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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:	CP 095
Project leader:	Dr Paul Alexander, The Royal Horticultural Society (RHS).
Report:	Annual Interim Report, June 2015
Previous report:	June 2014
Fellowship staff:	Dr Paul Alexander, Principal Horticultural Scientist, RHS, Wisley (Project leader/mentor) Rachael Tanner, Research Assistant, RHS Wisley (Technical Support) Dr John David, Chief Scientist, RHS Wisley (Project sponsor) Dr Steve Robinson: Senior lecturer, The University of Reading (Academic Mentor)
(“Trainees”)	Dr Gracie Barrett: Fellowship trainee, horticultural scientist
Location of project:	RHS Garden Wisley

Industry Representative:	Neil Bragg (NB): Product development director, Bulrush Horticulture Ltd
Date project commenced:	13th November 2012
Date project completed (or expected completion date):	13th 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
RHS

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1. Progress Against Objectives

Summary of Progress

In the year since the last report, a large field experiment has been completed and a follow up experiment has now been established. These are described in sections 2 & 3.

Objective 1: *Develop experiment(s) examining novel substrates, water efficiency, various substrates and plant performance using indicator plants:*

- Experiment 3, in which bespoke growing media were designed, characterised and tested has been completed. This was an extensive piece of work involving more than 1,600 plants and utilising 14 fully replicable growing media mixes. These mixes will now be used to conduct further work on novel nutrients and nutrient-use efficiency in containerized plants. Up until this point we had been concentrating on proprietary growing media, however these products showed much batch to batch variability. The production of our own growing media will improve consistency and allow us to more meaningfully compare results between experiments.
- Five of the growing media mixes designed and tested in experiment 3 are being used to investigate the effectiveness of sewage sludge biochar (SSB) as a novel source of phosphate (experiment 4). This experiment is outlined in section 3.
- **Original completion date/revised completion date:** Dec. 2015/March 2015

Objective 2: *Laboratory based experimentation at Reading University:*

- In May 2014, several weeks were spent at the University of Reading (UoR) exploring nitrogen draw-down in different growing media materials and mixes of materials. This work sought to examine the appropriateness of existing methods (e.g. Handreck, 1992) and also establish where necessary new standard methods. Training was completed in the use of various pieces of equipment for the analysis of nitrate and ammonium in water extracts.
- More laboratory work is planned for the autumn of 2015, when material from experiment 4 (see section 3) will be assessed for nutrient content.

Original completion date/revised completion date: July 2015/May 2014 (on-going until December 2015)

Objective 3: *Identification of knowledge gaps, written proposals presented for spin-off funding opportunities:*

- Meetings have been held with several other research groups and discussions regarding collaborative projects are under-way.
- A collaborative student project is commencing at the UoR this summer to further investigate nitrogen draw-down in growing media.
- In December 2014 the trainee horticultural scientist applied for, and was awarded an RHS travel bursary. This funded a study tour to the United States in April 2015, to meet with prominent researchers from North Carolina State and Arkansas Universities. It is anticipated that this experience will lead to future collaborative opportunities and joint proposals for funding.

Original completion date/revised completion date: July 2015/ongoing

Objective 4: *Presenting information at grower meetings/technical meetings/scientific conferences. Exposure to and experience of talking to all audiences:*

- Dissemination of research to various interest groups has taken place this year:

Date	Group	Sector
23-10-14	HDC HNS Panel – Presentation at Wisley about HNS experiment and work with growing media. Included a visit to experiment 3 field site and some visual assessments of experimental plants	Industry
19-11-14	University of Lancaster – Presentation about work on growing media to initiate collaborative opportunities	Academia
11-02-2015	HDC Herbaceous perennial discussion group – Presentation about research work on growing media	Industry
20-21/02/2015	Helped run stand at the RHS plant and potato fair in London on soils and soil health	Public/outreach
17-03-2015	Designed and ran workshop for groups of secondary school children on growing media	Public/outreach
20-04-2015	North Carolina State University – Presentation of research findings to Horticulture Department staff and students	Academia
23-04-2015	Arkansas University – Presentation of research findings at departmental seminar to share information and initiate collaborative opportunities	Academia
09-06-2015	Presented overview of my career development through the fellowship to the AHDB –Horticulture board	Industry

Original completion date/revised completion date: July 2015/May 2015 & ongoing

Objective 5: *Present research findings to RHS Science committee, HDC studentship meeting and at appropriate staff seminars at UoR, EMR & RHS*:

- Invitations to give talks on the US study tour have been received from RHS advisory and the RHS bursary committee.
- Attendance of the HDC studentship conference is planned and results will be presented as requested.
- Invitation to present an update of my work to the RHS Science committee (July 2015).

Original completion date/revised completion date: July 2015/ ongoing

Objective 6: Scientific publication, HDC report, article in RHS publications and general gardening press:

- Pieces have been written for the Sunday Telegraph (January 2015) and RHS Garden magazine (April 2015) on growing media. Experiment 3 was also featured in the RHS science blog https://www.rhs.org.uk/science/staffprofile?ID=23606
- An abstract of the paper 'The Response of Pelargonium to Different Growing Media and Liquid Fertilizers – An Experimental Comparison' has been accepted for oral presentation at the ISHS growing media conference in Vienna in September 2015 (Appendix 1). Publication of the paper in Acta Horticulturacae will follow this presentation.
- Analysis of data from experiment 2 (years 1 and 2), which further examined the interaction between growing media and liquid fertilizers has been completed and a second paper is in process. Publication is expected by the end of the year (December 2015).
- A draft of the growing media literature review has been circulated to fellowship staff for comment and submission is planned for November 2015.

Objective 7: *To develop and submit collaborative research proposal to relevant funding body:*

- Several possible collaborations are currently under discussion. It is anticipated that publication of fellowship research over the next year will lead on to collaborative proposals for external funding. It is hoped that these will sustain research work beyond the 5 year remit of the fellowship.

Training undertaken

An RHS Social Media Workshop was attended, which covered a range of social media tools (Facebook, Twitter, Pinterest etc.). The RHS is increasingly using these tools to communicate with its membership and they are likely to be useful in disseminating fellowship findings to the gardening public.

Expertise gained by trainees

The preparation, submission and award of an RHS travel bursary has not only given the trainee valuable experience of applying for competitive external sources of funding, but allowed results of the fellowship to be presented to a much wider audience.

Other achievements in the last year not originally in the objectives

Participation in the RHS drive to engage the public with horticultural science has continued this year. In addition to helping to run a science education stand at the London plant and potato fair in February 2015, a growing media workshop was designed and run for secondary school children in March 2015.

The trainee is working more closely with the RHS Advisory team to help communicate the results of the fellowship research to the RHS membership and deal with day to day soil and growing media themed enquiries. This experience has helped to better develop the trainee's communication skills, particularly when dealing with amateur and non-specialised audiences.

Changes to Project

Are the current objectives still appropriate for the Fellowship?

No changes planned to this year's objectives.

