Project Title:	The production of effective peat replacements media by composting organic wastes
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the Hanson environment fund

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Commercial benefits of the project

The substitution of peat by compost results in significant cost savings.

Background

Composting of organic material is increasingly being recognised as a viable management option for the treatment of certain biodegradable wastes. There is a recognition within the industry that as more compost is being produced, the market for composts will have to expand. The Department of the Environment, Transport and the Regions (DETR) set up a working group to examine this issue[1]. This report found that the horticultural industry is one of the key high-value markets into which compost could be sold. However, it is an industry which has very strict quality requirements of any material which it uses, and that material must be shown to be able to compete with peat as a growing medium. The DETR report found that there had been insufficient investment in research into peat alternatives. There is a huge opportunity within the industry if a quality compost (or range of composts) can be produced.

The quality issue can be tackled in two ways. Firstly, suitable and consistent feedstock mixes can be used to improve the nutrient status of the composts. Secondly, the composting process itself can be controlled to improve the consistency of end product - this can be achieved by using a computer controlled containerised composting system. This project was designed to use both these approaches to produce a peat replacement compost.

Project Objectives

This project aimed to develop a methodology for producing a quality peat replacement medium by the manufacture of compost using a controlled composting operation. This aim would be met by meeting the following objectives:

1. The assessment of the suitability of local waste streams for composting
2. The establishment of a containerised composting facility
3. Optimisation of composting parameters with respect to end-product quality
4. Large-scale testing of finished composts under commercial growing conditions

The results from the project will allow the composting industry as a whole to increase the quality of the waste derived composts being produced, and will give the horticultural market sector confidence in the quality of waste derived composts. This added quality will translate into financial benefit for the compost producer. In addition, once professional horticulture starts using waste derived composts, the amateur gardeners will start to follow suit, opening yet another market for high value composts.

[1] Report of the Composting Development Group on the Development and Expansion of Markets for Compost, DETR (1998)

The whole project was intended to last for two years, and work is still ongoing. This report covers work funded by The Hanson Environment Fund (first three objectives).

Summary of Results

Objective 1: The assessment of the suitability of local waste streams for composting:

There are several factors that need to be taken into account when sourcing materials to be composted with the aim of producing a component of growing media:

- Material transport costs
  Transportation of wastes over ~25 miles can be uneconomic. Local wastes should be sourced, or arrangements should be made so that the waste producer delivers material at no or low cost.

- Waste costs/ alternative opportunity costs
  Some materials may be identifiable as wastes, but may have value in alternative uses. In this case, in addition to transport costs, there may be an additional cost in buying in the material e.g. chicken manure, straw and material from certified organic production systems. These materials should only be bought in if they add value to the compost, or are required to enable the composting process to take place.

- Consistency of waste streams
  Some waste streams are highly seasonal, others may vary between batches; it is important that these variations do not compromise the effectiveness of the composting process.

- Contaminants
  Some waste streams are more prone to contaminants such as plastics, metals, glass, and stones, which will be unaffected by the composting process. These contaminants may then feed through into the finished product. Procedures should be put in place to minimise contamination levels at source.

- Chemical properties of wastes

  The key chemical property of the waste (or mixture of wastes) is its Carbon to Nitrogen (C:N) ratio. If this is too low (below 20:1) then excess Nitrogen may be released as ammonia, giving odour problems. If the C:N ratio is too high (>40:1) then the rate of composting will be low, leading to low composting temperatures and lack of pathogen and weed kill.

  Wastes may also contain potentially toxic elements, PTE's, such as heavy metals; these are unaffected by composting and may be concentrated during the process. The Composting Association's quality standard details acceptable levels for these chemicals.

- Moisture content of wastes

  Too low a moisture content (<40%) is easily remedies by addition of water during composting. If the moisture content of the wastes is above 65% then drier amendments (eg straw, paper) may need to be added – these will then impact on the chemical properties of the wastes.

- Physical properties of wastes

  A range of particle sizes is desirable during composting, to ensure adequate air flow through the pile. Bulking agents such as wood chips may be needed, especially if the majority of the waste is putrescible eg fruit/vegetables.

Objective 2: Establishment of containerised composting facility.

The type of composting technology required will vary depending on the nature of the wastes being composted, the volumes of material being processed, land availability, and regulatory requirements.

- Nature of the wastes

  Whilst in-vessel composting is more expensive than windrow composting, it is a more appropriate technology for wastes which are:

    - Wet
    - Odorous
    - Hazardous eg microbial contamination

  In-vessel systems minimise the potential of environmental pollution by containment of leachate and treatment of potentially contaminated air using bio-filters.

  In-vessel composting appears not to be as well suited for composting of woodier materials.

- Volumes of material being processed

  In-vessel composting of large volumes of material will require significant capital investments. Management of the process for quality compost production becomes difficult, mainly due to problems of tracking contaminants and ensuring process parameters are optimised for all compost batches. This can result in problems maintaining the consistency of the finished product.

- Land availability

  If land is at a premium then in-vessel composting may be necessary as the footprint of these systems is much smaller than that of a windrowing operation.

- Regulatory Requirements

  Composting of catering waste is restricted under Animal By-Products Legislation; where composting of this material is being proposed the facility must be approved by the State Veterinary Service.

  Composting sites may require a waste management licence, or an exemption from waste management licensing regulations; the Environmental Agency (or equivalent) should be consulted prior to setting up a composting operation.

  Planning permission may also be required for a new site; the local authority planning department should be consulted.

  Where licensing is required the regulators are more likely to be sympathetic to in-vessel composting than to open air windrowing.

<u>Objective 3: Optimisation of composting parameters with respect to end-product quality</u>

Unless one has a very consistent feedstock there will be a need to modify the mix of compost feedstocks on a batch by batch basis. The key parameters are C:N ratio, water content and porosity. For in-vessel composting the latter may be the most important, as this will affect airflow through the compost. For windrow composting it is more important to ensure that the water content of the feedstocks is not too high – if it is potential for anaerobic conditions to develop leading to odour problems and affecting compost quality.

<u>Objective 4: Large-scale testing of finished composts under commercial growing conditions</u>

The majority of these trials were outside the scope of this project. However, trials were conducted to examine the effects of compost maturity on herb growth. Maturity (ie age of the compost) was found to be a key parameter when predicting compost suitability as a growing medium. Standard tests (ie the Solvita test) were found not to be accurate enough to determine how a compost was likely to perform. Any grower considering using composts should conduct bioassays using their own crops as test plants – the results from bioassays on other plants may not be relevant.

The length of time that an individual compost will take to mature will depend on how it is made; what feedstocks are combined and what process is used.

Science Section

1. Introduction

The main driver of the project work (initially) was to produce a growing medium which met Soil Association rules i.e. one which was organically certified. Conventional, peat-based growing media could not be used, and there was no one product available to the grower that could match peat in terms of performance and cost. This project aimed to develop a methodology for producing a quality peat replacement medium by the manufacture of compost using a controlled composting operation. This aim would be met by meeting the following objectives:

1. The assessment of the suitability of local waste streams for composting
2. The establishment of a containerised composting facility
3. Optimisation of composting parameters with respect to end-product quality
4. Large-scale testing of finished composts under commercial growing conditions

This report is written to enable other horticultural producers to understand the key steps that should be taken when developing a compost-based product for their crop.

Prior to commencing practical work on the project a brief literature review was prepared. This is presented below.

2. Literature review

Summary

The inclusion of compost into growing media for horticultural production can result in the production of plants of equal or higher quality than those grown in conventional media. Composts performed best when diluted with an inert structural material and/or blended with composts produced from different feedstocks. The main diluents used are coir, bark and peat and the most successful blends were created using green waste compost and chicken manure composts.

There is little information on the specific growing media needs of herbs. The literature shows that herbs such as coriander, oregano and lemongrass can perform well in compost, both during transportation and in shelf life.

Although in the search for a peat replacement, composts have been thoroughly tested in growth trials, the actual production technique used has not been a focus of research. This review has found no trials where different composting techniques have been compared in their ability to produce a growing media.

To produce a high quality compost the mix must be prepared to provide the best environment for microbial activity using C:N ratio moisture content and particle size. The moisture content and aeration must be optimised throughout the process to achieve the best result.

Compost maturity is a critical factor in producing quality growing media. Immature composts contain high levels of phytotoxins. Quantitive measurement of these pytotoxins is difficult as their affect on plant growth is dependent on the physical and biochemical complexes of which they are a part. Therefore bioassays may be the most meaningful method of examining the phytotoxicity of the compost. The other negative effects of immature composts are that they have high microbial activity which leads to oxygen depletion in the root zone and nitrogen lock up.

Background

The use of peat as a growing medium

Peat can be used in a wide variety of sectors because it varies according to the region of origin, the climatic conditions it formed under and the grading/blending carried out after it is harvested. This variation means that the individual needs of each sector can be met by blending peats from different origins and depths. Peats all share specific characteristics low pH, low nutrient levels and low bulk density (Bragg et al 2000). These characteristics increase the versatility of peat further as they allow accurate, cost effective chemical amendment to provide the ideal pH and nutrient status for each specific crop. Low bulk density is especially important in production of containerised plants as low bulk density leads to low transport costs.

Peat provides a good structure which provides a consistently good balance between the needs of the plant to have oxygen to the roots and its need for a good water holding capacity in a compost (especially important in containerised systems). A growing media hoping to compete with peat must provide a good balance between these two factors. Any inconsistency would mean nurseries would need more careful water management.

Bragg et al (2000) state that ‘For some species, it may be that other substrates can produce as good, or even better, plants, but peat has provided commercial growers with the advantage of being able to grow many different species, sourced from hugely varying natural habitats originally, in one basic substrate.’ It goes on to say that ‘It must be borne in mind that the growing systems used by commercial nurseries in the UK, including the irrigation systems, nutritional systems and disease/pest management systems have been developed for peat-based substrates.’ This is an important point as changing from peat to an alternative substrate would require re-education of growers alterations to current nursery practice.

Barriers to the use of composts

DETR (2000) show that roughly one third of commercial nurseries have tried various peat free growing media but many of these have no plans to continue using alternatives. It goes on to say that ‘the main problems encountered with peat free media are related to watering, feeding, growth rates achieved during propagation and product consistency.’

Bragg *et al* (2000) cite grower’s previously bad experience of composts and composts high bulk density as key issue’s preventing the more widespread use of composts. It also highlights the problems caused by high pH and high electrical conductivity (salinity) in composts, which limits the levels at which they can be used in a blend. Spiers and Fietje (2000) stated that ‘green waste compost is unsuitable as a growing media owing to inadequate air space, high salt content and high pH.’ However, they went on to say that ‘ the incorporation of green waste compost as a component in soil less media may provide desirable properties such as improved nutrient retention, greater pH buffering capacity, reduction in fertilizer requirements and suppression of soilbourne diseases.’

In an article in Biocycle (April 2001) Michelle Miller reported on the use of green waste composts as growing media in Oregon. Nurseries had had disappointing results - lack of consistency and poor quality were the most common problems. There was much variability between batches in terms of both chemical and physical composition of the compost. The article went on to give parameters that a growing media must consistently meet for use in containerised systems. Soiless media pH must fall between 5.5 and 6.5 for almost all greenhouse crops. Most composts are neutral to alkaline with a pH of about 7-9. This limits the amount of compost that can be added to a mix before it raises the pH too high. High final pH will limit the availability of trace elements like iron zinc copper and manganese. Salinity in a containerised system can be a serious problem. Unlike a soil based system the plants’ root systems are restricted in pots and cannot escape toxic salt levels. The article recommends that salinity in the finished media should not exceed 3.0 dS/m for nursery crops and 2.0 dS/m for glasshouse production. Particle size influences the pore space available for air and the level of water retention in the compost. As the particle size reduces so does the porosity of the compost reducing the levels of oxygen available to the plant roots. The article recommends that the percentage of dust-sized particles be kept below 20% of the volume of the compost. Carbon to nitrogen levels should be 25:1 or below to avoid nitrogen lock up in the media.

In addition to the problems highlighted above, Rainbow and Wilson (1998) point out that levels of water soluble nitrogen and phosphorous are usually too low in comparison to levels of water soluble potassium. This nutritional imbalance in composts can lead to poor plant growth.

Rainbow and Wilson overcame many of the problems of composts by amending it using the Compaid Process. This involves the incorporation of phosphoric acid to reduce the pH and give additional phosphorous and the incorporation of ammonium nitrate to further reduce pH and provide additional nitrogen. The compost was then diluted using reconstituted coir or some other suitable low nutrient substrate. This process changed the compost to a much more suitable growing media. Compaid amended composts and untreated composts were compared to peat free growing media in growth trials. Performance of the compaid treated composts far exceeded that of the peat free controls. However composts which hadn't been treated with compaid showed very poor results.

Another method of treating compost is leaching. Leaching can be used to reduce the salinity of the compost and reduce the concentration of elements such as boron, increasing the suitability of the medium for plant growth (Inbar *et al,* 1993; Purves and Mackenzie, 1974; Lopez and Real, 1994; Smith, 1992). However this technique may have a negative effect on the levels of nutrients available in the compost by leaching out soluble nutrients with the other salts.

Because of the nature of their completely artificial conditions, pot-grown plants are particularly susceptible to possible negative side effects of compost use. These effects are discussed in more detail below.

Requirements of individual herbs

Herbs are plants that are grouped together only by their attributes as medicines and flavourings. They naturally occur in a wide range of habitats and are from different plant families. This makes it difficult to define one set of parameters in a growing media that will suit all the plants grown by producers, which may include basil, parsley, coriander, dill, chives, oregano, thyme, sage plus some odd seasonal plants like rocket, chervil and celery.

An example of the variation in growing environment of herbs is given by Phillips and Rix (1998) dill, coriander, basil, thyme and oregano all prefer well drained soil. Chives and lovage grow best in moisture retentive soils. The recommendations of Phillips and Rix (1998) are for soil based growing systems. The information is not directly transferable as the plants root systems are confined in the pot system; they are more sensitive to problems in their growing media as they can't grow out of the problem zone. There was little information found on the needs of different pot grown herbs. Some fairly detailed information on field herb production was published by the British herb trade association in its technical journals, however the information was so field specific that it has little relevance to this project.

Compost use in horticulture

Corti *et al* (1998) compared the physical and hydrological characteristics of composts with peat and professional and amateur growing media. They found that the composts had a lower water capacity than peats and commercial media. Water buffering capacity tests (water released at –50 to –100 cm suction) showed that composts have a far smaller water capacity than the commercially available peats and soils. Composts displayed levels of porosity that were marginally below those of the peats. Mean air capacity was similar over all the media tested although slaughterhouse waste compost had a higher than average air capacity and green waste compost had lower than average. Bulk density tests confirmed that peat has a low bulk density. This leads to low transport costs but also means a lack of stability in pot systems. The bulk densities of the composts were high in comparison with peat and had much higher ash levels, illustrating their greater capacity for plant nutrition. In organic carbon tests green waste composts had the lowest organic carbon content of all the tested media and were highly variable. The highest organic carbon levels were found in peat.

Vogtmann *et al* (1993) compared results from two media used to produce glasshouse tomatos in containers. The first mix used 60% compost to 25% peat and 15% sand and was compared with commercial potting soil (40% clay, 60% peat with urea added). They found that the volume of compost used induced calcium deficiency due to high levels of potassium in the compost. However there was no significant difference between yields produced from the conventional and compost growing media. The authors pointed to a significant positive relation between compost fertilisation and plant nutritional qualities and conservation properties, when compared to mineral fertilisers.

Composted municipal solid waste (MSW), composted liquid sewage sludge (LSS), composted cake sewage sludge (CSS) and peat were mixed in pots with an impoverished acidic sandy soil at rates of 0, 25, 50, 75 and 100 % by volume for greenhouse production of Petunia grandiflora (Smith, 1992). Half the pots received NPK (20:10:10) equivalent to 100 kg N ha-1, 25 kg P ha-1 and 41,5 kg K ha-1. The results show that: a) increasing MSW and LSS concentrations increases salinity of the media; b) for heavy metals contamination in soil, CSS>LSS>MSW, however, MSW treated soil contained more lead than the others. There was no detrimental effect on plant growth due to heavy metal contamination; c) Compost application increased significantly the number of petunia flowers, LSS>MSW>CSS>peat.

Spiers and Fietje (2000) set out an experiment to examine the potential of green waste composts as components in soilless growing media. Different mixes were produced using green waste compost, composted pine bark and pumice. The green waste compost had a high pH and salt content compared to peat and composted bark. It also contained a large amount of water extractable K which was considered to be mainly responsible for the high EC. Nutrient retention tests showed that nitrogen and potassium remained at nearly constant concentrations although organic matter quickly absorbed phosphorous and so extra was added. In the pot trials the levels of nutrients were adequate for growth in all the mixes. Mixes with 40% green waste compost had high levels of salinity (1.37-2.29 dS m^{-1}) that may cause severe damage to young seedlings or sensitive crops. The authors conclude that green waste compost can be successfully used as a component of high quality growing media. The compost should comprise no more than 30% of the volume due to its high salinity although if the salinity was lower the volume used could increase

Chen *et al* (1988) investigated composts produced from the solids of separated cattle manure and grape marc. The composts were studied for their performance as potting media for Ficus benjamina cv. Starlight. The composts were used in 1:1 (vol/vol) mixtures with peat moss or as a sole component of the potting medium and were compared with peat and peat + 20% vermiculite. Plant growth was improved and several important horticultural parameters, such as dry weight, stem diameter, height and leaf colour, were improved in plants grown on compost-containing media. Physical and chemical properties of the media and composition of the plant material were determined. It was concluded that both composted separated cattle manure and composted grape marc were high-quality substitutes for peat.

Sawan *et al* (1999) tested twenty-five combinations of peat, vermiculite, composted sawdust and crop residues compost as growing media for cucumber (cv. Katia) seedling production. Seedlings grown in sawdust media were either similar to or superior to controls grown in peat + vermiculite (1:1, v/v) for each of the parameters plant height, number of leaves, chlorophyll content and fruit yield (both early and total), as well as number of fruits per plant. The best plant growth and the highest yield were obtained by mixing the control medium with sawdust and plant residues compost 2:2:1 (v/v/v), i.e. reducing the peat volume from 50% to 20% in the mixture. These results indicate that sawdust can be used as a substitute for high percentages of peat in media for cucumber seedling production. Ku and Bowkamp 1999 evaluated the performance of chrysanthemums grown in 32 substrates. They tested several different types of compost, lime dewatered biosolids, polymer dewatered biosolids, poultry litter and green wastes. These were mixed with perlite and peat and compared to commercial soilless mixes Sunshine mix 1 and Pro Gro 300S. They found that blended composts from different feedstocks were significantly better amendments to substrates than unblended composts. All the compost-amended substrates produced good quality plants at all compost levels. Of the blends, the substrates amended with polymer dewatered biosolids + poultry litter compost blend and the polymer dewatered biosolids + green waste compost blend, produced premium quality plants at all compost concentrations. They conclude that good quality potted chrysanthemums can be produced from 100% unblended compost, dependent on the source, green waste performed best unblended at 100%. The best-blended composts at 100% were green waste + poultry litter, lime dewatered biosolids + poultry litter and polymer dewatered biosolids + green waste.

Obrian and Barker (1996) investigated the effects of different composts (mixed municipal solid wastes, sewage sludge + wood chips composted for 30 or 90 days, cranberry fruit pomace + chicken manure, autumn leaves or green wastes) on the growth of peppermint (Mentha x piperita). Shoot growth was vigorous in all composts except the thirty-day-old sewage sludge and wood chip compost and green wastes composts. All composts except the leaf and green waste composts had sufficient N for plant growth. High initial concentrations of ammonia and high salinity were responsible for reduced shoot growth in the thirty-day-old sewage sludge and woodchip compost. These high ammonia concentrations decreased with time due to nitrification and ammonia volatilisation.

