Royal Horticultural Society

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AHDB HORTICULTURE

Horticultural Fellowship Awards

Interim Report Form

Project title:	Sustainable resource use in horticulture: a systems approach to delivering high quality plants grown in sustainable substrates, with efficient water use and novel nutrient sources.
Project number:	CP095
Project leader:	Dr Paul Alexander, Royal Horticultural Society (RHS)
Report:	Annual report, June 2016
Previous report:	Annual report, June 2015
Fellowship staff:	Dr Paul Alexander, Head of Horticulture and Environmental Science, RHS, Wisley: Project leader/mentor Dr Alistair Griffiths, Director of Science and Collections, RHS Wisley: Project sponsor Dr Steve Robinson: Senior lecturer, The University of Reading (UoR): Academic Mentor
("Trainees")	Dr Gracie Barrett: Post-doctoral horticultural scientist
Location of project:	RHS Garden Wisley, Woking.

Industry Representative:	Neil Bragg (NB): Product development director, Bulrush Horticulture Ltd
Date project commenced:	November 2012
Date project completed (or expected completion date):	November 2017

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AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

Paul Alexander
Project Leader
The Royal Horticultural Society

Signature ....Paul Alexander............................ Date .....29/06/2016…………………

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Progress Against Objectives

Objectives

Objective	**Original Completion Date**	**Actual Completion Date**	**Revised Completion Date**
Further experiments: examining novel substrates, water efficiency, various substrates & plant performance (see science section)	December 2015	November 2015	N/A
Identification of knowledge gaps, written proposals presented for spin-off funding opportunities	July 2016	On-going	N/A
Presentation of information to a variety of audiences (grower meetings, scientific conferences etc.)	July 2016	On-going (appendix 1, table A)	N/A
Present findings to RHS Science committee, AHDB studentship conference & appropriate staff seminars at RHS, AHDB, UoR etc.	July 2016	On-going (appendix 1, table A)	N/A
Scientific publication, AHDB report, articles in RHS publications and general gardening press.	July 2016	On-going (appendix 1, table and see below)	N/A

Summary of Progress

In the year since the last report, the fellowship has explored the interaction between a novel nutrient source and the growing media mixes designed in 2014. Substantial progress has been made with dissemination of fellowship results and knowledge (Appendix 1, table A). An international conference was attended in which results were presented orally and a paper produced. This has just been accepted for publication in the Journal *Acta Horticulturae*:

Barrett, G.E., Alexander, P., Nevison, I., Robinson, S. and Bragg, N. (2015). The response of Pelargonium to different growing media and liquid fertilizers – an experimental comparison.

Milestones not being reached

All milestones are being reached, progress is satisfactory.

Do remaining milestones look realistic?

Yes

Training undertaken

January 2015: 'Train the trainer, teaching course'. GrB attended to improve communication and teaching skills

Expertise gained by trainees

- Work carried out this year has been much more focused on growing media chemistry and plant nutrition. GrB has had to acquire knowledge in order to work with a novel nutrient source. This work has included a literature review on biochar and its application in Horticulture.
- Submission of two scientific papers for publication has increased GrB's science writing skills.
- GrB was involved in the selection and interview of a new RHS research assistant. This provided a valuable insight into the RHS recruitment process and a chance to learn effective interview skills and techniques.

Other achievements in the last year not originally in the objectives

- As a condition of the RHS bursary award secured in 2014, GrB was required to write a comprehensive report of the fellowship US study tour which took place in May 2015, detailing aims and outcomes. The report won the RHS annual bursary report award. The report can be viewed here:

  https://www.rhs.org.uk/education-learning/bursaries-grants/rhs-bursaries/bursary-reports

- GrB has continued to develop links with the RHS education department and is in the process of producing a growing media themed workshop for secondary school teachers. Regular assistance is also being provided to the RHS advisory team. This has allowed GrB to develop communication skills with a range of audiences as well as transfer knowledge acquired, to the RHS membership.

Changes to Project

Are the current objectives still appropriate for the Fellowship?

Yes

GROWER SUMMARY

Headline

A Sewage sludge biochar (SSB), showed some potential as an additive when incorporated into a range of soilless growing media mixes. The trial explored the impact of this material on plant performance and whether it could be used as a substitute for a conventional phosphate source.

Background

At the present time, fertilization of container grown plants relies on inputs of base inorganic fertilizer which is then supplemented with either water-soluble fertilizers, applied during irrigation, or controlled release fertilizer (CRFs) granules. Phosphorus (P), is a key component of these fertilizers and is currently sourced exclusively from phosphate rich rocks. Reserves of rock phosphate are finite, declining, and found in only a few places on earth. Rock phosphate deposits are also frequently associated with problematic amounts of heavy metals such as cadmium, which need to be removed and disposed of. The fertilizer industry has long recognised the environmental challenges associated with the processing of rock phosphate, alongside the economic implications of declining and geographically isolated reserves. This alongside the desire to create a more circular and sustainable economy has stimulated an interest in the recovery and re-use of phosphate from waste streams. A recent report by the international fertilizer society highlights the problems with the global P cycle (Kabbe et al., 2015). World-wide, P use efficiency is low, with only about 20% of P in fertilizer ending up incorporated in food crops. The vast majority ends up in various waste streams; the largest of these is municipal wastewater treatment. As a result the grey water and sewage sludge generated from this process have become the focus of considerable interest as a renewable source of P for fertilizer manufacture. Promising new technologies are in development to recover and recycle phosphate deposits such as 'struvite' (magnesium ammonium phosphate), traditionally regarded as a problematic by-product of waste water treatment (Kabbe et al., 2015).

Pyrolysis, a thermal process in which organic materials are heated under oxygen deficient conditions, is an increasingly common way of generating renewable energy. This process also results in a carbon rich waste material known as biochar. The use of sewage sludge as a feed stock material for pyrolysis is well established; the biochars generated from this process have been shown to be an effective source of phosphate in soil based systems (Wang et al., 2012). However, little is known about how well they might work in soilless cultivation. The aim of this work is to assess the suitability of a sewage sludge biochar (SSB) as a growing media additive and renewable source of P for containerized hardy nursery stock.

Given the increasing diversity of component materials now used in professional growing media (to supplement and replace peat), the work also aimed to explore whether the impact of this SSB on plant performance might vary between different growing media types.

Summary

Five growing media mixes based on different proportions of five component materials; coir, garden waste compost (GWC), peat, matured pine bark and wood fibre were made alongside an industry standard (InS) peat-based mix. Mixes were manufactured with advice from a growing media manufacturer and included base fertilizer, horticultural lime, fritted trace elements and wetting agent. Each mix was then amended with either 10, 5, 1 or 0% SSB by volume, and samples of the mixes were characterised to determine the impacts of SSB incorporation on growing media properties. Liners (9cm) of *Viburnum tinus* 'Eve Price' and *Leucanthemum* 'White knight' (both 9cm) where then potted into these mixes (2L and 3L pots respectively) with a P free CRF, so that all additional P was coming from the SSB (where incorporated). A control nursery standard treatment was included for each mix, where SSB was excluded and a combined CRF (18-6-12) was used in place of the P free CRF. Plants were managed according to common commercial practice on a large mypex covered plot (image 1). Irrigation was provided by over-head sprinklers and adjusted according to ambient weather conditions. Plant quality was assessed after 11 weeks for *Leucanthemum* and 20 weeks for *Viburnum* by carrying out a qualitative visual assessment (image 1) in conjunction with quantitative measures of plant growth; shoot dry biomass and plant growth index.

Image 1. Experimental set-up with *Leucanthemum* 'White knight' and *Viburnum tinus* 'Eve Price'. Plants were laid out in randomised blocks with 1 plant from each treatment in each block (7 replicate plants per treatment and 30 treatments, giving a total of 210 plants of each species)

In general the response of both plant species to SSB incorporation was neutral with few clear positive or negative impacts. There was no significant difference in plant quality between those plants receiving the control nursery standard treatment (a combined CRF, no SSB) and those receiving SSB (and a P free CRF). However, there was also no discernable difference in quality between those plants receiving the nursery standard treatment, and those receiving no additional P source (0% SSB and a P free CRF). This would suggest that the overall P requirement of the two plant species tested here was low, and that P present in the growing medium was sufficient to meet demand. This might indicate that the 9cm liners potted into this trial had already achieved sufficient reserves of P at the liner stage, to sustain their growth during finishing in larger containers. The results may also have been influenced by the test plant species chosen. Many plant species have high P efficiency uptake mechanisms (Balemi and Negisho, 2012) and while little information is available on the relative P requirement of the two species investigated here, this may have been a factor driving the responses observed.

This apparent low plant P requirement somewhat negated a full exploration of the efficacy of this particular SSB as a P source in the context of this trial. However, given the 6% P content of the material, it may well be a useful novel fertilizer in other plant production systems. Moreover, the SSB investigated here exhibited other interesting chemical properties which also warrant further investigation. These included an ability to reduce the soluble phosphate concentration of the growing media when incorporated at 10 and 5% by volume. This characteristic may have application in increasing P use efficiency in container grown plants.

Notably, growing media type had a consistent impact on plant quality with both species performing better in some mixes than others regardless of SSB incorporation. This effect was particularly pronounced for *Viburnum* where participants of the visual quality assessment were able to clearly differentiate plants grown in particular mixes. This contradicts the findings of the previous year, where the same growing media mixes had little discernable impact on *Viburnum* performance. The reasons for this rather disparate response between years is uncertain. It may be attributable to more challenging environmental conditions over the course of this experiment relative to the previous one.

Conclusions

- The SSB sourced for use in this trial, may be incorporated into a range of soilless growing media at up to 10% of mix volume, with no detectable impacts on plant quality.
- While the SSB appeared to be an adequate substitute for a CRF containing P, there appeared to be a low overall P requirement in the two plant species tested. This may have been a result of the stage of plant production investigated and the test species selected.
- This highlights the need for consideration of the previous nutrition of plant plugs and liners potted into trials like this one, and a clearer understanding of the relative P requirement of different ornamental plant species.
- Contrary to work carried out in the previous year, growing media type had a strong influence on plant quality. This highlights the importance of testing novel growing media formulations under a range of environmental conditions.
- The SSB used in this trial possessed a number of interesting chemical properties which may be useful to the industry. Further research is recommended with a wider range of SSB materials, plant species and production systems to better understand the possible benefits.