2. Science Section – completed work

Experiment 3: A detailed assessment of a range of commonly used growing media materials in the production of containerised hardy nursery stock (HNS)

Introduction

One of the most important resources required for the commercial production of high quality ornamental plants is an effective growing medium. This medium must fulfil a range of criteria in order to meet the needs of the grower. It must act as a physical matrix, providing adequate quantities of air and water to the roots through-out the production process. The media must also meet the practical and economic requirements of grower; be affordable, easy to obtain and work within existing irrigation and fertilisation regimes (Bragg, 1995). Finding materials and combinations of materials that can satisfy such a complex range of criteria is a challenge. Since the 1960's peat-based growing media have dominated containerised plant production in the UK. This is largely due to the favourable physical and chemical properties of peat (Robertson, 1993, Wallach, 2008) combined with its widespread availability and low cost (Robertson 1993, Maher et al. 2008). However, in the last decade legislators, retailers and consumers have become more environmentally aware and there is an increasing onus on growers to improve the sustainability of their growing practices (Carlile, 2004a, Alexander et al., 2008, Schmilewski, 2014). As a result the extraction of peat, a non-renewable resource, for use in growing media has become increasingly unpopular and a wide range of alternative materials are being used in its place.

In the UK significant progress has already been made to increase the diversity of materials used for container growing media and reduce the reliance of the industry on peat. The most recent published figures on growing media manufacture in the UK indicate an overall decrease in the amount of peat used in both absolute and proportional terms (Denny, 2013). Between 2011 and 2013 the amount of peat used in professional growing media has slowly but consistently reduced from 72% in 2011 to 67% in 2013. This has been accompanied an increase in the usage of other alternative materials particularly coir (+ 4%), wood-based materials (+ 2.6%) and bark (+2%). These trends indicate that there is now a need to better understand; firstly how a wider range of raw materials can work within professional growing systems and secondly how best to combine different proportions of these materials to provide the cost effective, high quality growing media options. This is particularly important for the bedding and nursery stock sector, which accounts for more than half of all professional growing media used in the UK (Denny, 2014).

In order to address this, 14 bespoke growing media mixes were produced based on the 5 most commonly available raw materials; peat, coir, green waste compost, wood fibre and matured pine bark. These mixes were manufactured according to standard industry practice and fully characterised to determine their physical and chemical properties. The performance of these mixes was then assessed in an experimental set-up mimicking standard nursery practice. Plant quality was assessed after 6 months of growth, the aim was to identify the best performing combinations of raw materials relative to an industry standard (IS) peat-based mix.

Materials & Methods

Growing media design

Raw materials for the experimental growing media were selected according to common use in the UK. The most recent published figures indicate these to be *c.* 55% peat, *c.* 18% wood-based, *c.* 9% Coir, *c.* 9% composted green waste and *c.* 5% bark (Denny, 2014). The emphasis for the UK horticultural industry is on peat-reduction so mixes were designed to be peat-free or substantially peat-reduced (peat to make up no more than 40% of the medium by volume). Four professional standard raw materials were obtained: Irish sphagnum peat graded to 18mm. Coir from Sri Lanka, washed and buffered. 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.

Identifying a high quality, consistence source of municipal green waste compost was problematic. After consultation with growing media manufacturers it was decided that the green waste compost produced on site at RHS garden Wisley would be used. This material was comprised of clean garden trimmings, turned and matured until temperatures had reduced and the resultant material was considered stable. This material, referred to going forwards as garden waste compost (GWC), was then hand screened to 20mm.

Each of the five raw materials were subject to physical and chemical characterisation according to the most appropriate methodologies. Physical properties measured are summarised in table 1. Chemical properties measured are displayed in table 2. Due to its potential nutrient content and general variability, the GWC was further characterised by analysing its total N and organic C content using the Dumas method (AOAC, 1990).

Physical properties	Standard Method
Total porosity (%)	Modified method, (appendix 2)*
Container Capacity (%)	Modified method, (appendix 2)*
Air-filled porosity (AFP) (%)	Modified method, (appendix 2)*
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
Particle size distribution (%)	BS EN 15428:2007
Easily available water (%)	BS EN 13041:2011 & de Boodt & Verdonck, (1972)**

Table 1. Physical properties measured and standard method used for characterisation of the five raw materials.

*Total porosity, container capacity and air-filled porosity (AFP) were measured using an *approach modified from Bragg & Chambers (1988), Byrne and Carty (1989), Fonteno et al. (2003) and Bilderback, (2009) which is outlined in appendix 2. Container capacity and easily available water both describe the ability of the raw materials to retain water. Container capacity is a measure of all water held, while easily available water measures just the volume which is readily accessible to plant roots.*

***Water content of the materials was measured at 1, 5 and 10kPa of suction and easily available water was calculated as the amount of water removed from the sample between a suction of 1 and 5kPa (de Boodt and Verdonck,1972).*

Chemical Properties	Method
pH	BS EN 13037:2011
Electrical Conductivity (EC)*	BS EN 13038:2011
Plant available (water soluble) nutrients	BS EN 13652:2001

Table 2. Chemical Properties measured and standard method used for characterisation of the five raw materials.

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

Suitable ranges for compacted fresh bulk density and AFP were identified by reviewing the literature (Bragg and Chambers, 1988) and through consultation with a professional growing media manufacturer. Raw materials were combined by hand to produce 16 preliminary growing media mixes and values for compacted fresh bulk density and AFP were determined. Fourteen of these mixes had a compacted fresh bulk density of between 250 – 500 Kg m^3 and an AFP of between 20-40% and were identified as broadly suitable (fig.1). Two mixes (mix 9 and mix 12) were excluded from the study at this point because their physical properties fell outside the desired suitable ranges. The 14 acceptable mixes were then manufactured uniformly alongside a peat-based industry standard (IS) mix for HNS species which comprised of 70% peat and 30% wood fibre. Mixes were made up uniformly in 120 litre batches using a cement mixer. Base fertilizer, fritted trace elements (vitreous enamel powder containing boron, zinc, iron manganese, copper and molybdenum) and wetting agent were added at industry standard rates. Lime was applied where necessary to bring mix pH into an acceptable range and to provide a source of calcium. Supplemental calcium ammonium nitrate was applied to all mixes to compensate for possible microbial uptake of nitrogen. The rate of application varied by mix according to the proportion of woody materials included based on the work of Scott (1986) and summarised by Pennell (2013). Once manufactured the growing media mixes were transferred to porous bags and used within 1 week. All growing media mixes were physically and chemically characterised in the same way as the raw materials (with the exception of easily available water and organic matter content).