Raviv *et al* (1998) investigated the use of compost as a peat substitute for organic vegetable transplant production. Lettuce and cabbage were sown in seedling trays containing a growing media produced from a mix of Cabutz, Vermicompost, peat and vermiculite. For both lettuce and cabbage the use of compost increased shoot height weight and chlorophyll content.

The experiments detailed above use a variety of types of compost and a variety of plant types but in all cases the introduction of compost into a growing media mix produced plants as good as or better than those produced in peats. One issue highlighted in these experiments is the benefits of blending composts from different feedstocks and with other substrates (Ku and Bouwkamp 1999, Spiers and Fitji 2000, Corti et al 1998). There may not be an opportunity in this project to fully investigate the effect of compost blending however using the insights of Ku and Bouwkamp 1999 and Corti et al 1998 it may be possible to focus on the most suitable blends.

Lima et al (1998) studied coriander (*Coriandrum sativum)* grown in pots of domestic waste compost alone or mixed 2:1 or 3:1 with soil and compared with that grown in soil alone. Heavy metal contents were higher in the compost than in the soil except for Cadmium and iron. There was no clear relationship between substrate and plant concentrations of Cadmium, Copper, manganese and lead but there was a clear relationship in the case of zinc. The greater the proportion of compost in the growing medium the less was the absorption of metals by the plant (in relation to substrate concentration). Coriander grew best in compost alone and least well in soil alone.

Putievsky *et al* (1998) conducted trials on pot grown oregano and lemongrass they found that after a simulated shipping and shelf life period oregano did not regenerate well after cutting. The compost used by Putievsky *et al* was digested slurry (fermented cow manure) and it produced the best results in both lemongrass and oregano. Oregano performed least well in peat moss substrate

Lima *et al* (1998) also looked at the relationship between heavy metals in the growing media and their uptake by the coriander grown in pots. Heavy metal contamination of plants is a serious issue especially when the plants are for human consumption as heavy metals are toxic in high concentrations. Lima *et al* found that the greater the proportion of compost in the soil the less the uptake of heavy metals by the plants in relation to substrate concentration. Smith (1992) also tested for the effect of heavy metals and found that there was no negative effect on petunia growth from heavy metal contamination. This would indicate that the chemical, biological and physical complexes in the compost prevent heavy metals from being absorbed by plants to the same extent as they do in other substrates i.e. peat. A higher concentration of heavy metals might therefore be acceptable in compost based growing media, as it is less able to be absorbed by the plant. This project will be using feedstocks that should produce composts with relatively low levels of heavy metals (Donkin 2001).

Effect of feedstock on quality

Corti *et al* (1998) compared composts produced from a variety of wastes with professional growing media, amateur growing media and peat. Their work showed a large amount of variation not only between the compost and the peat's and professional growing media but also between composts formed from different feedstocks. The paper also showed significant variation between composts produced from the same type of feedstock. Composts were grouped according to the feedstocks they were based on into green waste composts, animal manure compost, municipal waste compost (source segregated and unsorted), sewage sludge and slaughterhouse waste compost. They then attempted to assign the most suitable use to each type of compost based on their chemical and hydrological characteristics. They decided that animal manure and sewage sludge composts would best be used in agriculture due to their high salinity. Slaughterhouse waste composts were very uniform but displayed few agronomic characteristics and so it was advised that they be used in limited quantity in pot growing media or used in agriculture. Unsorted municipal solid waste composts were so variable and contaminated as to be unusable for most uses. Sorted MSW composts were similar to amateur gardeners media and so could be used in agriculture or in mixes with more suitable materials for pot growing. Green waste composts were fairly uniform although their physical characteristics were less suitable than peat. They recommend that green waste compost would be well used in agriculture and if suitably mixed would work well in containerised systems.

Chicken manure compost has had good results from experiments conducted by Ku and Bowkamp, 1999; Corti *et al,* 1998; O'Brian and Barker, 1996. It can produce compost too strong for some plants and can be very saline (Corti et al 1998). The papers show that chicken manure is a good component of compost but tends to produce poorer results when used on its own. Leaching chicken manure compost may provide a solution to salinity problems (Lopez and Real, 1994; Smith, 1992); alternatively diluting the compost with an inert bulking material may be a solution to some of these problems (Rainbow and Wilson, 1998).

The On farm-composting guide (1992) suggests that raw materials should be tested for density, moisture content, carbon content, nitrogen content and pH. Table 1 gives values for the feedstocks most likely to be used in this project.

Table 1 - Typical analysis of different feedstocks, (On farm composting handbook 1992)

WASTE TYPE		%N dry basis	C: N Ratio	MC % wet weight	Bulk density (kg/m3)
Veg produce		2.7	19	87	940
Veg waste		2.5-4	11-13		
Broiler litter	Range	1.6-3.9	12-15	22-46	449-609
	Average	2.7	14	37	513
Straw	Range	0.3-1.1	48-150	4-27	34-224
	Average	0.7	80	12	135
Shrub trimmings		1	53	15	255
Tree trimmings		3.1	16	70	769
Leaves	Range	0.5-1.3	40-80		
	Average	0.9	54	38	
Grass clippings	Range	2-6	9-25		
	Average	3.4	17	82	

Mix parameters

When selecting component feedstocks, it is important to calculate the best mixing ratio for each feedstock in order to provide the ideal environment for microbiological activity. The key parameters are density, moisture content, carbon content, nitrogen content and pH. The overall mix of feedstocks should fall within the mix parameters in table 1. In containerised systems these parameters cannot be altered once the process begins although in open systems like windrows the mix can be augmented during the composting process.

Carbon to nitrogen ratio.

Microbes need both carbon and nitrogen in their food source. Therefore the breakdown of materials like straw, where there is very little nitrogen and a great deal of carbon proceeds very slowly. To optimise the breakdown of organic material the ratio of carbon to nitrogen should match the ratio with which the microbes consume them. The carbon to nitrogen ratio is a function of the types of feedstocks used to make the mix. It can be altered as composting progresses in windrow systems but when dealing with in vessel systems the ratio has to be right at the start.

Carbon to phosphorous ratio

Although C: P ratio is not mentioned in table 1, Brown et al (1998) found a need for additional phosphorous when composting municipal solid waste. They found that they needed a carbon to phosphorous ratio of 120:1 to 140:1. Although in theory balancing all the nutrients to provide the ideal C: P, C: N and Moisture content etc will provide the best environment for microbial activity, it would not be practical on a large scale to deal with more than the usually accepted C: N and MC balancing. For this reason C: P ratio is not widely used in the calculation of the best feedstock mix.

Moisture content

At moisture contents below 45% lack of water limits the composting process (Stoffella and Khan 2001). However if there is too much water (60% and above) not enough air reaches the compost and the process becomes anaerobic. To provide the best initial environment the moisture content of the feedstocks must be analysed and the mix created to provide the optimum level.

pH

The Initial pH of the mix is important, as it will affect the end pH of the compost. A starting pH of 7 to 7.5 is usual for most feedstocks and provides and environment which favours the majority of microorganisms. The initial pH also affects the final pH of the compost. The mix is not usually calculated to produce a specific pH but if the feedstock used has an unusual pH (e.g. lemons) it may become a factor.

Particle size

Particle size affects the rate of the composting process in two ways. It affects the surface area to volume ratio of the particles. The greater the surface area exposed relative to the volume of material the greater access the microbes have to the material and the quicker it can be broken down. However particle size also affects the flow of air and water through the compost. Small particles that provide higher surface area to volume ratios also retain water and prevent airflow into the compost, this leads to anaerobic conditions. Particle size is affected by the feedstock used and the processing technique (i.e. macerator, shredder).

Key Composting Process parameters

The process parameters are the tools by which the operator can optimise the process, whatever the initial feedstock mix.

Moisture content

To keep the optimum moisture content throughout the compost process it may be necessary to apply more water or to remove it by allowing the temperature of the pile to rise to a point where moisture evaporates as steam from the compost.

Free air space, bulk density, oxygen concentration

These are all different ways of ensuring that enough oxygen for aerobic respiration can penetrate the mix. They are different direct and indirect measures of quantity of air available in the compost. This is a function of the feedstocks used in the initial mix as well as the size to which the feedstock is broken down to in any pre processing. The oxygen content can be directly measured or the temperature of the compost can be monitored to determine when more air needs to be added to the compost. If more air is needed the compost can be turned or force aerated depending on the system.

Temperature

The temperature is also an important parameter when optimising the speed of the process. The composting process proceeds most quickly at 45°C (Winship, N. 2001), as it is at this temperature that the greatest microbial population can be maintained. A higher temperature must be achieved for some of the process to denature any pathogens in the compost, but if after this period the compost can be kept at 45°C the process will move much faster. Temperature can be used to monitor the composting process. Composting proceeds along a recognised temperature curve. If the compost temperature differs from this there may be a problem with the process and one of the mix or process parameters may need altering. For example if the oxygen in the compost begins to run out the compost may initially cool as respiration rates drop this cooling period could be identified and the compost turned before it becomes anaerobic.

Review of technology available

The range of technologies available for composting is wide and varied. The American composting association recognises 5 different groups of composting technologies (TMECC 2001), the characteristics of which are shown in the table below.

Table 3 – Composting technologies

	GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5
Weather protection	Open	Open	Covered	Covered	Covered
Pile configuration	Piles	Windrows	Piles and Tunnels	Winrows trenches beds and bays	Tunnel and Vessil systems
Process	Passive	Active	Active	Active	Active
Pile	Undisturbed	Turned	Static Structure	Turned	Turned
Feedstock nutrient balance	Unmanaged	Initial C:N ratio set	Initial C:N ratio set	Initial C:N ratio set	Initial C:N ratio set
Pile Oxygen and pH	Unmanaged	Convective aeration	Forced aeration	Mechanical Aeration	Forced Aeration
Pile Moisture	Unmanaged	Mix in Make up	Mix in Make up	Mix in Make up	Mix in Make up
Pile Temparature	Unmanaged	Turning control	Blower control	Blower control	Blower control
Retention Time	12-14 months	2-12 months	2-6 months	2-5 months	2-4 months

The most commonly used technology in the UK is the turned windrow system (see Table 4). This system offers the lowest capital costs and greatest throughput of compost. Despite the increase in speed which the in vessel system offers, its high cost and low volume reduce its popularity.

Table 4 – Types of composting process, all site types (Slater et al 2001)

Process type	Number of Sites	Material Composted	% of total throughput
Open air mechanically turned windrow	121	736,529	88%
Covered/Containerised mechanically turned windrow	5	35,124	4%
In-Vessel	7	32,717	4.5%
Open air static pile with no aeration - centrallised	5	15,967	2%
Open air static pile with no aeration - On farm	3	630	<1%
Open air static pile with no aeration - Community	23	751	<1%
Vermicomposting	1	250	<1%
Other centralised - 1 mixed, 1 not known	2	9,889	<1%
Other - 2 not known, 28 community mixed	30	1,187	<1%
Total	197	833,044	100%

Review of maturity effects

In order that composted organic wastes can be used safely the compost must be correctly stabilised or 'matured', i.e. the original organic matter has to be converted to a form which is more resistant to degradation, containing minimum amounts of phytotoxic compounds and soil contaminants, free of plant and animal pathogens (Parr & Papendick, 1982; Zucconi & de Bertoldi, 1986; Senesi, 1989; Lopez-Real, 1990; Dick & McCoy, 1993; Brinton and Evans, 2001).

The main chemical problems associated with immature composts are high ammonia levels as well as high levels of volatile organic acids both of these cause phytotoxicity. However Brinton and Evans (2001) show that 'the mode of delivery and concentration of the compounds relative to other physical and biochemical factors will significantly determine acceptable concentration levels'. It is therefore difficult to determine the exact levels at which these compounds become phytotoxic. It may therefore be necessary to use growth trials as well as quantitative analysis to determine the phytotoxicity of the compost. Immature composts also suffer from nitrogen lock up (Brinton and Evans 2001), A state that occurs through microbes using fertiliser nitrogen to break down 'raw' carbon in the compost. This removes much of the nitrogen from the fertiliser and prevents it from reaching the plant.

Oxygen depletion and nitrogen lock up are significantly negative effects caused by the high levels of microbial activity in immature composts. Brinton and Evans 2001 looked at the effects of compost maturity on container grown plants. They tested three maturities, Immature after 21 days of composting, semi cured after 81 days and cured after 271 days. They identified phytotoxic ammonia and volatile organic acid levels. The main focus of the paper is on the oxygen depletion effects of immature compost, an issue that is also highlighted by Spiers and Fitjie (2000). They found that the oxygen content in the pots diminished with depth from the surface and correlated closely with the apparent maturity of the composts. When the root balls were examined there was very little growth found in the immature compost, the rootlets had formed in the lip and edges of the container, the places where there was most oxygen. In the cured treatment the roots extended to the bottom of the pot.

Problems related to compost maturity can be solved with the correct management of the composting process. For example the presence of phytotoxic compounds and soil contaminants are related to feedstock materials (Lopez-Real, 1994). While high levels of microbial activity will cease once the readily available organic matter has been broken down.

Conclusions

There is a lack of published data on the performance of composts in pot-based growing systems. There are indications that composts may perform as well as peat when blended with other materials.

Where composts have been tested as a horticultural growing medium the type of compost and how it has been produced is often not clear. There is a real need to ensure that compost production is standardised in order to be able to compare the results from different tests.

Composting in the UK has largely been driven by the waste management and not with a view to manufacturing compost for a specific purpose. Whilst the key parameters for the composting process have been identified, there has been little work done on examining the effects of process modifications on compost quality.

3. Assessment of the suitability of local waste streams for composting

3.1. Background

The key to economic compost production is to minimise transport requirements for both input material (feedstocks) and the end product. Not all feedstocks will make good compost, and there may be regulatory barriers to the composting of certain materials. This section delivers a procedure whereby feedstocks can be identified and assessed for their suitability as input material for quality composts

3.2. Methodology

Previous research (Bastow, unpub.) had shown that if material had to be transported more than 30 miles to or from a compost site, then the economics of the operation would be marginal. A postal survey, followed by telephone and face-to face conversations, was carried out. Waste producers were identified by reference to local waste management companies and through the Chamber of Commerce.

Wastes were classified by their C:N ratio (from published figures); by their availability over the course of a year; by their suitability for organically certified compost production. Wastes which were classified as animal by-products were not considered, as composting was not a permissible treatment route for these materials at the time of the project.

Two other restrictions had to be considered. Firstly all feedstocks have to comply with the conditions laid down by the Environment Agency as part of the Waste Management Licensing Conditions.

The second restriction was the requirement to have the capability to produce compost suitable for the production of organically certified produce.

3.3. Results

The feedstocks that were available in greatest volumes and with greatest consistency of supply were; potatoes/soil, onions, other vegetables, and green waste. The composition of the vegetable waste is very seasonal however and so was deemed not suitable for making a consistent product. This leaves the potato soil waste, onion waste and green waste. Although there is some seasonality in the green waste (levels fall off during the spring period) during the lowest month (March) there is still 37.6 tonnes available for composting. Onion waste is available throughout the year and in significant volumes. Whilst the mass of soil and potato waste is relatively consistent throughout the year, the ratio of soil and potato waste varies considerably from batch to batch. This variation may or may not affect the consistency of the product due to its prolonged maturation period, however for the sake of the trial work it may be better to use a more consistent feedstock. The green waste available for composting varies from batch to batch, however it is practice to stockpile green waste on site an to then shred large quantities. This has the effect of partially homogenising before being incorporated into the mix.

Feedstock	Yearly Total (tonnes)	Highest Month (tonnes)	Lowest Month (Tonnes)	Mean (tonnes)
Veg	5971	794	195	459
Green waste	5734	863	38	441
Onion	10567	1027	638	813
Potato/Soil	4107	513	77	316

Sources of organic chicken manure and spent mushroom compost were also identified. Potentially these would provide benefits to compost (high nutrient availability). However, they were being sold as a commodity rather than given away as a waste, and would add considerably to the costs of compost production.

Other wastes that were identified included wood waste from a pallet making company and cardboard boxes. The wood waste will not be suitable as it may be treated and is not allowable in the restrictions of the licence. The cardboard is very substantial, it contains no tape but has metal staples in it which would have to be removed using a magnet when the material is screened. This would increase the cost of screening the product. Neither of these waste streams would add to the nutrient status of the compost, although they could be useful if additional porosity is required.

3.4.Conclusions

Overall, green waste, potatoes/soil and onions provide the highest volumes of acceptable consistent materials. Organic coir could be used as a bulking agent to blend it off. Organic chicken manure is another possible feedstock but will have to be used in low concentrations, and has cost implications. Cardboard may be a possible feedstock but it contains staples that would have to be removed. By focusing on the most consistent waste streams currently available, it is likely that the quality of the compost made will be reproducible in the future

4. Composting trials

4.1. Introduction

The aim of these trials is to produce compost suitable for peat replacement made from locally sourced waste materials. Consistency is vital for a good quality end product; two ways of improving consistency were identified. These were ingredient consistency, which can be achieved through recipes, and process control. To this end two different composting systems were compared in producing identical batches of compost, the high process control in vessel system and the potentially more variable windrow composting method.

4.2. Materials

There were three key factors in identifying feedstocks, these were consistency of material, regularity of supply through the year and volumes available. A waste survey was carried out to find the materials that matched these criteria in the local area. The most promising materials were identified as

- ONION WASTE
- POTATO WASTE
- STRAW
- MUSHROOM COMPOST

Green waste was widely available but varies in quality throughout the year.

These materials were taken to The University of Aberdeen and analysed for carbon to nitrogen ratio and moisture content. This information was used to calculate recipes based on a C:N ratio of 25:1 and a moisture content of 60%.

4.3. Systems

Introduction to the systems

Two composting systems have been compared. These are the Alpheco in vessel system and the Organic Recycling open-air windrow composting system.

The Organic Recycling Site

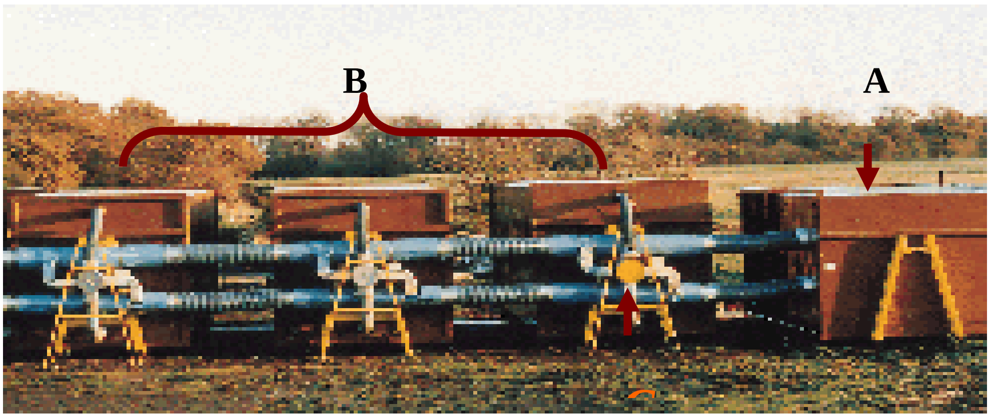
Both systems will be compared on the organic recycling ltd composting site (figure 1). The site is comprised of a weighbridge, a 1.45 acre concrete pad and leachate collection system. The site also owns the surrounding farmland and this is used to dispose of the leachate collected.