Financial Benefits

The results presented represent a primary investigation into the potential use of one SSB as a growing media additive and source of P. While there are some promising avenues of further research, it is too early to understand the financial implications that might result from uptake of this material by the industry.

Action Points

Further research is required before a novel material like the SSB investigated here can be taken up commercially. However, this work does indicate it may have a useful application as a soilless growing medium component or additive with benefits which might include improved nutrient-use efficiency and nutrient provision.

The work also highlights the problems associated with estimating plant nutrient demand both at different stages of plant production and between different species. Data presented here indicate that the P requirement of some HNS species grown on from established liners or plugs may be low. This might warrant further investigation, as to whether this nutrient can be applied more sparingly going forwards.

SCIENCE SECTION

EXPERIMENT 4: Assessment of a sewage sludge biochar (SSB) as a phosphate (P) source for container grown hardy ornamental plants, in different types of soilless growing media

Introduction

Context of the work within the fellowship project

In previous years, we have investigated the efficacy of a range of growing media made from different component materials. This reflects the increasing diversity of materials being used to supplement or replace peat in professional growing media.

Work in years 2 and 3 of the fellowship showed that fertilizer performance could vary substantially according to the type (coir-, wood fibre-, green compost- or peat-based) of growing media to which it was applied. This indicated that some growing media component materials may offer an unexplored matrix in which novel, more sustainable sources of nutrients may be utilised.

Fourteen bespoke growing media mixes were designed, characterised and trialled in year 2. These mixes are comprised of different proportions of five materials (peat, coir, wood fibre, pine bark and garden waste compost) and exhibited a broad range of physical and chemical properties. The aim of the work described below, was to take a selection of these mixes and investigate how a novel, renewable source of phosphate might perform across a range of different growing media.

Background

Since the 1960's fertilization on container plant nurseries has been based on combinations of base fertilizer (incorporated into the growing media), the application of water soluble fertilizer through the irrigation system (fertigation) and from the 1970's onward the use of resin or polymer coasted granular fertilizers known as controlled release fertilizers (CRFs). Phosphorus (P), is a key component of soluble fertilizers and is derived from phosphate rich-rocks, whose supply is finite. Within Europe, where there are no significant phosphate mines, fertilizer production is dependent on the import of phosphate ore (Schoumans, 2015). In addition, due to its geological nature, rock phosphate is often associated with heavy metals, particularly cadmium (Aydin et al., 2010). The fertilizer industry has long recognised the environmental challenges associated with the processing and recovery of these contaminants alongside the economic implications of declining and geographically isolated rock phosphate resources. The development of more efficient fertilizer delivery technologies (such as CRFs and other slow-release products) has been one approach to addressing these problems. More recently, awareness of P scarcity and the need to create more circular economies has stimulated an interest in the recovery of phosphate from waste streams (Shoumans et al., 2015). World-wide, P efficiency is low with about 20% of the P mined for fertilizer, ending up in food crops. The majority is wasted; in industrial countries like the UK, much of this (about 691 Gg, or 50%) is lost via municipal waste streams (Kabbe et al., 2015). The human digestive system is capable of absorbing only 50-70% of phosphate consumed in food (Gropper et al., 2009). This combined with increasing usage of phosphate rich products (such as detergents) mean municipal grey water and sewage sludge (the by-product of municipal waste water treatment) have the potential to offer substantial and renewable sources of phosphate. Consequently, phosphate deposits such as 'struvite' (ammonium-magnesium-phosphate), which have been historically regarded as a problematic contaminant of waste water processing, are now being investigated as raw materials for fertilizer manufacture (de-Bashan and Bashan, 2004; Kabbe et al., 2015). Similarly the use of phosphate rich sewage sludge as a fertilizer is of interest but the presence of harmful contaminants such as heavy metals, particularly zinc (Hossain et al., 2010) and toxic organic contaminants e.g. polycyclic aromatic hydrocarbons (Stevens et al., 2003) are costly to remove and limit current uptake.

Interestingly, the use of sewage solids for energy capture through pyrolysis is well advanced (Rulkens et al., 2008). This is a thermal process in which the sewage sludge is heated under oxygen deficient conditions to produce energy and a carbonaceous residue referred to as biochar. Sewage sludge biochar (SSB), may be a useful raw material for fertilizer production because the pyrolysis process concentrates plant nutrients such as P, while reducing the bioavaibility of heavy metals and other toxic elements (Zhang et al., 2015). Whilst current understanding of the impacts of SSB on plant nutrition are extremely limited, biochars made from other nutrient rich feed-stocks such as green-waste and poultry manure have shown fertilizer potential in soil-based studies (Chan et al., 2008; Hossain et al., 2010). More specifically, biochars made from dairy manure and waste-water treatment solids have been shown to be an effective source of plant available phosphate (Wang et al. 2012).

While the use of biochars in soilless cultivation has not been widely investigated (Altland and Locke, 2013), there is some evidence in the literature that they may impact positively on plant growth in this context. Benefits vary with biochar type but include nutrient provision (Ruamrungsri et al., 2011; Atland and Locke, 2012), reductions in the leaching rate of phosphates and nitrates (Beck et al., 2011), beneficial shifts in microbial populations (Graber et al., 2010) and improved physical properties such as moisture retention (Dumroese et al., 2011).

Table 1. The pH and macronutrient content (N, P and K) of biochars made from a number of feedstock materials. Biochars derived from municipal sewage sludge (also referred to as wastewater sludge or biosolids) have a typically higher phosphate content than those made from other waste material feedstocks (e.g. manure, or wood). In some of the studies referenced here, the same feedstock materials have been subjected to different pyrolysis temperatures. These are noted in brackets and have an important influence on biochar nutrient content. The sewage sludge biochar (SSB) used in this study is included at the top of the table for comparison. nr indicates where values have not been given in the referenced studies.

Biochar Feedstock	pH	N	P	K	Reference
		%	%	%	
Municipal waste water					
Sewage Sludge	***9.9***	***2.3***	***6.2***	***0.5***	***This Study***
Wastewater Sludge	8.2	2.3	0.11	nr	Hossain et al., 2010
Biosolids (250°C-550°C)	5.6-8	1.8-1.9	3-5.6	nr	Wang et al., 2012
Sewage Sludge (300-600°C)	nr	3.4-5.4	4.3-6	0.2-0.3	Lu et al., 2013
Sewage Sludge (300-600°C)	nr	2-3.4	3-3.6	0.2-0.3	Lu et al., 2013
Sewage Sludge (300-600°C)	nr	2.7-4.4	3.3-4.1	0.2	Lu et al., 2013
Sewage Sludge (300 & 800°C)	5.6 & 6.6	5.5 & 3.4	nr	nr	Yachigo & Sato, 2014
Sewage Sludge	7.3-7.5	2.8	nr	nr	Waqas et al., 2014
Other wastes					
Dairy manure (250°C-450°C)	6.6-10.5	1.4-1.8	0.8-0.4	nr	Wang et al., 2012
Rice Hulls	10.5	0.18	0.3	0.98	Altland & Locke, 2013[a]
Sawdust	nr	0.2	0.07	0.5	Altland & Locke, 2013[b]
Bark and Wood	nr	0.52	0.03	0.34	Altland & Locke, 2013[b]

As shown in table 1, chemical properties of biochar such as nutrient content vary widely, according to the feedstock material and to the thermal conditions of the pyrolysis process. Due to the phosphate rich nature of municipal sewage sludge, biochars derived from this material tend to be higher in P than those made from other waste feedstock (such as animal manures). The SSB selected for use in this study had a particularly high phosphate content (*c.* 6%), which indicated that it might form a suitable basis for a P fertilizer.

The aim of this work was then, to investigate the potential of this SSB to replace a CRF source of P in container grown hardy nursery stock (HNS). Where possible, UK industry standard practices were followed so that a realistic assessment could be made of whether such a material might be appropriate for use on ornamental nurseries. This included a determination of whether the SSB interacted differently with different organic growing media. The research aimed to address three objectives:

1. Determine whether SSB can be used as an effective P source for container grown HNS
2. Determine whether the effect of the SSB varies between growing media made from different component materials
3. Perform a preliminary characterisation of the SSB to determine its suitability as an additive for soilless growing media

Materials and methods

Sewage Sludge Biochar (SSB)

The sewage sludge biochar (SSB) was supplied by a regional water company and sourced from their local waste water treatment plant. Dried sewage sludge was subjected to flash (heated rapidly) pyrolysis at 850°C with a retention time of 2 minutes at just above atmospheric pressure. The process was highly controlled and able to generate a large volume of consistent material. A preliminary physical and chemical characterisation of the material was undertaken following British Standard methods (table 2). Due to the chemical transformation of base cations into oxides, hydroxides and carbonates during pyrolysis, many biochars have an intrinsic liming effect. To determine the extent of this effect, the neutralising capacity of the SSB was determined using a titration method (AOAC, 1975). The results were expressed as calcium carbonate equivalent (% CCE) and effective neutralising value (ENV %). The ENV accounts for the fineness of the material by using the particle size distribution – the finer the material, the more effective it will be at neutralising acidity.

Table 2. Physical and chemical properties measured and standard method used for characterisation of the five raw materials and SSB.

