars.

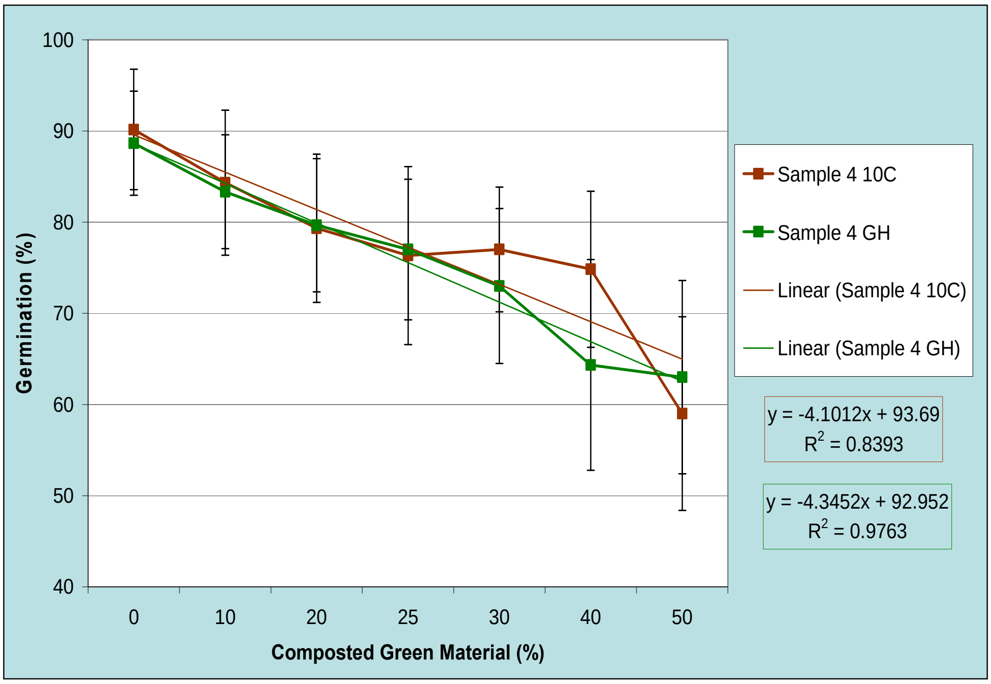


Figure 6.3.14. The relationship between tomato germination and the proportions of composted green material. The 95% confidence limits are indicated by error bars

With respect to fresh weight, similar correlations that were found within the peat-reduced mixtures were also seen in the peat-free mixtures, however with more significant correlations (Figure 6.3.15, 6.3.16 and Table 5.3.1). As the percentage of composted green material increased, the fresh weights increased. This was indicated by high R^2 values ranging from 0.90-0.92 for both the 10˚C and glasshouse storage conditions. For both the 10˚C constant temperature and the glasshouse conditions, the 40 and 50% peat-free mixtures had similar fresh weights to the ‘commercial peat-free standard’.

Recording dry weight values produce more accurate findings, as the values only concern the actual plant tissue produced. Similar findings were observed for the dry weights and the fresh weights. The peat-free mixtures containing 40 and 50% composted green material mixtures produced similar values to the ‘commercial peat-free standard’ for both storage conditions, Figure 6.3.17. There is a correlation between the dry weights and the percentage of composted green material, as the percentage of composted green material increases, the dry weights increase, producing R^2 values ranging from 0.83-0.87, indicating there is a strong correlation, Figure 6.3.18.

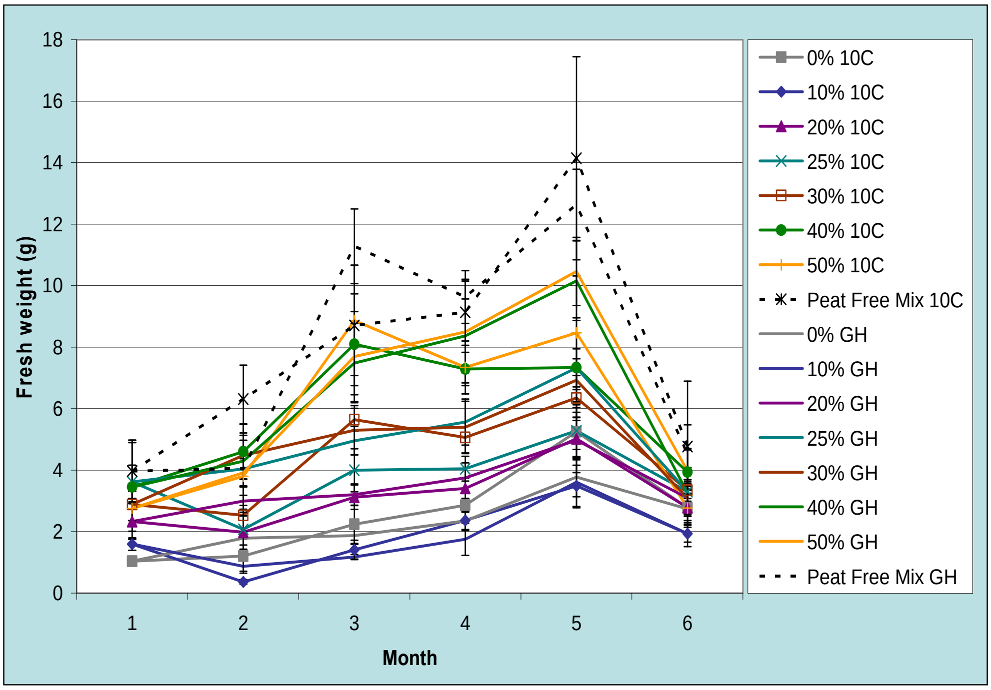


Figure 6.3.15. Fresh weight values for the peat free growth/storage trial. The 95% confidence limits are indicated by error bars.

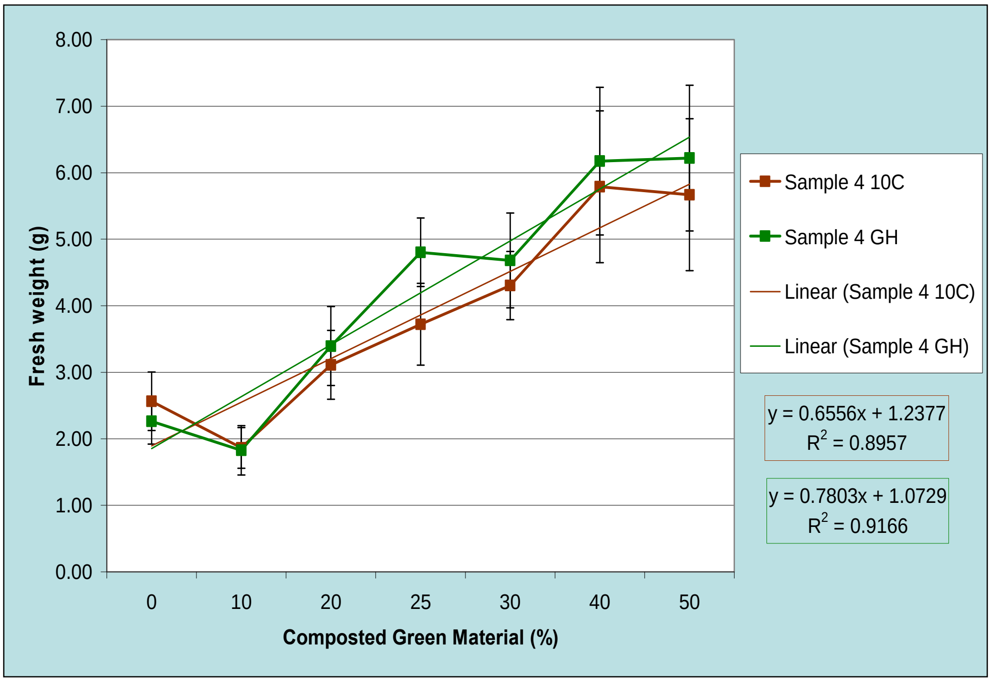


Figure 6.3.16. The relationship between fresh weight and the proportions of composted green material. The 95% confidence limits are indicated by error bars

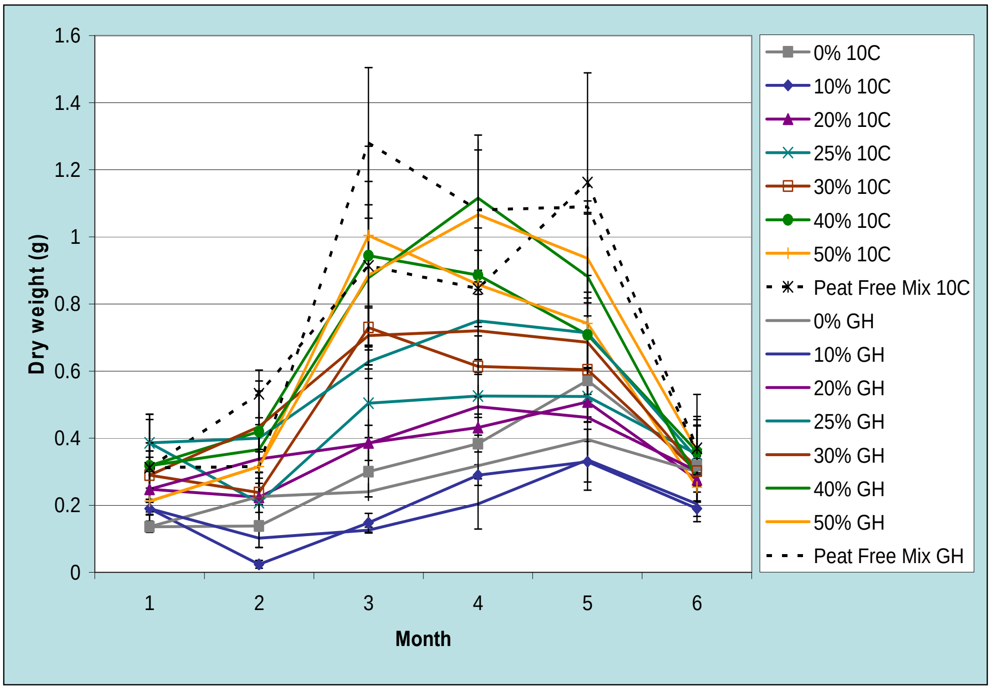


Figure 6.3.17. Dry weight values for the peat free growth/storage trial. The 95% confidence limits are indicated by error bars.

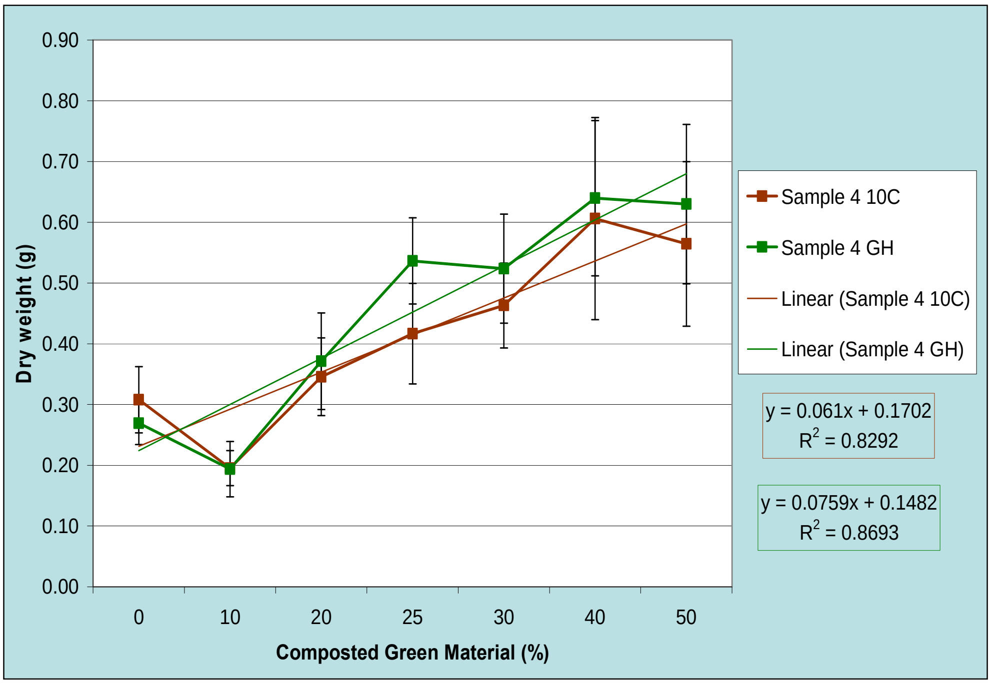


Figure 6.3.18. The relationship between dry weight and the proportions of composted green material. The 95% confidence limits are indicated by error bars

Chemical Analyses

The pH values for the peat-free mixtures produced a similar correlation to the peat-reduced mixtures. As the proportions of composted green material increase, the pH increases (Figure 6.3.20). The pH values of the peat-free mixtures were fairly constant over the six month storage trial, Figure 6.3.19. This was indicated by low 95% confidence limits. However the pH values obtained for the 'commercial peat-free standard' in both the 10˚C and glasshouse storage conditions, varied considerably. For example the initial pH for the 'commercial peat-free standard' stored under glasshouse conditions was 7.85 +/- (0.0) which decreased to 6.23 +/- (0.08) within the six month storage studies. This initial high pH could be a result of the high ammonia content.

Overall the pH values obtained in the peat-free mixtures were similar to the peat-reduced mixtures. The mixtures containing lower percentages of composted green material had slightly lower pH values for the peat-reduced mixtures compared to the peat-free mixtures. For example, the peat-reduced mixture containing 10% composted green material stored under glasshouse conditions had an average pH of 5.91 +/- (0.26) compared to the peat-free mixture containing 10% composted green material stored under glasshouse conditions which had a pH of 6.09 +/- (0.04), this is due to the low pH of peat.

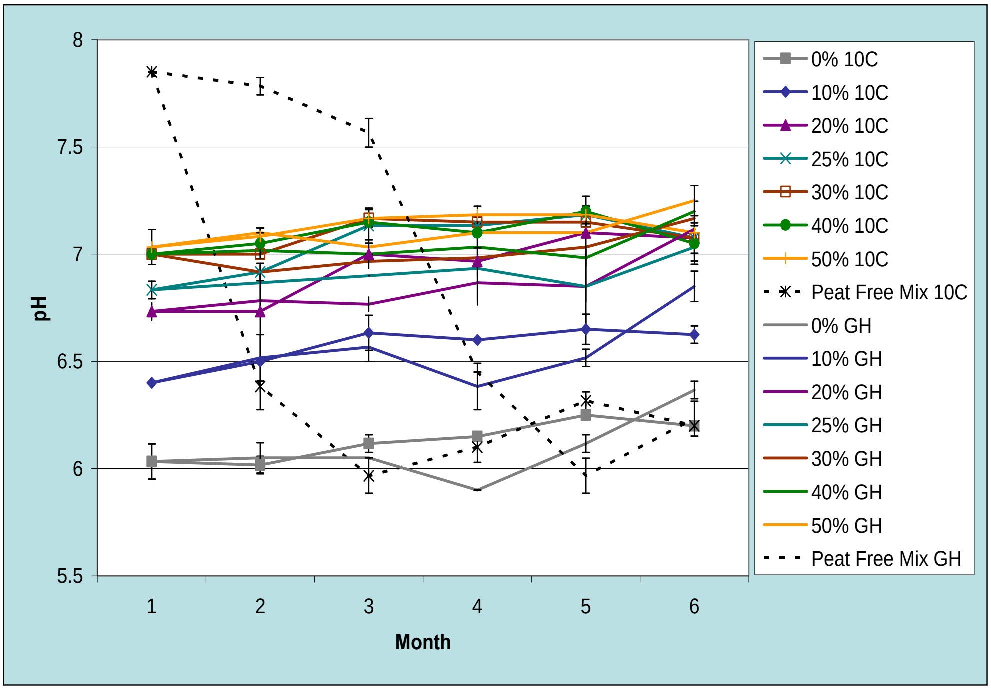


Figure 6.3.19. pH values for the peat free growth/storage trial. The 95% confidence limits are indicated by error bars.

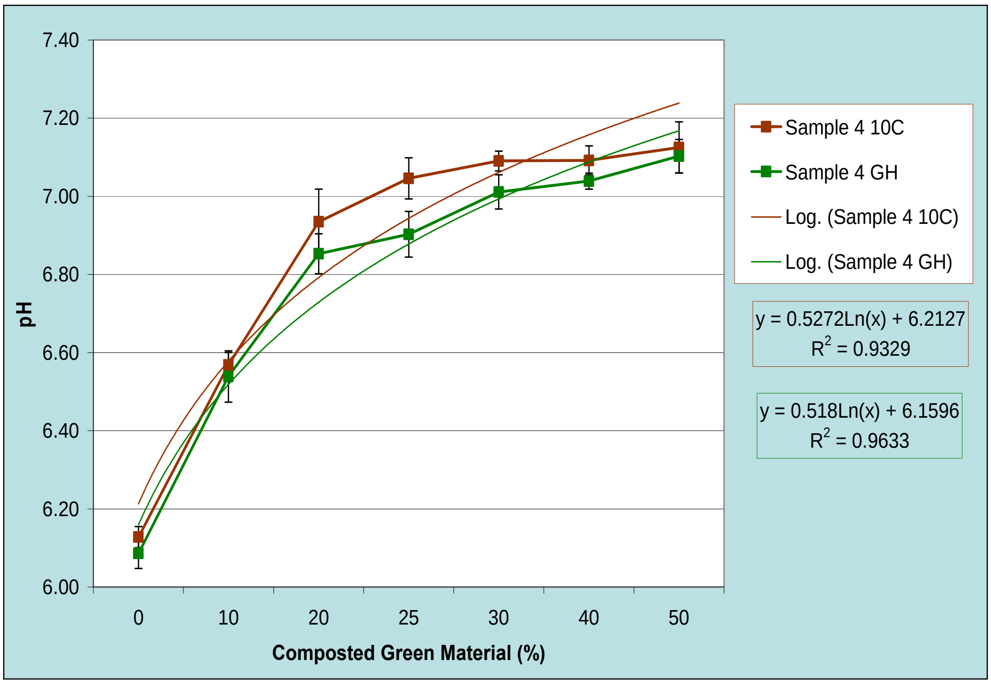


Figure 6.3.20. The relationship between pH and the proportions of composted green material. The 95% confidence limits are indicated by error bars

With electrical conductivity, again there is a similar correlation to the peat-reduced mixtures, Figures 6.3.21 and 6.3.22. However the average electrical conductivity values obtained for the peat-free mixtures were considerably higher than the peat-reduced mixtures. For example the peat-reduced had an electrical conductivity of 988.75µmhos +/- (139.31µmhos) compared to the peat-free mixture containing 50% composted green material stored under glasshouse conditions which had an electrical conductivity of 1669.44µmhos +/- (61.46µmhos). This increase in electrical conductivity is due to the increased electrical conductivity within the composted green material. By comparing Table 5.1.1 and 6.2.1, the electrical conductivity values for Sample 4 used in the peat-reduced trial are considerably lower than the Sample 4 used in the peat-free trials, again indicating the variation in composted green material.

For both the 10˚C and glasshouse storage conditions, the 'commercial peat-free standard' had initially lower electrical conductivity values, which then increased throughout the six month trial. Many of the macro and micro nutrients in the 'commercial peat-free standard' had an initially lower concentration, which then increased. This is probably to gain a lower salt content for germination.

The peat-free mixture containing wood waste, composted pine bark and composted bark i.e. the 0% mixture containing no composted green material had a very low electrical conductivity value, indicating very little nutritional value for the plant.

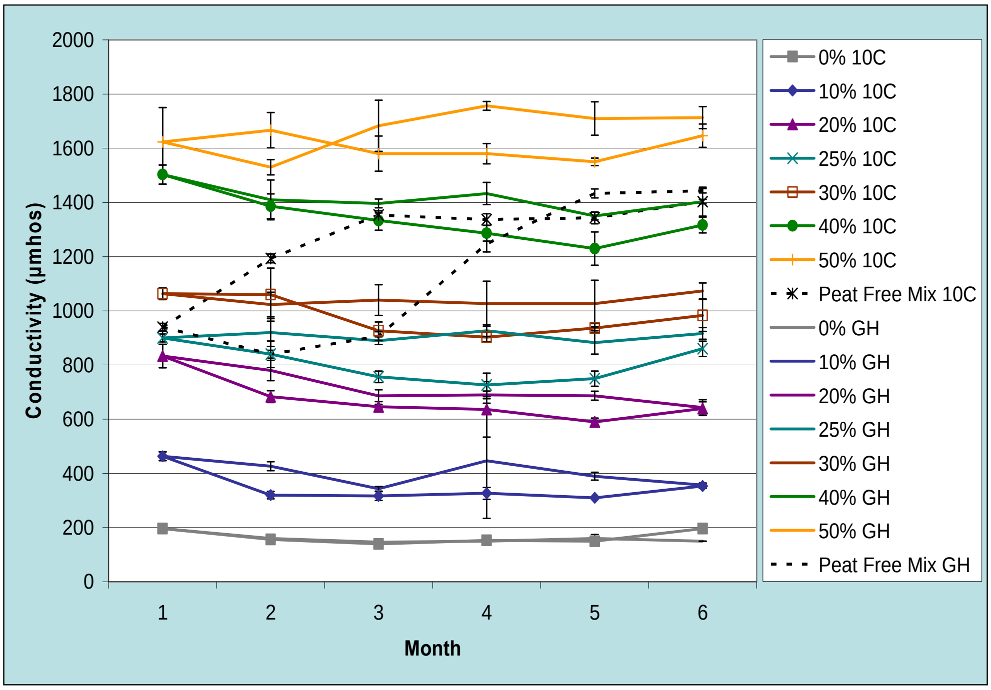


Figure 6.3.21. Electrical conductivity values for the peat free growth/storage trial. The 95% confidence limits are indicated by error bars.

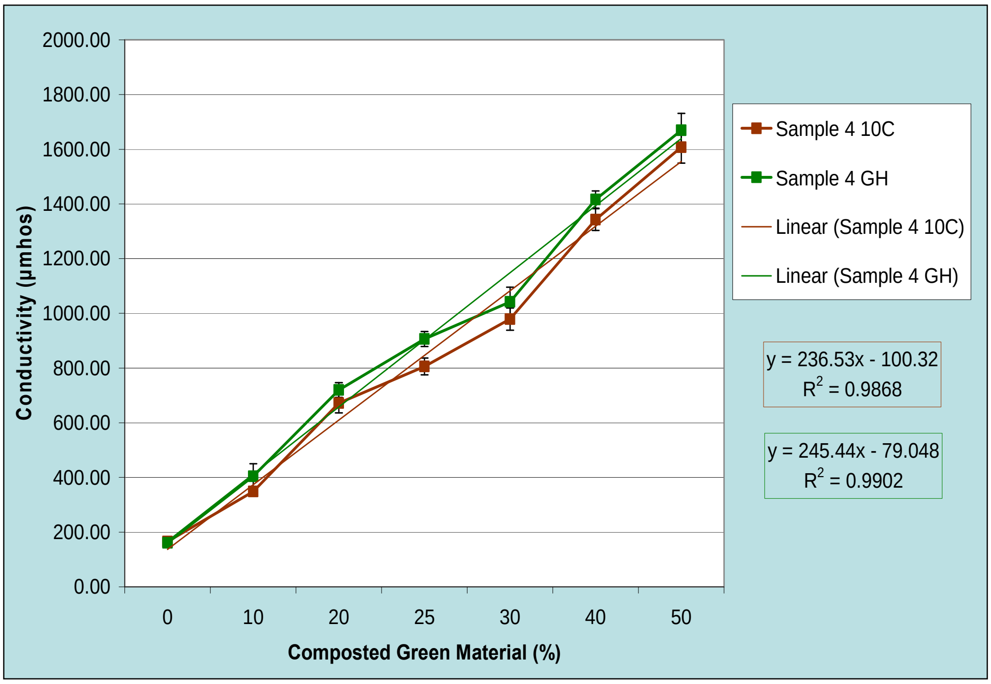


Figure 6.3.22. The relationship between electrical conductivity and the proportions of composted green material. The 95% confidence limits are indicated by error bars

A similar correlation occurred within the nitrate-nitrogen, phosphorus and potassium concentrations. As the proportions of composted green material increased, the nutrient concentration increased.

Overall the nitrate concentrations between the proportions of composted green materials and nitrate concentrations in the media varied a little over the six month storage trial (Figure 6.3.23). As the percentage of composted green material increased, the nitrate concentration increased, with R^2 values ranging from 0.91-0.96, (Figure 6.3.24). For both the 10˚C and glasshouse storage conditions the 'commercial peat-free standard' had initial low concentrations of nitrates which then increased to a constant level. For example the 'commercial peat-free standard' stored under glasshouse conditions had an initial nitrate concentration of 73.5mg/L +/- (3.24 mg/L), and then rose to 1743.33 mg/L +/- (46.01 mg/L) and then remained at approximately 1305.86 mg/L +/- (33.88 mg/L). Compared to the peat-reduced mixtures, the nitrate concentration in the peat-free mixtures were considerably higher. The sample of composted green material used in the peat-free trial had higher concentrations of nitrates compared to the sample used in the peat-reduced mixtures, again indicating the variation in composted green material, from the same source!

The peat-free mixtures contained very low concentration of ammonium, in both storage conditions (Figure 6.3.25). However the 'commercial peat-free standard' in both the glasshouse and 10˚C storage conditions had initial high ammonium concentrations which fell dramatically during the trial. For the 'commercial peat-free standard' stored under glasshouse conditions the initial concentration was 171.73 mg/L +/- (0.03 mg/L), which decreased to 0.75mg/L(+/-0.26mg/L).

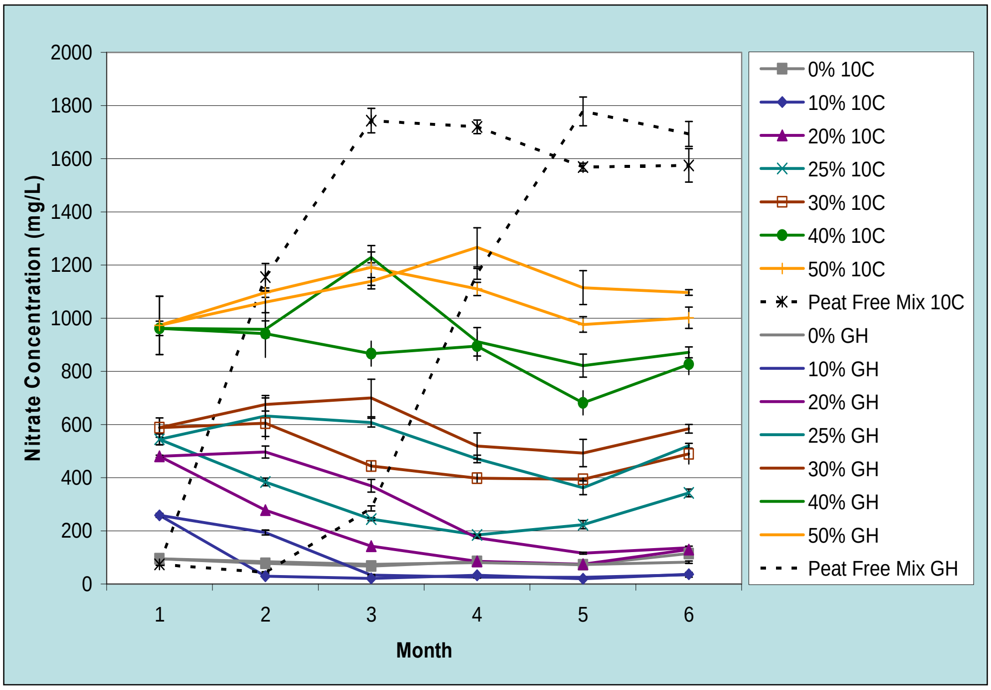


Figure 6.3.23. Nitrate concentration for the peat free growth/storage trial. The 95% confidence limits are indicated by error bars.