Figure 1 – The Site at Organic Recycling Ltd

The Alpheco In Vessel System

The alpheco system is a batch in vessel type composting system. It is composed of one control box (Figure 2a), which contains a computer to log compost temperatures, a fan and heat exchange system and a biofilter to purify exhaust air. It is designed to run off mains electricity and the computer can be attached to a telephone cable to allow for remote access of the temperature data.

Figure 2 – The Alpheco System



The composting containers (Aergestors) measure 5 metres long x 2.5 high x 2.5 metres wide externally, the Aergestors (Figure 2b) are built on Rollonoff (hook-loader) sub-frames This has been designed into the system to allow easy transportation of the container for emptying off site.

The system is loaded using the mixer loader system (figure 3) and emptied using the rollonoff lorry. Each aergestor has two temperature probes, one at the top of the container and one at the bottom. This records the temperature every 3 minutes. The system is designed to force air through the container either from the top down or the bottom up (through a floor louver system and the aeration units (Figure 2c)).

Figure 3 – The mixer loader system

Each control box is capable of running 6 aergestors at one time. The Organic Recycling site where the alpheco system was to be tested was not mains connected and did not have an on site telephone. Therefore the system was run from a diesel generator system and daily checks were made of the temperature readings. The temperature profile was designed as follows:

Phase 1: **Warm up** from ambient temperature; raise temperature to 55^{o}C within 3 days

Phase 2: **Sanitization** at elevated temperature to destroy pathogens and weed seeds, 3 Days at 55^{o}C

Phase 3: **Stabilization** at optimum thermophyllic temperature to convert feedstocks in to a product, albeit immature but non-polluting and with an equilibrium microbial population. Continue at 45^{o}C.

4- 4 The Organic Recycling Windrow Composting System

Organic Recycling uses the Open Air Windrow Composting method to compost 25,000 tonnes of waste material per year, Windrow composting accounts for over 85% of all composting in the UK (The Composting Association). The system aerates the compost through physical turning of the waste material. This can be achieved using a range of equipment from windrow turners to front end loaders, Front-end loaders are used at Organic Recycling. All the composting takes place on a concrete pad and leachate is collected into a central system. The management of the compost is based on several factors, wind direction (for odour control), space on site and compost temperature therefore the process is considered less effective than 'In Vessel'.

The material is mixed using bucket on the loader and is heaped up to form the windrow (figure 4).

Figure 4 – Windrow formation at Organic Recycling

The aim is then to turn the composting material at once a week for the six weeks of initial composting. The windrow is then stored in fields until mature and ready for use. Organic Recycling requires that each batch reach 60°C for at least 3 turns on the concrete pad to ensure pathogen kill.

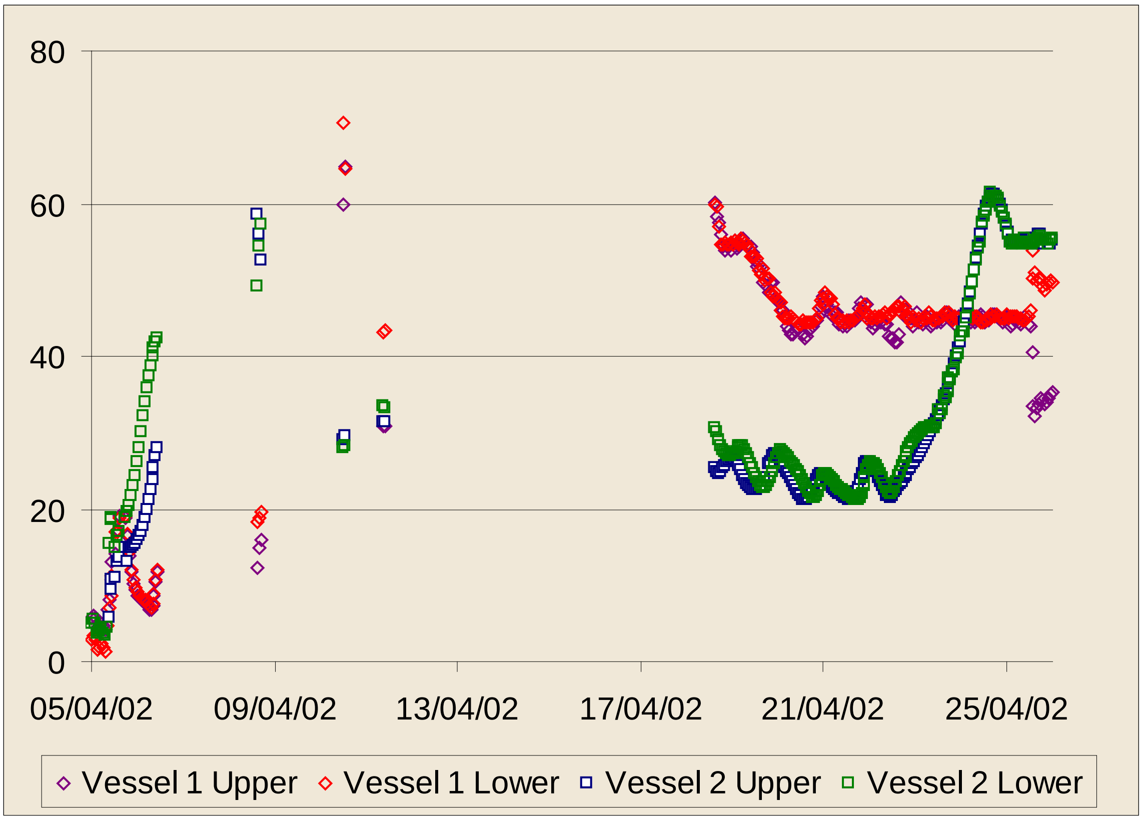
4.4. Trial 1

Trial 1 used shredded green waste, full onions and potatoes. It was produced using both aergestors of the Alpheco system and a companion windrow. The trial began on the 8th April 02, the aergestors ran for 23 days and the windrow for 39. There were significant problems in loading the aergestors with this mix as the material bridged over the augers in the mixer loader. Only $3m^3$ could be in the loader at any one time without causing this bridging effect. Therefore in the other trials, materials were mixed using the front-end loader on the concrete and the mixer loader was used to load only.

Table 1 – Trial 1 Summary

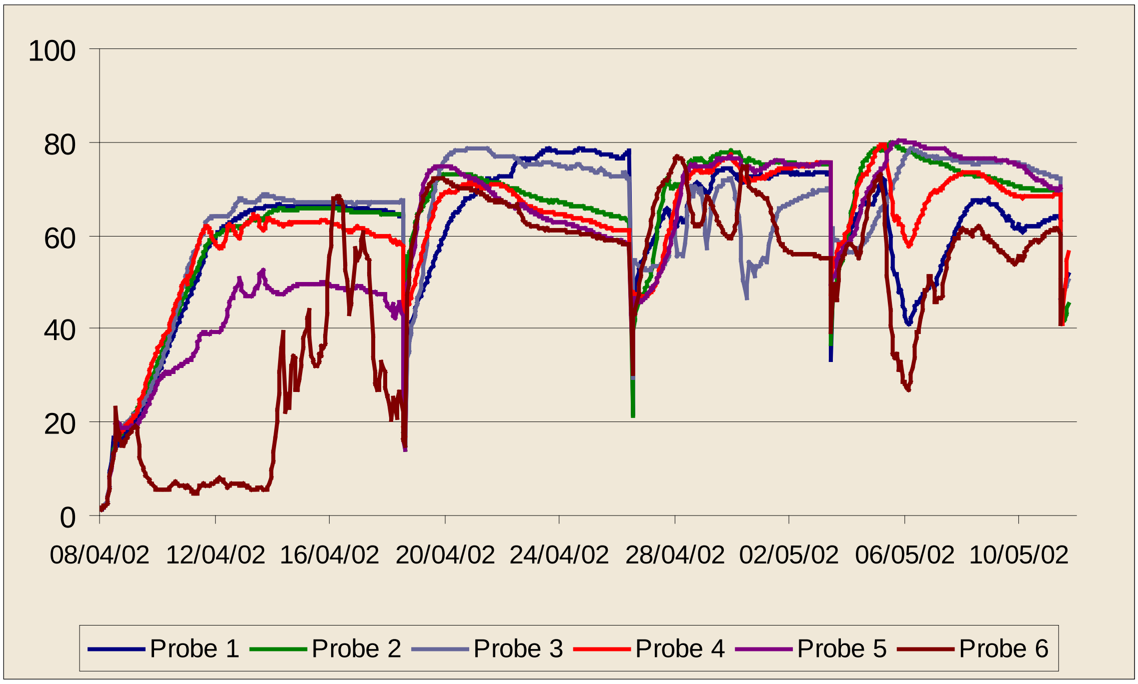
TRIAL 1 *Maturing since 1 May 02*	***MASS (kg)***	***VOLUME (bucket or bale)***	***Treatment***
GREEN WASTE (SHRED)	32,240	52	Vessel 1
ONION (WHOLE)	19,760	52	Vessel 2
POTATO/SOIL	14,260	16	Windrow

Graph 1 - Temperature Profile Trial 1 Alpheco system (mean hourly Temperature)



The temperatures in aergestor 2 of the Alpheco system (graph 1) did not reach Heat treatment until the end of the composting period and there had been breakdowns in the probes early on in the run. However the system was successful in creating a uniform temperature throughout each aergestor.

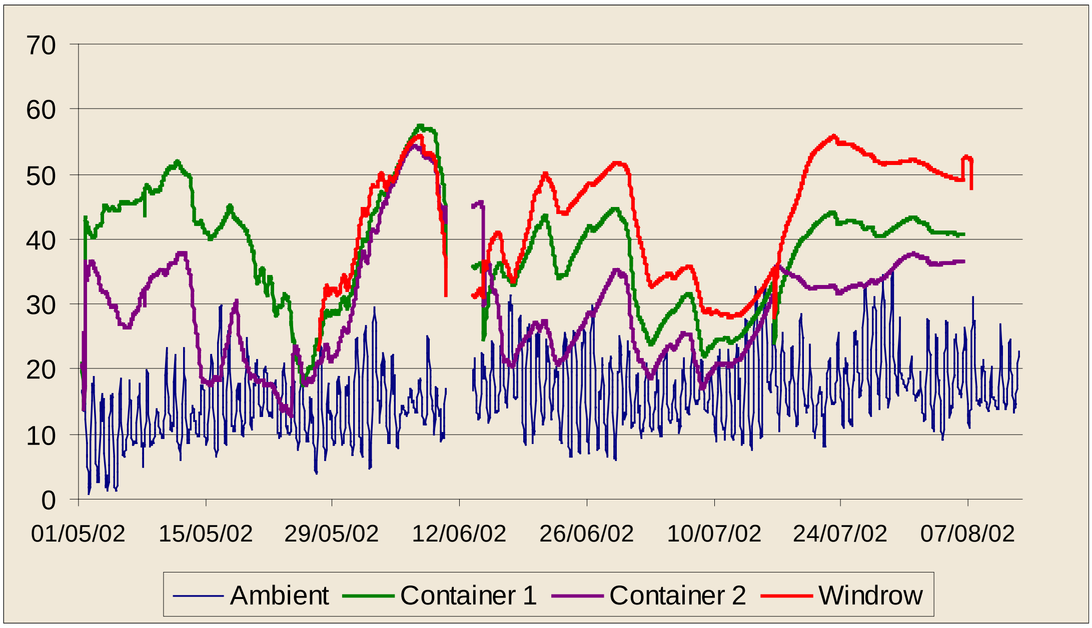
The windrow (graph 2) showed very high temperatures throughout phase one and throughout the pile (probes were placed at various depths in the windrow from 2.5cm to 10cm).



Graph 2 – Temperature Profile Trial 1 Windrow (mean hourly temperature)

The decision to run the system for 23 days was based on the recommended retention time for the Alpheco system rather than a recognised temperature drop in the material. This is reflected in the maturity temperatures (graph 3) of the Alpheco produced composts, the temperatures remained high and when turned the temperatures rose steeply in response, however this was also seen in the windrow produced material which had been turned weekly over the 39 day period (based on Organic Recycling windrow retention averages). This suggested that phase one in both composting systems took much longer than expected. This was due to the shredded green waste and whole onions, which remained recognisable and whole up to 4 months into the maturing period. The whole onions gave off a strong odour as they decomposed anaerobicly and those on the surface of the container began to germinate.

Graph 3 – Maturity Profile Trial 1



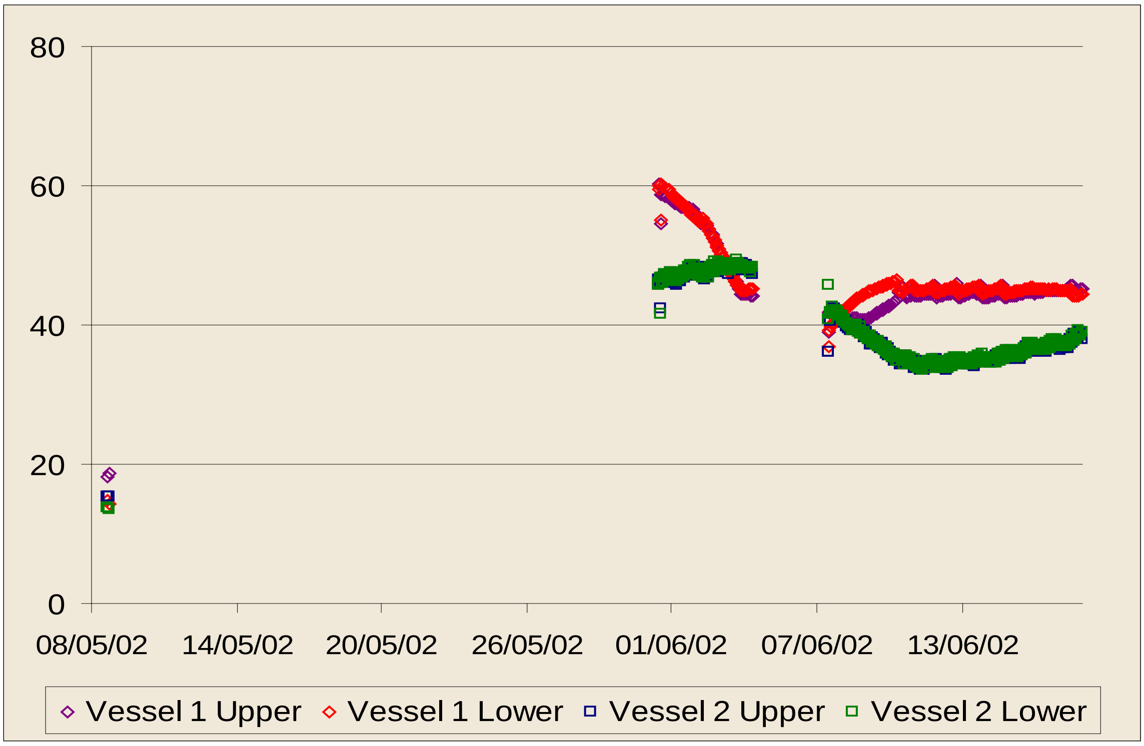
4.5. Trial 2

Experiment 2 achieved the Soil Association requirements for annex 1 growing media. It was composed of mushroom compost, onions and straw all whole. It had no companion windrow but used both aergestors of the Alpheco system and was run until the temperatures in the aergestors dropped in this case this was 41 days.

Table 2 – Trial 2 Summary

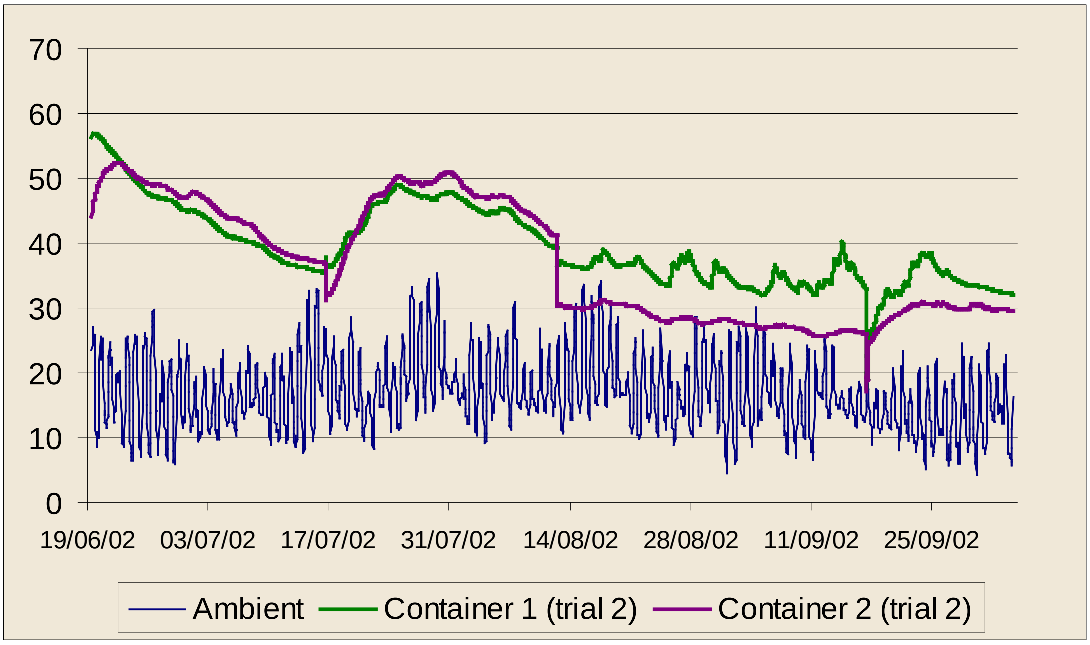
TRIAL 2 *Maturing since 18 June 02*	*MASS (kg)*	*VOLUME (bucket or bale)*	*Treatment*
MUSHROOM COMPOST	19,600	28	Vessel 1
ONION (WHOLE)	17,160	26	Vessel 2
STRAW	8,640	12	

Graph 4 - Temperature Profile Trial 2 aergestors (mean hourly temperature)



Graph 4 shows the temperature profile of the composts in the aergestors. The first two weeks data was lost due to a downloading problem. As in trial one the aergestors were successful in keeping regular temperatures throughout the aergestor and the Heat treatment period proceeded as planned. The compost was manually probed twice a week with a 1m long temperature problem. The aergestors were emptied after 41 days when the mean temperatures dropped to below 45-^{o}C.

Graph 5 – Maturity Profile trial 2



When the composts were moved for maturation (graph 5) there was a steep temperature rise this dropped off until the material was turned 3 weeks after maturation bean. There was then another steep response. This is attributed to the presence of whole onions in the mix that, as in trial one, persisted throughout the process.

This experiment highlighted a difficulty with a non-agitated composting system. The manual readings of the compost temperatures never found a temperature above 40°C in the first 3 cm of either aergestor surface, without turning or moving the compost the surface remains a source of pathogens as it does not reach sufficient temperatures for heat treatment, despite good temperature readings from the two temperature probes. This was further emphasised in this trial through the germination of onions on the surface of the composting material.