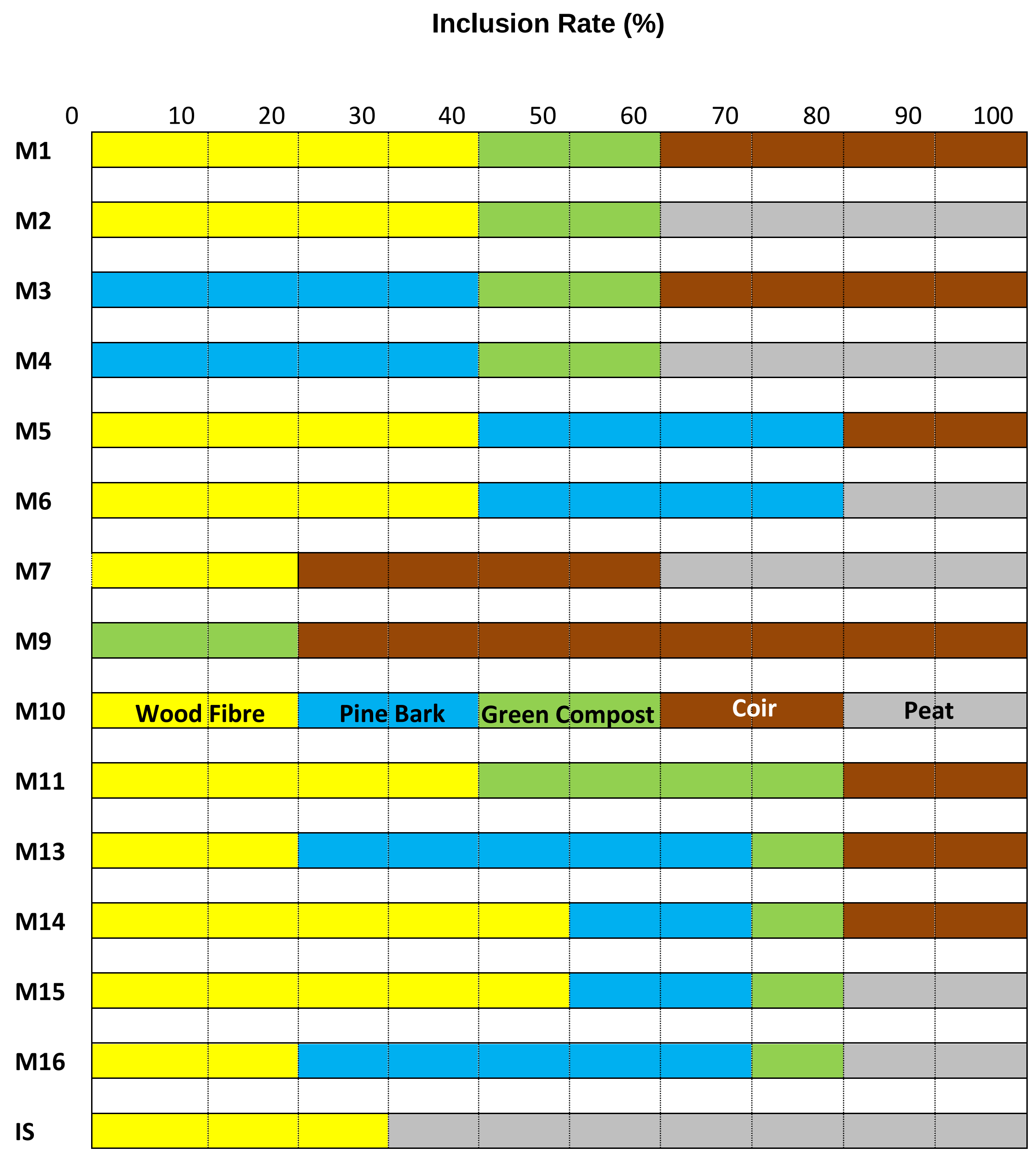

Figure 1. Composition of the 14 experimental growing media mixes and industry standard (IS) mix. Mixes were based on different proportions of five raw materials coir (brown), green compost (green), peat (grey), mature pine bark (blue) and wood fibre (yellow bars). Mixes 8 and 12 were excluded at the preliminary screening stage due to undesirable physical properties.

Assessment of growing media mix performance

The performance of the 14 experimental growing media mixes was compared with that of the (IS) mix in a large-scale replicated field experiment.

Fifty-four uniformly trimmed 9cm liners of *Viburnum tinus* 'French White' were potted on into each of the growing media mixes (14 experimental mixes plus the IS mix). Two-litre black plastic pots were half filled with growing media, 12 month controlled release fertilizer (CRF) was then dibbled in at the appropriate industry standard rate before placement of the liner and completion of infilling. The fifty-four *Viburnum* pots were then laid out over half the area of a 15m x 23m mypex covered plot in six randomised blocks. Each of the six replicate blocks was 1m^2 and comprised of nine uniform plants. The same process was repeated for a second HNS species; *Hebe albicans* 'Red Edge' and replicate blocks were laid out on the second half of the plot. Experimental conditions for both plant species were the same, expect for the rate of CRF application which was 1g/L lower in the *Hebe* to account for a perceived lower nutrient demand. In total there were 90 replicate blocks of 9 plants per HNS species giving a total of 1,620 individual plants.

Plants were watered with over-head sprinklers laid out to optimise efficiency following industry standard practice (AHDB Horticulture, 2005: Factsheet 16/05). The amount of water applied was varied according to ambient weather conditions with 60 minute irrigation periods once or twice daily if required. All plants were watered according to the requirements of the plants in the IS mix which were monitored with a moisture probe (Delta-T, WET-sensor). Measurements were taken from the central plant in each of the 6 replicate blocks of the IS mix. The experiment was established on 17th April 2014 and ran until the 4th November 2014 to replicate the 6-7 month retention time on commercial UK nurseries. Large weeds were removed monthly from the pots and inspections for pest and disease were made weekly. Several measurements of plant quality were made in order to assess the performance of the growing media mixes. Plant growth index was measured every 6 weeks over the course of the experiment (Plant height x widest plant width x perpendicular plant width) with measurements taken from the central plant within each replicate block. The time of first flowering and number of flowers was recorded weekly for *Viburnum* after the commencement of first flowering (flowering did not occur in *Hebe*). At the end of the experiment plants were subject to visual assessment by a group of 12 professional growers and a group of 12 amateur growers (see appendix 4). Each assessor was asked to score every replicate block of plants on a scale of 1-5 according to their suitability for sale at a garden centre with 1 being extremely poor quality and 5 being excellent quality (plants scoring 3 or above were perceived to be commercially marketable by professional growers and purchase worthy by amateur growers).

Example plants for each quality category were displayed to guide the assessors, with leaf colour, canopy cover and flower number all used as indicators of quality. Six replicate plants in each replicate block of nine were then destructively sampled and shoot fresh weights were recorded. Plant material was then dried in an oven at 60°C for 48 hours and dry weights measured.

Analysis of the data for this experiment is still on-going but preliminary results are presented. For growth index and shoot dry weight data, transformation was not required and analysis was carried out using one-way analysis of variance (ANOVA)) (GenStat, edition 10). The visual assessment scores were converted to percentages, an angular transformation was applied before analysis with one-way ANOVA using growing media mix as the treatment term. All data are displayed untransformed as means ± 95% confidence interval (CI)

Results

Physical properties of the raw materials and growing media mixes

The physical properties of the 5 raw materials are displayed in Table 3. AFP was lowest in the GWC at 6.4% and highest in the pine bark at 42.8%. Coir and GWC contained the highest proportion of fine particles (< 1mm), whilst the pine bark had the lowest (Table 3b). Wood fibre had the highest total porosity of all the materials and the highest easily available water, in contrast pine bark had the lowest total porosity and easily available water. Interestingly the GWC had a substantially lower organic matter content than any of the other 4 materials, most likely because it was mixed with soil during the composting process (table 3a)

a)

Raw material	CFBD	DBD	TP	CC	AFP	EAW	OM
	Kg/m^3	Kg/m^3	%	%	%	%	%
Coir	377	73.8	83.6	65.4	18.1	26	84
GWC	856.3	483.5	72.3	65.5	6.9	19	24
Peat	351	156.9	78.7	68.9	9.8	27	97
Pine Bark	290	168.7	70.5	27.8	42.8	4	96
Wood Fibre	144	73.2	87.5	47.8	39.8	42	98

b)

Raw material	< 1mm	1-2mm	2-4mm	4-8mm	8-16mm	> 16mm
	%	%	%	%	%	%
Coir	67	26	7	1	0	0
GWC	54	16	15	11	4	0
Peat	35	10	12	26	17	0
Pine Bark	11	9	22	41	17	0
Wood Fibre	56	20	12	8	3	0

Table 3. Mean values for the measurements describing the physical properties of the raw materials displayed are: a) Compacted fresh bulk density (CFBD) (Kg m^3); *n*=3, Dry bulk density (DBD) (Kg m^3); *n*=3, total porosity (TP) (%); *n*=5, container capacity (CC) (%); *n*=5, air filled porosity (AFP) (%); *n*=5, easily available water (EAW) (%); *n*=3, organic matter content (OM) (%); *n*=3 and b) particle size distribution (PSD) (%) at dry weight; *n*=3.