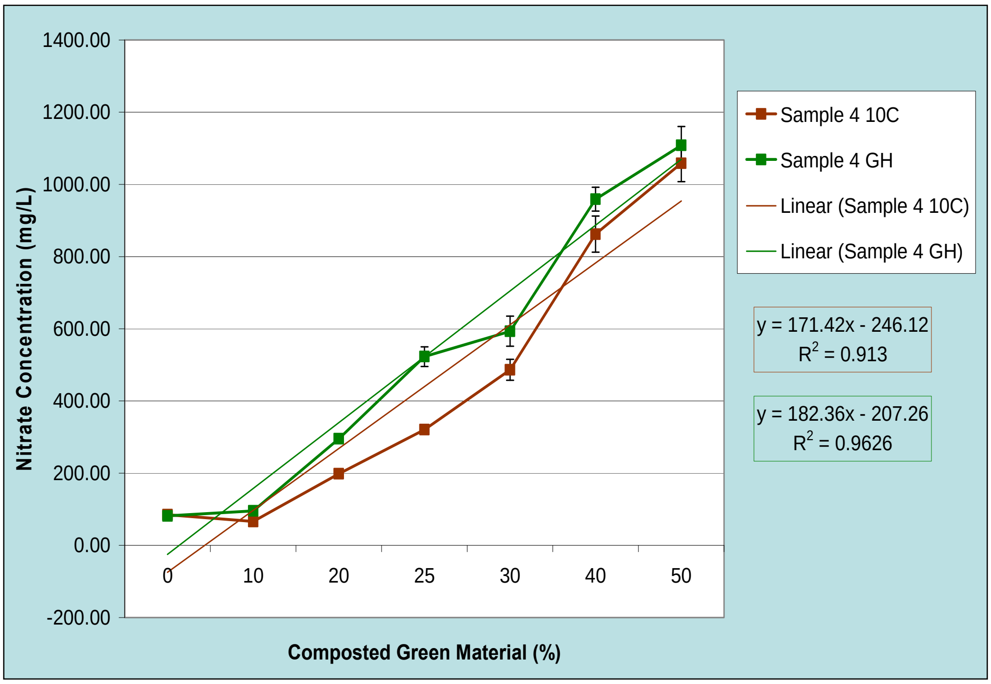


Figure 6.3.24. The relationship between nitrate concentration and the proportions of composted green material. The 95% confidence limits are indicated by error bars

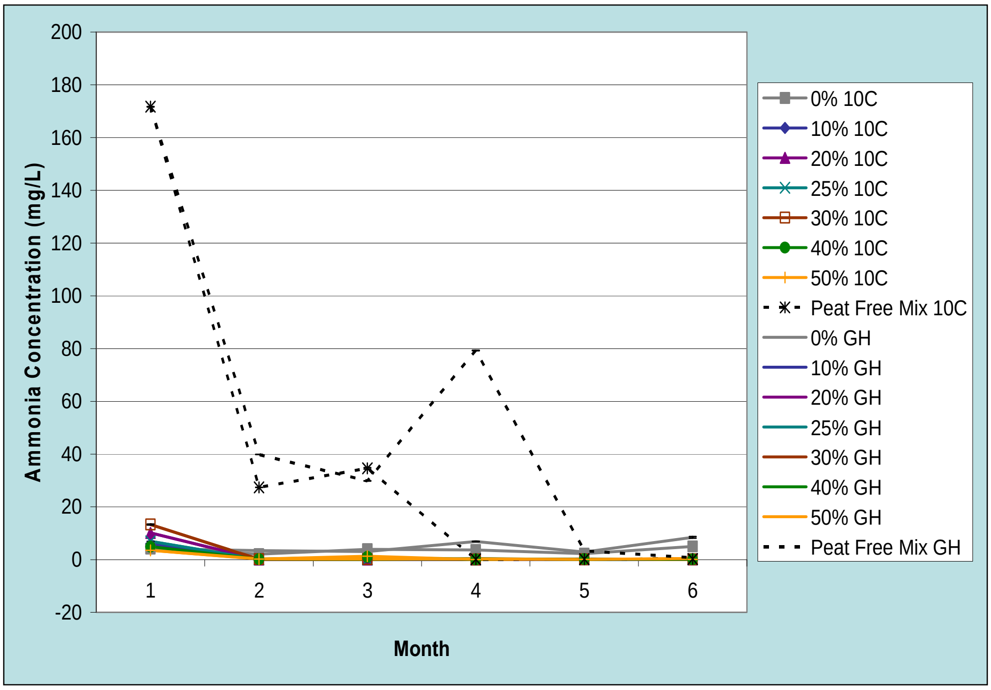


Figure 6.3.25. Ammonia concentration for the peat free growth/storage trial. The 95% confidence limits are indicated by error bars.

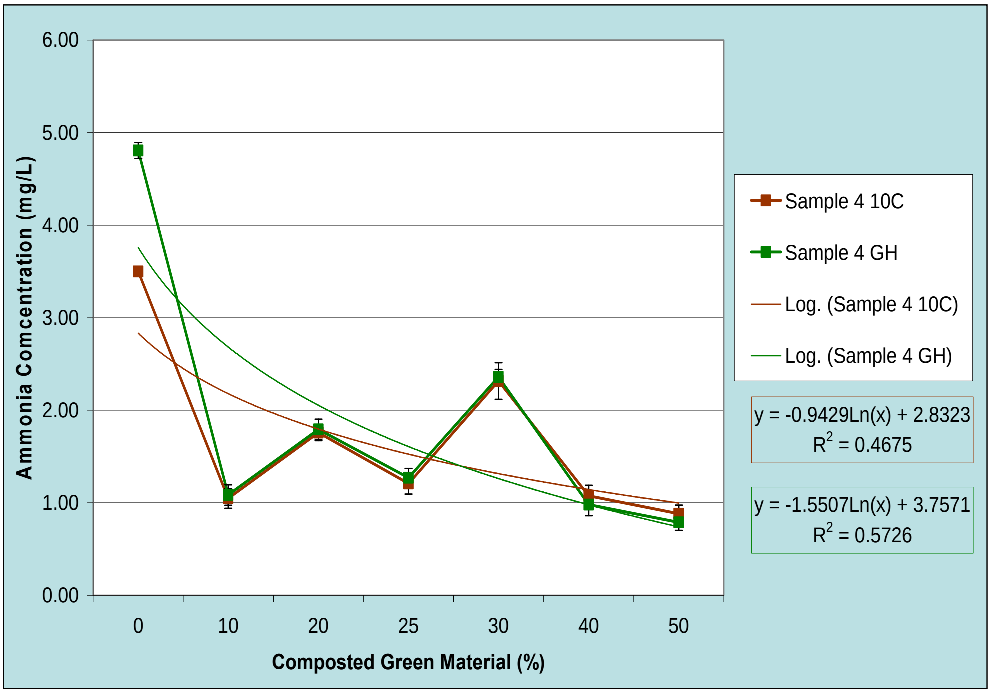


Figure 6.3.26. The relationship between ammonia concentration and the proportions of composted green material. The 95% confidence limits are indicated by error bars

As with nitrate-nitrogen, when the percentage of composted green material increased, the concentration of phosphorus increases (Figure 6.3.28). The mixtures stored at 10˚C produced a strong relationship with an R^2 value equal to 0.94 however the mixture containing 30% composted green material, stored under glasshouse conditions had a lower concentration of phosphorus throughout the six month trial and therefore reduced the correlation value producing a lower R^2 value. As storage time increased, the concentration of phosphorus increased, for example the mixture containing 30% composted green material stored at 10˚C has an initial concentration of 8.44 mg/L (+/- 3.66 mg/L), this increased throughout the six month trial to 21.49 mg/L (+/- 1.22 mg/L), and this pattern is observed within both the 10˚C and glasshouse storage conditions. This indicated a slow release form of phosphorus within the composted green material, Figure 6.3.27.

The same pattern occurs within the 'commercial peat-free standard' but not to the same extent. The mixtures containing higher percentages of composted green material had similar phosphorus concentrations to the 'commercial peat-free standard'. The peat-free mixtures contained higher concentrations of phosphorus compared to the peat-reduced mixtures.

A similar correlation for peat-free and peat-reduced mixtures was observed in the potassium results, with high R^2 values, Figure 6.3.30. Overall the peat-free mixtures had higher potassium concentration than the peat-reduced mixtures. The mixtures containing lower percentages of composted green material had fairly constant potassium values throughout the six month trial; however the mixtures containing higher proportions of composted green material had varied concentrations of potassium, as shown in Figure 6.3.29.

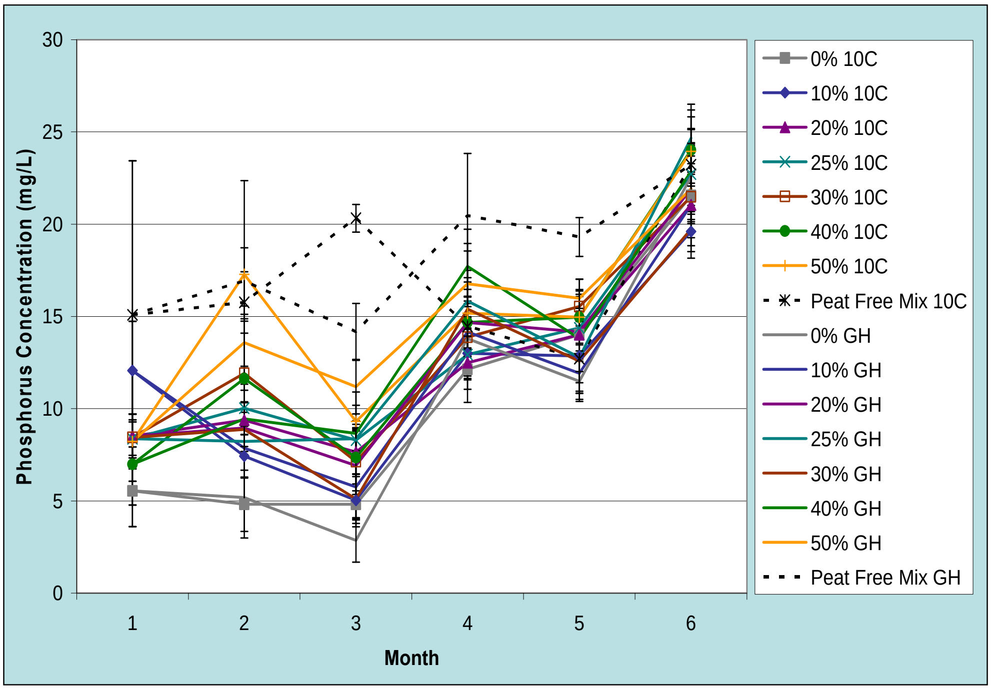


Figure 6.3.27. Phosphorus concentration for the peat free growth/storage trial. The 95% confidence limits are indicated by error bars.

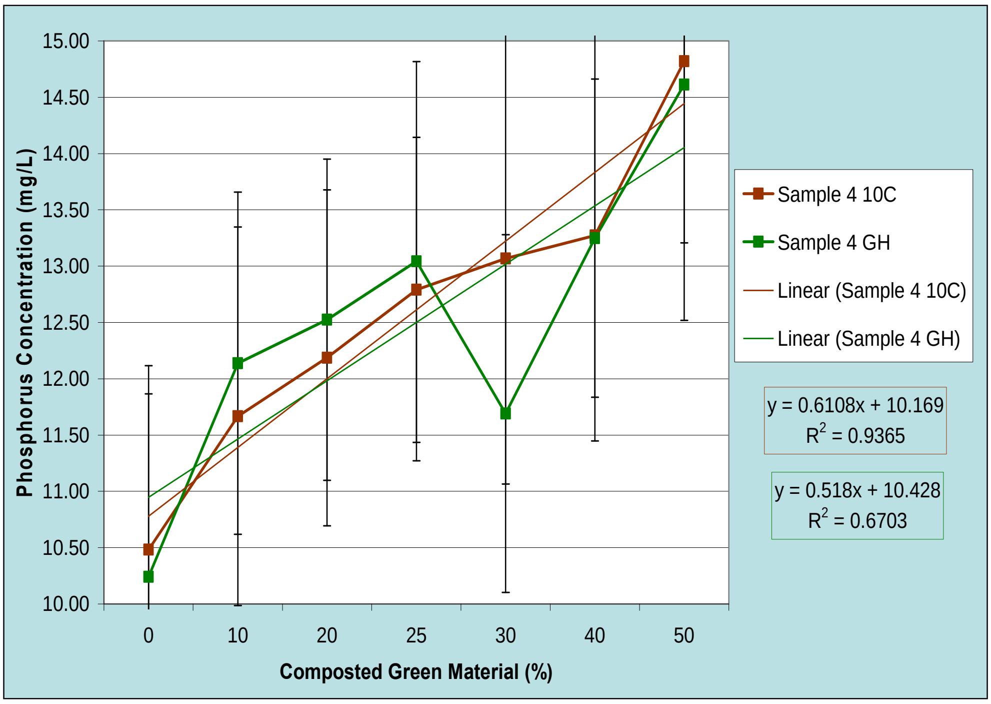


Figure 6.3.28. The relationship between phosphorus concentration and the proportions of composted green material. The 95% confidence limits are indicated by error bars

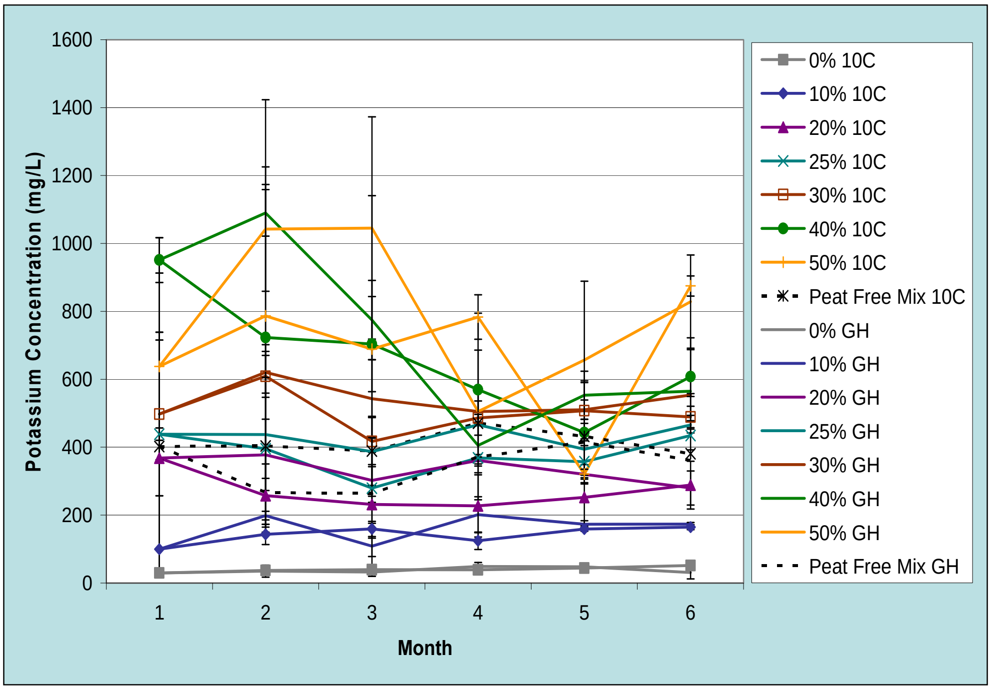


Figure 6.3.29. Potassium concentration for the peat free growth/storage trial. The 95% confidence limits are indicated by error bars.

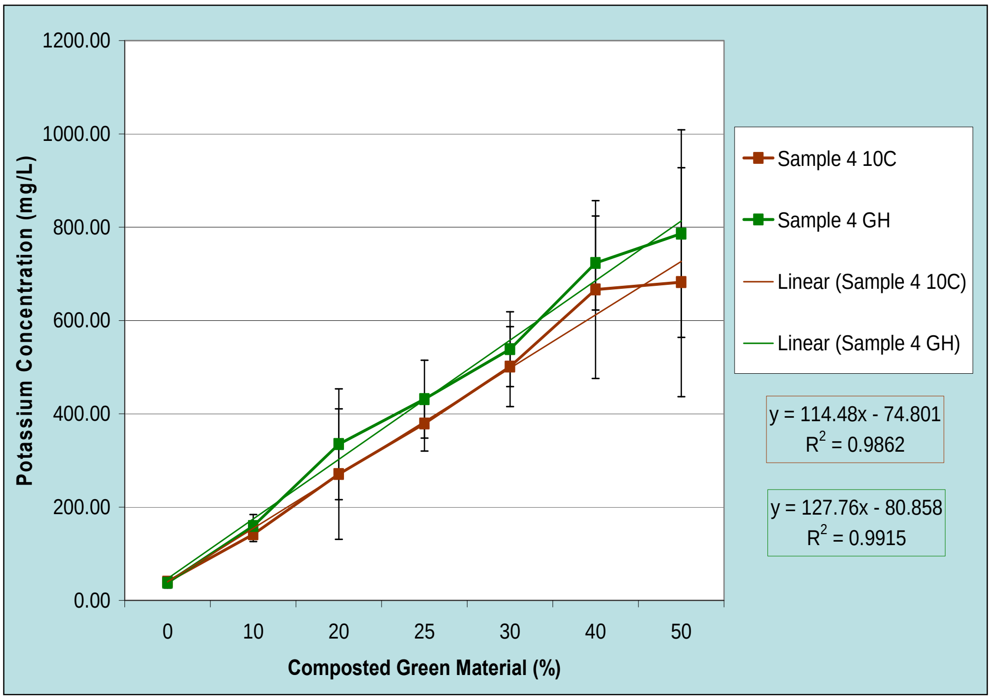


Figure 6.3.30. The relationship between potassium concentration and the proportions of composted green material. The 95% confidence limits are indicated by error bars

Magnesium concentrations within the peat-free mixtures were fairly low, but remained stable throughout the six month storage study (Figure 6.3.31). An opposite correlation to the peat-reduced mixtures was seen, with high R^2 values. As the percentage of composted green material increased, the magnesium concentration increased, Figure 6.3.32.

Calcium concentrations were somewhat low in the peat-free mixtures. However the concentration remained fairly constant for the duration of the trial (Figure 6.3.33). A similar correlation to the peat-reduced mixtures, between the percentage of composted green material and the calcium concentration was seen, Figure 6.3.34, with high R^2 values ranging from 0.97 – 0.99. As the proportions of composted green material increased, the calcium concentration increased.

Within the 'commercial peat-free standard' a similar trend to the nitrate-nitrogen concentrations was observed for both magnesium and calcium concentration. For both the 10˚C and glasshouse stored 'commercial peat-free standards' the initial concentrations of magnesium and calcium were lower and then increased before stabilising. For example the 10˚C 'commercial peat-free standards' had an initial magnesium concentration of 4.43mg/L +/- (0.76 mg/L), this increased to 91.06mg/L +/- (4.67 mg/L) and then stabilised at approximately 58.11 mg/L +/- (8.05 mg/L). The 'commercial peat standard' stored at 10˚C had an initial calcium concentration of 18.96mg/L +/- (2.07 mg/L), this rose to 314.43mg/L +/- (12.47 mg/L) and then stabilised at around 203.61 mg/L +/- (23.96 mg/L).

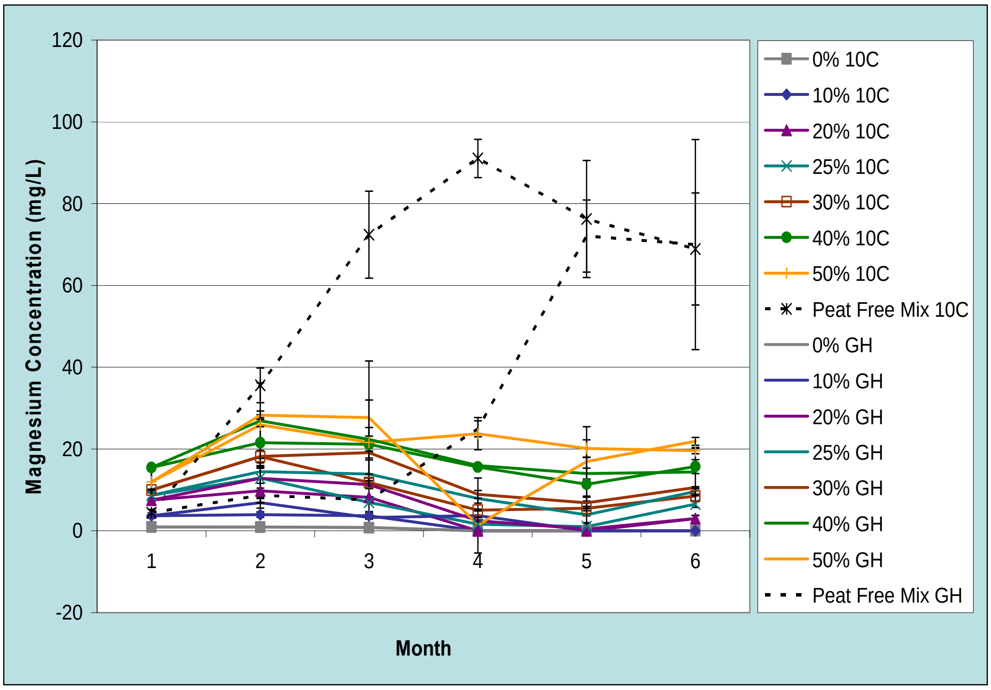


Figure 6.3.31. Magnesium concentration for the peat free growth/storage trial. The 95% confidence limits are indicated by error bars.

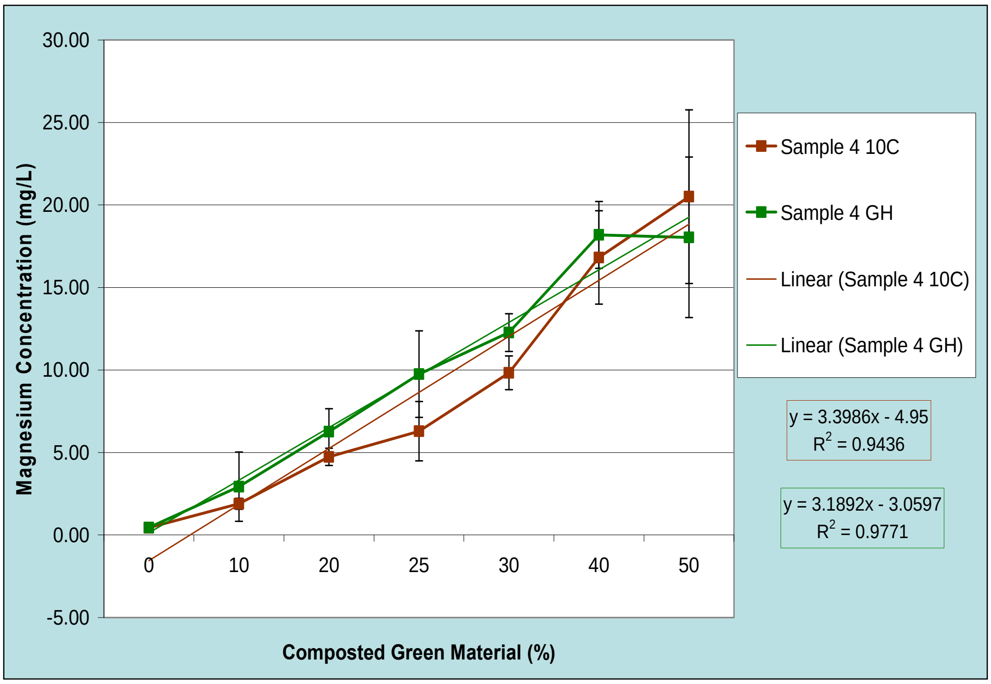


Figure 6.3.32. The relationship between magnesium concentration and the proportions of composted green material. The 95% confidence limits are indicated by error bars

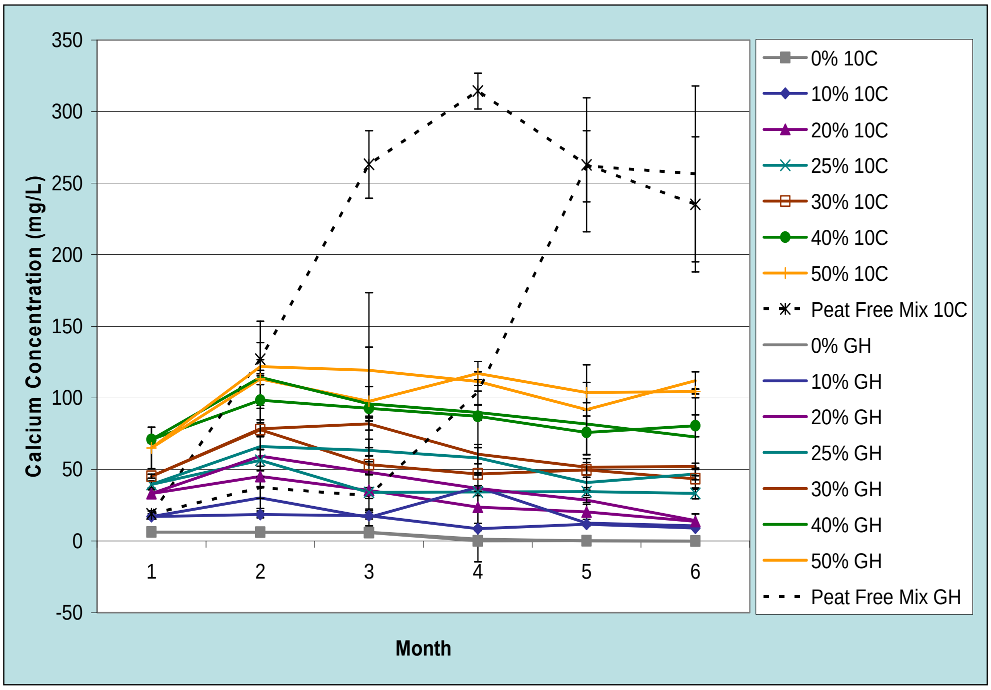


Figure 6.3.33. Calcium concentration for the peat free growth/storage trial. The 95% confidence limits are indicated by error bars.