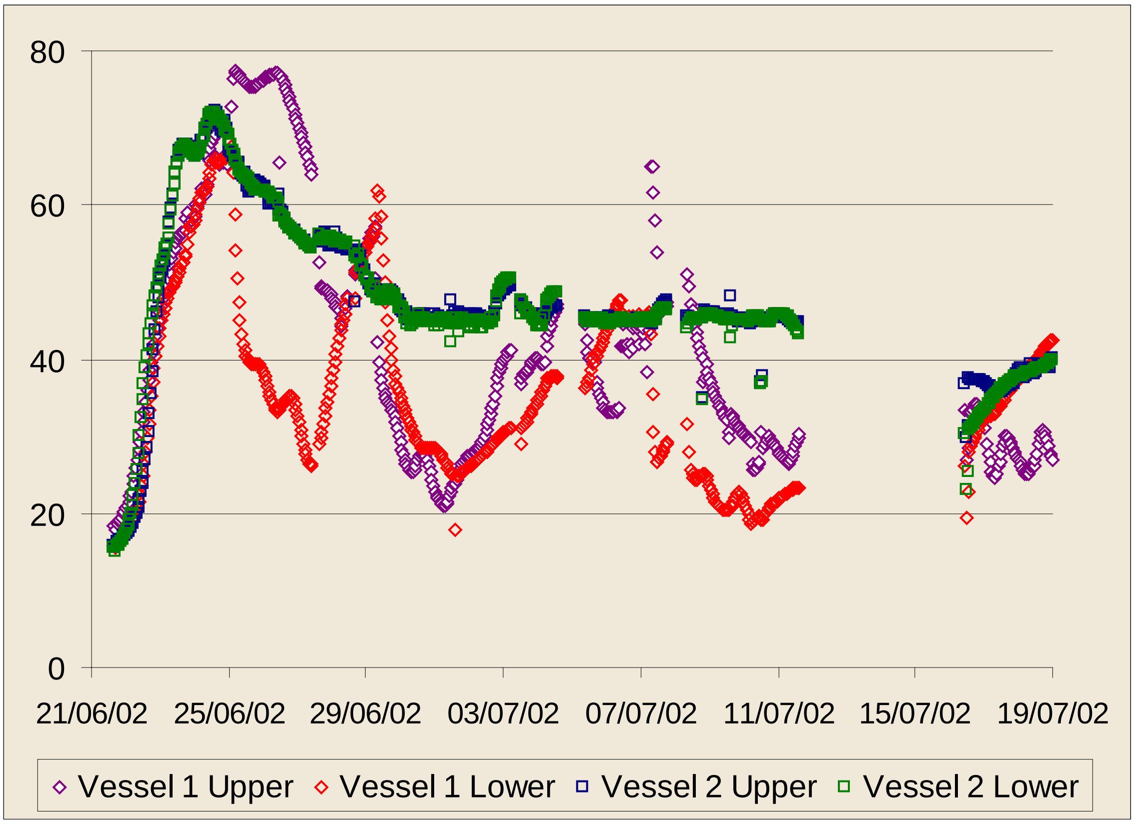
4.6. Trial 3

Trial 3 was a replicate of trial 2 (table 3), however the onions used were shredded before composting to increase the surface area to volume ratio and so speed up the composting process and reduce odour production from the material. A companion windrow was produced to provide a comparison. Both the windrow and aergestors ran for 48 days (based on temperature drop as mentioned in trial 2).

Table 3 – Trial 3 Summary

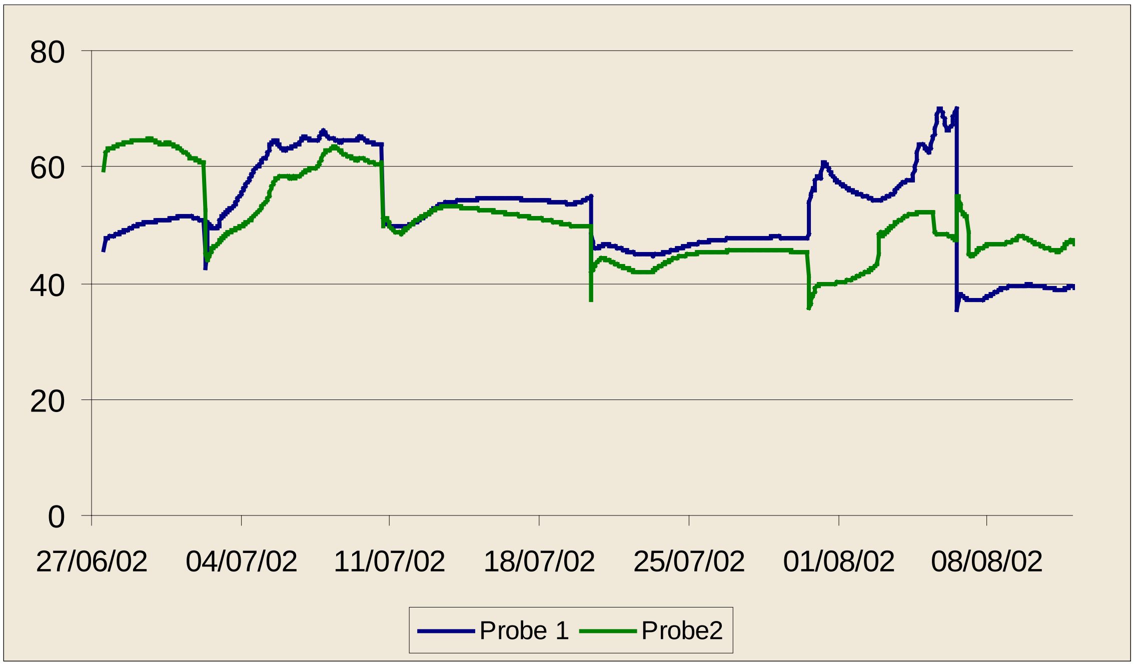
TRIAL 3	*MASS (kg)*	*VOLUME (bucket or bale)*	*Treatment*
Maturing since 5 August 02			
ONION (SHRED)	6,840	18	Vessel 1
MUSHROOM COMPOST	5,250	8	Vessel 2
STRAW	1,080	2	Windrow

Graph 6 – Aergestor Temperature Profile trial 3 (mean hourly temperature)



Graph 6 shows the temperatures achieved in the aergestors for trial 3. airflow through the compost was restricted by the lack of structural components in the material. This was the result of reducing the particle size of the component feedstocks. Control was made more difficult as the louvers in the floor had partly sealed with rust giving uneven airflow and the valve controlling the direction of air flow through the material was stuck in position for several days during the run. As a result and due to sticking of valves in vessel 1 and some corrosion on the floor louvers of both aergestors, the Alpheco system was not able to control the upper and lower temperatures in each container as well as in previous trials. This is particularly evident in aergestor 1, where not only are the set points exceeded, the upper and lower temperatures do not match.

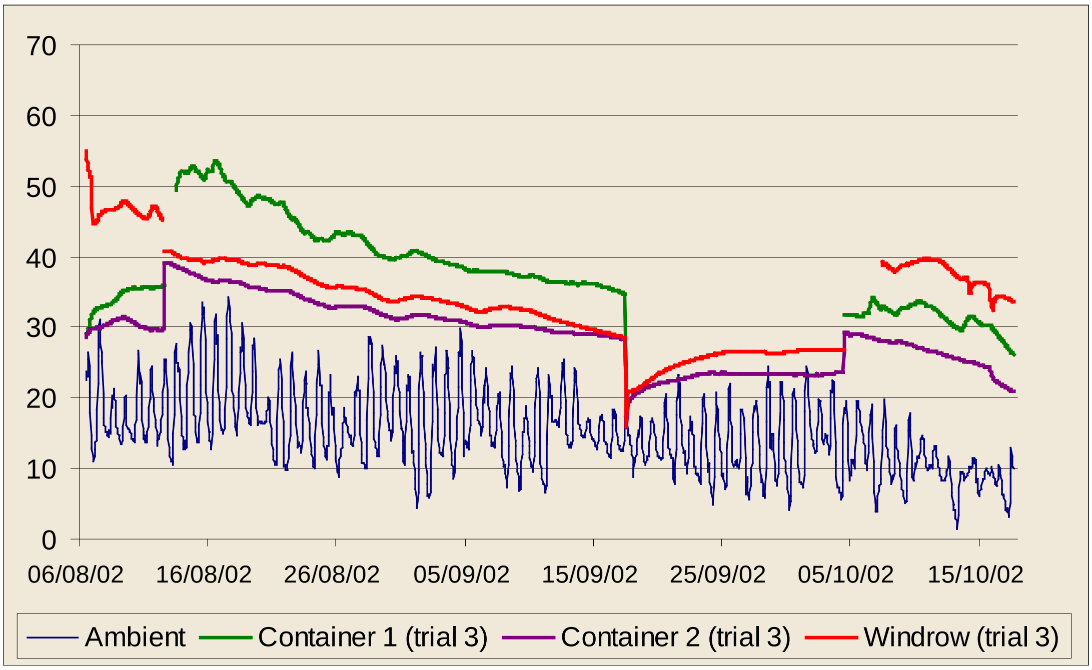
Graph 7 – Temperature Profile – windrow trial 3 (mean hourly average)



The windrow-produced material (graph 7) did not reach the high temperatures that the aergestor compost did. However it consistently rose to Heat treatment levels post turning and showed a gradual decline in temperature that lead to the carting off of the material after 48 days. This is a week longer than the usual phase one composting time for Organic Recycling.

The compost temperatures were recorded during maturity (graph 8) until they dropped below 45 °C.

Graph 8 – Maturity temperatures for trial 3



The sharp drops in temperature indicate points where the maturing material was turned (this is an operation done on an irregular basis at the Organic Recycling site). The material from the aergestors showed a pronounced temperature response when turned, the windrowed material showed less reaction although its temperature was high on entering the maturation phase (due to the turning action of moving the material to a new area).

4.7. Trial 4

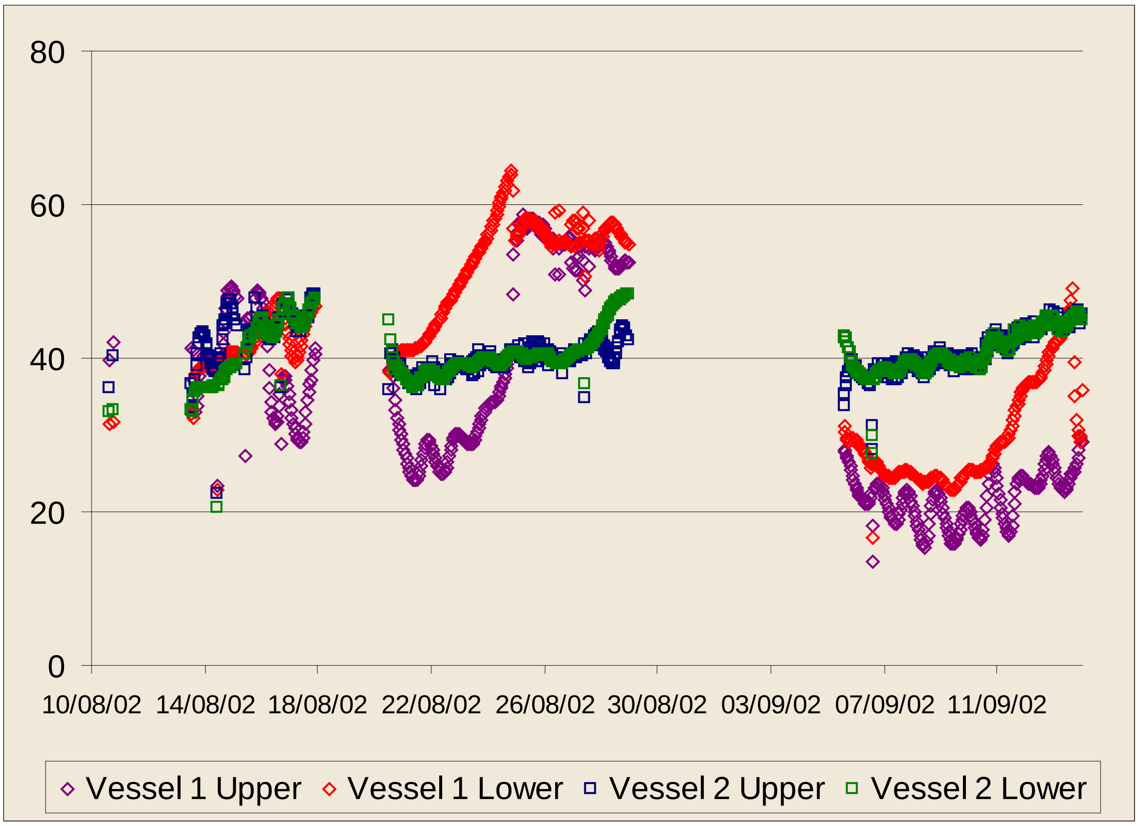
Trial 4 used the same feedstock mix as trial 1 but increased the surface area to volume ratio by using chipped green waste and shredded onion. The green waste gave good structure and prevented the slumping found in trial 3 due to onion shredding. The material was kept in the aergestors for 45 days and a companion windrow was produced which ran for 45 days from the 4th October to the 18th November. Graph 12 shows temperatures in the windrow until 23rd November, between the 18th and the 23rd the material was in the maturing area.

Table 4 – Trial 4 Summary.

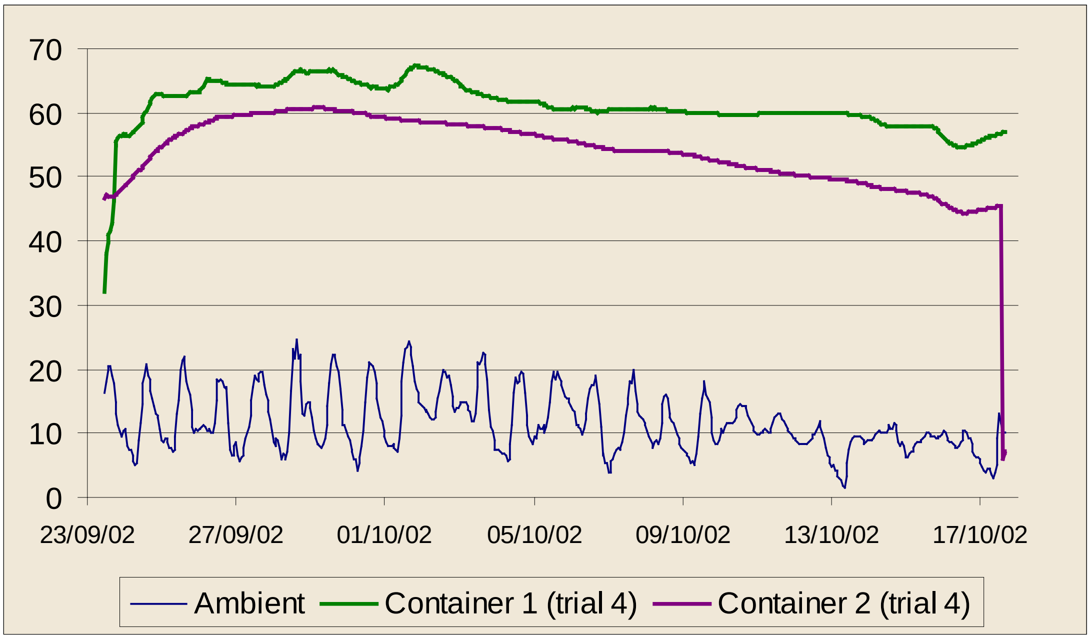
TRIAL 4 *Maturing since 23 September 02*	*MASS (kg)*	*VOLUME (bucket or bale)*	*Treatment*
GREEN WASTE(CHIP)	10,000	25	Vessel 1
ONION (SHRED)	5,940	9	Vessel 2
POTATO/SOIL	4,600	5	Windrow

Graph 9 - Temperature Profile for Trial 4 (mean hourly average)

The temperature data in trial 4 indicates that the control system in the Alpheco was no longer working. This has been attributed to rusting over of the floor louvers in the aergestors (due in part to the corrosive nature of the onions used) and the constant sticking of air control valves. The data gaps in graph 9 indicate points at which the temperature probe failed. Problems with the diesel generator and power supply added to the variability in control shown for example the data missing between the 28th August and 6th September, when the system lost power completely. Manual probe readings of both aergestors were taken weekly and show variation in temperatures between 80°C and 34°C in the same aergestor on the same day.



Graph 10 – Maturity Profile for Trial 4



This poor initial composting is demonstrated further in the temperatures of the maturing compost. The temperatures were measured for less than a month and during this time the maturing pile was not turned. However the temperatures ran above 50^{o}C for the majority of this time.

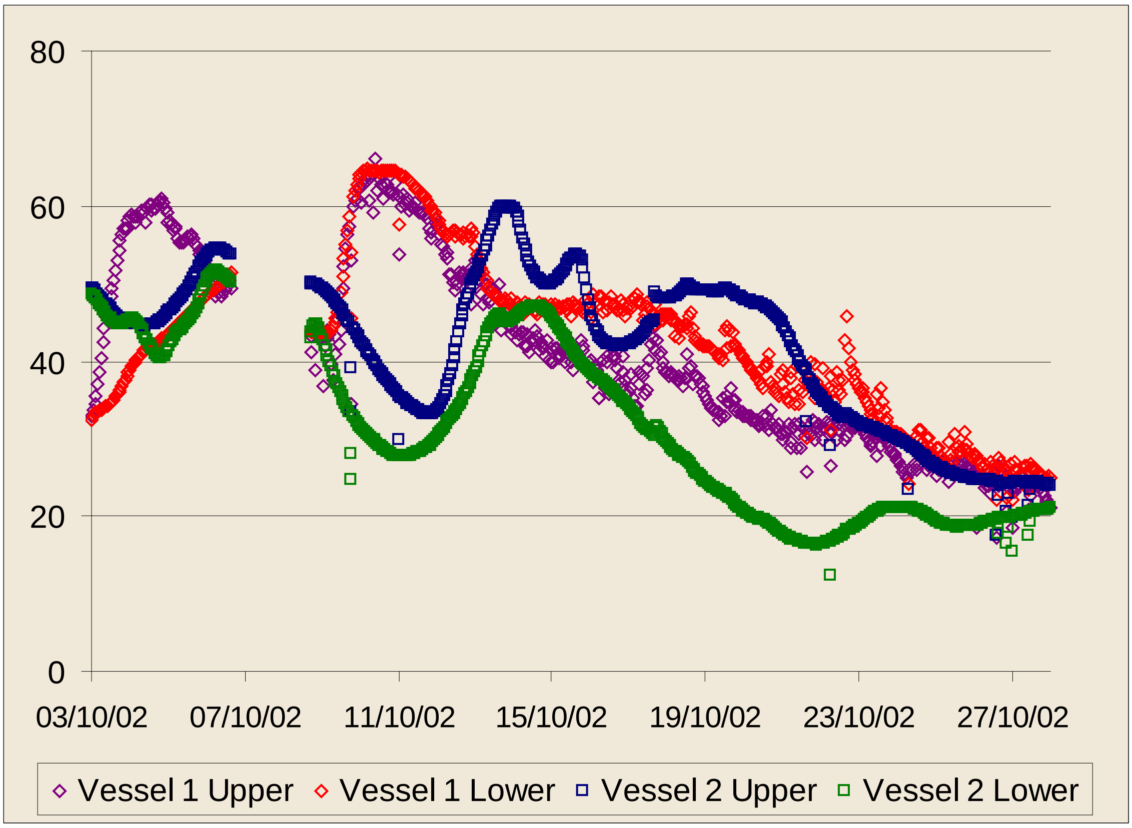
4.8. Trial 5

Trial 5 used the same basic mix as trial 4 but excluded potato and soil due to the high stone contamination found in this feedstock. The trial ran for 39 days in the Alpheco system from the 3rd October to the 11th November, and for 45 days in the windrow from the 4th October to the 18th November. Unfortunately the Alpheco system failed several times during this trial (see appendix 1) and stopped working on the 5th November, the containers were emptied on the 11th.