Physical properties of the 14 growing media and industry standard (IS) mix are displayed in table 4 and varied quite widely. AFP ranged from a maximum value of 35% in mix 5 to a minimum value of 12% in Mix 2 (table 4a). Container capacity was equally variable with a range of 64.9 - 44.3% (table 4b). Compacted fresh bulk density of the mixes ranged from 577-284 Kg/m^3. Two of the mixes (mix 4 and M11) exceeded the upper range of desired compacted fresh bulk density (500 Kg/m^3), despite falling below the threshold when screened as preliminary mixes. Particle size distribution was equally variable (table 4b), with the proportion of the mixes made up of particles < 1mm ranging from 30-64%, 1-2mm; 9-19%, 2-4mm; 10-17%, 4-8mm; 0-16%. None of the mixes contained particles exceeding 16mm in size.

a)

	Raw material proportion					Physical properties				
Growing media	**WF**	**GWC**	**C**	**PB**	**P**	**CFBD**	**DBD**	**TP**	**CC**	**AFP**
	%	**%**	**%**	**%**	**%**	Kg/m^3	Kg/m^3	%	%	%
M1	40	20	40	0	0	419	211.2	80	61.5	18.4
M2	40	20	0	0	40	480	255.4	76.9	64.9	12
M3	0	20	40	40	0	466	237.7	74.3	52.1	22.2
M4	0	20	0	40	40	514	306.3	71.5	53.4	18.1
M5	40	0	20	40	0	284	157.6	80.3	45.2	35.1
M6	40	0	0	40	20	295	175.8	78.1	45.6	32.6
M7	20	0	40	0	40	354	128.1	83	67	16
M9	0	20	80	0	0	479	213.1	80.5	66.3	14.2
M10	20	20	20	20	20	448	228.9	75.5	60.3	15.2
M11	40	40	20	0	0	577	321.4	78.2	62.7	15.5
M13	20	10	20	50	0	363	217.4	76.1	44.3	31.8
M14	50	10	0	20	20	312	174.4	78.3	55.5	22.8
M15	50	10	0	20	20	364	217.3	79.9	50.1	29.7
M16	20	10	0	50	20	361	223.8	74.7	48.7	26
IS	30	0	0	0	70	383	158.9	79.4	64.1	15.3

b)

	Raw material proportion					Particle size distribution (%)					
Growing Media	**WF**	**GWC**	**C**	**PB**	**P**	**< 1mm**	**1-2mm**	**2-4mm**	**4-8mm**	**8-16mm**	**> 16mm**
	%	**%**	**%**	**%**	**%**	%	%	%	%	%	%
M1	40	20	40	0	0	60	16	12	10	3	0
M2	40	20	0	0	40	53	12	11	13	11	0
M3	0	20	40	40	0	45	13	13	21	7	0
M4	0	20	0	40	40	41	10	14	24	11	0
M5	40	0	20	40	0	33	12	18	28	8	0
M6	40	0	0	40	20	32	10	15	30	13	0
M7	20	0	40	0	40	49	14	10	18	9	0
M9	0	20	80	0	0	62	19	12	7	0	0
M10	20	20	20	20	20	49	13	13	18	8	0
M11	40	40	20	0	0	64	15	12	6	4	0
M13	20	10	20	50	0	33	11	16	27	13	0
M14	50	10	0	20	20	49	13	14	18	5	0
M15	50	10	0	20	20	39	9	13	24	16	0
M16	20	10	0	50	20	30	10	17	30	14	0
IS	30	0	0	0	70	46	10	11	20	12	0

Table 4. Mean values for a) Compacted fresh bulk density (CFBD) (Kg m^3); *n*=5, Dry bulk density (DBD) (Kg m^3); *n*=3, total porosity (TP) (%); *n*=5, container capacity (CC) (%); *n*=5, air filled porosity (AFP) (%); *n*=5 and b) particle size distribution (PSD) (%); *n*=3 at dry weight of the 14 growing media and Industry standard (IS) mix. Growing media composition is given as the proportion of each of the 5 raw materials; wood fibre (WF), garden waste compost (GWC), coir (C), pine bark (PB) and peat (P) making up each of the 15 mixes.

Chemical Properties of the raw materials and mixes

Chemical properties of the raw materials are shown in table 5. With the exception of the garden waste compost (GWC), materials contained little plant available nitrogen (table 5a) and few micronutrients (table 5b). The GWC contained a total nitrogen content of 0.88% and a total carbon content of 18.8% giving it a C:N ratio of 21.1. Given the higher nutrient (particularly K) content of the GWC relative to the other materials it had understandably higher conductivity (table 5a). The relatively low EC, sodium and potassium levels indicated that the coir had been washed and buffered to an adequate standard (table 5a).

a)

	pH	**EC**	**NO_3^-**	**NH_4^+**	**P**	**K**	**Ca**	**Mg**	**Na**	**SO_4**
		(µS/cm)	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Raw material										
Coir	6.6	157.2	1.3	21.9	4.6	140.5	0.7	0.7	45.5	36.4
GWC	8.6	438.3	14.7	57.3	36.1	685.7	20.2	5.1	52.7	2.7
Peat	4.4	40.8	1.9	17.6	< 0.6	1.1	< 0.6	< 0.6	14.4	46.8
Pine Bark	4.0	100.8	<0.6	11.3	9.5	118.6	10.5	7.6	15.9	28.8
Wood fibre	4.4	9.6	<0.6	5.9	< 0.6	2.8	< 0.6	< 0.6	4.7	15.9

b)

	Fe	**Mn**	**Cu**	**Zn**	**B**	**Cl**
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Raw material						
Coir	3.2	<0.06	<0.06	<0.06	0.2	183.1
GWC	11.1	0.4	0.2	0.2	0.2	138.6
Peat	<0.06	< 0.06	< 0.06	< 0.06	< 0.06	15.1
Pine Bark	0.2	3.0	0.1	0.2	0.2	36.5
Wood Fibre	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	7.3

Table 5. Mean values for a) pH, electrical conductivity (EC) (µS/cm) water soluble macronutrient content (mg/l) and b) water soluble micronutrient content (mg/l) of the 5 raw materials; coir, garden waste compost (GWC), peat, pine bark and wood fibre, *n*=3.