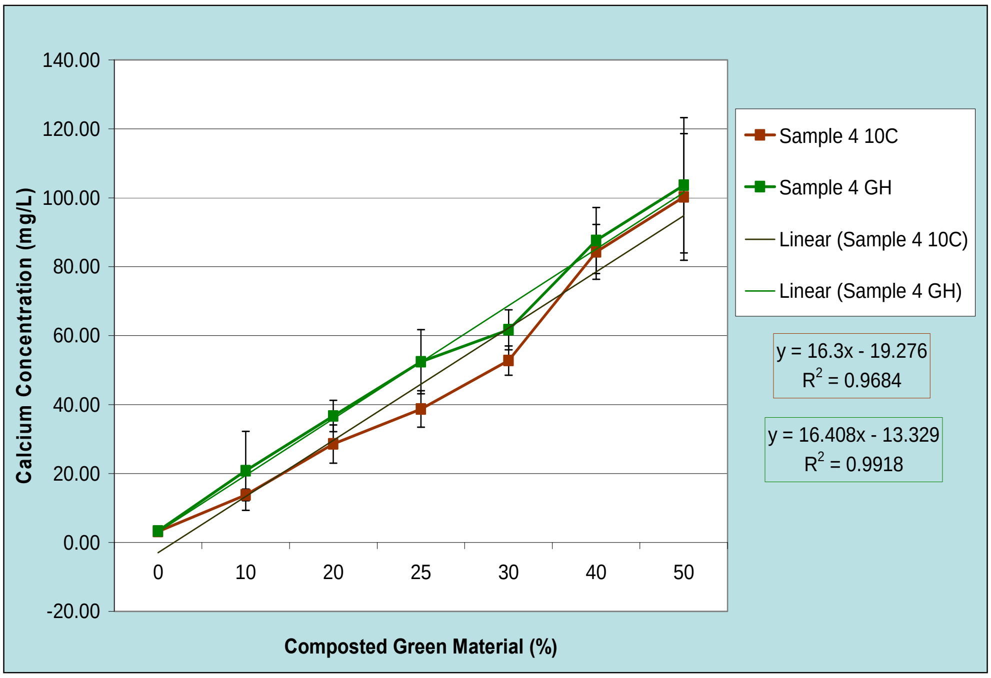


Figure 6.3.34. The relationship between calcium concentration and the proportions of composted green material. The 95% confidence limits are indicated by error bars.

All mixtures contained negligible concentrations of Zinc and Manganese. The highest concentrations were recorded in the ‘commercial peat-free standards’. The ‘commercial peat-free standards’ contained 3.11 mg/L +/- (0.12 mg/L) of manganese in Month 1; this fell to 0mg/L by Month 6 (Figure 6.3.36). The highest initial Zinc concentration in Month 1 was 2.18 mg/L +/- (0.02 mg/L) were found in the ‘commercial peat-free standards’ stored under glasshouse conditions (Figure 6.3.35). However the concentration varied throughout the six month trial.

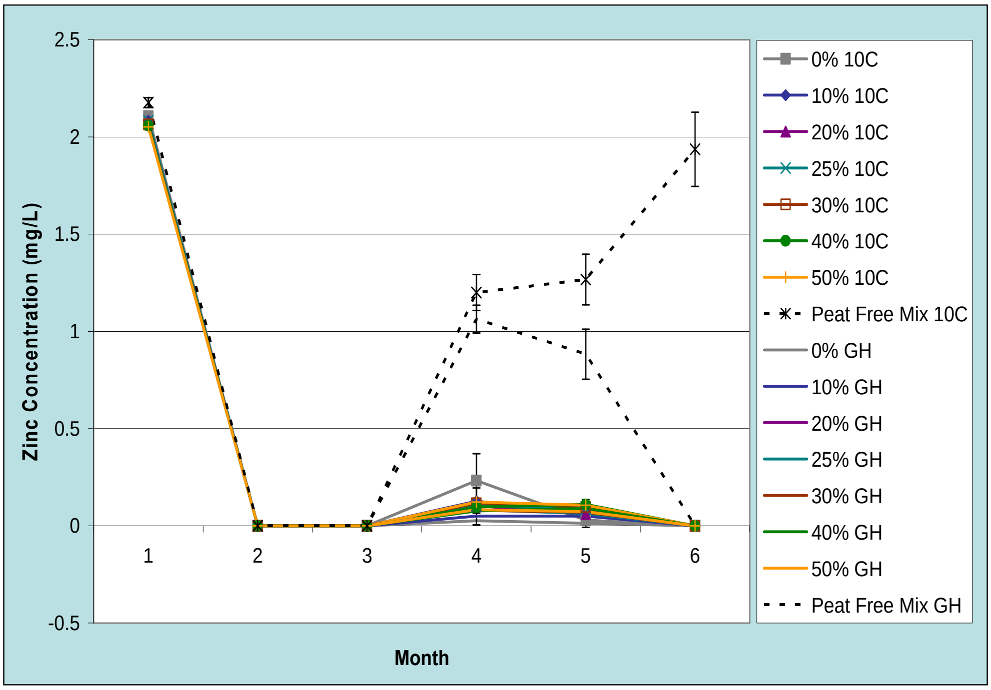


Figure 6.3.35. Zinc concentration for the peat free growth/storage trial. The 95% confidence limits are indicated by error bars.

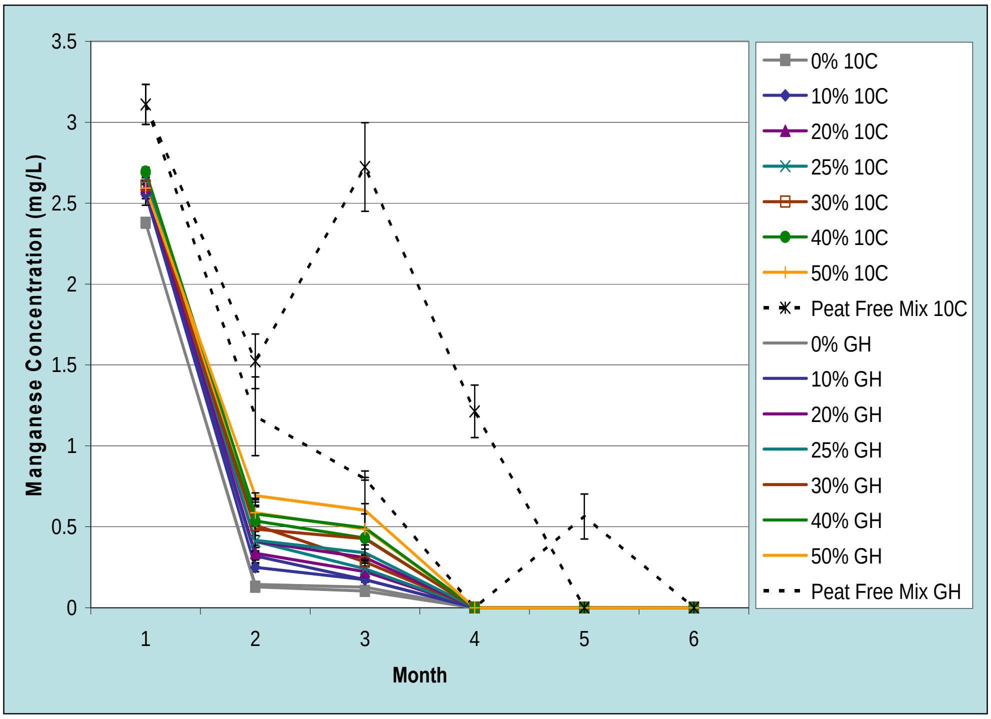


Figure 6.3.36. Manganese concentration for the peat free growth/storage trial. The 95% confidence limits are indicated by error bars.

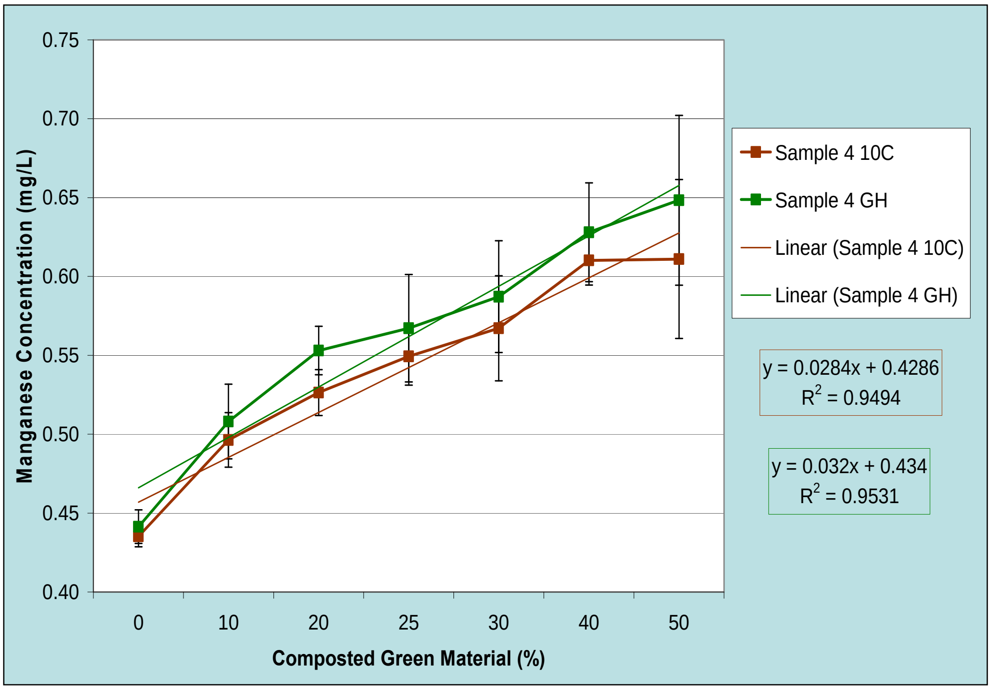


Figure 6.3.37. The relationship between manganese concentration and the proportions of composted green material. The 95% confidence limits are indicated by error bars.

Dehydrogenase activity in general varied between the mixtures of composted green material (Figure 6.3.38). However, activity in the mixtures containing composted green material, as a whole, declined during the six month trial, from 780.60µg (+/- 123.67µg) to 576.49µg (+/- 90.32µg) at 10˚C and 859.76µg (+/- 161.34µg) to 621.16µg (+/- 89.22µg) under glasshouse temperatures (Figure 6.3.39).

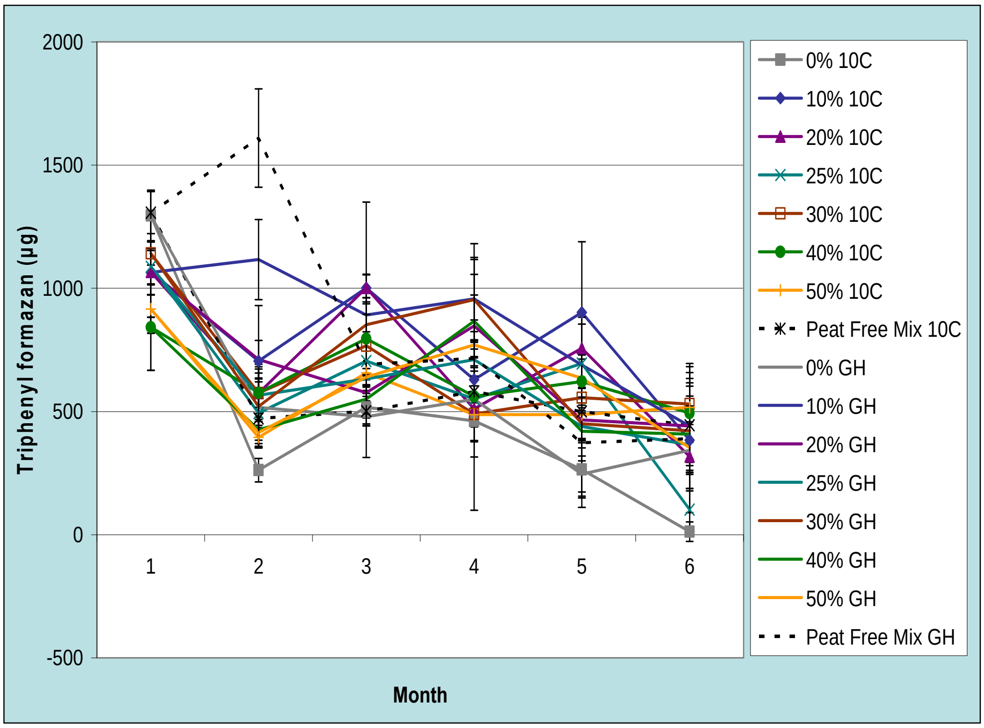


Figure 6.3.38. Dehydrogenase activity assay for the peat free growth/storage trial. The 95% confidence limits are indicated by error bars.

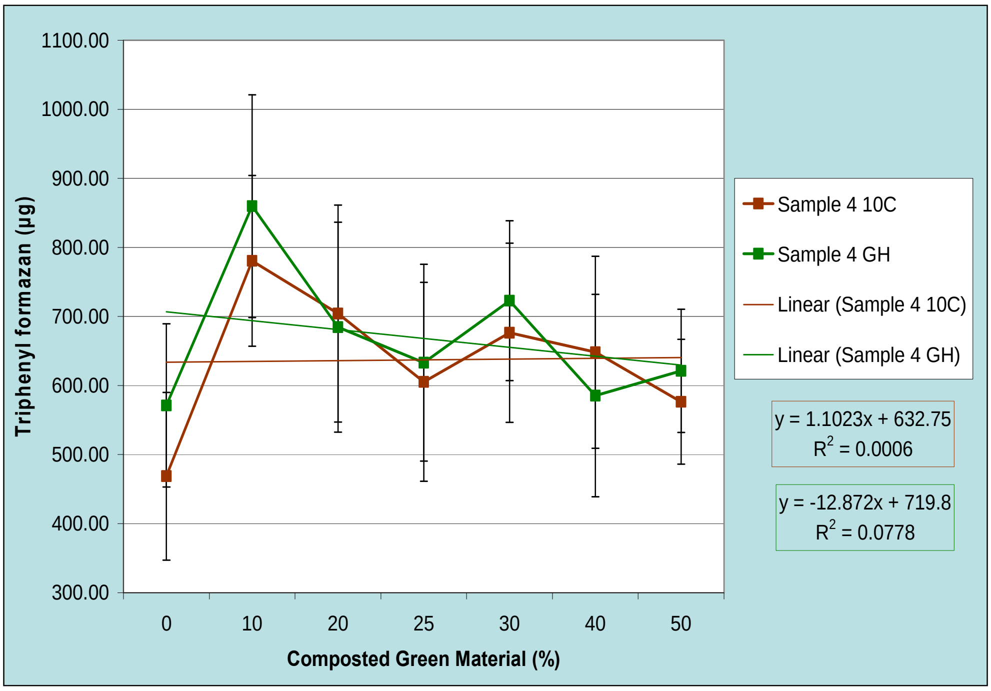


Figure 6.3.39. The relationship between dehydrogenase activity and the proportions of composted green material. The 95% confidence limits are indicated by error bars.

6.4 Discussion

Similar findings to Chapter 5 were observed. Both the pH and electrical conductivity values obtained in this trial were fairly constant over the six month trial. By using other alternative material such as the composted pine bark with a low pH value, similar pH values to the peat–reduced trial were obtained. A similar pattern occurred within the organic matter contents. By the addition of wood waste and composted barks, with an organic matter content of approximately 85-98% (Table 6.2.1), the organic matter contents were higher for the peat-free mixtures compared to the peat-reduced mixtures containing composted green material. This then had the resulting decrease in ash content, with the peat-free mixtures having lower ash contents compared to the peat-reduced mixtures. The bulk density was significantly related to the ash content (Appendix 5), therefore the bulk densities of the peat-free mixtures decreased with the addition of alternative material such as wood waste and barks. The bulk densities of the peat-free mixture containing composted green waste were lower than the peat-reduced mixtures. As stated in Chapter 4, the bulk density has huge implications on the transportation cost of growing media. The bulk density was fairly constant over the six month peat-free trial. Similar findings were found by Richardson & Rainbow (2005) when working with alternative material such as bark fines and forest brash.

By the addition of composted green material, there was a higher overall nutrient status achieved within the peat-free mixtures. Figure 6.3.22 indicates the resulting increase in electrical conductivity by increased proportions of composted green material. Trials conducted by Richardson & Rainbow, (2005) found conflicting results, with decreases in electrical conductivity over a one year storage trial. With the largest decreases seen in mixtures containing composted green material mixed with matured forest brash and /or matured bark fines. This decrease in electrical conductivity was mainly due to the immobilisation of nitrates (Richardson & Rainbow, 2005). Indicating that the peat-free mixtures were not as stable as the peat-free mixtures used in this current peat-free trial. Table 6.2.1 contains an analysis of Sample 4 indicating the high nutrient status within this material. Nitrate-nitrogen, phosphorus, potassium, magnesium and calcium concentrations are all increased with increasing proportions of composted green material.

Within the results gained in the peat-free trial, the peat-free mixtures contained a slow release form of phosphorus. This is evident from Figure 6.3.27. Within the peat-free trial, there was additional phosphorus obtained from the composted pine bark. Similar findings were observed by Holmes (2006). The nutrient levels in the reduced peat mix containing composted green material were superior to those in the peat mix, due to the slow release nutrients supplied by the compost.

Germination and seedling growth are most affected by salinity (Mayer & Poljakoff-Mayer, 1989). The germination percentages gained from the peat-free trial were similar to the peat-reduced trial. The germination results were unaffected by the elimination of peat within the peat-free trial. Variation was seen in the peat-free mixtures containing a higher percentage of composted green material, this may be due to increasing electrical conductivity and corresponding increase in salinity.

The increasing proportion of composted green material had a beneficial effect upon plant growth. For both fresh and dry weight values, the peat-free mixtures containing 40-50% composted green material had similar fresh and dry weights to the 'commercial peat-free standard'. By comparing the results for the peat-free to the peat-reduced trial; the average fresh weight for the peat-reduced mixtures in both storage conditions for mixtures containing 50% of Sample 4 ranged from 4.20g +/- (0.66g) – 4.27g +/- (0.6g) compared to the peat-free mixtures containing 50% of Sample 4 ranged from 5.67g +/- (1.09g) – 6.22g +/- (1.14g), indicating that the fresh weights increased by using the peat-free mixtures. Similar findings have been observed by Keeling, Paton and Mullet, (1994). Plant yields obtained using refuse-derived compost were substantially greater than the yields produced from peat based growing medium in most cases. Indicating the advantages that could be gained from the improved physical and chemical characteristics by the inclusion of composted green material in peat –free growing media i.e. increased nutrient content and decreased bulk density.

Other researchers have found contrasting results. Prasad & Maher (2001) found reductions in growth of mixtures containing 50% composted green material diluted with peat. However there were reductions in the availability of nitrogen. The reduction in nitrogen implied that microbial activity was still extensive in the composted green material and that the microbial population were still absorbing N. The nitrate–nitrogen concentration varied a little in storage for the peat-free trial, however there was no significant reduction, indicating that this material may be of a higher quality than the material used in Prasad & Maher (2001) trial.

The effects of storage of composted green material are a key issue in the incorporation of composted green material in growing media. The dehydrogenase activity assay was used to gain an assessment of the stability of the peat-free mixtures *via* the measurement of microbial activity. The method was taken from Dickinson (1995). Dickinson, (1995) stated that the consistency of results between replicates and the measurements of low levels of activity in peat based medium indicated that the dehydrogenase activity assay would be suitable for storage experiments. Figure 6.3.39 indicated that the sample of composted green material was fairly stable over the six month trial. Within the initial month there was evidence of microbial activity, this could be due to the initially high oxygen content in the bag following the mixing process or the initial activity could reflect immobilisation of substrates such as nitrate-nitrogen, however this is not evident in the nitrate-nitrogen values obtained in this research. Except for the 'commercial peat-free standard' where ammonia was quickly converted to nitrate which might reflect in the occasional high dehydrogenase activity in the 'commercial peat-free standard'. For example the commercial peat-free standard stored under glasshouse conditions indicated high microbial activity in the second sampling date, Figure 6.3.38.

As with Chapter 5, stepwise regression analysis was used to establish which parameters were having the largest effect upon plant growth. In this particular case, the response variable was the dry weight values and the predictors were the other parameters investigated. From the parameters investigated the stepwise model produced a subset of predictors containing five parameters which had the most significant effect upon the plant yield (Table 6.4.1). The results for the Stepwise Regression Analysis are contained in Appendix 6.

Parameter (P-value <0.001)	Composted Green Material Sample Sample 4
Nitrate Concentration	+ve
Percentage	+ve
Magnesium Concentration	-ve
Phosphorous	-ve
Time	+ve

Table 6.4.1: Simplified version of stepwise regression analysis for the determination of dry weight

As found in Chapter 5, the nitrate concentration was a prominent parameter in the dry weight production, indicated by the significant correlation between dry weight and nitrate concentrations with R^2 values ranging from 0.86-0.89 (This can be seen in Appendix 7) and by positive correlations from the stepwise regression analysis.

The percentage of composted green material was identified as having a positive effect upon the dry weights; this is evident from the high correlation values obtained, (Figure 6.3.18) and the associated high electrical conductivities.

Magnesium concentrations were fairly constant, but low throughout the six month storage trial. The subset-regression analysis indicated that the magnesium content had a negative effect upon the plant growth. The low concentrations of magnesium within the peat-free mixtures suggested a limiting effect upon growth. Phosphorus was also present at low concentrations within the mixtures, also indicating a limiting factor on dry weight production.

The last parameter within the subset was time, having a positive correlation on the dry weight production. This indicated that the length of storage had a positive effect upon the dry weights. However this was independent of storage conditions as the storage conditions were a separate parameter within the stepwise regression analysis. As storage increased, the dry weights also increased. This is evident in Figure 6.3.17. This could be due to the maturing of the sample during storage or it could be due to increasing temperature rise within the glasshouse, indicated by Figure 6.2.1.

By comparing the peat-reduced and the peat-free mixtures containing composted green material, the peat-free mixtures appear to be a superior product compared to the peat-reduced mixtures. By the addition of composted bark, composted pine bark and wood waste in varying quantity combined with the composted green material, the average values taken from the six month trial indicated that; the bulk density was reduced which as stated would have a large implication on transportation cost, the organic matter content was increased with the corresponding decrease in ash content, improving the structure of the material. The concentrations of nitrate-nitrogen, phosphorus and potassium, all increased which in turn increased the electrical conductivity, this could reduce the need for the addition of fertilisers, reducing production costs.

Parameter	Specification/labelling
Bulk Density (g/L)	<600
Maximum screen size (mm)	10mm
Particle size distribution	Labelling Only
Moisture Content (%m/m)	Minimum 35% Maximum 55%
Organic Matter Content (%m/m)	Labelling Only
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
Water –extractable Chloride (Total Chloride)	Labelling Only
pH	Maximum 8.5
Electrical conductivity (µS/cm or mS/m)	Maximum 1000

Table 6.4.2: BSI PAS 100 specifications for growing media (Enviros Consulting Ltd, 2004)

By comparing the peat-free products to the BSI PAS 100 specification (Table 6.4.2), the bulk density and the pH are within the standard and the mixtures containing 0-25% of composted green material are below 1000mS/m.

There were limitations within this trial, for example the use of one sample of composted green material does not provide a comparison. However the analysis conducted in Chapter 4 enabled this material to be selected from the best practice analysis. There was only the use of 1-2 host plants. It would have been more representative to have used a variety of plants i.e. plants that are tolerant and intolerant of high salinities, to observe the effects on germination and growth studies. To gain a better understanding of all the parameters and how they interact with one another, further analyses could have been investigated for example other stability tests, CAT-extraction and cation-exchange capacity. The extension of this trial to one year would have produced a useful indicator of this material in longer storage conditions There are limitations within the watering regime that may have affected the results. In both the fresh and dry weights, Month 6 produced some irregular findings.

As the trial was initiated in November, it would be expected that the fresh weights would increase as the temperatures increased in the glasshouse through the duration of the trial, which is the pattern in Months 1-5. However there was a problem with the watering due to a power cut over a bank holiday weekend. Therefore lack of water is the dominating factor in the decrease in fresh and dry weights. Figure (6.2.1) indicated that the temperatures in Month six had risen to approximately 40˚C within the glasshouse.

Chapter 7.0 Final Discussion

The initial focus of this research was to establish various trends in green waste production for example variation in source and treatment of green waste. The impetus for the scientific part of the thesis came from the initial survey of green waste material on an essentially regional basis.

The findings from Chapter 3 indicated that there were large variations within the samples of composted green material. The difference was due to variation in source and collection of green waste i.e. the identification of source separation which reduced the variability between samples and varying production of composted green material i.e. windrow, in-vessel composting. These processes produce a wide spectrum in the quality of the final product (Butler *et al*. 2001; Reinikainen & Herranen, 2001).

As variation within the production of composted green material was evident, the next step in the research was to investigate this variability using physical/chemical analyses as well as biological to quantify this variability. The analyses conducted confirmed the variability which in turn led to varying qualities of the composted green material. However there were beneficial qualities to be gained from the use of composted green material, for example increased water-holding capacity and higher nutrient content, especially in regards to the nitrogen concentration, which gave this material the potential to be an alternative material to peat for the inclusion in growing media.

As stated in Chapter 1 and 2 the United Kingdom government has set the target for the increased use of alternatives in soil conditioners and growing media; to be 90% peat-free by 2010 (Wallace *et al.* 2006). The United Kingdom uses a high percentage of peat within growing media; this has resulted from the presence of peat bogs, particularly lowland raised mires, such as Thorne and Hatfield moors in England, which have reserves of high quality peat. Environmental pressures brought upon producers have resulted in lowland raised mires being virtually unavailable to peat producers.

At the moment peat is cheaper compared to many of the alternative substrates i.e. coir. This has hindered the uptake of alternatives, as consumers have been unwilling to pay extra for plants grown in these substrates. However the availability of peat in the United Kingdom will decrease, but this may be replaced by increasing extraction in the Baltic States. Currently peat from the Baltic States is relatively cheap, but following the accession of these countries into the European Union it is anticipated peat costs may rise (Holmes, 2004). However the availability of peat in the Baltic States may be restricted, for example Estonia has an environmental policy that peat extraction may not use more than 1% of the country's peatland (Holmes, 2004).

For the above reasons alternatives to peat are the focuses of much research in the United Kingdom. This has led to consideration of the use of composted green material within growing media. (Pronk, 1995; Prasad & Maher, 2001; Ribeiro *et al*. 2000). Pronk, (1995) conducted a trial to ascertain the suitability of vegetable, fruit and garden waste (VFG) compost in a potting media. The parameters investigated were; pH, electrical conductivity, nutritional aspects and physical properties of mixtures combining VFG and peat. Prasad & Maher, (2001), conducted a trial to study the effects of additional composted green material to peat on the physical and chemical properties of growing media and on plant performance. This paper assessed the variability between three samples of composted green material. Ribeiro *et al*. (2000), focused upon the possible application of municipal solid waste compost (MSWC) as a fertiliser for potted geraniums, investigating varying percentage composition of peat and MSWC. From the research mentioned previously, none of the workers focused upon the storage of composted green material.

Part of the research work in this thesis investigated the inclusion of composted green material in peat-reduced and peat-free growing media. Analysis of samples of composted green material was undertaken by a variety of methods, however there are limitations to these methods and in the context of this thesis a critical evaluation of these methods is required.