*EC was measured at a dilution factor of 1:5

Physical properties	**Standard Method**
Compacted fresh bulk density (Kg m^3)	BS EN 13040:2007
Dry bulk density (Kg m^3)	BS EN 13041:2011
Organic matter (%)	BS EN 13041:2011
Chemical Properties	**Standard Method**
pH	BS EN 13037:2011
Electrical Conductivity (EC)*	BS EN 13038:2011
Plant available (water soluble) nutrients	BS EN 13652:2001

Growing Media

As detailed in last year's report (*link*), a range of 'Fellowship' growing media have been previously designed and tested in a previous experiment. Briefly, five commonly used materials (peat, pine bark, wood fibre, coir and garden waste compost) were combined in various proportions to produce 14 bespoke growing media mixes. The physical and chemical properties of these mixes were measured and their performance assessed with two commonly grown HNS plant species *Hebe albicans* 'Red Edge' and *Viburnum tinus* 'French white. All 14 of these mixes produced plants of acceptable quality.

For this experiment five of the best performing mixes; 1, 2, 7, 15 and 16 (figure 1), were selected and manufactured in exactly the same way as in the previous year. To make them, four professional raw materials were obtained from the same supplier:

- Irish sphagnum peat (graded to 18mm).
- Coir from Sri Lanka (washed and pre-treated (or 'buffered') with calcium nitrate to displace phytotoxic concentrations of sodium and potassium).
- Mature (aged) potting grade pine bark (a mixture of particle sizes from 3-15mm).
- Wood fibre (comprised of machine extruded pine chips compensated with additional nitrogen)

As in 2014, garden waste compost (GWC) was sourced from the composting site at RHS garden Wisley and screened to 20mm (details provided in 2015 report).

The chemical and physical properties of the five component materials were measured using British Standard methods (table 2). In order to establish the consistency of the growing media between years, these values were then compared to those obtained in 2014.

The five selected mixes and a peat-based industry standard (InS) mix for HNS (figure 1) were manufactured using a cement mixer. Each mix was produced in four batches which contained either 10, 5, 1 or 0% SSB by volume. Base fertilizer, fritted trace elements (vitreous enamel powder containing a rage of trace elements) and wetting agents were applied at industry standard rates, following the protocol designed for the 2014 experiment. Lime was applied where necessary to bring pH into acceptable range. Supplemental calcium nitrate was incorporated at varying rates to compensate for possible microbial uptake of nitrogen (based on the work of Scott, 1986 and summarised by Pennell, 2013). Once manufactured, the growing media were transferred to porous bags and used within 1 week of manufacture. A one litre representative sample was taken from all bagged mixes for physical and chemical characterisation (table 2).

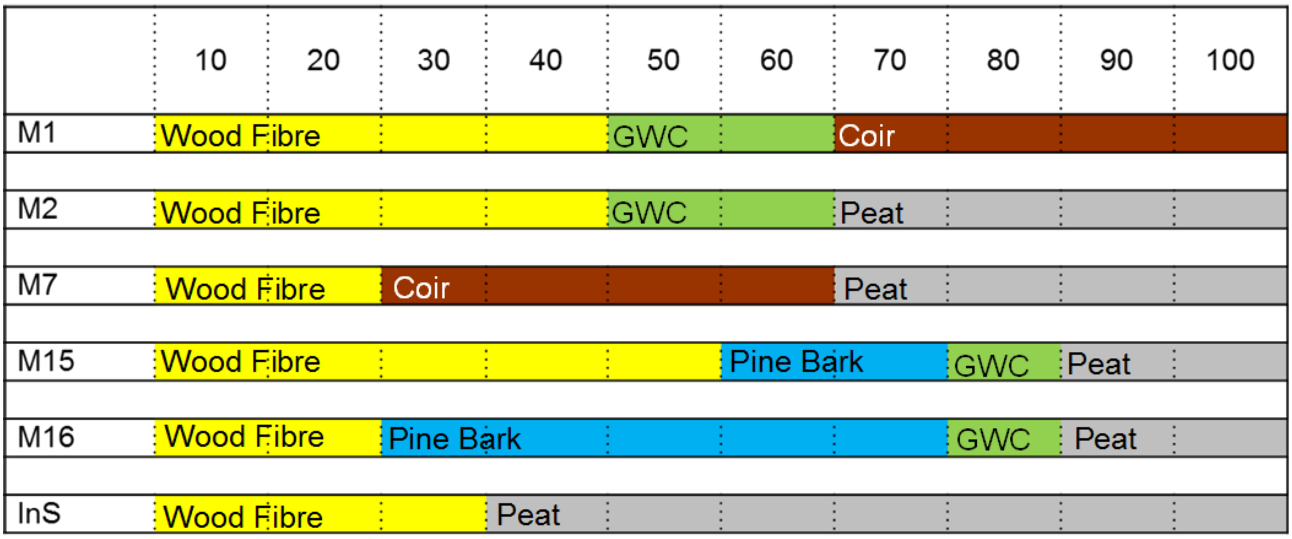

Figure 1. Composition of the 5 bespoke growing media mixes and the industry standard (InS) mix. Mixes are based on different proportions of five raw materials; coir, garden waste compost (GWC), peat, mature pine bark and wood fibre

SSB application rates

To investigate the extent to which SSB could replace a CRF form of P, three different rates of SSB; 10, 5, and 1%; were used to replace a standard combined CRF (18-6-12). All other macro and micro nutrients were provided at nursery standard rates (as advised by a professional grower), by using two P free CRFs; one containing just N and K (12 and 43% respectively) and one containing just N (at 43%). Two control treatments were included, the first a nursery standard, which contained the CRF (18-6-12) with no biochar (application rate of 0.4g/L for *Viburnum* and 4.5g/L for *Leucanthemum* as advised by a professional grower). The second contained the P free CRFs and no biochar (0% SSB). This treatment was designed to elucidate whether any serious deficiency would arise in the absence of either SSB or a CRF form of P. For each of the 6 growing media detailed above, five P treatments were established (giving a total of 30 growing media x P treatment combinations):

1. 10% SSB – no additional P, all other nutrients at industry standard rates
2. 5% SSB – no additional P, all other nutrients at industry standard rates
3. 1% SSB – no additional P, all other nutrients at industry standard rates
4. 0% SSB – no additional P source, all other nutrients at industry standard rates
5. Nursery standard – No SSB and a combined CRF (18-6-12)

Experimental design and set-up

Uniformly trimmed 9cm liners of the woody species *Viburnum tinus* 'Eve Price' were potted into all six media mix and five SSB combinations. Two-litre black plastic pots were half filled with growing media, the appropriate combination and amount of CRF was then dibbled into the pot before placement of the liner and infilling. The plants were placed on a mypex covered field plot, in seven randomised blocks of 30 plants. Each block contained 1 randomly allocated replicate plant from the 30 established treatments (7 replicate plants per treatment). The same process was repeated for the second HNS test species, a fast growing herbaceous species *Leucanthemum* 'White Knight'. Experimental conditions for both plant types were the same except that the *Leucanthemum* were potted into 3L pots and CRF application rate was 0.5g/l higher (as detailed above). The entire experimental set-up comprised 14 blocks of 30 plants, giving a total of 420 plants.

Plant management followed the protocol established in the previous year; briefly rainfall was supplemented with over-head sprinklers (optimised according to AHDB Horticulture, 2005: Factsheet 16/05). Irrigation application varied according to ambient weather conditions (60 minute irrigation periods once or twice a day as required). All plants were watered according to the requirements of the plants in the InS mix which were monitored with a moisture probe (Delta-T WET-sensor). Large weeds were removed from pots monthly and pest and disease inspections were made weekly. The plant growth index (GI) of all plants was measured every six weeks (plant height x widest plant width x perpendicular plant width). The time of first flowering and then flower number was recorded weekly for *Viburnum*. *Leucanthemum* commenced flowering prior to experimental set-up, thus flower counts were not deemed worthwhile.

Plant Quality assessment

The *Leucanthemum* were harvested after 14 weeks at which time growth rate had reduced and the plants were deemed to be of 'saleable' quality (established in consultation with a professional grower). *Viburnum* were harvested after 27 weeks to replicate the *c.* 6 month retention time for this plant on commercial UK nurseries. Prior to harvest a final GI measurement was taken of all plants. Both species were then subject to a visual quality assessment by a group of amateur growers (20 assessors for the *Leucanthemum*, 24/08/15; 18 for the *Viburnum*, 19/10/15). Each assessor was asked to score every plant in the experiment on a scale of 1-5 according to whether they would purchase them at garden centre, 1 being the worst possible quality and 5 being the very best. Plants scoring 3 and above were perceived to be worthy of purchase. Example plants representative of each of the 5 quality categories were displayed to guide the assessors, with leaf colour, canopy cover and flower number all used as indicators of quality (Appendix 2, figure A). Plants were then destructively harvested, oven dried at 60°C for 48 hours and dry shoot biomass recorded.

Data Analysis

Analysis of both growing media and plant quality data is still ongoing at the time of writing but preliminary results are described below. Plant quality data (growth index, shoot dry biomass and visual quality scores) were transformed as required and a two-way analysis of variance (ANOVA) was performed using growing media type and SSB incorporation as the two treatment terms (GenStat, Edition 10). One *Viburnum* plant died (mix 1, 5% SSB), this was early on in the experiment and attributed to a random incident of disease, rather than any experimental condition.

Physical and chemical characterisation of the InS mix and mix 1 at all levels of SSB incorporation (10, 5, 1 and 0%) has been included (further characterisation data will be added when available). All data are displayed as untransformed as means.

Results

Physical and chemical properties of organic growing media components

The key physical and chemical properties of all 5 growing media components are displayed in table 3 and 4, with comparative values taken from the 2014 experimental work. Raw material components were generally very similar between years, the most variable chemically tended to be the pine bark with electrical conductivity values in 2015, half of what they were in 2014 (table 3). The inverse was true of pH which increased from 4 in 2014 to nearly 5 in 2015. The main difference in macronutrient content between years was exhibited by peat, where soluble nitrate (NO_3-) concentration was around 50% lower in 2014 than 2015 (table 4). The opposite was true for soluble ammonium (NH_4+) concentration (table 4a). Similarly both the coir and GWC contained notably more soluble ammonium in 2014 (table 4). Soluble micronutrients contents were generally similar between years for all materials (Appendix 3, table B).