The pH, EC and soluble nutrient concentrations were measured in the finished growing media just prior to potting up and after amendment with additives (table 6). Plant available nitrate (197.5- 476.5 mg/L) and ammonium (10.6-120.3 mg/L) depending on the proportion of GWC and woody materials in the mix (table 6). The most variable nutrient was potassium which ranged from 136.8-1028 mg/L and was largely a result of the proportion of GWC in the mix. Plant available phosphate levels ranged from 23.2-46.1 mg/L and again tended to reflect the proportion of GWC in the mixes. Chloride levels ranged from 19.7 - 210.4 mg/L with the highest levels being correlated with the proportion of GWC (mix 9, see table 6).

	pH	***EC***	***NO_3^-***	***NH_4^+***	***P***	***K***	***Ca***	***Mg***	***Na***	**Cl**	***SO_4***
Raw material		(µS/cm)	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
M1	6.6	787	368.3	58.2	31.3	747.3	160.2	50.9	70.6	87.3	255.3
M2	6.2	709	335.5	113.8	35.8	456.7	145.9	55	42.8	25.9	296.6
M3	6.5	766	321.3	83.1	46.1	736.9	116.6	39.9	68.3	107.2	268.8
M4	6.5	737	316.1	120.3	43	471.1	153.8	49.7	42.7	35.8	293.3
M5	6.2	642	309.2	86.3	39	421.4	159.3	54.9	45.9	78.2	226
M6	5.8	556	273.4	99.4	38.2	238.7	147.2	55.4	25.3	28.6	234.7
M7	6	537	203.4	92.1	38.1	355.7	68.5	37.7	65.8	102.2	248
M9	6.8	914	386.3	10.6	37.1	884.9	157.4	55.3	121.3	210.4	276.9
M10	6.5	686	289.7	89.2	34.9	524	109.4	36.7	53	71.6	239.3
M11	6.9	968	476.5	12.4	23.2	1028.3	234.8	65.2	65.8	77.1	287.9
M13	6.2	626	270.1	104	38	458.2	92.1	33.9	44.3	67.5	219.2
M14	6.6	643	281.4	72.6	28.5	509.9	135.9	44.1	49.6	71.7	252.5
M15	6.3	623	279.7	87.4	33.8	368	143.7	49.7	303.3	26.9	256.2
M16	5.8	538	252.9	83	37.8	318.5	101.6	39.3	28.7	28.8	210.3
IS	5.8	470	197.5	79.7	38.6	136.8	110.5	64.2	35.5	19.7	271.8

Table 6. Mean values for the pH, electrical conductivity (EC) (µS/cm) soluble macronutrient (mg/L) and selected soluble micronutrient concentrations (mg/L) in the 14 growing media and industry standard (IS) mixes, n=3.

Impacts of the growing media on Hebe performance

There was statistical evidence that growing media mix had an impact on plant quality for the *Hebe*. Mean shoot dry weight of the plants at harvest was strongly influenced by growing media treatment (Fig. 2b, p<0.001). However, only the plants in mix 4 out-performed plants grown in the IS mix, producing *c.* 3g more shoot tissue than in the IS mix (table 7). All other mixes produced plants of a similar shoot dry weight to those in the IS mix. The difference in mean shoot dry weight between the worst (mix 14) and best performing mix (mix 4) was about 20% or *c.* 9g. There was some statistical evidence (p=0.020) that growing media mix had an effect on the plant growth index of the *Hebe* plants. The poorest performing plants were those grown in mix 14 which had a mean growth index of 37% lower than the best performing plants grown in mix 3 (table 7). With the exception of Mix 14, all growing media mixes produced plants with a similar mean growth index index to the IS mix (table 7).

Similar to the growth index and shoot dry weight measures, data from the visual assessment of the *Hebe* plants indicated that the assessors were able to identify differences in plant quality depending on the growing media mix used (Fig 2a, p<0.001).Three mixes produced plants with mean scores that were significantly different from those growing in the IS mix; mixes 10 and 4, which produced plants that were perceived to be of higher quality and mix 14 which produced plants of perceived lower quality (table 7). However, all plants (including those grown in mix 14) were perceived to have achieved marketable quality (a score of at least 3 or above) regardless of the growing media treatment. All three measures of plant quality indicated that mixes 14, 5 and 1 produced the poorest quality plants (table 7). The best quality plants varied according to the plant quality measure being assessed. Only mix 4 produced plants that were of consistently higher quality than the IS mix for more than one plant quality measure (shoot dry weight and visual assessment only, table 7).

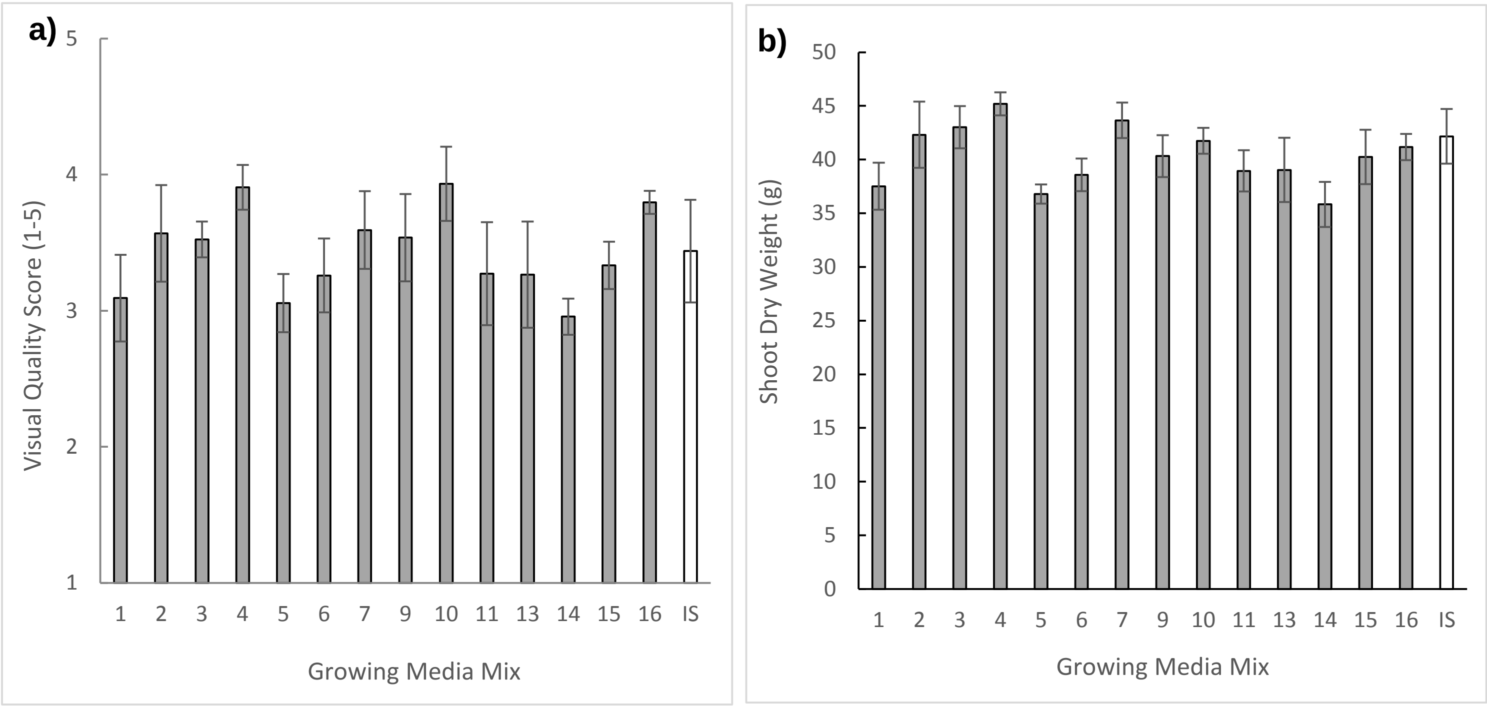

Figure 2. The effect of the 14 experimental growing media mixes (filled bars) and industry standard (IS) mix (un-filled bar) on a) mean visual quality score (1-5) and b) mean shoot dry weight (g) of *Hebe albicans* 'red edge' 6 months after potting on. The visual score was determined by 27 assessors on a scale of 1-5 with 1=poor, 3=acceptable/marketable quality and 5=excellent. Data are means ± 95% CI, *n*=36.