Within the analyses, where applicable a majority of methods were taken from the International Society for Horticultural Science (ISHS) – Laboratory Manual from Commité Européen de Normalisation (CEN) – Standards for Chemical and Physical Analysis of Growing Media. This manual was produced to gain international methods for the physical and chemical analysis of growing media, which will hopefully enable comparisons within analysis to be made on an international basis.

As opposed to the other studies conducted on behalf of WRAP Peatering Out Ltd, (2005a) and Richardson & Rainbow, (2005), all growth studies and analyses were conducted using three replicates.

Fresh weight and germination counts may have been hindered by water availability within the glasshouse. A controlled temperature glasshouse with supplementary lighting was used thus only a few minor problems were encountered in this thesis. During the heat wave of 2006 one or two instances of rapid drying out of capillary beds occurred. In one instance this did affect the results; this is discussed further in Chapter 6.

The physical methods included bulk density method (ISHS, 2003). This was accurate when using homogeneous material therefore whilst this method is suitable for peat and materials of low or consistent particle size, it may not be suitable for heterogeneous material of mixed size such as growing media. The sample size used within this analysis was 1L. It may be more appropriate to use a sample size of 20L, which is used for commercial comparisons.

The principal method used for extraction of soilless media for nutrient analysis was distilled water. Stronger solutions such as acidic solutions were not needed as the cation exchange capacity of composted green material is weaker compared to other material, for example clay, therefore distilled water extraction was found to be a suitable method for assessing plant nutrients (Turner, 1983). However since this research was initiated, general acceptance of extraction methods using Diethylene Triamine Penta Acetic Acid (DTPA) has occurred. DTPA is a chelating reagent. CAT extractions help to reveal the level of nutrients that are available to the plant. Prasad (2001a) conducted research into the comparisons between extractions using 1:1.5 distilled water and 1:1.5 CAT. The results indicated that the distilled water methods produced similar results for the extraction of anions, i.e. nitrates and phosphorus; however the relationship between distilled water and CAT for the extraction of cations varied, with the extraction of cations increasing with the use of CAT. These findings indicate that the concentrations of potassium, magnesium and calcium would have been higher using the CAT extraction method. In further work to gain a representation of the cations, it may be more appropriate to use CAT extraction.

Both the nitrate and ammonia (Ion Specific Electrode) ISE were sensitive and needed recalibrating often, which was time consuming. In the laboratory at the Nottingham Trent University access to an auto analyser for NPK was not available, therefore ISE were used. Both the nitrate and ammonia ISE were sensitive to temperature, with readings fluctuating at higher temperatures. Ammonia concentrations needed to be analysed as soon as possible after extraction as ammonium-N may be converted to nitrate-N in warm conditions.

From mid 2005, an ICP-OES became available for use. This allowed the analysis of potassium, magnesium, calcium, zinc and manganese. This shortened the time of analysis. Sole use of the machine was not only for the determination of nutrients in growing media.

Time and equipment constraints to some extent limited the number of analyses that could be undertaken, this included dry weight for peat-reduced analysis and stability analyses such as C/N ration to indicate organic matter decomposition. As composted green material has a rich and diverse microbial flora compared with the low levels of microbial activity found in peat (Carlile & Wilson, 1991), the stability is an important parameter for the inclusion of composted green material in growing media.

The production of quick simple methods that could monitor the stability/maturity of compost during the production process would be beneficial to the producer of composted green material, especially to aid the BSI PAS 100 standard. Parameters such as temperature and oxygen patterns were found to be useful in monitoring the progression of maturity (Boulter-Bitzer *et al*. 2006). Examples of simple tests which could be used to assess the maturity/stability of composted green material, which are commercially available are the Dewar self-heating test, Oxitop and Solvita.

The Dewar self-heating test is simple to use (Brinton *et al.* undated). The sample of growing media must be adjusted to the optimum moisture content. The sample is then placed into the Dewar flask (vacuum flask) at ambient 20˚C temperature. Any microbial activity within the sample will cause the temperature to rise, which normally stabilises after 2-5 days. The higher the temperature achieved, the less stable is the substrate. To obtain a classification of stability, class 5, which is the highest level of maturation and that recommended for growing media use, the temperature rise should not go above 30˚C (Richardson & Rainbow, 2005). Francou *et al*. (2005) found that the Dewar Self-heating test was highly correlated with the compost organic matter stability and therefore could be recommended to compost producers, as a relatively simple method to assess stability.

Measurements using Oxitop are based on pressure measurements in a closed system: micro-organisms in the sample consume the oxygen and form carbon dioxide. This is absorbed by sodium hydroxide (NaOH), creating a vacuum which can be read directly as a measurement value as mg/L BOD. The sample used in this analysis is what is referred to within this thesis as filtrate. The filtrate is diluted according to the COD value. The method requires 5 days at 20˚C to gain an accurate reading (WTW, 2004).

The Solvita test produced a maturity index for the compost. Carbon dioxide respiration and ammonia volatility are measured simultaneously. The sample must be prepared before use. Within the Solvita testing kit, there are two paddles, individually marked carbon dioxide or ammonia. The gel paddles are pushed into the compost sample contained in the jar. The lid is then screwed on tightly. The jar must be kept at 20-25˚C out of direct sunlight for 4 hours. The results can be observed by comparisons made with two colour charts. A computation table is used to determine the compost maturity index (Woods End Research Inc, 2000).

Physical tests such as the air-filled porosity and water holding capacity would have been beneficial parameters to have tested, as composted green material tends to have a higher bulk density compared to many alternative materials, therefore the effects imposed by a higher bulk density on the physical parameters would have been a useful tool within the analysis (Mohee & Mudhoo, 2005; Searle & Sorensen, 2004). Increased water-holding capacity is a desirable trait in growing media, in light of the summer draught in 2006.

Many researchers have shown that the use of composted green material could have beneficial properties for disease suppressiveness. These properties would be beneficial within potting and container media (Veeken *et al.* 2005; Termorshuizen *et al.* 2006; Groenhof, 1998) and this might also have been studied.

Not withstanding the factors influencing methodology, the results in this thesis indicate that some sources of composted green material could be used as a diluent in growing media. The use of composted green material as a sole component of growing media would not be possible due to physical parameters such as the bulk density and chemical parameters such as the high conductivity values. However diluting the composted green material with other alternative materials, to produce a growing medium may prove beneficial. The peat-free trial reported in Chapter 6 indicated that the inclusion of; wood waste and composted barks with lower bulk densities in addition to composted green material produced a good quality product, which reduced the problems encountered in Chapter 4 such as high bulk density and conductivity values. The composted green material used in Chapter 6 appeared to be a relatively stable material. Combining this with improved physical and chemical properties, produced an overall product that was superior to the peat-reduced mixtures in Chapter 5. Other workers who have found similar positive results with the inclusion of composted green material are Holmes, (2006); Prasad & Maher, (2001), Ribeiro *et al.* (2000).

However the variations between the samples of composted green material were evident, as indicated in Chapters 3, 4 and 5. There is a definite need for best practice, to eliminate the variation within production. Best Practise was identified from the production of Sample 4. The method used for the compost production could be adopted by other producers to eliminate variation produced by the production methods (Ward *et al.* 2005). The composting process was undertaken by MID-United Kingdom Recycling Ltd. There are four main sources of green waste mainly from local authorities and landscapers. South Kesteven is a local authority, who pays for their recycling bins. This reduced contamination in the material. North Kesteven is a local authority, where the recycling bins are provided at no cost, by the local authority. MID-United Kingdom found contamination to be more of an issue within this source. The green waste produced from the local authorities has a high proportion of grass contained in it. Lincolnshire County Council civic amenity site and landscapers, provide a higher woodier fraction of green material, which is shredded by MID-United Kingdom. The material from the local authorities i.e. grass fraction and the oversized screening product (wood) are then blended together, improving the C/N ratio.

The composting process used by MID-United Kingdom is windrow composting; the windrows are turned 5 times per week. The pile will be dormant for two weeks and moved across the site and screened a week later. For use in growing media the material is screened to 15mm. Once screened, the material is moved to a stock pile. If the material is to be used in growing media, the material will be left to mature for a further 5/8 wks, giving a longer composting process.

As stated in Chapter 3, a large variation between the samples was apparent. To eliminate this variation between sources, separate source collections are needed to improve the quality of the material and eliminate contamination issues (Wolkowski, 2003). Production of the BSI PAS 100 (TCA, 2005) and the Composting Association 'Code of Practise' (Duckworth, 2005) has enabled producers to have a more uniform production process. The key elements within the BSI PAS 100 standard are; process control, input materials, compost activity i.e. sanitation and stabilisation, compost quality requirement, product preparation, compost maturation, compost sampling and analysis, final product storage and classification and labelling of the material. Within these key stages producers of composted green material are having to implement procedures i.e. procedures to achieve stabilisation. This standard will enable a more homogeneous composted green material to be produced.

Storage is of paramount important for the retail sector. Multiple retailers in the United Kingdom account for 59% of the horticultural market (Wallace *et al*. 2006). The retailers may store growing media in varying conditions; outside in cooler temperatures, inside in warmer condition and even in supermarkets. The material may also need to be stored for periods of up to a year. Stability of the material in storage is therefore an important aspect of compost quality. Stability in storage is reflected in the current thesis as well as work undertaken elsewhere at the same time (Peatering Out Ltd, 2005a; Richardson & Rainbow, 2005).

At the beginning of these studies little information was available on the effects of storage on performance of growing media (Wallace *et al.* 2006; Butler *et al.* 2001; Wu & Ma, 2001). During the period of this research authors on behalf of Waste Recycling Action Programme published two papers on the effects of storage on growing media containing composted green material. The first report to be published was the 'Report on the evaluation of storage stability on growing media based on green compost and other recycled material' (Peatering Out Ltd, 2005a).

Within this trial, two different sources of composted green material were used. No surveys of the type reported in this thesis in Chapters 3 and 4 were evident in the work reported by Peatering Out Ltd, (2005a)

Within the Peatering Out Ltd (2005a) study a comprehensive analysis of substrate was undertaken prior to mixing. The sources selected were characterised for stability. Stability was assessed by using the C/N Ratio. A stable compost should have a ratio of between 15 and 20 i.e. 15:1 - 20:1 (Enviros Consulting Ltd, 2004). Both samples appeared to have reached maturity. The Waste Recycling Group (WRG) sample had a low C/N ratio of (9.3:1) compared to the more standard (13.1:1) of Eco-Composting (Eco) sample. The two samples varied, with WRG having higher levels of dry matter, electrical conductivity, chlorine, potassium (CAT-Extraction) and sulphur (CAT-Extraction) concentrations and higher levels of fines than the other. The phosphorus concentration by CAT extraction was lower in the WRG sample.

Within this trial reported by Peatering Out Ltd (2005a), three separate conditions were used; ambient (in an unheated barn), ambient storage under load (simulating stacked pallet) and warm conditions (in a polythene tunnel). The trial was conducted over nine months. The analyses were undertaken prior to mixing and at 1, 3 and 9 months, with temperature readings taken within the stored material and germination studies conducted using garden cress.

The analysis of the trial conducted by Peatering Out Ltd, (2005a) are listed in Table 7.1.1

Storage conditions: warm conditions ambient storage under load ambient
Visual observations and temperature recordings of mixtures
Bulk density (BD)
Bioassay tests – Germination test
Fresh weight
pH
Electrical Conductivity
Cation Exchange Capacity (CEC)
Water-extractable nutrients; NH_4-N, NO_3-N, P, K, Mg, Ca, S, B, Cu, Fe, Mn, Mo, Zn
CAT-extractable nutrients; N), P, K, Mg, Na, S, B, Cu, Fe, Mn, Mo, Zn
Air-filled Porosity (AFP)
Water Holding Capacity (WHC)
Wettability
Particle Size Distribution (PSD)

Table 7.1.1: Analyses undertaken by Peatering Out Ltd (2005a)

It seems clear from the paper by Peatering Out Ltd, (2005a) that analysis was carried out sporadically, for example air-filled porosity and water-holding capacity were only conducted on eight treatments at Month 0, CAT-extraction was carried out in Month 1 on eleven treatments and in Month 9 on ten treatments. Within the results reported by Peatering Out Ltd (2005a) no error bars appear on the graphs and there is evidence of lack of replication in the work. Budgetary constraints prevented analysis of all treatments for every parameter after each storage interval unfortunately this leads to a diminished value of the work. Trends can not be observed therefore it was very difficult to establish trends in storage associated with many of the parameters.

However, from the results gained from one or two of the parameters, it is possible to comment on the storage effects for example bulk density and cation exchange capacity appear to be constant over the period of the trial. Cation exchange capacity was not included in the analysis in this research. However the bulk density observations of Peatering Out (2005a) coincide with the work reported in this thesis using samples in both twelve and six month trials.

Despite the deficiency of the work, the authors of the WRAP study suggest there is no obvious or consistent effect within the key properties within storage conditions in their trial Peatering Out (2005a). This was not necessarily the case of the findings of research reported in this thesis. For example, for peat-reduced mixtures more constant performance appeared in the trial over one year at 10˚C storage conditions. On the other hand the peat-free mixtures showed no significant difference at 10˚C and glasshouse conditions over the six month trial.

In the trial conducted by Peatering Out Ltd (2005a) for WRAP a reduction in water soluble nitrogen was evident with the greatest reduction in mixtures containing higher proportions of composted green material. Within the peat-reduced and the peat-free trials within this research there was no overall loss of nitrogen. The samples of composted green material used within this research may have been more mature, than those used in the WRAP trial.

Further more in the WRAP trial the pH and the electrical conductivity proved rather unstable in mixtures containing composted green material. However within the results gained in this research the pH and electrical conductivity values were fairly constant over both the twelve and six month trials. In common with the WRAP trial results, the mixtures with the higher concentration of composted green material had the highest electrical conductivity values.

In both the current work and the WRAP trial germination of mixtures containing composted green material improved with time. The results indicate that the maturity of the media improved with storage, rather than deteriorated (Carlile, 2004).

Within the WRAP findings, water extractable phosphorus, potassium and magnesium concentrations decreased in the peat-free mixes during storage. The authors considered this was due to the higher water soluble nitrate levels maintained in these treatments during

storage, increasing the solubility of other ions, especially highly soluble cations such as potassium.
However, the results gained in this research indicated; that the levels of magnesium were fairly constant and the potassium concentration varied in the peat-reduced and peat-free trials. The phosphorus concentration increased in the six month peat-free trial.

A second report was produced by WRAP researchers Richardson & Rainbow (Richardson & Rainbow, 2005). The objective of this project was to investigate the storage characteristics of retail growing media incorporating composted green material. However only one sample of composted green material was used. This sample was classified as acceptable as it had been given the BSI PAS 100 certification indicating this material was of a higher quality than the two samples used in the previous study conducted by WRAP.

In the studies of Richardson & Rainbow (2005) preparation of mixtures was undertaken using commercial facilities. Mixtures were prepared using 20%, 33.3% and 100% composted green material with respectively Irish Peat, Finnish Peat, matured brash and matured bark, giving a total of thirty three samples (including replicates). These were stored and sampled at 0, 1, 3, 6 and 12 months after mixing.

All samples were analysed in triplicate for the following parameters:

Moisture Contents (105˚C)
Laboratory Compacted Bulk Density
Water-extractable suite; pH, conductivity, NH_4-N, NO_3-N, P, K, Mg, Ca, Na, Cl, S, B, Cu, Fe, Mn, Zn
Total N
Organic Matter (loss on ignition)
C/N Ratio (calculated from C and N content)
Dewar self heating test
Nitrogen Drawdown Index (NDI)

Table 7.1.2: Analyses undertaken by Richardson & Rainbow (2005)

The storage conditions were not well defined. The material was left outside on a concrete base at an exposed site, with sample collections at intervals to asses the physical and chemical characteristics. The project focused on the stability of the mixes rather than the storage conditions. Another important factor is that no growth analyses were included in this research.

The trials indicated that bulk density, moisture content, dry matter, organic matter, total N, pH, copper, manganese, chlorine and the C/N ratio varied little over the twelve month storage trial; similar results were found with peat-reduced and peat-free mixtures in the current research for bulk density, organic matter, and pH. Richardson & Rainbow (2005) reported that; electrical conductivity, phosphorus, potassium, magnesium, sodium and calcium concentrations all decreased during the twelve month trial. In terms of micro-nutrients a slight decrease in boron concentration was observed, with a slight increase in zinc concentration. However the concentration limits were very close to the detection limits. This differed from the results reported in this thesis where phosphorus increased in the peat-free trial, potassium varied and magnesium remained constant within both the peat-reduced and the peat-free trial. Zinc concentrations in the current study were also very close to the detection limits. Sodium and boron were not analysed within this research. The electrical conductivity values varied little in the peat-reduced and the peat-free experiments, indicating little variation in the nutrient contents. The analyses indicated that the composted green material in the current study was stable particularly as no reduction in N concentrations was observed. However in both trials conducted for WRAP N-reduction was evident.

There were three methods used to assess the compost stability: NO_3/NH_4 ratio, the Dewar self-heating test and the Nitrogen Drawdown Index (NDI) in the Richardson & Rainbow (2005) study. The results for the NO_3/NH_4 ratio indicated lack of stability within the composted green material. Within all treatments containing composted green material there was a reduction in nitrogen due to loss of NO_3-N. The NDI produced erratic results with no final conclusions. The Dewar self-heating test only exceeded 30˚C with two mixtures: the mixture containing 30% v/v brash, 33% v/v bark fines and 33% composted green material and the other similar mixture of 40% v/v brash with 40% v/v bark fines and 20% composted green material. Although the C/N ratios remained stable, they did not use this parameter in estimates of stability, most likely because of the different types of carbon present in the substrates.

Richardson & Rainbow (2005) found that the Dewar self-heating test and the Total N (NH_4-N +NO_3-N) values showed close negative correlations, indicating that the Irish peat mixes had the least self heating and least N loss, the Finnish peat has slightly more self heating and greater N loss and that the peat-free mixes had the most self heating and greatest loss of N. Rainbow and Richardson (2005) concluded that the Dewar self heating test proved to be the most reliable tool for prediction of marked N immobilisation. However the results for the mixture containing 80% Irish peat and 20% composted green material (as the results from the Dewar self-heating test were similar to the mixture containing 80% Finnish peat and 20% composted green material) indicated that the Dewar test was not totally reliable and should be used in tandem with an N-immobilisation test.

Within the trials conducted on behalf of WRAP there was a wide range of analyses. Large quantities of the analysis were conducted in laboratories. However there were infrequent analyses from the trial carried out by Peatering Out, 2005a. This was due to budgetary constraints. The analysis conducted within this thesis was more in-depth, with frequent and complete analysis of all the parameter investigated. However there was less breadth in this study. Within the current study there was little analysis conducted on stability, however the growth assessment was carried out thoroughly with germination and fresh/dry weight recordings. The two studies conducted on behalf of WRAP and the current studies rather complement each other in regards to the analysis as a whole.

For the professional market variability in a growing medium must be minimal. Reinikainen & Herranen, (2001) stated that to gain a material that has the high specifications required by the professional market, the material must include, among others, the absence of pathogens and phytotoxicity, have a suitable pH and nutrient content and have a homogeneous structure.

Professional growers have more stringent quality requirements due to production of large numbers of uniform grade plants. The market is more specialised with growers using particular formulations according to the crops grown, and the growing systems used, therefore the materials used are of a higher quality. They must be consistent, reliable, stable and homogeneous, where as the retail market is based upon amateur gardeners, who mainly purchase multi–purpose composts used for a variety of purposes i.e. raising plants, filling tubs and baskets. The retail market has always been seen to require a lower specification of material (Wallace *et al.* 2006).

The continued dominance of peat in the amateur gardening market is partly due to the very cost-competitive nature of this market giving manufacturers less opportunity to use more expensive materials. There have also been concerns associated with technical issues and long term supply of reliable alternative materials for this market. The shelf live of

growing media sold *via* retail outlets to amateur gardeners is important as stated previously the growing media may be stored for a year before they are used (Carlile, 2005).
Economic issues and lack of confidence in alternative material have hindered the use of alternative material in growing media. The most significant influence on the adoption of reduced peat growing media by professional growers has been that of their multiple retailer customers. Most of these now have policies on peat reduction as part of their Corporate Social Responsibility programmes for example Marks and Spencer's (Wallace *et al.* 2006).

Workers Waller & Temple-Heald (2003) have looked at composted green material from a different view point, for example the bulk density of composted green material is a limiting factor in the use of this material. The cost implications of transporting large volumes of heavy material are high; however other alternative materials such as the material used within the peat-free trial described in Chapter 6 have much lower bulk density and are thus cheaper to transport (Waller & Temple-Heald, 2003). Therefore a locally sourced composted green material might be sought, reducing the transportation of heavy material. The alternative is to transport the lighter raw material to where the composted green material is produced. However this would need a reliable, consistent, homogenous sample of composted green material to be sourced.

To establish a locally sourced material, a survey would need to be undertaken similar to the survey used within the East Midlands (Chapter 3). The best performing product found from the survey undertaken in Chapter 3 was Sample 4 with regards to the analyses conducted. The results are indicated in Table 7.1.3.

Parameter	Composted Green Material: Sample 4
Bulk Density (g/L)	665.29 +/- 8.83
Organic Matter Content (<2mm) (%)	27.43 +/- 2.31
Organic Matter Content (>2mm) (%)	18.45 +/- 4.10
Ash Content (<2mm) (%)	72.57 +/- 1.89
Ash Content (>2mm) (%)	81.55 +/- 3.35
pH	7.72 +/- 0.04
Conductivity (μmhos)	2733.33 +/- 40.82
Nitrate Concentration (mg/L)	1660.00 +/- 62.85
Phosphorus Concentration (mg/L)	10.91 +/- 1.92
Potassium Concentration (mg/L)	2088.83 +/- 33.36
Ammonia Concentration (mg/L)	14.07 +/- 0.39
Magnesium Concentration (mg/L)	17.56 +/- 0.84
Calcium Concentration (mg/L)	78.12 +/- 2.92
Zinc Concentration (mg/L)	2.09 +/- 0.06
Manganese Concentration (mg/L)	2.43 +/- 0.03
Dehydrogenase Assay (μg of TPF)	831.85 +/- 257.02

Table 7.1.3: Specification of Sample 4.

The parameters in Table 7.1.3 were identified as being of a higher quality compared to the other composted green materials. A product specification could be sought similar to one in Table 7.1.3.

Composted green material has many benefits that could be gained from the use of this material in growing media. As shown in Chapter 6, the use of composted green material combined with other alternative material to peat has produced a superior product to the peat-reduced mixtures in Chapter 5.

This research has stemmed from external pressures from the increased extraction of peatlands and demand for an alternative waste disposal route for green waste due to increased waste production. External pressures due to the extraction of peat are still evident. Peatlands are a finite resource; therefore the need for an alternative material produced in large volumes must be sought.

The production of a higher quality composted green material could reduce the pressures on peat use within horticulture. The variability within this material is mostly due to the initial green waste content and the production process, therefore a more in-depth analysis of the initial in-put material is needed. For example source separation of green waste, combined with comparisons made between production methods using similar samples of composted green material and then to assess the quality and variability within these methods.

As this material has such a high nutrient content, reducing the need for additional fertilisers, composted green material may be beneficial within the organic industry. However issues such as pesticide contamination may need to be considered.

References

Aaker, D., Kumar, V., and Day, G., 2001. Marketing Research Seventh Edition. John Wiley & Sons, United States of America.

Abad, M., Noguera, P., Puchades, R., Maquieira, A., Noguera, V., 2002. Physio-chemical and chemical properties of some coconut coir dusts for use as a peat substitute for containerised ornamental plants. Bioresource Technology, 82, 241-245.

Albiach, R., Canet, R., Pomares, F., Ingelmo, F., 2001. Organic matter components and aggregate stability after the application of different amendments to a horticultural soil. Bioresource Technology, 76, 125-129.

Bernal, M.P., Paredes, C., Sánchez-Monedero, M.A., Cegarra, J., 1998. Maturity and stability parameters of composts prepared with a wide range of organic wastes. Bioresource Technology, 63, 91-99.

Boss, C.B., Fredeen, K.J., 1997. Concepts, Instrumentation, and Techniques in Inductively Coupled Plasma Optical Emission Spectrometry. USA: Perkin Elmer.

Boulter-Bitzer, J.I., Trevors, J.T., Boland, G.J., 2006. A polyphasic approach for assessing maturity and stability in compost intended for suppression of plant pathogens. Applied Soil Ecology, 34, 65-81.

Bourque, L.B., and Clark, V.A. 1992. PROCESSING DATA The Survey Example (Sage University Paper series on Quantitative Applications in the Social Sciences, series no. 07-085). Sage Publications Inc, Newbury Park, California

Bragg, N., 1998. Grower Handbook 1 Growing Media. Kent: Nexus Media Limited.

Brinton, Jr, W.F., Evans, E., Droffner, M.L., Brinton, R.B., undated. A standardised dewar test for evaluation of compost self-heating. Maine: Woods End Research Laboratory.
Bristol: Environment Agency.

Brown, P., 2002. Government pays £17m to save endangered peat bogs. Manchester: Guardian Unlimited. Available at:http://www.guardian.co.United Kingdom/United Kingdom_news/story/0,3604,659211,00.html [Accessed 5 December 2006].

Bunt, A.C., 1988. Media and Mixes for Container-Grown Plants: a manual on the preparation and use of growing media for pot plants. 2nd ed. London, Unwin Hyman Ltd.

Butler, T.A., Sikora, L.J., Steinhilber, P.M., Douglass, L.W., 2001. Compost age and sample storage effects on maturity indicators of biosolids compost. Journal of Environmental Quality, 30, 2141-2148.

Carlile, W.R., Wilson, D.P., 1991. Microbial Activity in Growing Media – A Brief Review. Acta Horticulturae, 294, 197 – 206.

Carlile, W.R., 1997. The effects of the environment lobby on the selection and use of growing media. Acta Horticulturae. 481, 587 – 596.

Carlile, W.R., and Dickinson, K. 1997. A Microplate Method for Determination of Urea and its use in Studies of Nitrogen Mineralisation in Growing Media. Acta Horticulturae 450: 71–77.

Carlile, W.R., 2004. Changes in Organic Growing Media during Storage. Acta Horticulturae. 648, 153 – 159.

Carlile, W.R., 2004 (a). Soil Science Manual. 9th ed. Nottingham: Nottingham Trent University.

Carlile, W.R., ed., 2005. International Symposium on Growing Media, Angers, 4 – 10 September, 2005. France: International Society of Horticultural Science (ISHS).

Ceram, 2006. Testing and analysis – Inductively Coupled Plasma (ICP) [online]. Staffordshire: Ceram. Available at:http://www.ceram.com/testing/icp.htm [Accessed 03/07/2006].

Chisnall, P. 2001. Marketing Research Sixth Edition. McGraw-Hill Publishing Company, Berkshire.

Churchill, G.A., Jr. 1995. MARKETING RESEARCH Methodological Foundations Sixth Edition. Elizabeth Widdicombe, United States of America.