Table 3. Key physical and chemical properties of the five organic growing media components (coir, GWC (garden waste compost), peat, pine bark and wood fibre) used in the 2014 and 2015 experimental work. These are compacted fresh bulk density (CFBD, kg m^3), dry bulk density (DBD, kg m^3), electrical conductivity (µS/cm) and pH. Data were obtained from 1 representative sample of each raw material.

	CFBD		DBD		EC		pH	
	kg m^3		kg m^3		µS cm			
	2014	2015	2014	2015	2014	2015	2014	2015
Coir	377	415	73.8	68.5	157.2	101	6.6	6.6
GWC	856.3	761.7	137.8	358.7	438.3	518.7	8.6	8.7
Peat	351	362	156.9	150.2	40.8	46	4.4	4.0
Pine Bark	290	294	168.7	178.2	100.8	51	4.0	4.9
Wood Fibre	144	130	73.2	59.3	9.6	17	4.4	4.6

Table 4. Water soluble macro nutrient content (mg/l) of the organic growing media components coir, garden waste compost (GWC), peat, pine bark and wood fibre) used in the 2014 and 2015 experimental work. Data were obtained from 1 representative sample of each raw material.

	NO_3^-		NH_4^+		P		K	
	mg/l		mg/l		mg/l		mg/l	
	2014	2015	2014	2015	2014	2015	2014	2015
Coir	1.3	<0.6	21.9	4.4	4.6	3.7	140.5	89.1
GWC	14.7	18.6	57.3	12.6	36.1	21.8	685.7	810.8
Peat	1.9	4.2	17.6	8.7	< 0.6	<1	1.1	2.1
Pine Bark	<0.6	<0.6	11.3	3.6	9.5	14.7	11.6	55.9
Wood Fibre	<0.6	<0.6	5.9	1.2	< 0.6	1.4	2.8	8.2

Physical and chemical properties of the SSB

The physical properties of the SSB are displayed in table 5 and show that the particle size distribution of the material was fairly homogenous with most particles falling into the range 150µm - 3.35mm. As predicted, the material did have some neutralising capacity with a calcium carbonate equivalence (CCE) of 23%, and an effective neutralising value (ENV) of 13.1% (table 6). Chemically the SSB was alkaline with a pH of nearly 10, and an EC of *c.* 2000 µS/cm (table 6). The values for water soluble macronutrients (table 6) were low compared with the total nutrient content of the material, particularly for soluble P. This suggested that a relatively low proportion of the P content of the material may have been immediately available to the plants. Soluble micronutrient content of the SSB is displayed in table 7; most notably, it was very high in soluble calcium (Ca), chloride (Cl) and sulphate (SO_4). Soluble magnesium (Mg) and sodium (Na) were also present in significant concentrations although of several orders of magnitude lower.

Table 5. Key physical properties of the SSB. Shown are compacted fresh bulk density (CFBD, kg m^3), dry bulk density (DBD, kg m^3) and particle size distribution (PSD) from less than 150µm to more than 6.3mm. Data were obtained from 1 representative sample.

		Particle Size Distribution				
CFBD	DBD	< 150µm	150µm-3.35mm	3.35-5.0mm	5.0-6.3mm	> 6.3mm
kg/m^3	kg/m^3	%	%	%	%	%
517	506.7	4.7	92.4	2.6	0.1	0.2

Table 6. Key chemical properties of the SSB. These are calcium carbonate equivalent (CCE %), effective neutralising value (ENV %), electrical conductivity (µS/cm), pH and water soluble macronutrients N (as ammonium and nitrate), P and K (mg/l). Data were obtained from 1 representative sample.

**For comparison, horticultural lime comprised of dolomitic limestone has a CCE of c. 100-110%*

*CCE	ENV	EC	pH	NO_3^-	NH_4^+	P	K
%	%	µS/cm		mg/l	mg/l	mg/l	mg/l
23	13.1	1982	9.9	BDL	9.7	< 1	76.2

Table 7. Soluble micronutrient content (mg/l) of the SSB. Data were obtained from 1 representative sample.

Ca	Mg	Na	Cl	SO_4	B	Cu	Mn	Zn	Fe
mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
2492.7	66.1	74.1	1159.5	4554.5	1.78	<0.01	0.05	<0.02	<0.05

Physical and chemical characteristics of growing media at the start of the experiment

Table 8 summarises the impact of the SSB on the physical and chemical properties of the InS mix and mix 1 (analysis on the other 4 growing media mixes is still ongoing). In general, mixes containing 1% SSB were very similar to those containing 0%, suggesting inclusion at this volume was of little consequence to growing media properties. Incorporation of the SSB had little impact on fresh bulk density in either mix, but it did increase dry bulk density, particularly when added to the InS mix (table 8). When incorporated into mix 1, SSB had a negligible impact on pH even at the 10% rate. In contrast, when added to the InS mix, there was evidence that it increased the pH at the 10% incorporation rate, with a lesser impact at 5% (table 8). There was also evidence in both mixes that the incorporation of higher rates of SSB reduced the concentration of soluble P. For mix 1, mean soluble P concentration was 3x lower when 10% SSB was incorporated into the mix compared with where it was omitted. An even larger reduction in soluble P was apparent in the InS mix, with the incorporation of 10% SSB reducing soluble P concentration by about 4x compared with where it was omitted (table 8). For mix 1 there was also a marked reduction in soluble ammonium concentration at the 5 and 10% SSB incorporation rates. This was as much as 5x times less when 10% SSB was included in the mix relative to where it was omitted. The impact of SSB incorporation on the other soluble macronutrients was less marked (table 8).

Table 8. Impact of SSB incorporation (at 10, 5, 1 and 0% by volume) on physical and chemical properties of the growing media mixes 1 and InS. Data are displayed for compacted fresh bulk density (CFBD, kg m^3), dry bulk density (DBD, kg m^3), electrical conductivity (µS/cm), pH and the water soluble macronutrient concentration of nitrate (NO_3^-), ammonium (NH_4^+), phosphate (P) and potassium (K) (mg/l). Data were obtained from 1 representative sample of each growing media x SSB combination.

Mix	SSB %	CFBD	DBD	pH	NO_3^-	NH_4^+	P	K
		kg/m^3	kg/m^3		mg/l	mg/l	mg/l	mg/l
1	10	417	196.8	7	326.4	12.3	15.9	845.3
1	5	392	168.6	6.8	323.6	14.6	19.2	849.3
1	1	409	162.8	7.1	345.3	107.8	36.9	915.9
1	0	411	157.8	6.9	302.4	77.2	46.8	870.5
InS	10	368	191.4	6.2	181.4	65.7	15.8	246.6
InS	5	361	173.3	5.4	191.4	57.3	24.4	222.4
InS	1	364	166.7	5	209	77.3	43.8	213.1
InS	0	334	146.3	5	221.2	83.3	65.2	213.5

Table 9 shows that SSB had an impact on the concentration of some soluble micronutrients, most obviously increasing base cation concentration at the 10 and 5% incorporation rates in both mixes. This effect was most pronounced in mix 1, where the incorporation of 10% SSB increased soluble calcium concentration by more than three times and magnesium concentration by more than 4 times. In the InS mix, where 10% SSB was added the concentration of soluble calcium and magnesium was more than doubled compared with where it was omitted. SSB incorporation at the two higher rates had a less pronounced impact on soluble sodium concentration but substantially increased sulphate and chloride concentration. This was particularly evident in the InS mix, where the addition of 10% SSB led to a large increase in soluble chloride (9 times higher than where it was omitted).

Table 9. Impact of SSB incorporation rate (10, 5, 1 and 0%) on the soluble concentration of the micronutrients (mg/l) calcium (Ca), magnesium (Mg), sodium (Na), chloride (Cl), Sulphate (SO_4), Boron (B), Copper (Cu), Manganese (Mn), zinc (Zn) and iron (Fe) in the growing media mixes 1 and InS. Data are obtained from 1 representative sample of each growing media x SSB combination.

Mix	SSB %	Ca	Mg	Na	Cl	SO_4	B	Cu	Mn	Zn	Fe
		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
1	10	305.6	166.8	111.7	314.3	1055.2	0.23	0.1	0.08	1.28	0.68
1	5	265.9	120	101.4	247.4	820.3	0.24	0.11	0.08	1.19	0.68
1	1	120.3	50.2	91	219.4	527.5	0.23	0.13	0.09	1.3	0.95
1	0	100.2	37.1	81.7	186.6	417.8	0.22	0.13	0.15	1.24	1
InS	10	281.9	176.6	64.9	179.7	1031.8	0.24	0.12	0.75	0.69	0.85
InS	5	194.8	135.1	53.2	109.5	718.1	0.23	0.09	0.76	0.3	0.94
InS	1	128.5	87.6	40.9	43.2	394.6	0.23	0.08	0.77	0.17	1.32
InS	0	130.1	83.4	36.1	18.7	349.9	0.23	0.08	0.78	0.14	1.27

Summary of material characterisation (SSB and growing media components)

- There was consistency in the physical and chemical properties of the growing media component materials between 2014 and 2015.
- SSB was a strongly alkaline material, with a low concentration of soluble nitrogen and phosphorus and a high concentration of soluble calcium, chloride and sulphate.
- Analysis on the InS mix and mix 1 suggests that SSB incorporation at the 10 and 5% by volume influences the physical and chemical properties of these growing media; but has negligible impact at 1%.
- The analysis indicated that SSB incorporation rate at 10 and 5% increased the pH of the InS mix but not mix 1.
- SSB incorporation at 10 and 5% decreased the concentration of water soluble P considerably in both mixes, and water soluble ammonium concentration in the InS mix.

- SSB at the 10 and 5% rate substantially increased the concentration of soluble base cations (particularly calcium and magnesium), chloride and sulphate in both growing media.