Table 5 – Trial 5 Summary

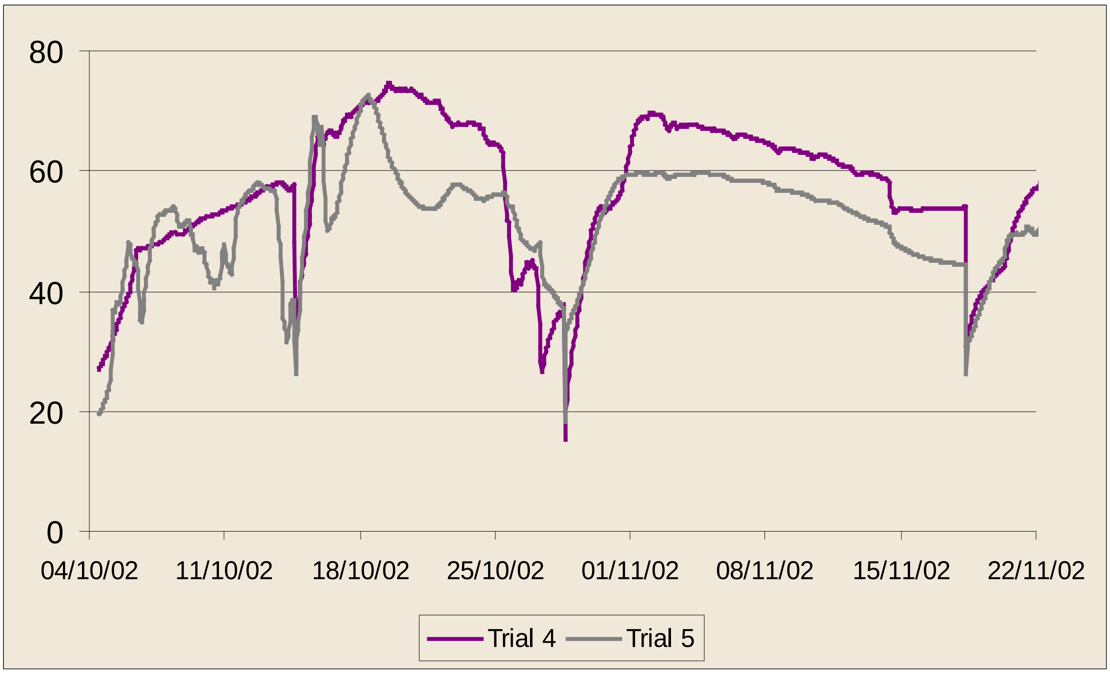
TRIAL 5 *Maturing since 11 November 02*	*MASS (kg)*	*VOLUME (bucket or bale)*	*Treatment*
GREEN WASTE(CHIP)	7,000	18	Vessel 1
ONION (SHRED)	5,890	9	

Graph 11 - Temperature Profile for Trials 5 and 6 (mean hourly average)



The reduced control seen in trial 4 continued in this trial and upper and lower aergestor temperatures differed greatly.

Graph 12 – Windrow temperatures for Trial 4 and 5 (mean hourly average)



Graph 12 shows the temperatures for the windrows of trial 4 and 5. Very high temperatures were reached in these trials and continued throughout the 45-day phase one period and into maturing (between 18/11 and 23/11).

4.9. Trial 6

Trial 6 (graph 11) utilised the 25% annex 2 material (green waste) by volume accepted by the Soil Association for growing media. the green waste was chipped and used to give the mushroom compost/shredded onion/straw mix more structure. The loss of structure in trial 3 due to the shredding of the main structural components in trial 2 (onions) lead to highly anaerobic conditions in the material. It was hoped that by adding green waste this problem could be overcome. The temperature profile in graph 11 shows a large gap between the upper and lower probes. This indicates that the air is not flowing through the material with ease. The finished material still caused some odour while maturing. It is difficult to judge how much of this is due to the poor mix and how much due to the technical problems encountered during the run

Table 6 – Trial 6 summary

TRIAL 6 *Maturing since 11 November 02*	***MASS (kg)***	***VOLUME (bucket or bale)***	***Treatment***
ONION	6,667	10	
MUSHROOM COMPOST	6,557	9	Vessel 2
STRAW	2,880	4	
GREEN WASTE(CHIP)	1,667	4	

4.10. Compost Production Process Discussion

The Alpheco system used did not provide the level of control or the speed of phase one composting expected. The lack of control in the system was partly due to the poor condition of the Alpheco System used by the project and through running the system from a diesel engine. The diesel engine control was an experimental addition to the machine that caused significant technical problems. These technical problems with powering the Alpheco affected all the runs in the machine. It is therefore difficult to make solid conclusions as to the control given by In vessel technology as compared to Windrow. Although the control in the system began well in trial 1 the corrosive nature of the materials to be composted took their toll on the floor louvers of the aergestors and there was progressive decline in temperature control throughout the experiments. Retention times were much longer than initially expected. It appears that the in vessel system will heat treat (sanitise) a feedstock mix much more quickly than a windrow due to the increased temperature control. However the actual time it takes for phase one composting (for temperatures to drop below 45^{o}C) does not decrease. The reliability of the Heat Treatment phase is also questionable due to the large edge effects found within the containers. These showed temperatures as low as 31^{o}C 5 cm into a material that was recorded by the system as being well into the Heat Treatment phase of composting.

The main feedstocks identified were vegetables. In trials 1 and 2 the vegetables were kept whole. In the In vessel system these remained whole and although those within the mix were visibly rotting by the end of phase one onions on the surface of the material in the aergestor were seen to germinate. In the comparison windrow the physical action of turning ensured that very few onions were still whole by the end of phase one. When the onions were shredded to reduce this problem the mixture lacked structure and there was reduced temperature control in both the windrow and in vessel as a result.

4.11. Human pathogen survival

Pot herb production in the UK is considered a food production system. As such each part of the finished product must be assessed for potential risk to human health. This is particularly important regarding human pathogens as most people do not wash herbs prior to use and they are often eaten raw. It would be a major benefit to Swedeponic UK if the control in the in vessel system could guarantee that the media was free from human pathogens post phase one composting.

Table 7 – Human Pathogen analysis of each compost (taken after Phase 1)

	Salmonella (cfu/g)	E Coli	Listeria
Trial 1 Vessel 1	Not detected	<300000	Not detected
Trial 1 Vessel 2	Not detected	<10	Not detected
Trial 1 Windrow	Not detected	<10	Not detected
Trial 2 Vessel 1	Not detected	>3000	Not detected
Trial 2 Vessel 2	Not detected	>3000	Not detected
Trial 3 Vessel 1	Not detected	<10	Not detected
Trial 3 Vessel 2	Not detected	<10	Not detected
Trial 3 Windrow	Not detected	80	Not detected
Trial 4 Vessel 1	Not detected	<10	Not detected
Trial 4 Vessel 2	Not detected	<10	Not detected
Trial 5 Vessel 1	Not detected	1700	Not detected
Trial 6 Vessel 2	Not detected	54000	Not detected

The Alpheco system had previously been used for the composting of sewage sludge's and the high levels of e.coli found in trial 1 is attributed to improper cleaning of the aergestor. The reason for the high levels in trials 5 and 6 are unknown. The poor temperature control achieved in later trials and the lack of uniformity throughout the aergestors could lead to pathogen survival especially given the edge effects identified and the low temperatures achieved in the top few cm of the mix.

4.12. Analysis

In order to compare the composts to currently available growing media the samples were taken at the end of phase one composting and sent to Natural Resource Management Ltd for analysis. The analysis was Water-soluble nutrients determined by extraction of 1/15th density in 400mls deionised water to BS4156 1990. pH and conductivity measurements have been made at 20^{o}C. The results of this analysis are shown in table 8. One replicate has been used so no statistical analysis can be made of the data in table x however there are identifiable trends that will be statistically analysed in the nutrition growth trial (this will use mature composts)

The mushroom compost based products (Trial 2 and 3) are much higher in

- Conductivity
- Chloride
- Sodium
- Potassium
- Calcium
- Sulphate

The Green waste composts are higher than mushroom based in

- Iron

Trial 1 windrow compared to trial 1 vessels, Windrow compost has higher

- Conductivity (990 vs 657-777 uS/cm)
- Calcium (262.1 vs 126.9 – 155.9 mg/l)
- Sodium (109.5 vs 77.6 - 82.9 mg/l)
- Sulphate (1182.6 vs 65.9 – 257.4 mg/l)

Trial 3 windrow compared to trial 3 vessels, Windrow had less

- Conductivity (1505 vs 2996 – 3333 uS/cm)
- Chlorine (493.9 vs 907.1-1004.4 mg/l)
- Potassium (2388.3 vs 4119.3-4950.0 mg/l)
- Magnesium (85 vs 220-244 mg/l)
- Calcium (389 vs 1452-1531 mg/l)
- Sodium (162.6 vs 327.9-381.1 mg/l)
- Sulphate (2157.2 vs – 6399 – 6779 mg/l)

When the material from the two windrows is compared it is possible to theorise that the composting technique is having a greater effect than the initial feedstock in dictating the levels of

- Calcium
- Sodium
- Sulphate
- Conductivity (as a result of the above)

As the levels of the above elements are more similar between the two windrows produced from different feedstocks than between the vessel and windrows composts produced from the same feedstock type.

4.13. Conclusions

Using a static composting system can leave significant areas of the mix un-sanitised and leads to insufficient biological action in whole vegetables. Shredding all whole vegetables leads to a loss of structure in the mix; this leads to poor temperature control as the material becomes too dense for air to be forced through evenly.

Due to prevailing wind direction problems and mixes not reaching consistent high temperatures the material in the windrows failed to meet the Heat Treatment requirements of the windrow system in several of the trials. However 60^{o}C was achieved by all the trials for at least one turn and 55^{o}C was achieved for at least 2 turns

Table 8 – Analysis of composts 1-4 taken after phase one composting

		Trial 1 Vessel 1	Trial 1 Vessel 2	Trial 2 Vessel 1	Trial 2 Vessel 2	Trial 3 Vessel 1	Trial 3 Vessel 2	Trial 4 Vessel 1	Trial 4 Vessel 2	Trial 1 Windrow	Trial 3 Windrow
pH		8.63	8.48	7.87	7.89	8.05	8.24	8.56	7.91	8.11	8.11
Density	kg/m^3	578.00	582.00	543.00	444.00	481.00	482.00	433.00	494.00	538.00	443.00
Dry Matter	%	76.00	56.30	41.90	35.20	30.80	30.40	50.10	43.20	63.70	29.30
Dry Density	kg/m^3	439.30	327.70	227.50	156.30	148.10	146.50	216.90	213.40	342.70	129.80
Conductivity	uS/cm	657.00	777.00	3,811.00	2,855.00	2,996.00	3,333.00	386.00	543.00	990.00	1,505.00
Chloride	mg/l	354.90	336.60	935.90	741.80	907.10	1,004.40	213.10	211.60	366.50	493.90
Phosphorous	mg/l	47.40	42.30	21.60	18.60	27.70	20.10	22.40	14.10	12.60	28.80
Potassium	mg/l	1,149.70	1,403.80	4,873.80	3,272.40	4,119.30	4,950.00	729.50	797.40	1,284.80	2,388.30
Magnesium	mg/l	58.20	28.30	304.60	233.50	220.50	244.80	14.40	21.60	45.30	85.00
Calcium	mg/l	155.90	126.90	1,986.60	1,923.10	1,531.20	1,452.70	64.20	89.80	262.10	389.50
Sodium	mg/l	82.90	77.60	376.10	244.80	327.90	381.10	33.30	38.20	109.50	162.60
Ammonia - N	mg/l	3.80	11.70	2.60	3.20	26.60	19.70	15.20	0.60	6.60	6.00
Nitrate - N	mg/l	1.30	28.80	34.40	3.20	35.80	6.30	0.70	0.60	8.80	34.20
Total - N	mg/l	5.10	40.50	37.00	6.40	62.60	26.00	15.90	0.60	15.40	40.20
Sulphate	mg/l	65.90	257.40	9,253.10	6,851.90	6,399.50	6,779.40	106.20	202.80	1,182.60	2,157.20
Boron	mg/l	1.62	1.11	0.40	0.25	0.58	0.54	0.59	0.45	0.58	0.92
Copper	mg/l	0.91	0.76	0.60	0.58	0.52	0.76	0.38	0.27	0.40	0.62
Manganese	mg/l	3.74	1.08	0.21	0.36	0.55	0.14	0.57	0.31	0.52	0.33
Zinc	mg/l	0.90	2.67	0.23	0.22	0.23	0.18	0.17	0.12	0.14	0.17
Iron	mg/l	63.38	34.20	2.72	1.91	3.06	1.32	32.36	21.03	22.63	2.09

In this project, In Vessel composting did not speed up phase one of the composting process or give much greater control of the composting material than the windrow system. This can be partly attributed to the age and condition of the Alpheco System used and the experimental nature of the diesel engine used to power it. Conditions within the vessel are more controllable. However as leaching (through the effect of rainfall) is prevented there may be problems with retention of ions that willl contribute to high conductivity. This is of concern where such material is to be used to germinate and grow young plants.

5. Testing of finished composts under commercial growing conditions

5.1. Introduction

The main problems associated with immature composts

- High ammonia and volatile organic acid levels, both of which cause phytotoxicity.
- Nitrogen lock up, a state that occurs through microbes using fertiliser nitrogen to break down 'raw' carbon in the compost. This removes much of the nitrogen from fertiliser and prevents it from reaching the plant.
- Oxygen depletion in the pot that occurs when microbes use the available oxygen in the pot before the plants can use it.

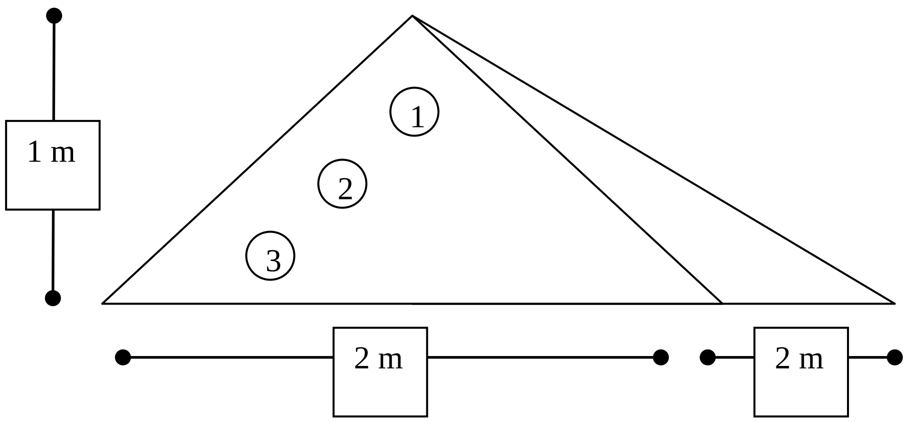
To evaluate when the composts produced by the project reached suitable maturity a series of maturity bioassays were planned. These were to be used in conjunction with the Solvita compost maturity test, which will provide a marker for points of suitable maturity that can be used in commercial production of the finished compost to evaluate its suitability for use. The composts were diluted 50% with coir before use in the bioassay to allow meaningful results to be gathered at an early stage.

5.2. Materials and Methods

5.2.1. Sampling method

A shovel was used to cut three sampling points into the windrow. Minimum of 1 litre samples were then collected from 2 depths (surface to 30cm and 30 cm to 60cm at each of the sample points. The samples were then blended by hand in a bucket and sub samples removed.

Figure 1 – Diagram showing a sampling point on a maturing windrow, based on the Composite sampling system suggested by *Test Methods for the Examination of Composting and Compost* (August 2001 draft). Three samples to be taken from different depths in each sample point (marked 1 to 3). These are then mixed together and subsampled to get the final analysis sample.



5.2.2. Solvita testing

A sample was obtained using the sampling method shown. The moisture content of the sample was checked and standardised by feel. The moisture content was judged to be appropriate if when a sample was gripped it balled together without producing any excess water. If the sample needed moisture content alteration it was left overnight in a warm room to dry or water was added and the material was left overnight.

Once the moisture content was considered optimum the sample was placed in the Solvita container to the level of the guide line. The material was left overnight in the unsealed container for carbon dioxide levels to reach equilibrium with the outside atmosphere. The Ammonia sensitive paddle was then inserted into the compost as was the Carbon Dioxide sensor and the material was left for four hours. The colour of the Ammonia and Carbon dioxide paddles was then used to calculate the maturity of the compost on the Solvita index.

5.2.3. Maturity Bioassays - Growth compost protocol

Samples were taken from the maturing heaps once the temperature had fallen below $40^{o}C$. The composts were then sieved to 5mm and mixed by volume with coir at a 1:1 ratio. They were potted into 9cm pots and sown with organic coriander seed using standard potting and sowing equipment. Controls were set up using proprietary organic media for coriander and peat. Once sown the pots were labelled and stored in the germination room at 90% humidity, $15^{o}C$, for 6 days before being placed out in the organic glasshouse in a Latin square design.

Once the harvest date (based on current weather and rate of growth, usually 30 days) for the herbs has been reached they are assessed for germination, height and fresh weight of foliage.

5.3. Results

5.3.1. Solvita Test Results

Table 1 – Solvita results for Compost 1

Age (weeks)	**5**	**17**	**21**	**24**
Vessel 1	7	7	8	8
Vessel 2	7	7	8	8

Age (weeks)	**2**	**17**	**21**	**25**	**28**
Windrow	7	8	8	8	8

Table 2 – Solvita results for Compost 4

Age (weeks)	**1**	**3**	**6**
Vessel 1	6	6	8
Vessel 2	6	6	7

Table 3 – Solvita results for Compost 2

Age (weeks)	**6**	**10**	**14**	**17**
Vessel 1	7	7	7	7
Vessel 2	6	7	7	7

Table 4 – Solvita results for Compost 3

Age (weeks)	**3**	**6**	**10**	**13**
Vessel 1	7	7	7	8
Vessel 2	7	7	7	8
Windrow	7	7	7	8

5.3.2. Discussion

The Solvita results above do not effectively pinpoint the moments of changing maturity for herb growth in the composts. The difference between the performance of the herbs throughout the maturity that is for example Solvita 8 is massive and an unacceptable level of variation for commercial production in the composts as growing media. There are also differences between the Solvita scores that are suitable. In compost 2 composts week 17 shows very good herb performance but the Solvita result shows that it is still only Solvita 7 mature. The windrow for compost 1 only starts to do well at Solvita 8. it is possible to double the amount of time used to get a reading from a Solvita kit and use this to effectively double its sensitivity. However significant work would have to be done to gauge the values got in this way against herb growth in the composts. The most effective way to evaluate compost maturity will be through a bioassay similar to that used in the majority of the testing shown here.

5.3.3. Compost 1 maturity profile

Figure 2 - Germination of coriander seeds in 50% coir 50% in compost 1 5mm sieved material as a percentage of a peat control. Alpheco Vessel 1, 2 and Windrow produced material sown into at intervals between 5 weeks from phase one composting to 35 weeks.