a)

MIX	Mean Score (1-5)	Rank
10	3.9*	1
4	3.9*	2
16	3.8	3
7	3.6	4
2	3.6	5
9	3.5	6
3	3.5	7
IS	3.4	8
15	3.3	9
11	3.3	10
13	3.3	11
6	3.3	12
1	3.1	13
5	3.1	14
14	3.0*	15

b)

MIX	Shoot Dwt (g)	Rank
4	45.18*	1
7	43.65	2
3	43.02	3
2	42.31	4
IS	42.16	5
10	41.75	6
16	41.17	7
9	40.33	8
15	40.24	9
13	39.03	10
11	38.95*	11
6	38.58*	12
1	37.51*	13
5	36.79*	14
14	35.83*	15

c)

MIX	GI (cm)	Rank
3	4679	1
2	4510	2
9	4335	3
4	4259	4
7	4161	5
IS	4129	6
13	3839	7
11	3809	8
15	3667	9
10	3650	10
6	3555	11
16	3436	12
1	3434	13
5	3370	14
14	2935*	15

Table 7. Ranked performance of *Hebe albicans* 'Red Edge' in the 15 different growing media mixes measured by a) mean visual quality score (1-5), b) mean shoot dry weight (Shoot Dwt.) (g) and c) mean growth index (GI) (cm). Each mix has been given a rank from 1-15, 15 being the worst and 1 being the best for each plant quality measure. All three measures of plant quality identified the same three worst performing mixes (highlighted in red), the three best performing mixes (highlighted in green) varied according to the plant quality parameter measured. Means marked with * indicate where plant quality differed significantly from the IS (industry standard mix), *n*=36.

Impacts of the growing media on Viburnum performance

In contrast to the results for the *Hebe*, there was no statistical evidence that growing media mix had any impacts on the quality of the *Viburnum* (shoot dry weight; p=0.631, growth index; p=0.182 and Visual quality score; p= 0.841; data shown in Appendix 3). All plants obtained a score of 3 or above in the visual assessment indicating that they were of acceptable marketable quality.

Discussion

The most striking result of the above experiment, is the general uniformity of plant growth and good quality that was achieved across all of the growing media investigated. While care was taken at the outset of the experiment to ensure the growing media mixes fulfilled some basic physical and chemical criteria to minimise plant failure, the properties of the resulting mixes varied widely. For instance AFP across the growing media ranged from 15-35% (table 4a). Within the literature AFP is commonly cited as one of the most important factors determining the efficacy of growing media and is often used as a stand-alone assessment of suitability. For instance Bragg and Chambers (1988) suggested an optimal range of between and 10-15% AFP for UK nursery stock, while Handreck and Black (1994) suggest a range of 13-20% AFP for containers up to 20cm deep. Our results indicate that HNS species may in fact grow well across a much broader range of air-filled porosities from 15-35% without any discernible impact on their marketability. It is possible that previous authors have based their recommendations on growing media comprised of one major or two components such as peat and bark or peat and grit in the UK (Bragg and Chambers, 1988) or pine bark in Australia (Handreck and Black, 1994). Growing media based on a more complex mix of materials may be more flexible with regard to the minimum and maximum AFP required to support high quality plant growth. For instance, mix 16 performed well in this study for both *Hebe* and *Viburnum*. It was comprised of 50% pine bark with an AFP of 26%, higher than recommended by previous authors. However, the 20% wood fibre content of this mix may have buffered plants against water stress. The wood fibre had a high water holding capacity and much of this water was easily accessible to plant roots (container capacity = 42% easily available water = 47.8%). This may have been why despite the large variation in the AFP and container capacity of the growing media, no extra watering was required between scheduled irrigation events and there was no evidence of any differential water stress between growing media treatments. This certainly warrants further investigation and perhaps a revision of previous recommendations for the AFP of growing media, with a broader range of raw material combinations included.

Hebe was clearly the more sensitive plant species with regard to growing media type and there were some mixes which produced consistently poorer quality plants than others. Mixes 14, 5 and 1 were ranked as the bottom three mixes across all 3 measures of plant quality. There is no evidence of any common shared physical or chemical property which might explain this result, although trends may become apparent on further analysis. It seems likely that a number of physical and chemical properties were contributing to influence plant response and that the importance of these varied between materials. This may mean relying on any one or two key physical properties as indicators of growing media efficacy across a wide range of growing media is problematic.

Interestingly, certain properties that may have been anticipated as being challenging had no discernible impact on plant quality. M9 and M11 had potentially problematic concentrations of plant available potassium at the start of the experiment (884.9mg/L and 1028.3 mg/L respectively, table 6). However, there was no indication of plant stress as a result and no significant reduction in plant quality at the end of the experiment. This again highlights the importance of interpreting chemical and physical properties of growing media within the context of a specific mix. The impact of any given property on a plant, will depend very much on complex interactions occurring in that specific mixture of materials.

Nitrogen drawn-down (NDD) is often associated with the raw materials used to make peat-free growing media, which includes green waste or woody materials (Carlile, 2004b). While these materials present few issues with NDD when correctly stabilised and processed they can present significant problems if not appropriately treated by growing media manufacturers. As a result much work has focused on predicting and correcting for NDD in susceptible raw materials used to make growing media such as pine bark (Handreck, 1992; Jackson et al. 2009) and sawdust (Sharman and Whitehouse, 1993). Most of our mixes contained high proportions of materials which are generally perceived to have a potentially large nitrogen demand (wood fibre, pine bark, GWC), as much as 80% in some cases (Mixes 13, 14, 15 and 16). Currently published methods for determining NDD are costly and labour intensive, they also require a high level of analytical capability which is hard to achieve outside of a formal research environment. Thus for the purposes of study, designed to mimic industry standard practice, a simple and practical approach was employed to correct for possible NDD. This was based on the work of Scott (1986), who found supplemental calcium ammonium nitrate could be applied according to the proportion of pine bark included in a peat based mix. This approach worked well here and we could find no evidence of mix induced N deficiency. This is a useful finding because calcium ammonium nitrate is a fairly cheap material and our preliminary cost analysis (data not presented here) indicates that even at its highest rate of application, it adds only a negligible cost to mix manufacture. It is therefore likely that a fairly simple, practical approach to over-coming NDD may work for many peat-free and peat-reduced growing media. That said, the authors emphasise that this approach is not a substitute for the careful selection of high quality raw materials for peat-free and peat-reduced growing media. Unless raw materials with a potentially high nitrogen demand are correctly stabilised (as was the case in this study) e.g. suitably aged (pine bark) or composted (GWC), N immobilisation is still likely to be an issue even in the presence of supplemental calcium ammonium nitrate.

Conclusions

The results presented here show that a wide range of peat-free and peat-reduced mixes have the potential to support high quality plant growth with little or no modification to existing growing practices. By ensuring that mixes of high quality raw materials adhere to a few simple physical criteria and then adjusting chemical properties accordingly, many different combinations of materials have the potential to work as well and in some cases better than peat-based media. While this is encouraging, uptake of these growing media will ultimately depend on whether they are cost effective in professional production systems. It is hoped that by conducting a cost-benefit analysis of the 14 experimental mixes compared with the IS mix (see section 3) this study can better highlight the economic realities of moving production from peat-based to peat-free growing media.

3. Science Section - Work in Progress

The following section outlines the work that is currently in progress focusing on the aims and expected outcomes.

Experiment 3 - Work to be completed

Experiment 3 was a very large scale experiment and the results presented in section 2 will be followed by further analysis.