Department for Environment, Food & Rural Affairs (Defra), 2000. Waste Strategy 2000 for England and Wales. London: Defra Publications.

Department for Environment, Food & Rural Affairs (Defra), 2000a. Waste Strategy 2000 Update [online]. London: Defra Publications. Available at: http://www.Defra.gov.United Kingdom/environment/waste/localauth/practice-guidance/pdf/infosheet05.pdf [Accessed 13 December 2006].

Department for Environment, Food & Rural Affairs (Defra), 2000b. Limiting Landfill: A consultation paper on limiting landfill to meet the EC Landfill Directive targets for the landfill of biodegradable municipal waste. United Kingdom: Waste Strategy Index.

Department for Environment, Food & Rural Affairs (Defra), 2003. Municipal Waste Management Survey 2001/02. London: Defra Publications

Department for Environment, Food & Rural Affairs (Defra), 2005. Municipal Waste Management Survey 2003/04. London: Defra Publications.

Department for Environment, Food & Rural Affairs (Defra), 2006. Municipal Waste Management Statistics 2004/05 [online]. London: Defra Publications. Available at: http://www.Defra.gov.United Kingdom/news/2006/060324a.htm [Accessed 5 June 2006].

Department for Environment, Food & Rural Affairs (Defra), 2006a. Municipal Waste Management in the European Union [online]. London: Defra Publications. Available at: http://www.Defra.gov.UnitedKingdom/environment/statistics/waste/kf/wrkf08.htm [Accessed 25 August 2006].

Department for Environment, Food & Rural Affairs (Defra), 2006b. Materials collected from household sources for recycling, 2005/06 [online]. London: Defra Publications. Available at: http://www.Defra.gov.UnitedKingdom/environment/statistics/waste/kf/wrkf05.htm[Accessed 31 January 2007].

Department for Environment, Food & Rural Affairs (Defra), 2006c. Composting [online]. London: Defra Publications. Available at: http://www.Defra.gov.United Kingdom/environment/statistics/waste/topics/compost/index.htm [Accessed 13 December 2006].

Department for Environment, Food & Rural Affairs (Defra), 2006d. Guidance on Directive 2000/76/EC on the incineration of waste. 3rd ed. London: Defra Publications.

Department for Environment, Food & Rural Affairs (Defra), Enviros Consulting Ltd, Wilson, S., Hannan, M., 2006e. Review of England's Waste Strategy. Environmental Report under the "SEA" Directive. London: Defra Publications.

Department of the Environment (DoE), 1995. Minerals Planning Guidance 13: Guidelines for peat provision in England. Norwich: The Stationary Office.

Dickinson, K., 1995. Plant Growth, Nutrient Status & Microbial Activity in Peat-Free Growing Media During Storage. Ph.D. Thesis, The Nottingham Trent University.

Duckworth, G., 2005. The Composting Industry Code of Practice. Northamptonshire: The Composting Association.

East Midlands Regional Local Government Association (EMRLGA), 2002. Development of a Regional Waste Management Strategy for the East Midlands: Technical Report. Leicestershire: EMRLGA.

East Midlands Regional Local Government Association (EMRLGA), 2002. Development of a Regional Waste Management Strategy for the East Midlands: Technical Report. Leicestershire: EMRLGA.

Ell, P., 2007. A review of visualisation tools – questionnaire responses [online]. The Queen's University of Belfast at:http://www.qub.ac.uk/cdda/visual/index.html [Accessed 13 June 2007].

Environment Agency, 2001. Technical Guidance on Composting Operations.

Environmental Data Services (ENDS), 2004. Major retailers still not tackling peat destruction [online]. ENDS Ltd. Available at: < http://www.endsreport.com/index.cfm?action=report.article&articleID=12690&q=peat&booleam_mode=all> [Accessed 31 January 2007].

Environmental Data Services (ENDS), 2006. United Kingdom could miss landfill targets, warns NAO [online]. ENDS. Available at: < http://www.endsreport.com/index.cfm?action=bulletin.article&articleID=16160> [Accessed 27 July 2006].

Enviros Consulting Ltd, 2004. To support the development of standards for compost by investigating the benefits and efficacy of compost use in different applications. Oxon: The Waste & Resource Action Programme.

Enviros Consulting Ltd, 2004. Planning for Waste Management Facilities: A Research Study. London: Office of the Deputy Prime Minister ODOM.

Envocare, 2006. Incineration of Waste [online]. Envocare Ltd. Available at: http://www.envocare.co.United Kingdom/incineration.htm [Accessed 13 December 2006].

Erhart, E., Hartl, W., Putz, B., 2005. Biowaste compost affects yield, nitrogen supply during the vegetation period and crop quality of agricultural crops. European Journal of Agronomy, 23, 305-314.

Eriksen, G.N., Coale, F.J., Bollero, G.A., 1999. Soil Nitrogen Dynamics and Maize Production in Municipal Solid Waste Amended Soil. Agronomy Journal, 91, 1009-1016.

Francou, C., Poitrenaud, M., Houot, S., 2005. Stabilization of organic matter during composting: influence of process and feedstock's. Compost Science & Utilization, 13 (No 1), 72-83.

Friends of the Earth, 1998. Bill and Ben take Peat Protest to Chelsea Flower Show [online]. London: Friends of the Earth. Available at:http://www.foe.co.United Kingdom/resource/press_releases/19980521110050.html [Accessed 31 January 2006].

Gajdoš, R., 1998. Bioconversion of organic waste by the year 2010: to recycle elements and save energy. Resources, Conservation and Recycling, 23, 67-86.
Gilchrist, D., 2003. Growing Media: A Forum For The Future, The Conference Centre, Church Street, 30 April 2003. London: Defra, Department for Environment Food and Rural Affairs.

Gardening from Which, 2007.

Groenhof, A.C., 1998. Composting: renaissance of an age-old technology. Biologist, 45 (4), 164-167.

Growing Media Association (GMA), 2004. Growing Media – the foundation for healthy plant growth [online]. United Kingdom:GMA. Available at:http://www.growingmedia.co.United Kingdom/markettrends.html [Accessed 18 November 2006].

Guérin, V., Lemaire, F., Marfa, O., Caceres, R., Giuffrida, F., 2001. Growth of *Viburnum tinus* in peat-based and peat-substitute growing media. Scientia Horticulturae, 89, 129-142.

Hartl, W., Putz, B., Erhart, E., 2003. Influence of rates and timing of biowaste compost application on rye yield and soil nitrate levels. European Journal of Soil Biology, 39, 129-139.

Holmes, S., 2003. Growing Media: A Forum For The Future, The Conference Centre, Church Street, 30 April 2003. London: Defra, Department For Environment Food and Rural Affairs.

Holmes, S., 2004. Peat and Peat Alternatives: Their use in Commercial Horticulture in England and Wales in 2003. Boxworth, ADAS Horticulture.

Holmes, S., 2006. Aldingbourne Nurseries – final report. Oxon: The Waste & Resources Action Programme (WRAP).

Horsham District Council, 2003. Brookhurst wood landfill site information [online]. United Kingdom: Horsham District Council. Available at:http://www.horsham.gov.United Kingdom/brookhurstwood/ [Accessed 16 March 2007].

International Society of Horticultural Science (ISHS), 2003. CEN – Standards for chemical and physical analysis of growing media, Freising, 23-25 September, 2003. Munich: ISHS.

Jennings, G., 2006. LATS – everything you need to know [online]. Environment Agency. Available at: < http://www.environment-agency.gov.United Kingdom/business/444217/444663/landfill/986852/1102546/?lang=_e >[Accessed 25 August 2006.

Joshua, R.S., Macauley, B.J., Mitchell, H.J., 1998. Characterisation of Temperature and Oxygen Profiles in Windrows Processing Systems. Compost Science & Utilization, 6, 15-28.

Keeling, A.A., Paton, I.K., Mullett, J.A.J., 1994. Germination and growth of plants in media containing unstable refuse-derived compost. Soil Biology & Biochemistry, 26 (No 6), 767-772.

Keeling, A.A., Mullett, J.A.J., Paton, I.K., 1994a. GC-Mass spectrometry of refuse-derived composts. Soil Biology & Biochemistry, 26 (No 6), 773-776.

Keeling, A.A., Griffiths, B.S., Ritz, K., Myers, M., 1995. Effects of compost stability on plant growth, microbiological parameters and nitrogen availability in media containing mixed garden-waste compost. Bioresource Technology, 54, 279 – 284.

Kristoffersen, A.O., Riley, H., 2005. Effects of soil compaction and moisture regime on the root and shoot growth and phosphorus uptake of barley plants growing on soils with varying phosphorus status. Nutrient cycling in agroecosystems, 72, 135-146.

Lasaridi, K.E., Stentiford, E.I., 1998. A simple respirometric technique for assessing compost stability. Water Resource, 32 (No 12), 3717-3723.

Lindsay, R.A., Immirzi, C.P., 1996. An inventory of lowland raised bogs in Great Britain. Scottish Natural Heritage Research Survey & Monitoring Report, no 78. Scottish Natural Heritage.

Mayer, A.M., Poljakoff-Mayber, A., 1989. 4th ed. Oxford: Pergamon Press PLC.

Mazuela, P., Urrestarazu, M., Salas, M.C., Guillén, C., Sánchez, J.A., 2004. Comparisons between different fertigation parameters and yield using pure compost and coir waste fibre in tomato (*Lycopersicon Esculentum* cv *pitenza*) crop by soilless culture. Acta Horticulturae, 659, 653-656.

Meade, R., 2006. The Value of Peat [online]. London: Defra Publication. Available at:http://www.Defra.gov.United Kingdom/hort/peat/hgmf/index.htm [Accessed 18 November 2006].

Mohee, R., Mudhoo, A., 2005. Analysis of the physical properties of an in-vessel composting matrix. Power Technology, 155, 92-99.

Mondini, C., Dell'Abate, M.T., Leita, L., Benedetti, A., 2003. An Integrated Chemical, Thermal, and Microbiological Approach to Compost Stability Evaluation. Journal of Environmental Quality, 32, 2379 – 2386.

Mondini, C., Fornasier, F., Sinicco, T., 2004. Enzymatic activity as a parameter for the characterization of the composting process. Soil Biology & Biochemistry, 36, 1587 – 1594.

Noguera, P., Abad, M., Noguera, V., Puchades, R., Maquieira, A., 2000. Coconut coir waste, a new and viable ecologically-friendly peat substitute. Acta Horticulturae, 517, 278-286.

Parkinson, R.J., Fuller, M.P., Groenhof, A.C., 1999. An Evaluation of Green waste Compost for the Production of Forage Maize (*Zea Mays* L.). Compost Science & Utilization, 1, 72-80.

Peatering Out Ltd, 2005. STA0013: 'Research into increasing the use of recycled material in the production of growing media'. Report on the growing trial at Stockbridge

Technology Centre, Cawood, Yorkshire: propagation of vegetables. Oxon: The Waste & Resources Action Programme (WRAP).

Peatering Out Ltd, 2005a. STA0013: 'Research into increasing the use of recycled material in the production of growing media'. Report on the evaluation of storage stability of growing media based on green compost and other recycled materials. Oxon: The Waste & Resources Action Programme (WRAP).

Prasad, M., Maher, M.J., 2001. The use of Composted Green Waste (CGW) as a growing medium component. Acta Horticulturae, 549, 107-113.

Prasad, M., 2001a. Relationship between the 1:1.5 water extraction and $CaCl_2$/DTPA (CAT) extract in various growing substrates. Acta Horticulturae, 548, 269-278.

Prasad, M., Maher, M.J., 2004. South Pacific soilless culture conference (SPSCC), New Zealand, 10-13 February, 2003. New Zealand: International Society of Horticultural Science.

Pronk, A.A., 1995. Composted Vegetable, Fruit and Garden Waste as a substitute for peat in container-grown nursery stock. Acta Horticulturae, 401, 473- 480.

Reinikainen, O., Herranen, M., 2001. Different methods for measuring compost stability and maturity. Acta Horticulturae, 549 99-104.

Ribeiro, H.M., Vasconcelos, E., dos Santos, J.Q., 2000. Fertilisation of potted geranium with municipal solid waste compost. Bioresource Technology, 73, 247-249.

Richardson, S., Rainbow, A., 2005. Storage trials of retail growing media products containing composted green materials. Project Code: ORG0019. Oxon: The Waste & Resources Action Programme (WRAP).

Robinson, J., 2006. The Professional and Retail Growing Media Market [online]. London: Defra Publication. Available at:http://www.Defra.gov.United Kingdom/hort/peat/hgmf/index.htm [Accessed 18 November 2006].

Schofield, R.K., 1955. Soils and Fertilisers, 373 – 375.

Searle, B.P., Sorensen, I.B., 2004. Soil Compaction effects on early plant growth of squash. Agronomy New Zealand, 34, 177-182.

Solbraa, K., 1979. Composting of Bark I: Different bark qualities and their uses in plant nutrition
Composting of Bark II: Laboratory Experiments.
Composting of Bark IV: Potential growth reducing compounds and elements in bark.
Composting of Bark III: Experiments on a semi-practical scale.
Report of the Norwegian Forest Research Institute.

Stern, N., 2007. Stern Review on the economics of climate change. Cambridge: Cambridge University Press.

Teg Environmental PLC, 2005. Composting Systems [online]. United Kingdom: Teg Environmental PLC. Available at:http://www.tegenvironmental.co.United Kingdom/compostsci_microbiology.asp [Accessed 6 March 2007].

Termorshuizen, A.J., van Rijn, E., van der Gaag, D.J., Alabouvette, C., Chen, Y., Lagerlöf, J., Malandrakis, A.A., Paplomatas, E.J., Rämert, B., Ryckeboer, J., Steinberg, C., Zmora-Nahum, S., 2006. Suppressiveness of 18 composts against 7 pathosystems: variability in pathogen response. Soil Biology & Biochemistry, 38, 2461-2477.

The Composting Association (TCA), 2005. Introduction to PAS 100:2005. Northamptonshire: The Composting Association.

The Parliamentary Office of Science and Technology (POST), 2000. Incineration of Household Waste. London: POST.

The Royal Society for the Protection of Birds (RSPB), 2005. ‘Plugging’ the peat-free message [online]. RSPB. Available at:http://www.rspb.org.United Kingdom/advice/gardening/peat/peatfreeplants.asp [Accessed 31 January 2007].

The Royal Society for the Protection of Birds (RSPB), 2006. Peat-free gardening [online]. RSPB. Available at:http://www.rspb.org.United Kingdom/advice/gardening/peat/index.asp [Accessed 31 January 2007].

Transform Compost Systems. In-Vessel Composting Systems [online]. United Kingdom: Transform Compost Systems. Available at:http://www.transformcompost.com/in-vessel.html [Accessed 6 March 2007].

Turner, C.P., 1983. Nutrient Salinity and the Growth of Lettuce (Lactuca sativa L.) Ph.D. Thesis, Trent Polytechnic.

Turner, C.P., Carlile, W.R., 1982. Nutrient status and the growth of lettuce in blocking composts. Acta Horticulturae. 126, 213 – 218.

Veeken, A., de Wilde, V., Woelders, H., Hamelers, B., 2004. Advanced bioconversion of biowaste for production of a peat substitute and renewable energy. Bioresource Technology, 92, 121-131.

Veeken, A.H.M., Blok, W.J., Curci, F., Coenen, G.C.M., Termorshuizen, A.J., Hamelers, H.V.M., 2005. Improving quality of composted biowaste to enhance disease suppressiveness of compost-amended, peat-based potting mixes. Soil Biology & Biochemistry, 37, 2131-2140.

Wallace, P., Holmes, S., Richardson, S., Brown, S., 2006. Monitoring of peat and alternatives products for growing media and soil improvers in the United Kingdom 2005. Bristol: Defra, Wildlife Habitat and Biodiversity.

Waller, P., Temple-Heald, N., 2003. Compost and Growing Media Manufacturing in the United Kingdom, Opportunities for the use if composted material. Oxon: The Waste & Resources Action Programme (WRAP).

Ward, C., Litterick, A., 2004. Assessment of the potential variation of composted materials across the United Kingdom. Literature Review: Project ORG0005. Oxon: The Waste & Resources Action Programme (WRAP).

Ward, C., Litterick, A., Stephen, N., 2005. Assessment of the potential for site and seasonal variations of composted materials across the United Kingdom. Final report: Project ORG0005. Oxon: The Waste & Resources Action Programme (WRAP).

Weaver, R.W., Angle, J.S., Bottomley, P.S., 1994. Methods of soil analysis. Part 2 – Microbiological and Biochemical Properties. Soil Science Society of America: USA.

White, B., 2004. Alternative Hydroponic Substrates [online]. Greenhouse Product News. Available at:http://www.onhort.com/Alternative-Hydroponic-Substrates-article5363 [Accessed 13 February 2007].

Wissenschaftlich-Technische Werkstatten (WTW), 2004. Instruction manual: Operation of the single measuring system. Germany: WTW.

Wolkowski, R.P., 2003. Nitrogen Management Considerations for Land spreading Municipal Solid Waste Compost. Journal of Environmental Quality, 32, 1844-1850.

Woods End Research Laboratory Inc, 2000. Solvita. USA: Woods End Research Laboratory Inc.

Wu, L., Ma, L.Q., 2001. Effects of sample storage on biosolids compost stability and maturity evaluation. Journal of Environmental Quality, 30, 222-228.

Zmora-Nahum, S., Markovitch, O., Tarchitzky, J., Chen, Y., 2005. Dissolved organic carbon (DOC) as a parameter of compost stability. Soil Biology & Biochemistry, 37, 2109-2116.

APPENDICES

APPENDIX ONE

Results from the waste management survey, Chapter 3.

From the basic data analysis, key trends in green waste production and disposal can be obtained. 272 local authorities within England were sent the questionnaire, 138 replied producing a response rate of 51%.

The initial information search was to gain the principal sources of green waste within local authorities. Each local authority included within the questionnaire was asked for their main sources of green waste, primary sources is equivalent to their main source, as shown in Figure 1.

Primary Sources

- The main source of green waste produced in the largest quantities by surveyed Local Authorities was Domestic waste (D), which has not been classified as either garden or kitchen waste (70 local authorities).
- Domestic Garden waste (DG) was the second major source of green waste production (31 local authorities).
- Grounds Maintenance was the third method of green waste production, but was produced from a much smaller number of local authorities than the previous two methods.

Secondary Sources

- Grounds Maintenance was the principal method of green waste produced in the second largest quantities by surveyed Local Authorities (32 sources).
- Household Waste Centre (HWC) was the second largest source of green waste production (12 local authorities)
- The third largest source of secondary production of green waste was Domestic waste (11 local authorities).

Further Sources

- Grounds Maintenance is the greatest producer of green waste for tertiary methods of green waste production, with commercial producers of green waste positioned as second in the tertiary producers of green waste.
- Quaternary and quinternary producers of green waste were compiled from other sources of green waste producers for example Community Groups, CG, and Allotments, A, that only had 1 or 2 sources within the questionnaire data received.

Green Waste Collection Methods

The second issue to be addressed within the questionnaire is how green waste is collected as shown in Figure 2 (a).

- 40% of Household Waste Centres (HWC) collected green waste. These sites are operated by the County Council; the green waste is taken to these sites by the public.
- 21% of green waste collections are undertaken using Pre-Paid sacks (PP),
- 14% of local authorities collected their green waste *via* Bulky Household Waste (BHW) collections.
- 13% of the local authorities used Wheelie bins/Twin Bins (WB/TB) as their green waste collection method.
- Pre-Paid compostable (PC) bags were the least favoured method for green waste collections, with only 3% of local authorities using this method.

Figure 2 (b) - Other Methods of Green Waste Collections

- 12 Local Authorities are trialling Wheelie bins/Twin Bins schemes with two local authorities trialling an annual rental fee system for their wheelie bins. This system is actually in progress within one local authority.
- Christmas tree recycling, CT (12 Local Authorities).
- Community composting (5 Local Authorities).
- Free Freighter Service collections (Lorry collections) are in progress within 12 local authorities and are being trailed within 1 local authority.

Cost of Pre-Paid Disposal - Figure 2 (c) (Number of Sources & (c) (i) (Percentage Values)

- A high proportion of the local authorities had standard charges for Pre-Paid Sacks.
- 32% of local authorities imposed payments of 26-50p.
- 31% of local authorities imposed a payment of 51-76p.
- 4.4% of local authorities imposing payments of £2.01-£3 per bag.
- A small portion of local authorities had price concessions on Pre-paid disposal (3 sources).

Cost of Pre-Paid Compostable Bags

- 6 local authorities used Pre-Paid Compostable Bags as their method of green waste collection. There is insufficient data to produce any results for the costs of this method

Cost of Bulky Household waste Collections (BHW) - Figure 2 (d)

- The cost of Bulky Household Waste collection for green waste had a wide range of results, indicating no universal pricing policy within local authorities.
- 22% of local authorities had no charge for this service.
- 4% had no charge on a limited amount, for example up to six bags per house per month.
- 22% of local authorities implemented a charge for green waste disposal, but no information was provided on the cost of this.
- 33% of the local authorities gave the public a charge for a limited amount, for example £30 per hour, £15 for up to 0.5 tonnes.
- For one off collections, a price of £10.01-£15 was imposed by 7% of local authorities.

Frequency of Green Waste Collections – Figure 3

Figure 3 was an overall conclusion on how frequently green waste collection were undertaken:

- Most green waste collection are undertaken on a weekly (7) 34% or fortnightly (14) basis 37%.
- A number of local authorities had chosen to collect their green waste during the summer months only; others had monthly (28) collection constantly throughout the year (2%).

Local Authorities recording Tonnages of Green Waste - Figure 4

- 58% of the local authorities questioned had recorded tonnages of green waste.
- 42% had no records or no green waste collection and therefore no records.

Figure 5 & 5 (i) - Green Waste Production.

- Domestic waste was the only section where the local authorities consistently had records of the tonnages of green waste.
- Domestic waste was the major source of green waste. 30% of local authorities produced between 0-500T of green waste per year/per trial.
- Commercial and municipal waste streams for green waste were only recorded by a very small number of local authorities.

Figure 6 - Surveying Components of Green Waste

- 85% of local authorities surveyed had undertaken no green waste analysis or had no green waste management.
- Only 15% of local authorities have surveyed the components of their green waste.

Figure 6 (a) - Components of Green Waste within Local Authorities Green Waste Collections.

- Very basic analysis has been conducted on the components of green waste.
- Green waste, which included grass, hedge cuttings, weeds etc accumulated to 38% of the components of green waste.
- 13% of the green waste surveyed was kitchen waste.
- Other components such as wood chipping and cardboard achieving 3 – 8% of the total components in green waste.
- 3% of local authorities had cooked or uncooked meat within their green waste streams.

Disposal Methods for Green Waste – Figure 7

Figure 7 provided the most expected results.

- Landfill was the primary method of waste disposal for 56% of the local authorities surveyed.
- Compost production contributes to 41% of the primary waste disposal method for green waste.
- Within the secondary waste disposal methods, composting attributed to 68% of the

total, with landfill contributing only 29%.

- Incineration and other methods such as on-farm composting dominated the tertiary and quaternary methods of waste disposal.

<u>Figure 8 - Who undertakes the composting process?</u>

- Most of the local authorities who replied to this questionnaire contract out the composting process to local companies, who were not named (51% of local authorities).
- With 5% of the local authorities undertaking the process themselves.
- Other composting processes are undertaken by the County Council (9%) and On-farm composting (6%). There are many companies such as LAWDAC, ONYX, Waste Recycling Group who undertake the composting process for a single or small number of local authorities. These companies were named within the data received.

<u>Figure 9 - Method of Compost Production from Green Waste</u>

- Windrows composting method is used by 78% of the local authorities surveyed as the main composting process method.
- In-vessel composting methods only contributed to 8%.
- There were other methods used but these processes were only undertaken by a single or small number of local authorities, for example Basic Pile composting

<u>End-product Sales - Figure 10</u>

The local authorities were then asked to provide information on the sales of the end-product.

- 52% of the local authorities sold the end-product.
- 48% (including no green waste management values) did not sell the end-product, producing roughly equal proportions for both sales and non-sales.

<u>Figure 11 - Cost of end-product</u>

- Few local authorities provided data on the cost of the end-products
- Little information provided on the quantities which the bags held
- A majority of local authorities supplied 25Kg loads and sold these for £2-£3 per load

<u>Recycling Initiatives</u>

The main Recycling initiatives indicated in Figure 12 (Tangible) and 12 (a) (Intangible) are:

- The most common tangible recycling initiative is subsidised compost bins (8%) and Community Compost Schemes (3%) (Figure 12)
- The most common intangible recycling processes is the promotion of home composting with 25% of local authorities undertaking this process (Figure 12 (a)).
- Many of the local authorities questioned were in the initial stages of a trial (7%) or had plans to extend their present green waste collection service (5%).
- 6% of local authorities surveyed had no green waste management strategies
- 25% of local authorities having no recycling initiatives for green waste

Key for Data Collection:

D = Domestic Waste, where there is no differentiation between garden and kitchen waste.

DG = Domestic Garden Waste produced by households.

DK = Domestic Kitchen Waste produced by households. This includes peelings and food waste.

HWS = Household Waste Sites. Grouped within this section are:
CA Sites = Civic Amenity Sites/ BS = Bring Sites
HWRC = Household Waste Recycling Centre
These sites are under the management of the County Council

GM = Grounds Maintenance. This includes grass cuttings, leaf collections, and the maintenance of flower beds. Grouped within this section are:
P = Parks, Park waste
SC = Street Cleansing, collections of leaves
CA = Council Activities
TC = Town Council Activities
PGS = Private Garden Squares, grass cuttings

C = Commercial Green Waste. This section includes trade waste, for example tree surgeons and paid gardeners waste. Grouped within this section are:
TW = Trade Waste
H = Horticulture waste
LW = Landscape Garden waste

FFS = Free Freighter service, this is the collection of green waste using large vehicles for collections. Included in this section is:
CS = Crunch Service, a service which visits different areas each Saturday to collect green waste and refuse.