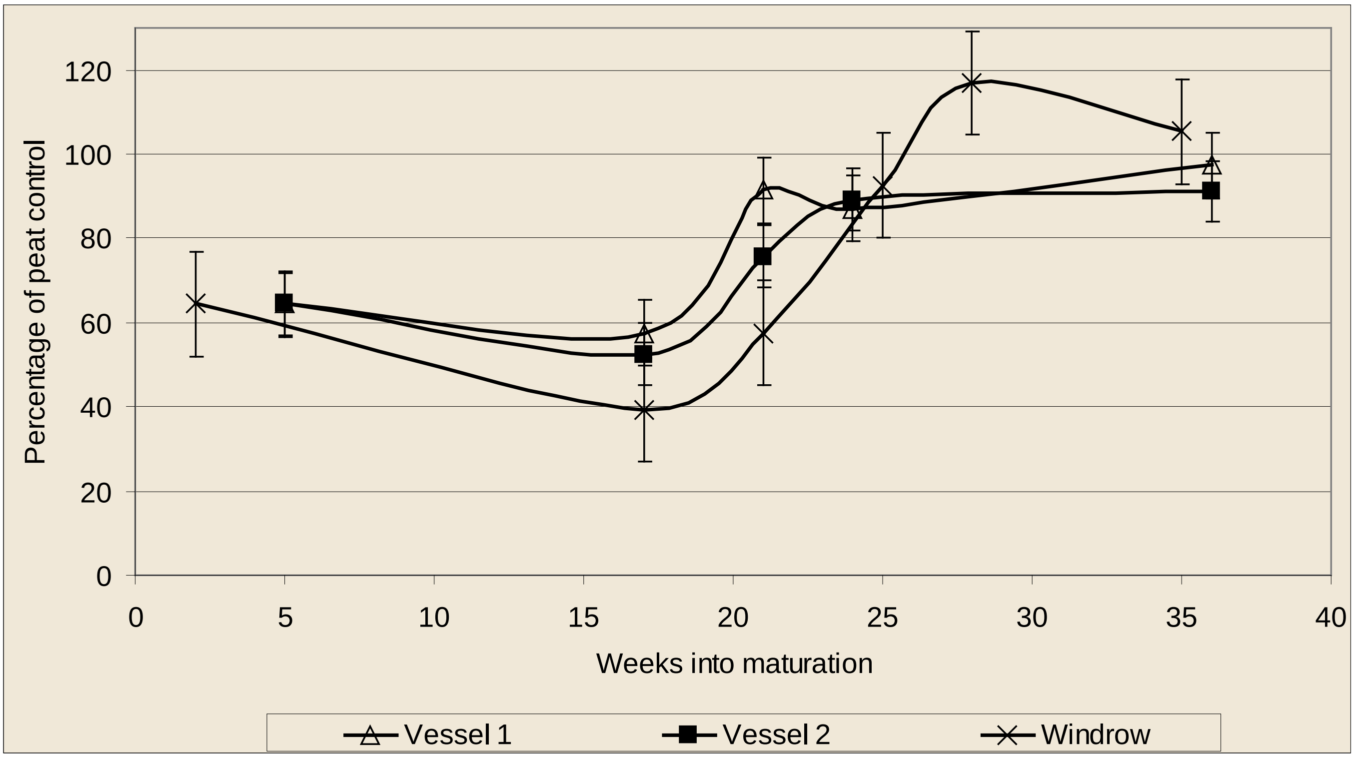


Figure 3 - Height of coriander plants grown in 50% coir 50% in compost 1 5mm sieved material as a percentage of a peat control. Alpheco Vessel 1, 2 and Windrow produced material sown into at intervals between 5 weeks from phase one composting to 35 weeks.

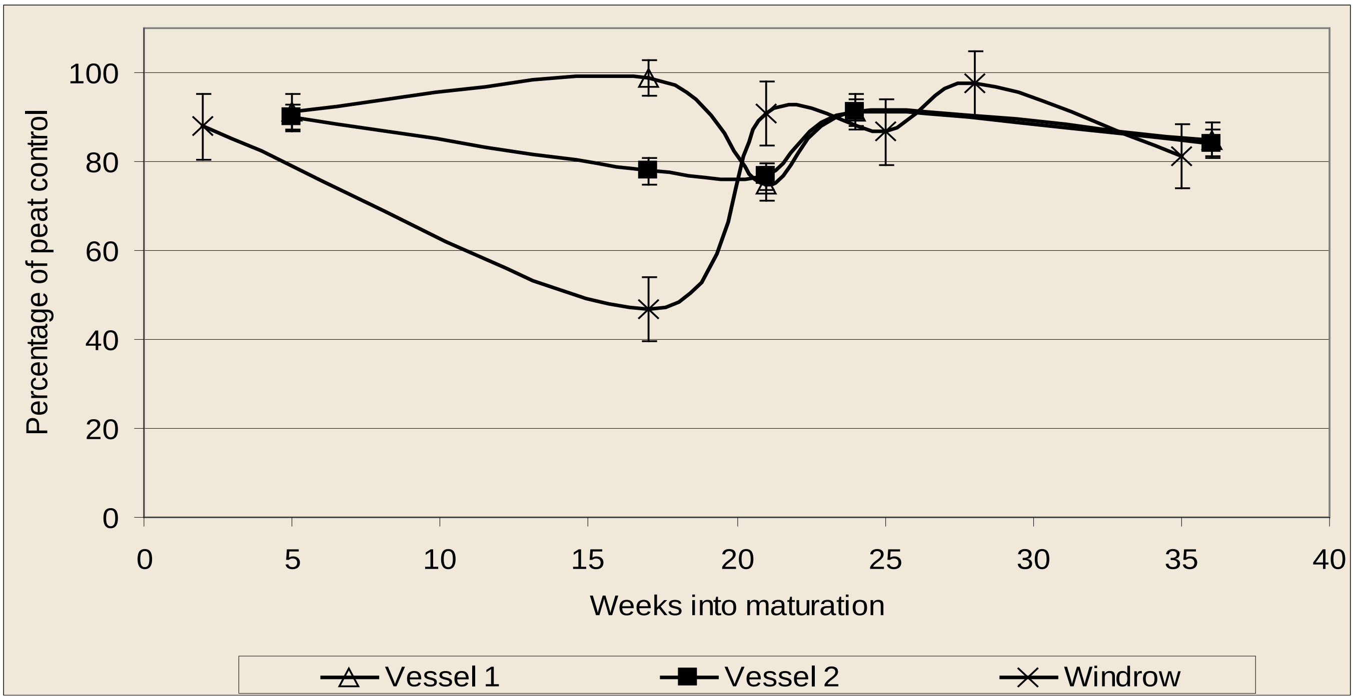


Figure 4 - Fresh Weight of foliage per germinated Plant of coriander plants grown in 50% coir 50% in compost 1 5mm sieved material as a percentage of a peat control. Alpheco Vessel 1, 2 and Windrow produced material sown into at intervals between 5 weeks from phase one composting to 35 weeks. Fresh weight measurements were not taken until growth compost on week 17.

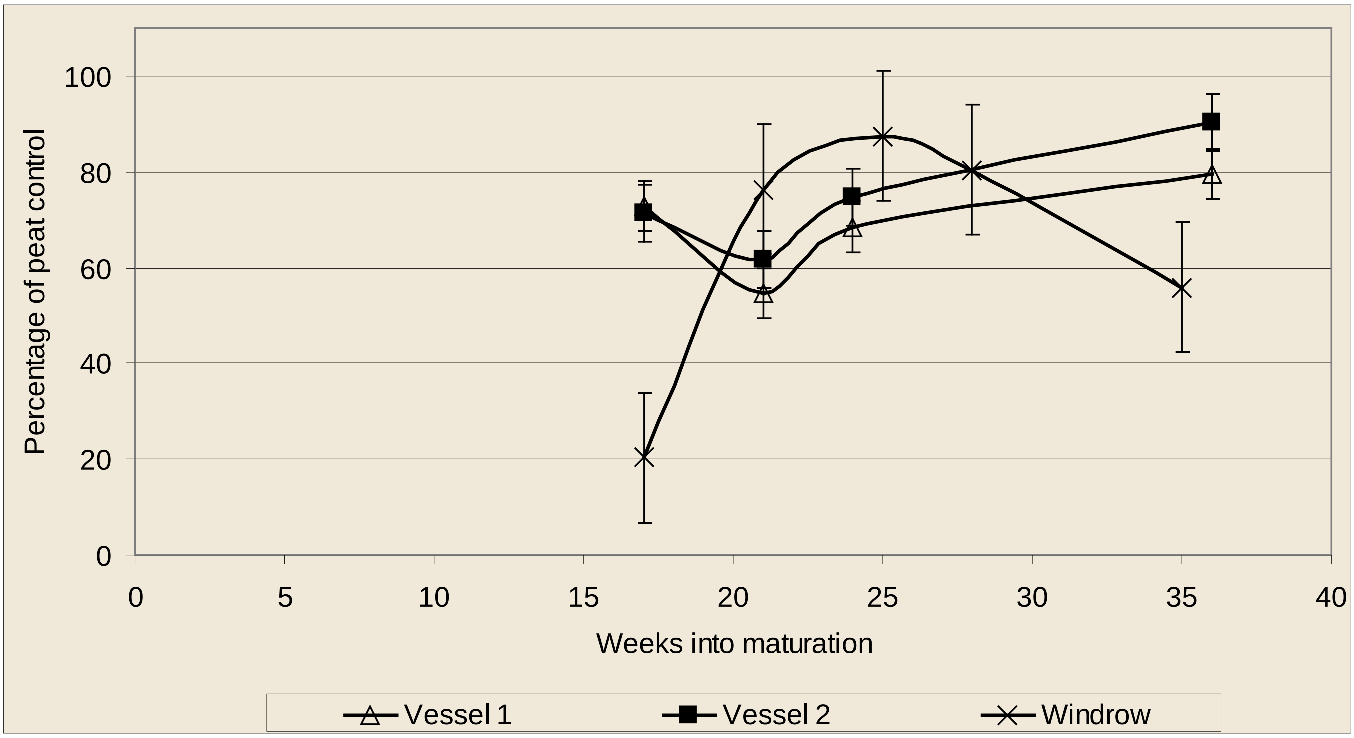
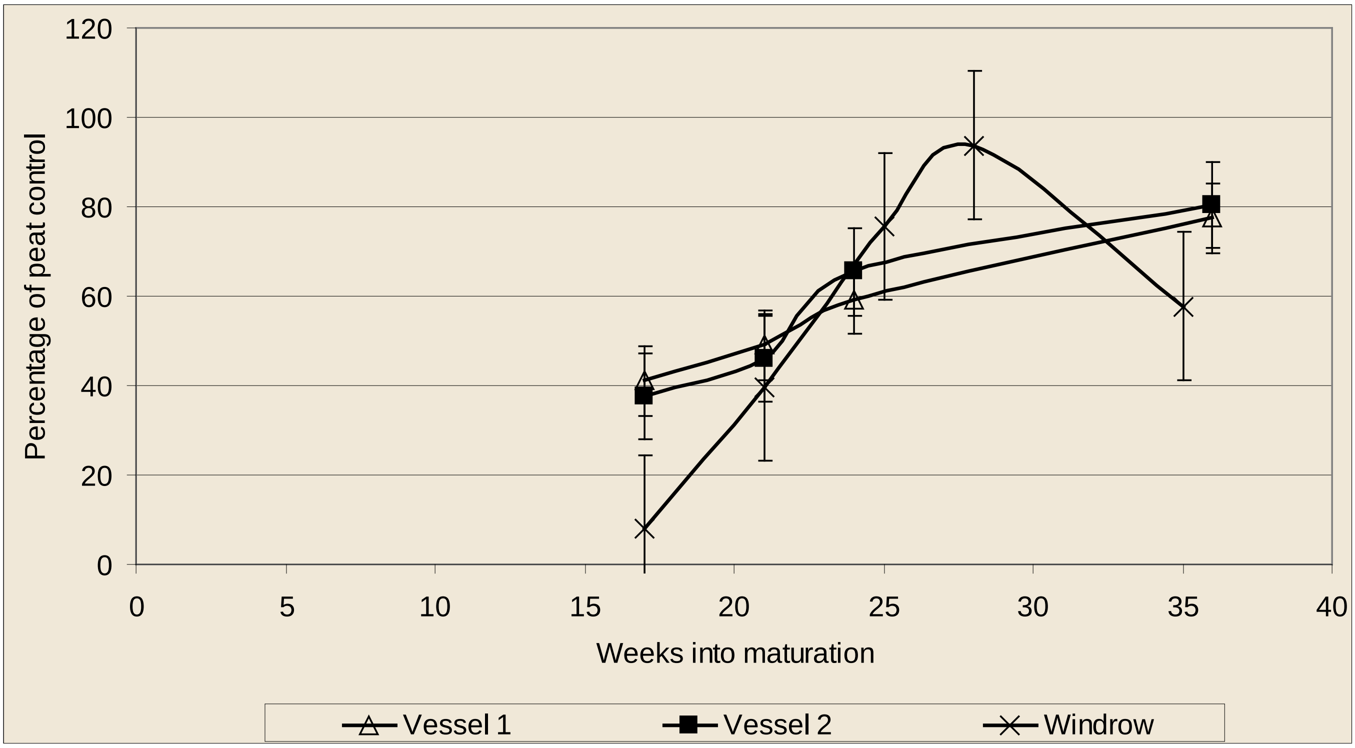


Figure 5 - Fresh Weight of foliage per pot of coriander plants grown in 50% coir 50% in compost 1 5mm sieved material as a percentage of a peat control. Alpheco Vessel 1, 2 and Windrow produced material sown into at intervals between 5 weeks from phase one composting to 35 weeks. Fresh weight measurements were not taken until the growth compost on week 17.



5.3.4. Discussion for compost 1

What we are looking to see in the above data is the point at which the composts perform best, this is the point of maturity. For compost 1 this peak in performance occurs at week 27 for the windrow produced and 35 for the both vessel produced composts.

Maturation in the windrow-produced compost shows a different pattern in germination and fresh weight per plant compared to the vessel produced plants. When these composts were phase one composting the Alpheco system was given 23 days to compost the materials and the windrow was given 39. This was done on the initial assumption that the Alpheco composted materials faster than the windrow. If the material did not compost in the Alpheco as well as initially thought (see section 2 phase one report) the maturity of the vessel produced composts would be behind that of the windrow produced. However this does not seem to be what is shown in graphs 1 to 4. Germination in the windrow produced does closely match that for the vessels. However height and growth as weight per plant show a different pattern of development to the two vessel produced composts, this is especially pronounced in the immature and then over mature composts, when maturity is reached the growth per plant in the composts becomes similar regardless of production method.

There seems to be little trend in height as a function of maturity for this compost.

5.3.5. Compost 2 maturity profile

Figure 6 - Germination of coriander seed sown in 50% coir 50% in compost 3 5mm sieved material as a percentage of a peat control. Alpheco Vessel 1 and 2 produced material sown into at intervals between 5 weeks from phase one composting to 35 weeks.

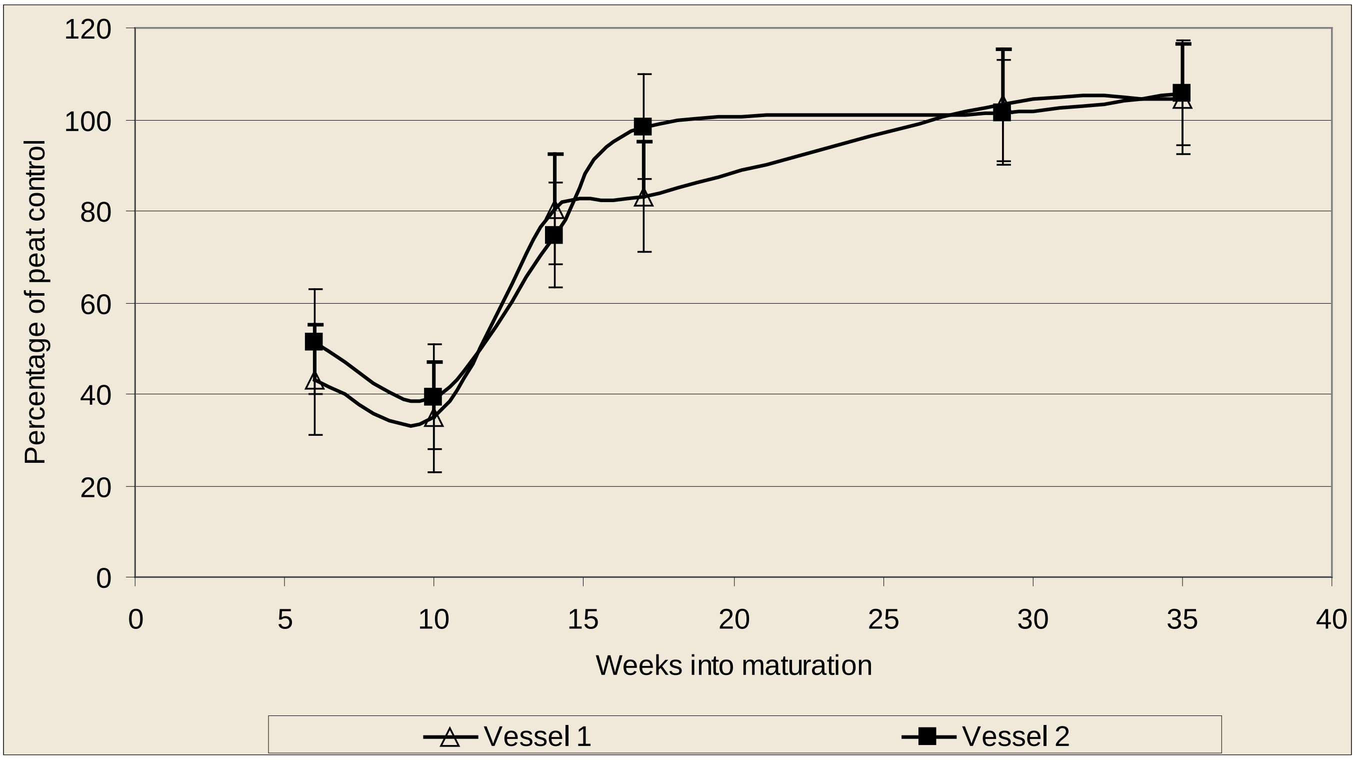


Figure 7 - Height coriander plants at harvest grown in 50% coir 50% in compost 3 5mm sieved material as a percentage of a peat control. Alpheco Vessel 1 and 2 produced material sown into at intervals between 5 weeks from phase one composting to 35 weeks.