1. **Cost: benefit analysis**

In addition to conventional measurements of plant quality reported above, the direct costs of mix production were recorded along with an assessment of indirect costs such as projected transport (based on bulk density measurements), medium shrinkage and medium moss and liverwort cover. One of the key aims of the work was to help growers better understand the true costs and benefits associated with switching from peat-based to peat-reduced/peat-free growing media mixes. To date researchers have tended to focus on the impact of different growing media materials on plant quality and often failed to consider the practical or economic implications of choosing one growing media over another. While we have been able to show that plant quality can be maintained in a wide range of growing media mixes, what we now intend to do is explore the true costs and benefits of one type of growing media vs. another. We aim to conduct a simple, informative cost:benefit analysis of each of our 14 experimental mixes compared with the IS mix.

Experiment 4 – The effectiveness of sewage sludge biochar (SSB) as a novel source of phosphate for container grown hardy nursery stock

Introduction

Work in year 1 and 2 (Appendix 1) indicated that there is an important interaction between different fertilizer types and growing media materials. An organic fertilizer containing more complex forms of nutrients, whilst reducing plant performance in peat-based media, worked as effectively as a conventional, inorganic fertilizer in some wood and green compost based growing media. This indicates that peat-reduced and peat-free media may offer a suitable matrix for novel, more sustainable source of nutrients. Currently, ornamental growers in the

UK rely on inorganic sources of the three key macro-nutrients nitrogen, phosphorus and potassium. These may be water soluble applied during irrigation or controlled release fertilizers (CRFs), incorporated into the growing media at the beginning of plant production. Inorganic fertilizers are relatively expensive, energy intensive and can lead to substantial pollution of ground water if not properly controlled. Control of nutrient release from CRFs is primarily temperature driven and therefore particularly difficult to optimise.

Phosphate is, vital for the growth of high quality nursery stock and is particularly important in the development of the root systems of young plants. The phosphate source in most conventional fertilizers is rock phosphate. This is a finite non-renewable resource and therefore its use has implications for the sustainability of the horticultural industry. Thus with regard to phosphate provision on UK nurseries there are two challenges; firstly to find sustainable, renewable sources of phosphate and secondly to improve nutrient-use efficiency in container grown plants so that fewer nutrients are lost to the environment.

The disposal of sewage sludge (SS), a by-product of the treatment of wastewater is becoming an increasing problem worldwide. The EU Urban Waste Water Treatment Directive implemented in 1992 has seen production of this material increase in the UK to more than 1 million tonnes per annum (DEFRA, 2002). While it has long been recognised that the high concentrations of micro- and macro-nutrients within this material present significant agronomic benefits when applied to land, SS may also contain toxic contaminants and elements. These include polycyclic aromatic hydrocarbons (PAHs), potentially high levels of heavy metals and the presence of human pathogens. Thus application to land is limited and a significant proportion of this material is either removed to landfill or incinerated (DEFRA 2002). However, in the last few years the conversion of SS to biochar has provided a possible solution for these problems. The pyrolysis of SS transforms it into biogas and bio-oil which can be used to generate energy. The carbonaceous residue left-over contains minimal pathogens, low levels of PAHs, has a much lower availability of heavy metals but crucially still retains useful levels of macronutrients such as phosphate (Waqas et al. 2014; Zhang et al. 2015).

Whilst sewage sludge biochar (SSB) has been shown to be an effective source of phosphate when applied to mineral soils (Wang et al. 2012), the effect of this material in soilless substrates used in greenhouse and nursery containers has not been investigated widely (Atland and Locke, 2013). However, there is some evidence that biochars in general may offer several benefits to soilless production. These include the supply of useful levels of nutrients (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).

SSB may therefore have the potential to offer UK growers a low cost, sustainable source of phosphate with additional benefits for reducing nutrient losses from growing media (particularly peat-reduced or peat-free materials with lower nutrient buffering capacities) over the course of production. The objective of this first piece of research with SSB is to use some of the fully characterised growing media mixes developed in last year's work, to address the following questions:

1. Can SSBC be used as an effective phosphate source for container grown plants?
2. Do different types of growing media influence its effectiveness?

The work will be carried out using industry standard practice where possible so that a realistic assessment can be made of whether using such a material in existing production systems is feasible.

Materials & Methods

Five growing media mixes (1, 2, 7, 15 and 16) designed and tested in experiment 3 have been selected. Mix selection has been based on best performance and on the relative proportions of the different materials contained within each mix.

Replicates of *Viburnum tinus* 'Eve Price' and *Leucanthemum* 'White Knight' will be grown in the 5 experimental mixes above and their performance will be compared with that of a peat-based industry standard (IS) mix. There will be 5 SSB treatments in which a conventional CRF source of phosphate will be compared to four different rates of SSB addition (10, 5, 1% and 0%). Levels of all other macro and micro nutrients will be applied at the same industry standard rates.

1. 10% SSBC, no additional phosphate (other nutrients given at industry standard rates)
2. 5% SSBC , no additional phosphate (other nutrients given at industry standard rates)
3. 1% SSBC, no additional phosphate (other nutrients given at industry standard rates)
4. 0% SSBC, no additional phosphate (other nutrients given at industry standard rates)
5. 0% SSBC, all nutrients supplied at industry standard rates (industry standard Control)

The experiment will be set-up as a randomised block design and plant husbandry practices will be as close as possible to standard nursery practice. Plant management will proceed as detailed in section 2, describing last year's work.

Plant quality will be assessed in the same way as outlined in section 2, with 6 weekly measures of growth index, and weekly flower counts where appropriate. Visual assessment will take place in the autumn of 2015 and will be followed by destructive sampling of all replicates. Shoot dry weights and tissue P and N concentrations will then be measured (at the UoR) and the impact of the treatments assessed. The experiment is anticipated to be completed by spring 2016.

4. Possibilities for future work

The direction of the fellowship over the next 12 months will depend very much on the outcomes of experiment 4. However in addition to the write-up of existing work it is anticipated that smaller, lab-based experiments over the winter (2015/16) may better elucidate nutrient-use efficiency in different growing media materials. This may include some work at the UoR to assess cation exchange capacity and leaching rates in some of the mixes designed and used in experiments 3 and 4.

Knowledge and Technology Transfer

In addition to the scientific publications outlined in section 1, a small article is planned for the garden magazine in September, followed by a more detailed one outlining the results of experiment 3 in the autumn.

Glossary

Air-filled porosity (AFP): Percentage volume of a growing media or raw material that is filled with air, after the material has been saturated and allowed to drain under gravity. It is therefore the minimum amount of air the material will hold and is affected by container height.

Container Capacity: The percentage volume of a growing medium or raw material that is filled with water, after the material is saturated and allowed to drain under gravity. It is the maximum amount of water that the material can hold (or water holding capacity). As drainage is influenced by the material height, container capacity will vary according to container size.

Easily available water: Percentage volume of water in the growing medium or organic material which is easily accessible to plant roots. It is determined by measuring the amount of water remaining in the substrate between container capacity (1kPa in a 20cm high container) and 5kPa of suction (to mimic root draw). This property gives an indication of the efficiency of the material to provide water.

FRF: Field Research Facility at RHS Wisley

Organic material: A single raw material that is combined in volumetric proportions with other raw materials to produce a growing medium with a suitable physical and chemical environment for plant growth.

Growing medium (*plural*: media): A combination of materials used to provide a suitable physical and chemical environment for plant growth

SS: Sewage Sludge

SSB: Sewage Sludge Biochar

Total Porosity: The percentage volume of a growing medium or organic material that is comprised of pores or holes. This is the volume of the material that provides plant roots with air and water.