BS = Bring Sites at waste depots

CT = Christmas Tree Recycling

HC = House Clearing

CD = Cardboard

F = Fly tip

A = Allotments

FWT = Food Waste Trade

CG = Community Group. This is community green waste collection and composting schemes. Included in this section is:
CoT = Countryside Teams

NGW = No Green Waste Management
NI = No Information

1 = Daily
3.5 = Twice Weekly
7 = Weekly
14 = Fortnightly
21 = Every Three Weeks
28 = Monthly

Figure 1: Green Waste Production

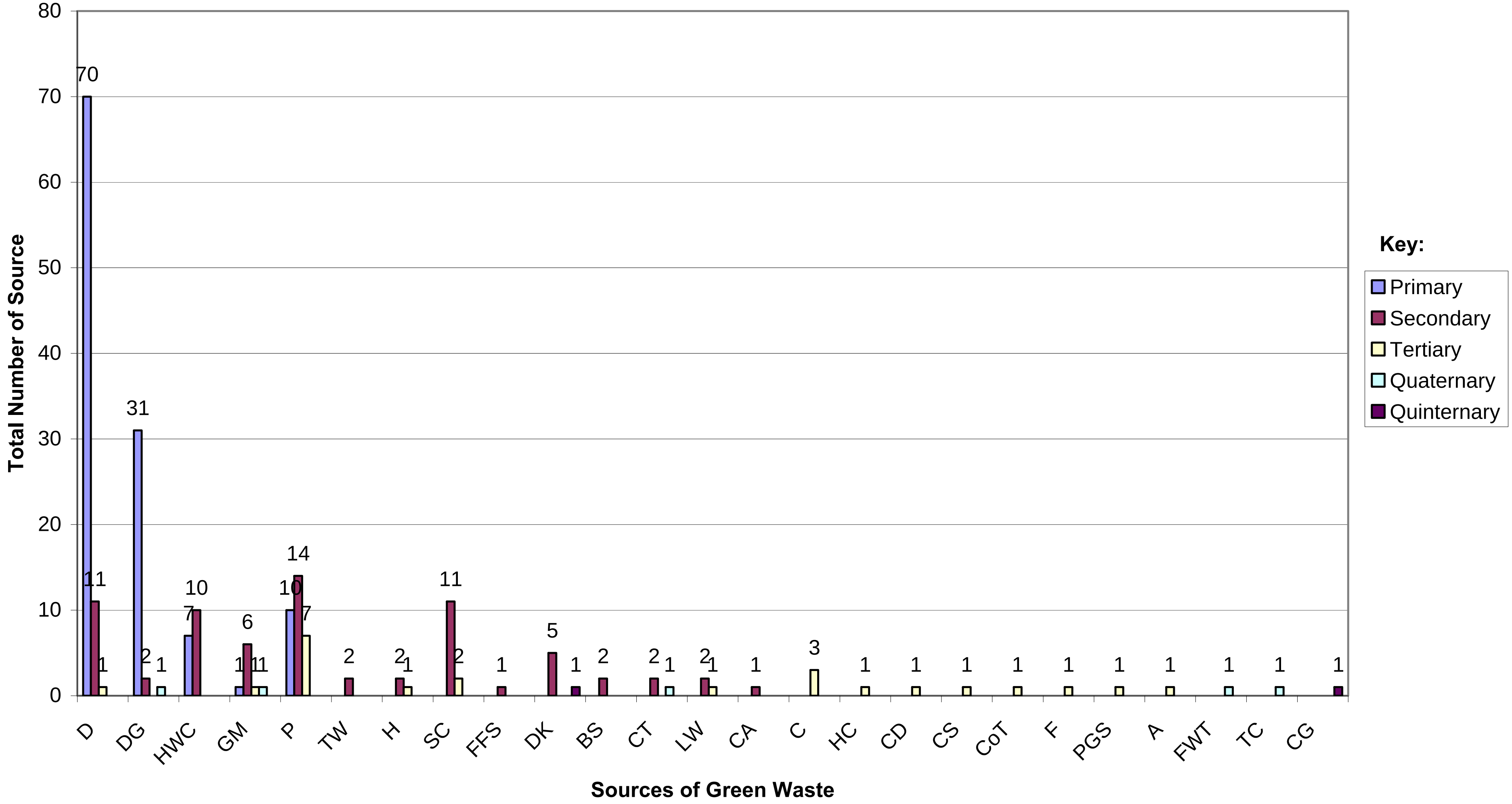


Figure 2 (a): Green Waste Collection Methods

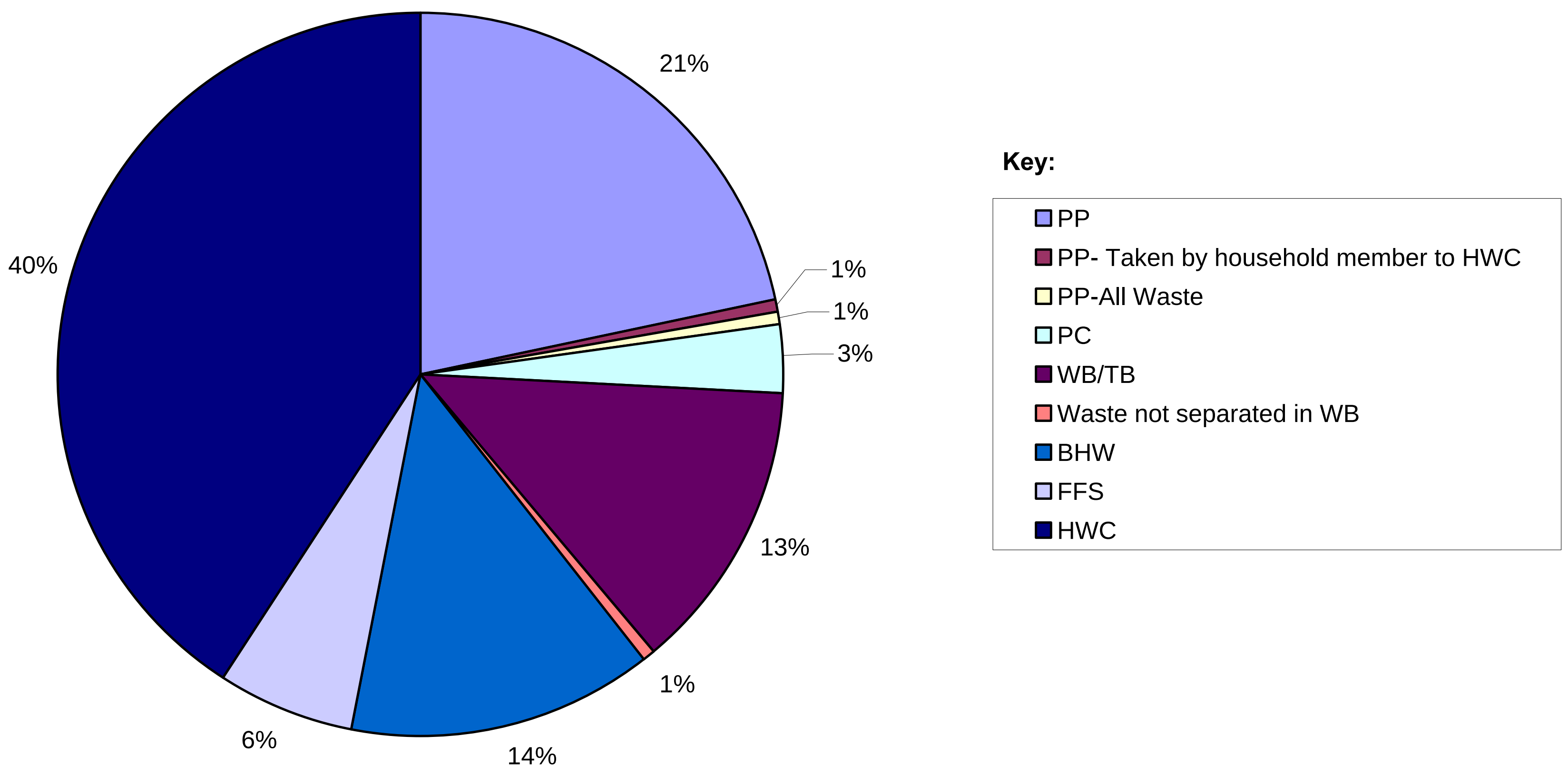


Figure 2 (b): Other methods of Green Waste collection

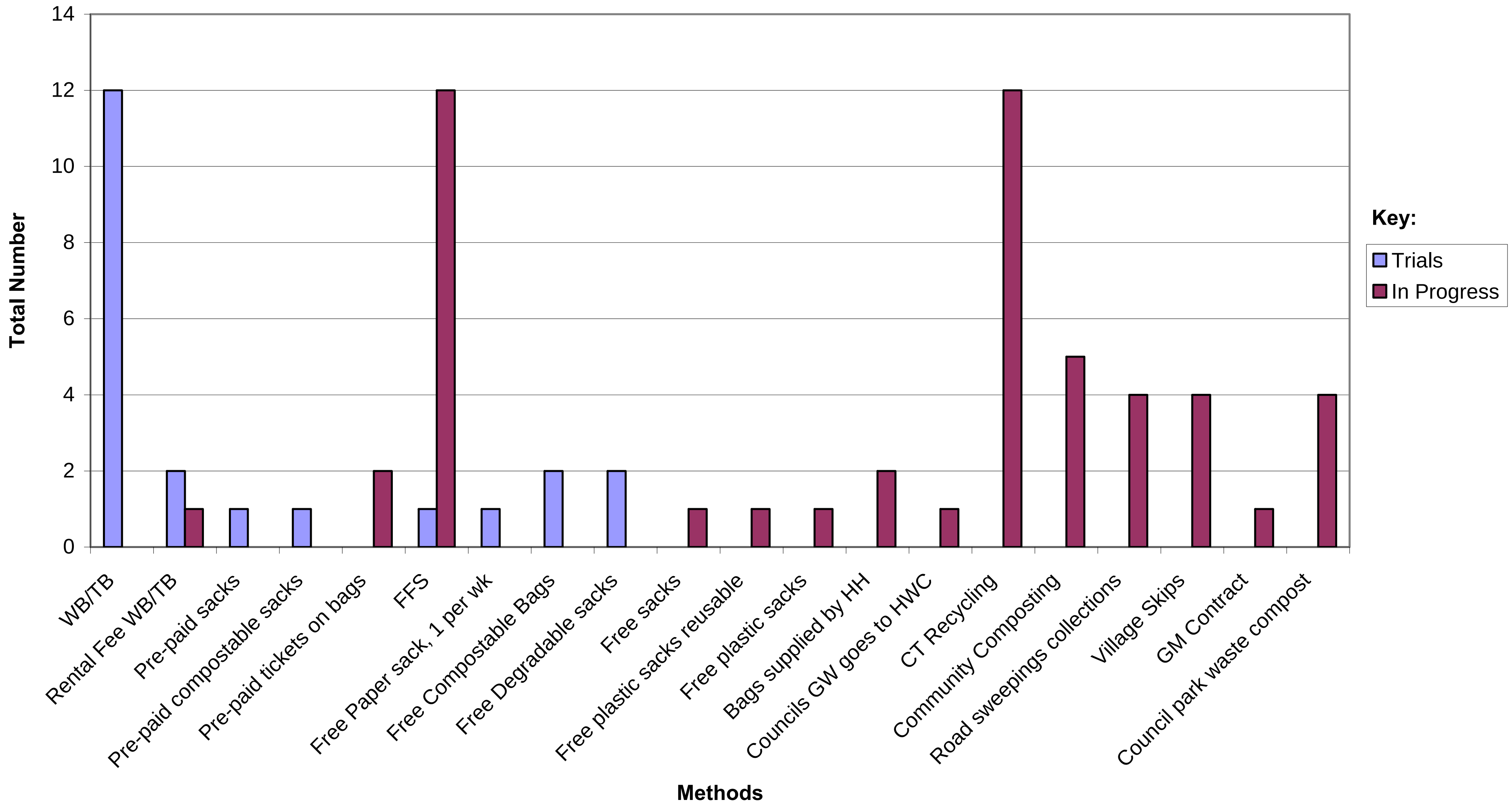


Figure 2 (c): Cost of Pre-Paid Disposal

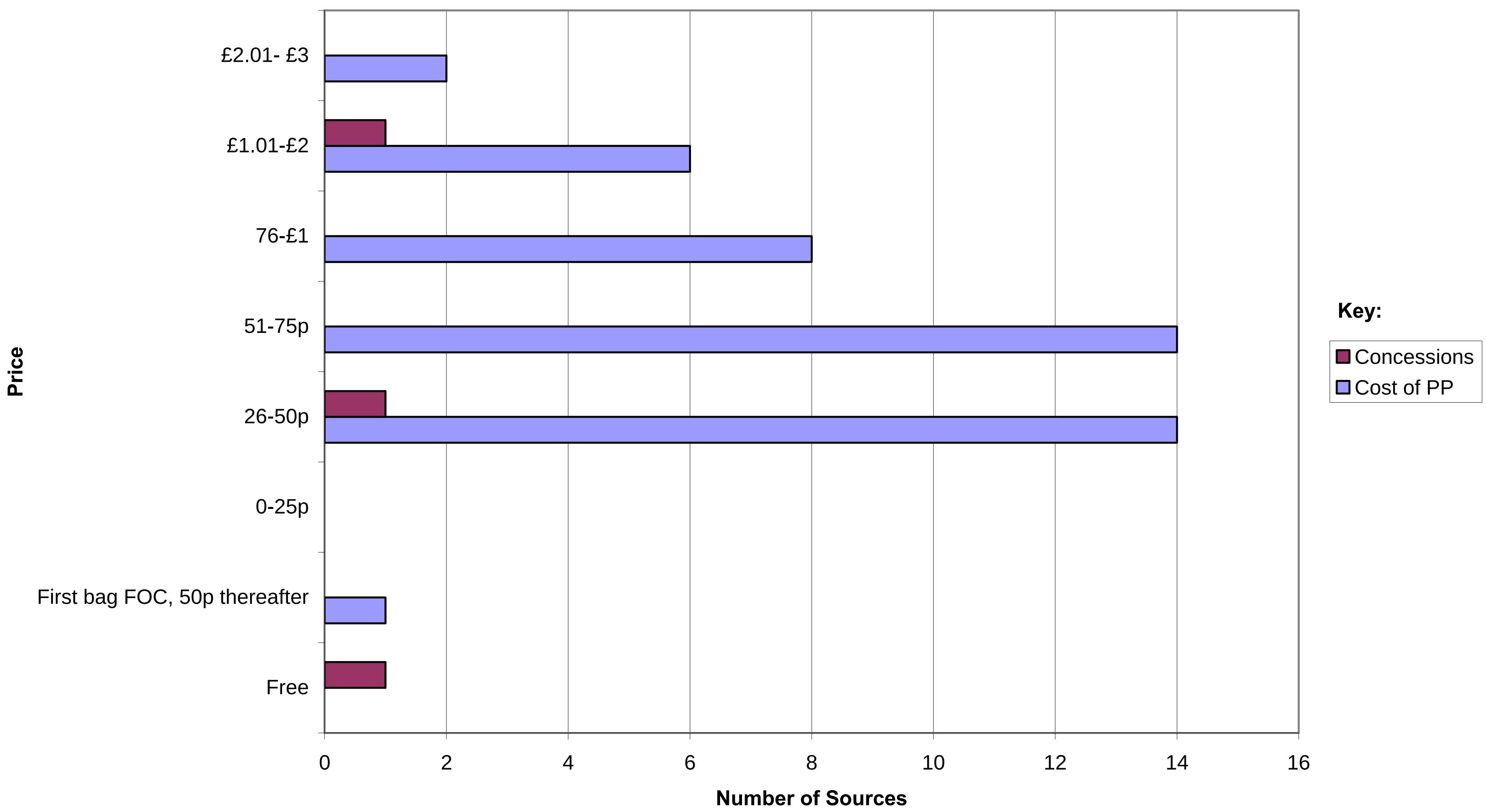


Figure 2 (c) (i): Standard Costs of Pre-Paid Sacks

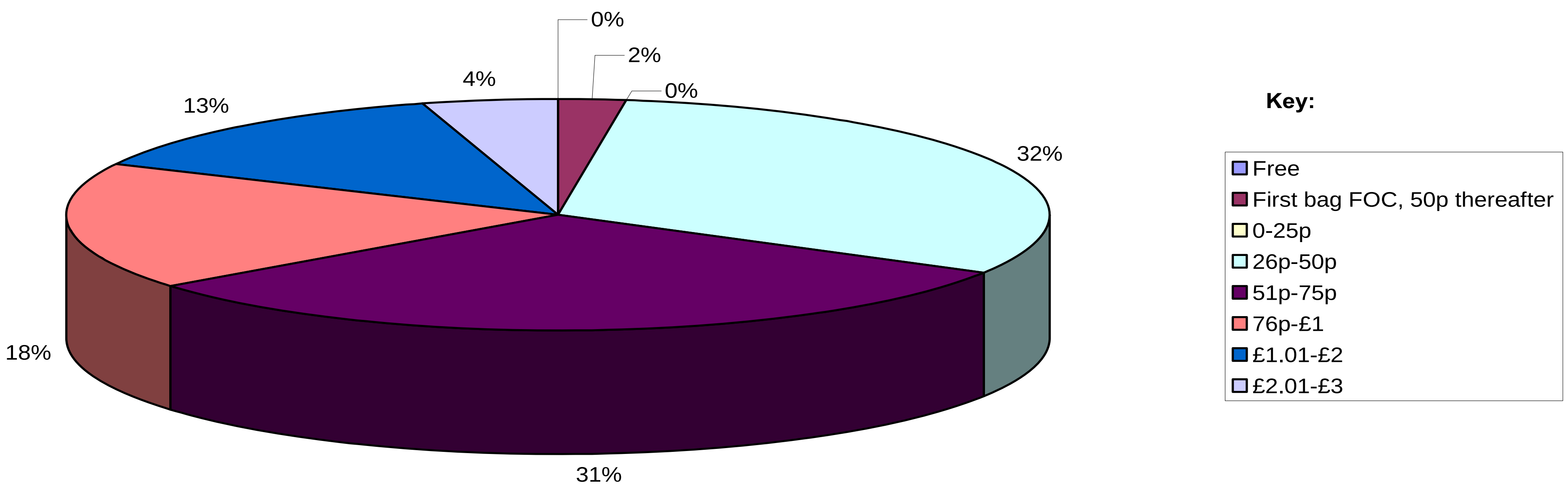
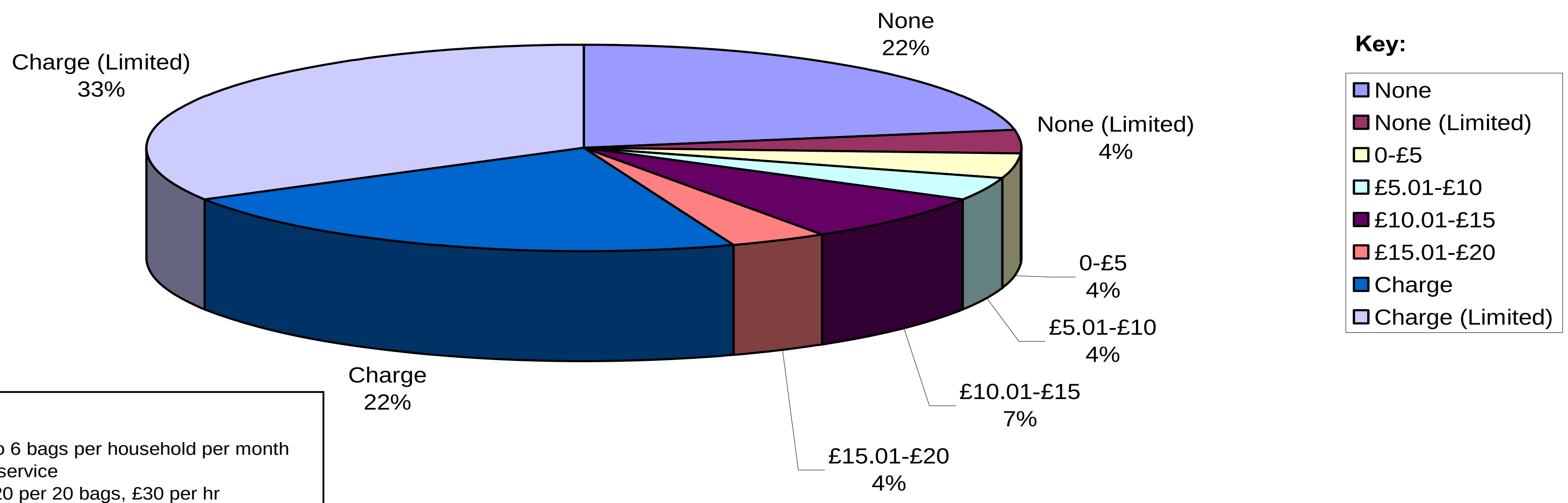


Figure 2(d): Costs to householder for Bulky Household Waste Collection including green waste



Key:
None: No Charge
None (Limited): Upto 6 bags per household per month
Charge: Charge for service
Charge (Limited): £20 per 20 bags, £30 per hr
£15 for upto 0.5 tonnes
£5 for 4 sacks, £6.50 for 6 items
Depend on volume, £21 for 3 items

Figure 3: Frequency of Green Waste Collections

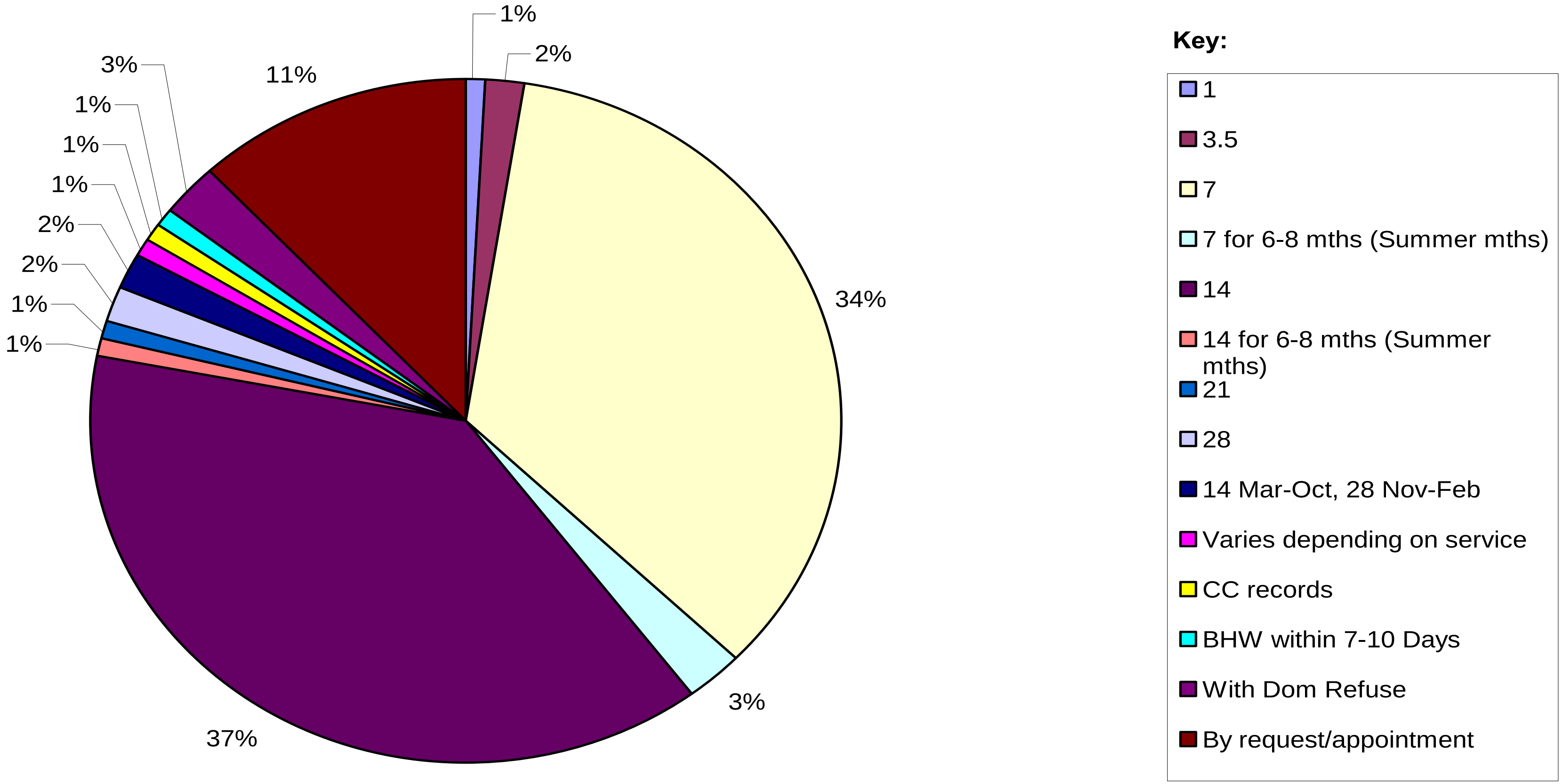
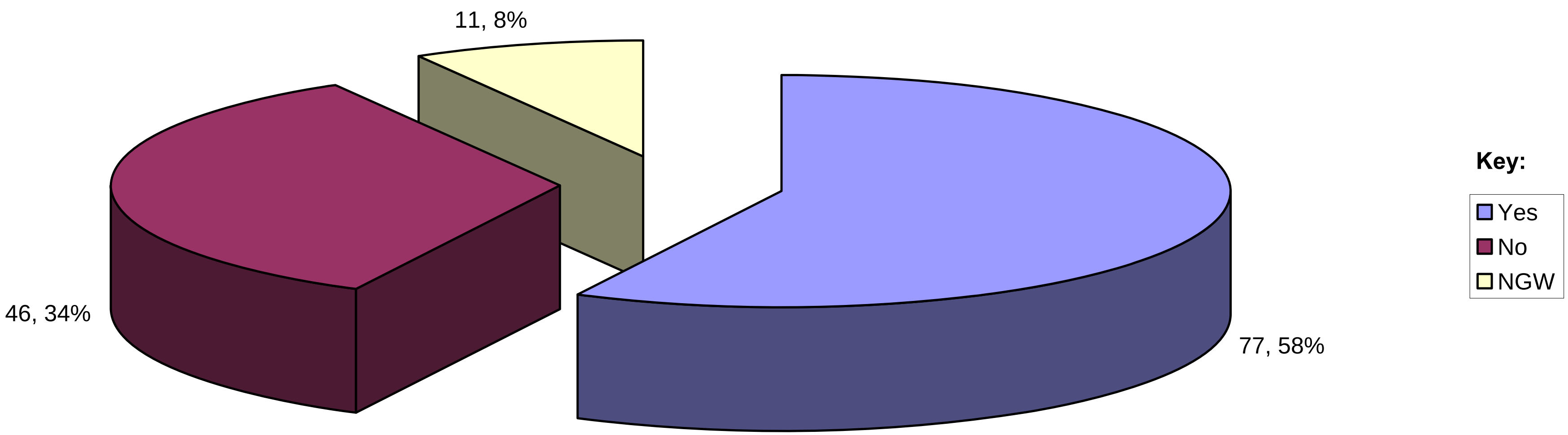