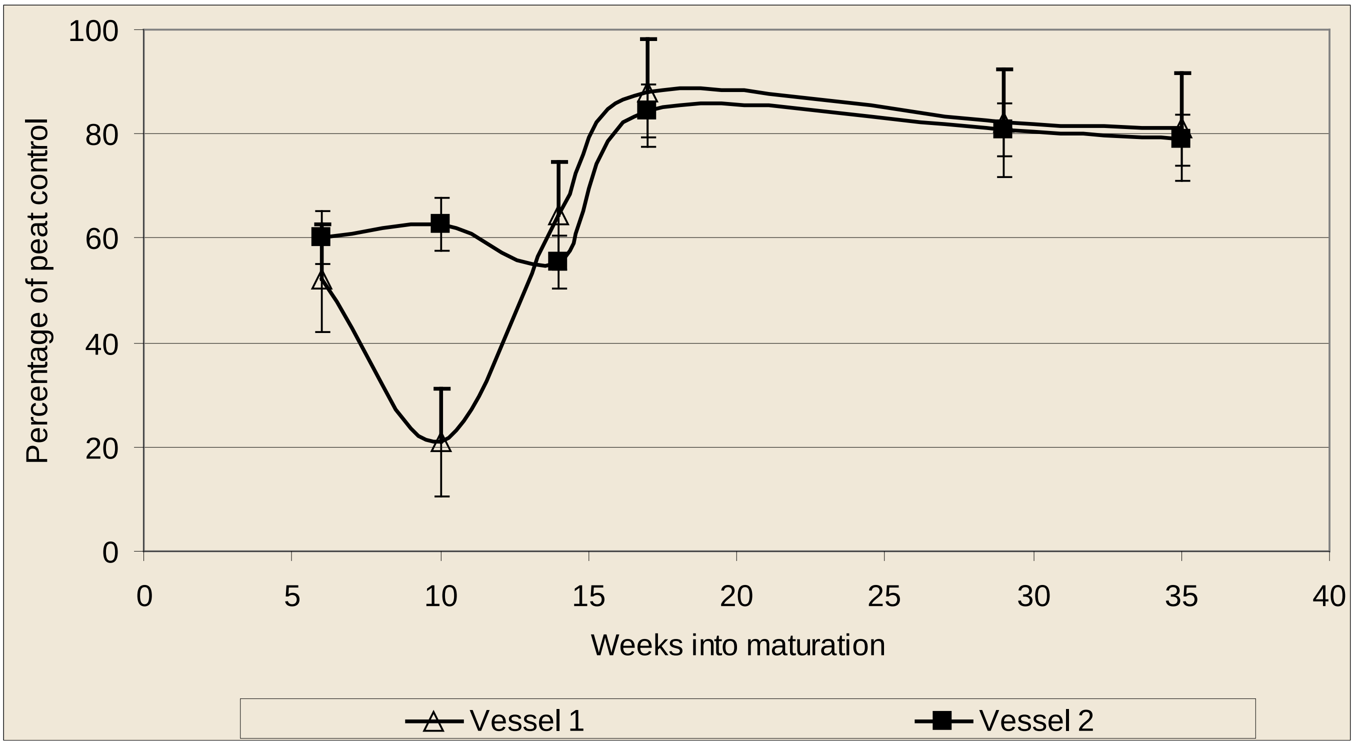


Figure 8 - Fresh weight of foliage per germinated plant coriander plants at harvest grown in 50% coir 50% in compost 3 5mm sieved material as a percentage of a peat control. Alpheco Vessel 1 and 2 produced material sown into at intervals between 5 weeks from phase one composting to 35 weeks.

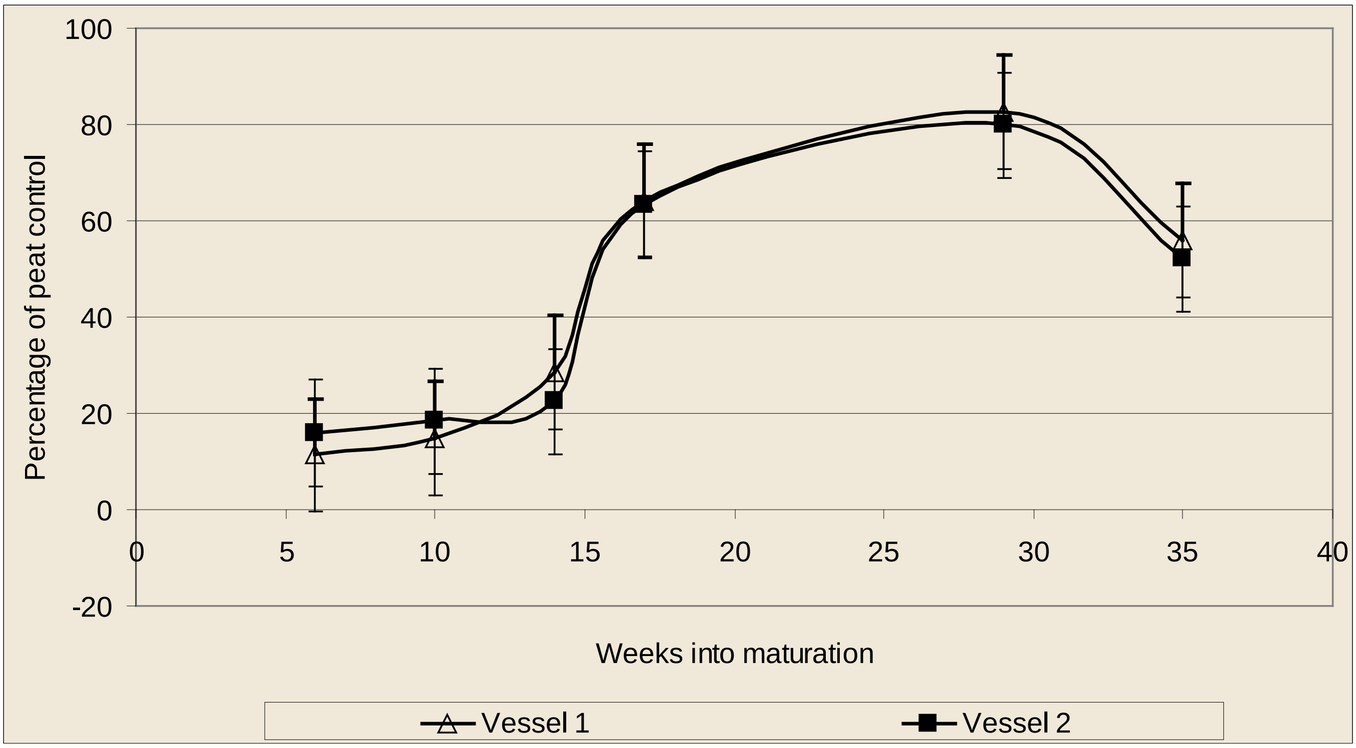
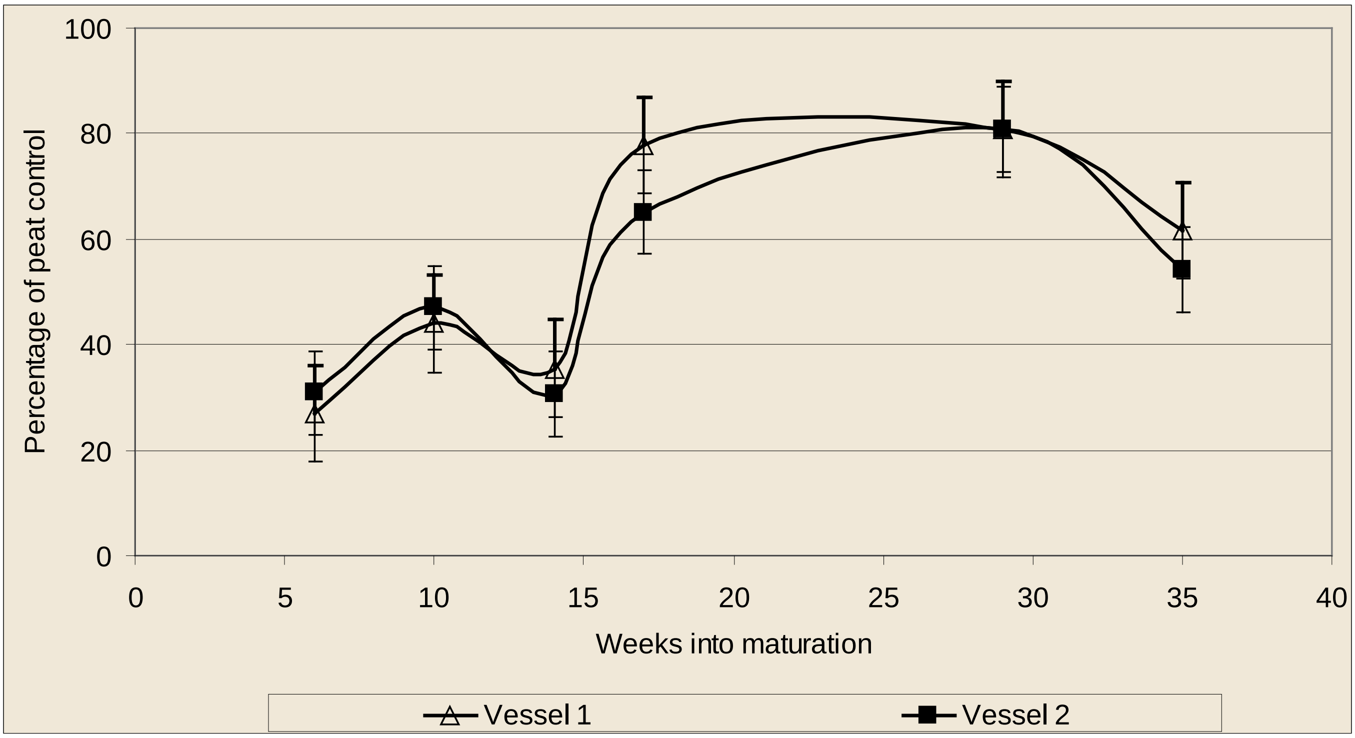


Figure 9 - Fresh weight of foliage per pot of coriander plants at harvest grown in 50% coir 50% in compost 3 5mm sieved material as a percentage of a peat control. Alpheco Vessel 1 and 2 produced material sown into at intervals between 5 weeks from phase one composting to 35 weeks.



5.3.6. Discussion compost 2

Germination in compost 2 shows the dip in performance, which is also seen in germination for compost 4. In compost 2 this occurs between weeks 5 and 14. By week 17 the germination in the compost has stabilised and changes very little from then on. A very similar trend can be seen in the height of the plants.

The growth per plant is very poor until week 17 where it improves from around 20% the fresh weight per plant of peat plants to just over 60%, by week 30 the plants are achieving over 80% the fresh weight per plant of the peat plants. Unlike the trend in germination the fresh weight per plant as a percentage of peat performance dips off after 30 weeks as the optimum maturity is exceeded.

As a consequence the weight per pot shows maturity at between weeks 17 and 30.

5.3.7. Compost 3 Maturity profile

Figure 10 - Germination results coriander plants at harvest grown in 50% coir 50% in compost 4 5mm sieved material as a percentage of a peat control. Alpheco Vessel 1, 2 and Windrow produced material sown into at intervals between 5 weeks from phase one composting to 35 weeks.

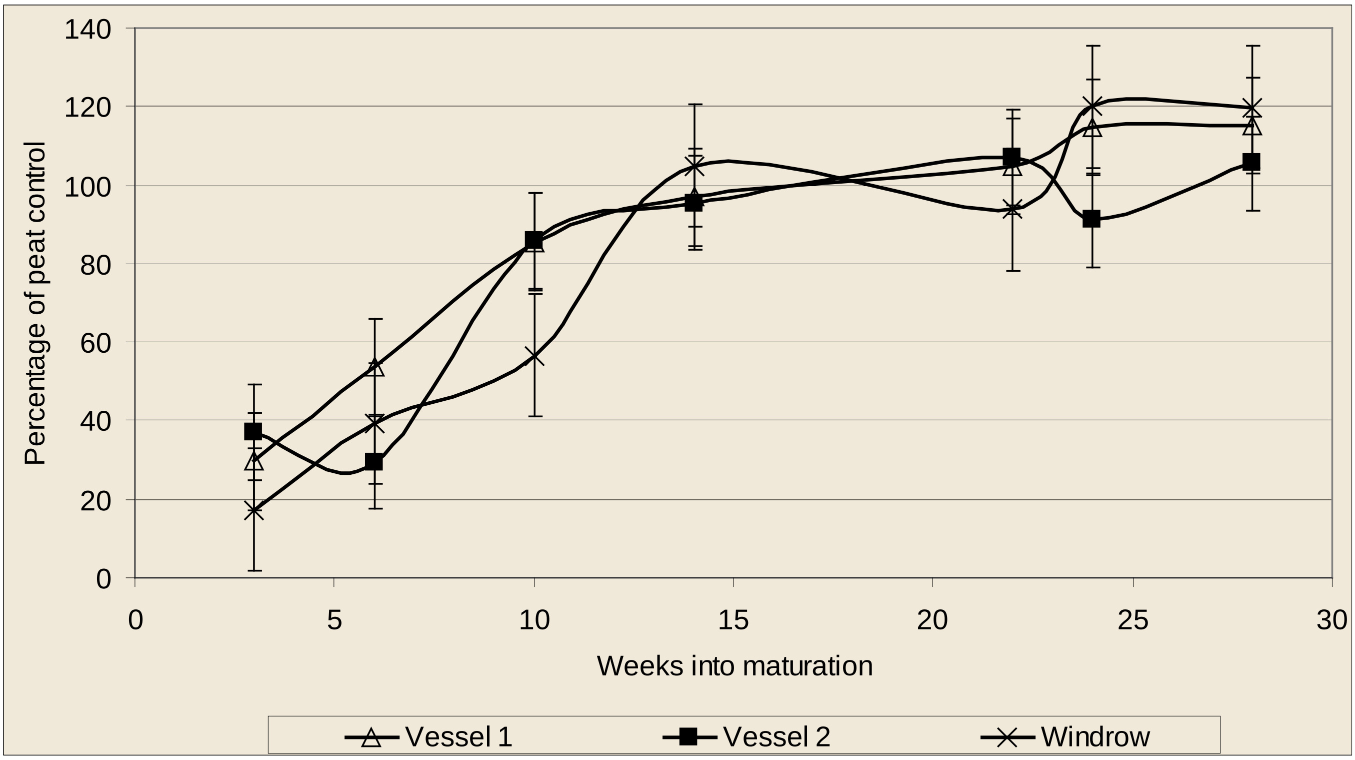


Figure 11 - Height results coriander plants at harvest grown in 50% coir 50% in compost 4 5mm sieved material as a percentage of a peat control. Alpheco Vessel 1, 2 and Windrow produced material sown into at intervals between 5 weeks from phase one composting to 35 weeks.

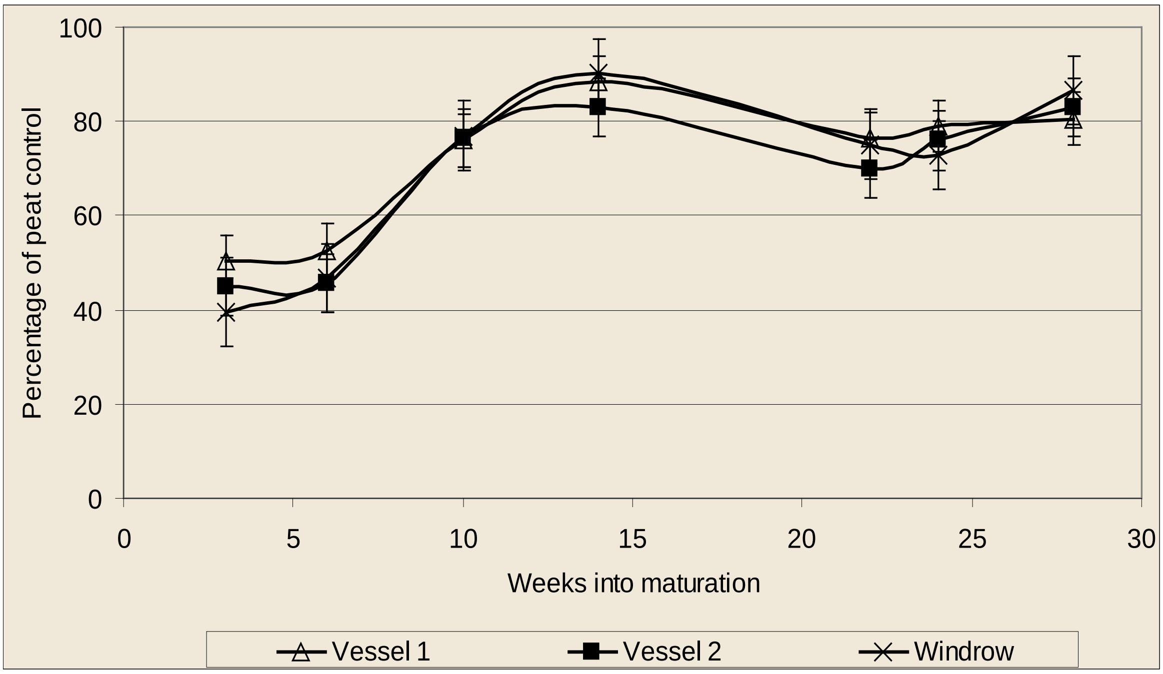


Figure 12 - Fresh Weight of foliage per germinated plant coriander plants at harvest grown in 50% coir 50% in compost 4 5mm sieved material as a percentage of a peat control. Alpheco Vessel 1, 2 and Windrow produced material sown into at intervals between 5 weeks from phase one composting to 35 weeks.

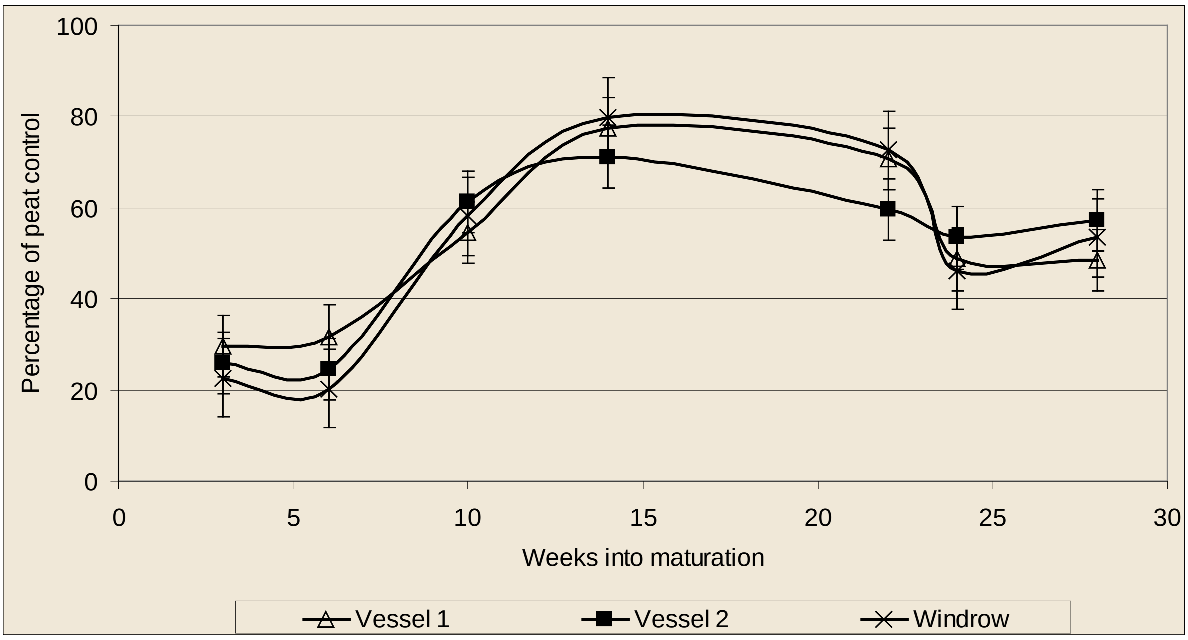
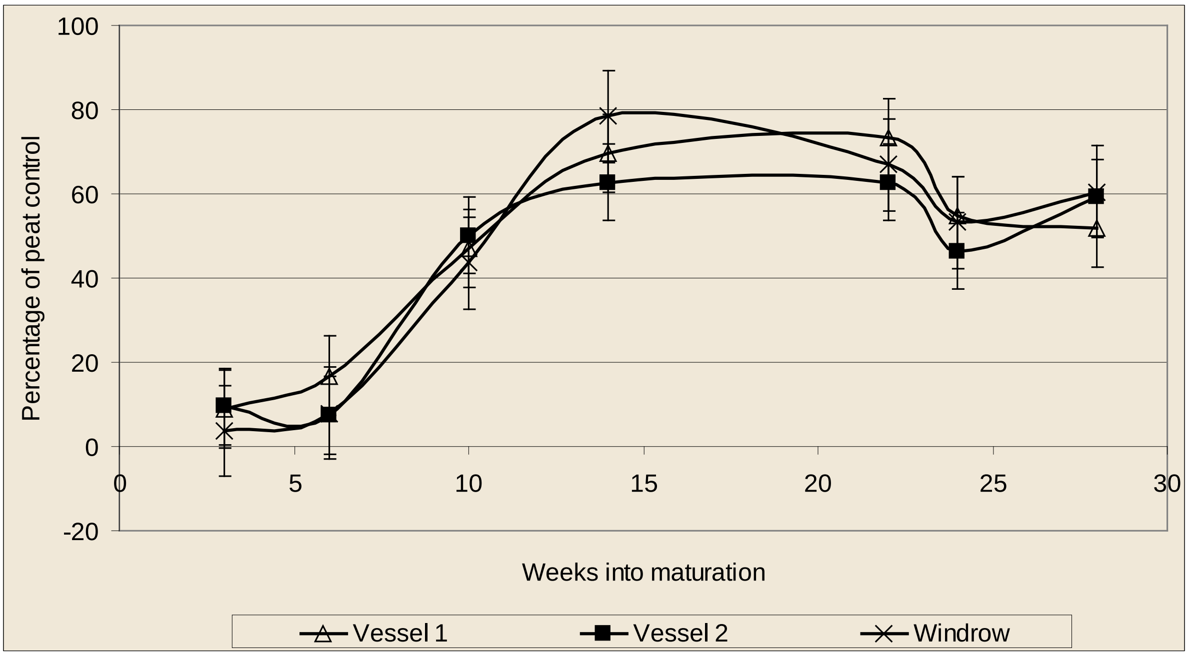


Figure 13 - Fresh weight of foliage per pot of coriander plants at harvest grown in 50% coir 50% in compost 4 5mm sieved material as a percentage of a peat control. Alpheco Vessel 1, 2 and Windrow produced material sown into at intervals between 5 weeks from phase one composting to 35 weeks.