UoR: University of Reading

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Appendices

APPENDIX 1 Paper abstract submitted for oral presentation at the ISHS growing media conference in September 2015. The paper will be submitted for publication in the journal Acta Horticulturae

The Response of Pelargonium to Different Growing Media and Liquid Fertilizers – An Experimental Comparison

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Keywords: Sustainability, coir, green compost, wood fibre, peat

Abstract

In the UK, the drive to improve the sustainability of horticultural practice has meant that a diverse range of materials are now being incorporated into growing media. Most gardeners and growers assume fertilizer products will perform similarly when combined with different growing media. We investigated the effect of two liquid fertilizer products on the quality of *Pelargonium* 'Maverick red' in four proprietary growing media mixes (based on coir, green compost, peat and wood fibre). Plants were subjected to three fertilizer treatments; unfertilized, fertilized with an inorganic liquid fertilizer (containing soluble N forms), and fertilized with an organic liquid fertilizer (containing urea and more complex N forms). Plant quality was assessed after 18 weeks by measuring dry shoot biomass, plant growth index and visual quality. Whilst plants grown in green compost and wood fibre based media tended to be of marketable quality regardless of fertiliser type applied, peat and coir grown plants were much poorer on all three quality criteria when the organic fertilizer was applied. As the effectiveness of one of the liquid fertilizer products depended very much on the type of growing medium in use, it is clear that gardeners and growers need to carefully consider their choice of growing media and fertilizer combinations. This will only be possible if

manufacturers provide more detailed information about the content and usage of their products.

APPENDIX 2 Measurement of air-filled porosity (AFP) in growing media based on mixtures of different materials.

For this study AFP measurements were required on a range of organic materials and mixes of these materials, each with markedly different physical characteristics. This presented some challenges because previous methods for measuring AFP have been devised to compare growing media based on the same organic component (e.g. peat in the UK or pine bark in the U.S. or Australia).

The method based on Bragg and Chambers (1988) was followed initially but several issues were encountered and the method had to be modified by consulting literature from a range of other authors. For example, the growing media did not wet uniformly within the AFP test cylinders and differential swelling during saturation and shrinkage during drainage caused large error even within samples of the same growing media. The pine bark and growing media comprised of pine bark were particularly problematic, exhibiting initial hydrophobicity with the tendency to float out of the AFP test cylinders. Shrinkage during drainage was also a problem for wood fibre and growing media containing a high proportion of this material.

The modified approach

To help encourage even wetting during the assay and reduce shrinkage/swelling issues a pre-moistening stage was introduced, modified from Bilderback, (2009). All organic materials tested were uniformly mixed with 1ml/L of wetting agent (diluted according to manufacturer's recommendations). The moisture content of the material was then tested by hand-squeezing; the correct moisture content had been achieved when a few drops of water could be seen between the fingers. All mixing was carried out carefully, to ensure the structure of the material was not disturbed. Once the material was at the desired 'wetness' it was left in a sealed container to equilibrate for between 12 and 24 hours. Once this pre-moistening stage had been completed, material was packed into 5 pre-weighed AFP test cylinders (12cm high with a capacity of 1L ± 0.03mls) topped with a collar (design from perspex as detailed in Byrne and Carty, 1989, see photo 2A).The bottom of each cylinder was lined with a 500µm mesh to retain fines but allow unimpeded drainage of water (several mesh sizes were tested to determine the best compromise between adequate drainage and retention of fines). The sides of the cylinder were lined with a course plastic mesh to prevent a layer of air forming between the inside surface of the cylinder and the material being tested (photo 2A). Cylinders were over-filled with material to the top of the collar and tapped firmly three times. Any excess material was then scrapped off until exactly level with the top of the collar. The packed cylinders were then weighed to ensure the volume of substrate in each of the 5 replicates was equal (± 10%). Re-packing was carried out where required.

A range of saturation and drainage cycles based on Bragg and Chambers, (1988) and Fonteno et al. (2003) were tested to determine the minimum time required to achieve consistent results across the range of materials tested. The following cycle was determined to be the best:

1) A 12 hour soak, followed by a 30 minute drainage period
2) 30 minute soak, 10 minute drain
3) 30 minute soak, 10 minute drain
4) 1 hour soak, 30 minute drain

After the third soak, and drain the collars were removed and excess material was scrapped away from test cylinders so that it was exactly level with the top lip. The cylinders were then returned to the water bath for a final soak. Before final drainage the holes at the bottom of the cylinder were closed and the cylinders were weighed. They were then allowed to drain for 30 minutes to establish container capacity. Total porosity, container capacity and AFP were then calculated according to Fonteno et al. (2003) except that the dry weights of the materials tested were determined by drying at 65°C for 4 days until the material achieved a constant dry weight.

Photo 2A. The custom made Perspex test cylinders used to determine the TP, CC, AFP and DBD of the raw materials and growing media mixes. The capacity of the test cylinders was 1L± 0.03mls and based on the design of Byrne and Carty, (1989)

APPENDIX 3 Ranked performance of *Viburnum tinus 'french white'* in the 15 different growing media mixes measured by a) mean visual quality score (1-5), b) mean shoot dry weight (Shoot Dwt.) (g) and c) mean growth index (GI) (cm). Each mix has been given a rank from 1-15, 15 being the worst and 1 being the best for each plant quality measure. All three measures of plant quality identified the same three worst performing mixes (highlighted in red), the three best performing mixes (highlighted in green) varied according to the plant quality parameter measured, *n*=36.

For information only, there was no evidence of any significant effect of growing media mix on any of the three plant quality measures.

a)

MIX	Mean Score (1-5)	Rank
1	3.8	3
7	3.9	1
2	3.8	2
15	3.8	4
14	3.8	5
3	3.7	6
16	3.7	6
5	3.7	8
4	3.6	9
10	3.6	10
IS	3.6	11
13	3.6	12
11	3.6	13
9	3.5	14
6	3.4	15

b)

MIX	Shoot Dwt (g)	Rank
7	42.12	1
2	41.87	2
3	41.37	3
1	41.33	4
5	40.89	5
15	40.49	6
IS	40.27	7
10	39.84	8
9	39.41	9
14	39.29	10
11	38.78	11
16	38.73	12
4	38.72	13
6	38.64	14
13	38.16	15

c)

MIX	GI (cm)	Rank
2	9921	1
1	8969	2
14	8436	3
7	8233	4
IS	8089	5
3	7978	6
4	7956	7
15	7912	8
11	7654	9
16	7643	10
6	7627	11
13	7209	12
5	6742	13
10	6729	14
9	6138	15

APPENDIX 4

***Photo 4A** Visual Quality assessment of experiment 3 took place in November 2014. Assessments were made by professional growers who scored the plants after attending a meeting of the AHDB Horticulture hardy nursery stock panel. Members commented on their surprise at the uniformity of plants given the diverse selection of growing media included in the experiment.*

Figure 4A. *Mean visual score for Viburnum plants growing in each of the 14 growing media mixes and the industry standard (IS) control. The data has been split to display the scores of the amateur growers (gardeners) group (n=12) and professional growers group separately (n=12). While there was no difference in the way the both groups were scoring it was clear that the professional growers were more conservative in there award of higher scores. Means are displayed ± 1 CI*

**There was no significant difference between the professional and amateur groups in the way they were scoring thus the data set was combined for the analysis displayed in Section 2.*