Impacts of SSB incorporation and growing media on plant quality

In general, the response to SSB incorporation for both *Leucanthemum* and *Viburnum* was neutral with no obvious signs of plant stress within any of the treatments. In contrast, growing media mix did have a consistent impact on all plant quality measures, with mix 2 producing the best quality plants in both plant species. All 5 fellowship formulations performed as well as the peat-based industry standard (InS) mix for both plant types.

Shoot dry biomass

SSB incorporation impacted on *Leucanthemum* shoot biomass (P<0.001), as displayed in fig. 2, the significant difference was between the 10% and 5% SSB treatments. In real terms, the difference in mean dry biomass between these treatments was small (about 3.7g) and all other SSB treatments produced similar shoot dry biomass.

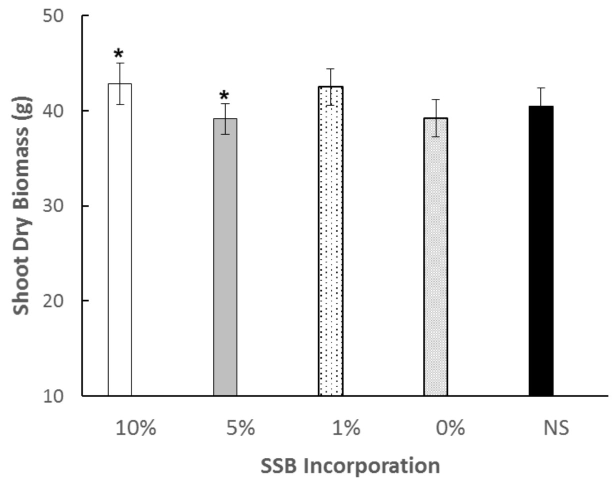

Figure 2. The impact of SSB incorporation (10, 5, 1, 0% and NS; nursery standard) on mean *Leucanthemum* shoot dry biomass. Significant differences between the 5 SSB treatments are indicated with asterisks. Data are mean values ± 95% confidence interval and *n*=42.

For *Leucanthemum*, there was no evidence of any interaction between the SSB treatment applied and growing media type suggesting that the effect of SSB incorporation was similar across all 6 growing media types (figure 3).

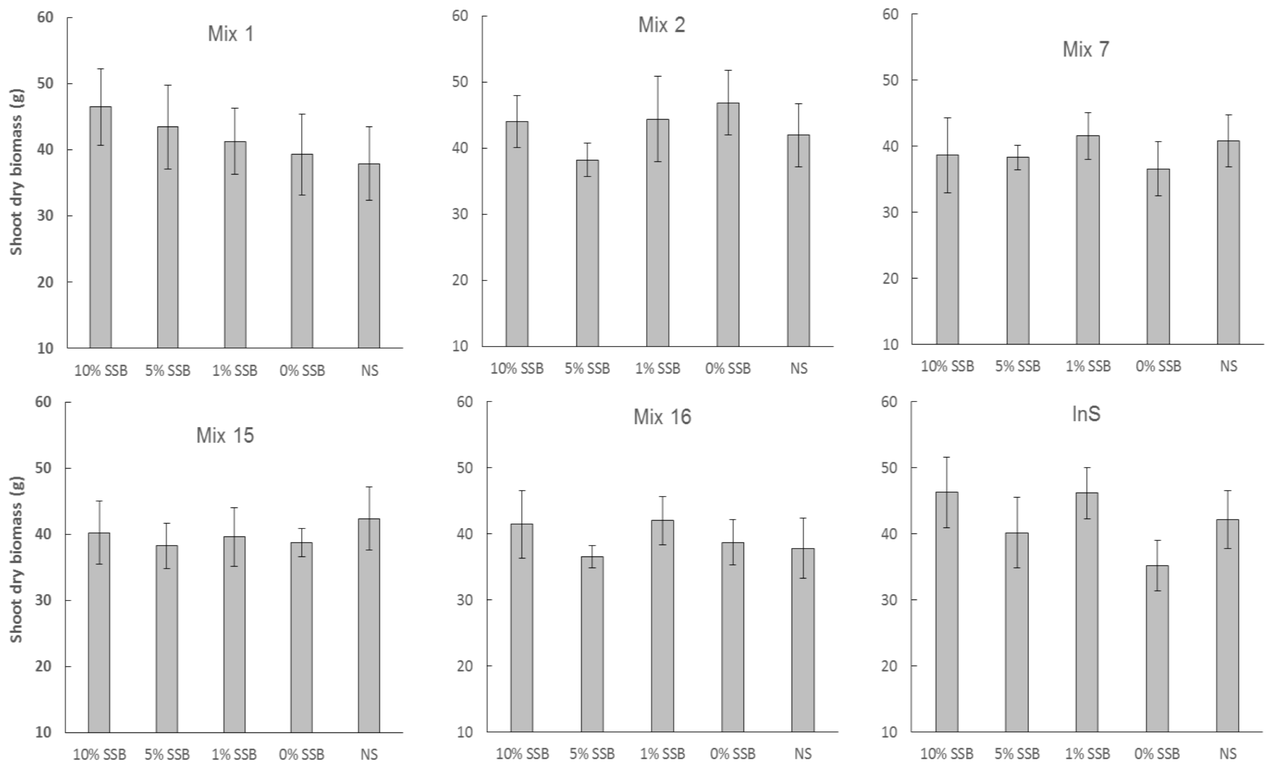

Figure 3. Mean *Leucanthemum* shoot dry biomass (g) for each growing media type (mix 1, 2, 7, 15, 16 or the InS mix) according to SSB application rate (10, 5, 1, 0 and NS; nursery standard). Means are presented with ± 95% confidence interval and *n*=7, excepting mix 1, 5% SSB where *n* =6.

In contrast, there was no significant effect of SSB treatment on *Viburnum* shoot dry biomass. However, a significant interaction (P=0.030) between growing media type and SSB incorporation, suggested that it may have had some influence on the relative performance of plants growing in different growing media (figure 2). While mixes 15, 16 and InS tended to produce a similar shoot dry biomass regardless of the SSB incorporation rate, the shoot dry biomass of plants grown in mixes 2 and 7 showed some differences between SSB application rates (figure 4).

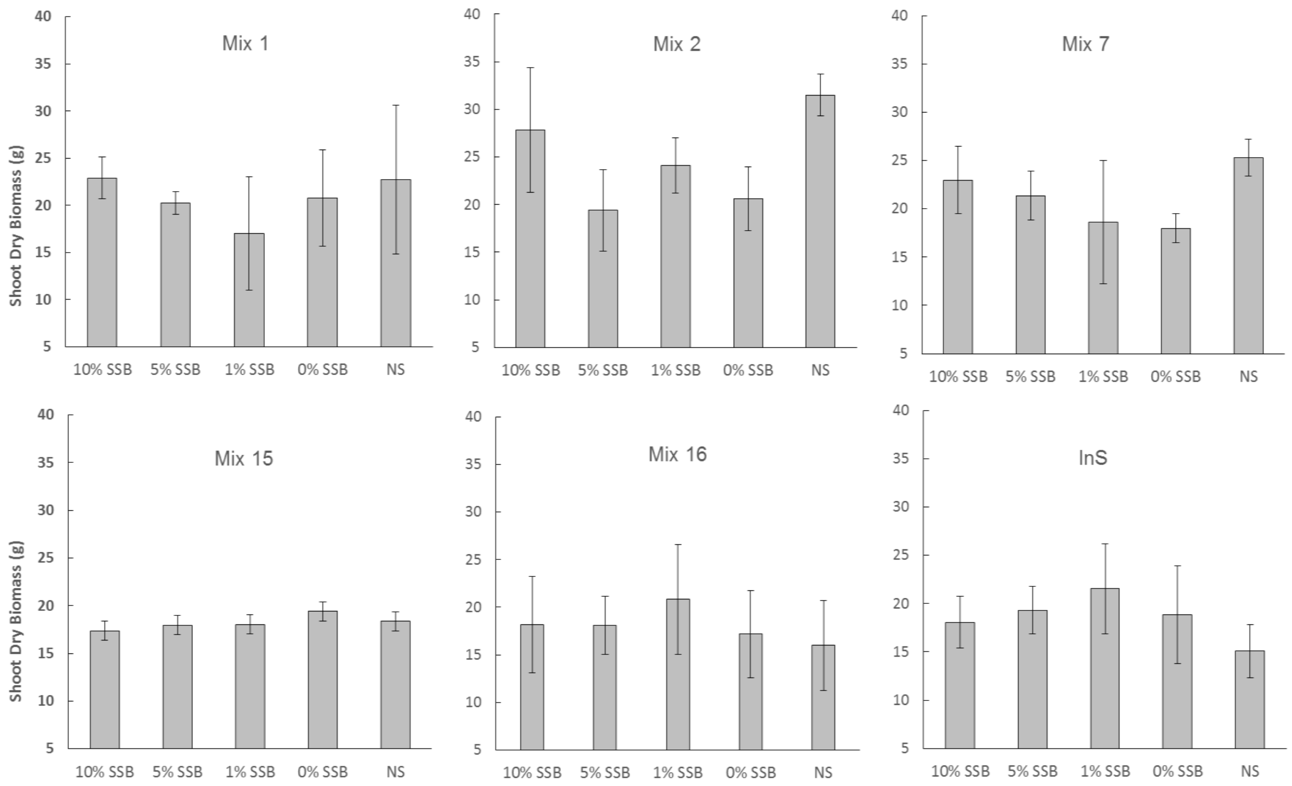

Figure 4. Mean *Viburnum* shoot dry biomass (g) for each growing media type (mix 1, 2, 7, 15, 16 or the InS mix) according to SSB application rate (10, 5, 1, 0 and NS; nursery standard). Means are presented with ± 95% confidence interval and *n*=7, excepting mix 1, 5% SSB where *n* =6.