5.3.8. Discussion compost 3

In compost 3 there is very little difference between the rate of maturity of the vessel produced and the windrow produced composts. This is different from in compost one where there was a pronounced difference between windrow and vessel produced. However in compost 1 the windrow was composted for longer than the in vessel. This may have had an unanticipated effect on the maturity patterns of the windrow and vessel produced composts.

Germination in compost 3 stabilises after a gradual rise at around 17 weeks. As in all the previous composts germination does not drop off once optimum maturity is exceeded. Height shows a similar trend.

Fresh weight per plant (growth) reaches optimum after 10 weeks and begins to drop off after 23, where a second plateau in growth is seen.

Overall pot weight per plant sees optimum (maturity) at between 14 and 23 weeks.

The pattern of maturity in compost 3 is very similar in germination, height and fresh weight trends to that seen in compost 2, which is based on the same materials.

5.3.9. Compost 4 maturity profile

Figure 14 - Germination of coriander seed sown in 50% coir 50% in compost 2 5mm sieved material as a percentage of a peat control. Alpheco Vessel 1 and 2 produced material sown into at intervals between 5 weeks from phase one composting to 25 weeks.

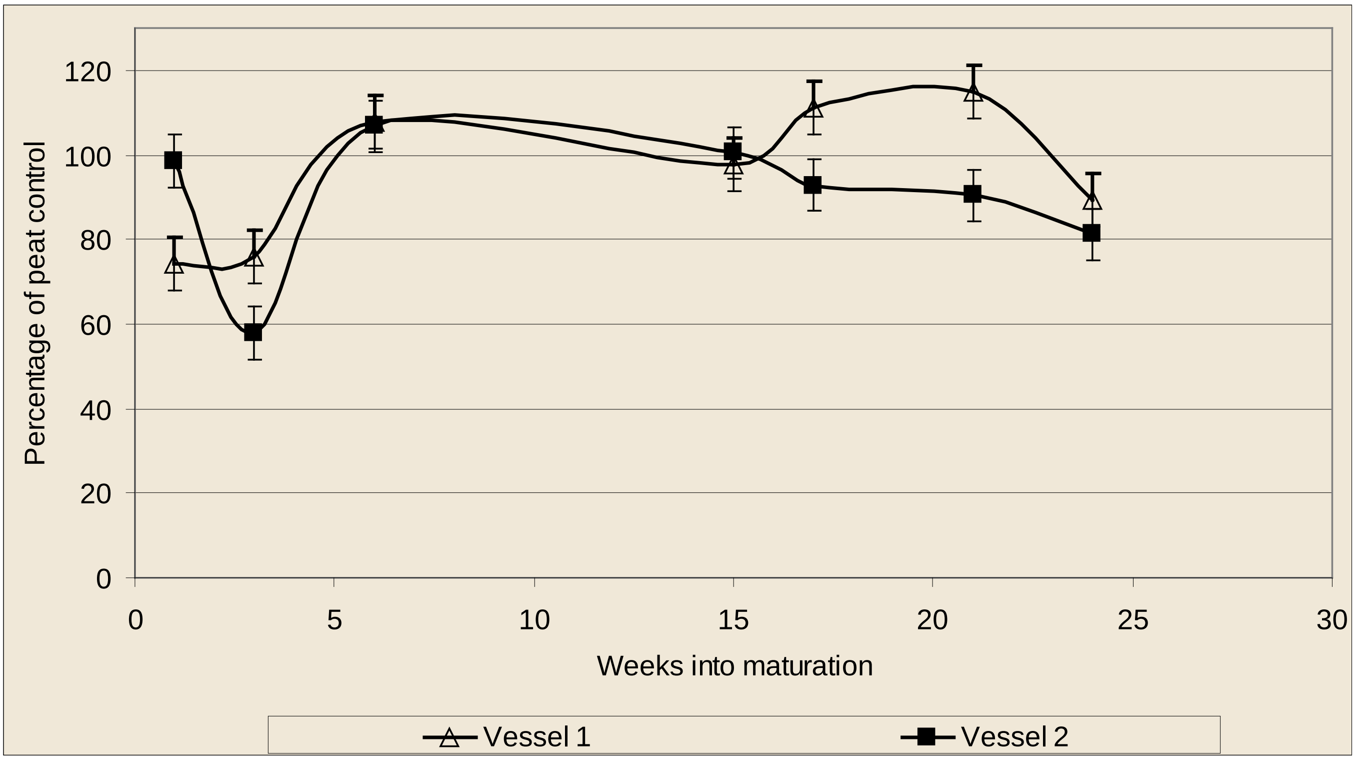


Figure 15 - Height of coriander plants at harvest grown in 50% coir 50% in compost 2 5mm sieved material as a percentage of a peat control. Alpheco Vessel 1 and 2 produced material sown into at intervals between 5 weeks from phase one composting to 25 weeks.

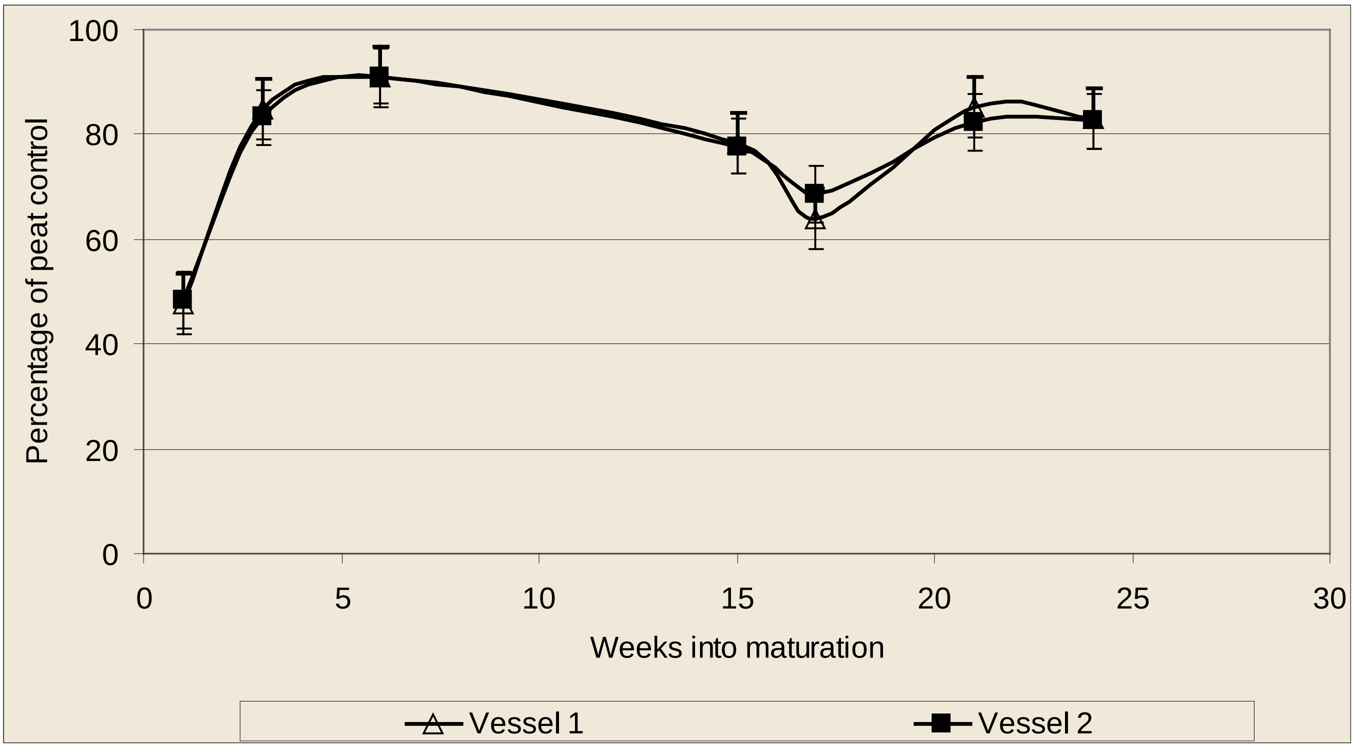


Figure 16 - Fresh Weight of foliage per germinated plant of coriander plants at harvest grown in 50% coir 50% in compost 2 5mm sieved material as a percentage of a peat control. Alpheco Vessel 1 and 2 produced material sown into at intervals between 5 weeks from phase one composting to 25 weeks.

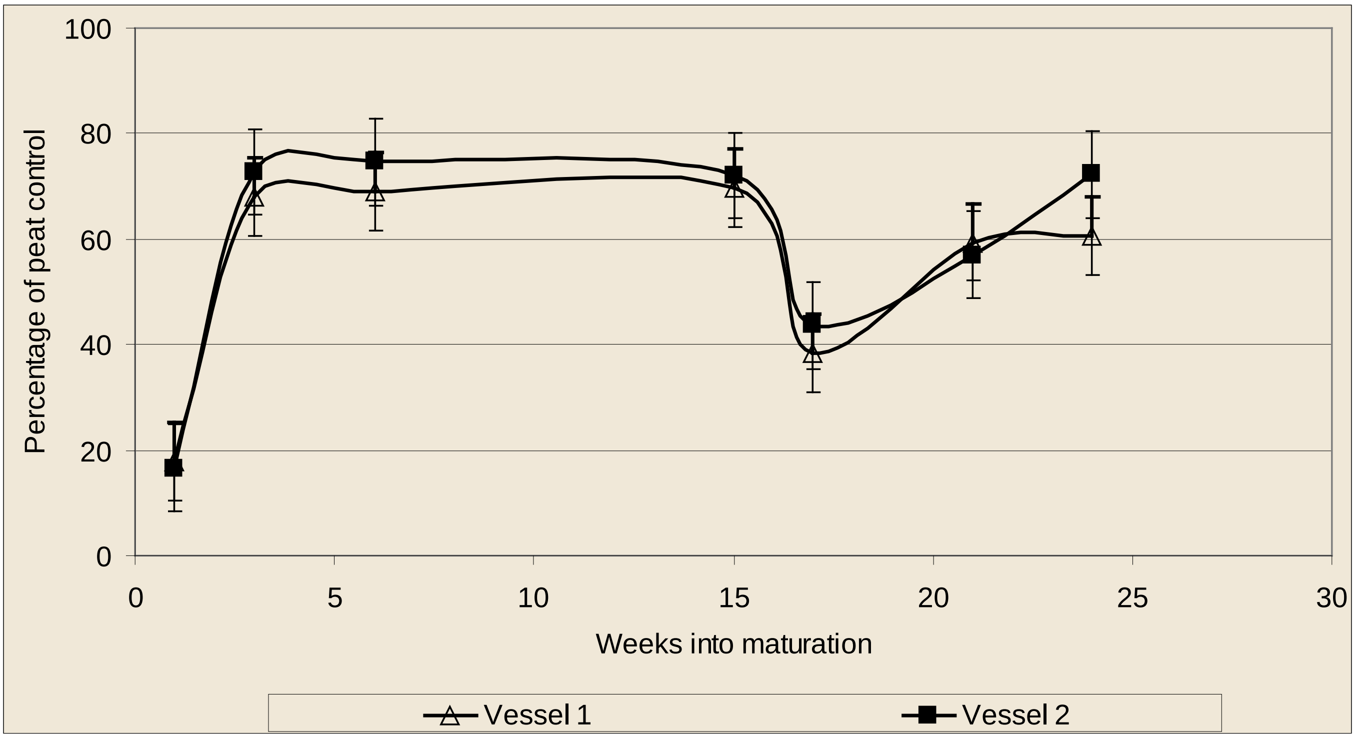
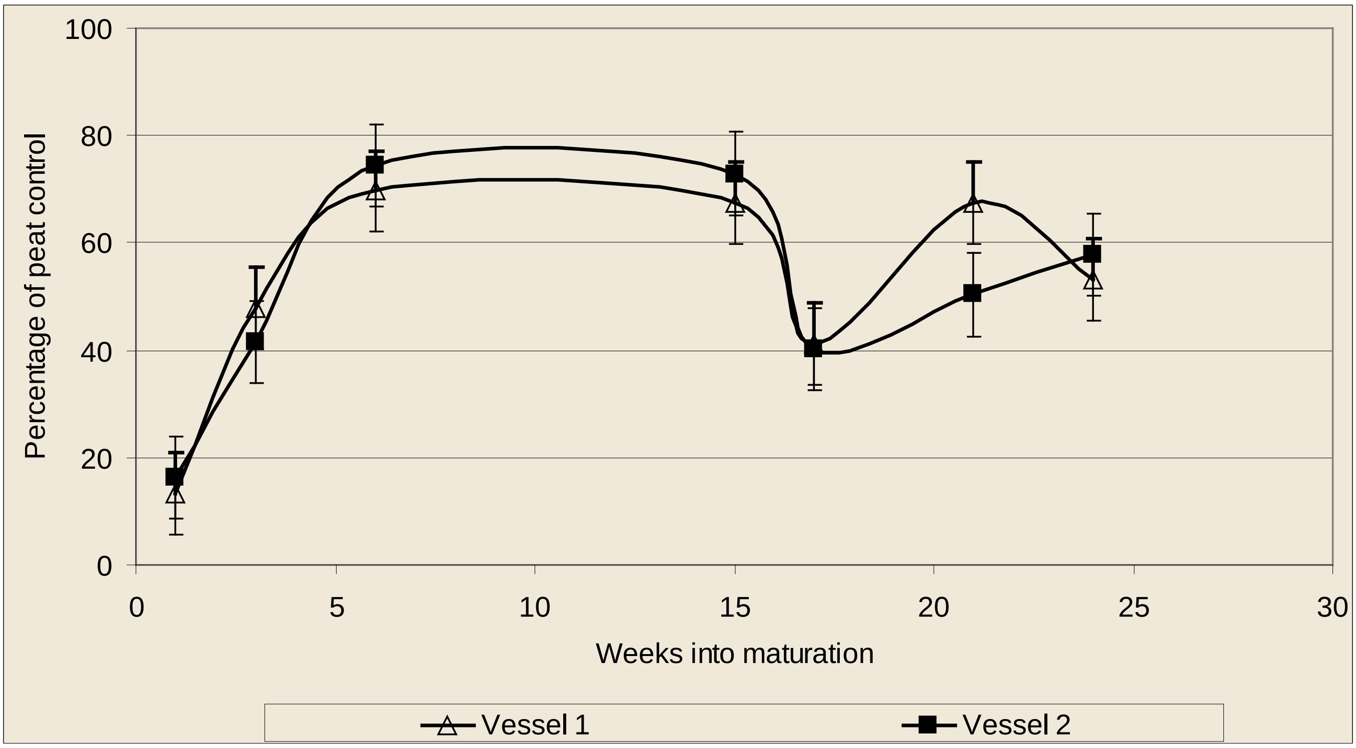


Figure 17 - Fresh Weight of foliage per pot of coriander plants at harvest grown in 50% coir 50% in compost 2 5mm sieved material as a percentage of a peat control. Alpheco Vessel 1and 2 produced material sown into at intervals between 5 weeks from phase one composting to 25 weeks.



5.3.10.Discussion Compost 4

Vessel 1 and 2 composts matured very consistently reaching their best performance between 5 and 15 weeks of maturing.

There is an initial dip in germination between weeks 1 and 7 but after this germination very quickly stabilises. Weight per plant stabilises after 5 weeks of maturing, as does height. This gives an overall weight per pot which reaches a stable plateau by week seven and continues to show this until week 17 where there is a dip in growth per plant, this recovers by week 23.

Compost 4 uses the same weight ratio of the same ingredients as used in compost 1 (32 tonnes green waste, 19 tonnes onions and 14 tonnes of potatoes) however in compost 4 the green waste was chipped and the onions were shredded. In compost 1 onions were whole and green waste was shredded roughly. The increased processing given to compost 4 feedstocks increased the surface area to volume ratio of the composting materials and seems to have accelerated the composting process, graphs 14 to 17 compared with graphs 2 to 5.

5.4. Overall Discussion

All the composts have a very similar pattern of maturation where the initial trend is poor germination and poor growth per germinated plant. Germination begins to recover after around 10 weeks at which point weight per plant also begins to pick up. Germination in all the composts reaches a maximum level and then remains consistent. i.e. there is no drop off in performance after maturity is reached. Growth per plant reaches a maximum level, which it stays at for a number of weeks before performance begins to drop off again.

All achieve around 80% the pot foliage weight of the peat grown plant at maturity. Windrow produced compost 1 compost exceeds this and reaches 90% at its optimum point in one compost.

Given that phase one composting is the same duration, windrow produced composts mature at the same rate and with the same pattern as vessel produced. And even when left for different time periods in phase one the optimum performance of the media is at the same level i.e. 80% the performance of peat.

5.5. Conclusions

In all the composts both containers from the in vessel system show the same maturity curves and characteristics.

For the first phase of maturation reduced germination is the main limiting factor on herb performance. Once germination reaches its optimum point it stabilises and continues at that level

The second limiting factor is reduced growth of the plants that do germinate. This shows a different profile, growth per plant increases, plateaus and then decreases. This causes the characteristic optimum ‘hump’ in fresh weight per pot values.

The optimum maturity occurs between week 25 and 30 for compost 1, weeks 15 to 30 for composts 2 and 3 and weeks 5 to 15 for compost 4.

There is a difference between the maturity profiles of in vessel produced and windrow produced batches in compost one but not in compost 3. Composts made with the same method mature in a similar timeframe regardless of composting method used.

The Solvita system is not a sensitive enough test of compost maturity for this purpose. A bioassay similar to that detailed above should be used.

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