Figure 4: Local Authorities recording tonnages of Green Waste



Number of responses: 134 Local Authorities

Figure 5: Green Waste Production

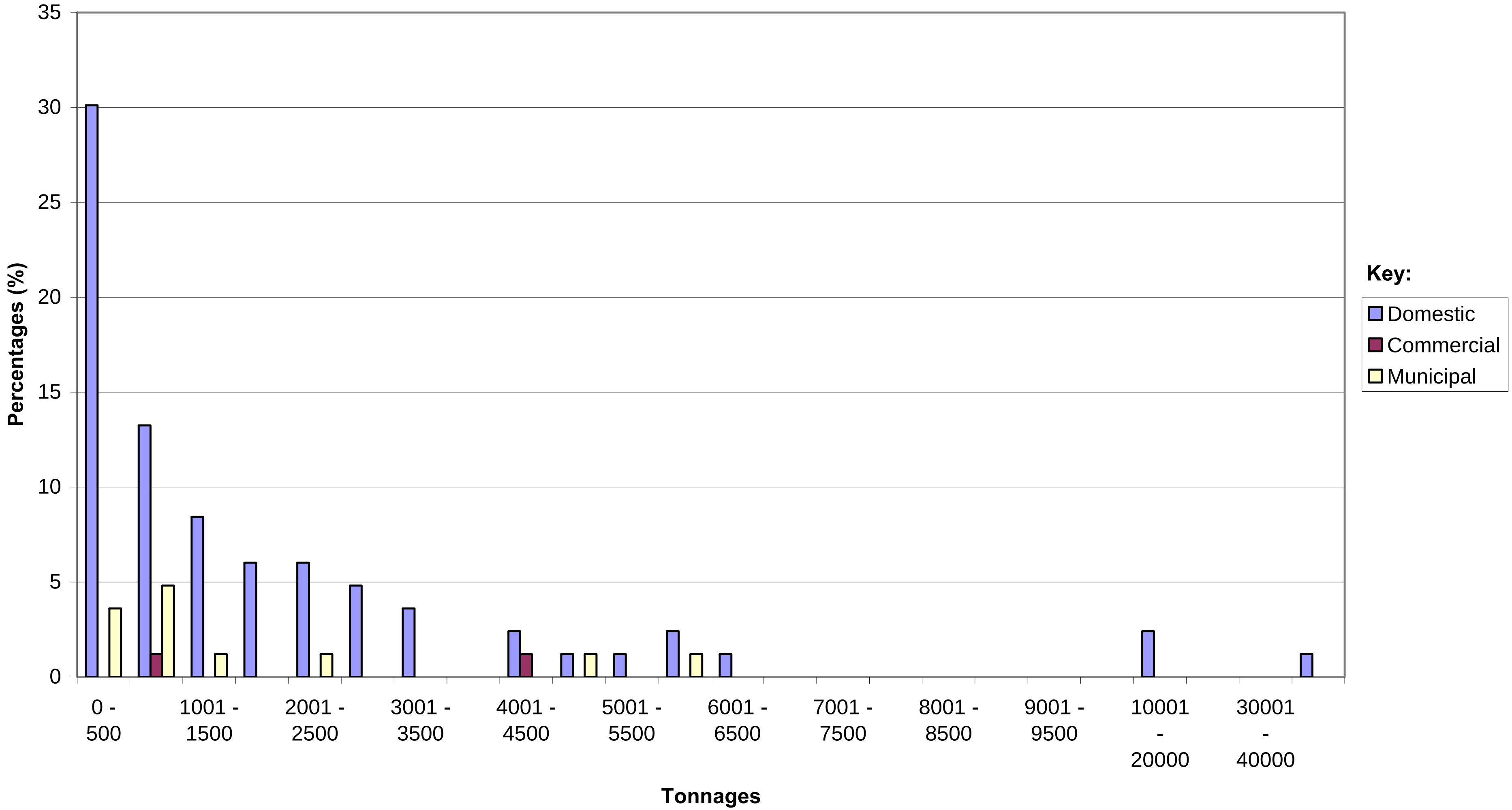
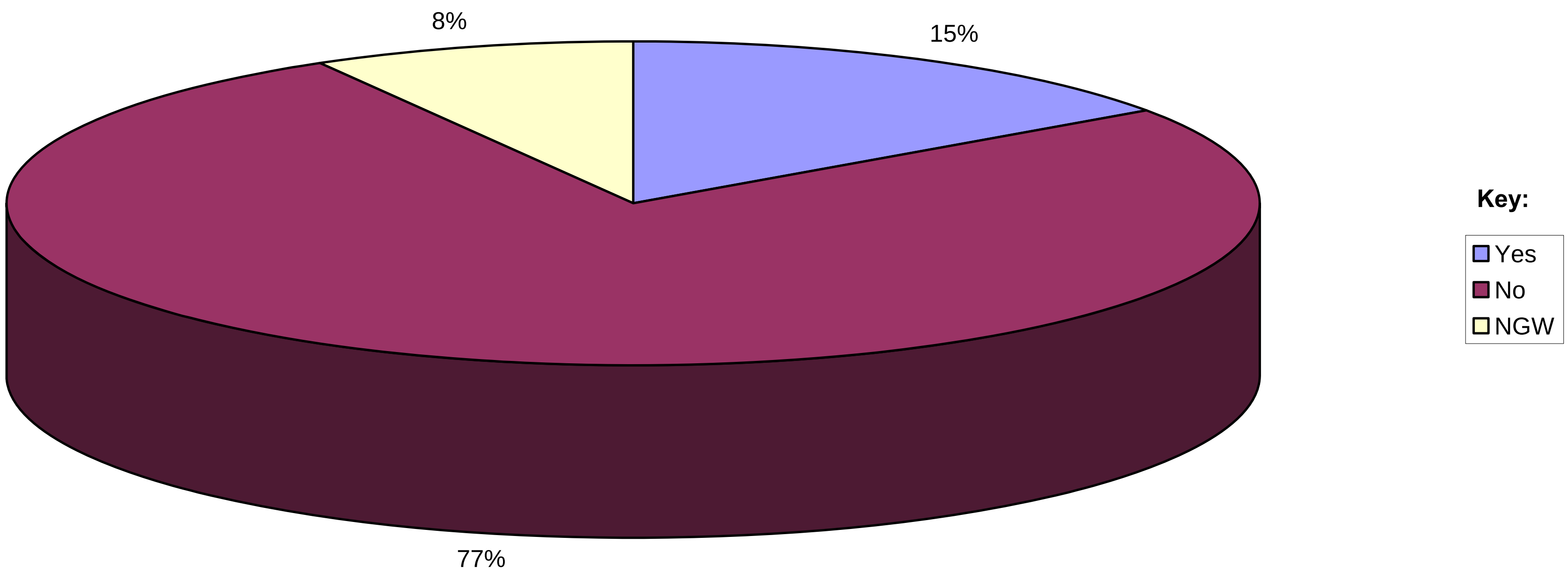
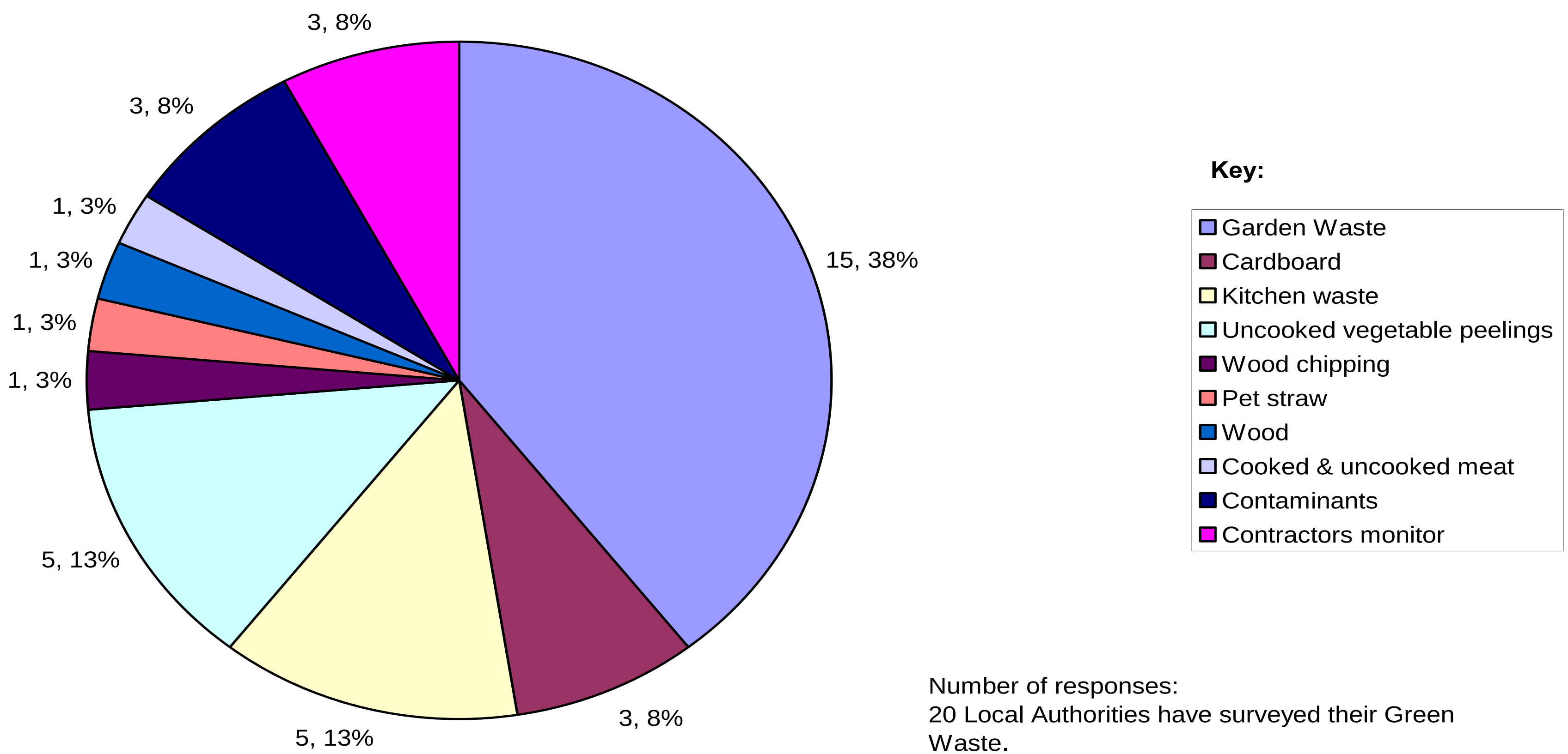


Figure 6: Do Local Authorities survey the components of their green waste



Number of responces = 132 local authorities

Figure 6 (a): Components of Green Waste within Local Authorities Green Waste Collections



Number of responses:
20 Local Authorities have surveyed their Green Waste.

Figure 7: Disposal Methods of Green Waste

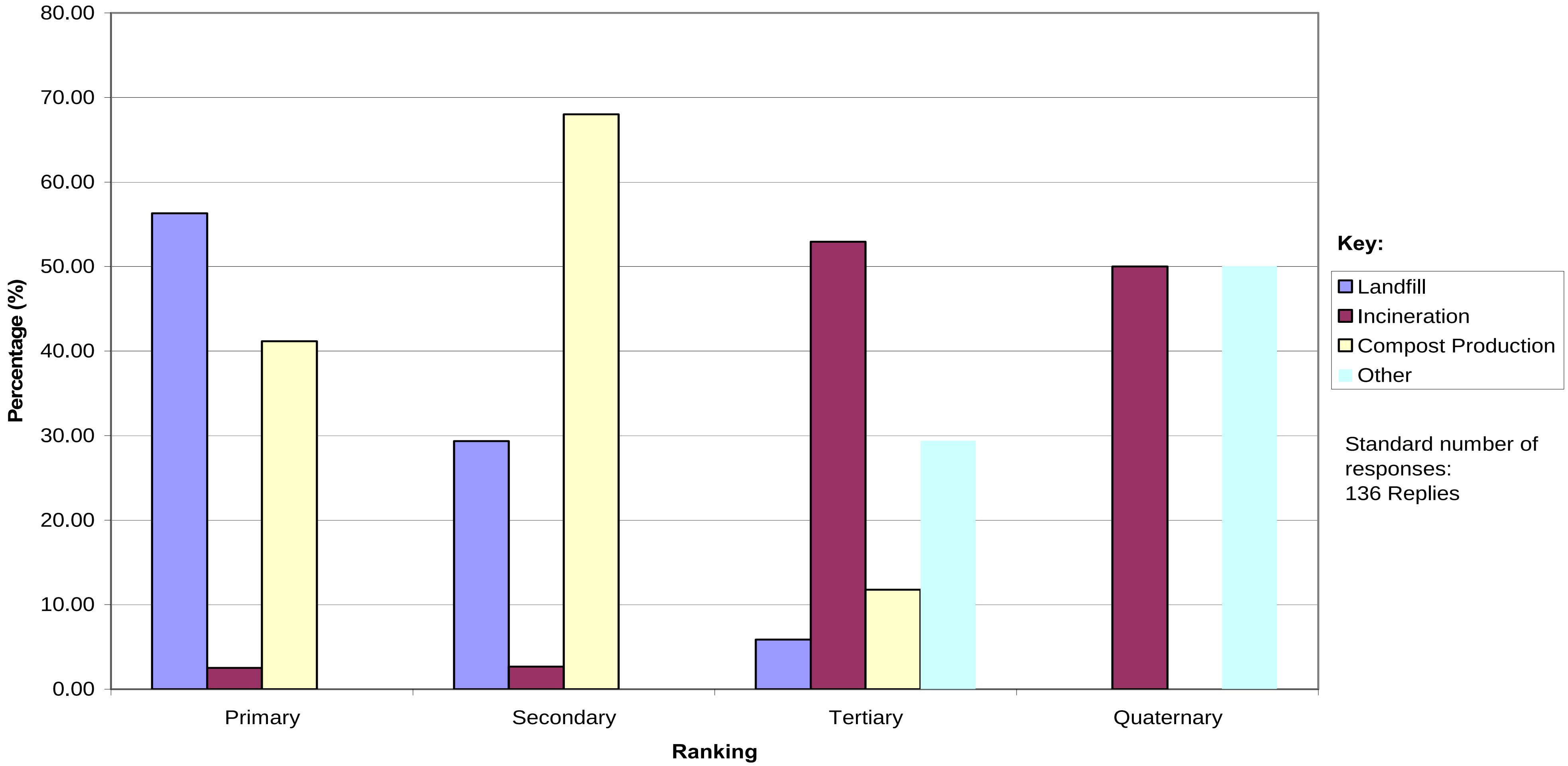
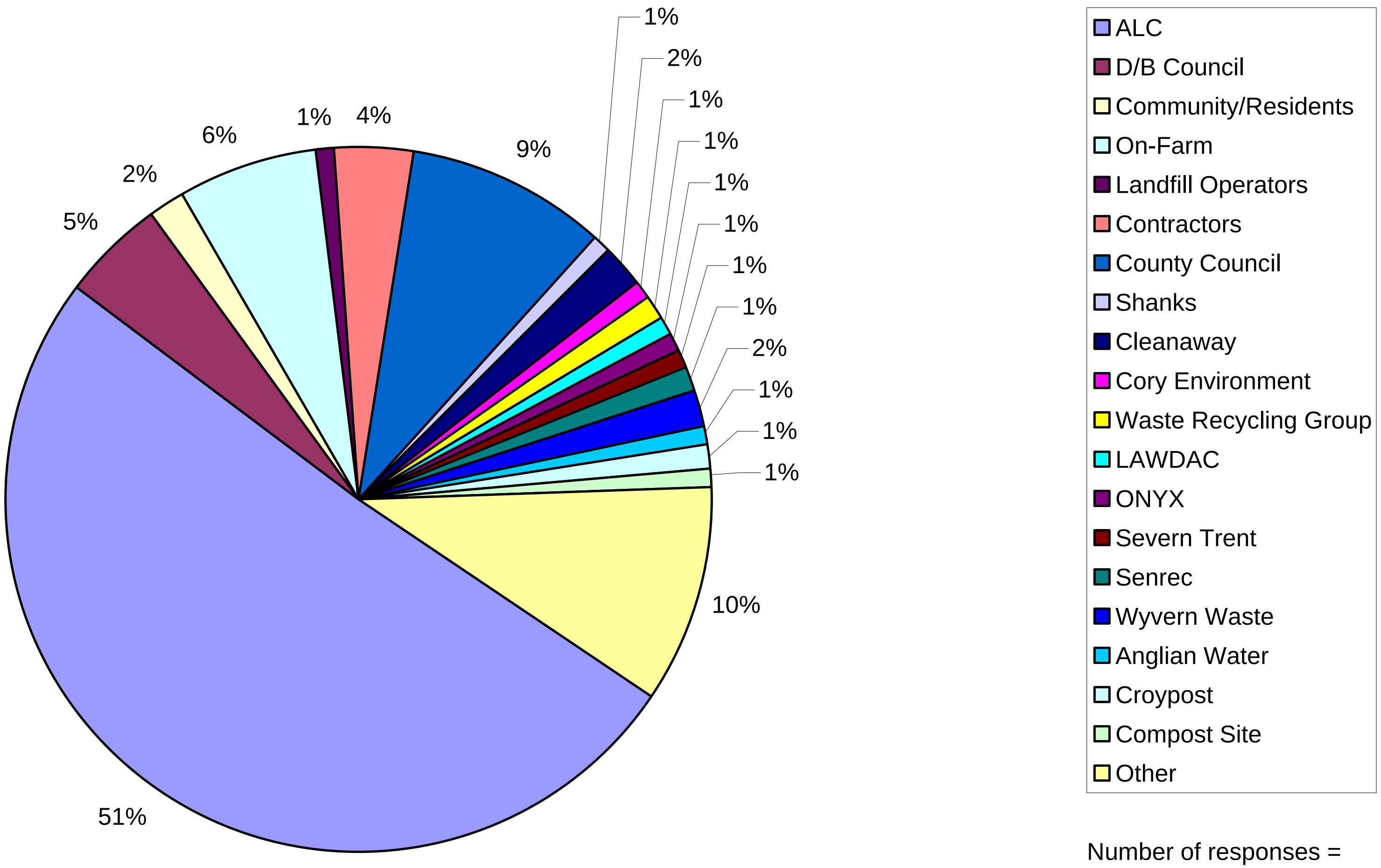
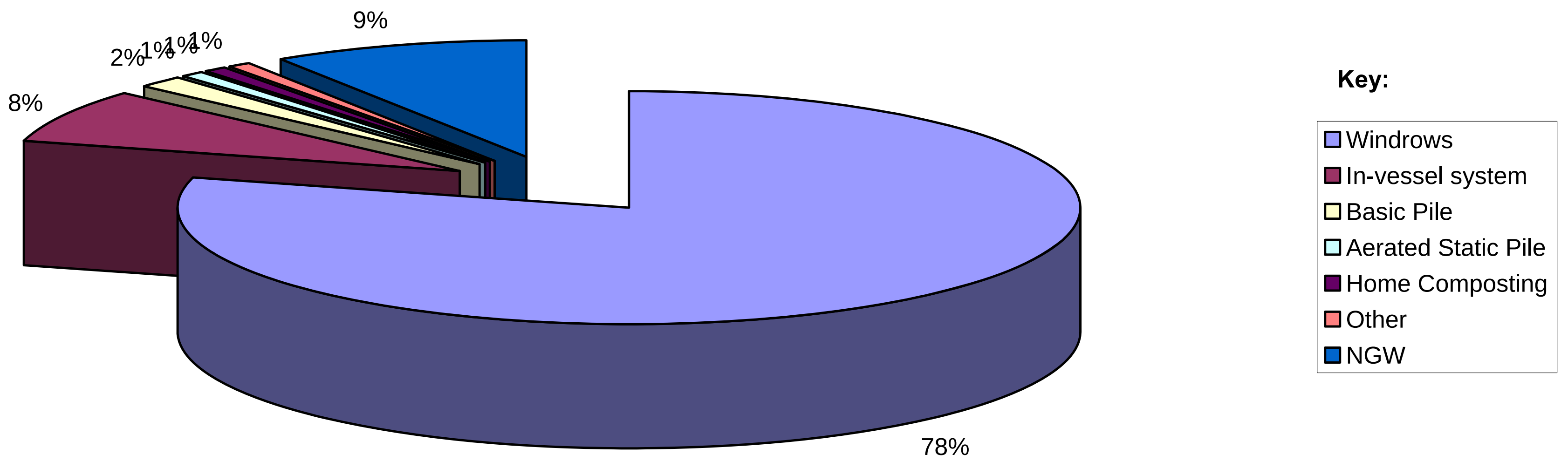


Figure 8: Who undertakes the compsting process



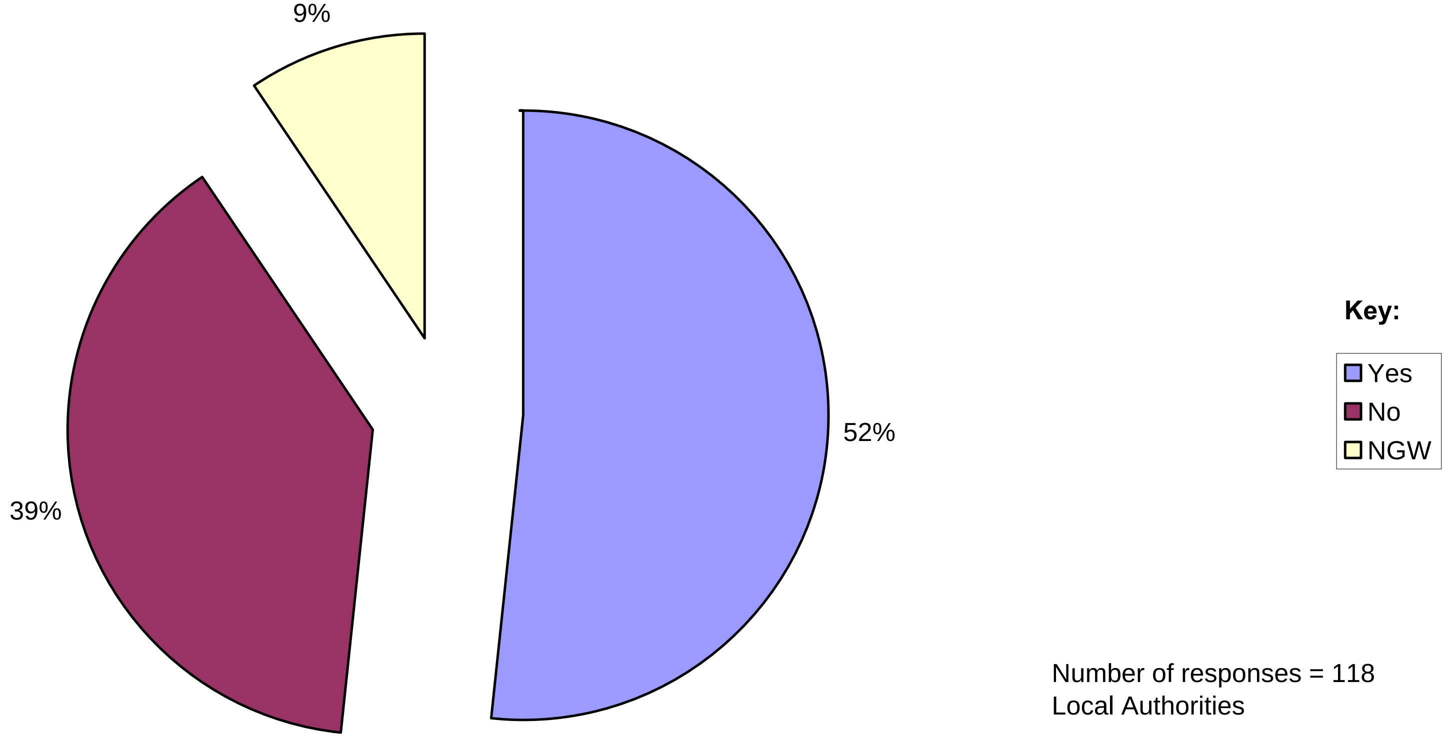
Number of responses = 110 local authorities

Figure 9: Methods of Compost Production



Number of responses = 120
Local Authorities

Figure 10: End-product Sales



Number of responses = 118
Local Authorities

Figure 11: Cost of End Products

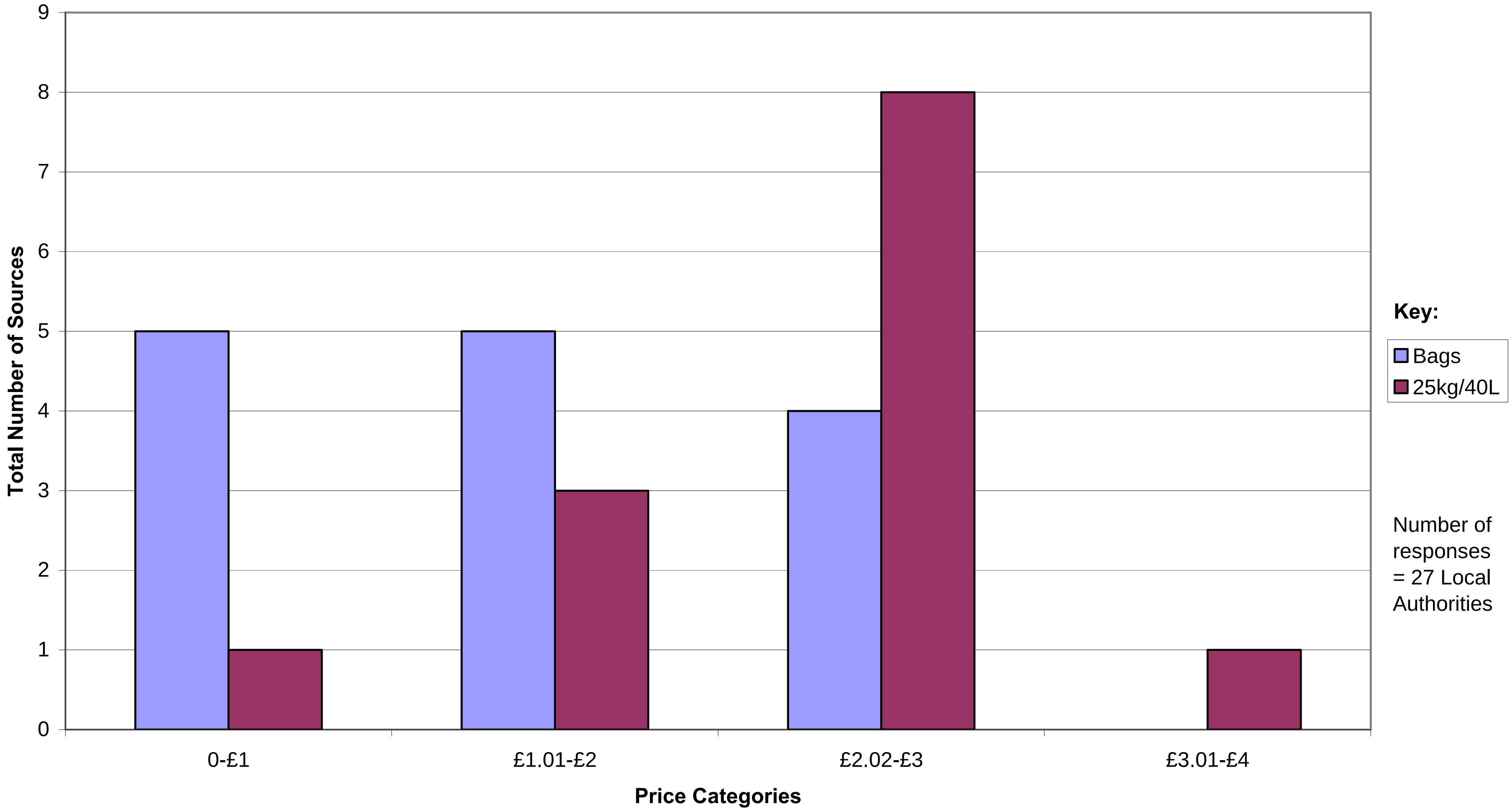


Figure 12: Recycling Initiatives (Tangible)