Growing media type had a strong effect on the shoot biomass of *Viburnum* (P<0.001) and a lesser one on *Leucanthemum* (P<0.05). For *Viburnum* plants grown in mix 2, plants had a significantly higher shoot dry biomass than those grown mixes 15 and 16 (figure 5a). These differences amounted to plants grown in mix 2, accumulating on average around 6g more shoot biomass than those grown in mixes 15 and 16. For *Leucanthemum*, mix 2 also produced plants with the highest mean shoot biomass although this was only significantly different from plants grown in mixes 7 and 16 (figure 5b). The differences in mean biomass between the best and worst performing mixes were smaller for this plant species (3.9 and 3.8g for mixes 16 and 7 respectively).

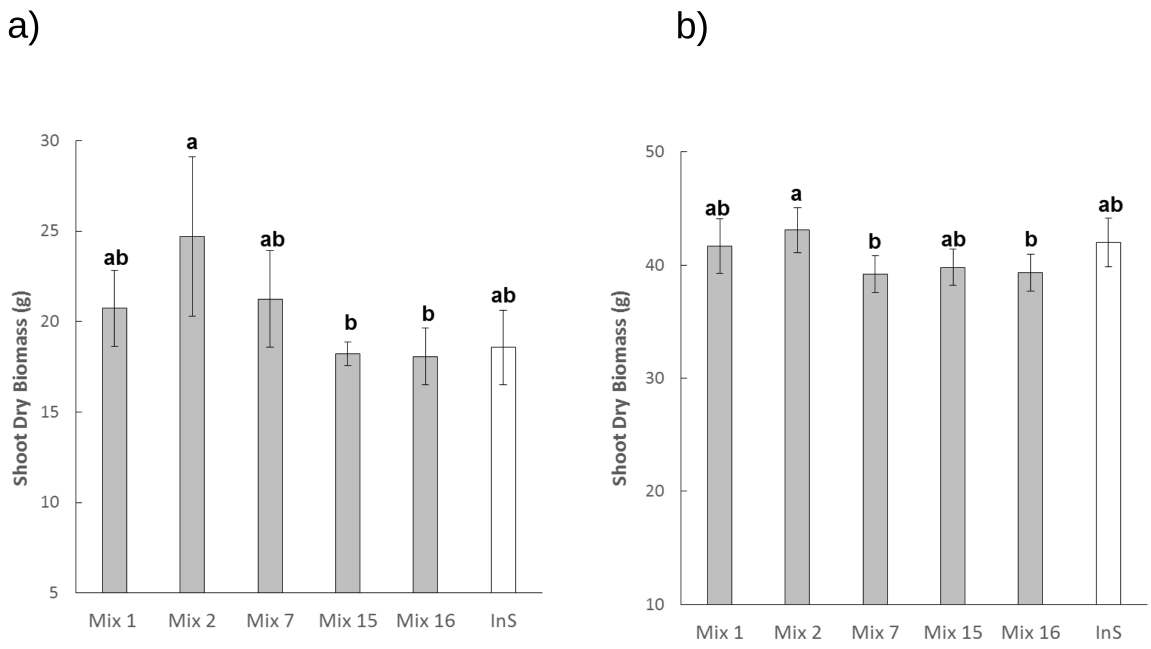

Figure 5. Shoot dry biomass means (g) for a) *Viburnum* and b) *Leucanthemum* grown in the 6 different growing media types; the industry standard (InS) mix is highlighted as an unfilled bar. Significant differences between treatments are denoted with letters. Mean values are displayed ± 95% confidence interval, *n*=42, excepting for *Viburnum* grown in mix 1, where *n* =41.

Growth Index

For both plant species, SSB incorporation had little impact on plant growth index (data not shown). For *Leucanthemum*, growing media type also had little impact on this measure (fig. 6a) with plants in all mixes having a fairly similar mean growth index. In contrast, growing media type had a strong effect ($P<0.001$) on the growth index of *Viburnum* plants (fig 6b). Mix 2 had the highest mean growth index (20082cm^3) compared with plants grown in mix 15 (11441cm^3), 16 (11565 cm^3) and the InS mix (13778cm^3) which were significantly smaller (figure 6b). For both plant species there was no statistical evidence of an interaction suggesting that the impact of the SSB incorporation on plant growth index was the same across all media types.

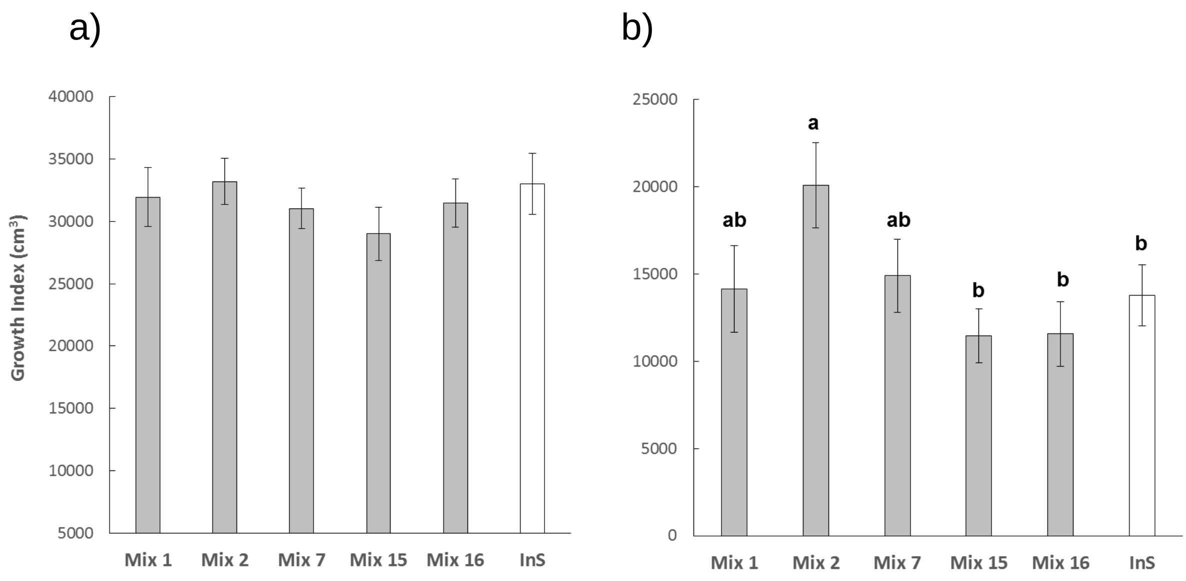

Figure 6. Mean growth index (cm^3) of a) *Leucanthemum* and b) *Viburnum* in the six different growing media types. Differences between mixes are denoted with letters. Means are presented with ± 95% confidence interval and *n*=42, except mix 1, Viburnum where *n* =41.

Visual Assessment

Participants of the visual quality assessments were generally able to detect differences in plant quality between growing media types (especially for *Viburnum*). In contrast, there was no statistical evidence that assessors were able to differentiate between SSB incorporation treatments for either *Leucanthemum* (figure 7) or *Viburnum* (figure 8). There was also no evidence of a significant interaction for either plant species suggesting that SSB incorporation had a similar impact on perceived visual quality across all growing media types.

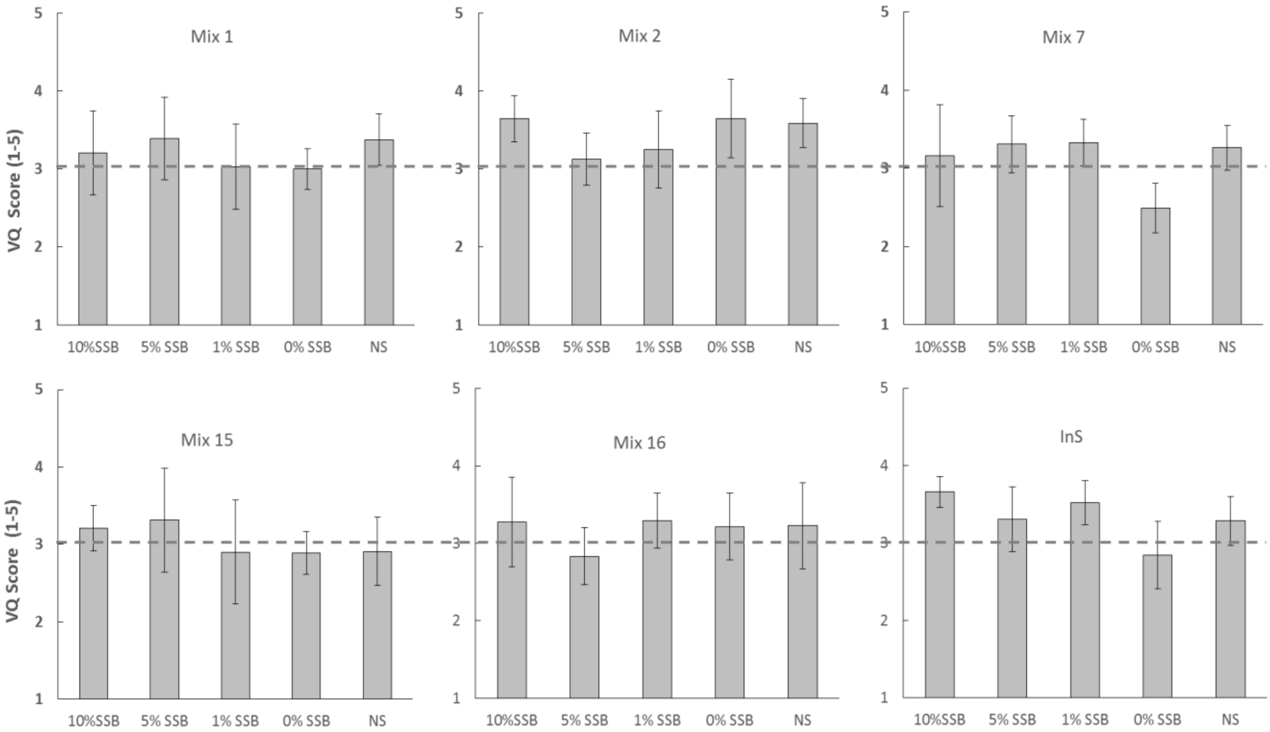

Figure 7. Mean *Leucanthemum* visual quality (VQ) score (1-5) in each growing media type (mix 1, 2, 7, 15, 16 or the InS mix) according to SSB incorporation treatment (10, 5, 1, 0 and NS; nursery standard). Plants were ranked for quality on a scale of 1-5, 1 being the worst and 5 being the best, a score of 3 (denoted with a dashed line on the graph) indicates saleable quality. Means are presented with ± 95% confidence interval and *n*=7.

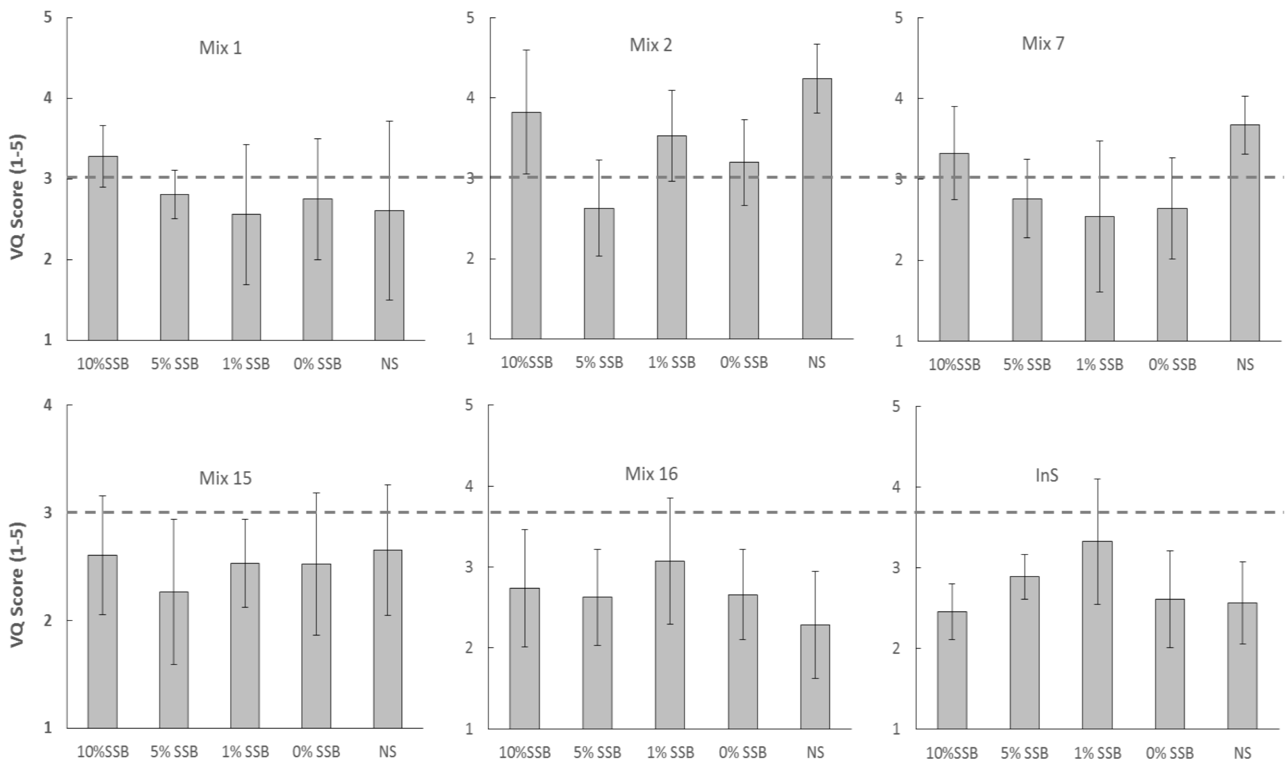

Figure 8. Mean *Viburnum* visual quality (VQ) score (1-5) in each growing media type (mix 1, 2, 7, 15, 16 or the InS mix) according to SSB incorporation treatment (10, 5, 1, 0 and NS; nursery standard). Plants were ranked for quality on a scale of 1-5, 1 being the worst and 5 being the best, a score of 3 (denoted with a dashed line on the graph) indicates saleable quality. Means are presented with ± 95% confidence interval and *n*=7, excepting mix 1, Viburnum where *n* =6.

Mean visual quality scores for each growing media type, are displayed in figure 9 and show that for *Leucanthemum* (figure 9a) plants grown in all media mixes achieved on average, a saleable quality score of 3 or more (the difference between the best and worst performing mix was only about 0.4). Growing media mix had a significant effect (P=0.048) on mean visual score with plants grown in mix 2 scoring better than those grown in mix 15; however many of the assessors noted that all plants appeared of equally good quality and consistency.

For *Viburnum* (figure 9b) mean visual scores were more variable, ranging from 2.5 for plants grown in Mix 15 to 3.5 for plants grown in Mix 2. For these plants, participants were able to identify a clear and pronounced impact of growing media type on plant quality. Plants grown in mix 2 scored particularly well, and significantly better (P<0.001) than those grown in mixes 1, 15, 16 and most notably the industry standard (InS) mix (figure 10).

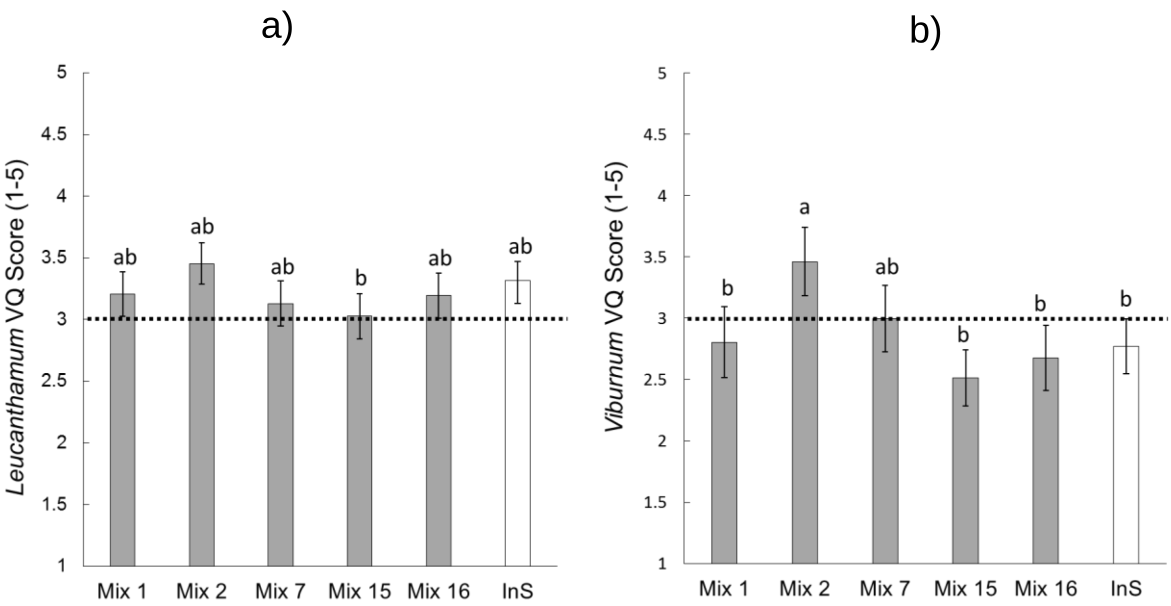

Figure 9. Mean visual quality (VQ) score (1-5) for a) *Viburnum* and b) *Leucanthemum* in the 6 different growing media types. Plants were ranked for quality on a scale of 1-5, 1 being the worst and 5 being the best, a score of 3 (denoted line on the graph) indicates saleable quality. Significant differences between mixes are denoted with letters. Means are presented with ± 95% confidence interval and *n*=42, excepting mix 1, viburnum where *n* =41.

Figure 10. The clear difference in visual quality between plants grown in different growing media types. Both plants were grown without SSB (0%) and with a nursery standard CRF source of P (only difference was the growing media mix). The plant on the left was grown in the Industry standard mix (InS) and deemed to be of very poor and unmarketable quality (1). The plant on the right was grown in mix 2 and deemed to be of excellent quality (5).

Summary

- There was some statistical evidence that SSB incorporation influenced *Leucanthemum* shoot dry biomass; plants receiving 10% SSB had a larger mean mass than those receiving 5%.
- There was also some evidence that the effect of SSB incorporation on *Viburnum* shoot dry biomass may have varied according to growing media type. Plants grown in mixes 2 and 7 were more variable between SSB incorporation rates than those grown in other mixes.
- However, these effects of SSB incorporation were not detected in either the plant growth index measure or the visual quality scores, suggesting they were small and of limited horticultural significance.
- In contrast, for all 3 measures of plant quality, growing media type had a clear and consistent effect on both plant species.
- For *Viburnum* and *Leucanthemum*, mix 2 tended to produced plants of the highest quality. Notably, participants of the visual assessment scored *Viburnum* plants grown in mix 2, of significantly higher quality than those grown in the InS peat-based mix.
- *Leucanthemum* growth was fairly consistent with plants performing well regardless of treatment. *Viburnum* growth was more variable, with plants receiving generally lower visual quality scores.