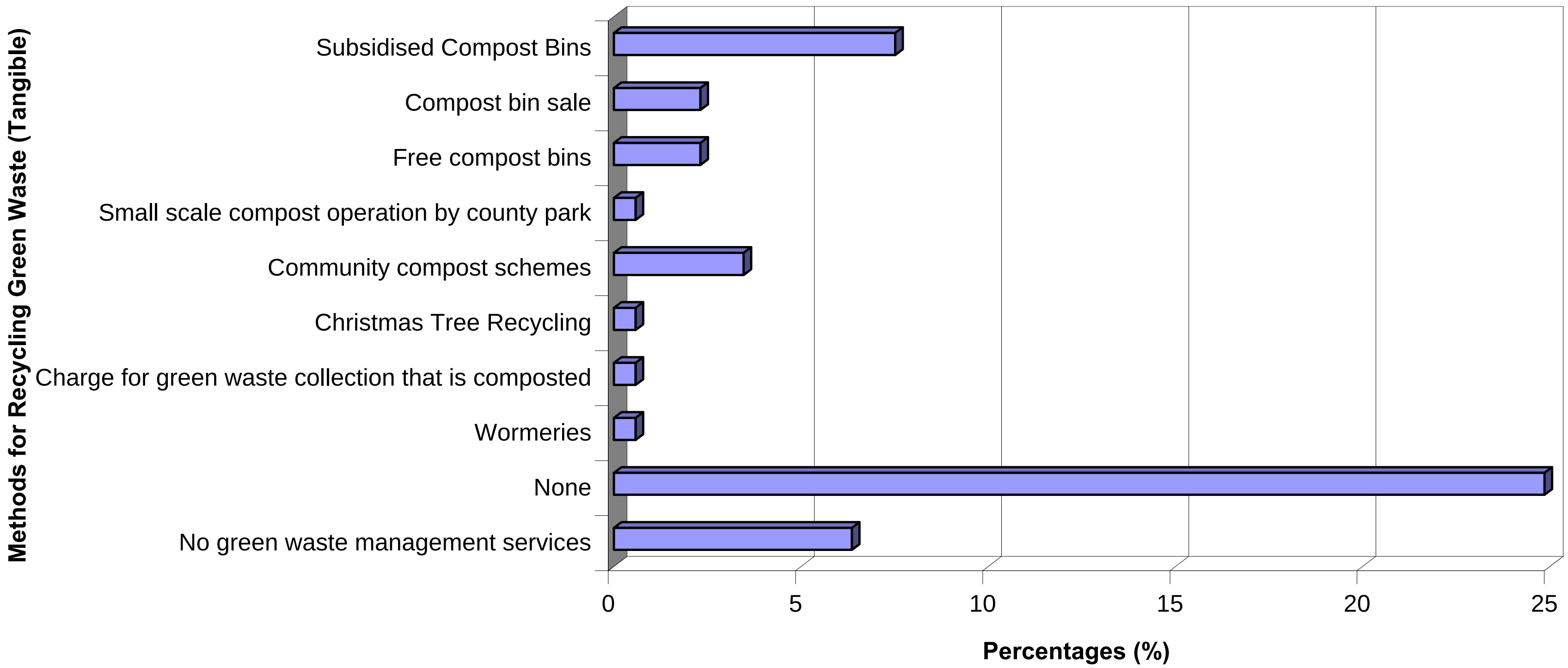
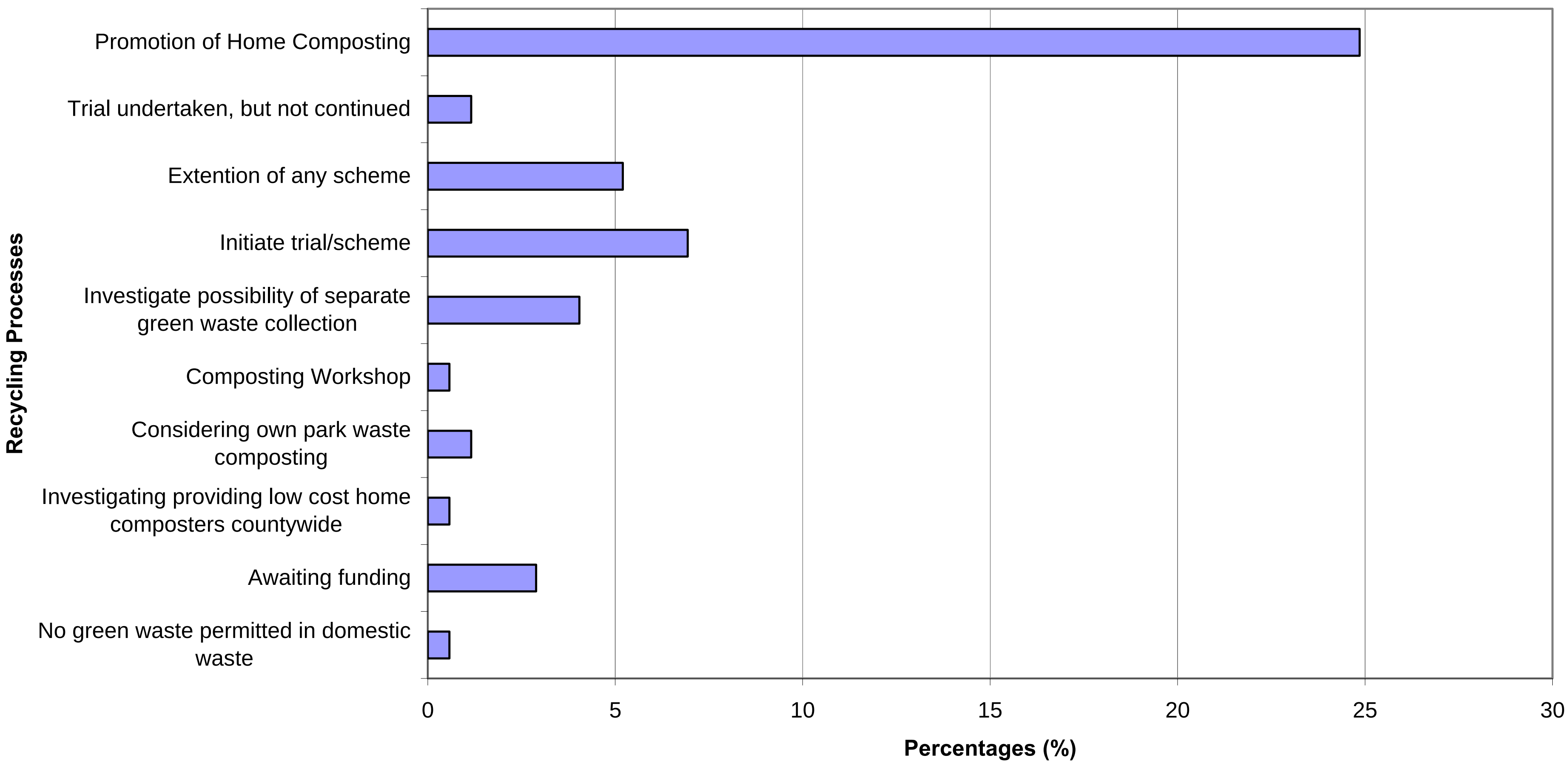


Figure 12 (a): Recycling Initiatives (Intangible)



APPENDIX TWO

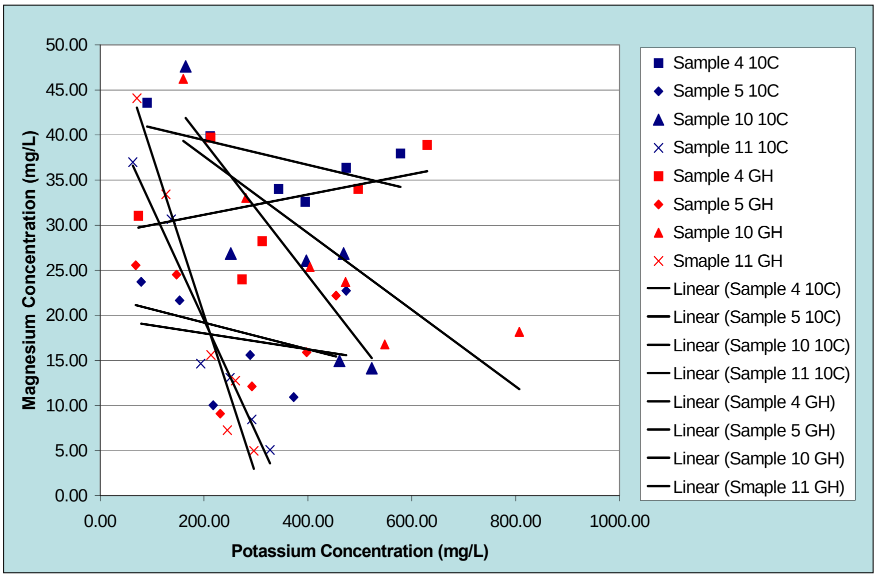


Figure 1: The relationship between magnesium concentrations and potassium concentrations within the peat-reduced mixtures.

Storage Condition	10˚C	+/- Trend Line	Glasshouse	+/- Trend Line
Sample 4 Correlation	.3661	Negative	.1341	Positive
Sample 5 Correlation	.0444	Negative	.1006	Negative
Sample 10 Correlation	.7385	Negative	.7595	Negative
Sample 11 Correlation	.9443	Negative	.9637	Negative

Table 1: The relationship (indicated by r^2 values) between magnesium and potassium concentrations within the peat-reduced mixtures.

APPENDIX THREE

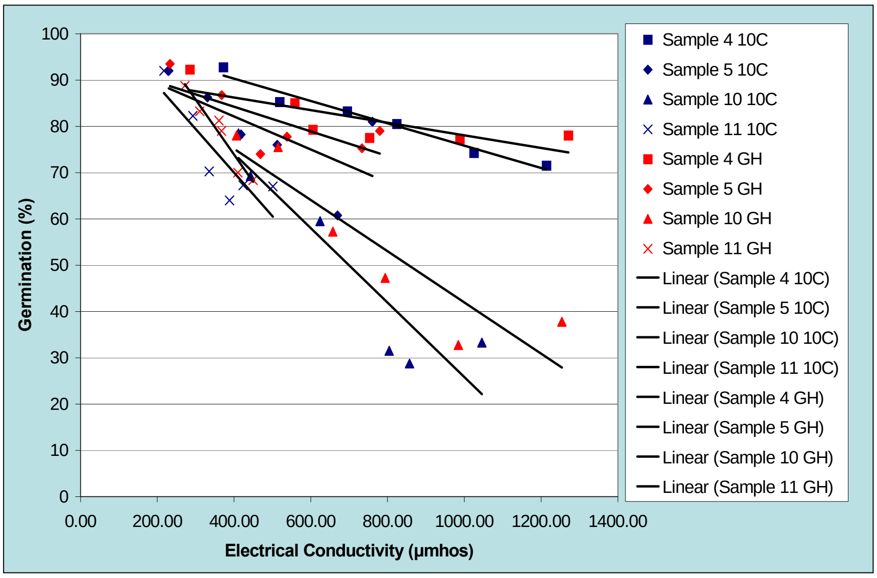


Figure 1: The relationship between lettuce germination and electrical conductivity within the peat-reduced mixtures

Storage Condition	10˚C	+/- Trend Line	Glasshouse	+/- Trend Line
Sample 4 Correlation	.6222	Negative	.9672	Positive
Sample 5 Correlation	.5307	Negative	.4577	Negative
Sample 10 Correlation	.8315	Negative	.855	Negative
Sample 11 Correlation	.9421	Negative	.7415	Negative

Table 2: The relationship (indicated by r^2 values) between lettuce germination and electrical conductivity within the peat-reduced mixtures.

APPENDIX FOUR

Stepwise regression analysis was undertaken on the fresh weights gained from the peat-reduced study.

Step	1	2	3	4
Constant	0.8016	8.9492	7.5546	10.3889
Nitrate	0.0185	0.0168	0.0166	0.0164
T-Value	14.39	14.54	15.45	15.19
P-Value	0.000	0.000	0.000	0.000
BD		-0.0156	-0.0162	-0.0241
T-Value		-5.71	-6.36	-4.33
P-Value		0.000	0.000	0.000
Storage			1.27	1.28
T-Value			3.97	4.02
P-Value			0.000	0.000
K				0.0033
T-Value				1.59
P-Value				0.116
S	2.40	2.08	1.93	1.92
R-Sq	68.54	76.65	80.04	80.57
R-Sq(adj)	68.21	76.15	79.39	79.72

NB: Response is Fresh weight on 15 predictors, with N = 97

Table 1: The stepwise regression analysis for mixtures containing Sample 4.

Step	1	2	3	4	5	6
Constant	0.8629	2.3858	0.9248	-1.0195	7.7938	7.8931
Nitrate	0.0188	0.0185	0.0153	0.0147	0.0130	0.0146
T-Value	17.28	18.14	11.53	11.47	10.01	9.19
P-Value	0.000	0.000	0.000	0.000	0.000	0.000
ASH NG		-0.044	-0.067	-0.073	-0.040	-0.034
T-Value		-4.00	-5.43	-6.12	-2.88	-2.36
P-Value		0.000	0.000	0.000	0.005	0.020
Conductivity			0.0052	0.0064	0.0086	0.0071
T-Value			3.51	4.34	5.74	4.19
P-Value			0.001	0.000	0.000	0.000
Storage				1.18	1.39	1.48
T-Value				3.25	4.04	4.29
P-Value				0.002	0.000	0.000
pH					-1.71	-1.59
T-Value					-3.78	-3.50
P-Value					0.000	0.001
time						-0.127
T-Value						-1.77
P-Value						0.080
S	2.60	2.43	2.30	2.20	2.07	2.05
R-Sq	74.35	77.83	80.24	82.13	84.39	84.87
R-Sq(adj)	74.10	77.39	79.65	81.41	83.60	83.94

Response is Fresh weights on 15 predictors, with N = 105

Table 2: The stepwise regression analysis for mixtures containing Sample 5.

Step	1	2	3	4	5	6
Constant	4.488	24.341	22.379	27.668	43.204	40.140
Nitrate	0.0123	0.0114	0.0118	0.0092	0.0081	0.0063
T-Value	8.91	8.80	9.66	6.15	5.59	4.03
P-Value	0.000	0.000	0.000	0.000	0.000	0.000
pH		-3.03	-3.10	-4.31	-5.71	-4.39
T-Value		-4.48	-4.86	-5.80	-6.92	-4.73
P-Value		0.000	0.000	0.000	0.000	0.000
Storage			1.61	1.94	2.18	2.21
T-Value			3.70	4.46	5.18	5.43
P-Value			0.000	0.000	0.000	0.000
Conductivity				0.0040	0.0063	0.0083
T-Value				2.91	4.22	5.14
P-Value				0.004	0.000	0.000
Phosphorus					-1.49	-1.96
T-Value					-3.31	-4.20
P-Value					0.001	0.000
ASH G						-0.074
T-Value						-2.77
P-Value						0.007
S	3.12	2.87	2.70	2.61	2.49	2.41
R-Sq	43.53	52.82	58.44	61.68	65.51	68.01
R-Sq(adj)	42.98	51.89	57.20	60.15	63.77	66.05

Step	7
Constant	42.51
Nitrate	0.0057
T-Value	3.56
P-Value	0.001
pH	-4.73
T-Value	-5.03
P-Value	0.000
Storage	2.17
T-Value	5.37
P-Value	0.000
Conductivity	0.0072
T-Value	4.17
P-Value	0.000
Phosphorus	-1.80
T-Value	-3.82
P-Value	0.000
ASH G	-0.103
T-Value	-3.27
P-Value	0.001
K	0.0040
T-Value	1.70
P-Value	0.092
S	2.38
R-Sq	68.94
R-Sq(adj)	66.70

Response is Fresh weights on 15 predictors, with N = 105

Table 3: The stepwise regression analysis for mixtures containing Sample 10

Step	1	2	3	4	5
Constant	0.5382	2.3238	0.4790	-1.3645	-0.4968
Nitrate	0.0208	0.0182	0.0122	0.0117	0.0137
T-Value	20.20	15.76	6.90	6.88	6.98
P-Value	0.000	0.000	0.000	0.000	0.000
percentage		-0.047	-0.068	-0.068	-0.060
T-Value		-3.97	-5.65	-5.98	-5.00
P-Value		0.000	0.000	0.000	0.000
Conductivity			0.0077	0.0088	0.0070
T-Value			4.28	5.02	3.54
P-Value			0.000	0.000	0.001
Storage				1.04	1.17
T-Value				3.19	3.55
P-Value				0.002	0.001
time					-0.127
T-Value					-1.98
P-Value					0.051
S	2.41	2.25	2.08	1.99	1.97
R-Sq	79.85	82.55	85.23	86.59	87.10
R-Sq(adj)	79.66	82.21	84.79	86.05	86.45

Response is Fresh weights on 15 predictors, with N = 105

Table 4: The stepwise regression analysis for mixtures containing Sample 11

APPENDIX FIVE

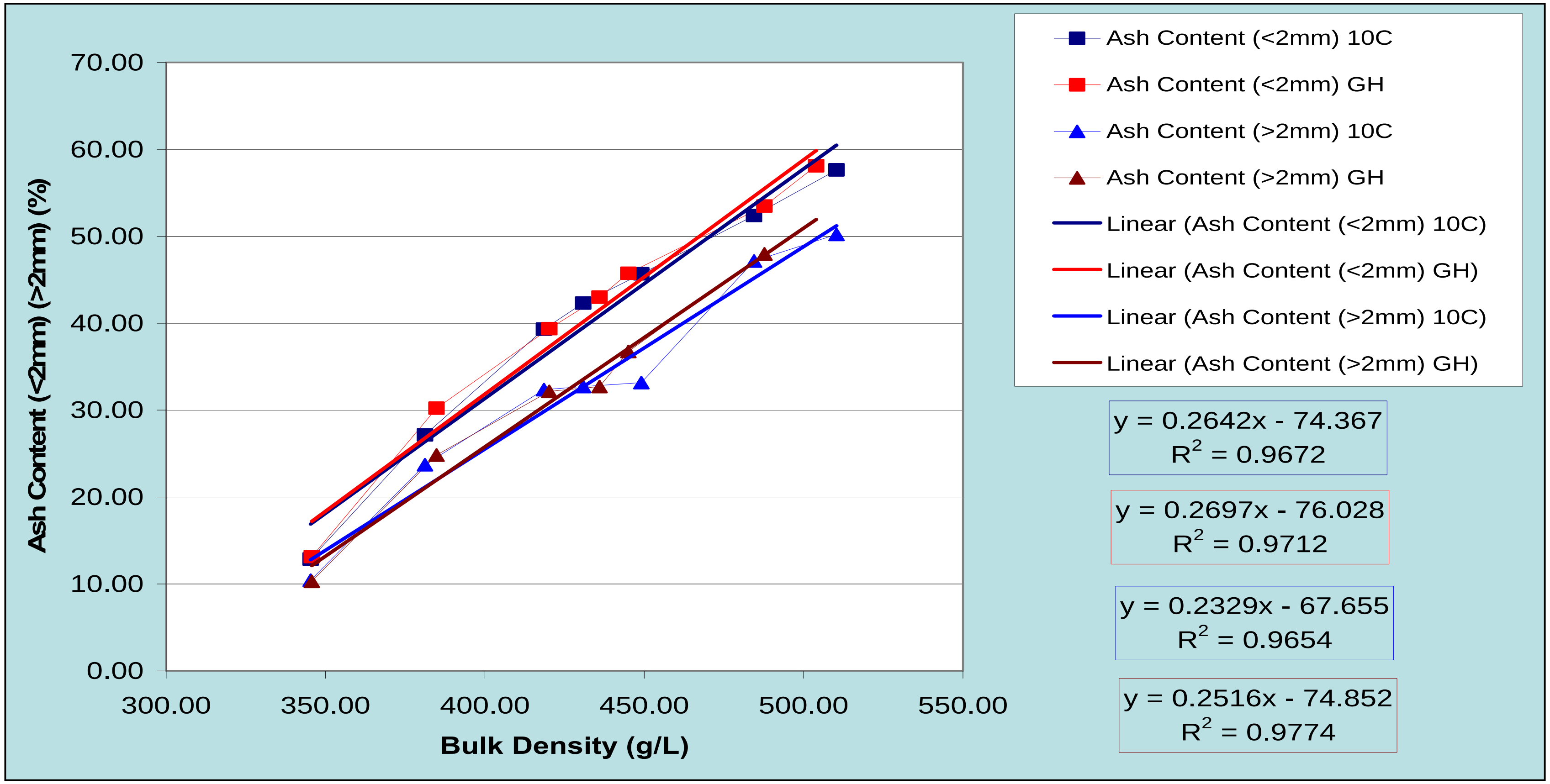


Figure 1: The relationship between bulk density and ash content within the peat-free mixtures

APPENDIX SIX

Stepwise Regression Analysis was undertaken on the dry weights gained from the peat-free study.

Step	1	2	3	4	5	6
Constant	0.3015	0.3250	0.2979	0.2530	0.4194	0.2239
Nitrates	0.00033	0.00035	0.00020	0.00038	0.00040	0.00043
T-Value	6.28	6.75	2.65	3.92	4.37	5.02
P-Value	0.000	0.000	0.010	0.000	0.000	0.000
Manganese		-0.076	-0.096	-0.099	-0.138	-0.038
T-Value		-2.43	-3.06	-3.29	-4.43	-0.93
P-Value		0.017	0.003	0.001	0.000	0.357
percentage			0.0035	0.0049	0.0065	0.0077
T-Value			2.69	3.63	4.71	5.75
P-Value			0.009	0.000	0.000	0.000
Magnesium				-0.0072	-0.0083	-0.0102
T-Value				-2.81	-3.40	-4.31
P-Value				0.006	0.001	0.000
Phosphorus					-0.0148	-0.0356
T-Value					-3.14	-4.77
P-Value					0.002	0.000
time						0.107
T-Value						3.47
P-Value						0.001
S	0.241	0.235	0.226	0.218	0.207	0.194
R-Sq	31.46	35.90	40.98	46.09	51.87	58.09
R-Sq(adj)	30.67	34.40	38.87	43.50	48.93	54.98

Step	7	8	9
Constant	0.1708	0.2227	0.2281
Nitrates	0.00044	0.00059	0.00045
T-Value	5.10	4.99	3.08
P-Value	0.000	0.000	0.003
Manganese			
T-Value			
P-Value			
percentage	0.0076	0.0077	0.0074
T-Value	5.71	5.85	5.57
P-Value	0.000	0.000	0.000
Magnesium	-0.0104	-0.0128	-0.0210
T-Value	-4.42	-4.82	-3.75
P-Value	0.000	0.000	0.000
Phosphorus	-0.0383	-0.0378	-0.0365
T-Value	-5.60	-5.60	-5.44
P-Value	0.000	0.000	0.000
time	0.127	0.121	0.111
T-Value	5.79	5.59	4.98
P-Value	0.000	0.000	0.000
Potassium		-0.00024	-0.00026
T-Value		-1.85	-2.05
P-Value		0.068	0.044
Calcium			0.0035
T-Value			1.65
P-Value			0.102

S	0.194	0.191	0.189
R-Sq	57.64	59.37	60.71
R-Sq(adj)	55.06	56.36	57.27

NB: Response is Dryweights on 18 predictors, with N = 88

Table 1: The stepwise regression analysis for the peat-free mixtures

APPENDIX SEVEN

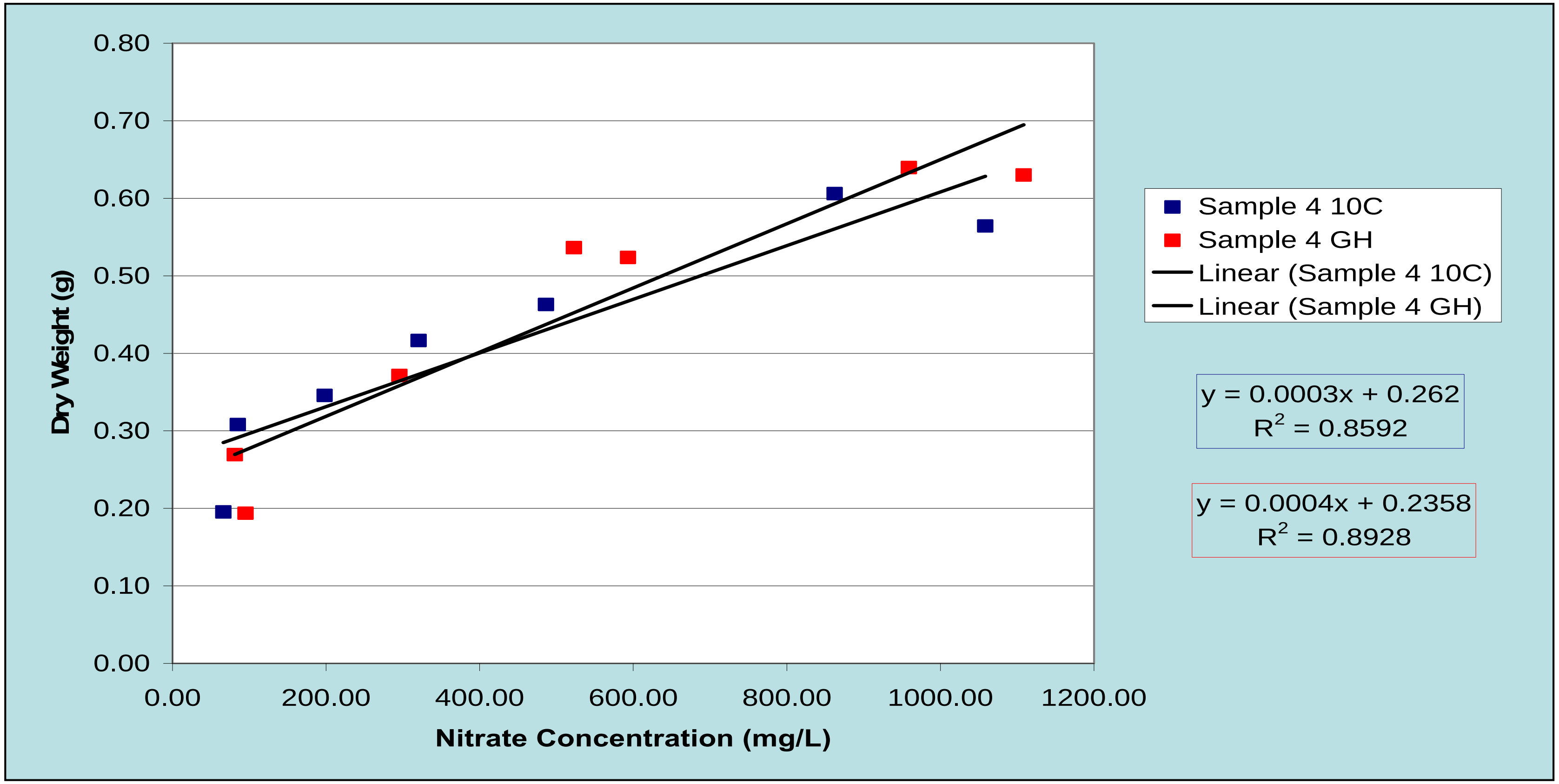


Figure 1. The relationship between nitrate concentration and dry weight within peat-free growing media