Discussion

The work described above took a novel waste stream material, rich in total phosphate and incorporated it into soilless growing media for container grown HNS stock. The first aim of the experiment, was to determine whether it might be utilised as P source. The evidence presented above shows that there was no consistent decrease in plant quality attributable to SSB incorporation. This implies that this material could be used as a substitute, at least in part, for other sources of P in containerised HNS production. The few previous studies which have incorporated biochars at similar rates (5-10% by volume) into soilless growing media have found them to be an effective source of nutrients. Altland and Locke, 2013, report that rice hull biochar incorporated into 85% peat: 15% perlite growing medium at 10% volume, was able supply plant available P at a rate equivalent to a standard application of water soluble fertilizer. Locke et al., 2013 also report that this biochar incorporated into the same growing medium was able to supply sufficient P to sustain a range of bedding plant species. The results presented here cannot absolutely confirm or rule out the possibility that SSB may also have been a net source of plant available P. The lack of any consistent decrease in plant quality between those plants receiving the nursery standard CRF source of P and those receiving neither a SSB nor CRF source of P (0% SSB), indicates that all plants, regardless of treatment, had sufficient P over the course of the experiment. This implies that the P present in the growing media itself was sufficient to meet demand in both plant species, without the need for an additional CRF or SSB source. This may in part be a result of the stage of plant production investigated. Liner plants (9cm in this case) are well established and may have acquired substantial reserves of P. Thus plant requirement during finishing in 2 or 3L container may be very low. The other factor which may have influenced plant P requirement is whether the species selected were particularly good at obtaining P. Many plant species have high efficiency uptake mechanisms for this nutrient (Balemi and Negisho, 2012), however little information was available on the relative P requirement of the two cultivars used in this study. Given the finite nature of P resources and their potential to cause eutrophication when leached, it is suggested that both these factors require further investigation to ensure over-application is avoided on nurseries.

The chemical characterisation work on mix 1 and the InS mix have also provided some fascinating avenues of further research. Perhaps the most promising is the evidence that SSB incorporation at the 10 and 5% rates reduced soluble P concentration quite substantially in both growing media (and ammonium concentration in mix 1). Whilst this is somewhat contrary to initial expectations, it is an extremely interesting property. Beck et al., 2011, report that the incorporation of 7% biochar (made from a range of agricultural wastes) into green roof substrate was able to reduce losses of nitrate and phosphate via run-off. This then does provide some anecdotal evidence to support a hypothesis that the biochar investigated here may have some potential to reduce or at least slow down soluble nutrient loss from containers. Further work is needed to better understand not only whether SSB can be a useful source of plant nutrients, but also how it might impact on nutrient-use efficiency. There are also some interesting questions to be asked about the extent to which different plant species may be able to access the P adsorbed by the biochar. Those ornamental species with high P efficiency uptake mechanisms may be particularly well suited to SSB incorporation in soilless growing media.

One of the more surprising outcomes of the study was that while SSB incorporation had little statistical effect on plant quality, growing media did. For both plant species, mix 2 (40% peat, 40% wood fibre and 20% GWC) produced the best quality plants, with those grown in mix 16 (50% pine bark, 20% wood fibre, 20% peat, 10% GWC) being of significantly poorer quality. This effect was particularly pronounced for *Viburnum*, which in the 2014 study displayed good, consistent growth across a range of growing media types (including the same six utilised in this work). As described above, batches of growing media were relatively uniform between years, it therefore seems unlikely that medium inconsistency was driving this disparate response. Table C (Appendix 4), provides a comparison of mean plant quality data for the two years and shows that *Viburnum* quality tended to be lower in 2015 across all media types. The weather conditions in the summer of 2015 had some notably hotter and drier intervals. For mixes such as 16 which had a higher AFP and lower water holding capacity, very hot and dry spells may have produced particularly difficult growing conditions. This perhaps highlights the importance of testing novel growing media under a range of conditions and within a number of different plant growth systems.

With an increasing number of organic materials being utilised in commercial soilless growing media, the second aim of this work was to determine the extent to which different growing media might influence the effect of SSB on plant quality. There was limited evidence that in some mixes (such as 2 and 7), SSB may have had more of a pronounced effect on shoot dry biomass than others. However, these effects were not consistent across all plant quality measures suggesting them to be of limited horticultural significance. This is noteworthy because chemical characterisation of mix 1 and the InS mix did indicate that the impact of SSB on growing media properties varied between mixes. This variable impact was not necessarily intuitive as demonstrated by mix 1, a peat-free formulation comprised of 40% coir, 40% wood fibre and 20% garden waste compost (GWC). Eighty percent of this mix was then, comprised of materials generally associated with a low chemical buffering capacity, yet SSB incorporation had little discernible impact on pH. In contrast, SSB incorporation had a distinct liming effect on the peat-based InS mix, (pH increase from 5 at 0% SSB, to 6.4 at 10% SSB) which comprised 70% peat; a material typically associated with the ability to resist chemical change.

The third aim of the work was to characterise the SSB in order to better understand how it might be used as a growing media additive or component. The data presented above revealed it to be strongly alkaline, with high concentrations of soluble chloride and sulphate - perhaps not an ideal choice for a growing medium component. However, its inclusion at a relatively substantial proportion of mix volume (10%), had no detrimental impact on plant growth in any of the mixes. This certainly indicates that it might well be a workable as a growing medium component and most importantly, that it might be effective in combination with a diverse range of other materials.

More than 1.5 million tonnes of municipal sewage sludge are produced annually in the UK (DEFRA, 2012). For the horticultural industry, pyrolysis of sewage sludge may offer an opportunity, because it generates a high volume waste product, rich in stable organic material and nutrients. The work presented here describes a preliminary investigation into the use of this material in soilless growing medium. At a time when growing media manufacturers are looking for responsible alternative materials to peat, the work presented here indicates that biochar made from SSB (and indeed many other renewable organic waste materials), presents a worthy avenue for further exploration.

Conclusions

- The work above describes the impacts of a novel, sustainable source of phosphate (SSB), on the quality of container grown HNS in six different types of soilless growing media.
- The HNS species *Viburnum* and *Leucanthemum* grown in the study were shown to have a low requirement for P, apparently met by the P content of the growing medium.
- This may suggest a potential over-application of P on some nurseries, particularly those growing on HNS liners.
- While the low P requirement of plants in this study negated a full exploration of its efficacy as a P source, SSB was shown to possess a number of interesting chemical properties which warrant further investigation
- Contrary to work carried out in the previous year, growing media type had a strong influence on plant quality. This highlights the importance of testing novel growing media under a range of environmental conditions.
- This work indicates that SSB may be suitable for use as a component, in growing media mixes and may be incorporated at a proportion of 10% volume, without any detrimental impacts on plant quality.
- SSB and other biochars from high volume renewable waste streams may offer potential as a sustainable organic growing medium component. More research is recommended to fully describe possible environmental and economic benefits.

Knowledge and Technology Transfer

After completion of further analysis it is hoped that the results of this experiment detailed above will be published through relevant AHDB and RHS publications. It is also hoped that this work will form the basis of a scientific publication for dissemination to the wider research community.

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Appendices

Appendix 1 Progress and objectives – supporting information

Table A. Summary of key presentations and communications to a wide range of audiences

Date	Group	Sector
16-7-2015	Presentation to the RHS science Committee giving an overview of experiment 4	Academia/public/RHS staff
4-8-2015	Presentation to the RHS bursaries committee on the fellowship US study tour	Academia/public/RHS staff
8-9-2015	Presented fellowship research at internal ISHS conference in Vienna	Academia/Industry
16-9-15	Attended AHDB studentship conference, presenting a poster of recent fellowship research findings	Academia/Industry
21-10-15	Lecture given to the Surrey Horticultural progress group for amateur gardeners on soilless cultivation	Public/outreach
16-2-16	Talk to AHDB Herbaceous perennial discussion group on fellowship progress as part of an RHS Departmental tour	Industry
17-2-2016	Recorded podcast for the RHS website on composting	Public/outreach
02-3-2016	Presentation at Sheffield University for the Knowledge transfer network on 'Innovation in soil free growing'	Academia/Industry
16-3-2016	Ran 45 minute workshops on growing media science for school children	Public/outreach
17-05-2016	Submitted growing media literature review paper 'Achieving environmentally sustainable growing media for soilless plant cultivation systems – a review' to peer reviewed journal	Academia

Appendix 2. The plant visual quality assessment

a)

b)

Figure A. Visual quality categories for a) *Leucanthemum* and b) *Viburnum*. Plants were ranked for quality on a scale of 1-5, 1 being the worst and 5 being the best; a score of 3 indicates saleable quality. Participants of the visual assessment were able to detect clear differences in plant quality with growing media type, particularly for *Viburnum*.

Appendix 3. Additional data - soluble micronutrient content for growing media components

Table B Water soluble micro nutrient content (mg/l) of the organic growing media components coir, GWC (garden waste compost), peat, pine bark and wood fibre) used in the 2014 and 2015 experimental work. Data were obtained from 1 representative sample of each raw material.

	Ca		Mg		Na		Cl	
	mg/l		mg/l		mg/l		mg/l	
	2014	2015	2014	2015	2014	2015	2014	2015
Coir	0.7	5.1	0.7	1.1	45.5	26.4	183.1	112
GWC	20.2	37	5.1	8.9	52.7	61	138.6	359.1
Peat	<0.6	4.7	<0.6	2.3	14.4	15.9	15.1	16.3
Pine Bark	10.5	3.9	7.6	0.9	15.9	9.8	36.5	21.6
Wood Fibre	<0.6	2.7	<0.6	0.4	4.7	2.2	7.3	9.4

Appendix 4. Additional data – *Viburnum* plant quality in 2014 vs 2015

Table C. Summary of mean plant quality measures for *Viburnum* grown in the same growing media mixes in both 2014 and 2015. Presented are visual quality (VQ) scores (1-5, 1 being the worst, 5 being the best and 3 saleable quality), shoot dry biomass (SDB) (g) and Growth Index (cm^3). Means for 2015 are for the control treatment only where industry standard rates of fertilizer were applied (*n*=7) and were the same as in 2014 (*n*=36).

	Mean VQ score (1-5)	
Mix	2014	2015
1	3.8	2.6
2	3.8	4.2
7	3.9	3.7
15	3.8	2.7
16	3.7	2.3
InS	3.6	2.6

	Mean SDB (g)	
Mix	2014	2015
1	41.3	22.7
2	41.9	31.5
7	42.1	25.3
15	40.5	18.4
16	38.7	16.0
InS	40.3	15.1

	Mean GI (cm^3)	
Mix	2014	2015
1	26907	14968
2	29763	27586
7	24699	20056
15	23736	11631
16	22929	10318
InS	24267	11511